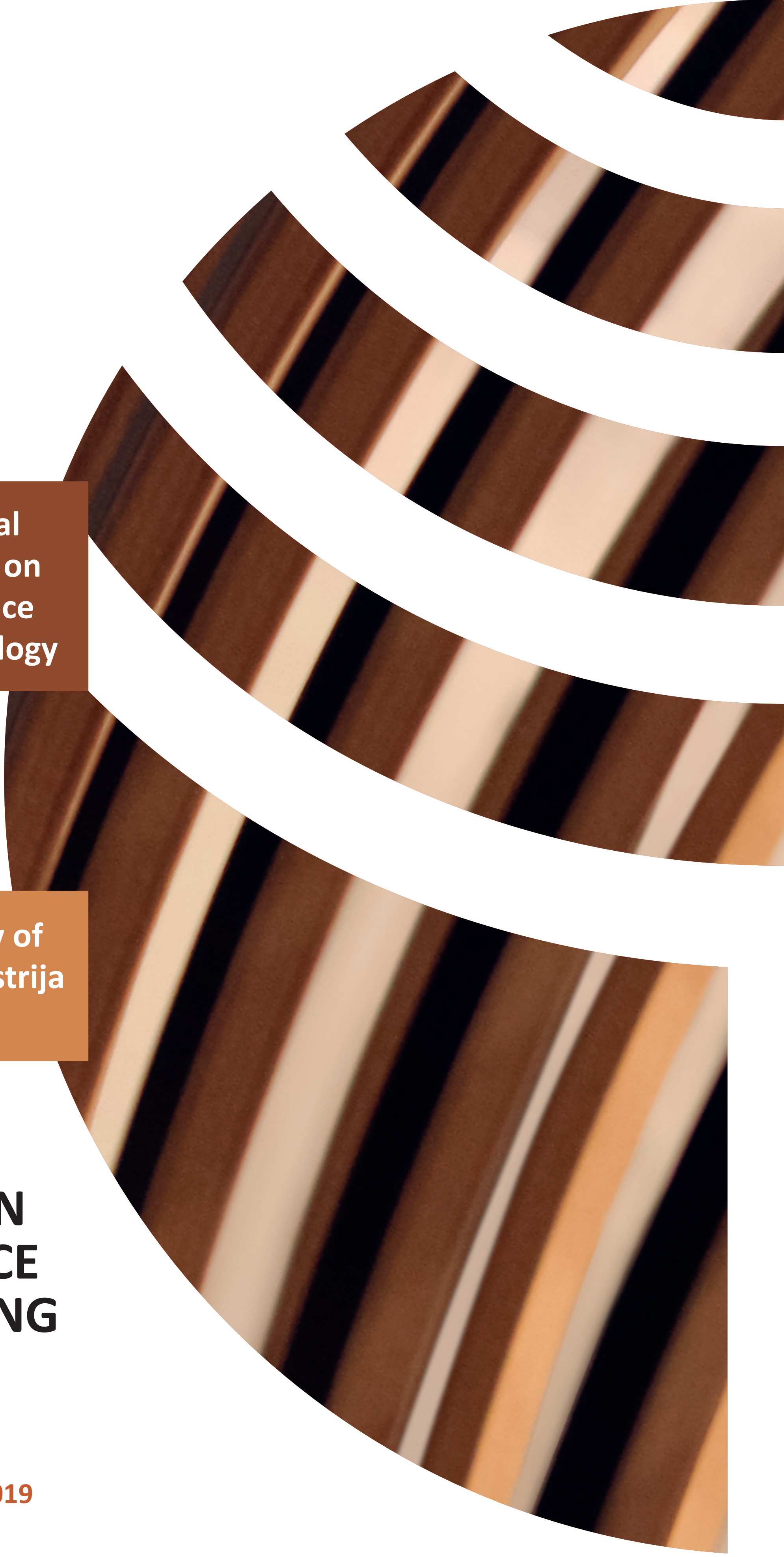
ICWST 2019

30th International Conference on Wood Science and Technology

70th Anniversary of Drvna industrija Journal



IMPLEMENTATION OF WOOD SCIENCE IN WOODWORKING SECTOR

PROCEEDINGS

Zagreb, 12th – 13th December 2019

• Faculty of Forestry, University of Zagreb, Croatia • Biotechnical Faculty, University of Ljubljana, Slovenia
• Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Czech Republic
• WoodEMA i.a. • InnovaWood

ORGANISERS

Department of Wood Technology, Faculty of Forestry, University of Zagreb, Croatia
Wood Science and Technology Department, Biotechnical Faculty, University of Ljubljana, Slovenia
Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Czech Republic
WoodEMA i.a.
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IN COLLABORATION WITH

Academy of Forestry, Croatia
Croatian Academy of Engineering
Association of Engineers of Wood Technology, Croatia
Ministry of Agriculture, Croatia
Zagreb Fair

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Disclaimer: This book of papers compiles the papers and posters presented at the 30th International Conference on Wood Science and Technology (ICWST) ***Implementation of wood science in woodworking sector*** held in Zagreb, Croatia on 12th and 13th December 2019. The opinions expressed within are those of the authors and not necessarily represent those of the host, the editors and or any institution included in organisation of this conference.

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FOREWORD

Over the past three decades the International Conference of Wood Science and Technology – ICWST became a tradition of the Faculty of Forestry, University of Zagreb, Croatia. Started as a professional single day event within the frames of Ambienta furniture fair in Zagreb, it later turned into a scientific two-day conference which takes place at the Faculty of Forestry, ordinarily every year in December.

Within frames of this year ICWST conference there is a double celebration – 30th edition of the conference and 70 years of Drvna industrija Journal – the only scientific SCI indexed journal in wood science field that has been issued in Croatia. The conference is organised by a number of prestigious scientific organisations: Faculty of Forestry, University of Zagreb; Biotechnical Faculty, University of Ljubljana; Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague; WoodEMA and InnovaWood.

As in previous years, this conference sets its target of bringing together scientists and researchers from at least 10 European countries and wider. The conference works comprising 58 papers and abstracts, among which5invited lectures, 33 oral presentations and 25 posters distinguish themselves either by their scientific novelty, by their potential for industrial applicability or by bringing out elaborated syntheses of some high impact subjects.

Plenary session of the first day is dedicated to the 70th anniversary of Drvna industrija journal during which the editor-in-chief prof. Ružica Beljo Lučić will shortly present past, present and future of the Journal and then, distinguished lecturers and devoted reviewers of the Journal will present their latest achievements or tackle the important issues for wood sector. These are prof. Pavlo Bekhta (Ukraine) – The Effect of Thermal Compression on the Surface Characteristics, Glueability and Coating Performance of Wood Veneers; prof. Eric Hansen (USA) – The Role of Wood Science & Technology Academicians in Innovation for a Circular Bioeconomy Transition; prof. Vassil Jivkov (Bulgaria) – The Current Situation, Problems and Challenges in Academic Education for the Furniture Sector; prof. Marko Petrič (Slovenia) – Comparison of Visual and Instrumental Assessment of Colour Differences on Finished Wooden Surfaces and dr. Jakub Sandak (Slovenia) – In-Line Measurement of Wood Surface Roughness.

Technical sessions are thematically organised to cover a wide range of research topics – wood anatomy; wood finishing and glueing; organisation and economy; wood processing; wood furniture and wood-based panels. The best papers selected for oral presentations will be considered for publication in Drvna industrija Journal after the regular reviewing process.

It is our pleasant duty to express gratitude to all the institutions and companies who provided financial support to the organisation of this conference.

This year's conference, the fifth in a row held under the title *Implementation of science in the woodworking sector* aims to ensure a multidisciplinary forum where all the participants have the opportunity to present and discuss innovations, trends and practical challenges they are facing in the world of wood science and technology, but also in relation to other materials, technologies, design and other related topics whose aim is to enhance and promote the wood industry.

We hope that this year's conference will contribute to awareness raising about significance of wood as an irreplaceable natural raw material for different productions in bioeconomy, which could be also used as a green building material in the battle with climate change, and that the application of scientific research has a positive impact on the wood sector as well as any user of wood.

Editors

CONTENTS

The Effect of Thermal Compression on the Surface Characteristics, Glueability and Coating Performance of Wood Veneers

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ABSTRACT

In this study the effect of thermal compression on the surface characteristics, glueability and coating performance of wood veneer was investigated. Wood veneer sheets underwent thermal compression at various temperatures and pressures before being adhesive applied and pressed into plywood panels using phenol formaldehyde glue resins. Moreover, thermally densified veneer was also used as substrate bonded to MDF panels for lacquer coating and adhesion strength of lacquer layers to such substrate was assessed. Panels were coated with lacquer in one, two and three layers without primer at different spread rates. The results showed that surface characteristics such as colour, gloss and surface roughness of thermally densified veneers improved but their wettability deteriorated. The bonding strength values of plywood panels made from densified veneer even with reduced adhesive spread were higher than those of plywood panels made from non-densified veneer. It was also found that MDF samples overlaid with thermally densified veneer resulted in enhanced adherence characteristics between finishing material and substrate as compared to that of overlaid MDF samples with non-densified veneer and reduction of the required lacquer application rate. The preliminary findings obtained in this study indicated that thermal compression of wood veneer surface before gluing and coating could be considered as an alternative method of producing wood panels with satisfactory aesthetic properties and reduced adhesive and lacquer product consumption by ≈30-50 %.

Key words: adhesion, bonding strength, coating, thermal compression, wood veneer

The Role of Wood Science & Technology Academicians in Innovation for a Circular Bioeconomy Transition

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ABSTRACT

Conferences such as ICWST are an example of a mechanism to diversify thinking via exposure to different people, expertise, and contexts. Innovation thrives when different perspectives, backgrounds, expertise areas are brought to bear on a problem. While the wood science academic community may be effective in pursuing innovative research and providing innovative solutions for forest sector companies, the current approach may be insufficient for the long-term health of those companies. The forest sector has long been noted as a mature, traditional industry, lacking of innovation and innovativeness. Quickly advancing information technology and a societal shift toward a circular bioeconomy create a fast-changing environment within which companies must adapt or risk survival.

Industry 4.0, smart manufacturing, and advanced manufacturing are alternative terms for the increased digitization of manufacturing environments and processes. Advances in this area present significant opportunity for forest sector companies, yet awareness and strategic adoption of technologies within the sector is not as pronounced as might be expected. Recent research focused on primary wood products manufacturers in the US paints a picture of an industry that is underprepared to embrace advanced manufacturing technologies.

Forest sector companies, as purveyors of renewable materials, have a unique opportunity to establish leadership in the future circular bioeconomy. Policy makers and academicians strongly advocate for cross-sector collaboration by forest sector companies in order to develop new products and services that meet the needs of environmentally conscious markets. However, cross-sector collaboration is not highly common among forest sector companies and recent research shows that companies are ill-prepared to embrace collaboration. In fact, the rhetoric between industrial sectors (e.g., wood and cement/concrete) is highly antagonistic and far from creating an atmosphere with potential for collaboration. This situation is unlikely best suited for a more sustainable society.

Various forms of open innovation, led by wood science and technology academicians, can be a critical ingredient in supporting forest sector companies as they adopt new manufacturing technologies, learn to collaborate across sectors, and generally improve their ability to innovate. Examples of open innovation efforts will be profiled with an aim for participants to contemplate their individual and collective roles in supporting the continued development of the forest sector.

The Current Situation, Problems and Challenges in Academic Education for the Furniture Sector

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ABSTRACT

In this study are open questions concerning academic education in the field of furniture industry in Europe that must be answered to identify the problems and the best practice and to be improved the situation in the sector. The furniture industry in most of the European countries has a permanent lack of professional human resources. The industry needs not only numbers but well-educated people with good professional skills, creativity, ability for teamwork, rapid adaptation in an ever-changing work environment, etc.

Many universities in Europe, especially in Eastern Europe, are offering study programs for the furniture sector in two main directions – Wood technology (Wood science) and Furniture and interior design. One the one hand, the industry needs urgently new engineers and designers, but from the other, these degrees, especially in Wood technology, are not any more attractive for the young generation. In the last few years, the universities are suffering from lack of more and better new coming students. In this study, the reasons why the students are becoming less are separated and detailed into four directions: objective, emotional, administrative and subjective. Analysis of each factor was made. All this poses new challenges for higher education in the field of furniture production. The new generation needs a new approach.

Finally, the paper list some of the challenges in the field of academic education in furniture sector which are described and divided into the following segments: marketing, quality of teaching, university facilities, strong connection with the business, and social life.

The study closes by making some recommendations. Nowadays the universities have to pay more attention to the way how to present their study programs, giving the attractive name of the study degree, the content of the curriculum has to be actual and to be taught in a modern way. Special attention has to be paid to the project-based learning, an approach that develope teamwork. The focus should be changed from theoretical to practical education. Strong co-operation between educational institutions and business is needed where industry-sponsored projects and companies provide "real" problems for a solution along with expertise and financial support. Good practices have to be presented continuously to the students. Social life has to be part of the education system.

Key words: education for the furniture industry, wood technology, interior and furniture design, higher education

Comparison of Visual and Instrumental Assessment of Colour Differences on Finished Wooden Surfaces

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ABSTRACT

Staining of wood with various substances and processes is an important part of surface finishing of wood. Colour differences as a result of staining and of exposure of coloured wood during its utilisation are usually evaluated by instrumental measurements. However, the measurement results can show something else compared to what our naked eye perceives. Due to inhomogeneity of wood this discrepancy can be even greater in the case of finished surfaces. The aim of our research was to evaluate distinctions between visual perception and numerically determined colour differences on differently finished wooden surfaces, to get information at which starting point the colour difference becomes visible, and if it is related to the nature of the surface. We established that the visual assessment is influenced by many factors and that there is a correlation between visual and instrumental assessments. The colour difference ΔE^* of 0.5 should be considered as a value when it is starting to become visible and at the value of 2.0 the colour difference was already considered by observers as a different colour. It was stated that we have some tolerance in perceiving the colour change. This tolerance is more expressed in the case of transparent coating systems.

Key words: coating, colour, instrumental measurement, visual perception, wood

In-Line Measurement of Wood Surface Roughness

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ABSTRACT

The latest progress in the field of optics and microelectronics resulted in development of new generation vision systems capable of scanning surface topography with very high sampling frequencies. The blue color of illuminating light as well as novel systems for controlling ultra-thin laser line thickness allows measurement of the porous surface of wood with a triangulation method. Three alternative sensors were tested here in order to verify their suitability for determination of surface topography in the industrial environment. The scanning head was installed at the exit zone of the four-side profiling moulder and was set to scrutinize the wood surface shape line-by-line, immediately after profiling. The sensor was also tested for automatic detection of surface defects appearing on elements after sanding, wetting and painting with diverse finishing products. The set of pilot test results, together with an original algorithm for real-time surface defects detection, is presented.

Key words: wood surface roughness, triangulation scanner, surface defects, on-line, at-line

Effect of some oil and wax finishes on the water permeability of spruce *(Picea abies)*

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ABSTRACT

Conventional solvent-based finishes such as lacquer and varnishes provide a durable, high quality finish at a reasonable cost. However, they can also be significant sources of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). An alternative approach is to use finishes made from plant oils and waxes. They are easy to apply, give almost fully proved results and leave wood looking both rich and natural. Water permeability of finishes is an important factor in their wood protective function. This study evaluates the permeability of some commercial oil- and wax-based wood finish systems and ascertaines effects of coating layering on water permeability of spruce (*Picea abies*). The permeability of finishes in terms of liquid water absorption was measured acccording to standard EN 927. For this measurement, six different oil- and wax-based wood finish systems were used as protection on spruce test samples. Number of layers and finishing compositions clearly influence on the results revealed for the water permeability.

Key words: oil, spruce, water permeability, wax

1. INTRODUCTION

The fibrous nature of wood has made it one of the most appropriate and versatile raw materials for a variety of uses. However, two properties restrict its much wider use: dimensional changes when subjected to fluctuating humidity and susceptibility to biodegradation by microorganisms. The varying moisture content of wood results in dimensional and conformational instability, which can compromise the performance of other materials combined with wood, such as adhesives and surface coatings (Mantanis, G. I. *et al.*, 2000).

Finishing is one of the most utilized surfacing methods (Salca, E. A. *et al.* 2016). Oil and wax finishes offer a natural and environmentally friendly alternative to coatings and vanishing of wooden surfaces. These products are mainly based on renewable, natural vegetable oils that penetrate deeply into the wood, keeping it elastic and healthy, whilst preventing it from drying and becoming brittle. Oils and wax finishes are easy to apply with a brush or a rag, give almost foolproof results and leave wood looking both rich and natural. There are many different types of oils but some of the most popular ones are boiled linseed oil, tung oil, teak oil, mineral oil and Danish oil. The oils add a bit of protection to the wood against moisture. Linseed oil is one of the oldest penetrating finishes, but it tends to become sticky in humid weather. Danish oil offers more protection than other oils because it is a mixture of oil and varnish.

Waxes are nowadays used more and more to prolong the service life of wood. Waxes are derived from a variety of mineral, vegetable and animal sources. As a finish, waxes don't penetrate into the wood, but rather sit atop. Liquid or paste wax typically contains some solvent, and the wax "cures" as the solvent evaporates. The fact that they are soft means they offer very little protection against scratches and wear. In the past, waxes were predominately used as additives in water-repellent finishes and wood preservatives (Evans *et al.*, 2005; Zahora, 2000)

Nowadays there are several commercial treatments based on the wax alone without biocides (Berninghausen *et al.,* 2006). However, their big disadvantage is their lack of durability.

Permeability represents a material property that is of specific importance for different technical processes in the wood furniture industry (Kavalov A. *et al.* 2000). Permeability determines the flow of liquid or gaseous phases through a solid surface. Siau (1984) defines permeability as a measure of the ease with which fluids are transported through a porous solid under the influence of a pressure gradient. Although wood is a porous material (60–70 % void volume), its permeability or flow of water is extremely variable. This is due to the highly anisotropic arrangement of the component cells and to the variable condition of the microscopic channels between cells. Wood is much more permeable in the longitudinal direction than in the radial or tangential directions. Moisture uptake in wood can be explained by three different mechanisms: liquid water absorption into the wood, water vapor absorption into the wood, and water vapor desorption out of the wood (Ekstedt *et al.*, 2001). Moisture in wood can result in a wide variety of protective and decorative problems. Any failure of the protective finishes will allow water to penetrate into the wood. Once the finishing has been breached, moisture will continue to migrate into the wood which can result in decay and other failures (discoloring of the wood, twisting and cracking of the wood). The solution to all of these problems is to keep moisture from entering into the wood, to reduce the moisture content in the wood, and/or improvement of the dimensional stability of the wood.

The purpose of this study is to evaluate water permeability of some commercial oil- and wax-based wood coating (finishing) systems and ascertained effects of coating layering on water permeability of spruce (*Picea abies*). A standard test procedure, EN 927-5, has been launched for assessment of the water protection efficiency. The standard method described in EN 927-5 was developed to evaluate the water permeability of coating films, rather than the water uptake in different wood types.

2. MATERIALS, METHODS, EQUIPMENTS

For the tests, spruce (*Picea abies*) with a density of 475 kg/m^3 (at an equilibrium moisture content of 8 %) was used. The samples were prepared with the dimensions 150x70x20 mm (longitudinal, tangential, and radial directions, respectively). All faces were planed. The test samples were manufactured in accordance with the specifications in EN 927 - 5. For accurate results, specimens were selected without any defects, such as knots, cracks, resin spots, etc. The specimens were conditioned before the coating applications according to standards (20 °C ± 2 °C and 65 % ± 5 % RH.

The following ready-to-use products were used: Proterra Cerafluid GE 100 - oil-wax combination, based on non-drying vegetable oils, beeswax and carnuba wax; Proterra HardOil GE 11014 - linseed oil with lead-free additive substance; Proterra HardOil GE 11066 - a low-viscosity linseed oil; Osmo Hartwachs-Öl - based on natural vegetable oils and waxes (sunflower oil, soybean oil, carnauba wax, etc.), paraffin, siccative and water-repellent additives; Levis Hardwood Oil - based on vegetable oils; wax Liberon Black Bison - contains a blend of natural waxes (paraffin microcrystalline, carnuba wax).

The coating application was performed according to the technical data sheets supplied by the producers. After the application of the coatings, all remaining sides were sealed with two-component polyurethane (PU) system. Full description of the coating systems and the technology of the coating application is given in *Table 1*.

Table 1. Coating systems applied on spruce (Picea abies) and tested for water permeability:
I - Proterra HardOil GE 11014; II -Proterra HardOil GE 11066; III - Osmo Hartwachs-Öl;
IV - Liberon Black Bison Fine Paste; V - Levis Hardwood Oil; VI - Proterra Cerafluid GE 100.

			First coating		Second coating		Third coating	
Coating system	MWA, g/m^2	Area, m^2	Solid, g/m^2	Liquid, g/m^2	Solid, g/m^2	Liquid, g/m^2	Solid, g/m^2	Liquid, g/m^2
a. I	449.51	0.0103	32.01	46.56	-	-	-	-
b. I+I	319.61	0.0103	32.01	46.56	30.3	44.75	-	-
c. I+I+I	176.42	0.0103	32.01	46.56	30.3	44.75	30.05	43.11
d. II	724.82	0.0104	28.91	54.90	-	-	-	-
e. II+II	584.80	0.0104	28.91	54.90	24.54	44.60	-	-
f. II+II+II	578.49	0.0104	28.91	54.90	24.54	44.60	22.25	40.35
g. III	162.28	0.0101	40.59	55.18	-	-	-	-
h. III+III	33.34	0.0101	40.59	55.18	23.40	45.35	-	-
i. III+III+III	27.5	0.0101	40.59	55.18	23.40	45.35	24.98	44.84
j. IV	501.29	0.01	36.73	75.55	-	-	-	-
k. IV+IV	195.65	0.01	36.73	75.55	37.20	66.62	-	-
l. IV+IV+IV	28.75	0.01	36.73	75.55	37.20	66.62	35.12	66.67
m. II+IV	617.99	0.0102	40.28	65.18	23.7	70.55	-	-
n. II+II+IV	592.78	0.0102	40.28	65.18	23.46	45.32	23.61	70.05
o. III+IV	28.85	0.0099	32.03	46.65	24.02	71.23	-	-
p. III+III+IV	17.69	0.0099	32.03	46.65	29.98	44.32	22.98	70.05
q. V+VI	181.25	0.01	36.8	78.8	41	63.19	-	-
r. V+V+VI	27.95	0.01	36.8	78.8	35.42	69.21	40.82	63

The European standard EN 927-5 specifies a test method for assessing the liquid water permeability of coating systems for exterior wood by measuring the water absorption of coated wood panels (EN 927-5:2006). The liquid water permeability was determined as the increase in weight of the test samples after 72 hours of floating in water as specified in EN 927-5. For each set of five replicates, the arithmetic mean value of the weight increase and the standard deviation were calculated. The arithmetic mean value of the weight increase after 72 hours of floating is reported as mass of absorbed water per test face area (*MWA*).

The density was determined by measuring the dry weight after drying at 105°C. The moisture content (per cent of wood dry weight) was calculated as the difference between the weights before and after the drying process according to Standard Method EN 384 (1995).

The water absorbed by each specimen was measured as mass of absorbed water per test face area (*MWA*, g/m^2) relative to the weight of the conditioned specimen prior to the test, in accordance with EN 927-5 (1):

$$MWA_1 = (w_1 - w_0) / A \qquad (1)$$

where:

MWA_1 = mass of absorbed water per area in g/m^2 at time 1
w_0 = weight in g at time 0
w_1 = weight in g at time 1
A = area of test face in m^2.

3. RESULTS AND DISCUSSION

The water absorbed by the samples for the tested homogeneous coatings systems are shown in Figure 1.

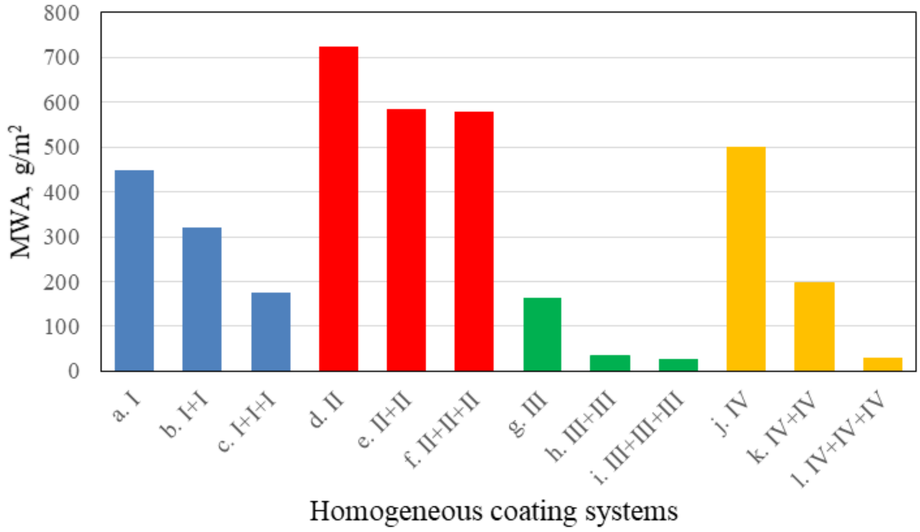

Figure 1. Mass of absorbed water per test face area (MWA) for the tested coatings systems:
I - Proterra HardOil GE 11014; II -Proterra HardOil GE 11066; III - Osmo Hartwachs-Öl; IV - Levis Hardwood Oil.

According to the European standard EN 927-2:2014, which classifies performance criteria for coating systems on exterior wood in relation to the expected dimensional changes, we have stable (maximum water absorption 175 g/m^2), semi-stable (from 175 g/m^2 to 250 g/m^2), and non-stable (over 250 g/m^2) end use categories. With single application of dominant part of the used oil- and wax-based products, the water absorption of the coatings falls into non-stable category. The best results regarding low water absorption of the coatings have been achieved with the brand Osmo Hartwachs-Öl.

For homogeneous coatings accomplished by the products Proterra HardOil GE 11014 and Levis Hardwood Oil the water absorption reduction is proportional to the number of layers applied. All coatings made with the low viscous linseed-oil based product - Proterra HardOil GE 11066 are characterized with very high water absorption.

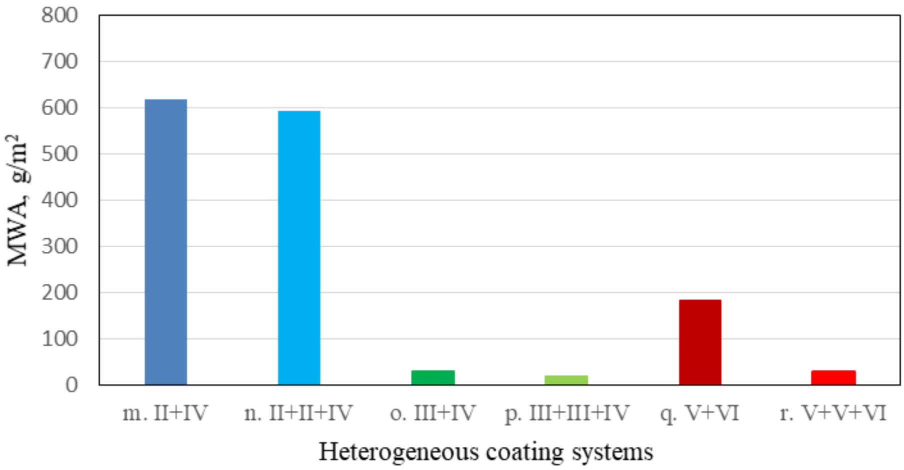

Figure 2. MWA for tested coatings systems:
II -Proterra HardOil GE 11066; III - Osmo Hartwachs-Öl; IV - Liberon Black Bison Fine Paste;
V- Levis Hardwood Oil; VI - Proterra Cerafluid GE 100.

The water absorbed by the samples for the tested heterogeneous coatings systems are shown in *Figure 2*. The combination of Proterra HardOil GE 11066 with finish coating from Liberon Black Bison Fine Paste does not result in considerable decrease of the water absorption of the so achieved heterogeneous coatings. The two-layer coatings of Osmo Hartwachs-Öl and Liberon Black Bison Fine Paste has very low water permeability. The three-layer coating *p* (2 layers - Osmo Hartwachs-Öl and finish layer - Liberon Black Bison Fine Paste) is with least value of absorbed water (mass of absorbed water per test face area) -17,69 g/m^2. The three-layer coating *r* (2 layers - Levis Hardwood Oil and 1 finish layer - Proterra Cerafluid GE 100) is again characterized with low water permeability thus classified in the stable category with respect to dimensional wood changes.

4. CONCLUSIONS

This study measures the water permeability of coating systems of six commercial oil and/or wax dispersions that resulted in wide variations of this property:

1. The water absorption is dependent on the producers of the coatings. These differences can be explained by the various content and composition of additives or by the modification of oils and waxes in tested coating systems.
2. Layering affected the permeability. By one-layer application of oil and/or wax-based products over a spruce surface, the water absorption of most of the coatings is over 250 g/m^2. This quantity of water results in dimensional changes of the wood. In this relation, in order to maintain the wood dimensions stable, it is recommended a 3-layer application of coating to be made. However, for part of the used ready products, the application of third layer leads to insignificant reduction of the water permeability of the coating.
3. The proper combination of vegetable oil and wax-based products reduces the water absorption of the coatings. The heterogeneous coatings produced with Osmo Hartwachs-Öl and Liberon Black Bison Fine Paste have very low water absorption. The same result is achieved also with the two-layer coatings (first layer - Osmo Hartwachs-Öl and finish layer Liberon Black Bison Fine Paste).

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Comparative Researches of the Effect of Deformation Smoothing of Veneer Furniture Boards through Lapping via Three Type of Different Working Tools

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ABSTRACT

This article presents the comparative analysis on the results from experimental researches performed for smoothing via lapping of veneer furniture boards made of beech (*Fagus sylvatica*) and iroko (*Chlorophora excelsa*) where three types of different working tools have been used. In the first case, for the contact area of the smoothing surface was used steel stick with diameter of 4 mm, in the second case – flexible steel wire with diameter of 2,2 mm, and in the third case – plastic cord with 3 mm-diameter. The evaluation of the smoothing effect has been made by the parameters "outlook". The results show that the best quality of processed surfaces is achieved when it has been used a working tool with active contact area from steel wire with diameter of 2,2 mm.

Key words: lapping, lapping regime, surface smoothing, veneer boards

1. INTRODUCTION

The surface of wood is the result of complex factors including the interaction of raw material used, types of processes and time. Usually the surface of manufactured wood elements results from a partitioning process achieved through one or more consecutive cutting and smoothing steps, which might include traditional sawing, planning, milling or sanding process. Each of these processes normally has their individual characteristics, which will result in wood surfaces with different properties (Sinn *et al.* 2009). It is well-known that the surface quality of the processed wood materials depends on various factors determined by the construction and characteristics of the cutting tool as well as by the parameters of the cutting mode of the machine. Among the main factors influencing the surface quality during processing are: the rotational speed of the cutting tool, the cutting speed, the feed rate and the thickness of the out-cut layer (Vitchev *et al.* 2018a; Vitchev *et al.* 2018b; Vitchev 2019).

Smoothing is a type of mechanical impact over the treated wood surface aimed at decreasing any available micro roughness on it up to size and shape that will meet the requirements for quality and economic production of film protective coatings. Depending on the used way for performing that impact, the smoothing is implemented via cutting (sanding or scraping) or via compression. Compression represents irreversible deformation of the roughness tops by applying pressure loading over them. Deformation is achieved either by thermal rolling or by lapping. The lapping of wooden surfaces (solid wood elements and veneered wooden boards) represents specific type of impact over the processed surface performed via throughfeed pressure sliding of appropriately shaped working instrument. Its active part is a hard smooth edge with a certain curvature radius, which is in tight contact with the processed surface. As a result, irreversible pressure of the tops of the micro roughness is achieved. In this way, the tops' height is decreased as well as they are rounded to a state that meets the regulatory requirements for achieving quality film coatings (Kavalov *et al.,* 2015).

The conducted studies, supported by the results from their implementation at production conditions prove that lapping has substantial advantages over other methods for smoothing.

Amongst those, the following worth pointing out:

- Lower specific energy cost compared to sanding and thermal rolling;
- Lack of dust separation and thinning of veneer layer, which is inherent in sanding process;
- More opportunities for automatic compensation of any deviation in the flatness of processed boards compared to thermal rolling;
- Compaction of the upper surface micro layer of the veneer, which results in economy of materials upon further forming of film coatings (Kavalov *et al.*, 2015).

Being a rather new smoothing method, the lapping has not yet gained popularity among furniture producers. Little known or barely studied are particular technical solutions for its implementation, wherefore lack of sufficient data for technological regimes and values for its characteristic mode parameters: linearly distributed pressure load q within the area in contact with the processed surface; radius of curvature R for the working tool in the same zone; feeding speed u, and number of lapping operations n.

The current article presents and discusses the results from the experimental studies, related to the creation and determination of the technological capabilities of a lapping instrument used for veneer furniture boards, prior to forming film coating on them (protective decorating coatings). Subject of the research are three kinds (options) of shaping the contact area of the lapping working instrument. The purpose of this study is to compare the smoothing qualities of the boards at variable values for some of the major factors on which it depends.

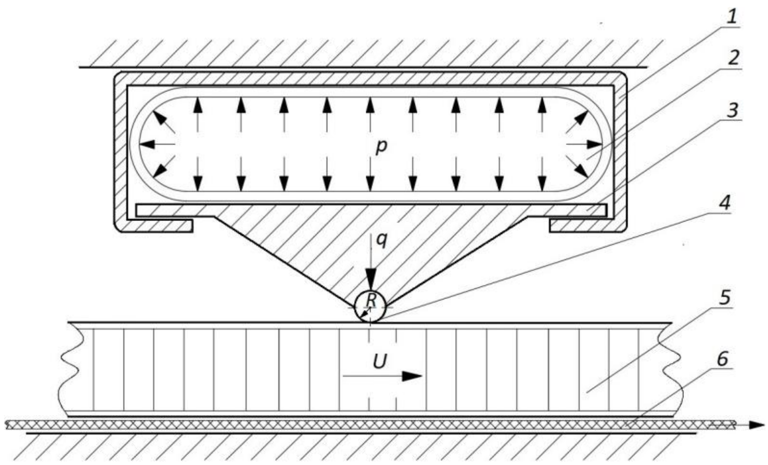

Figure 1. Scheme of the lapping device for veneered furniture boards: 1– supporting base (body); 2- pneumatic chamber; 3 – lapping tool; 4 – contact area of the lapping tool; 5 – processed board; 6 – transporter (feeder)

Fig. 1 presents the general scheme of the device used in this study. The body (1), made of steel profile, serves to fit the pneumatic chamber (2) and the working tool for lapping (3). By feeding the board (5) with a speed u, the end-piece tool (4) is pressed to board surface. The pressing is performed via pneumatic chamber, wherein air is pressurized p. The total pressure over the working tool (3) is transformed in linearly distributed load q, exerted along the line of its contact with the furniture board surface. The effect of the deformation is achieved from the pressed strain σ_p, which size can be determined with the formula (Kavalov *et al.*, 2014):

$$\sigma_p = A.q / R^{0,5} \quad (1)$$

R – curvature radius of the contact area (4);

A – coefficient, by which is accounted the elasticity of the materials in relation to the contact area (4) and the board (5).

2. MATERIALS, METHODS, EQUIPMENTS

In this specific study-case presented for conducting test lapping operations, have been used instruments equipped with three versions of the end-piece tools (4):

Version „A“– cylindrical body (stick) made of calibrated steel with smooth surrounding surface and diameter 4 mm;

Version „B“– elastic steel wire with diameter 2,2 mm;

Version „C“– reinforced hard polyamide cord with diameter 3 mm (cord for mechanical lawn mowing has been used).

The samples are prism-shaped parts, made of veneer furniture boards with roughness R_m = 28±3 μm, achieved by preliminary sanding done with sandpaper No. 80. It has been used two type of veneers - beech (*Fagus sylvatica* L.) and iroko (*Chlorophora excelsa*).

To determine the influence of two chosen parameters of lapping (*q* and *n*) on the smoothing quality, it was run two-factor experiments on optimal second order composite plans (B2-type). During the experiments, at constant level is maintained the factor feeding speed *u* -10 $m.min^{-1}$.

Quality assessment of the smoothing is made by the indicator „outlook“, whereas scoring points (*ranks*) are given as per a methodology, described in another publication we have (Angelski *et al.*, 2015). We need to explain, that the scoring points are in the range from 0 to 5, where rating 0 means perfect quality, while rating 5 – low quality that goes for scrap. Based on accrued experience is accepted that surfaces with score (*rank*) $B_в \leq 1$ fully comply with the technological standards for quality smoothing.

Table 1. Matrix compositional plan and average values from the test experiments

Factors			Outlook Bb, scoring points (ranks)					
	X1= q	X2= n	Beech veneer			Iroko veneer		
No.	kN/m	number	A*	B	C	A	B	C
1	3	3	0.6	0.4	1.0	0.4	0.0	1.5
2	1	3	2.0	1.5	2.1	1.8	2.0	2.8
3	3	1	0.5	1.0	1.3	1.0	0.3	2.0
4	1	1	2.7	2.0	3.0	2.2	3.0	2.6
5	3	2	0.7	0.6	1.2	0.8	0.2	1.4
6	1	2	2.1	1.3	2.4	1.0	1.6	1.8
7	2	3	0.7	0.7	0.9	0.9	0.6	1.7
8	2	1	1.0	0.8	1.4	1.0	1.3	1.9
9	2	2	0.8	0.6	1.2	0.7	0.7	1.5

* *A*, *B*, *C* - versions of the end-piece tools

Table 2. Values of regression models

	Beech veneer			Iroko veneer		
Indicators	A*	B	C	A	B	C
1. Regressors						
b0	0.80	0.54	1.16	0.61	0.62	1.36
b1	-0.83	-0.47	-0.67	-0.47	-1.02	-0.38
b2	-0.15	-0.20	-0.28	-0.18	-0.33	-0.08
b11	0.60	0.43	0.67	0.33	0.32	0.82
b22	0.05	0.23	0.02	0.38	0.37	0.52
b12	0.20	-0.03	0.50	-0.05	0.18	-0.18
2. Adequacy check						
Ftabl	3.18	3.18	3.18	3.18	3.18	3.18
Fcount	9.01	9.01	9.01	9.01	9.01	9.01
Adequate	Yes	Yes	Yes	Yes	Yes	Yes
3. Coefficients of multiple correlation						
R2	0.99	0.95	0.99	0.81	0.96	0.92

The lapping experiments are hold by the use of testing machine Heckert-FP10/1. Thus, additional devices have been adjusted, that allow strict determination, maintenance and reporting of the planned loads *q* during individual tests. The feeding speed *u* is achieved via the usage of purposely-designed feeding device, mounted nearby the testing machine.

The factor levels and the intervals of their variation for all fulfilled plans are presented in *Table 1*. In the same table are presented and calculated values for the target function Bв (Box, G.E.P. *et al.* 1951; Box, G.E.P. *et al.* 1999; Vuchkov, I. *et al.* 1986). Separately, in *Table 2*, are provided selected data from the regression analysis of all two-factor experiments performed.

3. RESULTS AND DISCUSSION

As observed from *Tables 1 and 2*, the results provide the basis for making scientifically comparative analysis of the achieved lapping quality at different experimental plans. On this basis, we can formulate conclusions and recommendations that might be useful for further researches and application in practice. Based on the data in these two tables, graphical solutions were constructed for all 18 models according to the planned two-factor experiments and shown in Figure 1 and Figure 2.

Light green background of the chart is used to mark the areas where could be found values combination of the factors *q* and *n*, appropriate for creating technology regimes that guarantee high-quality lapping at production conditions.

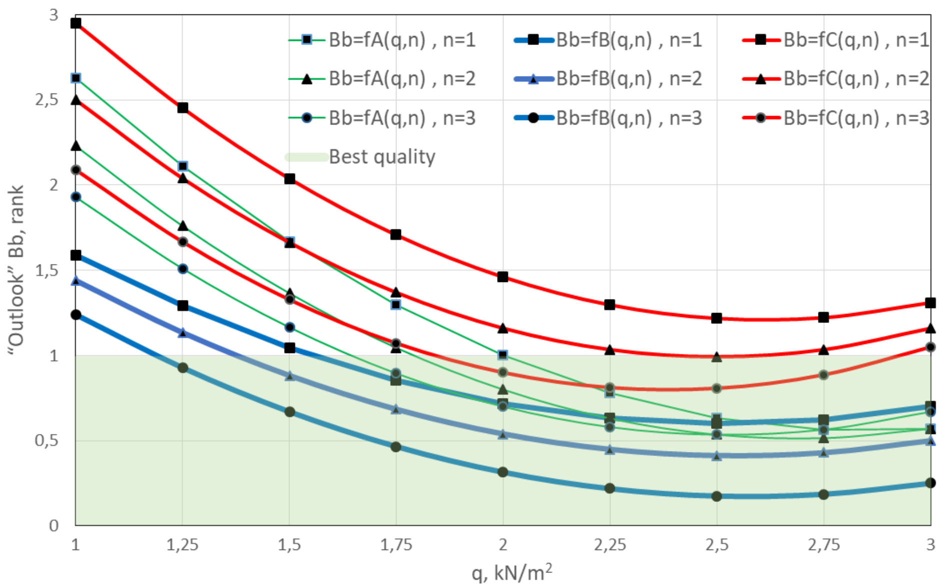

Figure 2. Graphic solutions of regression equation with type Bв=f (q,n) for the models. Two-factor experiments, built up using data from Table 2, applied for beech veneer

The analysis of the results achieved gives us grounds for summarizing the following substantial conclusions and recommendations:

1. There is clearly expressed dependence between the outlook (*Bв*) from one side, the linearly spread pressure loading *q* and the number of lapping at the same board surface *n* – from another side. It is obvious that all the time by increasing *q* and *n*, the smoothing quality is improved. Predominantly, quality smoothing where $Bв \leq 1$ can be achieved at $q \geq 2$ kN.m^{-1} and frequency of the lapping $n \geq 2$. This tendency is easily explained if we take into consideration that fact that by increasing *q* there is growth in σ_p, and also in the residual deformation of the micro roughness top surface. This results in decrease of their height and in reduction of the fibrous surface of the material that inevitably remains after the previously performed sanding. The increase of the number of lapping *n* from other side also results in additional pressure over the surface microlayer, which improves the smoothing equability. The comparison of the regression values with b_1 and b_2 type shows that the factor *q* influences considerably stronger

on the increase of the smoothing quality rather than the number of impacts *n*. This means that if there is a technical possibility for increase of *q* in the range above 3 kN.m^{-1}, it could be achieved for *Вв* scoring below 1, even if it's single lapping, which is the preferred case.

2. The comparison of the results for *Вв* in regard to used end-piece tools with different curvature radius *R* (see *versions A, B and C*) shows that the highest quality of smoothing is achieved at *version B*. Its advantages are mostly in the fact that the steel wire has the smallest *R*. The less the curvature the bigger residual deformations are achieved. This means less micro roughness, thus a better smoothing quality. It is therefore possible that under the same other conditions *q* may be reduced without worsening the quality. Lower values for *q* mean lower energy consumption and more efficient lapping. Another advantage of using end-piece tools made of elastic steel wire with small diameter is that thanks to the increased wire flexibility the lapping equability is improved in a direction perpendicular to the feeding direction. That possibility is the more limited the bigger is the curvature radius on the contact area and the bigger is the rigidity of the used material, which is the case with *version A*. The stiffness and rigidity from other side is related to the provision of higher durability of the working instrument – a fact that should not be ignored. In order to achieve really positive effect from the usage of elastic steel wires with small diameter, it is also necessary to ensure increased flexibility and elasticity of the working instrument towards which is the wire attached. The studies we have done show that such combination is completely achievable without making the lapping tools of the type concerned more expensive.

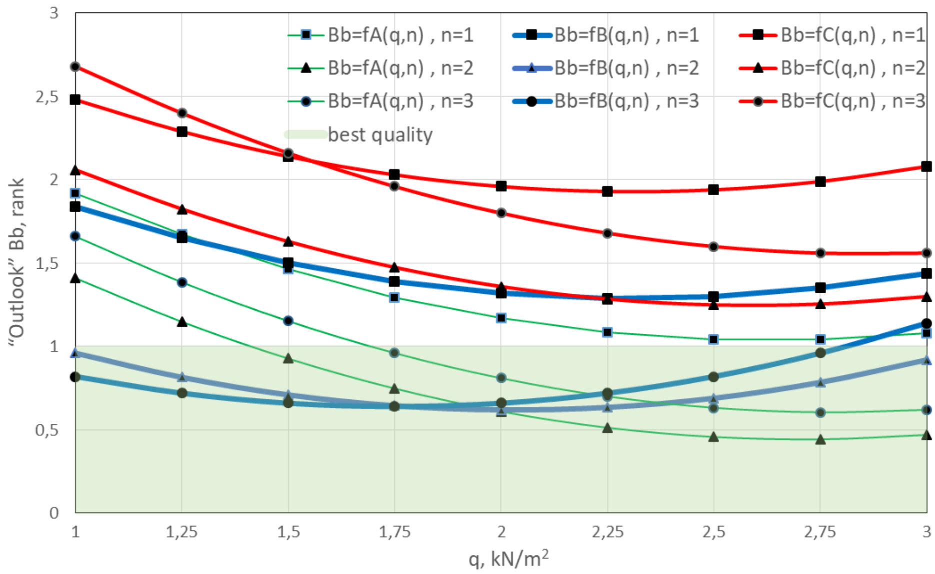

Figure 3. Graphic solutions of regression equation with type Вв=f (q,n) for the models. Two-factor experiments, built up using data from Table 2, applied for iroko veneer

The results from the usage of contact area with flexible plastic cord (*version C*) show that there are two controversial tendencies. From one side, thanks to the cord flexibility, conditions for high consistency of the lapping are achieved. Its less hardness, which does not let having considerable pressures, combined with less plastic durability limit significantly the usage opportunities specifically upon processing wooden boards, coated with veneers of harder wooden type. Completely as expected, the outlook scoring points for this type of working instrument are considerably higher, reaching even values above 2. Because of these circumstances, it is not recommended further planning of experiments with working instruments which contact areas are formed of plastic or other similar elastic materials with reduced hardness.

As for taking into account the influence of the veneer type over the results from the lapping process, the analysis show that no cases are registered where that influence is one-way expressed in respect to the chosen two types of veneers – made of beech and iroko. The better knowledge of the data from *Tables 1 and 2*, as well as the graphics at *Figure 2*, give us reason to state that beech-veneer smoothing is more stable and with less dispersions regarding the scoring points got for outlook. This can be explained with the less hardness and uneven texture of this type of veneer, thus the pressures at the same size of the factors q and n being with reduced consistency, therefore with less smoothing quality. The results from this experiment show that the veneer type reflects on the results from the smoothing via lapping. It follows that they cannot be summarized without any reserves and uncritically for all cases if respective test studies have not been performed.

4. CONCLUSIONS

The positive results achieved from the hold experimental researches definitely prove that deformation smoothing via lapping is foreseen to be established as equally competitive method compared to the remaining known and widely spread methods in the wooden furniture production practice. The expectation is that this method will find its rightful place among the modern technologies in leading enterprises of most countries in Europe and around the world.

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Possibilities for Manufacturing Eco-friendly Medium Density Fibreboards from Recycled Fibres – a Review

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ABSTRACT

The production of medium density fibreboards (MDF) is the second largest worldwide, preceded only by the production of plywood. A major advantage of this technology is the possibility for utilization of small-sized and low quality wooden raw material. However, the increased production and the expected average life cycle of panels of about 15-20 years result in significant amounts of post-consumer wood waste. Due to the content of synthetic adhesives the panels are not suitable for energy applications. On the other hand, their recycling and re-use will reduce the consumption of wood raw material.
Significant amounts of lignocellulosic waste and residues also remain in the production and recycling of paper and cardboard. This article presents a review and analysis of the current state of research in the field of recycling lignocellulosic fibres and possibilities for their use in the production of MDF panels. Different methods for recycling with and without the use of chemical reagents in terms of quantitative yield, quality of panels and production costs, are presented.

Key words: wood-based panels; wood waste, cascading use of wood; recycled fibres; MDF

1. INTRODUCTION

The transition to a circular and low-carbon economy have posed new actions and requirements towards a greater and more sustainable use of natural resources by sustainably increasing the primary production and conversion of waste into value-added products, enhanced production and resource efficiency. To meet these demands actions in a variety of areas are required, from the sustainable management of forests, to the more resource efficient use of wood in society (Antov *et al.*, 2018). Cascading use of wood resources, defined as *"the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system"* is one of the leading principles for achieving this goal (Stevulova *et al.*, 2016, Vis *et al.*, 2016). The wood-based industries produce significant amounts of waste and residues. According to Mantau (2012) 26 million tonnes of post-consumer wood (wood products that are disposed at the end of their life cycle, e.g. wooden furniture, window frames and wood-based panels, packaging, doors, windows, various construction materials, etc.) was generated in Europe in 2010. Currently, recovered wood is used for relatively low value applications including energy generation, particleboard manufacture, animal beddings and landscape uses (Irle *et al.* 2019).

Following the European economic recovery, European wood-based composite production increased by 2.8 % in 2016, to 74.7 million m^3 (European Panel Federation, 2017; UNECE/FAO, 2017). The consumption of fibreboard in Europe increased by almost 1 million m^3 in 2016. The annual consumption of medium-density fibreboard (MDF) in Europe increased by 15 % in 2016 (Mantanis *et al.*, 2018) as the main consumers of European MDF panels were furniture (45 %) and laminate flooring (32 %) manufacturers (European Panel Federation, 2017). This increased production and consumption in the recent years could subsequently generate significant quantities of waste wood-based panels at the end of their service life, requiring recycling instead of landfilling or incineration, due to the new stricter environmental legislation (Daian and Ozarska, 2009; Kim and Song, 2014). Moreover, most of the industrially produced wood composites are made with synthetic adhesives, which are cost-effective and perform very well regarding bonding performance, mechanical properties, thermal stability and water resistance (Jin *et al.*, 2010; Jivkov *et al.*, 2013a; Jivkov *et al.*, 2013b; Yang *et al.*, 2015) but have one major disadvantage, namely the free formaldehyde emissions, especially in indoor applications. This, together with the growing environmental consciousness related to sustainability of raw materials and end products has significantly increased the scientific interest towards the possibilities for recycling waste wood composites. The aim of this paper is to summarize the current state of research in the field of technologies for recycling waste and residues from wood composites in order to obtain fibres suitable for the production of MDF.

2. METHODS OF RECYCLING WASTE WOOD PANELS AND PRODUCTION OF MDF

Recycling used wood composites for their subsequent reuse in the production of new panels is a complex process which involves the disintegration of wood raw material, selection of an appropriate adhesive system and optimization of the hot press regime. Therefore, it is essential to understand the physical and chemical properties of wood and recycled materials, as well as the interactions between wood, recycled material, adhesive and technological conditions.

Three different principle methods can be applied for disintegration of waste wood panels: mechanical, thermo-hydrolytic and chemical, and combinations between them (Kharazipour and Kües, 2007; Lykidis and Grigoriou, 2008; Karade, 2010; Kim and Song, 2014; Roffael, 2002; Roffael *et al.*, 2002; Mantanis *et al.*, 2004; Michanickl and Boehme, 1995a; Michanicki, 1997; Moezzipour *et al.*, 2017a; Moezzipour *et al.*, 2017b; Athanassiadou *et al.*, 2005).

Mechanical disintegration severely damages the structure of wood fibres and the fibres have poor wettability with urea-formaldehyde resins and phenol-formaldehyde resins, but better wettability with isocyanate adhesives (Roffael and Schneider, 2003, Hameed *et al.*, 2005). In addition, disintegration in dry conditions leads to the formation of high quantities of dust and fine particles and partial charring of surfaces of larger pieces occurs as well (Ihnát *et al.*, 2017).

The thermo-hydrolytic disintegration, which uses steam and pressure to cleave the existing bonds in wood composites, glued by hydrolysable adhesives, produces better quality fibres than those of the mechanical disintegration. It is generally performed under pressure in the temperature range of 120–180 °C (Roffael and Kraft, 2004, Kharazipour and Kües, 2007).

Reclaiming fibres from the waste wood panels and residues with a twin extruder machine (Athanassiadou *et al.*, 2005), or a thermo-mechanic refiner (Roffael *et al.*, 2010) or a steam exploder resulted in a reduction of fibre length of about 30 % less than the virgin fibres because they may be mechanically damaged by the refining devices (Hui *et al.*, 2014; Qi *et al.*, 2006).

A comparison of the physical and mechanical properties of the MDF panels manufactured with the recycled fibres and the fresh fibres showed that a substitution of 15 % of the virgin fibres by recycling fibres had no negative effect on the physical and mechanical properties of the panels, but the replacement of 33 % virgin fibres resulted in a significant decrease in the physical and mechanical properties (Ju and Roh, 2017; Roffael *et al.*, 2016). MDF manufactured with higher amounts of recycled fibres (67 and 100 %) could not be produced without applying the hybrid bonding technology whilst MDF made from 100 % recycled fibres showed significantly lower thickness swelling values as well as a serious drop in the formaldehyde release compared with boards made from virgin wood fibres (Roffael *et al.*, 2016). It was considered this may be due to the effect of morphologic parameters and surface contamination of the recycled fibres with the expired urea-formaldehyde used as a primary adhesive in the production of the MDF panels.

The effect of recycled wood fibre content on the properties of MDF were also studied by Lubis *et al.* 2018. After preliminary treating of waste MDF panels, the authors used a refiner and hammer mill to isolate recycled fibres from two softwood tree species. Recycled MDF panels were fabricated using the obtained refiner and hammer mill recycled fibres at quantities of 0, 5, 10, 20, 30, 50, and 100 %. The highest internal bond strength of the recycled MDF was determined at 10 % recycled fibre content, regardless of isolation method and wood species. The mechanical properties, including modulus of rupture, modulus of elasticity, and screw withdrawal resistance showed behaviors similar to the internal bond strength with increasing the content of recycled fibres. However, the thickness swelling, water absorption, and formaldehyde emission of the new MDF decreased with increasing recycled fibre content. As a result of the performed statistical analysis it was determined that the minimum of 10 % recycled fibres can be used to replace virgin fibres without deteriorating the MDF properties. The improved properties of recycled MDF panels were attributed to the reinforcing effects of recycled fibres covered with cured resins.

According to a study, conducted by Hwang *et al.* 2005, replacing virgin fibres with recycled fibres adversely affected physical and mechanical properties of fibreboard. Bending properties and dimensional stability were linearly dependent on virgin fibre ratios. All panels with recycled fibre content above 40 % failed to meet any commercial requirement.

Another study investigated the effects of the addition of recycled fibres obtained from surface laminated MDF panels with three different materials to the properties of three-layer recycled MDF (Hong *et al.*, 2018). Three types of surface laminates (low-pressure laminate, polyethylene terephthalate, and polyester coating) were hammer milled, and then went through a patent-pending fibre recovery system to obtain the recycled fibres that were added to the core layer of the new recycled MDF at three contents (10, 20 and 30 %), blended with 12 % urea-formaldehyde resin to hot-pressing. The best internal bond strength, modulus of rupture and modulus of elasticity of the new recycled MDF panels were obtained at 20 % recycled fibre content. The authors reported that increasing the recycled fibre content resulted in reduced thickness swelling, water absorption, and formaldehyde emission.

Moezzipour *et al.*, 2018 studied the performance of the electrical method in MDF wastes recycling. To determine the practical aspect of the electrical method, the hydrothermal method as a known recycling method was also studied. Recycled fibres were analyzed by determination of the chemical composition of fibre and fibre classification. The results showed that some changes in the chemical composition of recycled fibres occurred in comparison with the virgin fibres, especially for the hydrothermal method where lignin content was significantly reduced. Fibre classification test showed significant reduction in the length of the fibres recycled by hydrothermal method as compared to other fibres. Investigations of the quality of manufactured MDF boards showed that the electrical method performed better in comparison with the hydrothermal method.

The pulp and paper industry generates large quantities of waste lignocellulosic materials which can be recycled and used for fabrication of MDF panels. Pulp and paper sludge can be recycled in the manufacture of MDF panels because it contains wood fibres. A comparative research studied the properties of MDF made from virgin fibres mixed with different pulp and paper sludge sources (Migneault *et al.*, 2010). The investigated factors were mill pulping processes, thermal-mechanical pulping, chemical-thermal-mechanical pulping, and kraft pulping, and percentage of sludge mixed with virgin fibres (0, 25, 50, and 75 %). According to the reported results the properties of MDF panels decreased mostly linearly with sludge content. Panel properties negatively correlated with the proportion of non-fibrous material such as ash and extractives. It was concluded that the amount of sludge that can be incorporated into MDF without excessive decrease in panel quality depends on the pulping process. At 25 % sludge content, all panels met the quality requirements for MDF used for interior applications.

Antov *et al.* (2019) studied the possibilities for utilization of low quality lignocellulosic paper mill waste, which had undergone only mechanical recycling, in the production of insulation boards with and without surface layer, using a technology, similar to the production of dry-process fibreboards. Several design variants of insulation boards with recycled lignocellulosic fibres were developed and manufactured in laboratory conditions. The main mechanical properties were determined in order to analyze the possibilities of application of the boards. It was determined that the experimental boards had very good water resistance and sound insulation properties. As a typical porous material the boards had better sound insulation properties at higher sound frequencies. However, the low bending strength values represent an impediment for standalone application of the boards which can be overcome by surface treatment with phenol formaldehyde resin or inclusion of a secondary material such as paper or veneer.

Nourbakhsh *et al.* (2010), investigated the use of old newsprint fibres as a raw material for laboratory MDF panels. The authors determined the effect of old newsprint fibres mixed with virgin aspen fibres and the press time (3, 4, and 5 min) on the properties of MDF panels. Panels were produced using aspen fibres in surface layer and combination of aspen fibres and old newsprint fibres in the core layer. The authors concluded that old newsprint can be considered as a potentially suitable raw material for manufacturing MDF panels without having any significant adverse influence on the panel exploitation properties.

Recycled fibres still contain cured resin residues and exhibit high formaldehyde emissions in recycled MDF panels (Roffael *et al.*, 2016). A research, carried out by Lubis *et al.* 2018 studied the removal of cured urea-formaldehyde resins from MDF panels by hydrolysis, finding that almost 75 % of cured resins were removed from MDF after acid hydrolysis, 50 % after neutral hydrolysis, and 25 % after alkaline hydrolysis. This indicates that 25–75 % cured urea-formaldehyde resins remain in the recycled fibres, depending on hydrolysis conditions.

Grigsby *et al.* (2014a) investigated the levels of cured urea-formaldehyde resins in MDF panels by water extraction. The authors reported a significant difference in water extractable resin components between cured pure resin and that from MDF panels.

The mechanical properties of MDF panels depend on the properties of the wood fibres (Ganz *et al.*, 2006; Lee *et al.*, 2006), fibre orientation or mat structure (Sliseris *et al.*, 2017), the adhesive system (Grigoriou, 2000), quantity and distribution of adhesives on fibre surface (Doosthoseini *et al.*, 2010) as well as hot-pressing technological parameters (Gul *et al.*, 2017). The fibre length and its distribution are related with fibre bulk density, affecting the construction of internal mat structure of MDF (Lu *et al.*, 2007; Townshend *et al.*, 2015), and all mechanical properties could be improved by increasing fibre length (Benthien *et al.*, 2017). In addition, the morphological and chemical characteristics of the fibres are also major factors affecting the properties of MDF panels (Grigsby and Thumm, 2004; Roffael *et al.*, 2010).

3. CONCLUSIONS

The technical possibilities to utilize different wood panel waste and residues in new products determine the physical boundary conditions for cascading use of wood resources. Despite the presented different methods and technologies for recycling waste wood-based composites and their reuse in the production of MDF panels, there are still many difficulties and drawbacks for their wide application at an industrial scale. These technical barriers should be addressed by future research and development activities aiming to further develop recycling in wood panel industry, including extensive research on solutions for closing the material loop. Strong efforts are also needed to address the recent imbalance between material and energy uses of industrial residues, where more significant potential for wood cascading exists.

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Influence of Different Wood Specie Chemical Composition on the Liquefaction Properties

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ABSTRACT

This paper presents the properties characterization of liquefied different wood species according to their chemical composition. Four hardwood species namely black poplar (*Populus nigra* L.), beech (*Fagus sylvatica*), sessile oak (*Quercus petraea* Liebl.) and common oak (*Quercus robur* L.) and two softwood species namely common fir (*Abies alba* Mill.) and spruce (*Picea abies* Karst.) were liquefied via catalytic liquefaction in the reactor using glycerol solvent as liquefaction reagent under defined reaction conditions: wood/glycerol=1:5, sulfuric acid as catalyst (3 wt%) at 150 °C for 120 min. The chemical composition analysis of the same wood species was carried out for their influence on liquefaction properties. The percentage residues, liquefaction degree and hydroxyl OH-numbers were determined as liquefaction properties. According to gained results and as the main aim, it determined the most suitable wood species for the liquefaction process in terms of obtaining the best liquefaction properties. Furthermore, this reagent system was showed suitable for liquefaction of a wide variety of wood species.

Key words: hydroxyl number, liquefaction degree, residue percentage, wood liquefaction, wood species

1. INTRODUCTION

As the current model of production and consumption which largely relies on fossil-based resources impacts irreversibly on the environment and the availability of natural resources is approaching a peak soon. Significant steps are being taken around the world to move from today's fossil based economy to a more sustainable economy based on biomass. A key factor in the realisation of a successful biobased economy or bioeconomy is the production of a range of biobased products and bioenergy to substitute their fossil-derived equivalents by processing a wide variety of biological feedstock. The EU has declared the biobased products sector to be a priority area with high potential for future growth, reindustrialisation, and addressing societal challenges. Furthermore, the circular economy is defined as an economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological-cycles, and focuses on the efficient use of finite resources and ensures that these resources are reused as long as possible (IEA Bioenergy, 2017; AEBIOM, 2017).

Wood as a lignocellulosic biomass is one of the most affordable and important renewable raw materials in the world that can partially replace fossil resources. Two fundamental aspects related to the use of wood biomass in the production of bioproducts are the extension and improvement of basic knowledge of chemical composition and properties and how to apply that knowledge to more advanced and sustainable use of biomass. It is a multicomponent, hygroscopic, anisotropic, fibrous, porous, biodegradable and renewable raw material, and it is generally clear that every wood species is unique in its chemical composition and varies from species to species, as well as their chemical, physical, and mechanical properties that show a wide spectrum of end-use possibilities. For these reasons, it can be assumed that basic knowledge of the structure and chemical composition of wood is of essential importance, considering the choice optimization of certain wood species for different applications (Antonović *et al.*, 2018).

Wood is complex heterogeneous mixture of key structural organic components such as cellulose, hemicellulose, and lignin along with accessory organic and inorganic matter. From the chemical point of view, wood consists 40–45 % cellulose, 25–35 % hemicelluloses, 15–30 % lignin and up to 10 % other compounds. All the main wood components are high-weight-molecular polymers and form an interwoven network in the wood cell wall; consequently we can say that the wood is a natural polymer. The chemical composition of wood tissues (sapwood and heartwood), as well as bark is equally complex, and varies between and within species. Comparing the chemical composition of tissues and bark, it can be concluded that the bark contains a higher content of ash, accessory materials (extractives) and lignin, and a lower content of polysaccharides cellulose and polyoses (hemicellulose). The qualitative and quantitative characterization of such components in the biomass is essential for its application perspectives (Antonović, 2010).

The chemical composition of wood depends on a number of different factors, such as wood species, anatomical parts of wood (heartwood, sapwood, stem, root, branches, leaves, etc.), geographic location, habitation, growth, climatic characteristics, and degree of fungal and insect attacks, as well as the applied chemical analytical isolation methods and calculation techniques (Rowell, 2005). Previous quantitative studies of the chemical composition of beech wood revealed the most significant differences in the content of certain components (accessory material and cellulose) from different sampling locations, which differ among themselves according to mentioned different ecological factors (Antonović *et al.*, 2007; Antonović *et al.*, 2008).

With an emphasis on enhancing sustainable development, new methods of alternative use of biomass are being explored, and major advances have recently been made in the development of new technologies for the effective utilization of biomass and the production of environmentally friendly bio-based products. Common methods used in the production of bioproducts (biofuels, bioenergy, biochemicals and biomaterials) from biomass are biochemical and thermochemical conversion methods. Of the thermochemical conversion methods, the most attention was drawn to the wood liquefaction in the presence of some organic reagents (Antonović *et al.*, 2017a; Antonović *et al.*, 2017b).

Liquefaction reactions with phenols and polyhydric alcohols are the most interesting methods in the previous researches and literature. After the discovery of the wood liquefaction phenomena, researches of different liquefaction parameters were conducted (types and ratios of reagents or solvents, catalysts types, liquefaction times and temperatures, wood or biomass species, anatomical part and sample granulations), in terms of (1) increasing of biomass concentration in liquefaction mixture, (2) achieving the real liquefaction degree with respect to solubility properties of liquefied biomass in organic solvents, (3) comprehension and understanding of the wood liquefaction mechanism, and (4) further application (Antonović *et al.*, 2011).

The influence of wood chemical composition on liquefaction behaviour of different species and the chemical properties of liquefied wood have not been studied much. Some articles reported strong influence of wood species on liquefaction process using polyethylene glycol as the liquefying agent at 3:1 liquid ratio and 120 minutes of reaction. The softwood species exhibited higher residual content as compared to hardwood species. Within hardwood species also significant differences were observed in liquefaction efficiency (Kurimoto *et al.*, 1999; Kurimoto *et al.*, 2001). Ertas *et al.* (2014) compared liquefaction efficiency of Eucalyptus and pine wood in PEG-400 /glycerine system and found significant differences in characteristics of liquefied wood from two species. Hardwood species are highly variable in terms of their anatomical structure, density and extractive content which can influence the liquefaction process. Chauhan and Karmarkar (2009) studied the liquefaction efficiency of Hevea brasiliensis wood in phenol with hydrochloric acid as a catalyst and found liquefaction efficiency of 49 % to 82 % under different reaction conditions. Kumar *et al.* (2018) studied the liquefaction behaviour of twelve tropical hardwood species also in phenol at 140 °C temperature for 120 minutes at different liquid ratios. It was concluded that the liquefaction efficiency vary with species and liquid ratio.

In this study, liquefaction properties of four hardwood species namely black poplar (*Populus nigra* L.), beech (*Fagus sylvatica*), sessile oak (*Quercus petraea* Liebl.) and common oak (*Quercus robur* L.), and two softwood species namely common fir (*Abies alba* Mill.) and spruce (*Picea abies* Karst.) were determined using glycerol solvent as liquefaction reagent under defined reaction conditions: wood/glycerol=1:5, sulfuric acid as catalyst (3 wt%) at 150 °C for 120 min. The liquefied wood was characterized for properties like percentage residues, liquefaction degree and hydroxyl OH-numbers. The chemical composition analysis of the same wood species was carried out for their influence on liquefaction properties. According to above, the main aim of this study was to determined liquefaction properties of different wood species in dependence to their chemical composition.

2. MATERIALS AND METHODS

2.1. Wood species and sample preparation

For this research were used four hardwood species namely black poplar (*Populus nigra* L.), beech (*Fagus sylvatica*), sessile oak (*Quercus petraea* Liebl.) and common oak (*Quercus robur* L.) and two softwood species namely common fir (*Abies alba* Mill.) and spruce (*Picea abies* Karst.).

TAPPI test method T257 cm-02 was used as a sampling procedure. As the method requires, samples were taken promptly after tree cutting, and the criterion for taking samples was cutting off a ring on first log from trunk, approximately at 2 m height. Thickness of hatched rings were between 5-15 cm. All samples have been fresh and without any wood defects.

Furthermore, samples were prepared according to previous studies (Hames *et al.*, 2008; Antonović *et al.*, 2010). After the laboratory drying during 14 days, bark was mechanically separated from sapwood and heartwood. Mixture of sapwood and heartwood was used in this studie. Air-dried samples were milled using a knife-mill Fritsch – Pulverisette 19 on different particles size. After milling, samples were sieved through standardized sieves. The milled particles which passed the screen of sieve 0.71 mm and stay on sieve 0.325 mm were used in further chemical analysis, due to their ideal particle size for all isolation methods of group chemical composition, and which is recommended in previous studies. For screening, laboratory electromagnetic sieves shaker Cisa RP.08 (shaking time t=15±1 min) was used (TAPPI T 264 cm-97). After sample grinding and sieving, three smaller samples were taken on which all the chemical analysis and liquefaction were performed, and the results are presented as the mean values of these three samples.

2.2. Group chemical composition isolation methods

Isolation methods for determining the content of different wood species samples group chemical composition (wet chemistry), namely ash, accessory materials (extractives), cellulose, hemicellulose (polyoses) and lignin were conducted in compliance with previous study (Antonović *et al.*, 2007; Antonović *et al.*, 2008; Sluiter *et al.*, 2005a; Sluiter *et al.*, 2005b; Sluiter *et al.*, 2008). Sample chemical compositional analysis consisted of a series of isolation methods of the main components, which can be schematically presented as shown in Figure 1. A small portion of the prepared sample was first used to determine the ash content, and the other major part for prior sample extraction (treatment with a solvent mixture of methanol, CH_3OH and benzene, C_6H_6 in the volume ratio 1:1) to remove the accessory materials from sample which could interfere during further chemical analysis. Thus, additional residual solid content was determined as a content of accessory materials or extractives. Furthermore, sulfonic acid lignin or Klason's lignin (treatment with 72 % sulfuric acid, H_2SO_4) and the polysaccharides cellulose (by treatment with a solvent mixture of nitric acid, HNO_3 and ethanol, C_2H_5OH in a volume ratio of 1:4) was isolated from the extracted sample. The content of hemicellulose (polyose) was determined by calculation according to share of other mentioned components in the samples. The hemicellulose content was calculated according to next expression: WP = 100 - (% A +% AM +% C +% L) in %. All used chemicals were high purity (p.a.) and were obtained from commercial sources.

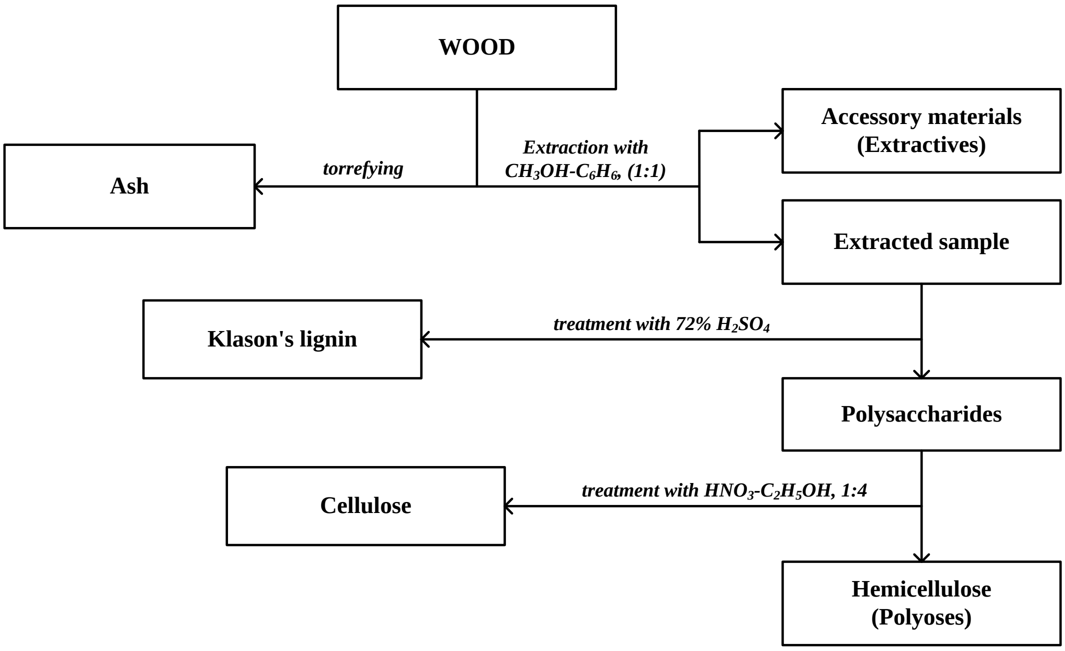

Figure 1. Shematic view of sample chemical analysis

2.3. Liquefied wood (LW) preparation

Liquefied wood was prepared based on previous study according to Antonović *et al.* 2014 (Figure 2). Smaller obtained samples (without any prior chemical treatment) of different wood species was liquefied with mixture of glycerol and sulfuric acid (H_2SO_4) by acid catalyst method during 120 min at 150 °C. Undissolved residue percentage and wood liquefaction degree, as well as hydroxyl number (OH-number) were determined as values which are describing polymer properties of LW for the purpose of selecting optimal liquefaction parameters.

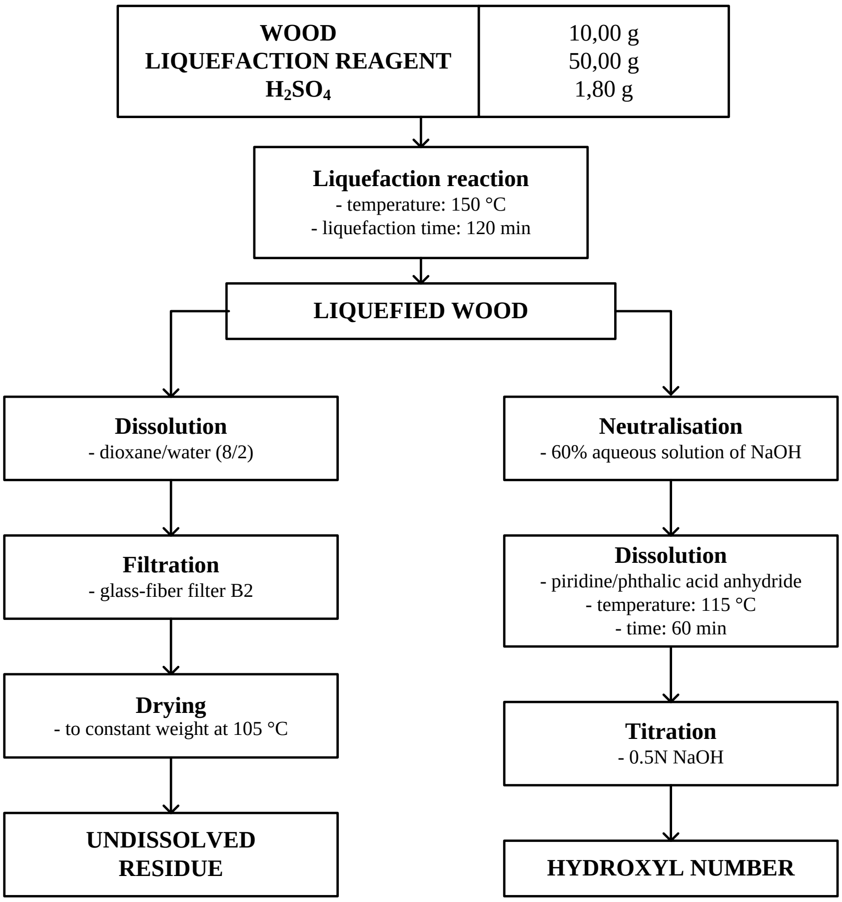

Figure 2. Liquefaction procedure and analytical methods for liquefied wood characterisation (according to Antonović et al. 2014)

2.4. Undissolved residue and liquefaction degree

After the liquefaction reaction, undissolved residue (UR) of liquefied wood was determined by the dioxane/water mixture, which is recommended as a universal diluent for liquefied biomasses. 1g of liquefied wood was diluted with dioxane/water mixture in ratio 8/2, and then stirred in a magnetic stirrer for 60 min. After that mixture was filtrated through glass-fibre filter B2 in a vacuum. The residue was rinsed by the same diluent repeatedly until a colourless filtrate was obtained, and then the undissolved residue was dried in oven at 105 ± 2 °C to a constant weight. Undissolved residue percentage was calculated by the following equation:

$$UR = \frac{weight\ of\ undissolved\ residue\ (g)}{weight\ of\ liquefied\ wood\ (g)}\ x\ 100 \qquad (\%) \qquad (1)$$

Liquefaction degree (LD) percentage was calculated according to next equation:

$$LD = 100 - UR \qquad (\%) \qquad (2)$$

2.5. Hydroxyl number (OH-number)

1,5 – 2,5 g of liquefied wood was weight into two 250 ml volume Erlenmeyer's flasks and then added 10 ml of reagent. Reagent was mixture of pyridine and phthalic acid anhydride. Into the third flask we added only reagent, for determination of blank solution. Each flask was equipped with condenser and magnetic stirrer with heater, and each magnetic stirrer had oil bath, which was used for keeping constant temperature from 115 °C, and with help of condenser we condensed reagent. Mixture in the flask was heated exactly one hour measured from the moment when first drop condensed. After that to the cooled mixture new 50 ml of pyridine was added and titrated with the 0.5M sodium hydroxide solution with presence of phenolphthalein until equivalent point was reached (the bright red staining should not appear at least 30 seconds). Hydroxyl number for liquefied wood sample in mg KOH/g was calculated from the following equation:

$$OH - number = \frac{(B-A)\ x\ c_{NaOH}\ x\ 56.1}{m} \qquad (mg\ KOH/g) \tag{3}$$

where is: A – volume of the NaOH solution spended for sample titration (ml); B – volume of the NaOH solution spended for blank solution titration; c_{NaOH} – normality of the NaOH solution (M); m – weight of liquefied wood sample.

3. RESULTS AND DISCUSSION

3.1. Chemical composition of different wood species

Wood chemical composition namely ash content, accessory materials (extractives) content, cellulose content, polyoses (hemicellulose) content and lignin content of the different species are given in Table1 and graphically presented in Figure 3. Ash content among the species was varying from 0.15 to 1.39 %, accessory materials content from 1.30 to 4.34 %, cellulose content from 39.18 to 48.38 %, polyoses content from 22.69 to 32.41 % and lignin content from 21.82 to 27.96 %. Obtained results for different wood species are in accordance to previous studies in literature which was mentioned in this article introduction chapter.

Table 1. Chemical composition of different wood specie

No.	Wood specie	Wood specie latin name	% A	% AM	% C	% P	% L
1	Black poplar	*Populus nigra* L.	0.58	2.71	46.67	26.93	23.11
2	Beech	*Fagus sylvatica*	0.51	2.25	42.27	32.41	22.56
3	Sessile oak	*Quercus petraea* Liebl.	0.17	4.34	42.77	29.12	23.60
4	Common oak	*Quercus robur* L.	1.39	4.09	47.23	25.47	21.82
5	Common fir	*Abies alba* Mill.	0.15	1.30	39.18	31.40	27.96
6	Spruce	*Picea abies* Karst.	0.28	2.36	48.38	22.69	26.29

A – ash; AM – accessory material; C – cellulose; P – polyoses; L - lignin

For low molecular weight wood substances, the ash content is similar for all wood species, while the extractive content is significantly higher for hardwoods compared to softwoods.

When it comes to the high molecular weight substances of wood, namely cellulose, polyoses and lignin, they vary considerably from species to species. It is a well-known fact that the polysaccharide content of wood (cellulose + polyoses) is higher in the hardwoods and the lignin content is much higher in the softwoods, as the results obtained in this study showed.

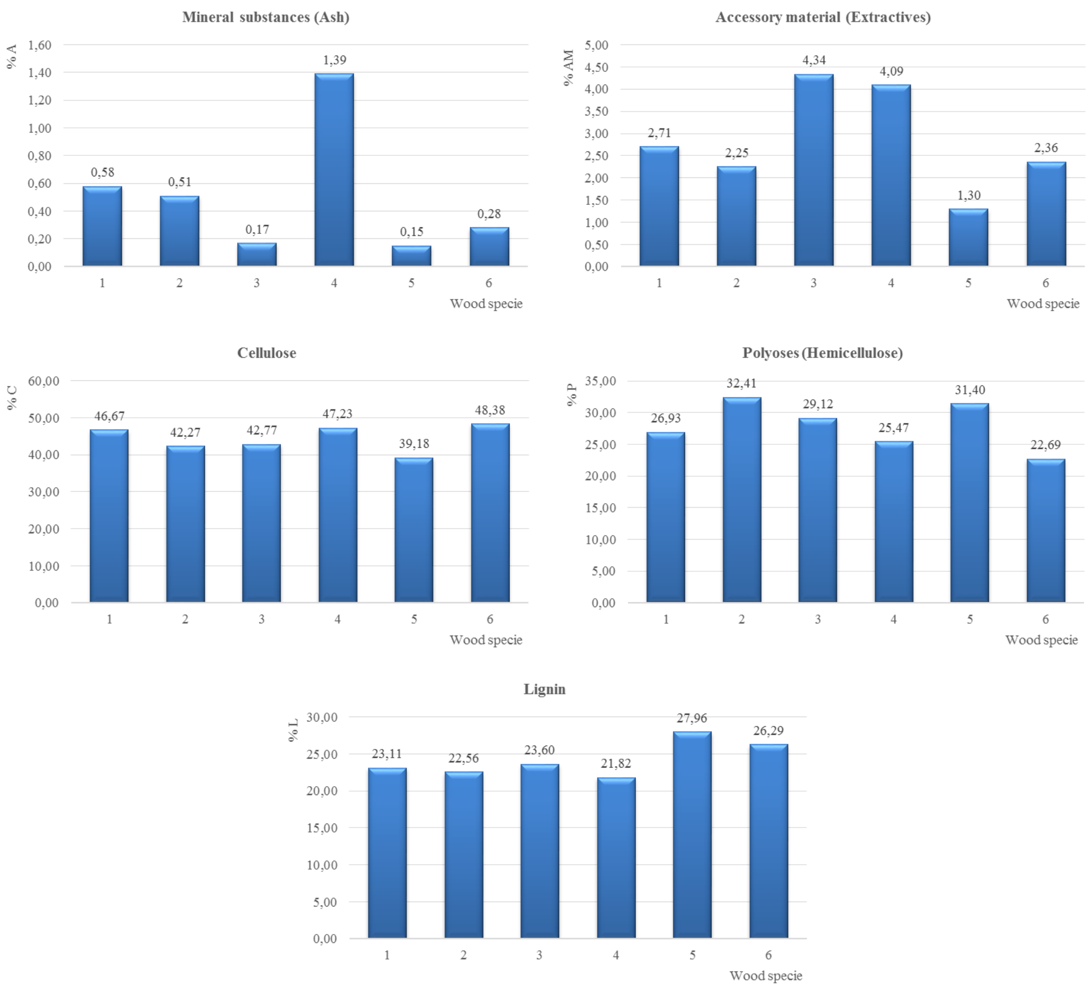

Figure 3. Chemical composition of different wood species

3.2. Liquefaction properties of liquefied different wood species

Liquefaction comprises a complex set of reactions taking place on the polymeric components of wood. They include derivatization such as esterification or etherification of free hydroxyl groups in cellulose or lignin as well as reactions that break the polymer chain of cellulose. In addition, liquefaction is affected by physical constraints on wood reactivity such as the high crystallinity of cellulose. The tight packing of cellulose in the crystalline domains makes the reaction kinetics of otherwise reactive functional groups dependent on the diffusion of reagents into the tightly packed system. To overcome this limitation and speed up the liquefaction, increasingly harsh catalysts and reaction conditions, mainly mineral acids and high temperatures, have been employed. In short, macromolecule compounds in biomass are degraded into micro molecules and the obtained small molecules are unstable, reactive and can re-polymerize into oily products with a wide range of molecular weight distribution.

The liquefaction properties of liquefied different wood species namely undissolved residue, liquefaction degree and hydroxyl (OH)-number are given in Table 2. Undissolved residue content among the liquefied wood species was varying from 5.06 to 11.53 %, liquefaction degree content from 88.47 to 94.94 % and hydroxyl (OH)-number from 544 to 798 mg KOH/g. Among the liquefied different wood species, the lowest undissolved residue content was achieved in spruce and the highest in beech, and opposite to that lowest liquefaction degree content was achieved in beech and highest in spruce. Hydroxyl number was lowest in common fir and highest in beech.

Table 2. Liquefaction properties of different liquefied wood species

No.	Wood specie	Wood specie latin name	% UR	% LD	OH (mg KOH/g)
1	Black poplar	*Populus nigra* L.	9.00	91.00	692
2	Beech	*Fagus sylvatica*	11.53	88.47	798
3	Sessile oak	*Quercus petraea* Liebl.	9.20	90.80	765
4	Common oak	*Quercus robur* L.	8.02	91.98	744
5	Common fir	*Abies alba* Mill.	6.20	93.80	544
6	Spruce	*Picea abies* Karst.	5.06	94.94	575

UR – undissolved residue; LD – liquefaction degree; OH – hydroxyl number

The hardwood species exhibited higher undissolved residue and lower liquefaction degree content as compared to softwood species. Within hardwood species also differences were observed in the same liquefaction properties. Although softwoods show the smallest undissolved residue content and the highest liquefaction degree content compared with hardwood, the hardwoods show a much higher OH-number. Hydroxyl number is very important in further liquefied wood application for various bioproducts, therefore it should be given priority over undissolved residue and liquefaction degree. According to that all hardwoods (692 to 798 mg KOH/g), and especially beech (798 mg KOH/g), show better properties in further application compared to softwoods (544 to 575 mg KOH/g).

3.3. Influence of different wood chemical composition on liquefaction properties

The influence of different wood chemical composition on liquefaction properties namely undissolved residue, liquefaction degree and hydroxyl (OH)-number can be shown by comparing Table 1 with Table 2. After comparison we found some differences in properties from different wood species chemical composition.

The results obtained in these studies have shown that increased content of accessory materials and polysaccharides (cellulose + polyoses) and decreased lignin content of the hardwoods compared to softwoods cause increased content of undissolved residue and OH-number and decreased content of the liquefaction degree. Different hardwood species with an increased content of cellulose show a reduced content of insoluble residue and OH-number and an increased liquefaction degree content. If we consider the OH-number as the most important liquefaction property, depending on the wood chemical composition, then hardwoods with reduced lignin content and increased accessory materials and polysaccharides content are more suitable species for the liquefaction process compared to softwoods.

At the end, liquefaction procedure via catalytic liquefaction in the reactor using glycerol solvent as liquefaction reagent under defined reaction conditions: wood/glycerol=1:5, sulfuric acid as catalyst (3 wt%) at 150 °C for 120 min showed suitable for liquefaction of a wide variety of wood species.

4. CONCLUSIONS

The study revealed that different hardwood and softwood species can effectively be liquefied in glycerol using H_2SO_4 as a catalyst with liquefaction efficiency ranging from 88.47 to 94.94 % under same liquefaction conditions.

Hydroxyl number as the most important liquefaction property in further application for various bioproducts have priority over undissolved residue and liquefaction degree, and according to that all hardwoods, show better properties in further application compared to softwoods. Furthermore, depending on the wood chemical composition, hardwoods with reduced lignin content and increased accessory materials and polysaccharides content are more suitable species for the liquefaction process compared to softwoods.

Liquefaction procedure via catalytic liquefaction with polyhidric alcohol glycerol showed suitable for liquefaction of a wide variety of wood species.

Finally, the present study indicated unimaginable possibilities of scientific research and development aimed to novel bioproducts derived from liquefied wood, and opened new challenges in the researches of natural, environmentally impeccable products with unlimited raw resources.

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Enhancing School Environment Design by Observing User's Behaviour

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ABSTRACT

School furniture design which follows the latest pedagogical guidelines is a neglected topic in the education system of many countries in the world. This paper highlights preliminary results of the project "Enhancing children's well-being by sustainable school furniture design", which has a goal to enhance the school environment and furniture design, environmental creativity, sustainability and well-being of elementary school students by new furniture concepts. The first phase of the project was to analysing school environment and furniture typology in New York Central District Elementary Schools (USA) vs Zagreb City Elementary Schools (Croatia) and observing user's behaviour using current equipment in NYS public school classrooms. Among all schools which have mostly traditional furniture but creative layouts, new efforts are found in Groton Elementary School, Groton NY. This school will be used as a starting point for the new observations and creative design concepts in the next phase of the project.

Key words: students, educational environment, creativity, well-being, user's attitudes, furniture design

1. INTRODUCTION

Design of school environment and school furniture represents a transdisciplinary insufficiently researched problem. During the year, students spend much more awake hours in the classroom than at home. Responsible and user-oriented design observes children and adolescents as a specific and sensitive user group, mostly because during the school period children pass through intense psychophysical, cognitive, social and emotional growth and development (Domljan, 2019).

Most people want their homes to be beautiful, functional and comfortable, in other words - we want to feel good and safe, and live in the vibration of well-being. This trend is spreading in almost all public spaces; office environments, hotels, workplaces and healthcare facilities. What about school environments? School environments and furniture design which follows the latest pedagogical guidelines is a neglected topic in the education system of many countries in the world (Domljan *et al*., 2015). Why do most people, especially those who are in responsible positions and deciding how to equip classrooms, not realize how crucial are design of school environment and furniture to the well-being of the students and their learning outcomes?

Even 40 years ago Sommer and Olsen (1980) founded that a renovated school classroom, including soft furnishings and designed to be more friendly and attractive, seemed to increase student participation. They report that student participation rates in discussions and in asking questions during classes were 'two or three times as high' as in comparable classes taught in traditional rooms. Ching Yee Wong *et al.* (1992) followed-up the former mentioned research on an innovative classroom designed to improve aesthetics and increase student participation. They confirmed that, despite a deterioration in aesthetics due to neglect and poor maintenance, the room continued to maintain a constituency among students and faculty, and to enhance student participation relative to straight-row classrooms. Unfortunately, many schools all around the globe have the same problem with furniture design and furniture purchase which is not in relation to the contemporary pedagogical guidelines, educational changes in learning behaviour, active learning methods or the needs of the users – either students or teachers. In the purchasing process neither teachers nor students were asked what they really need in school classrooms to improve their well-being. They are simply "getting used" to the layouts and furniture they get when purchasing and are content to get any product so they can work (Domljan 2011; Domljan *et al.*, 2015).

Research results from University of Newcastle, supported by the Design Council (Higgins *et al*., 2005) has confirmed that little is known about how school environment and furniture design affect the attitudes, behaviour and well-being of children, enhance their willingness to learn, increase creativity and desire to preserve the school environment. Almost fifteen years ago professor Stephen Heppell argued that "…whereas, traditionally, we have designed for productivity, processing large numbers of children through the effective use of buildings, designing a room for learning is very complex. (…) No one knows how to prevent *learning-loss* when you design a room "pedagogically", whereas we know lots about designing for minimum *heat loss*". (…) At the same time our understanding of learning itself is changing. Research on learning styles, formative assessment, multiple and emotional intelligences, constructivism and so on have combined with the rapid development of technology-enabled, peer-to-peer and self-directed learning to facilitate very different approaches to the *30-students-in-rows* model. But despite these changes, we do not yet have a robust research base for integrated and personalised learning environments" (Foreword by Greany, T., in: Higgins *et al*., 2005; pp. 3-4).

A lot has been done since then in research topics on school environment and on active learning outcomes vs traditional ones (*Figure 1*) (JISC, 2006; Azemati *et al.*, 2018; Deslauriers *et al*. 2019).

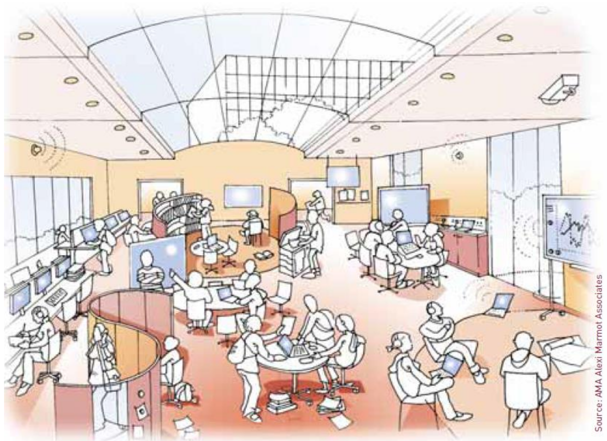

Figure 1. Learning Centre. Source: JISC, 2006; AMA Alexi Marmot Associates
Note: This illustration provides an overview of possible designs for 21st century learning spaces. It does not represent the design of any particular institution.

A wide range of stimulus conditions fall into the category of "classroom environmental variables and setting events". Some of these conditions are temperature, lighting, seating arrangement, noise level, and the presence or absence of peers or adults. Of interest is seating arrangement because variables related to seating arrangement, such as classroom position, have been shown to impact on educational interactions (Wannarka and Ruht, 2008). Although some results indicated that school furniture is not "the main problem" while learning or is considered as sub-factor, furniture layout has important influence on students learning outcomes and behaviour (Wannarka and Ruht, 2008; Baum, 2018; Azemati *et al.*, 2018). Many former results prove that furniture may cause a lot of physical and behavioural problems or disorders in future (Knight and Noyes,1999; Hastings and Wood, 2002; Hedge and Lueder, 2007).

Studies around the world confirm the mismatch between furniture and children in schools, child dissatisfaction and complaints about musculoskeletal disorders, back pain (MSD/BP) and headaches (Hedge and Lueder, 2007; Domljan *et al*., 2008; Jones and Macfarlane, 2005; Trevelyan and Legg, 2006; Azabagić *et al*., 2016). Today's school environment design is mostly discouraging and outdated, dysfunctional, does not follow secular trends in physical growth or encourage a sense of well-being at school (Domljan *et al*., 2015).

With all the above, numerous researches had confirmed that a well-designed environment with predominant sustainable wood materials positively affects the attitudes and behaviour of the user, increasing creativity, willingness to work and preserving the environment, calm people and enhance well-being (Rice *et al.*, 2006). Natural materials, such as wood, are associated with better user's outcomes with respect to recovery times, lower pain perception, and positive dispositions. Kelz *et al*. (2011) studied this use of wood in classrooms and found that over the course of a school year pupils' heart rates significantly decreased in the solid wood classroom. They noticed that perceived stress from interactions with teachers (e.g. being shouted at, being ignored) decreased significantly over the school year in the solid wood classroom, while it did not change for pupils in the control classroom. On the other hand, this study did not find significant differences or changes over time in pupils' concentration, but overall well-being is increased.

This paper highlights preliminary results of the project "Enhancing children's well-being by sustainable furniture design", which has a goal to enhance the school environment and furniture design, environmental creativity, sustainability and well-being of elementary school students.

2. PROJECT BACKGROUND

The project "Enhancing children's well-being by sustainable furniture design" seeks to enhance the environmental creativity, sustainability and well-being of students in educational institutions by listening to users' attitudes, observing their behaviour and preferences, in order to enhance school environment and furniture design.

As it mentioned above, the design of school environment and school furniture represents an interdisciplinary and insufficiently researched problem – from the architectural and designers, pedagogical, ergonomics, educational, psychological, environmental, sustainable, health, and other point of views. In addition to all these aspects and areas of research, this project emphasizes sustainable materials and the use of wood as a possible raw material in the design of school interiors and furniture. It confirmed that a well-designed environment with predominant sustainable wood materials positively affects the attitudes and behaviour of the user, increasing creativity and well-being.

The project is implemented in the period of two months during October and November 2019 in the cooperation with professors and students at Department of Design and Environmental Analyses (D+EA), College of Human Ecology, Cornell University, Ithaca NY, USA, and teachers and children from New York Central District Elementary Schools, USA.

Expected outcomes of the project are new product concepts/sketches in terms of user's-oriented design: visual perception, aesthetics, functionality, ergonomics, education, psychology and sociology, use of sustainable (wood) materials, production technology, environmental aspect, cost and quality. The project is fundamentally focused on the comparison of the state in the United States and the Republic of Croatia school environment and furniture typology, as well as creative analytical approaches and application of various design research methods. The methods can be: human/child-orientated design, critically design thinking, innovative and mosaic approach, observation and photo documentation, open-talks, children's drawings of ideal school environment, student's voluntary participation, and school environmental and educational practice. The goal is developing the new innovative design concepts of school furniture, sensory products or didactic materials by usage of sustainable wood materials.

This paper highlights preliminary results of the project's first phase. This phase included analysing school environments and furniture typology in New York Central District Elementary Schools (USA) vs Zagreb City Elementary Schools (Croatia) and observing user's behaviour using current equipment in NYS public school classrooms. Short observations are pointed out.

3. RESULTS AND DISCUSSION

Among observed elementary schools in NYS, which have mostly traditional furniture but creative layouts, new efforts were found in Groton Elementary School, Groton NY. This school will be used as a starting point for the new observations and creative design concepts in the next phase of the project.

3.1. Public Elementary Schools - New York Central District, USA versus City of Zagreb District, Croatia

Principals and teachers in public schools all around the world mostly face the same problem – lack of money and knowledge how to equip their school facility and classrooms (Domljan *et al*, 2015). The same problem has private schools – they might have more money, but still have a lack of information on how to equip school environment (Domljan, 2011). When searching for a good manufacturer to equip school facilities based on public procurement and tender documentation, most manufacturers of school furniture offers the same traditional products (web 1). This statement goes in the line with former research by Ching Yee Wong *et al*. (1992) who pointed out that problems remain in accommodating an innovative design within a bureaucratic system based on standardization of spaces and functions.

This problem is observed and noticed in all Public Elementary School's classrooms, both in USA and Croatia: standardized school tables and chairs, shelves, blackboards and similar products offered in catalogues and procured by City Offices / investors.

However, in all schools in NY district is marked more creative furniture layout, with more playful, rounded and freer typology of tables and chairs, with additional furniture such as armchairs, upholstered mattresses or mats, carpets and movable shelves (*Figures 2 and 3*). All chairs and tables have an adjustable size regulated by adjusting the height of the legs. Tables have metal legs and table tops made of chipboard covered with impregnated decorative paper that can be written with a felt-tip pen. Some types of chairs have wooden seats and backrests (plywood), but most have plastic backrest and seat connected in one module which is not either comfortable or durable (*Figure 4*).

Figure 2. Central New York Public Elementary School / classroom layout

Photo: Kowalsky, M.C., 2019

Figure 3. Central New York Public Elementary School / classroom layout

Photo: Domljan, 2019

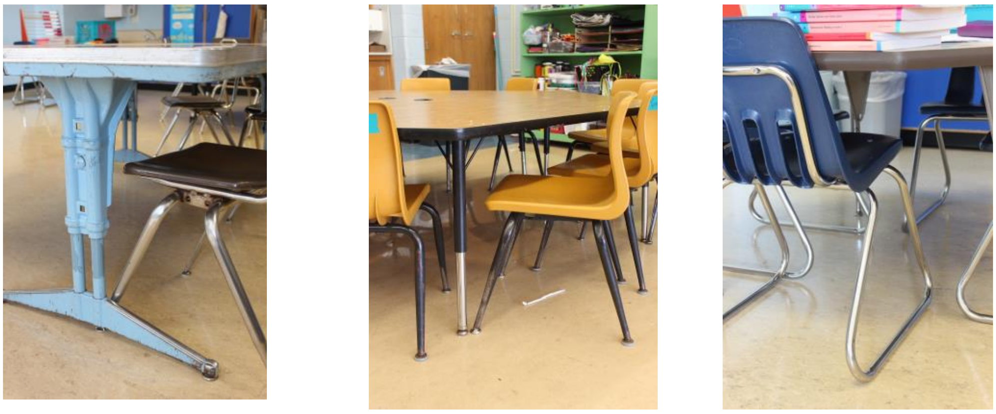

Figure 4. Adjustable sizes of tables and plastic chairs / CNY Elementary School classrooms

Photo: Domljan, 2019

Croatian schools have to face with one-size chairs and tables for two students, usually without additional furniture in the classrooms, which mostly depend on teacher's creativity and goodwill. Typology of the school furniture is prescribed by the Croatian Ministry of Education tenders and cover only two size marks according to HR EN-1729 (2015) (*Figure 5*).

Figure 5. City of Zagreb Public Elementary Schools / classroom furniture layout

Photo: Domljan, 2011

3.2. Groton Elementary School – Think Tank Rooms and The Wonder Space

Mr. Les Watson from Glasgow Caledonian University emphasized: "We spend a lot of time trying to change people. The thing to do is to change the environment and people will change themselves“ (JISC, 2006, p.1).

The same statement has given the Principal of Groton elementary school, Mr. Kent Maslin while observing the students in Think Tank Rooms (TTR) (*Figures 6 and 7*). He noticed that children still do not know how to use such a freedom and free movements which are allowed in TTR.

Observation results shows that to equip this rooms one has to think "out of the box". The most of these furniture types/products one ca not buy via web sites with key words "school furniture". There is a mixture of different functional typologies – office, home, restaurant, kindergarten or other environments. The dominant vision and concept here are that the different layout and typology of furniture that allows for comfort, comfort, joy and relaxation leads to a sense of well-being and a greater sub-productivity of students. Colours are vivid and bright, materials soft and shiny. Unfortunately, there is not much wood or sustainable materials, but this fact allows further settings in research and new concepts of furniture and environment in which it prevailed warm wooden or more sustainable elements.

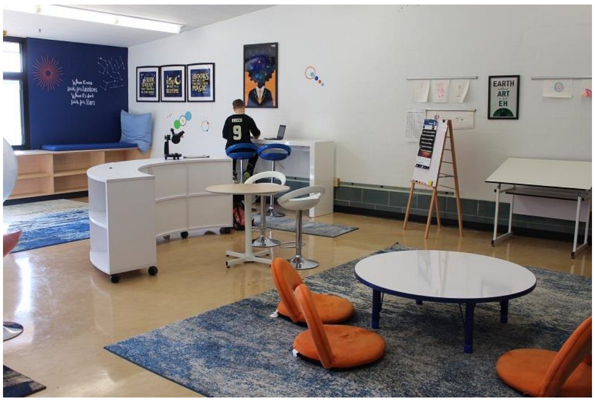

Figure 6. Think Thank Room 1 / Groton Elementary School, Groton NY (Photo: Domljan, 2011)

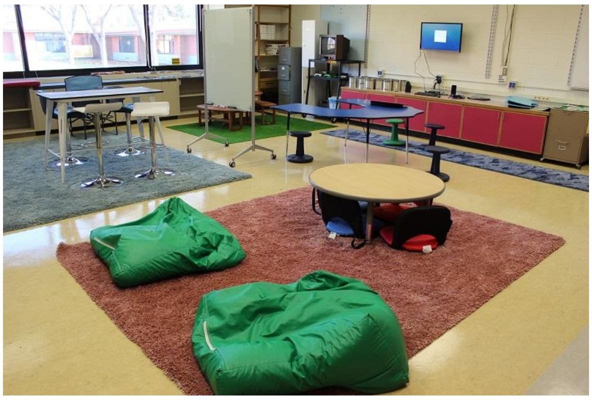

Figure 7. Think Thank Room 2 / Groton Elementary School, Groton NY (Photo: Domljan, 2011)

Think Thank Rooms (*Figures 6 and 7*) are quite new classroom environments for active learning and cosy behaviour, equipped with the main aim: to improve learning outcomes and children well-being in school environment. TTR have been designed during spring-summer 2019 by efforts of school teachers, children, Cornell students and professors, and have been opened in fall 2019.

Figure 8. The Wonder Space / Groton Elementary School, Groton NY (Photo: Domljan, 2011)

The Wonder Space (WS) in Groton school is still under construction but has the special background – it is aimed to be a school library with totally new approach to children reading attitudes. The cat Izzy is all around the room with the aim to help children to love reading books (*Figure 8*). This space is cosier, friendly, offers different body positions while reading books – lying, sitting, etc. Materials are soft (foams and textiles), there is more wooden furniture (shelves) and toys. The Wonder Space will open during winter 2019.

For all children (and the teachers as well), The Wonder Space and Think Thank Rooms represent rather new approach for learning, so observation in TTR and WS classrooms goes in the line with the project goals.

Several questions highlighted during the TTR and WS observations:

- Are children prepared for such new classroom design? (habits, learned behaviour, learning outcomes, savour, satisfactions, etc.)
- Do children know "how" to behave in such environment / or they think that something "is not allowed"?
- How long will it take students to get used to having a relaxing behaviour in classrooms like this, but with one goal: to do schoolwork, homework, or at least to have better learning outcomes?
- How much students pay attention on furniture design and furniture layouts?
- Is it important for learning outcomes and the sense of well-being that furniture in such classrooms is made from sustainable materials or not?
- How could we measure children satisfaction in such rooms?
- What would happen to student (and teachers) behaviour if this type of furniture arrangement were used in a "classic" classroom?
- Can this, more liberal approach to behavioural learning trigger the bureaucratic system and manufacturers to introduce standardized equipment beyond the traditional "school desk and four-legged" system?

These questions will be left open for the next phase of the project research.

4. CONCLUSION

Previous research efforts and results lead to the conclusion that the current design of school environment and furniture needs to be redesigned urgently. In this process must be involved inter- and transdisciplinary oriented experts in the fields of health, school medicine and occupational therapy, ergonomics, anthropometry, pedagogy, design and architecture, public procurement and production, and above all - children-oriented design, design thinking, innovative approach and practice in school environment design the most important requirements. The main goal is to achieve children's health and well-being in schools.

The main questions raised during the first phase of the project will be used for the next steps in the R&D project processes. It will focus on describing how to approach a good school environment design that uses sustainable materials, and how to achieve innovative results by involving children, teachers, students and professors in the creative multidisciplinary research process of developing conceptual solutions.

The main hypothesis put forward by this research are that creative furniture layouts and furniture functions, in combinations with sensory and didactic leisured behaviour as well as sustainable materials used for furniture/product design could be a potential method for future improving children's eco-attitudes, creative learning and behaviour, and enhancing well-being in school. We are looking forward for the next steps.

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3D Printed Age Simulator as a Tool Facilitating the Process of Furniture Designing for Seniors

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ABSTRACT

The demographical changes have caused a great interest in the subject of designing for seniors. Consequently, companies are motivated to modify their offer and adjust the products to the needs of the elderly. The process of recognition and understanding of body limitations resulting from different types of ageing-related dysfunctions can be however difficult. To gain a better view of the problems seniors face during their daily activities designers may use empathy training with the usage of age suits. Still, even though there are several solutions available, furniture manufacturers rarely use them in their daily practice. Thus, we created an alternative that is more accessible, especially for the SMEs. The aim of the article is to present the design process and evaluation of entirely 3D printed age simulator. It gives the user the emphatic view of the world of seniors and consequently facilitates the inclusive design process. We provided furniture manufacturers with a design support tool that is easy to use and affordable. It allows to develop empathy skills, feel age-related changes of limited mobility, body posture, reduced arms or legs movement, deterioration in vision, and thus experience and understand better how daily activities may become difficult while getting older.

Key words: age simulator, furniture design, seniors

1. INTRODUCTION

The demographical changes occurring all around the world have caused a great interest in the subject of designing for seniors. Due to permanently increasing number of seniors in modern societies, designers, companies and researchers face a great social and economic challenge. The predictions of the United Nations (2015) state that global ageing will accelerate in the coming decades. In the year 2015 over 900 million people (12 % of the global population) were 60+, however it is estimated that by 2050 seniors will comprise already 22 % of the world population (meaning over 2 billion persons). This is due to the projected overall reduction in fertility and the growing rate of population ageing worldwide (United Nations, 2015). Nowadays Europe is the oldest region of the world with 24 % of the population aged 60+ (He *et al.*, 2016). It is interesting to note that among 25 oldest countries in the world as many as 22 are located in Europe (with Germany and Italy at the top of the list). It is however projected that in the year 2050 Slovenia and Bulgaria will have the highest population of seniors in the Europe (Kinsella and He, 2009).

In view of the predicted changes companies will be forced to modify the range of their products and adjust them to the needs and expectations of the still increasing group of senior customers. Thus, it is crucial to be prepared for the changes that are about to come and develop a market offer that meets the needs of the elderly, especially those resulting from different types of ageing-related dysfunctions. Having in mind the new product development process targeted in the senior population, one should focus, first and foremost, on ensuring the safety and comfort of use. Functionality, understood as the adjustment of the product to the physical characteristics and abilities of the user plays here a superior role. It should be noted that such activities, although they seem natural, are still not frequent. It is estimated that only 10 % of products being currently on the market is adapted to the needs of an aging population. The rest is designed for young, healthy and active people (Hrovatin and Vižintin, 2013).

The preparation of products focusing on the user characteristic is of crucial significance. Due to the changes occurring in the human body as the aging process progresses, older people have special needs that should be recognized and considered when designing products for this group of consumers (Paetzold *et al.*, 2016). Therefore, in order to meet their needs and expectations in the best possible way, it is reasonable to take into consideration the multidisciplinary of design process.

It's also worth noticing that the subject of designing for seniors is gaining in importance due to the fact that seniors as consumers become more and more significant and more attractive group on the market as they are characterized by the increasing purchasing power. In connection with the growing social demand, in recent years a new term was created: "silver economy" understood as a new sector of the economy. It is a system of services and manufacture of goods aimed at using the purchasing potential of the elderly and satisfying their consumption, living and health needs (Rudnicka and Surdej, 2013). Moreover, there is also a need to focus on solutions that will reduce discrimination based on age (ageism) and on design of public spaces, homes and apartments that are friendly to all age groups (European Commission, 2007).

The aging process causes a number of changes in the body of the elderly person. In the post-productive age, anatomical, physiological and psycho-motor changes intensifies leading to reduced efficiency of the body activity. The easiest to see are the following: changes in the body posture, flaccidity and loss of chest and abdominal muscle tone, deepening of the thoracic kyphosis (hyper kyphosis): the torso gradually shortens and eventually forms the letter C. The phenomenon of deepening of the thoracic kyphosis begins already after turning 40 years old and increases with the age. Those changes are accompanied by compensatory bending of the lower limbs in the hip and knee joints. The above-mentioned phenomenon reduce the height of the body, both in standing and sitting position (Jarosz, 1998). Moreover, the range of head movement is reduced. The hyper kyphosis consequently reduces the range of motion in the joints of the shoulder, hip joints and joints of the lower limbs. It is also often observed that the entire body is tilted forward, which results in worse motor coordination and problems with motor skills. General, average torso inclination is 9-10° (Anwajler, 2010). As an effect of the above stated changes there is a reduction in the walking frequency and shortening of the step length observed. The step is shortened by 4 % between the age of 20 and 60, and then by 6 % between 60 and 70 years of age. People with the smallest strength reduce the step even to about 20 cm. In the older age the foot adheres to the ground for a longer time, giving the impression of not lifting it up or, in extreme cases, pulling the foot on the ground. This results in longer time necessary to stabilize posture after making the step. During walking, the feet are set wide and there is also a smaller height of raising feet above the ground. All these elements have an impact on a more secure and careful model of walking, in order to increase stability and reduce the likelihood of falls. Moreover, problems with vision, hearing and the ability to concentrate may appear in the older age.

The process of recognition and understanding of all the above-mentioned changes and limitations can be very complex and difficult, especially for young designers in the top of their physical abilities. Nevertheless, it cannot be omitted in the new product development process. The empathy phase constitutes the foundation of the human centred new product creation and is the stage where maximum knowledge about the end user is acquired. There is a number of tools used in this phase including direct interviews, photo journals, moodboards and role playing just to name the few. To gain a better view of the problems seniors face during their daily activities designers may use empathy training with the usage of age suits (Lavallière *et al.*, 2016). Simulation of the aging process, despite some alternative approaches (Kullman, 2016), is known as a useful and effective teaching method for educating professionals working with the elderly or designing such key objects from their surroundings as, for example, furniture. Those age suits allow designers to feel the selected limitations of the senior body.

Still, even though there are several solutions available on the market, our research showed that Polish furniture manufacturers rarely use them in their daily practice. Thus, while working on new tools supporting companies in the new product development aimed at raising comfort and safety of seniors living at home, we decided to create a solution that would be more accessible, especially for the SMEs. The aim of the article is to present the design process of creation of an entirely 3D printed age simulator dedicated to designers working in furniture companies.

2. AGE SUITS

The first age suits designed to mirror the changes occurring in the human body while getting older were used in the automotive industry. Then the idea was applied to the training of medical staff in order to develop the empathy of employees that were to deal with elderly patients. These tools allowed to simulate motor limitations as well as problems with sight and hearing - the most common changes associated with the old age.

In 2005 the Massachusetts Institute of Technology (MIT) created a suit called AGNES (Age Gain Now Empathy System). It mirrors the problems of e.g. limited mobility, weaker vision or hearing, a 70-year-old person may experience. In addition, the suit has lines fastened, for example, between the arms and the torso, and between the legs and the torso, which are supposed to limit the range of movement of arms and legs. The suit is also equipped with straps blocking the elbow and knee joints, preventing free movements of arms and legs. Another example of using the age suit is Ford company. It has developed a solution called Third Age Suit. The described solution has the form of a suit, on which the limitation of arms and legs is fixed. A similar suit is used in Volkswagen company.

Blum company, being a worldwide manufacturer of furniture hardware, uses a solution called Age Explorer. Similarly, as in the above-mentioned cases, it is produced in the form of a suit, to which pockets are sewn in. In those pockets load is placed to simulate the process of muscle weakness. In addition, there are connections between the arms and the body, as well as blockages of the elbow and knee joints. A comparable solution, which does not use the suit but is applied to the user's clothes, is GERT developed by the German agency Product + Design. It was primarily used to train medical staff, both at universities and in schools preparing staff to look after older people. Other versions of the discussed solution are also available on the market, e.g. the British Adam Rouilly Age Simulation Set or the Japanese Sakamoto New Aged Simulation Suit. The French consulting company Seniosphère, helps its clients to develop more accurate product strategies for older people through the use of "Empathy suit". Different versions of Senior Suit are also offered by SD & C company.

The solutions presented above consist of a whole set of accessories and replaceable parts. Very often they have the form of a full body suit. The ones that are mounted on the clothes of the user are sewn from the fabric and most often connected with Velcro strips.

3. DESIGN PROCESS

The multidisciplinary design team consisted of scientists and practitioners from the fields of design, engineering and medicine. The newest technologies were incorporated to develop state-of-art solution enabling manufacturers and designers to print their own age simulator. The process of creation of the 3D printed suit was preceded by a broad multidisciplinary research performed among seniors. Physical aspects of aging were investigated, using the experience and knowledge of researchers and practitioners from the field of medicine and occupational therapy. The broad literature review was performed as well. Medical knowledge on the process of aging was crucial in this respect. There is a large individual diversity of changes in body posture while getting older, and their pathophysiology is complex. However, to achieve our goal - creation of the age simulator - it was necessary to look for similarities rather than differences, so we searched for certain general trends that could be implemented in the developed tool.

Survey research and direct interviews were performed with 155 people aged 50+ years old to discover the most common problems they face during performing daily activities at home. The method of statistical grouping with age as a division criterion was incorporated. It showed that for more than 80 % of people over 70 years old, reaching objects from above is one of the major problems associated with the comfort of functioning in the household (*Figure 1*). Among the oldest participants a serious problem with getting up from the bed was also observed.

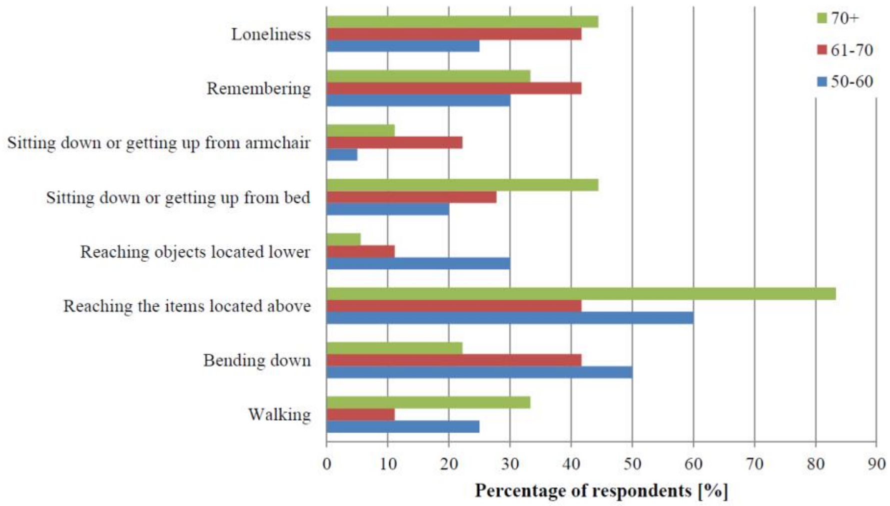

Figure 1. Problems faced by seniors while performing daily activities, depending on age
Source: Fabisiak et al., 2016

In the series of individual interviews with seniors it was stated that the problems of reaching items located above are caused by the pain that occurs in the area of shoulders and arms while rising arms above and by them getting smaller, as cabinets and shelves appear to be less reachable for seniors as years go by. These investigations showed how important it is for designer to acquire the knowledge about the anthropometric dimensions of the senior population but also the knowledge stemming from his or her own experiences in performing such easy activities as, for example, reaching the items located in the upper cabinets.

In order to test the existing market solutions and gain the more detailed knowledge on the user experience while wearing the age suit, the field studies with the usage of Age Explorer suit were performed (*Figure 2*). Various scenarios were developed to get a better picture of a person working in the kitchen area.

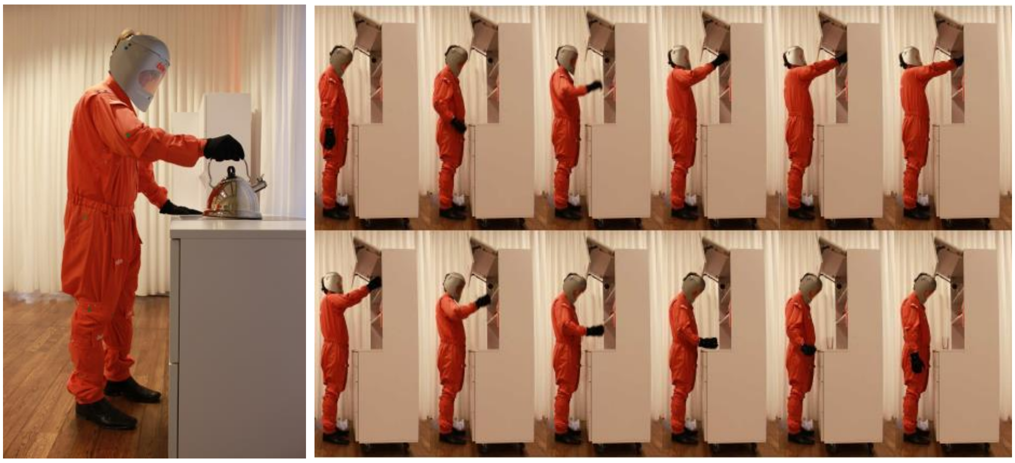

Figure 2. Laboratory tests performed with the use of Age Explorer Suit in Blum company

Further, the 3D scanning of senior person was incorporated to get the image about the changes in the body posture that are connected with the deepening of the thoracic kyphosis (*Figure 3*). As it was mentioned before those changes are individual for every senior person however the general shape and the range of values can be defined. The most valuable in creation of the age simulator were the general tendencies that we were able to observe and capture thanks to the implementation of the new technologies. The 3D scanning was performed using "Artec Eva" and "3D Sense" scanners.

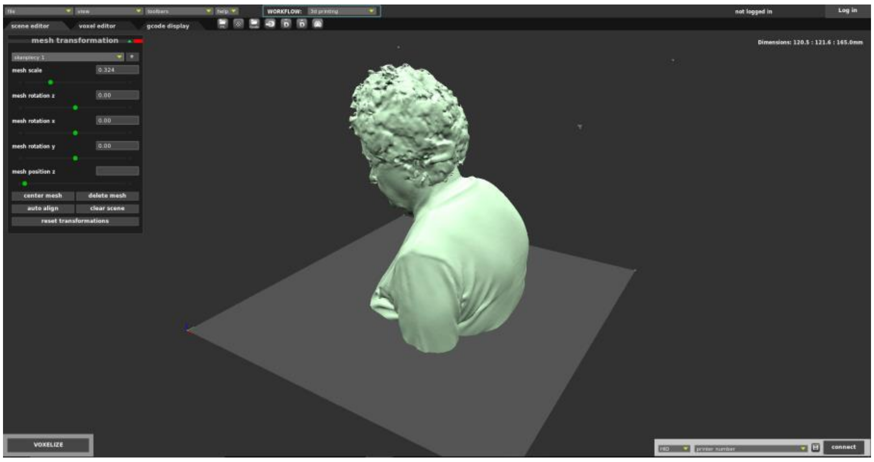

Figure 3. The 3D model of a senior posture being the result of the 3D scanning process

In the next phase, the 3D modelling process started followed by the great number of tests to find the optimal solution. The software 3ds Max allowed for visualisation and modelling of individual elements of the suit. The idea and the main goal of the design process was to make the age simulator as much accessible as possible. It did not work right away to create the entirely 3D printed age suit. In the first attempt, the prototype still consisted of some fabric parts. Step by step each element of the first prototype was changed into the 3D printed one. The biggest challenge was connected with the design, modelling and 3D printing of the elements that should be flexible and adjustable to the dimensions of the users, for example, to various thigh or calf circumference. A number of different prototypes were produced and tested with the end users to discover the fields for improvements. The intuitiveness and comfort of use while fastening the elements were important criteria in the evaluation of the developed solutions. In the latest phase, the whole suit was printed and assembled. The 3D print was performed with the use of Zmorph SX and Zmorph VX 3D printers. The elastic elements were printed from Ninja Flex and Semi Flex filaments while the stiff ones, like shoulders, from PLA. Those activities were supported by practitioners from Get Models Now company constituting the part of design team.

4. RESULTS AND DISCUSSION

The aim in creating the age simulator was to give the user the most possible emphatic view of the world of seniors and consequently facilitate the inclusive design process, having in mind that the tool should be as simple, cheap and usable as possible. We wanted to provide furniture manufacturers with a design support tool that is easy to access and affordable, so that the wide range of practitioners will be willing to use it in their new product development processes. The task of the age simulator is to show age-related changes associated with reduced mobility, body posture, reduced scope of shoulder or leg movement, and deterioration of vision, constituting the most crucial issues that need to be taken into consideration when designing furniture for the elderly. Age simulator is a "suit" consisting of a torso (restrictions on the shoulders, neck, belt - simulation of abdominal and iliac obesity) and legs (restraints on the thighs, calves and feet) (*Figure 4*). This solution is aimed at simulating selected motor limitations of elderly people especially important while designing for seniors. A set of glasses allows for the presentation of the most common vision disorders occurring in the elderly age.

This tool enables for the realistic mapping of aging changes in the human body. This was achieved by applying locally placed loads (weights) - in the waist around the abdomen, on the front surface of both thighs, on the upper back surface of both shins and on the metatarsal surface. These loads require increased mobility of muscles and joints in younger people, which allows them to evoke - as in the case of older people - an increased loading and activity of bone, joint and muscle systems, and fast fatigue together with the possibility of feeling discomfort and even pain (in case of young people who do not undergo systematic physical training).

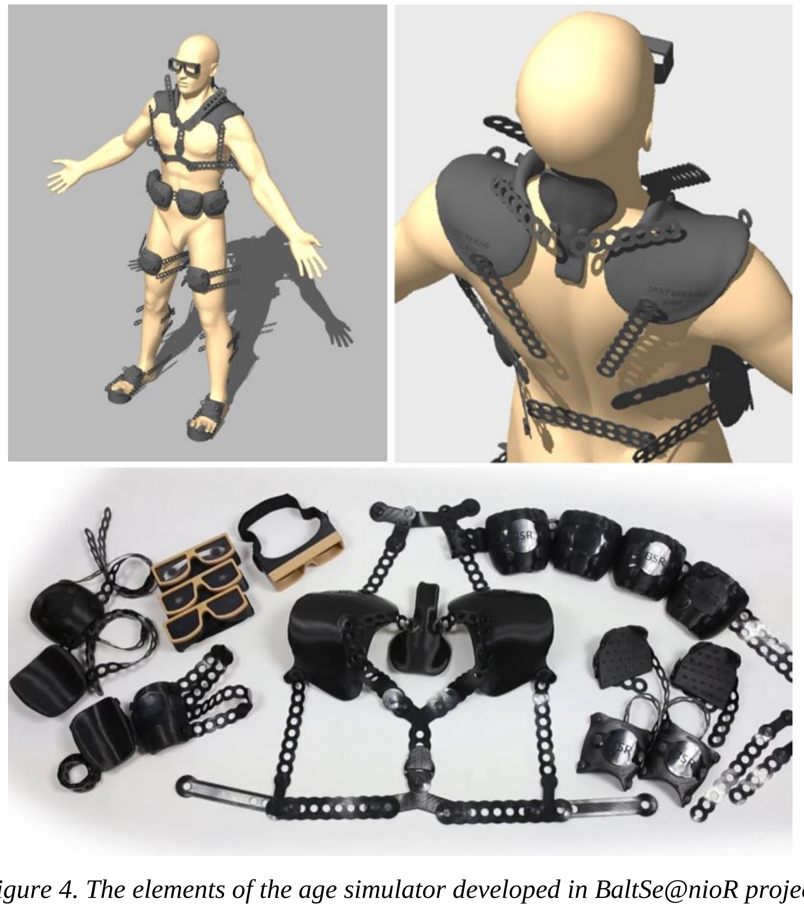

Figure 4. The elements of the age simulator developed in BaltSe@nioR project

The age simulator allows to develop empathy skills, feel age-related changes of limited mobility, body posture, reduced arms or legs movement, deterioration in vision, experience and understand how the simplest daily activities may become more and more difficult while getting older. The solution was tested among students, teachers and practitioners working with seniors on a daily basis, i.e. in Poland, Latvia and Finland (*Figure 5*).

Figure 5. The example of using the age simulator

The evaluation of the tool indicated that the age simulator can help to understand better the problems seniors face while daily functioning. As much as 71 % of users who tried the tool admitted that after this experience they have a more complex awareness of how the life of seniors may look like (*Figure 6*). It also helped to understand better the consequences of age-related limitations and opened themselves more on the needs of seniors (*Figure 7*).

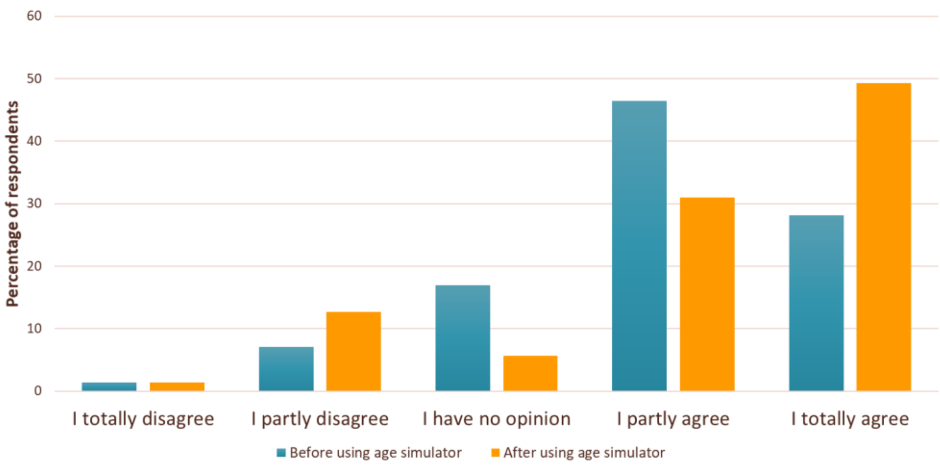

Figure 6. The evaluation of awareness of the consequences of mobility limitations of older people for their functioning at home and outdoors before and after using the age simulator

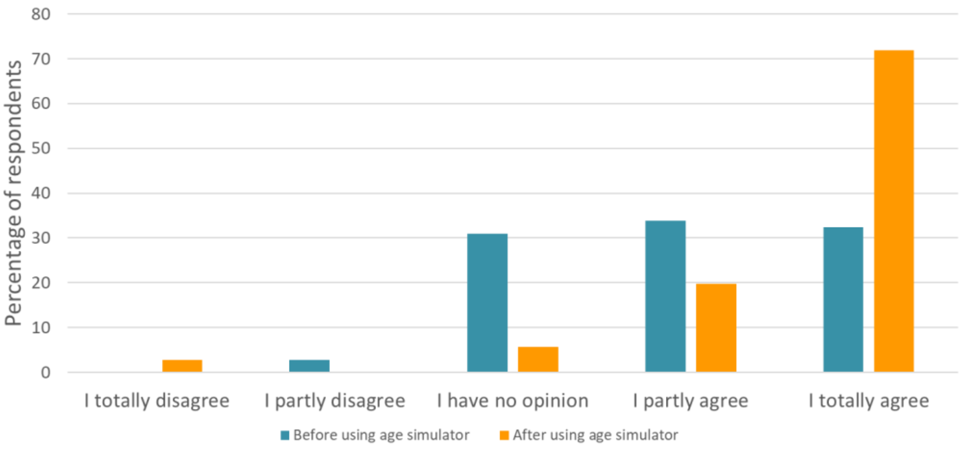

Figure 7. The evaluation of the age simulator as a tool helping to understand the problems an elderly person may have while functioning in the household before and after using the age simulator

5. SUMMARY

The issue of aging societies starts to constitute a serious problem that will gain in importance in the coming years. It is currently one of the most important challenges faced by the European Union, as it brings not only social but also economic consequences. The task to develop a product offer tailored to the needs of the ageing population is demanding, and at the same time highly socially responsible mission. It is significant that furniture designers and manufacturers will be able to identify the functional requirements allowing for increasing comfort and safety of furniture usage.

Support of the design process aimed at better understanding of seniors needs is of crucial importance as still many furniture companies (especially SMEs) doesn't have the proper know-how on this hitherto forgotten and constantly growing group of customers. Age simulator supports the phase of empathy, and thus a better understanding of the needs of the target group during the creation of new products. It is also a great tool enabling the training of employees working in institutions providing services for the elderly, and therefore giving the opportunity to improve the quality of customer service. By making it entirely printable we managed to make this design support tool much more accessible.

It's crucial to highlight that implementation of 3D scanning, 3D modelling and 3D printing technologies opens new possibilities for the shared economy and much wider dissemination of scientific results into practice.

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Determination of Performance Index and Effective Power for Sharpening of TC Planer Knives with PCD Abrasive Wheels

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ABSTRACT

This paper presents experimental results of sharpening of planer knives part of cutter head. The knives have TC (tungsten carbide) edges type K40 and K20 according to ISO grade classifications. The sharpening process do with abrasive wheels from polycrystalline diamond (PCD). Performance indicator and effective power for both direct and reverse motion are determined. The grits of PCD abrasive were with common heightened durability, anti-stick properties with organic and metal/organic binder. Based on the results of the research, the relevant conclusions and recommendations are made.

Key words: planning knives, cutter head, sharpening, abrasive tools, polycrystalline diamond, tungsten carbide tools

1. INTRODUCTION

Sharpening of planer knives for longitudinal milling of wood and wood-based materials is an important stage in their preparation. Sharpening is performed on the back side of the knives until the shape of the edge is restored by proper selection of the abrasive tool and appropriate sharpening mode (Gochev 2005, Gochev 2018). For the experimental studies, diamond abrasive discs with organic bonding were used and a combined metal/organic bonding produced in Bulgaria, as well as some qualitative indicators for normal and forced sharpening of planer knives with TC edges, type K40 and K20. The planer knives are part of assembled cutter head.

This article is a continuation of the article presented on the 4th International Scientific Conference ,,Wood Technology & Product Design“, held in Ohrid in September 2019, Republic of North Macedonia (Gochev *et al*., 2019).

2. MATERIALS AND METHODS

Experimental research was carried out using cutter head with HM insert knives for preliminary and fine planing of solid wood and wood composed materials on four-side processing machines (fig. 1).

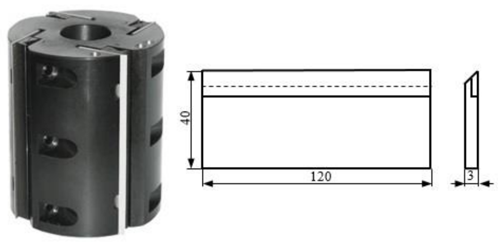


Figure 1. Assembled cutter head with HM insert knives, type K40 and K20

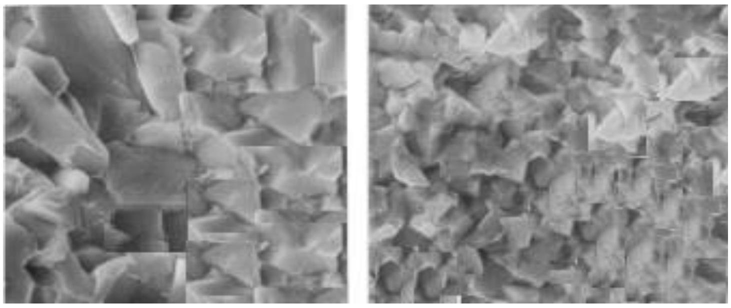
The basic parameters of the cutter head and the removable knives given in Table 1. The planer knives are with tungsten carbide tipped edges, type K40, K20 and heat-treated to hardness HRC 89.

Table 1. Basic parameters of the cutter head and knives

D, mm	*d*, mm	*L*, mm	*B*, mm	*s*, mm	*z*, mm	*β*, °	Type
123	32	120	40	3	4	45	T.C.T.

The indications in Table 1 correspond to:
D – Diameter of the cutter head;
d – Bore size;
L – Length of the knife;
B – Width of the knife;
s – Thickness of the knife;
z – Number of knives;
β – Angle of sharpening.
T.C.T. – Tungsten Carbide Teeth.

These cutter head have designed for shapers machine, spindle moulder machine. The cutting plates consist of sintered materials composed of metal carbides and metallic binders: WC – 92 % and Co – 8 %) with medium grain of WC – 1,0 - 2,0 μm (fig. 2 A) and those from K20 with micro grain of WC up to 1,0 μm (fig. 2 B) (https://carbide.ultra-met.com/viewitems/iso-grades/iso-grade-classifications-tungsten-carbide).



A B

Figure 2. Fracture of a standard tungsten carbide: A - Medium Grain 1,0-2,0 μm; B - Micro Grain up to 1,0 μm

The abrasive PCD grinding wheel (fig. 3) has 12A2 45° shape (conical cup - CC) and works with its front surface (manufactured in ZAI JSC - Bulgaria).

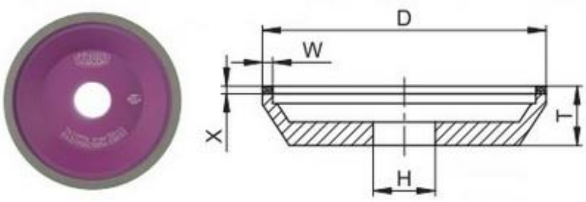


Figure 3. Abrasive grinding wheel shape 12A2 45° (conical cup)

The characteristics of the experimental abrasive wheels given in Table 2.

Table 2. Characteristics of the experimental wheels

Shape and dimensions	Abrasive type	Mesh Size	Bond Type	Concentration, %
12A2 45° 125x5x3x32	SD (Synthetic Diamond)	125/100	B8/A	100
12A2 45° 125x5x3x32	SD (Synthetic Diamond)	125/100	BM/A	100

Experimental diamond wheels SD are made of synthetic diamond with ordinary durability.

B8/A is an organic bond based on a phenol-formaldehyde resin with added filler of barium sulphate and talc and with the addition of anti-friction agents in order to control its wear resistance, heat resistance, grit retention and lubrication.

BM/A is a metal-organic bond made of phenol-formaldehyde resin, metallic powders of copper and potassium, and zirconium dioxide to increase the bond rigidity.

The studies have performed under the following sharpening modes:
- cutting speed (V) – 18 m/s;
- longitudinal feed speed (V_l) – 1,0 m/min;
- cross feed speed (V_{dm}) – from 0,03 to 0,23 mm/double motion.

The studies have carried out according to the scheme of Table 3 with cross-feed have performed before each gradual movement of the longitudinal feed.

Table 3. Scheme of the test carried out

Abrasive wheel	TCT	Cooling	Cross feed speed, mm/double motion							
			0.03	0.05	0.08	0.10	0.12	0.15	0.18	0.20
SD 12A2 45° 125x5x3x32 125/100 B8/A 100	K40	-		+		+				
	K40	+		+		+		+		+
SD 12A2 45° 125x5x3x32 125/100 BM/A 100	K20	-	+	+	+	+				
	K20	+				+	+	+	+	

Legend: + with cooling; - without cooling

Two studies have also carried out in forced sharpening with greater direct and reverse cross feed in the following modes:
- cutting speed (V) – 18 m/s;
- longitudinal feed speed (V_l) – 1,0 m/min;
- cross feed speed:

i. V_{dm} = 0,20 mm/double motion; $\vec{V}_{dm}$ = 0,15 mm – direct motion; $\acute{V}_{rm}$= 0,05 mm – reverse motion.
ii. V_{dm} = 0,23 mm/double motion; $\vec{V}_{dm}$ = 0,15 mm – direct motion; $\acute{V}_{rm}$= 0,08 mm – reverse motion.

The following performance characteristics of the abrasive wheels are defined (Zaharenko 1981, Gochev 2008, Ostrowskii 1981):

A. Coefficient of Cutting Capacity (Cc):

It is defined as the ratio between the real cross-feed and the theoretical cross-feed for each experiment and determined by the formula:

$$C_c = \frac{h_{rcf}}{h_{tcf}} \leq 1 \qquad (1)$$

Where h_{rcf} is real cross-feed, mm;
h_{tcf} – theoretical determined cross-feed, mm.

B. Corrected performance indicator (Cpi)

This indicator evaluates the performance of the diamond wheel and sharpening conditions and determined by the formula:

$$C_{pi} = \frac{c.V_l.F_c.V_{dm}}{Q_s} \qquad (2)$$

Where c is the coefficient reflecting the sharpening mode, the width of the diamond layer (b), etc.: for $V_{dm} \leq 0{,}1$ mm/double motion, $b = 5$ mm, $c = 0{,}20$; за $V_{dm} > 0{,}1$ mm/double motion, $b = 5$ mm, $c = 0{,}27$;
F_c – contact area, mm^2;
Q_s – specific consumption of diamond, mg/g.

C. Effective power of direct and reverse motion

For reporting of the effective sharpening power of direct ($\vec{N}_e$) and reverse ($\acute{N}_e$) motion a device *US301EM* (Figure 4) was used. It designed to measure current, voltage, active, reactive and full power in single or three-phase electric circuit. The voltage range of the device is 0-100 V, and the current 0-5 A. The results have reported using the respective software of the company and automatically converted into Microsoft Excel.

Figure 4. Measuring device, model US301EM of Unisist Engineering Ltd. - Bulgaria

D. Relationship between effective power of direct and reverse motion – $\frac{\vec{N}_e}{\acute{N}_e}$

The studies were carried out with the help of automatic high productivity grinding machine for flat knives, model HMS I of a firm „Vollmer" (Germany) and lubricant cooling fluid - 1~2 % an aqueous solution of calcined soda (Na_2CO_3).

The studies were carried out using an automatic, high-performance sharpening machine for planer knives, model „HMS I" of a firm „Vollmer" (Germany) and a lubricating-cooling liquid - 1~2 % aqueous solution of calcined soda (Na_2CO_3).

The knives of the cutter head have mounted on the table of the sharpening machine on the step plate (Figure 5) to ensure simultaneous sharpening (Gochev 2018).

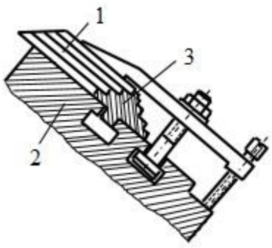


Figure 5. Mounting of knives on the table of a sharpening machine on the step plate: 1 - knife; 2 - table; 3 – step plate

3. RESULTS AND DISCUSSION

The results of the research have processed by the variation statistics methods with the software products QstatLab5 and Microsoft Excel (Vuchkov, Stoyanov 1986).

The next results are shown in Fig. 6 and 7: for the effective sharpening power of direct ($\vec{N}_e$) and reverse ($\acute{N}_e$) motion, coefficient of cutting capacity (C_c), corrected performance indicator (C_{pi}) and relationship between effective power of direct and reverse motion ($\frac{\vec{N}_e}{\acute{N}_e}$). These results are for different cross feed rates, including forced sharpening with greater direct and reverse cross feed for diamond wheels with B8/A and BM/A bond.

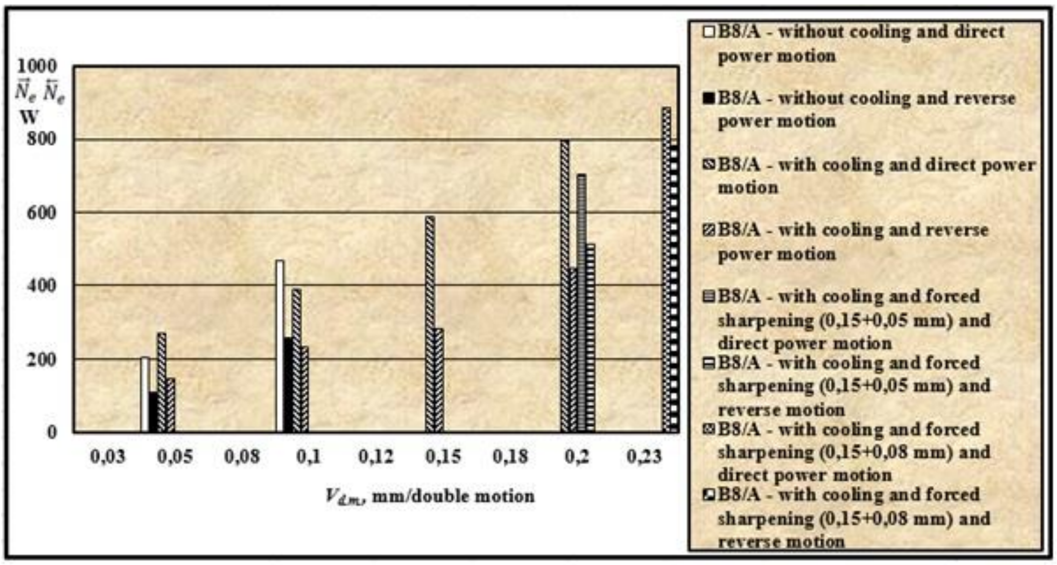


Figure 6. Dependence between effective sharpening power of direct ($\vec{N}_e$) and reverse ($\acute{N}_e$) motion from the rate of the cross feed (V_{dm}) for diamond weels with B8/A bond

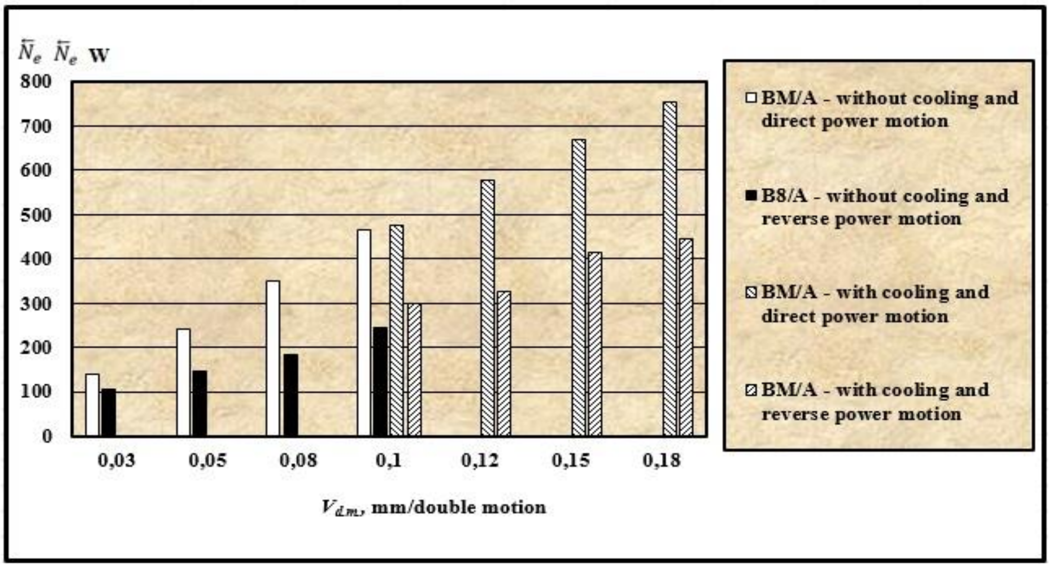


Figure 7. Dependence between effective sharpening power of direct ($\vec{N}_e$) and reverse ($\acute{N}_e$) motion from the rate of the cross feed (V_{dm}) for diamond weels with BM/A bond

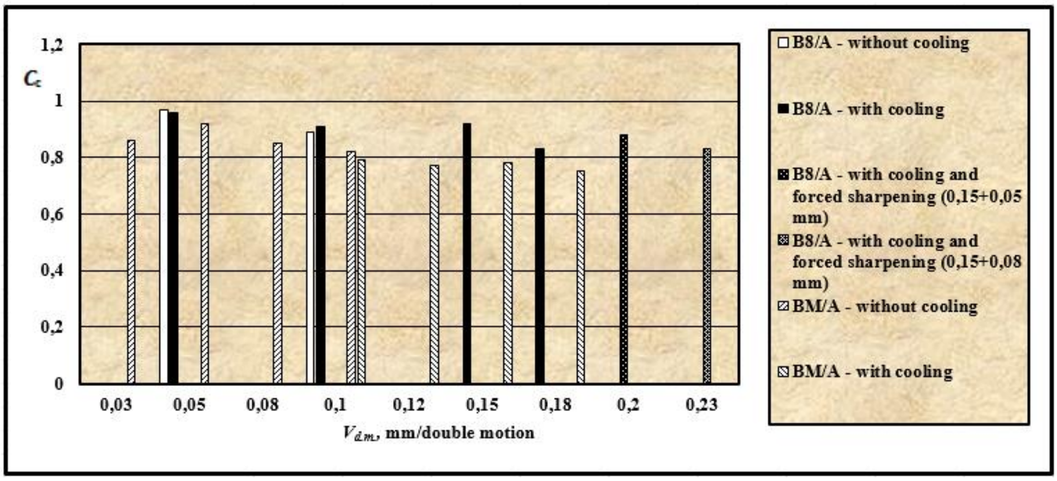


Figure 8. Dependence between coefficient of cutting capacity (C_c)and the rate of the cross feed (V_{dm}) for diamond weels with B8/A and BM/A bond

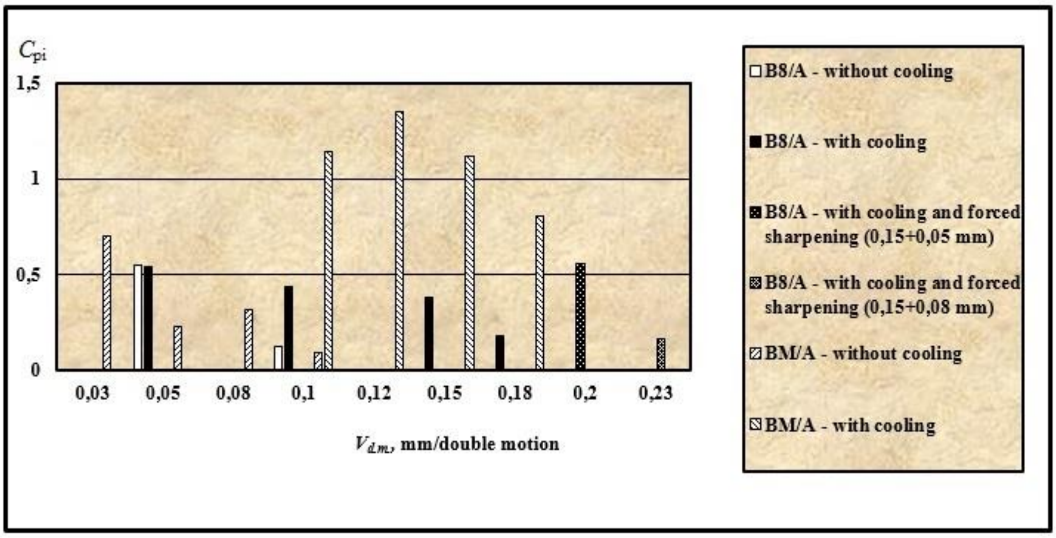


Figure 9. Dependence between corrected performance indicator (C_{pi}) and the rate of the cross feed (V_{dm}) for diamond weels with B8/A and BM/A bond

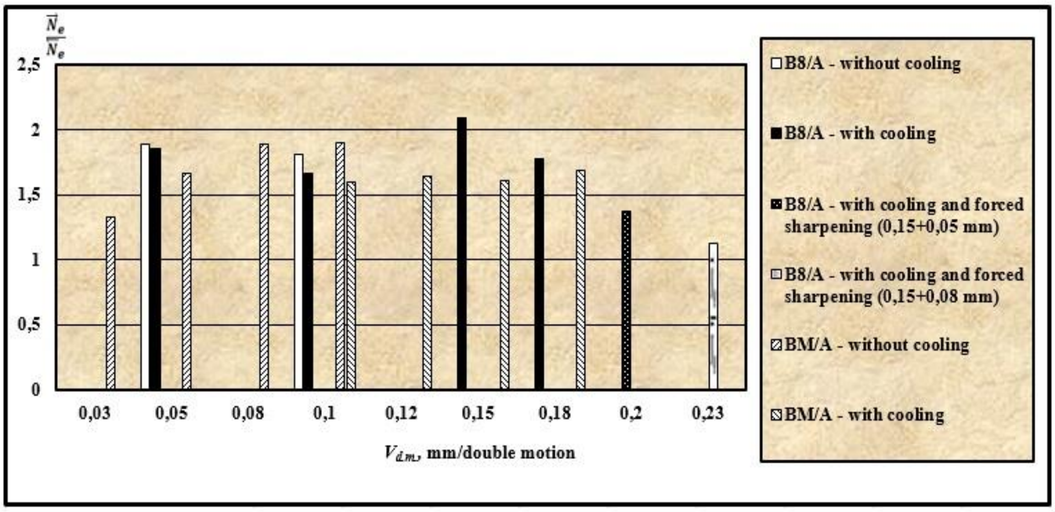


Figure 10. Dependence between relationship between effective power of direct and reverse motion ($\frac{\vec{N}_e}{\acute{N}_e}$) and the rate of the cross feed (V_{dm}) for diamond weels with B8/A and BM/A bond

It can be seen from Figures 6-10 that:

1. The cutting ability (C_c) decreases with an increase in cross-feed (V_{dm}) due to an increase in the repulsion forces between the diamond wheel and TC edges. This coefficient is greater when sharpening TC edges, type K40 and smaller at type K20.
2. With an increase in V_{dm}, C_c decreases, except for a wheel with BM/A bond and V_{dm} = 0,12 mm/double motion and use of cooling.
3. When working with the diamond wheels, effective power of direct and reverse motion progressively increases and decreases, indicating that the wheels have the ability to self-sharpened.
4. The relationship between $\frac{\vec{N}_e}{\acute{N}_e}$ under different modes and abrasive wheels is different, but usually grows with an increase in V_{dm}.
5. A diamond wheel with BM/A bond and cooling works very well with all sharpening modes. The corrected performance indicator (C_{pi}) is greater than 1, indicating high performance of this abrasive wheel.
6. The performance characteristics of the abrasive wheels in forced sharpening with B8/A and cooling, with c $\vec{V}_{dm}$ = 0,15 mm and $\acute{V}_{rm}$= 0,05 mm are better than the same wheels with V_{dm} = 0,20 mm/double motion.
7. The diamond wheel BM/A bond have better cutting capabilities than the wheel with B8/A bond, which is confirmed by the 3 times the corrected performance indicator (C_{pi}) at V_{dm} = 0.15 mm/double motion and cooling.

4. CONCLUSIONS

On the basis of the conducted experimental studies and the analysis made, the following conclusions can be made:

1. The diamond wheel with its bond, grain type, and sharpening mode, cooling, and type of TC knives have a steady effect on performance indicators performance indicators and sharpening quality.
2. Recommended to be used the following brands of diamond discs and sharpening modes:
   - abrasive wheel SD (PCD) 12A2 45° 125x5x3x32 125/100 B8/A 100; V = 16-18 m/s; V_l = 1,0 m/min; V_{dm} = 0,08-0,10 mm/double motion; without cooling;

- abrasive wheel SD (PCD) 12A2 45° 125x5x3x32 125/100 BM/A 100; V = 16-18 m/s; V_l = 1,0 m/min; V_{dm} = 0,05 mm/double motion; without cooling;
- abrasive wheel SD (PCD) 12A2 45° 125x5x3x32 125/100 BM/A 100; V = 16-18 m/s; V_l = 1,0 m/min; V_{dm} = 0,12-0,15 mm/double motion; with cooling.

3. It is recommended forced sharpening with B8/A abrasive wheel with cooling and with cross feed speed $V_{дв.х.}$ = 0,20 mm/double motion:$\vec{V}_{dm}$ = 0,15 mm – direct motion and $\acute{V}_{rm}$= 0,05 mm – reverse motion.

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Invasive Species as Raw Material for Pellets Production

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ABSTRACT

The study investigated the possibility of using non-native invasive wood species residuals i.e. black locust (*Robinia pseudoacacia* L.), boxelder maple (*Acer negundo* L.), horse chestnut (*Aesculus hippocastanum* L.), thorny locust (*Gleditsia triacanthos* L.) and tree of heaven (*Ailanthus altissima* L.) for pellets production. Pellets were made in laboratory conditions on a vertical pellet press Kahl 14-175. Furthermore, pure spruce (*Picea abies* L.) pellets were produced as a reference. The quality of produced pellets was tasted according to EN standard. The aim of the research was to investigate the differences in pelletization process and to assess the quality of pellets produced from different wood species. The production parameters for all wood species were similar; e.g. particle size of milled raw materials (2–4 mm) and moisture content (13-15 %). During pelletization, temperature of the die and the amount of produced pellets was recorded. The quality analysis showed great variability of the analysed parameters; mechanical durability (67-97 %), moisture contents (6-8 %), bulk density (630-750 kg/m^3) and ash content (0.3-1.3 %). Based on results we can concluded that wood species has an important influence on densification process and quality of the pellets, where the thorny locust, black locust and tree of heaven showed to be most promising for further investigations.

Key words: invasive wood species, pellet, pellet quality, pelletization

1. INTRODUCTION

Woody biomass is an important source of renewable energy and according to Lauri *et al.* (2014) it has the potential to satisfy 18 % of the word's primary energy consumption till 2050. Consequently, an increase in wood biomass prices can be expected in the next decades (Lauri *et al*, 2014). Due to increasing demand, traditionally used raw material from sawmills and pulp and paper industry may not be sufficient to meet future needs (Stelte *et al*., 2012).

Among the solid biofuels, the demand for wood pellets has the steepest growth curve (Stelte *et al.*, 2012). They are used in both industrial sized heat and power production plants, thermal gasification units, as well as for domestic properties (small installations). Pellets are densified form of wood fuels, and are therefore characterised with higher energy density, increased homogeneity and standardized size which enables high automation of the heating system (Stelte *et al.*, 2012). The most common raw material source for pellets is wood sawdust (predominantly spruce, pine or beech), a residue in sawmills plants.

There has been growing interest in utilising more varied biomass types for pellet production (Whittaker and Shield, 2017, Šafran *et al.*, 2017) such as straws (wheat, barley, oat) (Stelte *et al.*, 2012, Mani *et al.* 2006), coir fibre (Stelte *et al.*, 2018), corn stover and switchgrass (Mani *et al.* 2006), miscanthus, and even olive pulp (Škrokov 2018). As reported by Garcia (2019) the pellets for industrial use made from blends of woody (pine sawdust) and non-woody or alternative residual biomass (e.g. seasonal wastes from food industry, almond shells, coffee dreg, coca shells, grape pomace, pine kernel shells) have also a great potential.

Invasive species are often undervalued and underutilized compared to native species, thus they are typically used as biofuels (Mudryk, 2011). In the previous years, black locust wood was included in the European subsidizing program of tree species cultivation, therefore large quantities of this species is going to be harvested in the forthcoming years (Vasiliki, 2017). It needs to be emphasized that only low-quality wood or residues from wood processing industries should be used for energy production.

Sawdust from sawmills is usually free of bark (or other contaminants) and does not require substantial further processing, therefore it can be used for production of high-quality pellets. When using raw material of other (less known wood species) it is important to achieve similar level of pellet quality (Castellano, *et al*., 2015). The raw materials and its properties (e.g. compositions, particle size, moisture content) as well as pellets production conditions (i.e. feed speed, pelletization pressure) have a great influence on the quality of pellets.

We evaluated the pelletization behaveour and the pellet quality of five most common invasive wood species in Slovenia i.e. black locust (*Robinia pseuoacacia* L.), boxelder maple (*Acer negundo* L.), horse chestnut (*Aesculus hippocastanum*), thorny locust (*Gleditsia triacanthos*) and tree of heaven (*Ailanthus altissima*). Since these species vary in physical properties, we evaluated the impact of wood species density on the peletisation process. We assume that higher wood density affects the feeding speed and the production rate as well as the quality of the produced pellets.

2. MATERIALS AND METHODS

2.1. Raw material and samples preparation

Sawmills residues (slabs, edgings, trimmings) of five invasive wood species: black locust (*Robinia pseuoacacia* L.), boxelder maple (*Acer negundo* L.), horse chestnut (*Aesculus hippocastanum*), thorny locust (*Gleditsia triacanthos*), and tree of heaven (*Ailanthus altissima*) were tested. The chosen species were collected around Ljubljana, Slovenia, and investigated within the APPLAUSE project (Alien PLAnt SpEcies).

For each of the species without bark, the density, and ash content was determined. The residues were cut in cubes with dimensions app. 15 x 30 x 30 mm, chipped iusing knife mill CONDUX CSK 350/N1 and then further grinded in Retsch SM 100 mill using 2 and 4 mm screen (*figure 1*). Grinded samples of each species were stored in plastic airtight containers. Before pelletization the grinded raw material was conditioned by spraying water to reach the moisture content between 13 and 15 % for each sample. Spruce raw material was used as a reference material for pelletization and was obtained from local pellet producer.

Ash content was determined according to EN ISO 18122:2016 standard, using Nabertherm LE 14/22 B 300 oven in a for step procedure by heating the samples up to 550 °C.

Figure 1. Raw materials

2.2. Pelletization process

The raw material obtained from different tree species was pelletized with a press Kahl 14-175 equipped with a flat die (*figure 2*) and a feeding unit. The flat die is characterized with channel length and diameter of 22 mm and 6 mm respectively. Two rollers with diameter of 130 mm and thickness of 14.5 mm are used for the compression of material. The theoretical capacity of the pellet press is 30 kg/hour. During the pelletization process the feed rate was slowly increased in order to prevent jamming of the die. The feed rate as well as temperature at the die were constantly recorded during the pelletization process.

The pellets were cooled down for approximately two hours to room temperature and then packed in airtight plastic bags. At the end of each pelletization process the percentage of jammed channels in the die was estimated.

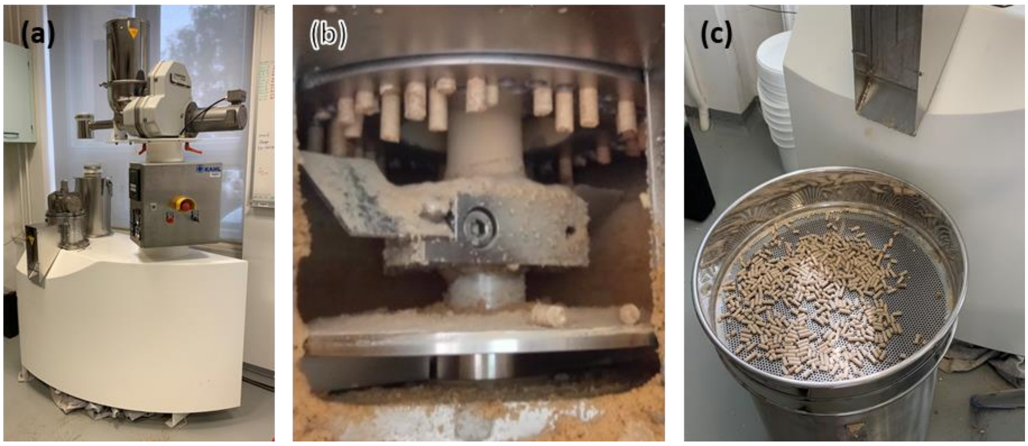

Figure 2. Laboratory pellet press Kahl 14-175

2.3. Pellets properties analysis

Pellet quality was evaluated according the standard EN ISO 17225-2:2014 based on the of following parameters; bulk density, pellet moisture content and mechanical durability.

The moisture content of raw material and of produced pellets was controlled with a fast method using moisture analyser (BEA-MA-110-1). After all samples were produced the moisture content was determined based on oven-dry method according the standard EN ISO 18134-2:2015, using Memmert drying chamber.

Bulk density of pellets was determined according to standard EN ISO 17828:2016, although the container volume was modified to 500 ml, due to smaller quantities of produced pellets.

Mechanical durability was determined according to standard EN ISO 17831-1:2016.

3. RESULTS AND DISCUSSIONS

3.1. Raw material

The density of investigated wood species are presented in *Table 1*. The variability in density between the invasive species is relatively large, the highest values were evaluated for black locust (726 kg/m^3) and the lowest for horse chestnut (490 kg/m^3). Ash content in raw material varied from 0.29 % to 1.7 %.

Table 1. Tasted characteristics of raw material

Raw material	Boxelder maple	Horse chestnut	Thorny locust	Tree of heaven	Black locust
Density [kg/m^3]	540	490	688	593	726
Ash content [%]	1.35	1.2	0.68	1.7	0.29

3.2. Pelletization

Since it is known that the raw material has a big influence on the process and quality of pellets we produced pellets from all species at the same conditions (die parameters) only the flow rate of raw material was adjusted according the motor current consumption (e.g. in case the current consumption exceeded the normal value). For each species the feeding speed at the beginning of pelletization varied between 50 to 100 rpm. In case there were no current consumption issues the feeding speed was adjusted / increased in regular 1 min intervals.

The average feeding speed (*figure 3*) of spruce and wild chestnut was the highest, which could be relate to low density of raw material.

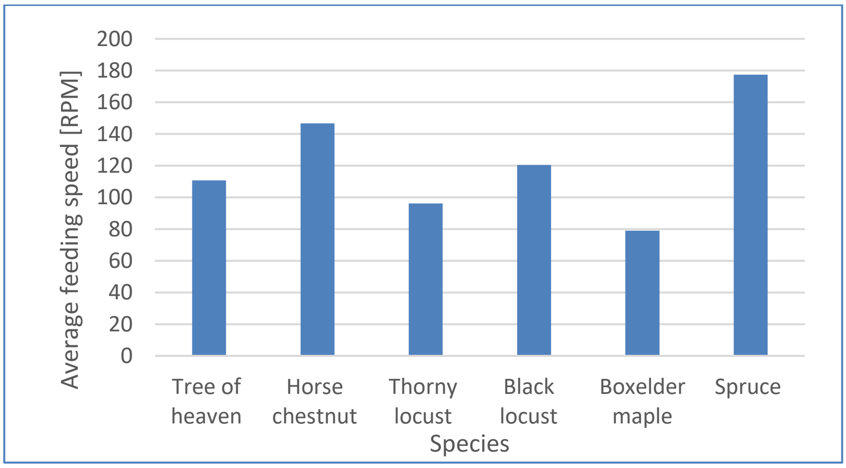

Figure 3. Average feeding speed during pelletization process

The duration of pelletization and quantity of produced pellets is represented on *figure 4*. These two parameters can be used to evaluate the differences between pelletization rate of the observed species. The highest (167 g/min) and lowest (78 g/min) pelletization rate was noticedfor horse chestnut and black locust respectively. Similar pelletization rates as for horse chestnut were noticed also for tree of heaven and thorny locust.

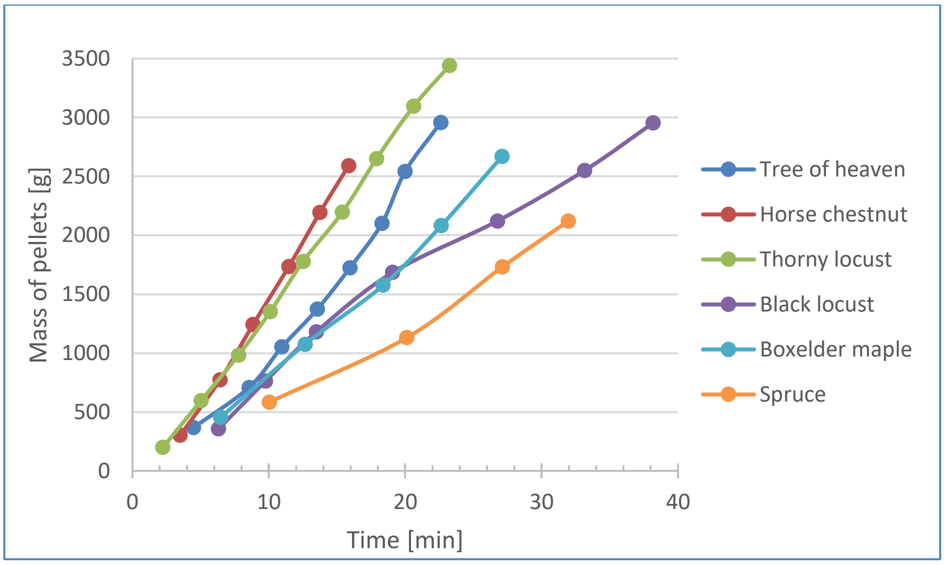

Figure 4. Quantity of produced pellets during pelletization process

One of the parameters to evaluate the pelletization behaviour between different species is the friction generated during pelletization in the die channels. Higher temperature is related to higher friction at the die. The highest average temperature at the die was measured during pelletization of horse chestnut and black locust (*figure 5*), on the contrary pelletization of tree of heaven and thorny locust caused lower average temperature. These measurements show that density and temperatures of die are not directly related. One of the reasons of the variability of temperature at die can be attributed to differences in chemical composition of investigated species.

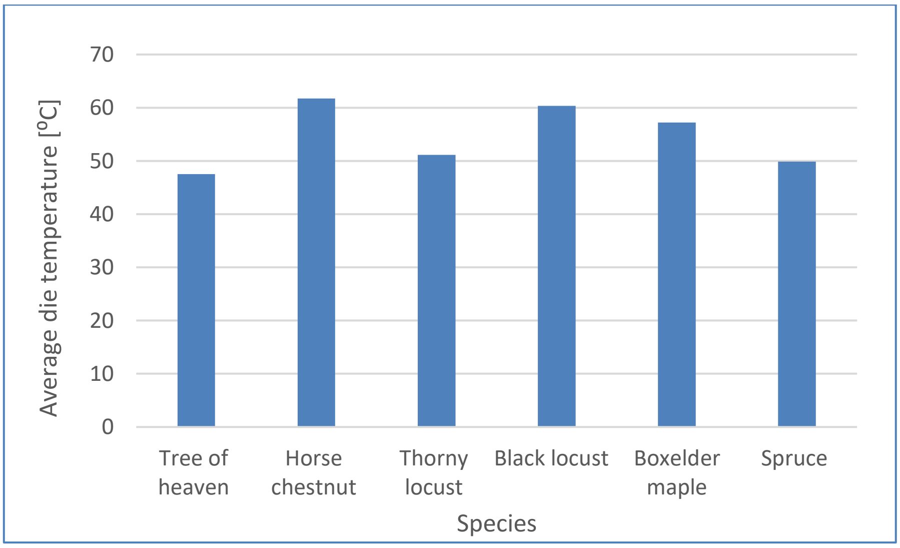

Figure 5. Average temperature at die during pelletization

If the friction in the die is too high some channels are jammed permanently. In case a higher number of channels is jammed, the pellet production rate can decrease significantly. At the end of each pelletization process, the die was cleaned and the remaining material was removed out of the channels. In case the channels were not jammed, the material was removed without effort, however for permanently jammed channels a hammer or borer was necessary. Thus, after cleaning of the die the share of permanently jammed channels was estimated for each species. After pelletization of black locust (45 %) and thorny locust (45 %) lowest share of jammed channels was observed. In case of boxalder maple the share was low in second run of experiment, while in the first run we had to stop the pelletization process due to very high die temperature (96 °C) and high percentage of jammed channels (75 %). In the second run, the temperature of the die did not exceed 86 °C (average temperature was 62 °C), and the share of filled channels was lower than 20 %.

3.3. Pellets properties

All samples of produced pellets (*figure 6*) were characterised with moisture content below 10 % and varied between 5.3 % for and 7.0 % for pellets produced from boxelder maple and spruce respectively (*figure 7a*). Average bulk density varied between 612 and 711 kg/m^3 (*figure 7b*). Both parameters meet the requirements for quality class A1 as specified in the standard EN ISO 17225-2.

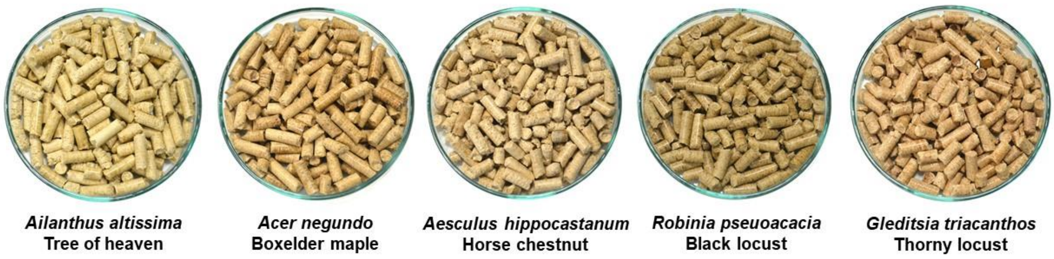

Figure 6: Pellets from invasive tree species

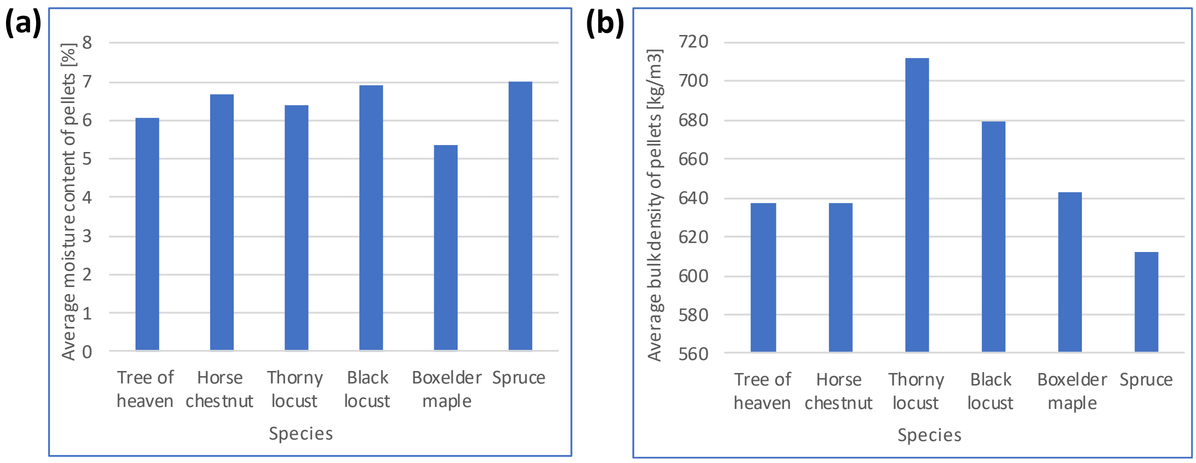

Figure 7: Pellets characteristic: Average moisture content (a) and average bulk density (b)

The average mechanical durability of produced pellets (figure 8) did not fulfil the requirements of the quality standards, where the mechanical durability should be greater than 97.5 %. The durability of pellets made from invasive wood species varied from as low as 67 % at boxelder maple to 95 % at thorny locust. The durability of spruce pellets was, as expected, very low (44 %), since the length of die channels was 22 mm and thus the press (compression) ratio to low (the ratio of the diameter of holes to the length of channels) (e.g. Obernberger and Thek, 2010). For low-density raw material, other dimensions of the die should be used. Mechanical durability of pellets produced from species of higher density (thorny locust, black locust and tree of heaven) is better, yet not sufficient. Optimization in the phase of raw material preparing and optimisation of pelletization parameters need to be done to improve the quality of pellets.

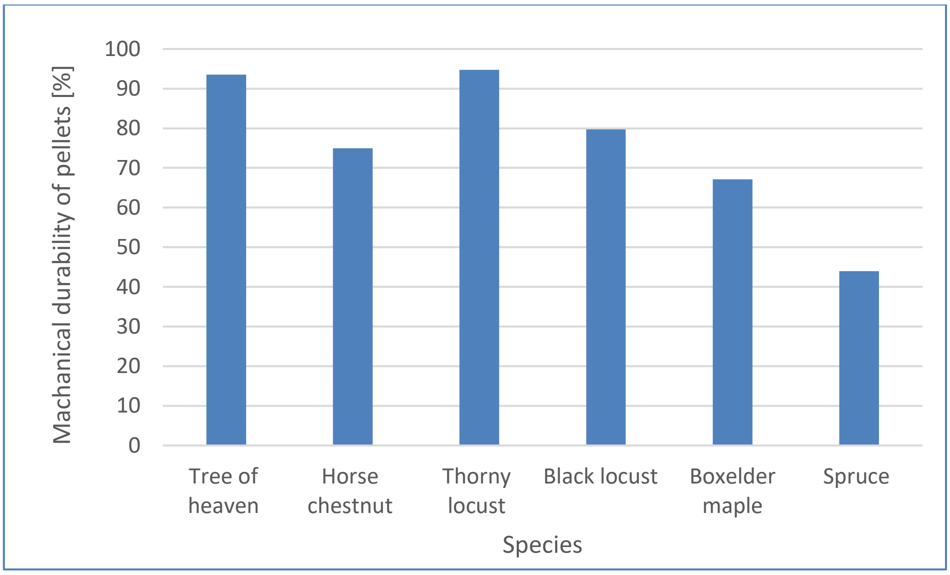

Figure 8: Average mechanical durability

4. CONCLUSION

Based on results we can concluded that wood species has an important influence on densification process and quality of the pellets, where the thorny locust, black locust and tree of heaven showed to be most promising for further investigations.

Produced pellets fulfil the individual quality requirements of standards e.g. moisture content and bulk density.

The temperature at the die in the performed experiment do not show correlation between die temperature and density of raw material, but the detailed chemical composition of raw material still need to be considered in further investigations.

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Production of Fuel Ethanol from Lignocellulosic Biomass

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ABSTRACT

An important source of renewable energy is biomass, in which solar energy is stored. Lignocellulosic biomass contains mainly cellulose, hemicelluloses and lignin. It includes agricultural production wastes, wood processing wastes and energy plants. Conversion of lignocellulosic biomass to ethanol is a complex process. Its treatment requires biological, chemical, physical and/or physicochemical treatment so as to break the connection between the lignin structure, cellulose and hemicellulose. Then biomass is prepared for enzymatic cleavage of cellulose and hemicelluloses to fermentable carbohydrates. The fermentation itself is also more complex and it is necessary to use microorganisms capable of fermenting mixture of C6 and C5 saccharides. At present, the technology of bioethanol production from lignocellulosic biomass is the subject of intensive worldwide research. Its main objective is to find the optimal relationship between the cost of its production and the environmental load of the technology being developed.

Key words: bioethanol, fermentable carbohydrates, lignocellulosic biomass, treatment, renewable energy

1. INTRODUCTION

Currently as renewable raw materials for the mass production of the fuel ethanol used especially sugar cane in Brazil and starch materials in the USA and Europe (bioethanol 1st generation). It can be produced from lignocellulosis biomass, too (e.g. wood, straw) and that ethanol was identified as the best alternative to fossil fuels and biofuels 1st generation by multiple authors. This is so for several reasons. Lignocellulosic biomass don't compete with the production of food by their nature and it is generally available. It also has a more favourable balance of greenhouse gas in comparison with the current sources of fuel (Gonzalez-García *et al.*, 2012; Smullen *et al.*, 2019). In this context Wang *et al.* (2012) reported the potential reduction in greenhouse gas emissions by 77 – 97 % or 101 – 115 % for the production of ethanol from *Panicum virgatum* or *Miscanthus sinensis* compared with fuels based on crude oil.

Conversion lignocellulosic biomass to ethanol, however, is a complex process. The cause is a complex structure lignocellulose consisting of several components, which are closely linked (Hassan *et al.*, 2018). Therefore, when editing is necessary biological, chemical, physical and / or physicochemical treatment, which will be able to break up bonds between lignin structure, cellulose and hemicellulose. The most crucial step for the utilization of lingocellulosic biomass is its delignification, through pre-treatment processes (Ramarajan and Manohar, 2017). After them is the biomass prepared for enzymatic cleavage of cellulose and hemicelluloses to fermented carbohydrates (Kumar and Sharma, 2017; Mosier *et al.*, 2005; Sun *et al.*, 2016). The actual fermentation is also more complex and it is necessary to use microorganisms capable to ferment C6 and C5 carbohydrates.

Despite this, the technology for producing bioethanol from lignocellulosic biomass is the subject of intensive research worldwide, with the main aim of finding the optimal relationship between costs and the environmental impact of the technology being developed.

2. TREATMENT OF LIGNOCELLULOSIC BIOMASS

Annually, 200 billion tons of lignocellulosic biomass is generated across the globe from agriculture, forestry, paper industries, and agro-based processing units (Chandel and Singh, 2011). Disposal of these wastes is an environmental concern, as they are accumulated rapidly and the natural rate of degradation is very slow. Lignocellulosic biomass is complex polymeric structures composed of cellulose, hemicellulose, and lignin (Chen, 2014). Their proportion in individual substrates is shown in *Table 1.*

Table 1. Content of cellulose, hemicellulose and lignin in biomass with potential use for the production of fuel ethanol (Sun and Cheng, 2002; Muktham et al., 2016)

Biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Hardwood stems	40 – 55	24 – 40	18 – 25
Softwood stems	45 – 50	25 – 35	25 – 35
Walnut shells	25 – 30	25 – 30	30 – 40
Corn stover	35 - 45	21 - 35	11-19
Grasses	25 – 40	35 – 50	10 – 30
Paper	85 – 99	0	0 – 15
Newspaper	40 – 55	25 – 40	18 – 30
Wheat straw	30 - 40	20 - 25	15 - 20
Cynodon dactylon	25	36	6
Panicum virgatum	45	32	12

Taghizadeh-Alisaraei *et al.* (2019) refer to wastes from date palm (*Phoenix dactylifera* L.) as a very promising substrate to produce fuel ethanol. Date is one of the main agricultural products of tropical regions of the North Africa and Middle East (Egypt, Iran, Saudi Arabia, Algeria - share on world production nearly 50 %). It was found high amount of carbohydrates with high percentage of cellulose and lignin is in different parts of the date palms (midribs, leaflets, fruit stalks).

Cellulose, as a major source of fermentable carbohydrates in biomass, is in such an interaction with hemicellulose and lignin that prevents its direct hydrolysis by enzymes. Another factor is the existence of crystalline regions in the polysaccharide chain of cellulose (Hamelinck *et al.*, 2005). Therefore, prior to enzyme hydrolysis, it is necessary to disrupt the chemical and physical structure so as to ensure better enzyme access to the substrate (Hahn-Hägerdal *et al.*, 2006). Several methods of biomass treatment are used to achievement these requirements - they are collectively called pre-treatment.

2.1. The pre-treatment of lignocellulosic biomass

For decades, researchers are trying to develop methods to depolymerize carbohydrates polymeric fractions into fermentable sugars with high efficiency and minimum generation of inhibitors at lower costs (Grethlein *et al.*, 1984; Canilha *et al.*, 2012; Chandel *et al.*, 2012; Raza-Amin *et al.*, 2017). Requirements for ideal pre-treatment of lignocellulosic biomass is shown on *Figure 1.*

Antunes *et al*. (2019) and Nargotra *et al*. (2019) reported that prior to the selection of a particular method for biomass pre-treatment, the knowledge about the chemical composition of the lignocellulosic biomass is of great importance. In general, pre-treatment methods can be divided into four groups: (a) physical, (b) physicochemical, (c) chemical and (d) biological (Alvira *et al.*, 2010; Silveira *et al.*, 2015). Physical methods include e.g. grinding, extrusion, hydrothermal treatment or use of ultrasonic resp. microwave processing. These methods can serve to increase the efficiency of other methods or to increase the available surface and pore size, reduce the degree of polymerization of cellulose and lignin, respectively for partial hydrolysis of hemicellulose. Tian *et al.* (2019) tested the use of hot water followed by extrusion

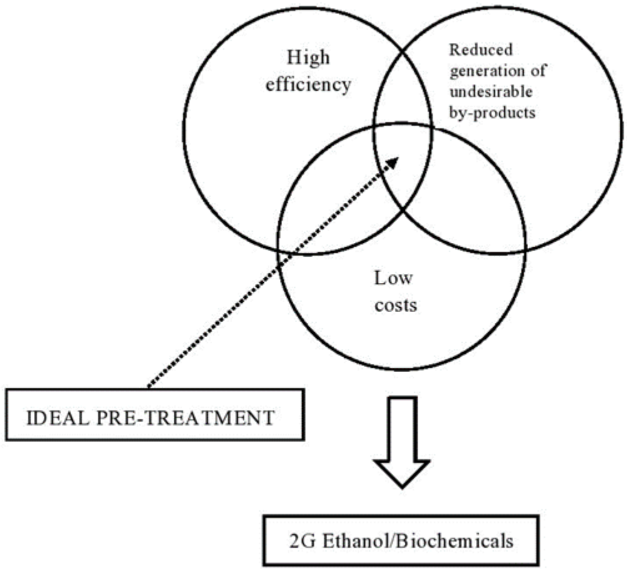

Figure 1. Ideal pre-treatment of lignocellulosic biomass for production 2G ethanol (adapted according Antunes et al., 2019)

to produce cellulose ethanol from aspen and eucalyptus wood without the use of chemicals. They followed up on the work of previous authors who have also described lignocellulosic biomass pre-treatment without chemicals in the context of environmental protection (Chen *et al.*, 2016; Kim *et al.*, 2016). In contrast, Zhang *et al.* (2015), Nakashima *et al.*, (2016) and Zhu *et al.*, (2016) reported that the physical pre-treatment must be combined with chemical pre-treatment to increase the efficiency. Chemical methods use solutions of acids, bases, liquid ammonia, hydrogen peroxide or organic solvents, sometimes in combination with each other. Although chemical methods have been shown to be effective in biomass deconstruction or lignin/hemicellulose fractionation, the associated disadvantages (high cost on chemicals, serious corrosion to equipment and environmental hazards) are challenges to the cellulosic ethanol biorefinery (Sathitsuksanoh *et al.*, 2013; Tadesse and Luque, 2011; Zhao *et al.*, 2009). In addition, some pre-treatment conditions can cause obvious degradation of carbohydrate components into various biological inhibitors which hamper the enzymatic hydrolysis or fermentation process (Jönsson and Martín, 2016; Qin *et al.*, 2016). Biological pre-treatment methods involve the use of different microorganisms such as bacteria, fungi, and actinomycetes and their enzymes for the degradation/hydrolysis of various constituents (lignin, cellulose, hemicellulose, and polyphenols) of biomass (Maurya *et al.*, 2015; Sindhu *et al.*, 2016). The main advantages of biological methods are low energy demand and mild conditions required (Akhtar *et al.*, 2016). Pathak and Navneet (2017) reviewed the association of both bacteria and fungi with the degradation of different polymers including those ones of plant cell wall. The bacteria such as *Pseudomonas aeruginosa*, *P. stutzeri*, *Streptomyces badius*, *S. setonii*, *Rhodococcus ruber*, *Comamonas acidovorans*, *Clostridium thermocellum*, *Butyrivibrio fibrisolvens*, etc., and fungi like *Aspergillus niger, A. flavus, Fusarium lini*, *Pycnoporus cinnabarinus,* and *Mucor rouxii* were reported as the most prevalent species among their respective community. In addition to above-mentioned advantages of biological pre-treatments, there are some disadvantages which mainly include problems of contamination and microbial mutation (Antunes *et al.*, 2019).

2.2. Enzymatic hydrolysis

The glucose yield after cellulose hydrolysis would be only 20 % of the theoretical amount if the substrate were not first treated. Up to 90 % yield of glucose can then be achieved (Sánchez and Cardona, 2008).

The enzymatic hydrolysis of cellulose and hemicellulose is carried out by highly specific cellulase and hemicellulase enzymes. It requires the synergistic effect of at least three major classes of enzymes: endoglucanases (EC 3.2.1.4), exoglucanases (EC 3.2.1.91) and *β*-glucosidases (EC 3.2.1.21). The complete enzymatic depolymerization of this complex network of polysaccharides requires the combined action of different enzyme activities like endo-*β*-1,4-xylanases, 1,4-*β*-xylosidases, *β*-L-arabinofuranosidases, *β*-glucuronidases, acetylxylanesterases, feruloylesterases, endo-1,4-*β*-mannanases, *β*-1,4-mannosidases and endo-1,5-*β*-L-arabinosidases (Berger *et al*., 2014).

Several types of bacteria and filamentous fungi are capable of producing cellulases and hemicellulases. They are genera of bacteria *Clostridium*, *Cellumonas*, *Thermomonospora, Bacillus, Bacteriodes, Ruminococcus, Erwinia*, *Acetovibrio, Microbispora* and *Streptomyces*. The fungi include the genera *Trichoderma, Penicillium, Fusarium, Phanerochaete, Humicola* and *Schizophillum.* Di-Donato *et al.* (2019) also tested cellulases from thermophiles for the saccharification of lignocellulose. Berger *et al.* (2014) describe the most used extremophilic species are the thermophilic bacteria, that are members of the genera *Pyrococcus, Sulfolobus, Thermotoga, Geobacillus, Caldicellulosiruptor, Thermus,* and *Bacillus*. Xylanases can be found in thermostable, thermoalkalophilic, thermoacidophilic, and thermohalophilic species belonging to the genera *Pyrococcus, Dictyoglomus, Sulfolobus, Bacillus, Geobacillus, Thermotoga, Acidothermus, Cellulomonas, Paenibacillus, Thermoanaerobacterium, Actinomadura, Alicyclobacillus, Anoxybacillus, Nesterenkonia, Caldicellulosiruptor, Enterobacter, Caldanaerovirga, Clostridium, Rhodothermus,* and *Thermotoga*. The main factors of enzymatic hydrolysis of lignocellulosic materials are substrate concentration and quality, substrate pre-treatment method, cellulase activity and hydrolysis conditions - temperature, pH and mixing. The optimum temperature and pH are determined by the substrate, the enzymes used and the duration of hydrolysis. The optimum temperature and pH of cellulases from different sources is usually in the range of 40 – 50 °C and pH 4-5. The addition of cellulases usually ranges from 5 to 35 FPU per gram of substrate (Taheradeh and Karimi, 2007).

Enhanced conversion of lignocellulosic biomass by enzyme hydrolysis can be achieved using surfactants such as sodium dodecyl sulfate (SDS), polyethylene glycol (PEG) 8000, PEG 6000, Tween-80, Tween-20. They may also have a stabilizing effect on enzymes (Kristensen *et al.*, 2007). Chang *et al.* (2017) describe for ethanol production by using consolidated bioprocessing (CBP) the use of surfactants in combination with ionic liquids (1-ethyl-3-methylimidazolium methane sulphonate/chloride/acetate/dimethyl phosphate or 1-butyl-3-methylimidazolium chloride). Surfactants effectively remove lignin and alter the biomass structure which results in enhanced surface area for action of ionic liquids, and subsequently of saccharification enzymes, thus, increasing the pretreatment and enzymatic hydrolysis. Tu *et al.* (2019) describe the use of PEG 6000 also in the processing of plywood. This biomass contains quite a lot of lignin (more than 30 %), which both limits cellulose accessibility and prevents cellulose from contacting enzymes. Using PEG 6000 at a concentration of 1 gL^{-1} increased glucose production by 35 % compared to the experiment where PEG 6000 was not used. The results suggest that PEG 6000 is a suitable potential additive for increasing the bioethanol production from plywood residue in upscale operations.

3. ETHANOL PRODUCTION

Generally, any biomass containing sufficient carbohydrates (sugar beet, sugar cane) or substances that can be converted to carbohydrates such as starch or cellulose is suitable for the production of bioethanol. The production of bioethanol from biomass containing simple carbohydrates is the simplest technological process. Bioethanol production from starchy raw materials is also commercially widespread. Conversion of lignocellulosic biomass to bioethanol differs from the above two technological processes. The hydrolysis and fermentation are more complicated. Fermentation step needs microorganisms, which fermentable both C6 and C5 saccharides. The process of converting lignocellulosic biomass to ethanol is schematically shown in *Figure 2*, there is also compared with the production of 1st generation bioethanol.

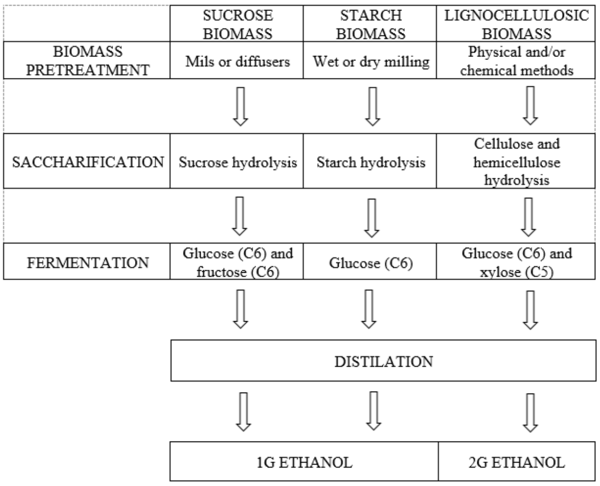

Figure 2. General schemes of first (1G) and second generation (2G) ethanol production (adapted according Di Donato et al., 2019)

The main technical and economic barriers to the development of lignocellulosic ethanol are represented by the cost of production of efficient enzymes for the saccharification and the need of separate steps and different microorganisms for C6 and C5 sugars' fermentation. Bioethanol from lignocellulosic biomass is economical only if the sugar concentration exceeds $40gL^{-1}$ (Chen and Fu, 2016). At present, the lignocellulose conversion to ethanol can be implemented by means of different process, i.e the separate hydrolysis and fermentation (SHF), the simultaneous saccharification and fermentation (SSF), the simultaneous saccharification and cofermentation (SSCF) (Aditiya *et al.*, 2016). These processes are schematically drawn in *Figure 3.*

The use of these processes has both advantages and limitations. In the SHF process, each technological step is carried out in the optimal conditions of pH and temperature, but glucose accumulated during saccharification inhibits cellulases, then is need of a cooling step after saccharification and need for separate vessel for saccharification and fermentation. Inhibition of cellulases does not occur in the SSF process but hydrolysis and fermentation steps cannot be maintained at their optimal operational conditions. The drawback for SSF and SSCF is the requirement of thermotolerant fermenting microorganisms that can operate at the higher temperatures (i.e. ≥50 °C) of the saccharification step. Now the main focus is on the consolidate bioprocessing process (CBP), the higher integrated process that is carried out by a single bacterial species that would be able to produce the hydrolytic enzymes, to degrade the polysaccharides and to ferment all formed sugars to ethanol. In this context, Bibra *et al.* (2015) report that recombinant strains *Saccharomyces* or *Zymomonas* would be suitable for fermenting both C5 and C6 saccharides.

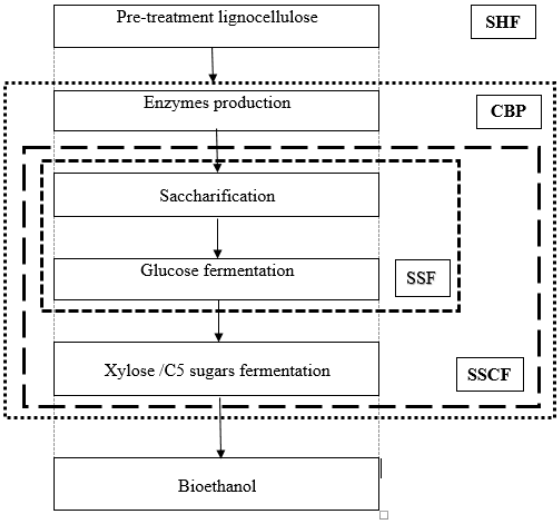

Figure 3. Main processes for conversion of lignocellulosic biomass into ethanol
(adapted according Di Donato et al., 2019)

According Di Donato *et al.*, (2019) the ethanologenic thermophilic bacteria are the ideal candidates since many of them are able to hydrolyse either cellulose or hemicellulose, and to ferment both hexoses and pentoses. The anaerobic bacterium *Clostridium thermocellum* is one of the most intensively studied species for CBP process since it produces cellulolytic enzymes besides being able to ferment sugars to ethanol. But microorganism which has possess all these abilities does not exist till date, however, much effort is still being made to genetic modifications and prepare a suitable microorganism.

4. CONCLUSION

Lignocellulosic biomass is a renewable energy source because it is a potential source of fermentable carbohydrates. However, its complex composition requires demanding machining. Carbohydrates formed by pre-treatment and enzymatic hydrolysis can be used for various products. They have great potential for bioethanol production. The treatment of lignocellulosic biomass as well as the fermentation of the resulting carbohydrates to ethanol has not yet been fully solved and is still the subject of intensive research.

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Bending Properties of Reinforced Plywood with Fiberglass Pre-Impregnated Fabrics

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ABSTRACT

One of the methods for achieving higher plywood properties is reinforcing the plywood structure trough applying different non-wood materials in it that will contribute in achieving higher physical and mechanical properties of the end product.

The aim of this research was to study the bending properties of plywood reinforced with fiberglass fabrics pre-impregnated with alcohol-soluble phenol-formaldehyde resin. The pre-impregnated fabrics were incorporated as layers in the structure of the plywood panel. Different models of reinforced plywood were made through a change of the position of the reinforcing layers in the structure of the panel. One additional model was made without reinforcements as comparing plywood model. Plywood was composed of eleven layers of peeled beech veneers with thickness of 1.5 mm and 1.85 mm. Alcohol-soluble phenol-formaldehyde resin was used as plywood binder. The bending strength and modulus of elasticity in bending of the plywood panels were tested in two directions: parallel and perpendicular to the face grain.

The research results showed that the values of bending strength and modulus of elasticity in bending are significantly affected by the use of pre-impregnated fiberglass fabrics as reinforcements in plywood structure.

Key words: bending strength, fiberglass fabric, phenol-formaldehyde resin, plywood, pre-impregnated, reinforcement

1. INTRODUCTION

World-wide research in the field of plywood is focused on finding methods and technical-technological solutions for the production of high quality structural boards. One of the ways to improve the properties of plywood is through reinforcement in their structure. These reinforcements relate to the application of various non-wood materials to the panel structure, which will transfer their properties to the end product, thereby enabling higher physical and mechanical properties to be achieved. Fiber-reinforced polymers as reinforcements of wood structures have shown the potential to improve its performance and durability (Davalos *et al.*, 2000).

Plywood is one of the most widely used wood-based materials in the construction industry. Overlaying plywood with fiber reinforced polymers offers the production of superior composites with significantly improved mechanical properties (Hardeo and Karunasena, 2002; Choi *et al.*, 2011). Plywood in combination with fiber-reinforced polymers layers combine the structural characteristics of plywood (durability, bending strength, stiffness and dimensional stability) with the durability and water resistance of surfaces made of polymer composite which also contribute to the strength and stiffness of the end product (Zīke and Kalniņš, 2011). Reinforced plywood panels also found their application in the transport industry, manufacture of shipping containers and wagons (Bulleit, 1984).

Many studies were carried on the research of the reinforcement of plywood with fiber-reinforced polymers, during which different types of fiber reinforcements (glass, carbon, aramid) and different resins as matrix were used (Xu *et al.*, 1996, Xu *et al.*, 1998, Brezović *et al.,* 2002, Brezović *et al.,* 2003, Brezović *et al.,* 2010, Biblis and Carino, 2000, Hrázský and Král, 2007, Maniņš and Zīke, 2011).

The possibilities to reinforce wood with pre-impregnated materials-prepreg were first explored by Rowland *et al.* (1986). They give a detailed overview on the possibilities of applying different types of synthetic fibers as reinforcement of wood-based composites including pre-impregnated fiberglass fabrics. Of the reinforcements used in the research, the most technically and economically suitable were glass fibers. Reinforced compositions with phenol-formaldehyde pre-impregnated fiberglass fabrics in these studies showed no degradation even after exposure to accelerated aging in wet conditions and retained high shear strength. Prepregs are suitable for wood reinforcement because they increase strength and rigidity and potentially reduce variations in mechanical properties of wood (Rowland *et al.,* 1986).

The influence of different types of technical fabrics embedded in the adhesive layer of plywood has been explored by Kohl *et al.* (2013). The application of pre-impregnated glass, carbon and aramid fiber materials results in a significant reduction in deflection and an increase in carrying capacity of plywood exposed to compressive loads (Hardeo and Karunasena, 2002; Choi *et al.*, 2011).

The advantages and excellent characteristics of fiber-reinforced polymer composites are a motive for exploring the possibilities for producing plywood reinforced with polymer composites such as fiberglass prepregs. The application of acceptable composite systems and processes will allow the use of lower quality wood for structural purposes. The application of such reinforcements can minimize variations in the mechanical properties of wood-based composites.

The aim of the research presented in the paper is to study the bending properties of plywood reinforced with pre-impregnated fiberglass fabrics-prepregs, inserted as reinforcements in adhesive layers of plywood structure.

2. MATERIALS AND METHODS

The models of the reinforced experimental plywood were obtained by inserting reinforcement layers of pre-impregnated fiberglass fabrics (prepreg) into the adhesive layers of the panels. By changing the position of the reinforcements in the plywood structure, four models of eleven-layered reinforced plywood were made. Each model had the same number of beech veneers of each thickness class: six veneer sheets with a thickness of 1.5 mm and five veneer sheets with a thickness of 1.85 mm. The orientation of adjacent layers of veneers in plywood structure is at right angle. For comparison of the results, one control model of plywood was made without reinforcements.

In three models of reinforced plywood, each reinforcement layer is consisted of four sheets of pre-impregnated fabric placed one above the other and inserted into the panel structure symmetrically on both sides with respect to its axis of symmetry. This means that the structure of these three models incorporates a total of eight sheets of pre-impregnated fiberglass fabrics. Modeling is done by changing the position of reinforcement layers in different adhesive layers throughout the panel structure. The composition and cross-section of plywood models is shown on Figure 1.

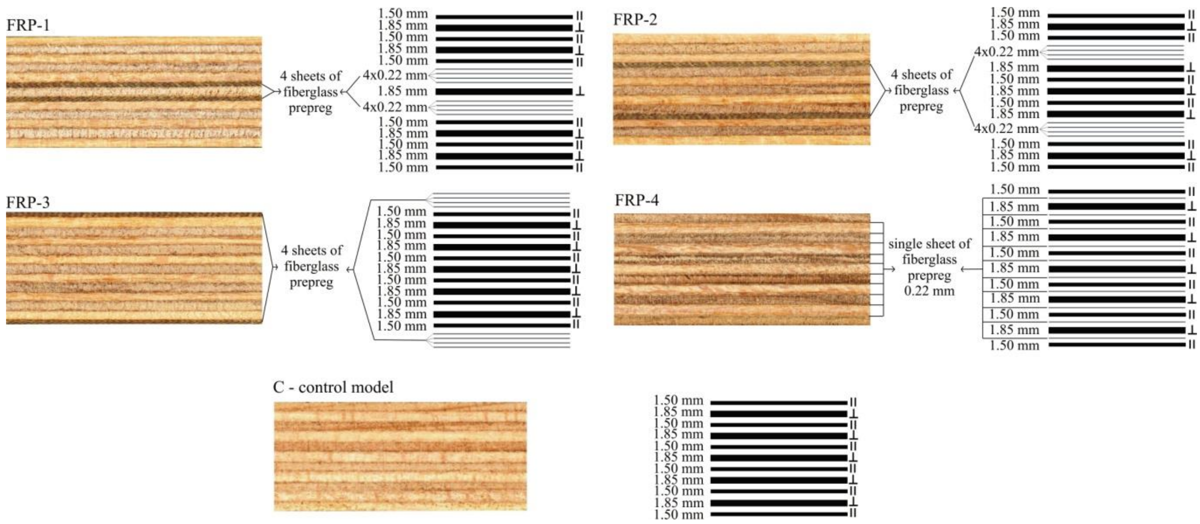

Figure 1. Pattern and cross-section of plywood models

In the structure of the first model, the reinforcements are positioned next to the central veneer sheet, respectively in the fifth and sixth adhesive layer, while in the structure of the second model they are inserted into the third and eighth adhesive layer. In the third model, the reinforcements represent the surface layers of the panel (Figure 1). The fourth experimental model of reinforced plywood was made by inserting single sheets of pre-impregnated fabric in each adhesive layer of the panel (Figure 1). Given that the structure of the plywood panels comprises ten adhesive layers, the reinforcement of this model is done by inserting ten sheets of pre-impregnated fiberglass fabrics.

In all models of reinforced plywood, the orientation of the wrap of the fabric is parallel to grain direction of the surface veneers.

Fiberglass fabric used for plywood reinforcement is a product of the Taiwanese company „Taiwan Glass" and is procured by the company "Laminati Com" from Prilep. This fabric is supplied in the form of a roll, which after impregnation with a resin is cut to the required format.

The fabric is made of E-glass fibers with simple "plain" weaving. The threads of the fabric are made from bundles of approximately 408 continuous filaments with diameter of 9 microns (G mark). The weight of the bundles is 66 tex (tex = g / 1000 m). The threads are made of single bundles.

The technical characteristics of the fabric, given by the manufacturer are shown in Table 1.

The threads that make up the wrap and fill of the fabric are identical.

Table 1. Technical characteristics of the fiberglass fabric

No.	Parameter	Result
1	Wrap threads	ECG-75 1/0
2	Fill threads	ECG-75 1/0
3	Wrap density (threads /10 cm)	173/10 cm
4	Fill density (threads /10 cm)	122/10 cm
5	Surface mass of the fabric (g/m^2)	202±3
6	Thickness of the fabric (mm)	0.173±0.020
7	Tensile strength to wrap (dN)	> 41
8	Tensile strength to fill (dN)	> 31

Pure alcohol-soluble phenol-formaldehyde resin was used for pre-impregnation of fiberglass fabrics used as reinforcements of experimental plywood. The same resin was also used for veneer bonding.

The resin was a product of company "Fenoplast 99" OOD, Ruse, Republic of Bulgaria, supplied under the name RFE-2 and has the following characteristics: form - brown-reddish viscous liquid, content of dry matters – 51 %, viscosity by Vz4/20°C – 33 s, gel time at temperature of 150 °C – 96 s. Methyl alcohol was used as resin solvent.

Pre-impregnation of the fabric was done on an impregnation machine, where the fabrics pass through a system of rollers that guide the fabric through the adhesive container so that it is applied double-sided to the fabric. In the later phase of impregnation, the impregnated fabric goes through a drying section, where the process of polycondensation of the resin begins, but not its complete hardening. The drying temperature gradually increases from 80 to 140ºC. Complete hardening of the resin occurs at the stage of pressing the plywood composition. The speed of the fabric passing through the impregnating machine was 2.5 m/min. At the exit of the drying section, the impregnated fabric was cut into the format corresponding to the dimensions of the plywood. The fiberglass fabric was pre-impregnated with resin in quantity of 140 g/m^2. The thickness of the pre-impregnated fabrics was 0.22 mm.

The veneers and fiberglass prepregs were assembled in plywood compositions according to the plywood model. Pure alcohol-soluble phenol-formaldehyde resin with concentration of 51 % was used as plywood binder, applied on the veneers in quantity of 180 g/m^2. The panels were pressed in a hot press using the following parameters: specific pressure of 1.8 kg/cm^2, pressing temperature of 155 °C and pressing time of 30 min.

After pressing process was completed, plywood panels were cooled to the ambient temperature of 20 °C into the press for 30 minutes under reduced pressure in order to obtain flat panels and to reduce the warping and deformation of the panels.

The plywood models were made in the following dimensions: 1180×910×d mm. The moisture content of the panels was 8.3 %.

The denotations of the experimental plywood models have the following meaning:

- model FRP-1 – eleven-layer plywood reinforced with four sheets of fiberglass prepreg on both sides of the central axis, positioned in the fifth and in the sixth adhesive layer of the panel (d=16.69 mm; γ=929.01 kg/m^3);
- model FRP-2 – eleven-layer plywood reinforced with four sheets of fiberglass prepreg on both sides of the central axis, positioned in the third and in the eight adhesive layer of the panel (d=16.15 mm; γ=934.88 kg/m^3);
- model FRP-3 – eleven-layer plywood reinforced with four sheets of fiberglass prepreg on each surface of the panel (d=16.38 mm; γ=939.67 kg/m^3);
- model FRP-4 – eleven-layer plywood reinforced with single sheets of pre-impregnated fabric in each adhesive layer of the panel (d=17.32 mm; γ=959.33 kg/m^3).
- model C – control model of eleven-layer plywood without reinforcements (d=15.70 mm; γ=822.69 kg/m^3).

The bending strength and modulus of elasticity in bending of experimental plywood panels were tested according to МКС EN 310. These properties were tested in two directions, i.e., parallel and perpendicular to the face grain of the plywood panel. A universal machine for testing mechanical properties "SHIMADZU", model AUTOGRAPH AG-X 250 kN was used for testing.

The obtained data were statistically analyzed. One way ANOVA was used to determine the significance of the effect of fiberglass prepreg reinforcements on plywood bending properties. Tukey's test was applied to evaluate the statistical significance between mean values of the bending strength and modulus of elasticity in bending of plywood with different layouts of reinforcements (different plywood models). The tests were conducted at 0.05 probability level.

Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

3. RESULTS AND DISCUSSION

The results for the bending strength parallel and perpendicular to the face grain of plywood panel are shown in Table 2.

The analysis of the obtained results for the bending strength parallel and perpendicular to the face grain of plywood shows that all models of reinforced plywood have higher values of these properties compare to the control model of plywood made without reinforcements. The highest value of bending strength in both directions of the panel is obtained in model FRP-3. Compare to the control model C, reinforcement of plywood with fiberglass prepreg positioned as surface layers of the panel increases the bending strength parallel to the face grain for 70.22 % and perpendicular to the face grain direction for 70.76 %.

The analysis of variance of the obtained data for bending strength parallel to the face grain (ANOVA: $F(4, 20) = 97.366$; $p << 0.001$) and perpendicular to the face grain (ANOVA: $F(4, 20) = 58.288$; $p << 0.001$) showed that the differences between the mean values of bending strength in both panel's direction of at least two plywood models are statistically significant. The conducted post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences in the mean values of bending strength parallel to the face grain between all tested models.

Table 2. Statistical data for bending strength of plywood

Bending strength	Model	N	Mean	Std. Deviation	Std. Error	95 % Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
Paralell to the face grain	FRP-1	5	117.69^{a}	7.82	3.50	107.98	127.41	107.34	124.70
	FRP-2	5	141.89^{b}	6.41	2.87	133.92	149.85	131.94	147.66
	FRP-3	5	162.80^{c}	2.83	1.26	159.29	166.31	159.61	165.90
	FRP-4	5	129.26^{d}	1.34	0.60	127.60	130.93	127.37	130.48
	C	5	95.64^{e}	7.17	3.21	86.74	104.55	86.21	105.36
Perpendicular to the face grain	FRP-1	5	90.62^{a}	2.12	0.95	87.98	93.25	88.33	93.57
	FRP-2	5	111.87^{c}	4.26	1.90	106.59	117.16	106.68	117.33
	FRP-3	5	143.22^{b}	14.77	6.60	124.89	161.56	118.77	155.75
	FRP-4	5	132.21^{b}	4.44	1.98	126.70	137.72	126.29	136.94
	C	5	83.87^{a}	4.66	2.09	78.08	89.66	76.96	87.67

The mean values with the same letters are not significantly different at 0.05 probability level

When panels are loaded in bending in cross-grain direction, positioning the reinforcements next to the central veneer sheet of plywood structure (FRP-1) does not cause significant increasing of bending strength in compare to the control model C. Also, there are no statistically significant differences in the mean values between model FRP-3 and model FRP-4.

Different positioning of the reinforcement layers in plywood structure leads to statistically significant differences between the mean values of bending strength in both panel's directions in reinforced plywood models. The ratio of the bending strength values between the individual models of reinforced plywood shows that by moving the reinforcement layers to the surface of the panel (FRP-1, FRP-2 and FRP-3), the values of bending strength parallel and perpendicular to the face grain increase.

Compare to the highest obtained value in model FRP-3, the mean values in models FRP-1, FRP-2 and FRP-4 are lower for 27.71, 12.84 % and 20.60 % respectively for bending strength parallel to the face grain, and lower for 36.73 %, 21.89 % and 7.69 % respectively for bending strength perpendicular to the face grain of the panel.

The mean value of bending strength in both panel's directions in model FRP-4 reinforced with single sheets of pre-impregnated fabric in each adhesive layer of the panel is between the mean values of model FRP-1 and FRP-2. Compare to the other reinforced plywood models, model FRP-4 has smallest difference in the values of bending strength between both directions of the plywood.

The results for the modulus of elasticity in bending parallel and perpendicular to the face grain of plywood panel are shown in Table 3.

Table 3. Statistical data for modulus of elasticity in bending of plywood

Modulus of elasticity in bending	Model	N	Mean	Std. Dev.	Std. Error	95 % Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
Parallel to the face grain	FRP-1	5	10886.17[a,b]	169.51	75.81	10675.69	11096.65	10657.77	11097.49
	FRP-2	5	11500.78[b,c]	538.08	240.64	10832.67	12168.90	10908.44	12342.48
	FRP-3	5	14668.51[d]	533.46	238.57	14006.13	15330.90	13741.69	15084.05
	FRP-4	5	11900.37[c]	428.94	191.83	11367.78	12432.96	11210.18	12228.73
	C	5	10354.27[a]	394.50	176.42	9864.44	10844.10	9816.12	10845.91
Perpendicular to the face grain	FRP-1	5	9174.80[a]	300.90	134.56	8801.19	9548.41	8752.81	9453.91
	FRP-2	5	10201.16[b]	264.81	118.43	9872.35	10529.96	9848.20	10517.45
	FRP-3	5	12486.15[c]	382.81	171.20	12010.82	12961.48	12090.76	13024.19
	FRP-4	5	9925.84[b]	332.36	148.63	9513.16	10338.51	9388.89	10305.09
	C	5	7532.42[d]	400.84	179.26	7034.71	8030.12	7207.76	8067.57

The mean values with the same letters are not significantly different at 0.05 probability level

Regarding the modulus of elasticity in bending in both direction of the panel, the highest values are also achieved in plywood model FRP-3. Compare to the control model C, reinforcement of plywood with fiberglass prepreg positioned as surface layers of the panel increases the modulus of elasticity in bending parallel to the face grain for 41.67 % and perpendicular to the face grain for 65.76 %.

The analysis of variance of the obtained data for the modulus of elasticity in bending parallel to the face grain (ANOVA: $F(4, 20) = 74.499$; $p \ll 0.001$) and perpendicular to the face grain (ANOVA: $F(4, 20) = 139.456$; $p \ll 0.001$) showed that the differences between the mean values of these properties of at least two plywood models are statistically significant. The conducted post-hoc Tukey's test for multiple comparison between models showed that the mean value of modulus of elasticity in bending in both panel's directions in model FRP-3 statistically significantly differs from the mean value of all other plywood models.

Compare to the highest obtained value in model FRP-3, the mean values in models FRP-1, FRP-2 and FRP-4 are lower for 25.78 %, 21.59 % and 18.98 % respectively for modulus of elasticity in bending parallel to the face grain, and lower for 26.52 %, 18.30 % and 20.50 % respectively for modulus of elasticity in bending perpendicular to the face grain of the panel.

The ratio of the values of modulus of elasticity in bending between the individual models of reinforced plywood shows that by moving the reinforcement layers to the surface of the panel

(FRP-1, FRP-2 and FRP-3), the values of modulus of elasticity in bending parallel and perpendicular to the face grain increase.

The stress-strain diagrams during testing the bending strength (Figure 2 and Figure 3) showed that the failure of the material happened at once without significant plastic deformation. When reaching the maximum stress, the relative deformation of the reinforced plywood models ranges from approximately 1.5 % to 1.8 % for bending parallel to the face grain and from 1.3 % to 1.8 % for bending perpendicular to the face grain, while in the control model the relative deformation is lower and it is approximately 1.2 % for bending parallel to the face grain and 1.45 % for bending perpendicular to the face grain. After reaching the maximum stress and the initial failure of the test specimen, an increasing and decreasing in stress is again observed, followed by an increase in deformations, until the complete destruction of the test specimen. The stress-strain diagram of model FRP-3 shows that before achieving maximum stress, certain failure of the material and decreasing of the stress occurs, after which the stress is increasing and achieving the maximum value.

The failure mode of the test specimens for determination of the bending strength is shown on Figure 4.

The visual analysis of the test specimens during bending tests showed that the failure of the test specimens initially occur in the tensile zone of the test specimen, where at first the veneers being cracked and destructed up to the zone where the bottom reinforcement is placed. After that, the failure of veneers in the zone between the reinforcements occurs. The failure of these veneers causes the destruction of the bottom reinforcement. Further destruction of the test specimens continues by breaking the veneer sheets over the upper reinforcement.

In model FRP-3, where the reinforcements represent the surface layers of the panel, the initial failure of the test specimens also occurs in the tensile zone, where the veneers between the reinforcements are firstly destructed and then the bottom reinforcement.

During the bending tests of model FRP-4 in which the single reinforcement sheet is inserted in each adhesive layer, the initial failure of the test specimens occurs in the tensile zone with successive failure of the layers, whereas first the veneer sheet is broken followed by the destruction of the reinforcement.

During the bending tests of reinforced plywood models delaminating in some of the veneer layers is observed as a result of shear stresses that occur during the deformation of the test specimens. This kind of deformation is observed in the research of the bending properties of plywood reinforced with impregnated synthetic fibers (Brezović *et al.*, 2003).

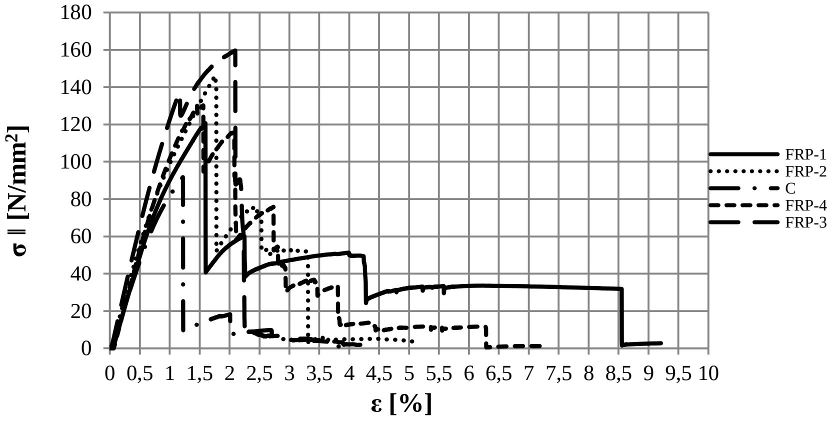

Figure 2. Stress-strain diagrams during testing the bending strength parallel to the face grain of plywood

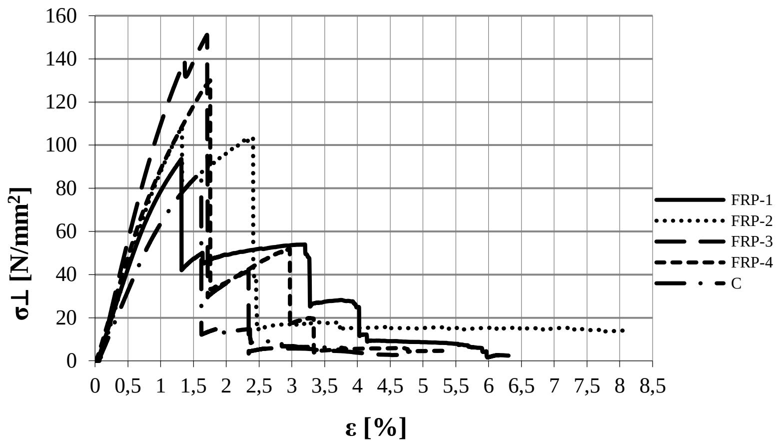

Figure 3. Stress-strain diagrams during testing the bending strength perpendicular to the face grain of plywood

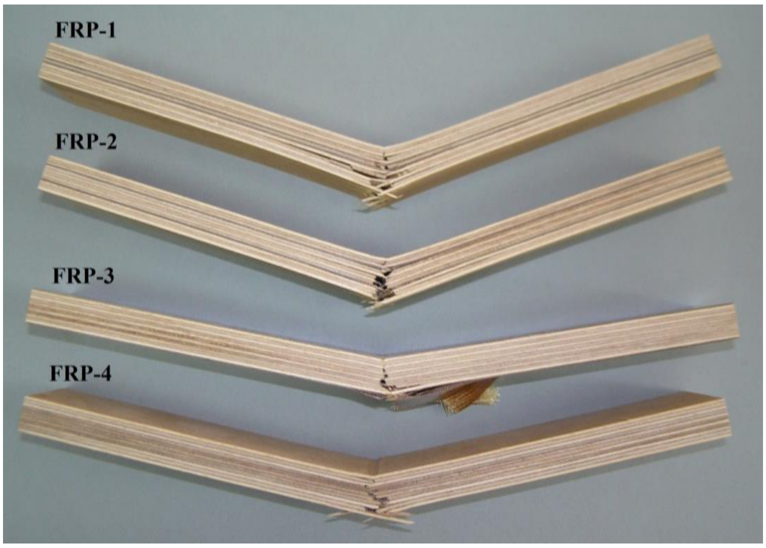

Figure 4. Failure modes of the test specimens for determination of bending strength parallel to the face grain

4. CONCLUSION

On the basis of the realized research it can be concluded that application of pre-impregnated fiberglass fabrics-prepregs in the structure of plywood panel significantly increases its bending strength and modulus of elasticity in bending.

The position of the reinforcements in the plywood structure influences the bending strength and modulus of elasticity in bending. By reinforcing the panels with pre-impregnated fiberglass fabrics applied as surface layers on the panel the bending strength in both directions of the panel is increased by 70 % compared to the control model of the non-reinforced plywood. Compared to the control model, the modulus of elasticity is increased by 42 % along the grain direction of the surface veneers and by 66 % in cross-grain direction.

Moving the reinforcement layers to the surface of the panel increases the values of bending strength and modulus of elasticity in bending in both directions of the panel. The mean value of bending strength and modulus of elasticity in bending in both panel's directions in model reinforced with single sheets of pre-impregnated fabric in each adhesive layer of the panel are lower than those of the model with surface reinforcements.

On the other hand, in model reinforced with single sheets of pre-impregnated fabric in each adhesive layer, there is greater uniformity of the values of bending properties in both directions of the panel than in other reinforced plywood models. The final decision on the application of an adequate reinforced plywood model will depend on the type of loads the panel will be exposed to during its exploitation period, according to the application area.

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Mechanical Properties of Some Thin Furniture Structural Composite Materials

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ABSTRACT

Fashion trends in furniture often require more unconventional structural design solutions. An example of this is the current design trend for creating "slim" furniture using thin structural elements in the construction of open and closed storage furniture, tables, chairs, etc. In such an application, it is of particular importance to know the mechanical properties of the structural panels.
For the purpose of this study eight different composites with a thickness between 6 and 14 mm were chosen. Four of them are wood-based composites: non-laminated 12 mm thick medium density fibreboard (MDF), beech-faced 10 mm thick MDF, MDF laminated with high-pressure laminate (HPL) and 3-ply panel made of MDF (overlayers, 4 mm) and plywood (inner layer, 4 mm). The other four composites are based on an acrylic solid surface – 6 mm and 12 mm thick; beech faced veneered 6 mm thick solid surface panel and 5-ply composites from 2 solid surface panels (6 mm) with beech veneer core and outer layers.
The results of this study show that the MDF laminated with HPL had the highest bending strength (MOR) , followed by beech veneered acrylic solid surface panel. The 12-mm thick MDF panels had the lowest strength. The solid surface panels with a thickness of 6 and 12 mm had the highest values of modulus of elasticity (MOE) , followed by MDF laminated with HPL and 12 mm thick MDF that had the lowest MOE values.

Key words: acrylic solid surface composites, mechanical properties, MOE, MOR, thin composites, wood-based panels

1. INTRODUCTION

Creation of furniture from thin and very thin structural materials has four main aspects: aesthetic, where elegance is at the forefront; economical, where the price is the basic criterion; utilitarian, where the weight must be reduced and ecological, where the economy of raw material is the most important. Designers and manufacturers are sometimes led by one, sometimes by two, or sometimes by all the factors. This refers to the need to use materials that have the necessary strength and deformation characteristics. The most common materials are wood composites, but other materials are also used, such as compact HPL) non-wood, or a combination of different wood-based and other composite materials.

It is well know from the practice that low thickness of the wood-based panels is a serious problem in their use for furniture structural elements, especially when they are subjected to greater loads.

Structural elements in furniture according to their technological properties and abilities for joining could be categorized into five groups: ultra-thin – under 10 mm thickness, thin – 10-15 mm thickness, standard – 16-19 mm, thick – 20-40 mm and ultra-thick – above 40 mm (Kyuchukov and Jivkov, 2016). To create and produce furniture with thin and especially with ultra-thin structural elements is a challenge not only because of the problems with joints but because of the strength characteristics of the conventional materials. Mostly they do not have enough stiffness to carry the functional loads, which cause an unallowable deflection or failure.

Wood-based composites are widely used as structural or nonstructural elements in furniture constructions and they are described as a combination of any wood material adhesive-bonded together (Youngquist, 1999). Mainly these are panels (plywood, particleboard, MDF, etc.), which can be laminated with veneer, HPL, or other decorative materials. For some purposes, the combination of different panels also can be used. The basic wood elements that can be used in the production of wood-based panels can be made in a great variety of sizes and shapes and can be used alone or in combination and the choice is almost unlimited.

Knowledge of the mechanical properties of these products is of critical importance to their proper use (Cai and Ross, 2010). Thin and ultra-thin components made of particleboards, plywood, or MDF are widely used in the construction of drawers as a bottom panel or as furniture rear panels. In recent years furniture design often requires the use of more unconventional design solutions, such as thin horizontal structural elements or even complete furniture made from very thin materials. In these cases, there are rare data to provide information on their strength characteristics. Given the nature of the storage function where different loads appeared, the strength of this type of furniture elements is essential.

In the literature, many studies can be found on the physical and mechanical properties of particleboard and MDF made from different materials, adhesives, or technological parameters (Cai and Ross, 2010). The influence of the type of overlay structure on mechanical properties is an object of other studies. The results obtained by Buyuksari (2012) showed that all of the particleboards laminated with compressed veneer had higher MOR and MOE values compared to unlaminated particleboard and particleboard laminated with non-compressed veneer. Other researches are giving information about the behavior of wood-based composites under critical conditions such as higher or lower temperatures (Ayrilmis and Buyuksari, 2010; Zhou *et al.*, 2012). Ayrilmis and Buyuksari (2010) established that the strength properties of the wood-based panels changed more at positive temperatures than at negative temperatures. According to the study of Büyüksarı *et al.* (2012), both modulus of elasticity (MOE) and modulus of rupture (MOR) of the specimens increased with increasing pressure and press temperature. In the research of Ayrilmis (2009) it was found that creep deflections of the panels increased with increasing heat-treatment temperature. Other studies showed that the mechanical properties of wood-based composites improved if they are laminated with reinforced materials (Ayrilmis *et al.* 2008; Büyüksari *et al.* 2012).

The mechanical properties of thin structural panels for furniture were significantly less studied. Savov *et al.* (2019) studied the opportunity for the production of ultra-thin eco-friendly medium density fibreboards based on calcium lignosulfonate. The MDF panels were manufactured with a thickness of 6 mm and density of 850 kg/m^3. The authors determined that no significant change in bending strength values was determined at 30 % concentration and increased pressing temperature. Zhou *et al.* (2012) determined that plywood and 2.6 mm thick MDF show a typical elastoplastic behaviour, while 12 mm thick MDF does not exhibit any plastic behaviour. Segovia *et al.* (2015) studied the influence of lamination of thin HDF, MDF, OSB, and aspen plywood with aluminum alloy sheets 3003 with a thickness of 0.6 mm. The results show that aluminum-laminated panels had higher dimensional stability and bending properties such as the modulus of elasticity and the modulus of rupture were significantly increased with face-lamination. Mohebby and Tavassoli (2010) have studied the influence of reinforcement with metal and woven synthetic nets on the mechanical properties of medium density fiberboard (MDF). Results revealed that bending properties (MOE and MOR), were significantly increased, 112 % and 79 %, respectively, due to the reinforcements which are more effective in increasing the strength than synthetic woven reinforcements.

As an alternative to the wood-based materials, compact HPL or acrylic solid surfaces can be used. They have high mechanical properties, but the higher density and relatively high prices. Compact HPL panels, known as solid phenolic, are modern materials with high strength and are applied to many products, particularly in the field of furniture and interior design. Wood may be combined with inorganic materials and with plastics to produce composite products with unique properties (Stark *et al.*, 2010). Solid surface known as decorative surfacing materials made of polymethyl methacrylate (PMMA) reinforced with aluminium trihydrate ($Al(OH)_3$, ATH) have an increasing number of applications (Wallenhorst *et al.*, 2015). Solid surface is classified as solid material according to ISO 19712-2: 2007 and is a generic name given to a polymerised decorative surfacing material invented by DuPont™ in the 1967 and is well known under the trade name Corian®. It is a solid, non-porous, homogeneous surfacing material with wide applications in the interior and furniture. There is very little information in the scientific literature on the use of acrylic solid surface materials in furniture. Machova *et al.* (2019) studied the load-carrying capacity and stiffness of corner wood-based and plastic joints, where the plastic is acrylic solid surface material. The results show very good load capacity and stiffness of the joints with such structural elements. Solid surface composites are recyclable but at a high price (Vovk *et al.*, 2017) and reusable which is of main advantage concerning circular economy. Additionally some research is done in the past few years for investigating the possibility of combining acrylic solid surface material with wood and producing wood-plastic composites (Vovk and Sernek, 2015).

Elastic and strength properties are the primary criteria to select materials or to establish design or product specifications (Cai and Ross, 2010). Due to this fact, the aim of the present paper is to evaluate the modulus of elasticity in bending (MOE) and bending strength (BS) of some thin and ultra-thin wood-based composites and other composites based on acrylic solid surface to give more confidence in using such materials as a structural and nonstructural element in furniture and interiors.

2. MATERIALS AND METHODS

2.1. Materials

In this study, eight types of thin and ultra-thin structural composites were considered. Out of them, four are wood-based composites with 20 samples each and four are non-wood and non-wood veneered composites with 10 samples each (fig. 1).

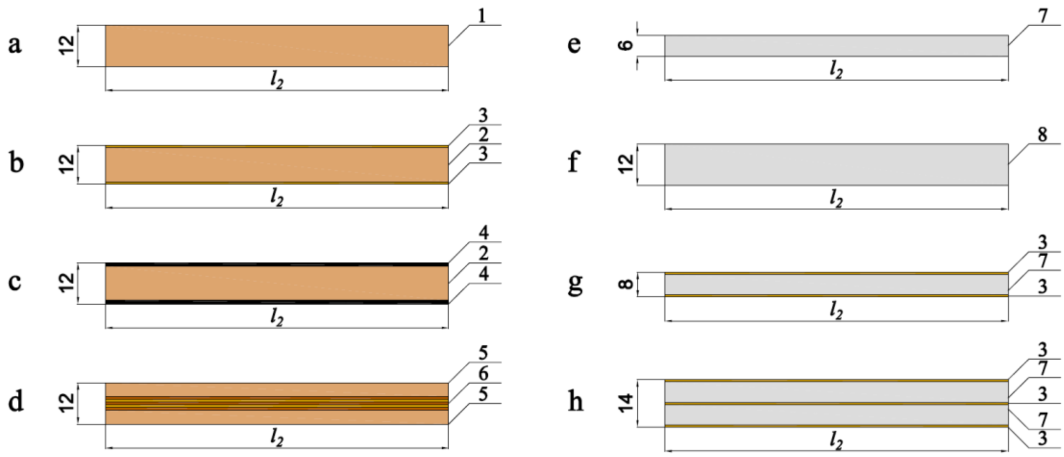


Figure 1. Thin structural composites panels

a – MDF; b – beech-faced MDF; c – laminated MDF, d – 3-ply panel with MDF and poplar plywood; e – acrylic-based solid surface-6 mm; f – acrylic-based solid surface-12 mm; g – faced veneer acrylic solid surface; h – 5-ply faced veneer double acrylic solid surface sheets and beech veneer for face and core layer;

1 –MDF (12 mm); 2 –MDF (10 mm); 3 –beech veneer (0.6 mm); 4 –HPL (0.9 mm); 5 –MDF (4 mm); 6 - poplar plywood beech faced (4 mm); 7 – acrylic-based solid surface (6 mm); 8 – acrylic-based solid surface (12 mm)

The test of wood-based composites were carried out on commercial medium density fiberboard (MDF) with thickness of 12 mm, beech-faced veneered 10 mm MDF with veneer thickness of 0.6 mm (BeV-MDF-BeV), laminated 10 mm MDF with HPL, produced by Abet Laminati, with a thickness of 0.9 mm (HPL-MDF-HPL) and 3-ply sandwich panel composed of poplar plywood beech faced with thickness of 4 mm as core ply and face of 4 mm MDF (MDF-PoPlW-MDF).

The structures of the panels are shown in Figure 1, from a to d. For composition of the panels, the industrial hydraulic press was used with hot-press (70 °C) adhesion processing under pressure of 1.1 MPa and press time of 10 minutes. PVAc adhesive by applying 120 g/m^2 was used for all panels under the trade name of FOLCO® LIT D2 Ex produced by Follmann GmbH & Co. KG.

As non-wood material in this study, acrylic-based solid surface sheets (PMMA/ATH) commercially produced by Kolpa, Slovenia with a trading name Kerrock® and a nominal thickness of 6 mm (ASS-6) and 12 mm (ASS-12) were used (fig. 1 e, f). Solid surface can be combined for aesthetic reason with veneer, and that is why two additional types of thin panels have been produced – faced veneer acrylic solid surface with 0.6 mm beech veneer (BeV-ASS-BeV) and 5-ply faced veneer double acrylic solid surface sheets with 0.6 mm beech veneer for face and core layer (BeV-ASS-BeV-ASS-BeV). According to the results achieved by Jivkov *et al.* (2013), PVAc adhesive is appropriate for joining solid surface materials with wood or wood-based material. In this study, PVAc adhesive FOLCO® LIT X 300 with a durability class D3, according to BDS EN 204 produced by Follmann GmbH & Co. KG was used by applying 100 g/m^2. For facing the veneer industrial hydraulic cold press was used under the pressure of 1.1 MPa.

The density was determined according to the weight method by measuring the weight of the tested sample, which is 50×50 mm and thickness, which matches the thickness of the studied panel (BDS EN 323:2001). In determine the thickness, a Mitutoyo digital caliper was used with 0.01 mm accuracy. The room temperature was 22 °C and relative humidity of 55 %.

Data for the thickness and density of the materials is given in Table 1.

Table 1. Thickness and density of the thin furniture structural composite materials

No.	Type of panel	Code	Number of samples	Thickness, mm	Density, g/cm^3
1	Medium density fibreboard	MDF	20	12.12	0.757
2	Beech-faced MDF	BeV-MDF-BeV	20	11.20	0.799
3	Laminated MDF with HPL	HPL-MDF-HPL	20	11.75	0.885
4	3-ply panel with MDF and plywood	MDF-PoPlW-MDF	20	12.79	0.776
5	Acrylic solid surface – 6 mm	ASS-6	10	5.99	1.712
6	Acrylic solid surface – 12 mm	ASS-12	10	12.01	1.709
7	Acrylic solid surface beech veneered	BeV-ASS-BeV	10	7.86	1.509
8	5-ply Acrylic solid surface beech veneered	BeV-ASS-BeV-ASS-BeV	10	14.61	1.577

2.2. Test methods

For evaluation of the modulus of elasticity in bending and bending strength, samples were subjected to a three-point test following BDS EN 310 "Wood panels. Determination of modulus of elasticity in bending and bending strength". The modulus of elasticity (MOE) in bending and the bending strength (BS) vertical to panel surface is determined by exerting load in the middle of the test sample supported on two points. Universal testing machine Zwick 250 (Zwick Roell

GmbH & Co. KG, Ulm, Germany) was used in the test, where the deflection was measured with an accuracy of 0.01 mm and the load with 0.01 N accuracy. The loading speed was set to 5 mm/min. All the test samples have been conditioned for 7 days at a room temperature of 22^0 C and relative humidity of 55 %. The width of all test samples was 50 mm and length (l_2) was calculated according to the requirements of BDS EN 310, where l_2 is equal to 20t plus 50 mm, t is the thickness of the panels.

The results obtained from the test were statistically analysed. One-way ANOVA (Addinsoft-2019, XLSTAT-statistical and data analysis solution, Boston, USA) was used to determine the difference between the modulus of elasticity and bending strength of different thin furniture structural materials and Tukey HSD test was used to determine whether the differences within groups have a significant level with a confidence interval of 95 %.

2.3. Determination of the material cost

Additionally, to the physical and mechanical properties, the cost of the materials was used as an economic factor. For that reason, the cost analysis was made based on available retail prices and the cost of the manufacturing process. However, it should be made clear that part of the costs are variable and may vary in different countries and production conditions. According to their value, the materials are divided into six price categories – 6-very economic, 5-economic, 4-intermediate, 3-expensive, 2-very expensive, 1-extremely expensive.

3. RESULTS AND ANALYSIS

The results from the ANOVA and Tukey HSD test for the MOE, MOR (or BS) and cost grade are given in *Table 2*. For better data analyses, the results are displayed graphically in *Figure 2* (MOE) and *Figure 3* (BS) in box plots.

The obtained mechanical properties of the wood-based materials show that the lamination of the MDF with HPL or veneer increases considerably the strength of the panels, which correspond to the results of Buyuksari (2012). The highest values of modulus of elasticity (8485 N/mm^2) and bending strength (80.98 N/mm^2) were determined for MDF laminated with 0.9 mm thick HPL, followed by beech-face MDF. The composition of 3-ply wood-based board with MDF and poplar plywood did not improve significantly the mechanical properties compared to the MDF with the same thickness.

In the second group of non-wood composites based on acrylic solid surface materials, the highest modulus of elasticity was determined for 6 mm (9898 N/mm^2) and 12 mm (9822 N/mm^2) materials and in respect of bending strength the highest values were determined for the beech-veneered 6 mm acrylic solid surface composite (76.52 N/mm^2), followed by 6 mm (71.21 N/mm^2) and 12 mm (69.75 N/mm^2) solid surface materials. The beech veneered 5-ply acrylic solid surface material had the lowest mechanical properties.

When comparing the two groups of materials – wood-based and non-wood, the thin structural materials made of MDF laminated with HPL are clearly distinguished. They have the highest bending strength (80.98 N/mm^2) and the third-highest modulus of elasticity (8485 N/mm^2), which can be explained with the very positive effect of the lamination with HPL on the bending strength and MOE. Good physical properties (low density) and low cost are factors that make them one of the best possibilities for usage in furniture construction where thin structural elements are needed.

Table 2. Modulus of elasticity, bending strength and cost grade of thin furniture structural composites

No.	Type of panel	Code	Number of the test samples	Mechanical properties MOE (SD) (N/mm²)	Mechanical properties BS (SD) (N/mm²)	Cost grade
1	Medium density fibreboard	MDF	20	3844 (63) f	33.94 (1.14) g	6
2	Beech-faced MDF	BeV-MDF-BeV	20	6216 (226) d	59.92 (2.80) d	5
3	Laminated MDF with HPL	HPL-MDF-HPL	20	8485 (130) b	80.98 (1.76) a	5
4	3-ply panel with MDF and plywood	MDF-PoPlW-MDF	20	4022 (407) f	43.97 (3.90) f	4
5	Acrylic solid surface - 6 mm	ASS-6	10	9898 (141) a	71.21 (2.67) bc	4
6	Acrylic solid surface – 12 mm	ASS-12	10	9822 (130) a	69.75 (1.91) c	3
7	Acrylic solid surface beech veneered	BeV-ASS-BeV	10	7487 (763) c	76.52 (8.60) ab	2
8	5-ply acrylic solid surface beech veneered	BeV-ASS-BeV-ASS-BeV	10	5260 (1105) e	48.04 (4.50) e	1

Values in parentheses are Standard Deviation (SD)

[a,b,c,d,e,f,g] Values with the same letter are not significantly different according to Tukey HSD test

Both 3-ply and 5-ply composites did not meet the expectation. They have relatively low mechanical properties, intermediate and extremely high cost and the 5-ply composite has very high density. As can be seen from *Figure 2* and *Figure 3*, both materials have a large distribution of results, which probably also affects the mechanical properties.

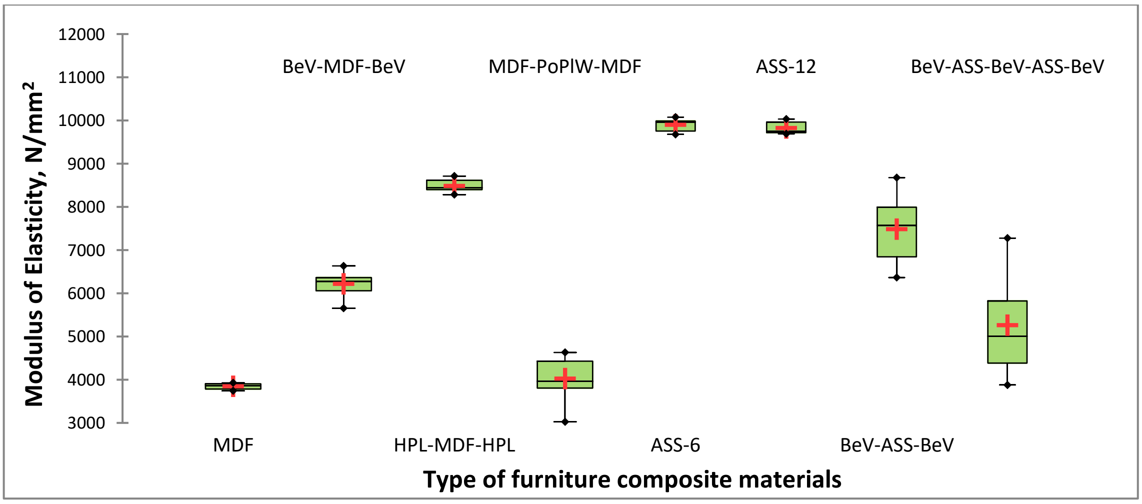


Figure 2. Modulus of elasticity of thin furniture structural composites

In respect of the design concept, a radar chart was created for the overall performance of the two groups of materials where the following criteria were put in consideration: physical properties (thickness and density), mechanical properties (BS and MOE) and additional, the cost of the panels was used as an economic factor. Physical and mechanical properties were categorized in six-level each (6-very high, 5-high, 4-upper-medium, 3-medium, 2-low, 1-very low) according to the One-way ANOVA statistical analysis where Tukey HSD test was performed to determine the differences within the groups with a 95 % level of confidence. As the cost of the material is a basic factor that influences the decisions of its potential use in specific applications it is included in the radar chart as a fifth factor.

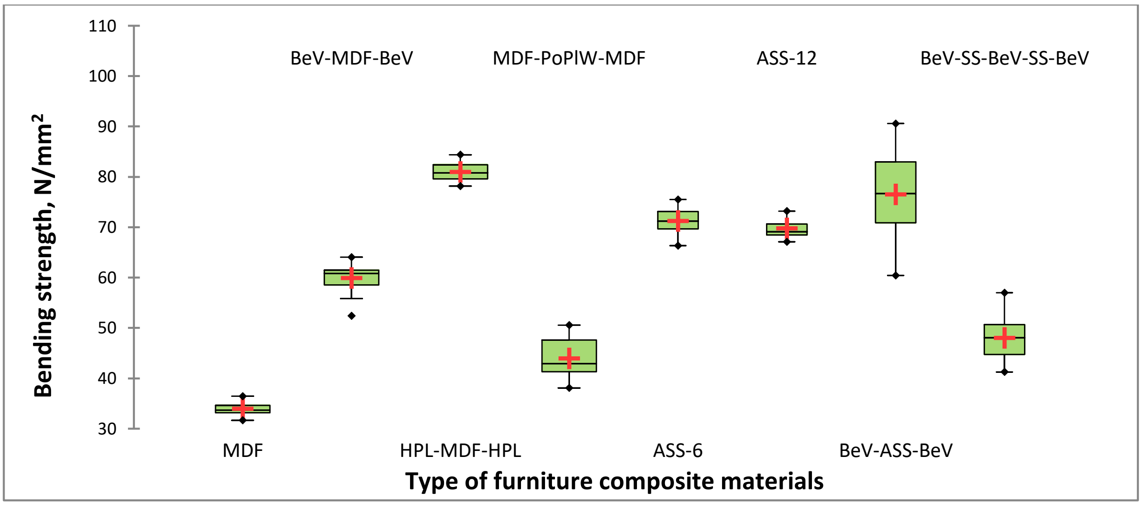
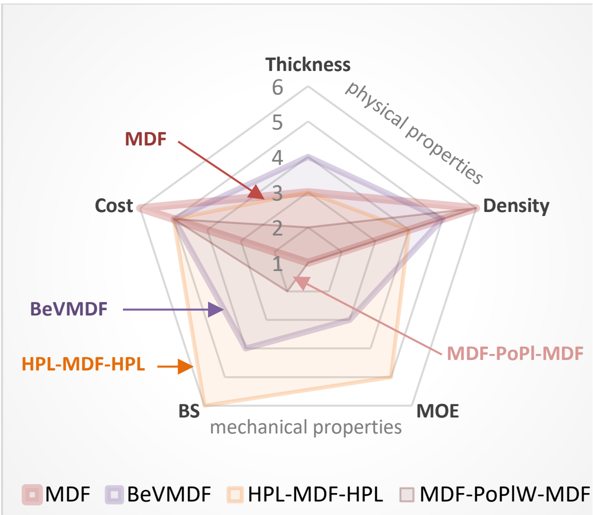
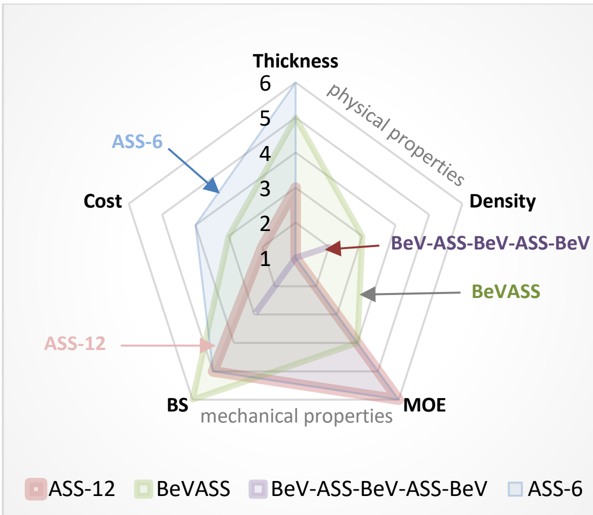


Figure 3. Bending strength of thin furniture structural composites

It is clearly visible from the charts that wooden-based materials have lower density and cost but higher thickness (*Figure 4 a*). Excellent bending strength and very good MOE was presented by MDF laminated by HPL (HPL-MDF-HPL). Opposite, the acrylic-based solid surface materials have lower thickness and higher mechanical properties, with the exception of 5-ply acrylic solid surfaces beech veneered (BeV-ASS-BeV-ASS-BeV), but their cost and density are very high (*Figure 4 b*).



a)



b)

Figure 4. Radar chart for evaluation of thin structural furniture materials in respect of thickness, density, mechanical properties and cost: a-wood-based materials; b-non-wood materials

4. CONCLUSIONS

In summary, on the one hand, we have studied thin materials available on the market, and on the other hand, we have designed and manufactured different thin and ultra-thin structural composite materials to investigate the possibility of using them in the design of furniture. Some of them showed very high and high mechanical properties, and some are just standard. Physical properties are in the wide ranges – very heavy, very thin, or with regular weight and thickness.

Following general conclusion can be made from this study:

1. MDF laminated with HPL with an overall thickness of 12 mm has excellent mechanical properties, relatively low cost and weight. This type of thin composites can be used as thin structural material for different furniture constructions applications.
2. Acrylic-based solid surface materials also performed very well and showed excellent mechanical properties at low thickness. Veneering with beech veneer increases the bending strength but decreases the modulus of elasticity.
3. Tree-ply and five-ply composites did not meet the expectation for higher mechanical strength.
4. If needed ultra-thin materials, 6 mm acrylic-based solid surface with or without veneer can be used.
5. The design concept for using thin and ultra-thin materials should be comprehensively considered according to the characteristics and the cost of the material and the specific requirements of the furniture structure.

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Preferences of Seniors Concerning Design of Outdoor Public Space Furniture for Sitting

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ABSTRACT

The number of seniors rises in all continents. As global aging accelerates, we face huge social and economic challenge. Being prepared for those changes is crucial for various actors both private and public ones. Modern public spaces need to evolve to reduce ageism and be friendly to all. Regions and cities more and more often think of redesigning the public space to meet the needs of their elderly citizens. In order to identify preferences of seniors in relation to characteristics of outdoor public space furniture for sitting the pilot survey studies and direct interviews with 127 respondents aged 60+ were conducted. It was found that the most important for senior’s issues concerned not only the external form and functional solutions implemented in the analysed furniture items but also their number, availability and maintenance. The most crucial features improving functionality of outdoor furniture for sitting indicated by respondents included functional dimensions adjusted to senior needs and additional handles facilitating standing up and sitting down. Moreover, the design enabling social interactions and integration while being in the public space was highlighted.

Key words: furniture design, public space, senior’s preferences

1. INTRODUCTION

Public space plays an important role in the lives of modern citizens, as well as in the development of society. To support formation of social bonds, the spaces necessary for their creation should be arranged (Wilk, 2016). It is crucial to remember that user enters the public space immediately after crossing the threshold of his/her household (Wysocki, 2015). Well-designed space is free of barriers and is characterized by proper compositional, architectural and urban planning. Public space is shaped by many factors including greenery and water, public toilets, information signs and advertisements, lanterns and furniture. There is no doubt that furniture is one of the main elements determining public spaces. It has a significant impact on how a given space is perceived by the users. Well designed and equipped with attractive furniture public space will motivate citizens to use it, enjoy it and relax. It also stimulates networking. Furniture that encourages users to stay in the space for longer, actually inspires them also to establish contacts with each other. Thus, when designing accessible, age-friendly public spaces, it is crucial to pay attention to furniture.

The number of elderly citizens has been growing rapidly in contemporary societies. According to the Central Statistical Office, elderly people constituted 24 % of the Polish society in the year 2017 (GUS, 2018). Forecasts indicate that in 2050 there will be as much as 39.3 % of elderly in the Polish population. Similar processes of changing the age structure of the societies take place worldwide. Given the continuous increase in the share of older people in modern societies, particular attention should be paid to this age group.

A well-designed public space allows older people to take full advantage of it, which has a positive effect on their quality of life (Wysocki, 2015). If the public space is not adapted to the needs of the elderly, it becomes for them an environment full of obstacles and barriers (Wysocki, 2009). At the same time, it should be noted that people aged 60 plus form the most heterogeneous group of users in terms of requirements. The observed diverse and increased needs are caused by e.g. limitations in the physical movement abilities. As a result of the aging process, the human body becomes weaker in respect of strength since due to changes in the musculoskeletal system, a significant decrease in muscle endurance can be observed. Compared to young people, seniors' physical fitness drops by as much as 40-60 % (Benek and Shevchenko, 2015). There are also noticeable changes associated with performing movements, a decrease in flexibility and maintaining balance. In addition to the weakening of physical form, older people struggle with deterioration of the senses of perception, mainly sight and hearing. To provide safe functioning in the space, older people need three to five times more light than young people (Trakul – Masłowska, 2015). The aging process also includes mental aging. It is characterized by memory impairment as well as dementia. Seniors find it harder to remember and less orientate in the space. With age, the ability to think abstractly also decreases and difficulties in acquiring information may appear (Benek and Shevchenko, 2015). Due to the diversity of problems seniors may face also their needs are fairly varied. This in turn makes the public space adapted to the elderly becoming a user-friendly space for other users as well (Wysocki, 2015). Thanks to properly adapted furniture, created according to the principles of universal design, public space becomes friendly to all users. The concept of "friendly public space" hides such features as: accessibility, intuitiveness and ease of use, safety and encouraging various types of activities (Magdziak, 2017).

The Polish CSO research, which was attended by 13.3 thousand people over 65 years of age shows that as many as 67 % of them spend their free time outdoors e.g. walking and spending time outside the households at least once a month. Also, the research performed by the Department of Furniture Design of Poznan University of Life Sciences concerning the type of public space that seniors use most often provided very interesting results indicating that nearly 75 % of people participating in the study were more likely to use open spaces, such as parks, promenades and spaces around their place of living. Thus, the aim of this study is to collect pilot data concerning preferences of seniors in terms of functional and design characteristics of outdoor public space furniture.

2. MATERIAL AND METHODS

To gather data concerning the most crucial features of outdoor furniture facilitating senior's usage of public space, survey research was developed and conducted among people aged 60+. The study was performed in the form of surveys (both paper and electronic ones) and direct interviews. The survey form consisted of open and closed questions of a different nature, focused on the subject of outdoor public space furniture and problems arising in the course of their usage. Open questions constituted significant part of the study as they enabled respondents to describe in more details their personal observations or comment on difficulties of daily activities performed in a public space. Conduction of direct interviews supported better understanding of the analysed issues and identifying individual problems that occur during the daily functioning of seniors in public spaces.

The researched population constituted of seniors living both in their own apartment and in the senior houses in the region of Greater Poland in Poland. Taking into account the percentage of fulfilled surveys and direct interviews performed, the statistical analysis was conducted on data coming from 127 seniors. The gathered data was entered into the database, coded, and subjected to statistical analysis. Using the statistical grouping method, the characteristics of the needs and preferences of seniors related to the analysed subject was developed. The analysis was conducted using STATISTICA 13 PL. The works performed consist the pilot study for international wide research, indicating paths of potential areas of interests when solving the problems seniors face while functioning in the public space and featured and preferred characteristics of the furniture being the equipment of the public spaces.

3. RESULTS AND DISCUSSION

When analysing senior-friendly features of outdoor public space furniture one should focus foremost on the barriers they encounter in their daily functioning and on the ways of using furniture in the analysed spaces. According to Mitchell and Burton (2006), who analysed the obstacles older people are most afraid of while being outside, mobility problems and fear of falling down turned out to be the most important ones. Also, research performed among 127 seniors indicated that the basic barriers in the use of public spaces by older people result from the decline in physical form. Thus, to encourage seniors to use the public spaces, furniture could support the users when they feel tired or unsafe. This is confirmed by the results of our study as the largest group of respondents (42 %) emphasized that they use public furniture primarily to rest when they feel tired. Respondents also indicated often that furniture in public spaces is used by them during meetings with friends or family (21 %). A more comprehensive analysis of this issue revealed that the oldest group of respondents aged 80+ like to use the furniture in the public space in order to leave the household and spend some time outside (60 %) (Figure 1). The second major reason for using the public furniture by this age group is the need to rest when they feel tired (40 %).

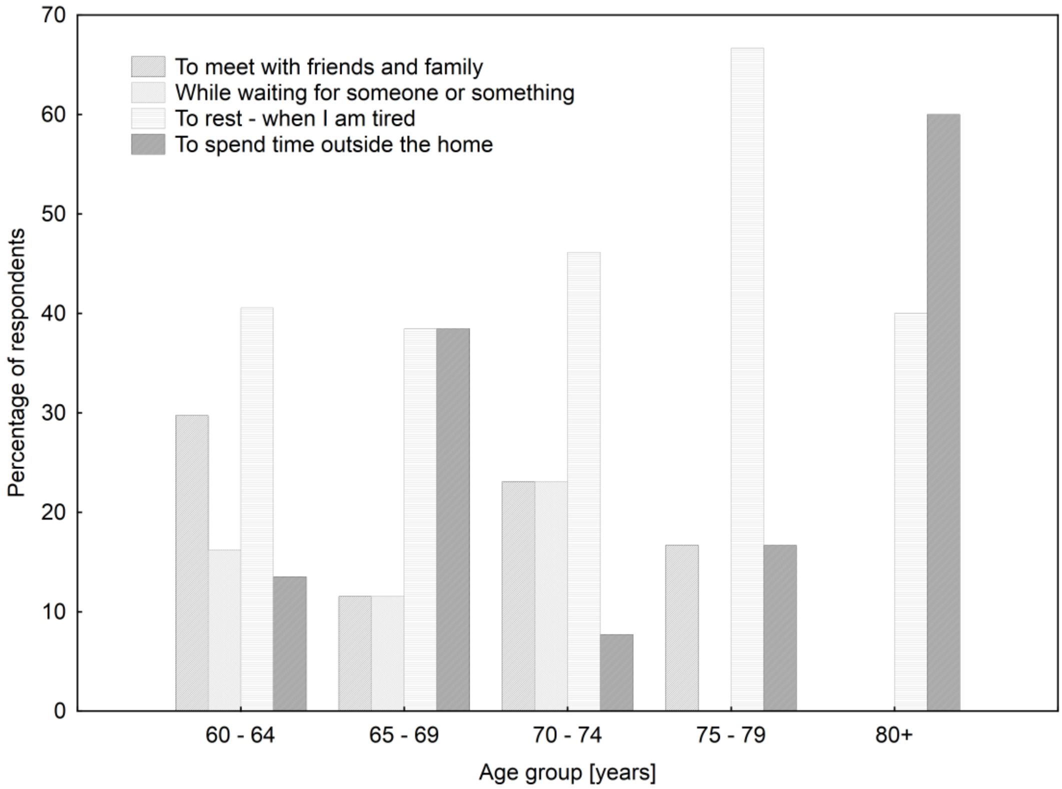

Figure 8. Purpose of use of outdoor public space furniture

Among the most interesting findings is also the fact that a vast majority of respondents (65 %) uses public furniture every time they are in open public spaces (Figure 2). The elderly surveyed declared that they use public furniture especially during walks, while going for shopping or waiting for someone.

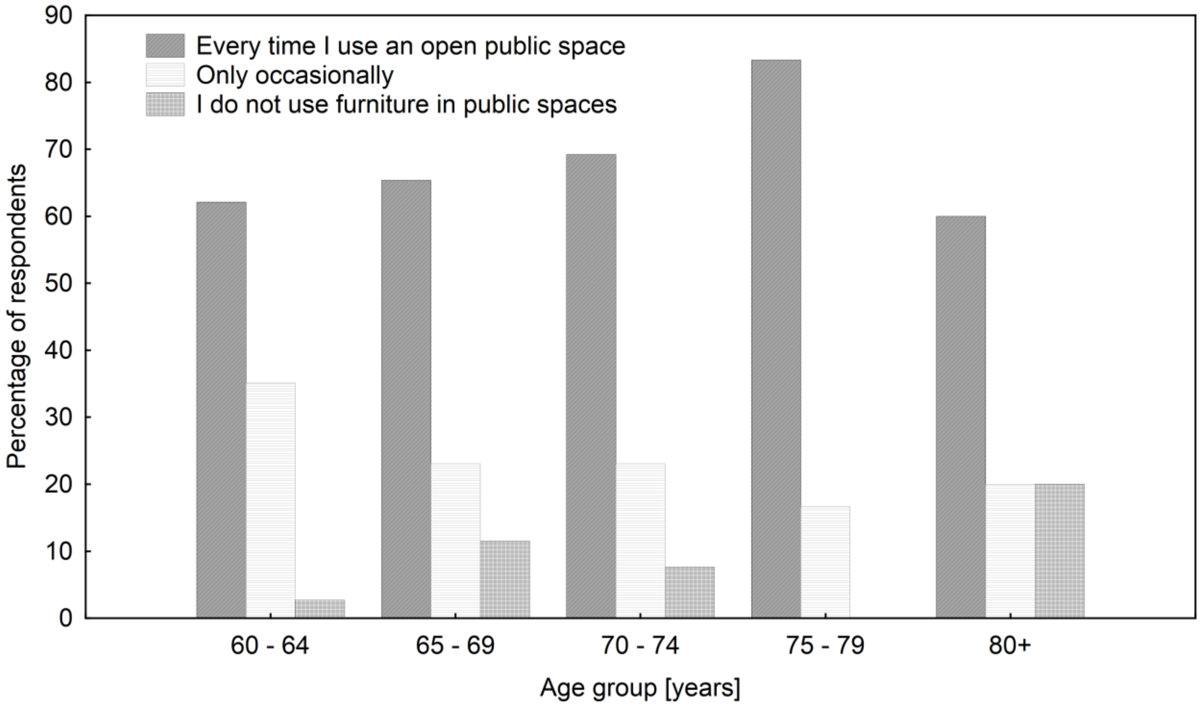

Figure 2. Frequency of using furniture in open public spaces

The obtained results indicate that elderly participating in the study most often use public furniture alone (34 %) (Figure 3). However, it should be noted that just a slightly smaller group of respondents (29 %), spend time in public space with their husband or wife. Despite the fact that seniors most often use public furniture alone, it is worth considering larger clusters of benches or seats next to each other, so that people of all ages can establish new contacts and interactions with each other.

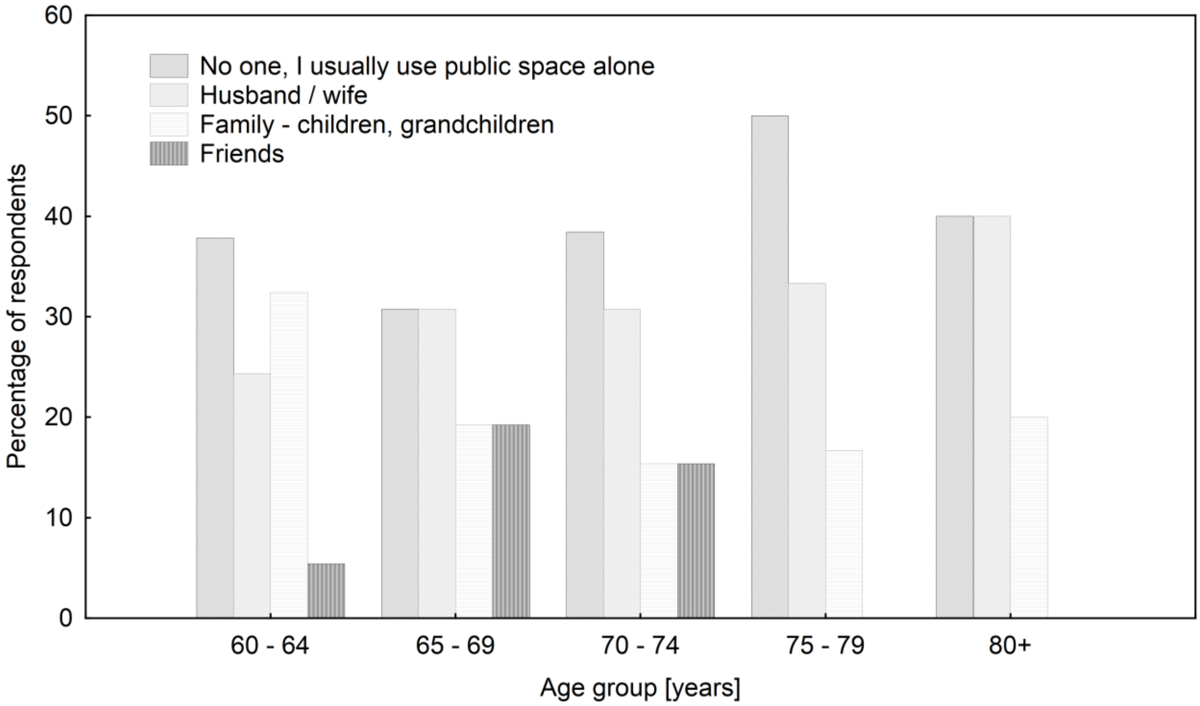

Figure 3. The company of the elderly while using public furniture

Even though seniors often use furniture in public spaces their opinion about their characteristics is not always the positive one. As much as 80 % of respondents indicated that outdoor public furniture for sitting are not adjusted to their needs. During the direct interviews they admitted feeling discomfort when using it. Furthermore, seniors reported that the number of this type of furniture in the public space is simply too small (61 %). This in turn means they cannot relax or spend time outside their households using public furniture for sitting whenever they feel like to or they are afraid to walk further as the distances between benches are too big (*Figure 4*). An important hint is to plan more places to sit in public places. Seniors also drew attention to the fact that a lot of furniture in public spaces is destroyed and neglected, which makes them unenthusiastic to stay in such space (43 %). They pointed out that the pieces of furniture for sitting located in frequently used public spaces like the ones near touristic attractions or city centres are in much better condition than the ones they are to use on a daily basis – near their block of flats, in older districts of the cities etc.

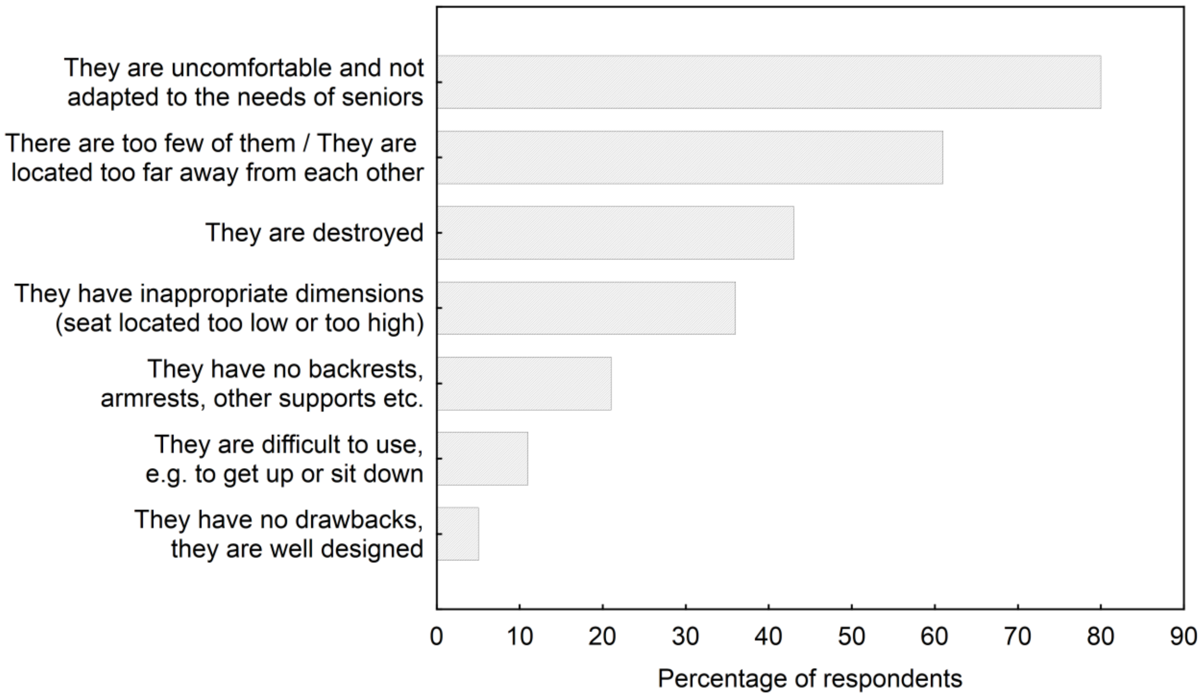

Figure 4. Disadvantages of public furniture for sitting according to the surveyed elderly

According to the respondents, public space furniture should be primarily comfortable and functional. Over 60 % of respondents have pointed out these features as the most preferable. The essential characteristics of furniture for sitting should therefore be elements supporting the user while sitting down or getting up. Majority of respondents (95 %) indicated here elements such as backrest and armrests. Seniors noticed that sometimes although the furniture itself was comfortable it was located on an uneven surface or in hard-to-reach places making it impossible or very difficult to use. During direct interviews also the observations were performed to notice the ways seniors use outdoor public space furniture and recognize the problems they face during functioning in the outdoor space (*Figure 5*).

Figure 5. Photographs showing the process of sitting down of an elderly person

When analysing preferable design features of furniture for sitting it is also important to consider the material. It was found that a vast majority, i.e. over 68 % of respondents prefer outdoor public space furniture for sitting made of wood. More detailed analysis of this issue confirmed seniors appreciate wood as pleasant to touch, warm and natural material that blends in well with open space surrounded by nature like in parks for example.

4. SUMMARY

Public space plays an important role in the lives of all residents, especially the elderly. It is a meeting place with both friends and strangers. Seniors often live alone, which may make them feel lonely. Many of them spend time only in their apartments, limiting going out just to necessary activities, such as shopping, visiting a doctor or throwing away garbage. A large proportion of these people encounter many barriers in the outdoor space due to the deterioration of health caused by age. These obstacles and various types of disabilities deter seniors from spending time in public spaces. Due to this, older people may give up social life, which in turn may contribute to depression. Interesting and adapted to their needs, places encourage seniors to spend time outside their household, and thus also motivate to meetings and social activity. Thanks to properly adapted public furniture, older people can fully participate in social life and are not afraid to use public spaces, which positively affects their quality of life. As a result of the lack of obstacles, seniors have the opportunity to function independently, which can improve their health and mobilize them for daily activities.

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Investigations upon Aesthetic-Decorative Features of the HDF Finished with Acrylic Lacquer Coatings

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ABSTRACT

The aim of this work was the estimation of the aesthetic-decorative features of acrylic lacquer coatings which determined the appearance. The cognitive aspect was to evaluate stability of gloss (photoelectrical manner – REFO 3 apparatus, colour ELREPHO 2000 spectrophotometer) and colour wiping resistance under the influence of thermal aging in a version of changing temperature acc. to PN-88/F-06100/07 standard (method A) and Cold check acc. to the IOS-TM-0002 procedure. Boards furniture elements were finished in industry conditions in pattern versions "white" "black", and in analogue printing technology with imitation of wood species "black oak" (*Quercus nigra*). Based on the results of the carried out experiments, it was stated among others that produced finishing showed no defects, presenting high aesthetic-decorative features and stability wiping resistance colour. The stability of colour finishing in terms of the effect aging test was high. Changes in the colour of lacquer coatings values of parameter $\triangle E^*$ in the range of 0.04 – 1.15.

Key words: acrylic lacquer, aging, appearance, coating, colour, gloss

1. INTRODUCTION

Wood-based composites are a widely used material in the furniture industry as an alternative to solid wood. They are used to produce various composite materials including lightweight boards commonly used in the furniture industry. Their surfaces in their basic state do not look very attractive, therefore, in order to increase the aesthetic-decorative features and the resistance upon different external factors, various finishing treatments for the finishing are used (Budakci 2010).

The choice of the finish system in the manufacture of furniture depends on the degree of exposure to external factors, which is closely related with the function of board elements to be fulfilled in furniture construction (horizontal working surfaces, horizontal surfaces for parking, vertical - visible, frontal, invisible or other). Various parameters are taken into account, such as appearance, ease of use, durability, and thus resistance of the surface to biotic, chemical and physical and mechanical factors. Selecting the right product for a given place of usage is a very important step before the substrate is finished. The normative acts of individual European countries contain guidelines concerning the basic requirements for specific assortments of furniture (Krzoska-Adamczak 2001).

One of the solutions is the use of lacquer products in the analogue or digital printing version. This creates significant possibilities for finishing the substrate with single-colour or diversified patterns, including those imitating wood and other materials. The important factor necessary to achieve the assumed decorative effects is the proper performance of all technological operations. As a result, it allows for the creation of unique arrangements in different types of rooms. The dominant position in the printing technology is occupied by lacquer products hardened with the energy of UV radiation, used as primer and surface layers. Manufacturers offer more and more enriching products for the furniture industry, which are different in composition and price, which affects the quality and resistance parameters. This requires conducting organoleptic and laboratory tests to verify their quality characteristics. The first of them concern aesthetic-decorative values, which in an individual way influence the consumer's decision to purchase a product. On the other hand, laboratory procedures use instrumental methods in the evaluation of resistance, which contributes to the objectification of the degree of materials usefulness.

In other studies, scientists paid attention to the investigations of coatings prepared in analogue printing technology (Krystofiak, Lis and Proszyk 2010, Krystofiak *et al.* 2009, 2016).

To the very important factors belongs resistance of coatings upon aging (Jirous-Rajković, Bogner and Despot 2004, Herrera *et al.* 2018). During accelerated aging finished surfaces change colour and gloss. In some papers colour changes of wood, wood based materials and coatings were investigated (Lesar *et al.* 2011, Živković *et al.* 2014, Nemeth *et al.* 2016). To this time mainly workers of the Department of Gluing and Finishing of Wood PULS have published results of the investigations of the aesthetic-decorative features of wood, veneers and coating. In some papers the influence of thermo-mechanical modification of veneers from different wood species was presented (Bekhta, Proszyk, Krystofiak 2014, Bekhta *et al.* 2014, 2018).

In this context, experimental investigations were undertaken in order to determine the aesthetic-decorative features of the surfaces of the furniture elements covered with acrylic lacquer products hardened with UV radiation prepared in industrial conditions. The investigations were focused on the evaluation of the appearance and evaluation of colour and gloss (GU) in the conditions of accelerated "artificial" aging imitating the natural influence of environmental factors.

The aim of the research was to determine the aesthetic-decorative features of the furniture surface elements finished with acrylic UV lacquer products prepared in industrial conditions.

2. EXPERIMENTAL

The experimental material in the form of tabletops with the trade name LACK (550 mm × 550 mm × 50 mm) prepared in industrial conditions was used. For the finishing, the multi-layer systems including acrylic UV primer and bottom and top lacquer products was used. Lacquer system in "white", "black" and "black oak" versions with the use of rollers was applied. In Table 1 and 2 (based on the manufacturer's catalogue data) selected physicochemical parameters of the lacquer products was given.

Table 1. Properties of the topcoat lacquer for "white" finish system

Parameter	UM/61363-182/ UM/61477-188
Physical state	liquid
Smell	slight smell
Flash point in the closed cup acc. to the ASTM 6450 standard [°C]	105
Relative density [g/cm^3]	1.12
VOC [g/l]	-
Solid content [%]	100

Table 2. Properties of the topcoat lacquer for "black" and "black oak" finish system

Parameter	"black oak"	"black"
	UV TOP 25922	UV TOP 20932
Physical state	liquid	liquid
Colour	colourless	colourless
Relative density [g/cm^3]	1.24	1.22
Viscosity [mPa·s] acc. To the Brookfield method at 23 °C	900-1100	800-900
Initial boiling temperature and boiling range [°C]	254-305	256-305
VOC [g/l]	44	7

The appearance, gloss, colour, and colour wiping out for the aged surfaces with reference to the control samples were determined.

The appearance of coatings acc. to the PN-90/F-06100/01 and PN-EN 438-2:2007 standard was evaluated. Investigations of gloss degree of coatings with the photoelectric method with REFO 3 apparatus were determined. Measurements of each sample at various angles (20°, 60° and 85° respectively) were carried out. The classification of gloss degrees at angle 60°, together with the verbal evaluation in Table 3 was given.

Table 3. Classification of gloss level values for an angle of 60° (Anonymous 2003)

Gloss degree	Gloss estimation
< 10	Matt
10 – 30	Semi-matt
35 – 60	Semi-gloss
60 – 80	Gloss
> 80	High gloss

Colour measurements were carried out with an ELREPHO 2000 spectrophotometer, recording the coordinates in the CIELab system.

The colour wiping determination was performed for "black" finishing in dry and wet testing to IOS-TM-0002/4 specification. Measurements were performed with a 16 ± 0.1 mm diameter mandrel on which a white textile was attached and then loaded with a 9 N weight. Estimation of the obtained results with the use of contrast grayscale acc. to IOS 105-A03 procedure was performed.

The stability of aesthetic-decorative features under the aging conditions of 2 test procedures was determined: of thermal aging in the version of changing temperatures acc. to the PN-88/F-06100/07 standard (method A) and IKEA requirements acc. with the specification contained in IOS-TM-0002 procedure. The measurements were carried out after 3, 6, 9 test cycles for control samples. Before the investigations, the elements in RT conditions for 168 hours were conditioned.

In the first method, called the changing temperature test, the samples were subjected to alternating interaction of elevated and low temperatures, using a dryer and fridge acc. to the following cycle:

- 1h at +50 ± 1 °C and RH from 15 ÷ 20 %.
- 1h at -20 ± 1 °C
- 15 min air conditioning at 23 ± 2 °C and RH 50 ± 5 %.

In the second test procedure, called "cold check test", the test material was subjected to cyclic changes in temperature and relative humidity. The experimental material was transferred to the climatic chamber and freezer acc. to the 24-hour cycle:

- 2 h in the climate chamber at 23±1 °C and RH 50±5 %.
- 2 h in a climatic chamber at 50±1 °C and RH 50±5 %

- 0.5 h in a climatic chamber at 55±1 °C and RH 90±5 %.
- 1.5 h in the freezer at -20±1 °C
- 0.5 h in a climatic chamber at 55±1 °C and RH 90±5 %.
- 1.5 h in a climatic chamber with temp. 50±1 °C and RH 50±5 %.
- 16 h in a freezer at -20±1 °C.

The appearance of the apparent surfaces (working surfaces and narrow edges) was assessed with the visual method.

Special attention was paid to the gloss and possible defects that may have occurred during the application of lacquer products or after coatings formation, as well as mechanical damage.

Measurements were made acc. to the DIN 67 530 and ISO 2813 standards at 5 locations with the use of REFO 3 glossmeter at three angles 20°, 60°, and 85° respectively. Before starting the tests, the apparatus was calibrated on a reference plate of black glass.

3. RESULTS

In Table 4 results of the gloss measurements in the function of aging procedures were presented.

Table 4. Gloss of tested lacquers in the function of aging tests

Kind of finishing	Angle [°]	Number of cycles			
		0	3	6	9
Cold check test					
"white"	20	83.1	82.2	85.3	84.1
	60	89.4	90.3	92.1	91.3
	85	98.5	99.6	100.2	100.5
"black"	20	0.9	1.0	1.0	1.0
	60	7.7	8.2	8.4	8.2
	85	4.1	4.5	4.7	4.7
"black oak"	20	1.6	1.6	1.6	1.4
	60	11.6	12.5	12.6	11.7
	85	10.3	11.1	12.0	11.6
Changing temperature tests					
"white"	20	84.4	84.0	81.6	80.5
	60	92.0	91.4	91.0	87.2
	85	100.5	101.0	100.4	100.0
"black"	20	1.0	1.0	1.0	1.0
	60	9.3	9.0	9.0	8.9
	85	7.1	6.9	6.7	6.7
"black oak"	20	1.9	1.8	1.8	1.8
	60	16.3	16.0	15.8	15.9
	85	20.1	21.5	20.1	21.8

The results are presented in Table 4 and the obtained results for the angle of 60° are interpreted according to the scale contained in Table 3. Moreover, changes in the gloss level as a function of the number of aging cycles were calculated and in Table 5 was given.

Table 5. Changes in gloss level degree for tested finish systems in the function of the number of aging cycles

Kind of finishing	Kat [°]	Number of cycles		
		3	6	9
Cold check test				
"white"	20	-0.9	2.2	1.0
	60	0.9	2.7	1.9
	85	1.1	1.7	2.0
"black"	20	0.1	0.1	0.1
	60	0.5	0.7	0.5
	85	0.4	0.6	0.6
"black oak"	20	-	-	-0.2
	60	0.9	1.0	0.1
	85	0.8	1.7	1.3
Changing temperature test				
"white"	20	-	-2.8	-3.9
	60	-0.6	-1.0	-4.8
	85	0.5	-0.1	-0.5
"black"	20	-	-	-
	60	-0.3	-0.3	-0.4
	85	-0.2	-0.4	-0.4
"black oak"	20	-0.1	-0.1	-0.1
	60	-0.3	-0.5	-0.4
	85	1.0	-	1.7

When assessing the appearance of the tested finishings, it was stated that they were characterized with high aesthetic-decorative features. The absence of defects on the surfaces was observed. After the aging tests, no visual changes were noticed, which proves the stability of the coatings. Only in the case of "black" finishing, slightly delamination of edges was observed. They could have been caused by insufficient resistance to changing climatic conditions included in the used aging procedures and thus generated during cycles of shrinkage, thermal and humidity stresses, which resulted in delamination of glue-lines. For the remaining systems, no changes were found as a result of aging.

On the basis of the obtained results of experiments on the stability of the gloss unit (GU) under aging conditions, various changes in the range of several degrees were found. However, this did not affect the final assessment. In accordance with the assessment criteria from Table 3, it was found that the "white" surface by a degree of gloss was characterized, described in the verbal assessment as a high gloss. On the other hand, a "black" coating showed a matt effect, while a "black oak" as semi-matt was classified.

The determination of colour with the Elrepho 2000 spectrophotometer was performed by using the CIELAB method. Prior to the investigations, a template was prepared on which 20 mm diameter circles were cut, so that the measurements were always taken in the same place. Before investigations, the device on the black and white standards were calibrated.

Each sample was measured three times by registering L*, a* and b* parameters. The obtained values were averaged and used to calculate the differences in colour coordinates and the total colour difference accordingly the following formula:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

In Table 6 the influence of aging tests on the course of colour parameters of tested coatings was presented.

Table 6. The course of differences in individual colour parameters for tested finishings in function of the number of aging cycles

Kind of finishing	Colour coordinates difference											
	ΔL*			Δa*			Δb*			ΔE*		
	Number of cycles											
	3	6	9	3	6	9	3	6	9	3	6	9
Cold check test												
"white"	-0.25	-0.43	-0.46	0.20	0.27	0.08	0.13	0.53	0.23	0.36	0.74	0.58
"black"	-0.69	-0.85	-0.61	0.00	-0.03	-0.03	0.00	-0.07	0.07	0.69	0.95	0.62
"black-oak"	0.88	1.59	1.11	0.20	0.17	0.17	0.23	0.20	0.13	0.96	1.67	1.15
υ												
"white"	0.08	0.08	0.07	0.10	0.06	0.30	0.06	0.66	0.06	0.09	0.02	0.04
"black"	0.18	0.32	0.36	0.00	0.06	0.05	0.10	0.58	0.06	0.18	0.41	0.35
"black-oak"	0.08	1.05	0.62	0.10	0.23	0.06	0.23	0.36	0.32	0.88	1.01	0.65
Changing temperature test												
"white"	-0.02	-0.03	-0.05	0.00	0.00	-0.03	0.20	0.17	-0.03	0.20	0.17	0.09
"black"	0.22	0.06	0.32	0.03	-0.03	0.07	-0.07	-0.20	-0.07	0.26	0.24	0.37
"black-oak"	0.41	0.18	0.32	-0.13	-0.17	-0.13	-0.07	0.03	-0.13	0.74	0.47	0.51
Y												
"white"	0.04	0.05	0.06	0.00	0.00	0.06	0.00	0.06	0.06	0.00	0.06	0.06
"black"	0.13	0.06	0.06	0.12	0.15	0.16	0.12	0.10	0.12	0.14	0.13	0.06
"black-oak"	0.86	0.12	0.29	0.12	0.23	0.06	0.31	0.45	0.32	0.56	0.16	0.12

Average values of measurement of attributes of colour of coatings with the standard deviation as a function of the number of aging cycles. The interpretation of the obtained results was performed on the following criterion in which (ΔE*):

- 0 and 1 are not visible
- 1 to 2 indicate a slight deviation which is identifiable by an experienced person,
- 2-3.5 suggest an average deviation differentiated even by a third party,
- 3.5-5 indicate a clear deviation,
- above 5 means a large colour deviation.

The analysis of the obtained results showed that under the influence of aging there were slightly changed in the registered parameters, which were more visible after the cold check procedure.

The most sensitive finishing to aging test conditions was "black oak", for which ΔE* exceeded the unit, indicating a small deviation, which can be identifiable by an experienced observer. For the other systems, lower values were obtained for this parameter, which was classified as invisible. "White" finishing proved to be the most stable among the tested systems. The difference in colour change after exposure to the selected aging conditions was 0.09-0.58 units.

In general, the smallest changes ΔL* after 9 aging cycles in both test methods for "white" coating was recorded, for which the lowest negative trend ΔE* values indicating its dimming were recorded at the same time. In the case of "black oak" samples, this parameter was positive, emphasizing the brightness of the surface. However, for the "black" finishing in the cold check procedure, a trend towards negative values was found, and a different trend was observed under conditions of changing temperatures. When evaluating the parameters Δa* and Δb* in a function of the number of aging cycles, different behaviour of the values oscillating between -0.17 and +0.66 was observed.

The noted data of a positive value indicate an increase in colour intensity in the case of a parameter Δa* red and Δb* yellow respectively, while the negative results highlight changes in the direction of colour less red and yellow. With this in mind, the cold check procedure noted positive values of these attributes for "white" and "black oak" systems, while for "black" the Δa* indicator assumed negative tendencies. In turn, under the test conditions of changing temperatures, a negative trend was observed for the Δa* parameter on the "black oak" and "white" surfaces and Δb* for the "black" coating.

During the assessment of colour wiping carried out on "black" finishing, it was found that this parameter for the tested coatings is stable in the function of cycles of both aging methods (classifying it as 5 in both dry and wet tests).

4. CONCLUSIONS

1. Tested surfaces were characterized by high and stable aesthetic-decorative values during the aging process, except for the "black" finishing for which the edge was slightly delaminated.
2. Lacquer coatings showed the different gloss degree for the "white" - high gloss, for the "black" matt and for "black oak" semi-matt.
3. Aging processes had a slightly negative impact on the colour parameters.
4. The most sensitive finishing to the aging test conditions was "black oak", while for other systems lower values of this parameter were noted.
5. Tested finishings showed comparable colour wiping resistance.

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Importance of Natural Materials for Good and Quality Sleep

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ABSTRACT

We are witnessing huge environmental pollution around the world. Excessive use of artificial materials has a very detrimental effect on our health. In order to prevent pollution, to stimulate the development of the wood- and furniture industry, agriculture and related activities, it is necessary to encourage people to use natural materials as much as possible. Sheep's wool is a unique and significant product that characterizes the animal species and is an example of neglected material. On the other hand, we have good utilization of wood, but there should be a greater degree of finalization of the product in Republic of Croatia. New ideas would stimulate new investments for the development of the mattress industry and enable the economy to develop. However, the aim of the paper is to remind users of the beneficial properties of natural materials and to encourage them to choose natural materials when purchasing furniture for sleeping. By choosing natural materials, in addition to not destroying the environment, we can ensure better and quality sleep, as well as prevent some health disorders, such as allergies. In addition, the production of products made from natural materials would be encouraged.

Key words: natural materials, wool, cotton, latex, wood, sleep, mattress

1. INTRODUCTION

The planet Earth inhabits plants, animals and humans that strive to live in symbiosis and create optimal equilibria on Earth. The whole system works ideally if that balance is established. It is necessary for people to respect nature to enjoy a comfortable and quality life. Civilization developed through different eras and periods. These developments have brought significant benefits and improved the quality of human life; however, some developments have disturbed the balance. Guided by those thoughts, it is necessary to spread awareness about the pollution of the environment on a daily basis to artificial materials, because materials that are not rapidly degradable or recyclable are creating a long-term problem for our planet. Using natural and environmentally friendly materials, we contribute to the positive planet development. At the same time, greater demand and importance for natural materials would encourage their production. One such, very significant and unique material of animal origin is sheep's wool. For example, the Republic of Croatia uses only half of its total production of wool and the rest ends up as waste polluting the environment (Stracenski Kalauz *et al.*, 2013).

Every life on Earth needs to renew and receive energy. Unique way of renewal energy, like recharging batteries, for the people is to lie down, rest, dream and enjoy. One of the objects, which allows human activity that meets all these needs, is – the bed. Through the development of civilization, humans have successfully assembled a set that serves us to sleep. The bed system is an assembly of frame, mattress and pillow (Grbac, 2006). By choosing natural materials, in addition to not harming the environment, we can ensure even better sleep quality, as well as prevent some health disorders, such as allergies.

This paper contributes to a better understanding of the importance of the role of natural materials in the daily life of human beings, and especially for sleeping and application of natural materials in the design and construction of bed systems. Paper is based on a research by several authors who highlighted and prove the benefits of cotton, wool, latex and wood in the production of healthy beds and sleeping areas.

2. RESEARCHES OF NATURAL MATERIALS IN BED SYSTEMS

The selection of materials for the bed system directly affects the health and sleep of the user. After researching the literature and the overall knowledge of the bed system and mattress construction, choosing the adequate materials in its design is a very important step. An eco-friendly and health-friendly bed system requires the use of natural materials, and for this reason, materials that are available in nature have been selected for the purposes of this work. Moreover, through studying the literature it has been confirmed that those materials have a positive effect on human health during sleep and rest.

Textiles, especially clothing, interact dynamically with skin functions. Mechanical properties like roughness of fabric surface are responsible for non-specific skin reactions like wool intolerance or *keratosis follicularis* (Wollina *et al.*, 2006). With the worldwide expansion of synthetic textiles the need for antimicrobial impregnation of textiles increased substantially as synthetic textiles absorb about 25 % less water vapour compared to cotton or wool. The blocking of evaporation of sweat results in a thin fluid film on the skin, which consequently impairs further the evaporation of sweat, providing an ideal environment for proliferation of bacteria and fungi. Soon, commercial interest was direct to the antimicrobial impregnation of natural fibres (Kramer *et al.*, 2006).

2.1. Cotton

Cotton is the natural material that is the most appreciated biodegradable material in the textile industry. It is consider as an ideal filling material in the mattress construction layers. Due to its texture and soft touch, as well as health-friendly textiles, this material fits perfectly with the concept of natural mattress.

Cotton is one of the most used product in the fashion industry. Unfortunately, most used cotton is produced with large amounts of pesticides that affect not only the environment, in which they are grown, but also the workers who harvested them and the people who wear them. Organic cotton is planted using the natural method of cultivation and has a significantly less harmful effect on the environment and as such has a higher level of quality and comfort. Organic cotton farms instead use natural techniques to protect against insects that are a threat to plants, such as covering with natural materials (Web 1).

Cotton is the most commonly used textile for patients with atopic dermatitis; it has wide acceptability as clothing material because of its natural abundance and inherent properties like good folding endurance, better conduction of heat, easy dye ability and excellent moisture absorption. In addition, its easy biodegradability is an added advantage.

However, it suffers from drawbacks like inflammability, poor crease retention and is prone to bacterial and fungal attack (Ricci *et al.*, 2006). Cotton fibres are sensitive to acids but are highly resistant to alkalis and organic solvents. The aging of cotton fibres is very good (if kept in a dry and sheltered place from the sun, the loss of strength for 50 years is minimal) (Kovačević, 2009). In addition, its simple biodegradability is ideal for the needs of today's ecological management (Ricci *et al.*, 2006).

Another benefit of organic cotton and the disadvantage of using pesticides, is that it is far better for human health. This is mainly due to respiratory problems that can be caused by the chemicals used to grow cotton. It has been shown to affect other people living near inorganic cotton farms. Furthermore, people carrying inorganic cotton may also be exposed to the residual amount of pesticides that can be absorbed through the skin. The non-organic cotton and chemicals used have been shown to cause many health problems, such as attention deficit hyperactivity disorder (ADHD), a weakened immune system, and even birth defects. The benefits of organic cotton are evident through their environmental impact, their impact on human health and the fact that they last longer and are more comfortable (Web 1). For this reason, cotton as a material in today's rapid stressful life is an ideal material for relaxing users, which is why cotton is suggest for use in fine mattress filling and in a part that is in direct contact with human skin.

2.2. Wool

Wool is a traditional natural material that has been beloved for centuries, it is ideal for implementation in mattress construction. Wool is a natural material that has been synonymous with softness and warmth for many years. Croatian mattress manufacturers also produce mattresses filled with natural materials such as wool and cotton. Marković (2017) found that three observed Croatian manufacturers have different models with this type of fine filling in their production gamma. In the first company, just two mattress models from entire production gamma are fill with wool. The quality of the wool contained in these mattresses is 400 g/m^2 of weight in combination with cotton of 200 g/m^2. Second manufacturer has only one mattress, which incorporates wool with a weight of 110 g/m^2 in combination with polyurethane fibres. While the third manufacturer has five models of mattresses filled with 300 g/m^2 quality of wool. With such properties, this traditional natural material is ideal for filling a mattress in which it is intend to use wool fiber in a second layer, below a fine cotton pad.

An aversion to next-to-skin wool garments has been attributed to discomfort or a sensation of prickle, and beliefs and experiences with wool in childhood can influence future use (Sneddon *et al.* 2012; Sneddon *et al.* 2012). Prickle is understood to be mechanical irritation to the skin by coarse fibre ends indenting the skin and activating nerve endings (Garnsworthy *et al.* 1988; Naylor, 1992; Naylor *et al.* 1997). Fibre, top, yarn, and fabric factors can influence the tendency of a fabric to exhibit prickle (Naylor, 1997; Naylor *et al.* 1997) e.g. length of fibre protruding from the fabric surface, presence of coarse fibre ends (Naebe *et al.* 2014). Methods for overcoming prickle effects include enzyme treatments (of fibers, yarns, fabrics e.g.) (Bishop *et al.* 1998; Das and Ramaswamy, 2006), and modifying yarn structure (Miao *et al.* 2005) (cited in: Laing and Swan, 2015).

Sheep's wool is a very fine mattress filler as it has good thermoregulatory properties. Its natural property is to absorbing moisture and evaporates it. Also, wool creates a dry and healthy sleeping climate. Such thermal properties are very important to humans because the human body sweats and loses half to one and a half litres of fluid at night, and its dry climate makes it possible to retain body heat. In addition to its excellent thermal properties, the wool fiber is permanently elastic, durable in shape and has very good anti-rheumatic properties. Wool is a material that has the ability to regulate the climate and create a sense of comfort. Due to such abilities, wool material will not be able to completely replace any other artificial fiber (Grbac and Ivelić, 2005).

Recent evidence confirms perception of warmth is affected by perception of wetness with warm temperatures suppressing the perception of wetness (Filingeri *et al.* 2014). Further, surface wetness of fabrics in contact with the skin influences more general perceptions of comfort (Scheurell *et al.* 1985). The thermal resistance of wool fabrics has also been attributed to improvement in specific aspects of user health. Use of wool undergarments (and bedding) over a six-week period was reported to reduce symptoms and drug use of patients suffering from fibromyalgia (Kiyak, 2009) (cited in: Laing and Swan, 2015). Details on construction, mass per unit area, thickness, and laundering practices were not reported for either the undergarments or the bedding (Laing and Swan, 2015).

2.3. Latex

The modern era has made various innovations today. Originally latex is a white milky juice that is extracted from many plants, the most famous being rubber tree *(Hevea brasiliensis)*. Natural latex is very expensive and demanding for production, which is why chemical treatment of latex is now possible to profit in various technological ways (Marković, 2019).

The mattress core can be design in various materials such as spring cores or polyurethane foams, however, the natural material that today occurs as the mattress core is the natural latex foam. Nevertheless, it is very important to note that nowadays this natural share in the production of latex foam is diminishing, and latex is based on artificial materials that mimic the properties of true natural latex (Marković, 2019).

There are different methods of obtaining a latex core, and one of them is "talalay" method. “Talalay” latex refers to the method in which the latex is formed. In this process the rubber is agitated into foam and poured into a mold and sealed in a vacuum. The mold is then flash-frozen to stabilize the rubber and subsequently heated to assure evenness and a consistent cell structure top to bottom and edge to edge. Latex mattress cores are perforated with holes. The size of the holes determined the softness of the core. The latex mattress cores contained sections with different sized holes regulating the softness in selected areas based on the participant’s sleeping position (Jacobson *et al.*, 2010).

The spring core mattresses, due to their construction and springs, provide excellent support and are known as "firm" and "hard" mattresses. Unlike mattresses that have a latex core, they are a very economical, yet quality product (Grbac and Ivelić, 2005).

Latex foam is a material that provides high quality support for the spine, because when loaded it adopt to the shape of the body, which makes such material extraordinary for such support.

Through the study of Low *et al.* (2016) found that latex foam can be an excellent replacement for polyurethane foam and spring core. Results in the same study confirmed that a latex foam core was ideal for the construction of hospital beds because the use of a latex core could significantly reduce the stiffness of a patient's muscles and joints. The ability of the latex mattress to achieve a more even and lower distribution of stress regions across the body can be attributed to its mechanical properties. Once such a core has been implemented, the mattress construction is complete and meets all the requirements and criteria laid down on the mattress: the materials are natural, physiologically acceptable with thermal balance and good permeability, outstanding durability and elasticity, with indispensable comfort and hygienic durability, but also unavoidable aesthetics.

In a study (Jacobson *et al.*, 2010) patients with back pain and sleep disorders had significant improvements when they slept on a sleep surface constructed of layers of viscoelastic polyurethane foam and latex.

Lee and Park (2006) in their study on the impact of mattress type on sleep quality and skin temperature, found that sleep efficiency and skin temperature were higher when subjects slept on an "uncomfortable" mattress. In addition, different bedding systems have caused different respiratory problems associated with sleep disorders and insomnia (Chen, 2014).

2.4. Wood

For wood is scientifically proven to have a positive effect on human health, whether as a tree or a raw material (Web 3). The benefits of wood in interiors are multiple physiological, psychological and environmental. Namely, wood in the interior improves a person's emotional state, lowers blood pressure (Sakuragawa *et al.*, 2005), heart rate and stress level (Kelz *et al.*, 2011), improves air quality, and in the long-term stores carbon and hereby helping to combat climate change. Figure 1 shows some of the benefits of wood usage in the interior (Web 2).

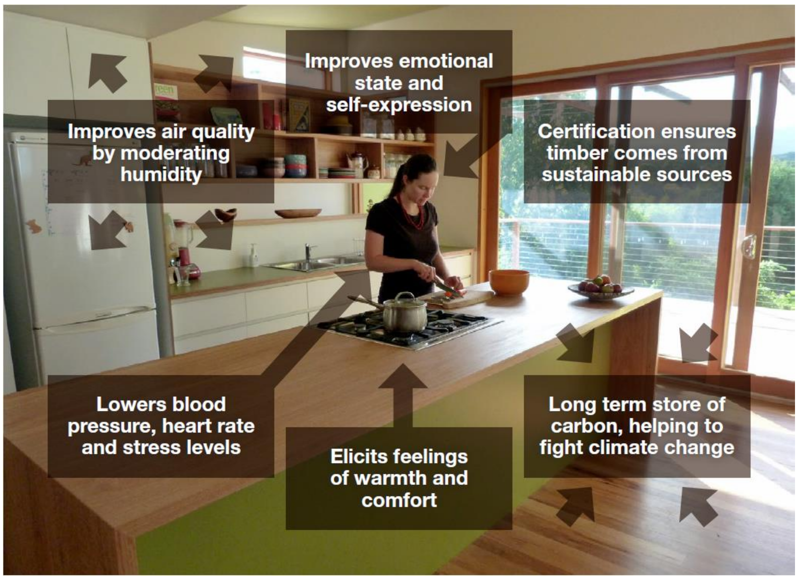

Figure 1. Positive effects of wood in interiors
Source: Web 2

Along with many studies on how wood affects people, it is very difficult to find an objective scientific research results. Most of them are based on the subjective assessments of the respondents, which is not always a relevant data for the research evidence.

Healthy homes are the concept of healthy and natural landscaping where people live. Due to increasing concern for the environment and the impact of various health factors, people are increasingly choosing natural and healthy materials to decorate their home (Spetic *et al.*, 2005). Users like to see wood in dining rooms, other rooms furniture, doors, kitchen cabinets, and floors, while the least attractive wood is to see them as wall coverings (Figure 2) (Rice *et al.*, 2006).

The usage of wood proved positive attitudes in classrooms. The study (Kelz *et al.*, 2011) proved that students who resided in a newly redecorated solid wood classroom had a much lower heart rate, unlike those in a classroom equipped standard materials. Ball *et al.* (2002) in New Zealand have proved the appearance of the working environment in offices can also affect people's work. Following the results, four of the top five ranked offices used wood in their interior design. The most common adjectives that describe ideal offices are: innovative, energetic and comfortable. As many as 95 % of respondents said they would like to work in an office that has visible wood products in their indoor environment, suggesting that users love being surrounded by wood and for its aesthetics, comfort and sense of well-being.

However, not every type of wood has the same effect on human health and recovery, which is especially important when sleeping. The *Pinus cembra* is known as "Swiss pine" or "stone pine" and is often referred to by the people as the "queen of the Alps". Human Research's study (Web 3) estimates the effects of this type of wood on stress and the ability to recover in 30 adults. Healthy individuals, with differences in the quality of recovery seen in humans over time spent in a room equipped with pieces of furniture, wall and floor coverings made of Swiss pine, and those who spent time in a room made of wood-imitating materials. The difference is express in lower heart rate during physical activity and mental stress, as well as in rest/autonomic recovery. In people who were staying in a room filled with wood-mimicking materials, the heart rate depended on atmospheric pressure, which was a sign of unstable circulation. It was not a case for people who were interviewed in a room whose interior is dominated by Swiss pine.

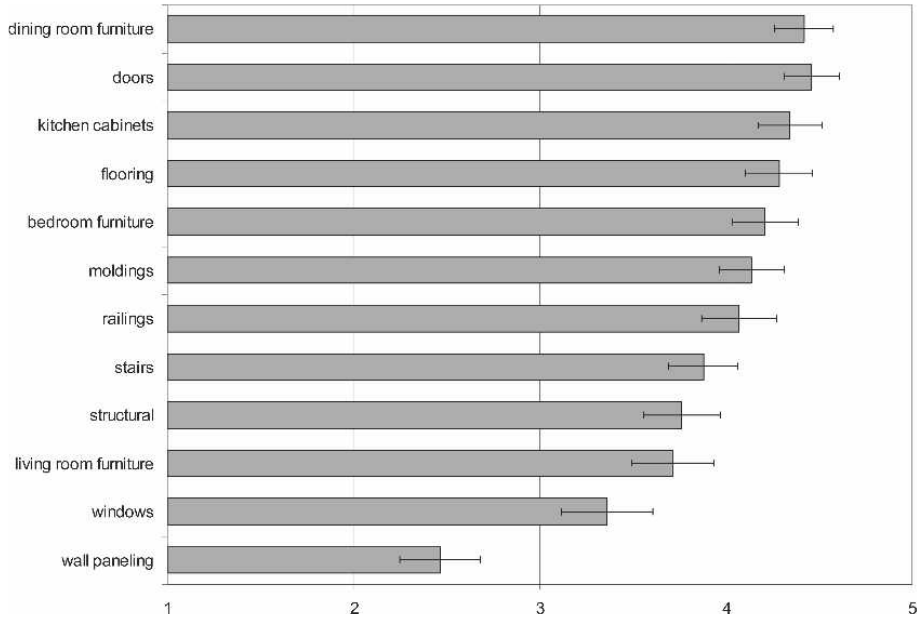

Figure 2. Mean preference ratings (and 95 % confidence intervals) for wood used in various home applications (1 = wood is the least preferred material for this application; 5 = wood is the most preferred material for this application). Source: Rice et al., 2006

The second part of Human Research's study (Web 3) was based on the impact of the bed material on sleep quality. The test period was three weeks, and the subjects slept on a bed made of Swiss pine wood, then in their own bed or a bed made of wood-covered materials. The results showed a significant influence of the type of material on the physical and mental state of the subjects. Sleep quality was significantly improved when sleeping in a bed made of Swiss pine wood, as opposed to sleeping in a bed of foil-lined wood panels. The outcome of the study was a better recovery followed by a decreased heart rate as seen in Figures 3 and 4. The average saving was 3500 heart-beats per day, which corresponds to approximately one hour of "heart-work". In addition, the respondents gave their subjective opinion after sleeping in a bed made of Swiss pine wood. Almost all respondents stated that they felt more relaxed, generally more comfortable, and more socially extroverted (open, communicative) than before (Web 3).

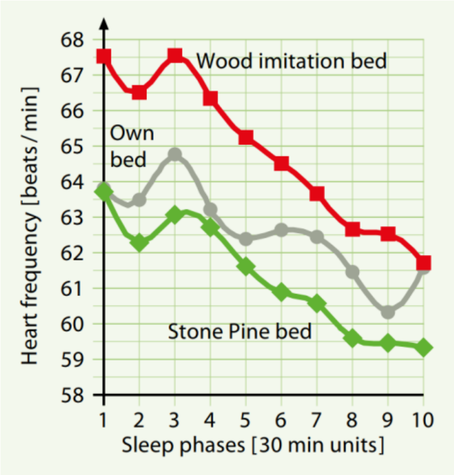

Figure 3. Heart frequency during the course of the night
Source: Web 3

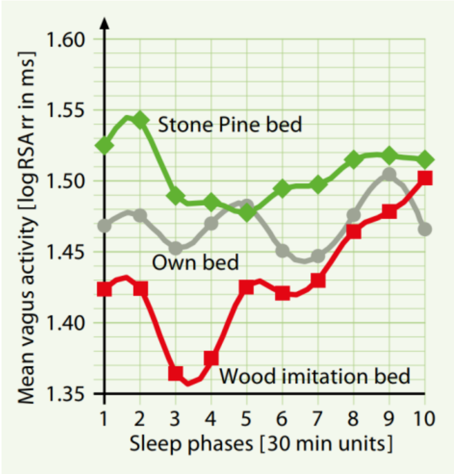

Figure 4. Autonomic recovery during the course of the night
Source: Web 3

Given today's hectic lifestyle and high exposure to stress, the influence of Swiss pine has a significant impact on the human body.

Its use in interior design offers people quicker recovery and relaxation, and a peaceful and quality sleep during the night (Celinšćak, 2019).

3. CONCLUSION

By choosing natural materials, in addition to not impact the environment, we can ensure even better sleep quality, as well as prevent some health disorders. The selection of materials for the bed system directly affects the health and sleep of the user.

Applying mostly synthetic materials such as polyurethane foam and synthetic fabrics in the upper layers of the mattress reduces the permeability and breathability of the bearing and thus does not fully meet the physiological requirements. In order to meet physiological requirements, moisture absorbent materials are used in the outer layer, they transport moisture in the inner layer, where hygroscopic materials are present. Those materials shortly retain moisture, which during daytime release into the environment.

An eco- and health-friendly bed system requires the use of natural materials, and for this reason, materials that are available in nature are wood, latex, cotton and sheep's wool.

Wood has a positive effect on human health. In addition to its beautiful appearance and positive effects on the emotional state of people, wood reduces stress, and has been shown to reduce heart rate. Due to its positive effects on human health, wood should be the main material for the design of the bed frame, but also in furnishing the interior. Considering nowadays fast lifestyle and high level of stress, the influence of natural solid wood has a significant impact on the human life.

Mattress materials can directly affect human sleep, dermatological problems, but can also affect the human musculoskeletal system. The materials used in the mattresses should be able to absorb moisture from the body and evaporate it into the environment, which means that must be used conductive and permeable materials. It is known that the human body secretes from 0.5 to 0.75 litres of fluid (according to some sources and 1.5 l) during sleep, so it is necessary that the mattress on which the body lies is permeable and breathable For this reason, the selection of materials is based on cotton, wool, latex and wood.

Latex is a natural soft and resilient material, with properties ideal for the mattress core. It offers comfort that adapts to a particular body shape, more precisely, supports the body that presses against it, and allows even distribution of mass on the surface. Such properties do not cause an unpleasant counter-pressure on the body, but only the necessary ones, thus facilitating blood circulation, helping to reduce muscle and joint stiffness and helping the body to relax completely. Latex is an excellent natural replacement for artificial polyurethane foam.

Wool is a natural material of animal origin. It is a very good fine filler because it has good thermoregulatory properties. Its natural property is that it absorbs moisture and evaporates it. It also creates a dry and healthy sleeping climate. The wool fiber is permanently elastic, durable in shape and has very good anti-rheumatic properties. Such properties are bearable but retain their hardness which means that they withstand the human body and its pressures while providing quality support.

Cotton is a natural fiber and considered to be the dominant fabric in the bed system, it is good for human health because it successfully solves dermatological skin problems in atopic dermatitis. With its properties, cotton as a hygroscopic fiber and comfortable to the touch is great for the mattress surface layer which is in direct contact with the human body.

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Bark, What Can We Do With It, What Is It Good For

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ABSTRACT

A material long waiting for its implementation for wood-based products is bark. Although bark constitutes between 10 % to 20 % of total tree volume its usability is limited. In present research we investigated the possibility to use bark for particleboard production, either as furniture grade material or as thermal insulation material. In two stage experiment single layer particleboards with different target density (0.65 g·cm^{-3} and 0.5 g·cm^{-3}), with different share of bark (10 % to 80 %) were produced and evaluated. Results of experiment showed that thermal conductivity of boards with bark was lower, compard to board without bark. Increase in bark share resulted in thermal conductivity decrease. Bending strength and internal bond of board with 10 % bark were higher that of board composed only from wood particles. Modulus of elasticity decreased with increasing the bark share.

Key words: bark, bending strength, modulus of elasticity, particleboard, internal bond, thickness swelling, thermal conductivity

1. INTRODUCTION

Increasing usability of wood demands from producers of non-veneer wood–based composites to search for different types of lignocellulosic material(s), that could be used for their products. Their quest for new types of lignocellulosic material(s) raw material widened from typical used wood species, towards lesser used (Barboutis, 2005; Rademacher, 2019), lesser known (Alma *et al.*, 2005; Medved *et al.*, 2109) wood species, agricultural residues like straw, hemp, kenaf, vine pruning, etc (Ntalos and Grigoriou, 2002; Kalaycioglu and Nemli, 2006; Mihajlova *et al.*, 2008; Ninkas *et al.*, 2019).

Possible material, long waiting for its implementation, is bark. Bark constitutes between 10 % to 20 % of total tree volume and varies regarding the wood species. Most of the bark, left during debarking in the forest, sawmill or during wood-based panel respectively pulp production, is mostly used for energy (not the best possible practice of bark utilization due to its caloric value), for landscaping, in pharmacology, for leather tanning, as bio-based adhesive, and for foam (Pizzi, 2008; Tondi and Pizzi, 2009; Ugovšek and Šernek, 2010; Miranda *et al.*, 2012; Čop *et al.*, 2015).

Bark was and still is avoided raw material in wood – based composite production due to its negative affect on mechanical properties as was determined by Dost (1971), Deppe and Hoffman (1972), Maloney (1973), Lehmann and Geimer (1974), Place and Maloney (1977), Muszynski and McNatt (1984), Suzuki *et al.* (1994), Blanchet *et al.* (2000), Nemli and Çolakoğlu (2005), Yemele *et al.* (2008), Gupta *et al.* (2011). A promising report related to usability of bark for different wood-based composites are related to low thermal conductivity (Sato *et al.*, 2009; Kain *et al.*, 2013; Kain *et al.*, 2015), as a substance to lower formaldehyde emission (Herrick and Bock, 1958; Maclean and Gardner, 1952; Roffael, 1982; Cameron and

Pizzi, 1985; Prasetya and Roffael, 1991; Lelis and Roffael, 1995; Roffael *et al.*, 2000; Nemli and Çolakoğlu, 2005; Takano *et al.*, 2008; Medved *et al.*, 2019) and as coating layer for flooring (Tudor *et al.*, 2018).

Aim of the paper is to present the possibilities to use bark for particleboards and as thermal insulation panels.

2. MATERIALS AND METHODS

For the purpose of the investigation wood chips and bark from coniferous wood species mixture were used for production of single layer particleboards. Wet chips (bark and wood) were broken down into particles in laboratory chipper, followed by drying at 100 ±5 °C until moisture content was approximately 2 %.

After drying, appropriate wood and bark mixture for one panel type (table 1 and table 2) were loaded into laboratory blender.

Table 1. Panel composition regarding bark share (target density 0.65 g·cm^{-3})

Board	Wood particles share	Bark particles share	Remark
A	100 %	0 %	Reference
B	90 %	10 %	
C	80 %	20 %	
D	50 %	50 %	

Table 2. Panel composition regarding bark share (target density 0.5 g·cm^{-3})

Board	Wood particles share	Bark particles share	Remark
E	100 %	0 %	Reference
F	80 %	20 %	
G	50 %	50 %	
H	20 %	80 %	

The boards where blended with urea-formaldehyde resin. Share of resin, applied on particle was 11.5 %. The resin spraying time was 3 minutes, followed by 3 minutes mixing time. Blended particles were hand formed info mat with dimensions 500×500 mm^2. Target thickness was 16 mm and was, during pressing, controlled by thickness bars. Mat was pressed at 180 °C and 3 N·mm^{-2} for 4 minutes (closing, degassing and opening included). Boards were than left for 60 minutes at room conditions to cool down and afterwards stored at normal climate conditions (temperature 20±2 °C and relative humidity 65±5 %) for 14 days. For boards A, B, C and D, following properties were determined:

- thickness and density (EN 323:1996): 50×50 mm^2, 6 samples
- moisture content (EN 322:1996): 50×50 mm^2, 4 samples
- thickness swelling (EN 317:1996): 50×50 mm^2, 8 samples
- internal bond (EN 319:1996): 50×50 mm^2, 8 samples
- bending strength and modulus of elasticity at bending (EN 310: 1996): 370×50 mm^2, 6 samples

At boards E, F, G and H density and thermal conductivity were determined. Thermal conductivity was determined at three different temperature settings:

- Setting 1: ΔT=10 K
- Setting 2: ΔT=20 K
- Setting 3: ΔT=30 K

The determination of thermal conductivity was conducted in accordance to EN 12667:2001 standard.

Size analysis of wood and bark particles was conducted by sieve analysis, where 100 g of particles were shaked for 10 minutes.

To assess the impact of used material we also determined their pH value. The pH value of particles was determined by Subramanian's method. Owen dried particles (25 g) were placed into 800 mL beaker with 250 g of distilled water and left in water for 4 minutes (hot water extraction) or for 24 hours(cold water extraction). The solution was then filtered, followed by the determination of filtrate's pH value.

3. RESULTS AND DISCUSSION

The differences between wood and bark were visible already at particles breakdown (figure 1), what was later also determined by sieve analysis (figure 2).

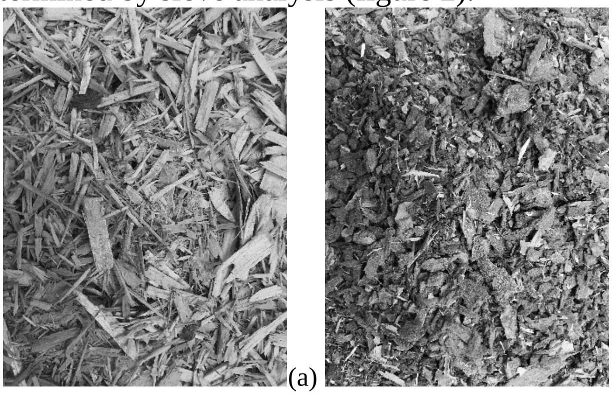
(a)

Figure 1. Wood (a) and bark (b) particles

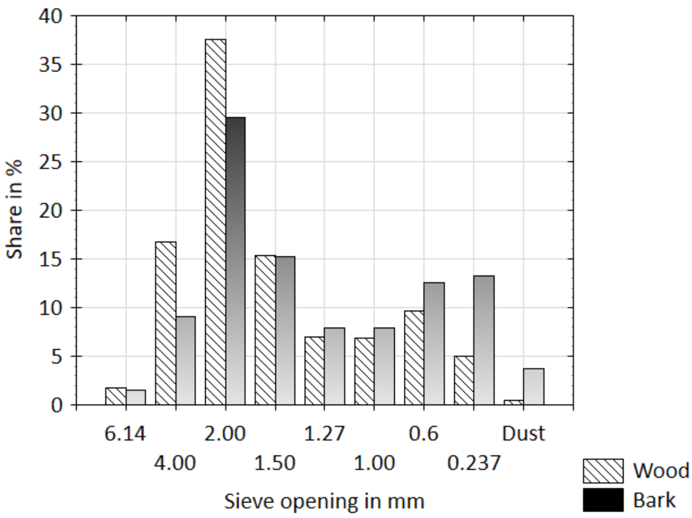

Figure 2. Sieve analysis of wood and bark particles

Breakdown of bark chips resulted in higher share of fines and mid-size particles (particles remaining on sieves with opening 1.27 mm and lower), while breakdown of wood resulted in higher share of mid-size particles and coarser particles (particles remaining on sieves with opening 1.5 mm and higher). According to some reports the negative impact on mechanical properties is on one side the consequence of differences in particle size and on other side also on the differences in chemical composition. The analysis of pH value determined by hot- and cold-water extraction showed higher pH value for wood (table 3).

Table 3. Wood and bark pH value

	Hot water extraction (4 minutes)	Cold water extraction (24 hours)
Wood	7.60	6.98
Bark	6.48	6.74

Difference in the pH value determined by hot water extraction is higher in comparison to cold water extraction.

The differences in thickness and density, regarding the share of bark were small or not significant (at α=0.05), while moisture content of boards with 20 % and 50 % bark was higher (table 4).

Table 4. Thickness, density and moisture content regarding the bark share (values in bracket presents the standard deviation values)

	Bark share	Thickness [mm]	Density [g·cm^{-3}]	Moisture content [%]
A	0 %	16.27 (0.136)	0.622 (0.066)	5,49 (0.068)
B	10 %	16.12 (0.121)	0.656 (0.034)	5.75 (0.059)
C	20 %	16.23 (0.099)	0.661 (0.045)	6.96 (0.160)
D	50 %	16.03 (0.074)	0.687 (0.034)	7.02 (0.195)

The impact of the bark presence in particleboard was visible at internal bond (figure 3), bending strength (figure 4) and modulus of elasticity (figure 5).

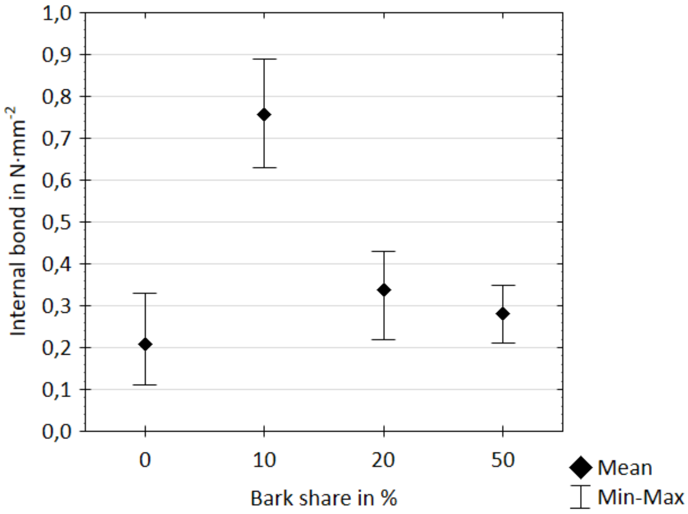

Figure 3. Internal bond strength with regard to bark share

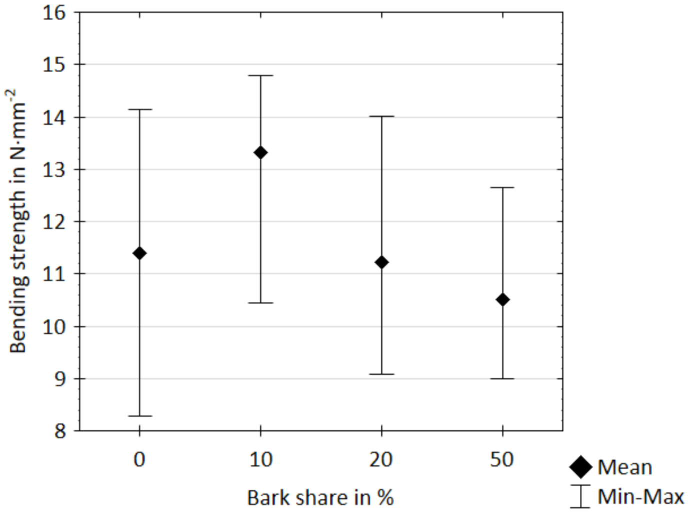

Figure 4. Bending strength with regard to bark share

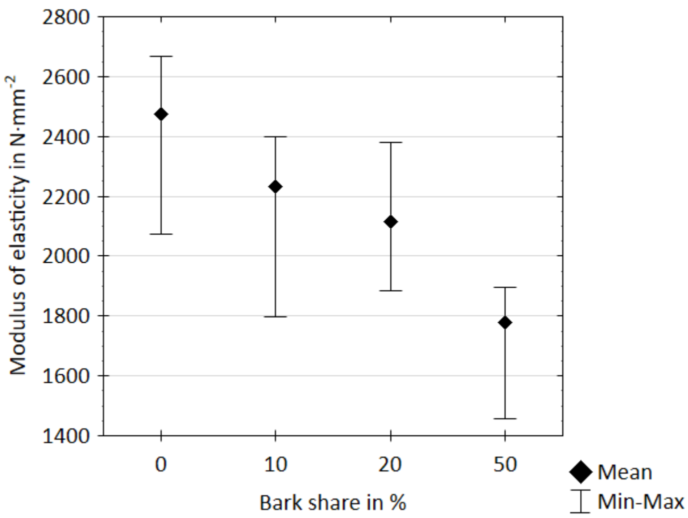

Figure 5. Modulus of elasticity with regard to bark share

In case of boards made with bark the internal bond strength was higher than it was determined for reference board (board "A", bark share 0 %), while for bending strength and modulus of elasticity the response of bark presence in board was different. For bending strength only the board "B" gave higher bending strength than the reference board, while modulus of elasticity for all boards with bark was lower.

Considering the particleboards strength related results in relation towards bark share, the effect of bark is ambiguous, especially when considering internal bond and bending strength. The results of internal bond strength indicate that bark particles help in creation of strong and stable bond, but the results of bending strength support above statement only for board "B", with 10 % bark share. To clarify this behaviour, we must investigate particle size and geometry differences. When substituting wood with bark particles, higher share of fines and mid-size particles (particles remaining on sieves with opening 1.27 mm and lower) are introduced into board composition. At smaller amount of substitution (10 %, board "B") those smaller bark particles acts as filler between particles (filling the voids), hence enabling better connection between particles, what was also determined by Yemele *et al.* (2008) and Marashdeh *et al.* (2011). Second reason for higher bond strength could also be related to chemical structure of bark and its activation during exposure to high temperature (during hot pressing). Polyphenolic components and tannins in bark reacts with formaldehyde hence helping in creation of more stable bond between particles. Comparing the results of boards with bark ("B", "C" and "D"), then the strength decrease with increasing bark share is determined. A strength decrease could be the consequence of lower bonding ability of bark (Blanchet *et al.*, 2000) lower thermal conductivity (decreased heat transfer rate) and in lower pH value. Formaldehyde based resin curing rate depends on the environment pH value, and if pH value is low (as in case of higher bark share could occur), than precuring of resin could occur, hence lower bond quality (Nemli *et al.*, 2004).

As results show, the highest bond strength and also bending strength was determined at board with 10 % bark, while at board with 20 % and 50 % bark the bond strength and bending strength was lower. High bond quality at board "B" and better strength properties could be related to the differences in share of fines in board. Since bark has higher share of fines (figure 1 and figure 2), those fine particles can fill the void(s) between particles, hence enabling better connection between particles.

Although higher bond strength of boards with bark (compared to reference board) was determined, results of bending strength and modulus of elasticity presents different relation. The difference in bending strength between reference board and board with 10 % bark (board "B", highest bending strength) was lower, and boards "C" and "D" (bark share 20 % and 50 %) had lower bending strength than reference board. Main reason for such behaviour is related to decreased amount of fibrous constituents and les appropriate particle geometry, especially in length and thickness ratio (slenderness ratio). In order to achieve good bending strength value and modulus of elasticity, particle needs to have higher slenderness ratio, while bark particles have low slenderness ratio.

Despite the fact that Muszynski and McNatt (1984), Blanchet *et al.* (2000); Nemli and Çolakoğlu (2005), Yemele *et al.* (2008) as well as Medved *et al.* (2019) determined that thicknesss swelling increases with increasing the bark share, the results presented in figure 5 show different behaviour.

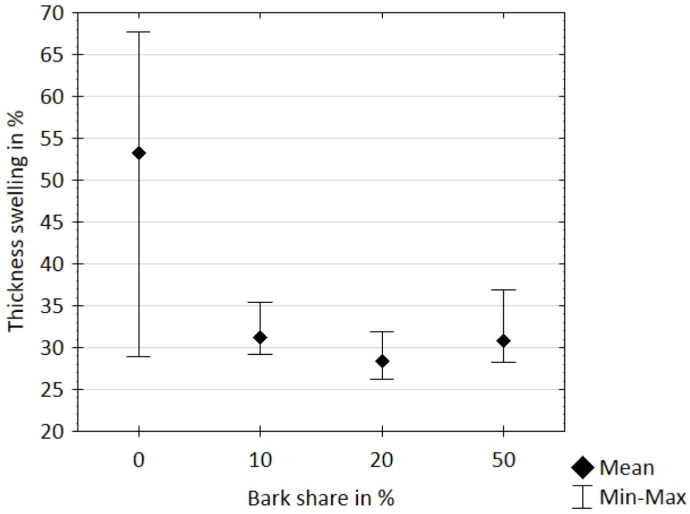

Figure 6. Thickness swelling after 24–hour immersion with regard to bark share

Swelling of boards with bark is lower compared to board composed only from wood particles.

Our second expermient, where boards with density between 0.5 g·cm^{-3} and 0.56 g·cm^{-3}, showed that particleboards made with bark had lower thermal conductivity (figure 6).

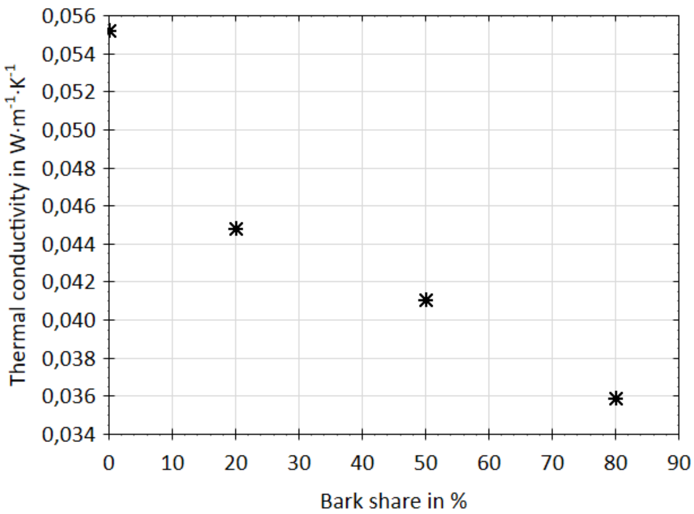

Figure 7. Thermal conductivity with regard to bark share

Thermal conductivity of board made with bark particless was significantly lower compared to board made from wood particles only. The decrease in thermal conductivity is due to the porous structure (high share of cell cavities) of bark.

4. CONCLUSIONS

The results of presented research showed that it is possible to use bark as a raw material source for particleboard production.

At boards, with target density 0.65 g·cm^{-3}, where 10 % of wood particles was substituted by bark particles internal bond and bending strength was higher, compared to bord made only from wood particles. Higher bark share (20 % and 50 %) resulted in lower internal bond and bending strength. Modulus of elasticity decreases with increasing bark share.

Thermal conductivity of single layer particleboards (target density 0.5 g·cm^{-3}) decreases with increasing bark share.

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Analysis of Wood Industry Employment Trends in Croatia and Macedonia Since 2011

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ABSTRACT

This article presents an analysis of the current situation in the Croatian and Macedonian woodworking sector on the basis of established values of labour resources in Wood processing and Furniture manufacturing for both countries in period 2011-2018. According to Croatian and Macedonian Standard Classification of Occupations for sectors Wood processing and Furniture manufacturing, the data of the number of employees are gathered from Croatian and Macedonian Bureau of Statistics. The dynamic economic analysis of time series data was performed and time series models for predicting the future employment trends for both countries were built. Prediction is limited to year 2023 because of the length of analysed time series data.

Key words: wood processing, furniture manufacturing, employment, trend, time series model

1. INTRODUCTION

Intense competition, which comes as a result of globalization leads us to the necessity of looking at the current market situation, in order to predict the situation in the future. Interpreting economic data and forecasting the future economic values are under the influence of environment and government policies, starting from the basic economic theories that operate in the market (Fair and Case, 1989). The key to survival and growth in the market is in organization's ability to adapt its strategy to the rapidly changing environment (Kotler, 2001). According to Samuelson and Nordhaus (2003), economic theories are dynamic by nature and now we are witnessing almost everydays changes that are caused by the penetration of IT and computer science revolution. In this new and dynamic conditions it is necessary to strive for a new standards using economic theory for the qualitative and quantitative analysis of markets.

The European Union has committed to the principle of sustainable development as its policies and actions, based on balanced economic growth, price range of stability, strengthening the internal market, research and development, innovation, education, competitive social market economy and a high level of protection and improvement of environmental quality (Lučić, 2009). According to Lovrinčević (2001), specific developments in some key macroeconomic variables, such as employment, production, imports, exports, the exchange rate of national currency, etc., characterize different turbulent periods of Croatian history. The last statement is also valid for all the countries of former Yugoslavia which shared a together marked for almost 50 years. In many European countries the sectors for Wood processing and Furniture manufacturing takes an important share in whole manufacturing sector, which is also reflected in the number of employees in the woodworking area.

This article offers a focus on the two main wood industry subsectors of Wood processing and Furniture manufacturing in Croatia and Macedonia, also a position of subsectors according to total number of employees in manufacturing sector, as well as comparison with the total number of employees in whole wood industry, on the basis of established values in the period 2011 - 2018. The territory of Croatia covers 56594 square kilometres which is 2.2 times more than 25713 square kilometres of Macedonian territory. According to the 2011 census, there were 4298889 inhabitants in Croatia (76/km2), while in Macedonia, according to the 2017 data, there were 2075301 inhabitants (81/km2), and according to these data the population ratio of Croatia and Macedonia is 2.1. The ratio of average income per capita is 1.7 (income 27664$ in Croatia vs. income 16253$ in Macedonia).

The prediction of number of employees for both countries is limited to the year 2023, because of turbulences in this market, and the length of analysed time series data. It is known that future projections of development can not predict the detail movement of market indicators, such is the number of employees. They are only a rough indication of the future course, assuming that the macroeconomic policies won't change significantly (Hanke and Reitsch, 2001). According to Rozga and Grčić (2002), by using models we got a picture of what happened in the (near) past, what is the current situation, and planned and future course of events, i.e. the movement of an employment indicator in the near future.

2. MATERIAL AND METHODS

The base of these research are data of the number of employees according to Croatian and Macedonian Standard Classification of Occupations and they are gathered from Croatian and Macedonian Bureau of Statistics. Database include the number of employees in Croatia and Macedonia for period 2011-2018 for Manufacturing sector (M) and Wood Industry sector (W), as well as the number of employees in two main wood industry subsectors: Wood processing (P) and Furniture manufacturing (F). Abbreviations for variable names are shown in legend in Table 1., and data gathered for these analysis are shown in Table 2.

Table 1. Legend for analysed variables

Variable	Number of employees according to	Croatia (1)	Macedonia (2)
M	**Manufacturing**	M1	M2
W	**Wood industry (P+F)**	W1	W2
P	**Wood Processing Sector**	P1	P2
F	**Furniture Manufacturing Sector**	F1	F2

Table 2. Number of employees in Croatia and Macedonia for period 2011-2018

Year	Croatia				Macedonia			
	M1	**W1**	**P1**	**F1**	**M2**	**W2**	**P2**	**F2**
2011	214302	20196	10839	9357	100878	5762	2349	3413
2012	207298	19959	11072	8887	101132	5760	2253	3507
2013	201950	19519	11072	8447	104214	5861	2257	3604
2014	198069	19964	11521	8443	111559	5924	2096	3828
2015	210072	21103	12501	8602	111208	5976	1920	4056
2016	208375	21802	12858	8944	111402	6270	1992	4278
2017	213019	22595	13379	9216	115614	6365	1935	4430
2018	213286	23092	13765	9327	124359	7046	2242	4804

Analysis of the number of employees in Croatia and Macedonia started with descriptive statistics which include the measures of central tendency: Minimum, Median, Mean and Maximum, followed by the measures of variability: Standard Deviation (*St.Dev.*), lower and upper limit of 95 % confidence interval (*C.L -95 %, C.L.+95 %*) and coefficient of variation (*Coef.V.*). Last three measures of variability are calculated by the formulas:

$$C.L.-95\% = Mean - t_{\alpha/2}\left(k\right)\cdot\frac{St.Dev.}{\sqrt{n}} \tag{1}$$

$$C.L.+95\% = Mean + t_{\alpha/2}\left(k\right)\cdot\frac{St.Dev.}{\sqrt{n}} \tag{2}$$

$$Coef.V. = \frac{St.Dev.}{Mean}\cdot 100\% \tag{3}$$

n – sample size
$t_{\alpha/2}\left(k\right)$ – critical values of Student's t-distribution
k – degrees of freedom ($k = n-1$)
α – level of statistical significance

The confidence interval was calculated according to 5 % significance level. Specifically, for these calculations, because of sample size, we used $t_{0.025}\left(7\right) = 2.365$.

Next step of analysis include the calculations of shares of the number of employees in wood industry sectors according to total number of employees in manufacturing for both countries, also a shares of the number of employees in two subsectors according to total number of employees in wood industry, followed by the calculations of ratios of these shares.

Comparison of the number of employees in Croatia and Macedonia followed by calculation of basic indices for all variables, and are presented with a common reference year, currently year 2011 = index 100. Also we calculate the chain indices for all variables.

For the purposes of forecasting the future trends in number of employees per year in the wood industry sectors and subsectors in Croatia and Macedonia, the dynamic economic analysis of time series data was performed and prediction models were built. Models for prediction a number of employees until the year 2023 are based on Average Rate of change (*Av.Rate*), which are calculated by the formula:

$$Av.Rate = \left(\sqrt[n-1]{\frac{I_n}{I_1}} - 1\right)\cdot 100 \tag{4}$$

n – sample size
I_1 – basic index in the first year of analysed period
I_n – basic index in the last year of analysed period

3. RESULTS AND DISCUSSION

In the analysed period 2011-2018, average number of manufacturing employees in Croatia (M1) is 208069, as opposed to 110046 in Macedonia (M2). The average ratio of number of employees in manufacturing in Croatia with number of manufacturing employees in Macedonia (M1/M2) is 1.9 since 2011, which slightly corresponds to the average per capita income ratio (1.7). The results of descriptive statistics for all variables included in this analysis are given in Table 3.

Table 3. Descriptive statistics for analysed variables

Variable	Valid N	Minimum	Mean	Median	Maximum	Std.Dev.	C.L.-95%	C.L.+95%	Coef.V.
M1	8	198069	208296	209224	214302	5761	203480	213112	2.77
M2	8	100878	110046	111305	124359	7918	103426	116665	7.20
W1	8	19519	21029	20650	23092	1340	19909	22149	6.37
W2	8	5760	6121	5950	7046	435	5757	6484	7.11
P1	8	10839	12126	12011	13765	1145	11169	13083	9.44
P2	8	1920	2131	2169	2349	167	1991	2270	7.82
F1	8	8443	8903	8916	9357	377	8588	9218	4.24
F2	8	3413	3990	3942	4804	491	3580	4400	12.30
M1/M2	8	1.72	1.90	1.88	2.12	0.14	1.79	2.01	7.12
W1/W2	8	3.28	3.44	3.47	3.55	0.10	3.35	3.52	2.91
P1/P2	8	4.61	5.74	5.82	6.91	0.87	5.01	6.47	15.22
F1/F2	8	1.94	2.26	2.16	2.74	0.27	2.03	2.48	11.82

The most interesting thing we can see from the table above is that for the analyzed period 2011 - 2018 we found the statistically significant differences between Croatia and Macedonia in average ratios W1/W2 (3.4) and P1/P2 (5.7), while the average ratio F1/F2 (2.3) corresponds to the average population (2.1) and territory (2.2) ratio.

Position of Croatian and Macedonian wood sectors (W1, W2) and subsectors (P1, F1 and P2, F2) according to number of employees is visible in comparison with total number of employees in Manufacturing for both countries (M1, M2). Comparison of Croatia and Macedonia is also visible through the ratio of shares in whole wood sector (Wc/m), the ratio of shares in Wood Processing sector (Pc/m), and the ratio of shares in Furniture Manufacturing sector (Fc/m). The results of these analysis are given in Table 4.

From Table 5. we can see that for the analysed period 2011 - 2018 the average ratio of shares for number of employees in Wood Processing compared to Furniture manufacturing is 58:42 in Croatia, as opposed to 35:65 in Macedonia. Looking at the average rate of change, the most significant seems the negative rate for share of employees in Croatian Furniture Manufacturing (-1.94 %) and negative rate for share of employees in Macedonian Wood Processing (-3.48 %).

Table 4. Shares of analysed variables W, P and F according to M

Year	Croatia			Macedonia			Croatia vs. Macedonia		
	Shares according to M1 (%)			Shares according to M2 (%)			Ratio of shares c/m		
	W1/M1	P1/M1	F1/M1	W2/M2	P2/M2	F2/M2	Wc/m	Pc/m	Fc/m
2011	9.42	5.06	4.37	5.71	2.33	3.38	1.65	2.17	1.29
2012	9.63	5.34	4.29	5.70	2.23	3.47	1.69	2.40	1.24
2013	9.67	5.48	4.18	5.62	2.17	3.46	1.72	2.53	1.21
2014	10.08	5.82	4.26	5.31	1.88	3.43	1.90	3.10	1.24
2015	10.05	5.95	4.09	5.37	1.73	3.65	1.87	3.45	1.12
2016	10.46	6.17	4.29	5.63	1.79	3.84	1.86	3.45	1.12
2017	10.61	6.28	4.33	5.51	1.67	3.83	1.93	3.75	1.13
2018	10.83	6.45	4.37	5.67	1.80	3.86	1.91	3.58	1.13
Mean	10.09	5.82	4.27	5.56	1.95	3.62	1.82	3.05	1.19
Std.Dev.	0.51	0.49	0.09	0.15	0.25	0.20	0.11	0.60	0.07
Av.Rate	2.00	3.54	0.02	-0.12	-3.59	1.91	2.12	7.40	-1.85

From table above we can see that for the analysed period 2011 - 2018 the average share of employees in wood industry compared to the total number of employees in Manufacturing sector was 10.1 % in Croatia (W1/M1) and 5.6 % in Macedonia (W2/M2), which lead us to ratio of shares 1.8 (Wc/m). Ratio of shares for number of employees in Wood Processing is 3.1 (Pc/m), as opposed to 1.2 for number of employees in Furniture Manufacturing (Fc/m). In the same time the average rate of change was positive for all analized shares and ratios, except for shares in Macedonia W2/M2 (-0.12 %), P2/M2 (-3.59 %) and ratio Fc/m (-1.85 %).

Position of Croatian and Macedonian wood subsectors (P1, F1 and P2, F2) according to number of employees is also visible in comparison with total number of employees in Wood industry for both countries (W1, W2). Comparison of Croatia and Macedonia is also visible through the ratio of shares in Wood Processing sector (Pc/m), and the ratio of shares in Furniture Manufacturing sector (Fc/m).The results of these analysis are given in Table 5.

Table 5. Shares of analysed variables P and F according to W

Year	Croatia		Macedonia		Croatia vs. Macedonia	
	Shares according to W1 (%)		Shares according to W2 (%)		Ratio of shares c/m	
	P1/W1	F1/W1	P2/W2	F2/W2	Pc/m	Fc/m
2011	53.67	46.33	40.77	59.23	1.32	0.78
2012	55.47	44.53	39.11	60.89	1.42	0.73
2013	56.72	43.28	38.51	61.49	1.47	0.70
2014	57.71	42.29	35.38	64.62	1.63	0.65
2015	59.24	40.76	32.13	67.87	1.84	0.60
2016	58.98	41.02	31.77	68.23	1.86	0.60
2017	59.21	40.79	30.40	69.60	1.95	0.59
2018	59.61	40.39	31.82	68.18	1.87	0.59
Mean	57.58	42.42	34.99	65.01	1.67	0.66
Std.Dev	2.14	2.14	4.01	4.01	0.24	0.07
Av.Rate	1.51	-1.94	-3.48	2.03	5.17	-3.89

Comparison of the number of employees in Croatia and Macedonia is followed by calculation of chain indices for all variables. Coasting in the number of employees through the analysed period 2011-2018 in the Croatian Wood Industry are shown by the chain indices in Figure 1., as opposed to Macedonian in Figure 2.

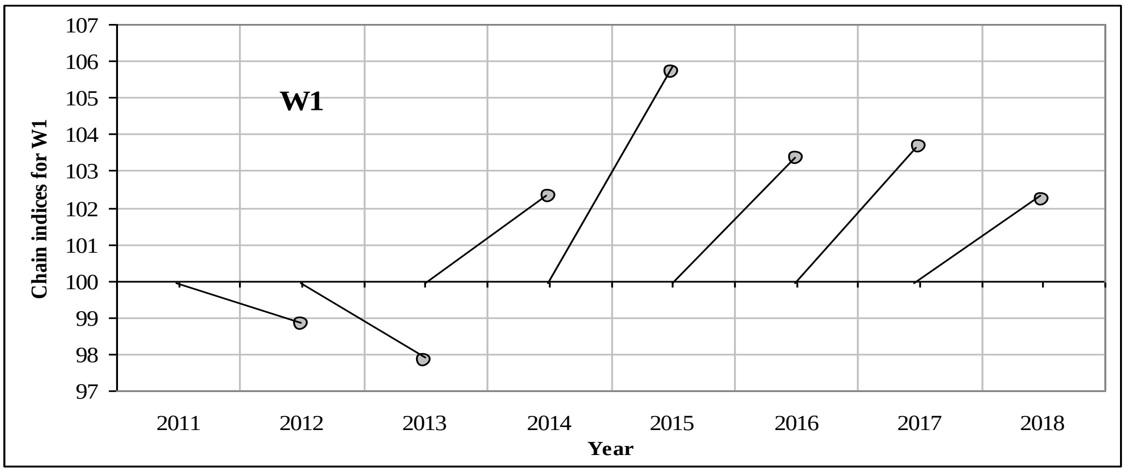

Figure 1. Chain indices for number of employees in Croatian Wood Industry

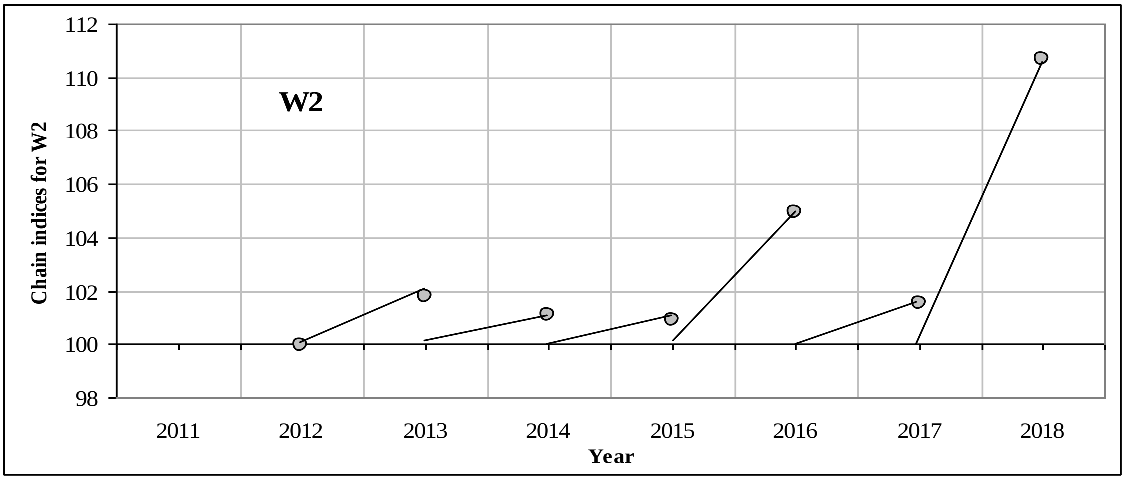

Figure 2. Chain indices for number of employees in Macedonian Wood Industry

As we can see from Figure 1., the biggest change in the number of employees in Croatian Wood Industry happened in year 2015 when we found increase of 5.7 % in regards to year 2014. From Figure 2. is obviously that the biggest change in the number of employees in Macedonian Wood Industry happened in year 2018 with increase of 10.7 % regards to year 2017. Chain indices for all variables are shown in Table 6.

Table 6. Chain indices for all analysed variables

Year	Manufacturing		Wood industry (P+F)		Wood Processing		Furniture Manufacturing	
	M1	M2	W1	W2	P1	P2	F1	F2
2011	-	-	-	-	-	-	-	-
2012	96.7	100.3	98.8	100.0	102.1	95.9	95.0	102.8
2013	97.4	103.0	97.8	101.8	100.0	100.2	95.0	102.8
2014	98.1	107.0	102.3	101.1	104.1	92.9	100.0	106.2
2015	106.1	99.7	105.7	100.9	108.5	91.6	101.9	106.0
2016	99.2	100.2	103.3	104.9	102.9	103.8	104.0	105.5
2017	102.2	103.8	103.6	101.5	104.1	97.1	103.0	103.6
2018	100.1	107.6	102.2	110.7	102.9	115.9	101.2	108.4

The basic indices for period 2011 -2018 for all variables are presented with a common reference year, currently year 2011 = index 100. Comparison of the basic indices for number of employees in Croatian and Macedonian Wood Processing sector are shown in Figure 3., comparison of the basic indices for number of employees in Furniture Manufacturing sector are shown in Figure 4., then follows Table 7. with the comparison of the basic indices for rest of analysed variables (M1, M2, W1, W2), also with associated average rates of change.

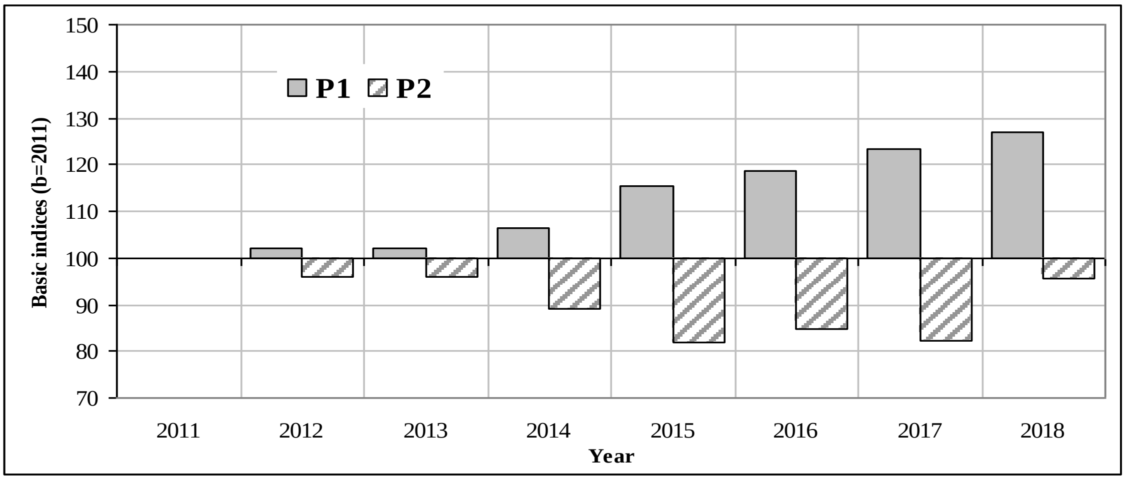

Figure 3. Comparison of the basic indices for variables P1 and P2

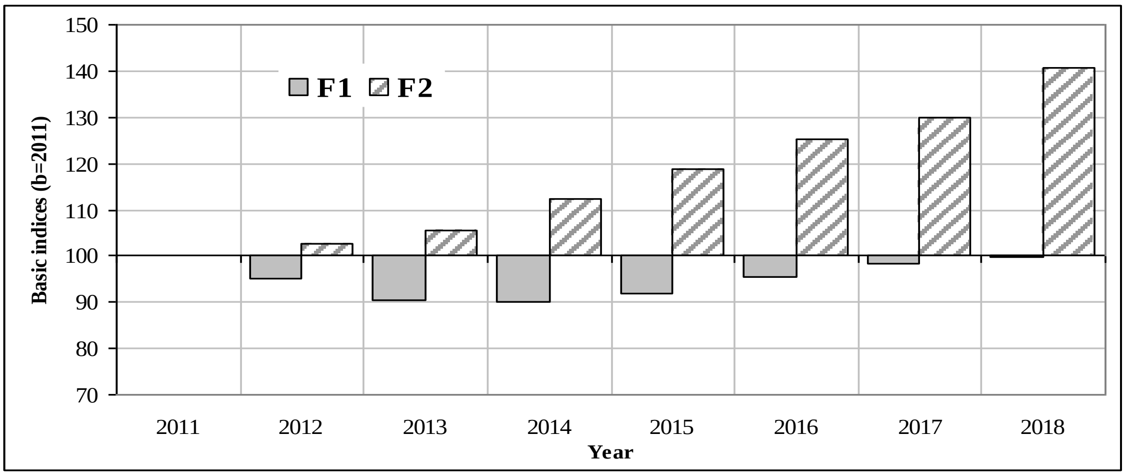

Figure 4. Comparison of the basic indices for variables F1 and F2

Table 7. Basic indices for variables M1, M2, W1, W2 (b=2011)

Year	Manufacturing		Wood industry (P+F)	
	M1	M2	W1	W2
2011	100.0	100.0	100.0	100.0
2012	96.7	100.3	98.8	100.0
2013	94.2	103.3	96.6	101.7
2014	92.4	110.6	98.9	102.8
2015	98.0	110.2	104.5	103.7
2016	97.2	110.4	108.0	108.8
2017	99.4	114.6	111.9	110.5
2018	99.5	123.3	114.3	122.3
Av.Rate	-0.068	3.035	1.933	2.916

Overall, since year 2011, we notice an increase in the number of employees in both the Croatian (1.9 %) and Macedonian (2.9 %) Wood industries. In Croatia, number of employees in Wood Processing is growing with average rate of 3.5 %, while the sector of Furniture Manufacturing has slightly negative rate of -0.05 %. Completely opposite situation in Macedonia, number of employees in Wood Processing is falling with average rate of -0.7 %, while the sector of Furniture Manufacturing has very high positive rate of 5 %.

Based on the average rates of change for all variables in the observed period (except M1 and M2), models for prediction the future values of the number of employees in Croatian and Macedonian wood sector and subsectors were developed (marked with * next to abbreviation of variable):

$$W1^*(t) = 1.01933^{t-1} \cdot 20196 \tag{4}$$

$$W2^*(t) = 1.02916^{t-1} \cdot 5762 \tag{5}$$

$$P1^*(t) = 1.03473^{t-1} \cdot 10839 \tag{6}$$

$$P2^*(t) = 0.99336^{t-1} \cdot 2349 \tag{7}$$

$$F1^*(t) = 0.99954^{t-1} \cdot 9357 \tag{8}$$

$$F2^*(t) = 1.05005^{t-1} \cdot 3413 \tag{9}$$

Because of bad fitting with original data, only for variable F1 we extra developed two regression models F1** (R^2=0.9748) and F2*** (R^2=0.8463):

$$F1^{**}(t) = -14.674 \cdot t^3 + 266.51 \cdot t^2 - 1334.7 \cdot t + 10490 \quad (10)$$

$$F1^{***}(t) = 68.411 \cdot t^2 - 578.97 \cdot t + 9763.8 \quad (11)$$

In all models *t* represent the mark for observed year, where *t=1* refers to year 2011, *t=2* refers to year 2012, etc., *t=13* refers to year 2023.

Existing and predicted values for the number of employees in wood industry of Croatia and Macedonia, also for two main subsectors, are graphically compared in Figures 5.-7., followed by calculated predicted values for the number of employees in period 2019-2023, which are shown in Table 8.

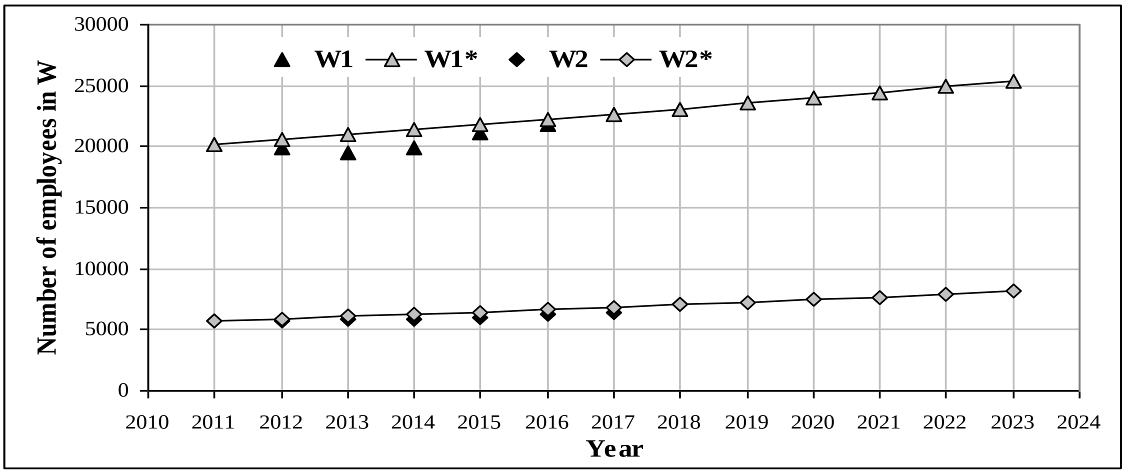

Figure 5. Comparison of existing and predicted values for W1 and W2

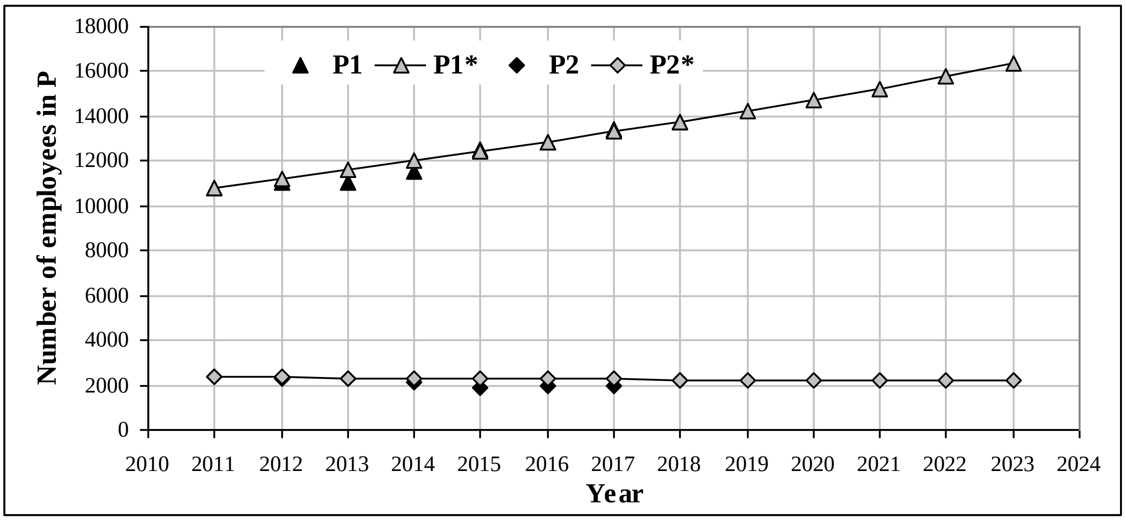

Figure 6. Comparison of existing and predicted values for P1 and P2

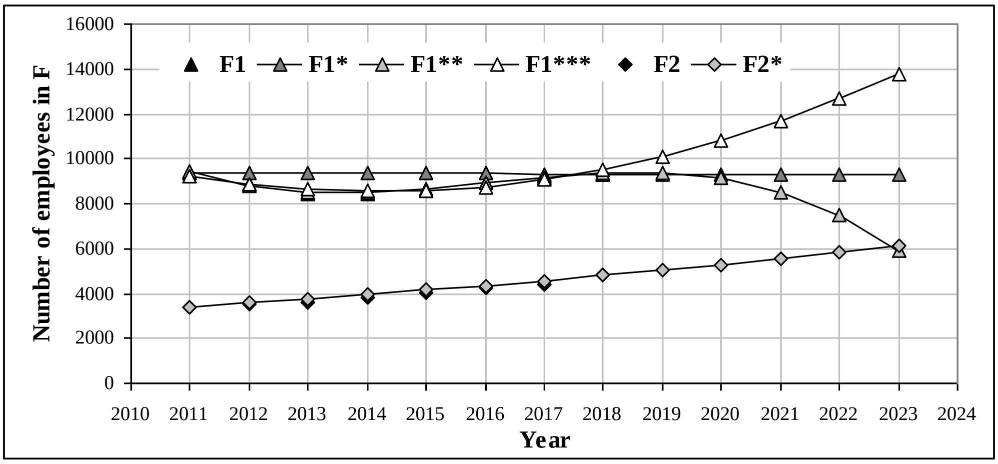

Figure 7. Comparison of existing and predicted values for F1 and F2

Table 8. Predicted values for number of employees in period 2019-2023

Year	Wood industry (P+F)		Wood Processing (P)		Furniture Manufacturing (F)			
	W1*	W2*	P1*	P2*	F1*	F1**	F1***	F2*
2019	23538	7251	14243	2227	9323	9368	10094	5044
2020	23993	7463	14738	2212	9318	9120	10815	5297
2021	24457	7680	15250	2198	9314	8525	11673	5562
2022	24930	7904	15779	2183	9310	7494	12667	5840
2023	25411	8135	16327	2169	9306	5940	13799	6133

4. CONCLUSION

For the analysed period 2011 - 2018 the average ratio of shares for number of employees in Wood Processing compared to Furniture manufacturing is 58:42 in Croatia (P1:F1), as opposed to 35:65 in Macedonia (P2:F2). According to developed models, it is estimated that the number of employees in Wood Industry by year 2023 will exceed 25 thousand in Croatia, and over 8 thousand in Macedonia. In the same time, it is estimated that the number of employees in Croatian Wood Processing will exceed 16 thousand, while for sector of Furniture Manufacturing we offered a three different scenario. Also we estimated that the number of employees in Macedonian Wood Processing will fall very slightly, strive to 2 thousand, while for sector of Furniture Manufacturing we estimated growth over 6 thousand employees by year 2023.

Assuming that the macroeconomic policies will not be changed, and assuming that the constructed models for predicting the number of employees satisfy all statistical and theoretical terms, the results of these research could become a great help for a future actions in woodworking sectors of Croatia and Macedonia.

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Quality Management in Specific Areas of Woodworking and Furniture Industry

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ABSTRACT

Contribution Quality management in specific areas of the woodworking and furniture industry will focus on the most important requirements of quality management in this area. Ensuring, improving and controlling the quality management system is an important prerequisite for the competitiveness and efficiency of small and medium-sized enterprises. The starting point of our contribution is the opinion of the European Economic and Social Committee on opportunities and challenges for a more competitive European woodworking and furniture industry - conclusions and recommendations.

Key words: quality management, woodworking, furniture industry, competitiveness

1. INTRODUCTION

The woodworking industry in the Slovak Republic has a specific position within the national economy and consists of sectors such as wood, furniture and pulp and paper industry. It is relatively independent of the import of raw materials inputs and is continuously able to generate an active foreign trade balance. The furniture industry is a sector that follows the initial woodworking by mechanical means and achieves a high degree of finalization for wooden products. A common feature for the woodworking industry and its sectors is the processing of raw timber and the production of timber products with various stages of finalization. The woodworking industry accounts for ca. up to 10 % of total revenues of the Slovak industry. All three sectors of the woodworking industry could be characterized as follows:

- Independent of imported raw materials;
- The large share of SMEs (where more than 80 % of companies are limited financially);
- High export performance compared to other sectors in the industry;
- The low purchasing power of the Slovak population;
- Low economic strength and high indebtedness;
- Lack of working force;
- Insufficient business activities pursued by companies in this sector;
- Lack of promotion of timber and timber products;
- The need to certify forests;
- Foreign capital investments...

(Ministry of Economy of the Slovak Republic, 2019).

In total there are 235 production companies of the woodworking industry with 20 and more employees statistically registered in Slovak Republic, employing more than 32 thousand workers. At the same time, there exist ca. 700 small business entities and several thousand self-employed individuals mainly in the area of timber and furniture production. Their performance is estimated at ca. 15 % of the total production of goods in woodworking industry.

The furniture industry can be described as an industry with a relatively high financial turnover. It is assumed that 10-15 % of furniture was produced by a small business and was predominantly placed on the domestic market, respectively was a part of provided services. However, in order for furniture industry to remain competitive, there is required an urgent mechanical and technological innovation in this environment. The development of the furniture industry is also largely dependent on how quickly and efficiently businesses can adapt to current trends in developed countries. Therefore, the implementation of quality management systems is an important part. Quality management is primarily focused on streamlining activities that accept customers' requirements and the process of continuous improvement and process management is a guarantee of better competitiveness. Therefore, organizations operating in the woodworking and furniture industry are also changing their way of production from a warehouse to custom made products. Here, the main accent on a specific approach to specific customer requirements begins to resonate. It is essential for SMEs in the woodworking and furniture industry to be able to adapt early to these specific requirements and be able to implement them. In mass production it is a bit more difficult to meet the specific requirements of customers and therefore individualization manifests itself mainly in the production:

- Standard products with customer-specific variants
- Standard products with specific supply variants.

It should not be forgotten that individual requirements are coming from e.g. tradition, culture, available information, and last but not least, the price a customer is willing to pay for a product plays a big role. Currently, environmental aspects are also strongly emphasized, and it is more often necessary to demonstrate in ISO 14 000 certifications.

One of the possibilities of how to ensure its own competitiveness in the European space is to secure activities through so-called Green Action Plan (GAP).

2. GREEN ACTION PLAN FOR SMES

Small and medium-sized enterprises are the economic backbone of the European Union. Numbering more than 20 million, these companies represent 99 % of European businesses and account for more than two-thirds of employment. As well as being economically important, SMEs are also environmentally important: although their individual impact is small their cumulative impact on the environment is significant. Although environmental policy can create challenges for SMEs, it also provides business opportunities. By increasing resource efficiency, providing circular economy solutions and participating in green markets, European SMEs can generate employment and growth as well as boost their productivity and competitiveness.

No coincidence, the European Organization for Quality called its congress in Helsinki in 2016 – „ Quality enables Growth and Competitiveness ".

Almost all European SMEs are taking some action to be more resource-efficient. The Green Action Plan (GAP) aims to help small and medium-sized enterprises (SMEs) take advantage of the opportunities offered by the transition to a green economy. It presents ways for SMEs to turn environmental challenges into business opportunities.

2.1. Objectives of the GAP

- To raise SMEs awareness of resource efficiency improvements and the potential of the circular economy for productivity, competitiveness and business opportunities;
- To inform SMEs about EU resource efficiency actions under the COSME, Horizon 2020 and LIFE programmes, and the European Structural and Investment Funds.

2.2. The GAP aims to help businesses by

- Improving productivity;
- Driving down costs;
- Supporting green entrepreneurship;
- Developing European leadership in green processes and technologies.

2.3. Emerging business opportunities in a green economy

- Greening SMEs;
- Green entrepreneurship;
- Opportunities for SMEs in a greener value chain;
- Access to markets for green SMEs;

(European Commission, 2019).

Small businesses often lack the knowledge of how they can achieve competitive advantages by investing in eco-efficient practices. The innovative potential of SMEs is at the center of regional interest and adding value can also bring the regional Smart Specialization strategies, regional cluster policies and support measures such as innovation vouchers and support of business R&D projects, as well as collaboration projects between businesses and research facilities.

In October 2011, the European Economic and Social Committee (EESC) adopted an opinion entitled "Opportunities and challenges for a more competitive European woodworking and furniture sector". This opinion is in accordance with the announcement of the European Commission "Towards a circular economy: A zero waste programme for Europe". There is declared so-called principle of the cascading use (recover, reuse, recycle, energy recovery) which it is feasible from an economic and technical point of view and is in accordance with national and regional specificities then it is the optimal way how to use the wood most efficiently. These requirements are also reflected in the document "A new EU forest strategy for forests and wood-processing industry". The European Economic and Social Committee (EESC) is rather against the introduction of legally binding rules, while promotes more open, market-oriented access and the freedom of market participants. At the same time, it encourages the European Commission to draw up guidelines and recommendations for the collection of wood waste and to propose procedures for the treatment of recycled wood in the near future. Meantime, it calls on the European Commission to introduce a standard for the use of wood as insulation material and to draw up national action plans aimed at diffusion of the wood used in construction and environmental infrastructure. Local authorities and organizations should be directly involved in the implementation of these action plans. A very good example of practice is e.g. Italian group Saviola (famous for its slogan "Help us save trees"), which is the world's leading processor of wood waste. Its recycling capacity is 1.5 million tonnes of recycled wood per year. Their production philosophy is based on the recovery and reuse of secondary materials (European Economic and Social Committee, 2015).

3. QUALITY MANAGEMENT IN SPECIFIC AREAS OF WOODWORKING AND FURNITURE INDUSTRY

The requirements for the implementation of quality management systems in the woodworking and furniture industry organizations are based on EU regulations. The main advantages of the implementation are in particular:

- Increasing the company's credibility;
- Increasing the level of management and implementation processes;
- Reducing the number of disagreements and complaints of customers and employees which results in reducing the overall costs;
- Responsibilities and competencies are clearly defined at the level of corporate governance;
- Increasing competitiveness;
- Improving the quality and efficiency of the products provided.

Based on a questionnaire survey (Gejdoš, 2016) conducted on a sample of 545 companies (the ratio of 64 % companies from the Slovak Republic and 36 % of companies from the Czech Republic) of the woodworking industry, the following results were found:

- In Slovakia, the quality management system in place has 73 % of the respondents;
- The most common reason for the introduction of a quality management system is to gain competitive advantages and obtain better sales orders;
- Another benefit arising from introduction and certification of the quality management system in Slovakia is the improvement of the company image and sales;
- 51 % of Slovak companies stated that the implementation of the quality management system required ca. from 6 months to 1 year;
- Most businesses could not clearly identify the economic benefits of implementing a quality management system.

In our paper, we would like to focus on companies that have established themselves in the so-called specific areas of the woodworking and furniture industry.

According to the Statistical Classification of Economic Activities SK - NACE (issued by the Statistical Office of the Slovak Republic), an important category of the production, which is part of code 16 Woodworking and manufacturing of products from wood and cork, except furniture, manufacturing of objects from straw and wickerwork.

This division includes the production of wooden products e.g. sawn timber, plywood, cardboard, wooden containers, wooden floors, wooden beams, and prefabricated wooden buildings. Manufacturing processes including sawing, planing, shaping, laminating and assembly of wood products starting with wood logs etc. The timber and other treated wood shapes can then be planed or smoothed and assembled into finished products, e.g. wooden containers.

The subgroups are then:

16.1 Sawing and planing of wood;

16.2 Manufacture of products from wood, cork, straw and plaiting materials.

Table1. Classification of selected specific areas according to code 16 (own elaboration with no claim for completeness)

NACE code	Classification	
16.21	Production of boards and wooden panels	
16.22	Production of floor parquet	
16.23	Production of other building carpentry and joinery	
16.24	Production of wooden containers	
16.29	Manufacture of other products from wood, production from cork, straw and plaiting materials	- Manufacture of various wood products - Wooden handles and main parts of tools, brooms, brushes - Wooden molds, hooves, shoe stretchers, clothes hangers - Household tools and wooden kitchen tools - Wooden statues and ornaments, awnings, inlaid wood - Wooden boxes for jewellery, cutlery and the like - Wooden spools, rolls, sewing rolls - Manufacture of articles from natural or agglomerated cork, including floor coverings - Manufacture of baskets and wickerwork products: pads, mats, screens, mirrors and picture frames, etc.

It is not possible, within our contribution, to categorize all specific areas related to the woodworking and furniture industry. Therefore, we selected only some. From the stated above it is clear that the production in question focuses rather on micro and small enterprises, which in most cases are carried out through open crafts self-employment. The following categories are known within the list of open crafts self-employment in the woodworking industry:

8.1. Woodworking;

8.2 Production of simple timber products, assembly of carpentry parts or parts of wood into final products and their maintenance;

8.3. Production of simple utility timber products;

8.4. Manufacture products from straw, husk, wicker, cork;

8.4.1 Manufacture wicker articles, baskets, gift baskets, boxes, wicker furniture (chairs, armchairs);

8.4.2 Manufacture of articles of straw and husk, manufacture of knitted fabrics of non-woven plant materials, manufacture of baskets, straw packaging for bottles, mats;

8.4.3. Manufacture of cork products: manufacture of natural and agglomerated cork (stoppers, gaskets, decorative plates, plates, trays, strips).

In the above-mentioned sectors of the woodworking and furniture industry, the average registered number of employees is approximately 10 367 (the approximate number of employees in the woodworking industry together is about 32 547).

Monthly labor productivity from value-adding wood and cork production, production of straw items, wicker, and similar materials was around 700, - EUR.

4. CONCLUSION

It is clear, from the above-mentioned information, that this is a production with a minimal impact on the GDP of the Slovak economy. Nevertheless, if manufacturers are interested in expanding their products to neighboring countries within the EU, they must meet the requirements of ISO standards for quality management systems, processes, and products.

It is not conceivable for all small business owners to document all their activities and processes in full, as currently required. On the other hand, if they want to demonstrate the fulfilment of customers' requirements and technological processes in a competitive environment, they must prove that they have an attestation or a certificate that approves the facts. In such cases, it is a vicious circle that has nothing to do with the effective assurance of quality management systems. The future trend will, therefore, be the so-called creative quality management that aims to be flexible in relation to customer requirements, but also to the demands of a constantly changing competitive environment in global markets.

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Management of Quality in Timber Industry within Context of Continuous Sustainable Forest Management

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ABSTRACT

Today, quality management is becoming an integral part of a comprehensive business management system. The management system focuses not only on the quality of production, but also includes the entire management system, human resources management and customer communication. It ranges from legislation to ecology, energy and occupational health and safety. Moreover, in the timber industry, Programme for the Endorsement of Forest Certification (PEFC) is also a requirement to prevent the use of timber from controversial sources (e.g. illegal logging) in products and thereby contribute to sustainable forest management. The introduction of the PEFC chain of custody in a timber industry requires application of basic management system requirements that are in line with the worldwide standards ISO 9001, ISO 14001, ISO 50001 and ISO 45001.

Key words: chain of custody, environment, ISO 9001, ISO 14001, ISO 50001 and ISO 45001, occupational health and safety, PEFC, quality.

1. INTRODUCTION

Term *certification* can be defined as an act or activity in which an independent third party confirms that the product, article or service complies with applicable international or national standards or agreed rules. The basis for creating a specific certification are type-tests based on test methods prescribed by official documents. In the Slovak Republic, certification (pursuant to Act 264/1999 Coll., As amended), is an activity of an authorized person who, by issuing a certificate, certifies that the characteristics of a specified product and activities related to its production are in accordance with the technical requirements for specified products as defined by related technical regulations. (Suchomel, J. 2011)

The basic prerequisite for obtaining the *Chain of Custody* Certificate is the introduction of a system for monitoring the flow of wooden raw material or forest products, respectively, according to the requirements of the technical documentation TD SFCS 1004: 2013 *Consumer chain of forest products*. This document is a Slovak translation of the international standard PEFC ST 2002: 2013 *Chain of custody of forest based products - requirements*. (PEFC Slovakia, 2010)

The certification process is applied at two levels:

1. Certification of sustainable forest management, which is focused on the certification of the place of origin of the raw material,
2. Chain of custody (C-o-C) certification, which affects the supply chain from timber producers, timber processors and producers of various timber products to end-users (traceability of timber at each stage of the production chain).

1.1. PEFC Ethical Standards

Through the promotion of sustainable forest management, PEFC ensures throughout the supply chain of forest products that timber and non-wood forest products are produced in compliance with the highest environmental, social, safety and ethical standards. Thanks to their eco-label, customers and users can identify products from sustainable forest management. Figure 1 shows a sample of the PEFC label where, at least 70 % of the wood comes from PEFC certified forests and the other wood originates from PEFC controlled sources.

Figure 1. PEFC Certification Label; (Source: www.pefc.org)

PEFC is a global organization covering national certification systems, which are created with the participation of all involved groups and are adapted to diverse national priorities and conditions. Each national forest certification system is a subject to a thorough international evaluation by an independent assessor who verifies the system's compliance with the PEFC requirements to ensure consistency with international requirements. (PEFC Slovakia, 2010)

The PEFC currently includes through its membership nearly 40 national forest certification schemes. Related documentation is publicly available on the PEFC Council website.

The PEFC is also recognized by a number of public and private wood procurement policies around the world. The current area of PEFC certified forests and the list of PEFC certificate holders of the forest product chain is available in the PEFC information register. (Suchomel, J. 2011)

At the end of August 2018, the number of the PEFC Consumer Chain holders (CoC) in Slovakia reached one hundred. The PEFC certification of the consumer chain is a mechanism for tracking certified raw material from forest to final products, ensuring that wood and wood fibers contained in wooden products and paper as well as non-wood forest products can be traced back to certified forests.

According to the land area of the PEFC certified forests in Slovakia, it is possible to estimate that more than 5 mil. m^3 of raw wood enter into the chain of certified suppliers. (Suchomel J. 2011)

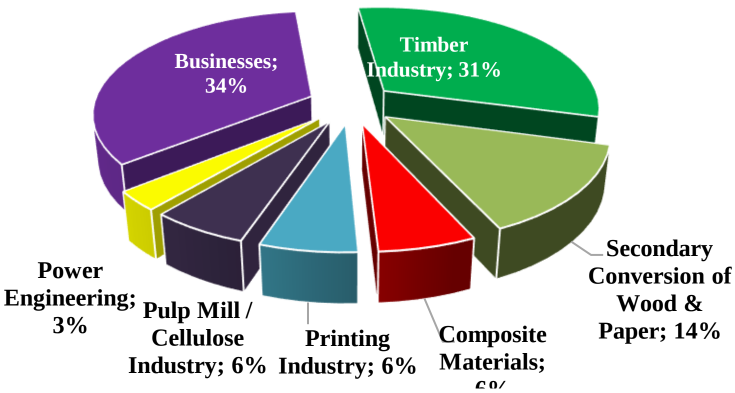

Figure 2. Certified Industry C-o-C (Source: Own elaboration)

2. CONSUMER CHAIN

The main objective of the PEFC Consumer Chain and its certification is to provide consumers of forest products with provable information on the content of the raw material derived from the PEFC certified and sustainably managed forests or recycled raw materials in products, respectively. Furthermore, the PEFC certification provides information on the origin of the raw material procured.

Certification requirements also include requirements for the chain management system. Requirements are defined in the technical documentation *TD SFCS 1004: 2013 Consumer chain of forest products - requirements*, which is a Slovak translation of the international standard *PEFC ST 2002: 2013 Chain of custody of forest based products - requirements.*

2.1. Consumer chain methods

There are two basic methods of tracing the origin of forest products depending on the needs of a certified company:

2.1.1. Percentage method

This method allows the mixing of certified and uncertified raw materials throughout the production process. The content of the certified raw material needs to be known. Calculation formula (1) of certified raw material in final product: (TD SFCS 1004: 2013, 2015)

$$P_C = \frac{V_C}{V_{C+V_O}} \cdot 100 \tag{1}$$

P_c - Percentage of certified raw material [%],
V_c - Volume of certified raw material [m^3],
V_o - Volume of other raw materials [m^3].

2.1.2. Physical separation method

This method requires strict separation of certified and uncertified raw material at all stages of the production process in order to avoid its mixing.

2.2. Due diligence system

In order to avoid the use of timber from illegal logging sources in products, the PEFC has put in place a strict safeguard mechanism to prevent raw material from controversial sources. This mechanism is a mandatory part of the PEFC consumer chain and consists of elements such as supply risk analysis, external evaluation and on-the-spot controls at suppliers to ensure the legality of the raw material which is uncertified. (PEFC Slovakia, 2010)

This safeguard mechanism is reviewed by independent auditors during regular annual audits. The latest review of the consumer chain requirements has defined controversial resources as forest management activities that:

a) Do not comply with local, national or international legislation, which relates in particular to the following areas:
    - Forestry activities and logging, including the conversion of forests to other uses;
    - Management in areas with important environmental and cultural values attached;

- Protected and endangered species, including CITES requirements,
- Health and employment matters related to workers in timber industry;
- Ownership and use rights of indigenous peoples,
- Paying taxes and fees

b) Use genetically modified organisms;

c) Convert forests into other vegetation types, including conversion of natural forests to forest plantations. (PEFC Slovakia, 2010)

3. IMPLEMENTATION OF THE CONSUMER CHAIN - BASIC MANAGEMENT SYSTEM REQUIREMENTS

Implementation of the consumer chain in an organization requires the application of basic management system requirements that comply with worldwide standards such as ISO 9001, ISO 14001, ISO 50001 or ISO 45001. It means that many of the requirements of quality management standards and environmental protection are the same.

Table 1 provides a detailed description of elements that could be integrated in the following standards: STN EN ISO 9001:2016, STN ISO 45001:2019, STN EN ISO 14001:2016 and STN EN ISO 50001:2019 a TD SFCS 1004: 2013.

3.1. Leadership

The first requirement is a leadership. The management of the organization must define and document its commitments, establish and maintain the requirements of the consumer chain in accordance with this document. Such an obligation of the organization shall be accessible to the employees of the organization, suppliers, customers and other involved parties. (TD SFCS 1004:2013, 2015)

Identical requirement is based on Chapter 5.1 of ISO 9001: 2015 (STN EN ISO 9001: 2016) and is also anchored in the new ISO 45001:2018 (STN ISO 45001:2019) in Chapter 5.1, where the main task of company management is leadership and confirmation of occupational safety and health obligations. This requirement is defined in ISO 50001:2018 (STN EN ISO 50001: 2019), Clause 5.1 as: *Ensuring the integration of the EnMS requirements into the organization's business processes*.

3.2. Responsibilities and authorities

In addition to leadership, the company management must delegate a person responsible for managing the C-o-C chain. The same requirement appears in other management systems. The management of the organization must delegate a person, along with defining all respective responsibilities, accountable for the functioning of the system and for reporting to senior management in particular.

Top management is also responsible for communication in the area of management and allocation of responsibilities and authorities in job positions. These responsibilities and authorities must be clearly defined and understood.

Table 1. Area of standards integration (Source: Own elaboration)

Requirements	ISO				TD SFCS
	9001: 2015	14001: 2015	45001: 2018	50001: 2018	1004:2013
Context of the Organisation Understanding the organization and its context; Understanding the needs and expectations; Determination the scope of the management system; Management system and its processes.	✗	✗	✗	✗	
Leadership Establishing the policy; Communication the policy; Roles, responsibilities and authorities.	✗	✗	✗	✗	✗
Planning Risks; Objectives; Of the consumer chain - due diligence system; Environmental protection; Environmental aspects; Energy management.	✗	✗	✗	✗	✗
Support Resources; People; Infrastructure; Organizational knowledge; Competence; Awareness; Documented information.	✗	✗	✗	✗	✗
Operation Requirements for products and services; Change management; Design and development; Control of externally provided processes; Production and services provision; Control of nonconforming outputs;	✗	✗	✗	✗	
Complaints;	✗	✗	✗	✗	✗
Performance evaluation Monitoring, measurement, analysis and evaluation;	✗	✗	✗	✗	✗
Internal audit; Management review.	✗	✗	✗	✗	
Improvement Nonconformity and corrective actions.	✗	✗	✗	✗	✗

3.3. Documented information

The organization shall document all procedures related to the chain of custody and keep the following records:

a) of all procurers of certified raw materials and all other raw materials, and all documents related to the procurement of raw materials,

b) of calculation of the percentage of certified raw material,

c) of all products sold / moved, including declarations,

d) related to the due diligence;

e) related to risk assessment and to management of procurements with significant risk,

f) related to all internal audits and systematic reviews of the consumer chain;
g) of complaints and their handling.

The control of documented information is also a requirement defined in Clause 7.5 of ISO 9001, ISO 14001 and ISO 50001.

3.4. Risk assessment

The organization must carry out a risk assessment of procurements from controversial sources (uncertified raw material). The assessment is carried out based on an evaluation of sources from the country of origin - if the activities *are* or *are not* defined as controversial sources. Furthermore, the assessment evaluates the likelihood of the supply chain being unable to identify a potential controversial source. Based on these probabilities, procurements must be categorized as significant, i.e. medium to non-acceptable risk or negligible, i.e. none, insignificant or low risk according to the following scheme on Figure 3.

Probability on the level of the supply chain		Probability on the source level: LOW	Probability on the source level: HIGH
	HIGH	Medium to non- acceptable risk level	Medium to non- acceptable risk level
	LOW	None, insignificant or low risk	Medium to non- acceptable risk level
		LOW	HIGH

Probability on the source level

Figure 3 Risk categories (Source: Own elaboration)

The calculation of risk is possible according to the following formula (2):

$$R = P \cdot C \tag{2}$$

R - Risk
P - Probability
C - Severity of consequence

Table 2. Numerical expression of the probability and severity of the consequence for risk calculation

	P – Risk probability	C – Severity of consequence	R - Risk	
1	Highly unlikely	Negligible	1÷2	No risk
2	Unlikely	Minor	3÷5	Insignificant risk
3	Possible	Moderate	6÷8	Low risk
4	Likely	Significant	9÷11	Moderate risk
5	Very Likely	Catastrophic to the system	12 and more	Non-acceptable risk

For procurements classified as hazardous, the organization shall require sufficient information and evidence from the supplier to classify the procurement as one with insignificant risk.

3.5. On-site inspection

The organization's control program shall include an on-site inspection of suppliers who provide procurement with significant level of risk. This can be done by the organization itself or by a third party. The size of a yearly control sample of procurements from suppliers is expressed by the following formula (3):

$$y = \sqrt{x} \tag{3}$$

x- is a number of procurements with significant risk per year rounded up to the nearest number (TD SFCS 1004: 2013, 2015)

3.6. Complaints

The organization must have a process in place to deal with complaints from suppliers, customers and other stakeholders. In the event of a complaint, it is necessary to receive, obtain and verify all information necessary to verify and evaluate the complaint. It is necessary to formally notify the claimant of the decision to deal with the complaint.

3.7. Corrective and preventive measures

The organization shall define written procedures for the implementation of corrective measures when discrepancies are identified as part of the organisation's control program or complaint. Acceptance of corrective and preventive measures is also a requirement of ISO 9001 and 14001, 50001 as well as the new ISO 45001 in Section 10.2.

3.8. Occupational health and safety requirements

The organization must define its commitment to occupational health and safety (OH&S). The working environment must be defined in such a way that it does not endanger safety and health at work. Occupational health and safety can be characterized as a set of measures, principles, principles, attitudes, behaviours and activities that help to eliminate the adverse effects of employment.

In the past, OH&S was perceived only as an *accident prevention* focusing primarily on the safety of technical equipment and working procedures. Later, emphasis was placed on a healthy work environment, human factor and, in particular, the adaptation of the work environment and work equipment to human needs and characteristics. Health protection itself takes on a new dimension in the approach of the World Health Organization (WHO), which *defines health* "not only as the absence of disease but also as a feeling of physical, psychological and social well-being". (National Labor Inspectorate, 2017)

The current understanding of the concept of OH&S stems from the philosophy of the reorganization of European Union legislation in this area in the late 1980s. Framework Directive 89/391 / EEC requires that occupational safety is ensured with respect to *all aspects related to work.* This means that the protection of employees includes conditions for satisfactory and dignified work, well-being at work, social protection of employees, favourable working relationships, as well as protection of material values, work and the environment.

Therefore, in connection with the protection of employees, it is necessary to address such factors as psychological or physical stress, monotony of work, working conditions, employment and employment law, psychosocial factors, equal opportunities (non-discrimination), fair remuneration, or appropriate workplace equipment, etc. (National Labor Inspectorate, 2017)

3.9. Energy management requirements

Procurement is one of many opportunities to improve energy performance through the use of more efficient energy using products as well as services. It provides an opportunity to work with the supply chain and influence its energy behaviour.

Energy purchasing specifications can vary from market to market. Specifications for purchases of energy can include energy quality, quantity, reliability, availability, cost structure and environmental impacts or alternative types of energy. The organization can use the specification proposed by an energy supplier, as appropriate.

A change to, or increase in, procurement of renewable energy from outside the scope of the ISO 50001:2018 (STN EN ISO 50001:2019) does not affect energy consumption, nor does it improve energy performance, but it can have positive environmental impacts. Firms can include renewable energy procurement as one of their energy procurement criteria or specifications.

4. CONCLUSION AND DISCUSSION

The main purpose of the paper was to highlight the importance of certification of the consumer chain in timber industry as well as to point out the interconnection of standards related to the environment, quality, health and safety and energy management.

This paper describes the basic requirements for the implementation of the consumer chain according to the requirements of the technical document TD SFCS 1004: 2013 *Consumer chain of forest products - requirements in coordination with the standards of management systems.*

Consumer chain certification is one means of ensuring that timber and timber products come from forests that are managed in a sustainable way, while respecting internationally accepted environmental, economic, social, safety and energy saving principles, which are the main pillars of sustainable development.

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Surfaces for Sports Areas - Characteristics, Requirements and Defects

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ABSTRACT

Surfaces for sports areas or sports flooring are special structures for (indoor) sports activities, consisting usually of three functional layers: elastic, dividing and wear. As changes in layers (composition of materials, their depth and density) change the characteristics of floorings, basic performance requirements are set for the entire structure. Assessment and verification of constancy of performance of basic characteristics is in general performed on new structures, although in years of use they can be significantly changed. Some defects occur in a short period of time and some in later period of life span. Presented paper focuses on technical specification requirements and on common surfaces for sports areas defects overview.

Key words: assessment, defects, sports floors, standards, surfaces for sports areas, time-related behaviour

1. INTRODUCTION

Surfaces for sports areas - commonly denoted as sports floors - present probably the most important part of sports equipment in facilities for multi-sports use. Multilayer structure of sports floors assures their functionality in the terms of elasticity, dividing and wear. With the main goal of protection of athletes form the injuries the purpose of elastic layer is to assure proper elasticity, in combination with dividing layer which divides the loads into substructure. The wear layer has to assure proper friction and resistance to wear related to durability. Different materials can be used for each layer - elastic from absorptive foam or wooden structure, dividing from laths or panels and wear from artificial material, rubber or wood based materials. Typical sports floor structures are presented in Figure 1.

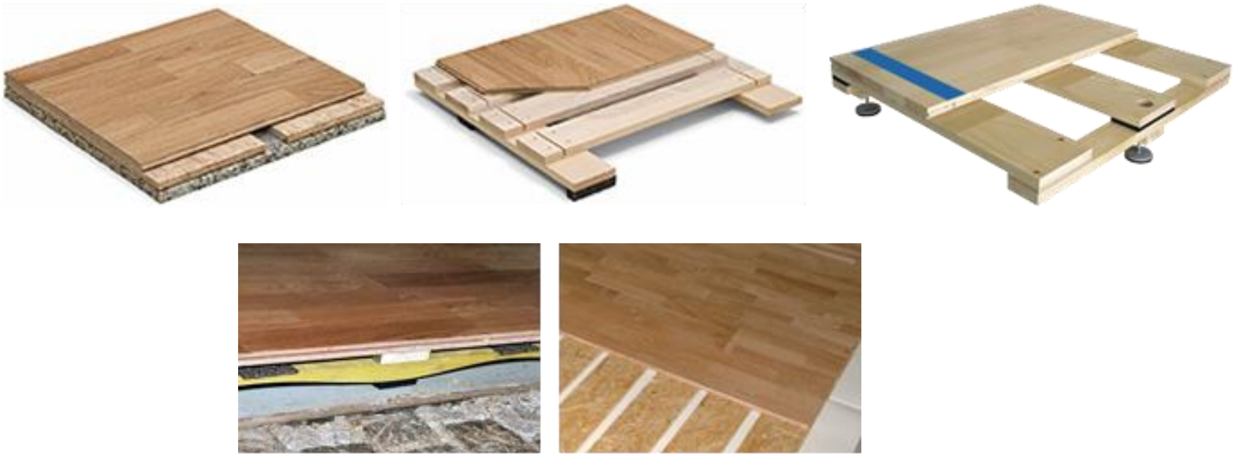


Figure 1. Characteristic compositions of sports floors.

As with all other construction products each material used in sports floors composition has to fulfil the basic performance requirements. As changes in layers (composition of materials, their depth, density and geometry) change the characteristics of floorings, basic performance requirements have to be set for the entire structure.

2. SPORTS FLOOR AND STANDARDIZATION

Similar as with other widely used products throughout the past decades several standardization attempts were made to provide a method of quantitatively comparing sports surfaces and to establish performance requirements to ensure that each community is getting a sports surface of comparable quality.

2.1. DIN 18032-2

Most notable and technically advanced technical specification for surfaces for sports areas with relatively strict requirements is German standard DIN 18032-2 (DIN V 18032-1, 2001). Standard is part of DIN 18032 family:

- DIN 18032-1:2014 *Planning principles*
- DIN V 18032-2:2001 *Floors for sporting activities; Requirements, testing*
- DIN 18032-3:2018 *Testing of safety against ball throwing*
- DIN 18032-4:2002 *Two-leaf partition curtains*
- DIN 18032-5:2002 *Telescopic grandstands*
- DIN 18032-6:2014 *Provisions for installation and anchorage of sporting equipment*

The first release of DIN 18032-2 was issued in 1965. Without any floor testing section standard was updated in 1975 where first requirements were set. However test procedures and equipment was quite different than it is today. Further, in 1978, force reduction was included as standardized testing method. After 1986 when complete DIN 18032-2 was issued, only minor changes and clarifications have been made, but the characteristics and test method remained similar (but not the same) throughout the revisions (Elliott, 2004). Therefore it is - with the results - always important to quote the standard release.

Standard DIN V 18032-2:2001 (further on marked as DIN 10832-2) defines several performance characteristics which can be in general grouped into two main categories: mechanical properties (ball rebound, rolling load behaviour, area indentation) and biomechanical properties (force reduction, slip resistance and vertical deflection) (ASET Services, 2005), defined through 10 different quantities (DIN V 18032-1, 2001). Standard defines four different types of sports floors (area-elastic, point elastic, combined elastic and mixed elastic). Beside properties the testing equipment and also acceptance criteria are defined.

Due to lack of national standards and due to very strict performance requirements DIN 18032-2 was referred to as de-facto standard for sports floors not just in publishing country but many times also in other parts of Europe and World.

2.2. EN 14904

With formation of European Union and setting up the regulatory requirements first with Construction Products Directive - CPD (EU 89/106/EEC) and later on with Construction Products Regulation - CPR ((EU) No 305/2011) sports floors are considered as construction products and as such have to be CE marked. EN 14904:2006 *Surfaces for sports areas, indoor surfaces for multi-sports use* (EN 14904, 2006), prepared by CEN/TC 217, was accepted as technical specification. After time consuming harmonization process the use of standard is mandatory form 1.2.2008.

Similar as German standard for sports floors EN 14904 also defines four types of sports floors: point-elastic (P), mixed elastic (M), area elastic (A) and combined elastic sports floors (C), as presented in Figure 2.

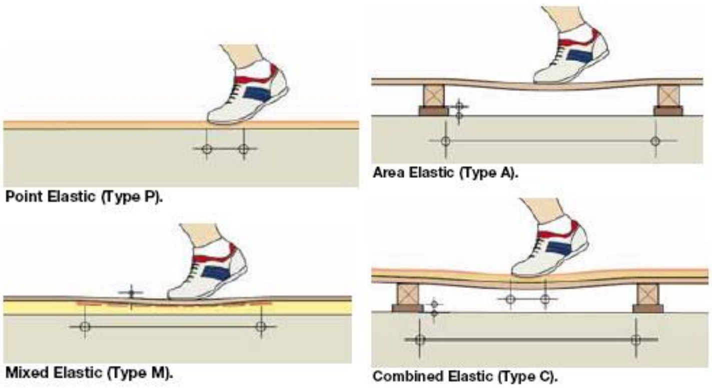


Figure 2. Types of sports floors according to EN 14904 (Sport England, 2007)

Although covering the same product the concept of EN 14904 is quite different form DIN 18032-2 approach. Following the general principles of CEN standards structure and construction products Basic Requirements for Construction Works (BRCW) the content is gathered in the following chapters: Scope, Normative references, Terms and definition, Requirements, Evaluation of conformity and Marking / Labelling. Requirements for sports floors are gathered in two groups:

- Requirements for safety in use (friction, shock absorption and vertical deformation).
- Technical requirements (vertical ball behaviour, resistance to rolling load, resistance to wear, reaction to fire, formaldehyde emission, content of pentachlorophenol, specular reflectance, specular gloss, resistance to indentation, resistance to impact and degree of evenness).

In comparison with DIN 18032 some characteristic were omitted (area indentation - as hardest of the criterion to fulfil), but some were added (reaction to fire, dangerous substances, specular reflectance, specular gloss). Test methods or measuring principles for the majority of characteristics were not changed, but not for all (friction for example where test method defined in EN 13036-4 is now used).

Further on, in the process of harmonization, Annex ZA was added. Only few requirements were recognized as relevant and harmonized: reaction to fire (when required), friction, resistance to wear / rolling load, shock absorption and release of dangerous substances. Annex ZA additionally defines the Assessment and verification of constancy of performance system (AVCP) defining the tasks of producer and notified laboratory.

The detailed description of all requirements is out of the scope of this paper. Only two most characteristics requirements will be presented in details: shock absorption and vertical ball behaviour. The latter characteristic is not recognized as harmonized but it is of great importance for usability of sports floors.

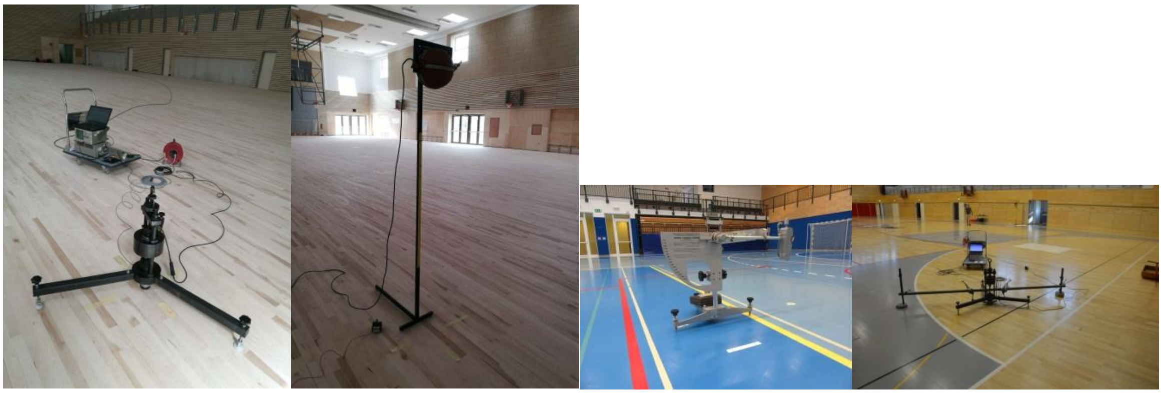


Figure 3. Measurements of shock absorption vertical ball behaviour, friction and vertical deformation.

In order to prevent injuries and to offer a sufficient level of comfort sports floors have to assure sufficient force reduction, commonly referred as shock absorption. The quantity defines the ability of sports floor to reduce the impact forces compared to impacts on concrete. Using the “Artificial athlete 95” the shock absorption is calculated as:

$$R = 1 - \frac{F_t}{F_R} \times 100 \tag{1}$$

R – Force reduction, expressed as a percentage (%);
F_t – measured maximum peak force for the test piece (N);
F_t – measured maximum peak force for the concrete (N).

DIN 18032-2 is well known on strict requirements regarding shock absorption: for example more than 53 % for the area elastic sports floor has to be achieved in every measuring point.

When referring to EN standards, the shock absorption is with the same principles defined in EN 14808 (EN 14808, 2006). However the requirements are less demanding - shock absorption has to be between 25 - 75 % and no individual result shall differ from the mean for more than ± 3 %. EN 14904 in informative Annex B defines more specific values of shock absorption for different types of sports floors.

Ball rebound (BR) is a criterion that evaluates the suitability of sports floor mainly for basketball but also for the other activities. The general principle of ball rebound property is to measure the rebound of specific type of ball on two different surfaces: rigid (concrete) and on sports floors. BR is calculated as ratio between rebound heights. This principle was used already in DIN 18032-2, where test setup was defined: device, drop height (1.80 m) and rebound height form concrete visually measured from the top (1.30 ± 0.025 m) achieved with proper inflating the ball. The BR result presents the average of 5 measurements. The average value in each measuring point should be ≥ 90 %.

When referring to EN standards, BR is defined in EN 12235 (EN 12235, 2013) with some minor, but relevant changes: 1.) Rebound is measured from the bottom of the ball allowing only acoustic reading; 2.) No individual results shall differ from the mean by ± 3 units. Regardless to the same basic principles different requirements for evaluation of results make the BR values not directly comparable.

3. SPORTS FLOOR AND DEFECTS

Assessment and verification of constancy of performance of basic requirements is in general performed on new structures, although in years of use they can be significantly changed. Some defects can occur in a short period of time (installation faults, moisture related issues, mechanical damage) and some in later period of life span (degradation of absorptive foam).

Not all sports floors defects can be assessed visually (like cracks, unevenness, poor parquet quality, line paint quality, …). In the previous chapter selected and presented requirements were not chosen randomly. Shock absorption from "Requirements for safety in use" and vertical ball behaviour from "Technical requirements" provide the most valuable information about the actual performance of sports floors. Due to the non-destructive nature of selected tests they are widely used to assess the performance of installed sports floors, especially when doubts occur about suitability of sports floor for different sport activities. If assumption of poor performance is confirmed with the tests than opening the sports floor structure on critical spots is commonly the only solution to validate / confirm the assumptions.

Majority of defects in sports floors is related to materials used and to their installation. With different layers different materials can be used (Figure 1):

- elastic (rubber, foam, timber substructre - net, timber elements with variating cross section;
- dividing (timber boards, wood based panels – installed as single on dobule layer);
- wear (timber, poyurethane, linoleum, PVC, …).

Slovenian National Building and Civil Engineering Institute has been inspecting sports floors for more than four decades. An effort is made to group identified defects, but this seems to be a difficult task since it is - in general - difficult to characterize them as a single cause occurrence.

Most trivial defects are installation errors where the compositions of sports floors do not follow the manufacturer technical specification: material / material properties of some layers are changed, their dimension, distances between elastic / dividing layers, orientation of structure (layers) and others. As proved with the initial type testing even minor changes can have a relevant influence on sports floor performance. In some cases sports floor manufacturer installation instructions might not be detailed enough (type of fasteners, gluing of layers, orientation of layers and others).

Figure 4. Left: According to presented DoP sports floor supose to be mixed elastic. Middle: Ommiting elastic layer on some supports. Right: Non-uniform grid of elastic substructure.

Important issue with installation of sports floors are also requirements regarding substrate, most commonly screed or concrete slab. Moisture content and dimensional tolerances proved to be most relevant issues. Due to different tolerances of screed / concrete slabs additional levelling of sports floor is commonly required. With the area elastic and combined elastic sports floors timber boards / panels with different thickness are used. Poor installation details presented in Figure 5 also include the usage of non-rigid materials like cardboard. Due to dynamic loads and consequently to the danger of shifting the levelling layers should be glued / screwed / stapled to elastic / dividing layers.

Figure 5. Poor instalation details

Next group of sports floor defects originates in moisture related properties of materials used, mainly timber (Srpčič, 2006). Due to size of sports areas the dimensional differences in timber might be 10 or more centimetres, even if moisture content in timber changes only for 3-4 %. Majority of parquets are made of deciduous species with shrinkage percentage almost twice as with coniferous. Two extreme situations are in general possible:

- Parquet with low level of moisture content (> 6 %) was installed. Due to its nature parquet absorbs moisture from the other not well dried materials (screed, concrete slab, etc.), commonly due to the project tight schedule.

Figure 6. Uneven surface due to the moisture related movement.

- Parquet was conditioned to the environmental conditions before installation. In the heating period (especially with the floor heating) the parquet dries out and the cracks occur between parquet boards / panels with extensive voids at entrance / joints.

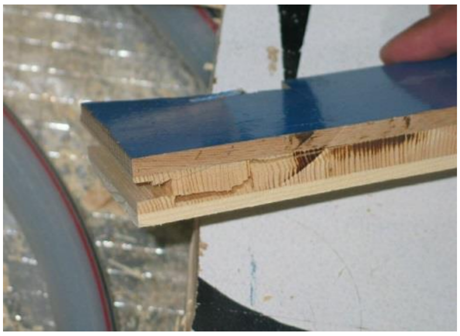
Figure 7. Cracks between parquet boards / panels with extensive voids at entrance / joints.

With specific sports floors it is important to remove the wedges after wear layer is completely installed. The wedges used in installation process disable the dimensional movement of timber (timber based materials) and therefore have to be removed.

Figure 8. Wedges disabling dimensional movement of wear layer.

Unusual but not so rare defect are mechanically damaged sports floors. Defects can occur in all three layers, most commonly with timber and timber based materials. Most of the damage on wear layer occurs in commonly panel parquet elements which are not properly supported on longitudinal joints. This defect occurs with sports floors with relatively rare timber dividing / elastic layers where the grids do not match: Joints are consequently not supported systematically but randomly. Non-supported joints are prone to breaking under concentrated loads - with the multilayer parquet the middle layer is loaded perpendicular to grain (Figure 9). Installation of additional timber boards in the area of parquet element joints might not be trivial solution since this can have an effect on sports floor mechanical properties.

With the area elastic and combined elastic sports floors the size of knots and slope of grain proved to be the main reason for damage on dividing / elastic layer resulting in mechanically damaged sports floor (Figure 9). Presented defects in timber can be exploiting as an example of insufficient quality control of base materials and can be as such also marked as an installation error.



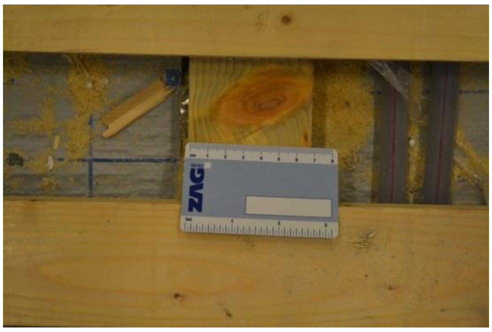


Figure 9. Left: Not properly supported wear layer. Right: Size of knots and slope of grain.

Improper use of sports floors might also be a reason for damage. Water outflow - even as a one-time event - requires immediate measures otherwise permanent damage might occur (Figure 10). Overloading floors with telescopic grandstands, transport baskets or maintenance lifts can cause permanent damage of wear layer (Figure 10).

Figure 10. Left: Consiquences of water outflow. Right: The result of overloading the sports floor.

With the assessment of sports floors it has to be taken into consideration that their properties might change through the product life span - however this issue is not discussed in EN 14904. Ageing of artificial materials (foam, rubber, PVC an others) might also be the reason that requirements for safety in use and also technical requirements are not fulfilled in later stages of the product lifespan. One of concerning conclusions of research (Jurak *et al.*, 2012) is that aging of materials has greater influence on the shock absorption property than on the ball rebound.

4. CONCLUSIONS

Sports floors are complex structures. In the absence of installation requirements and in a variety of different types of sports floors it is up to designers to choose the appropriate type of sports floor. According to DIN 18032-2 all characteristics of sports floors had to be defined. Unfortunately the article 5 of CPR allows producers to assign the product with CE marking and place it on the marked with at least (or only) one essential characteristic leaving all other not declared (NPD). In these terms the current release of EN 14904 together with CPR constraints can be considered as a drawback. With this approach even poor performance sports floors might fulfil the requirements of EN 14904, but - for example due to low ball rebound - they can hardly be used for sports activities. Inspite of compulsory use of EN standard some investors and also some sports associations’ still demand compliance with standard DIN 18032-2.

Draft of new release of EN 14904 was published in 2016. Standard is structured in three parts (-1: Essential Characteristics, -2: Specifications, -3: In-situ testing). Although the status of part 2 and 3 is approved, the part 1 is still under approval (11/2019) (CEN/TC 217, 2019), most likely following the complexity and time consuming standard acceptance and furthermore harmonization process. Due to CPR constraints it is not reasonably to expect that issues discussed in the previous paragraph would be solved with the new standard release - the definition of installation requirements seems proper solution to tackle this issue.

Some typical defects occurring in the product lifespan were presented in the paper. Regardless to different grouping approaches the majority of defects originate in poor installation details. Consequently the installation of sports floor is as such importance as initial type testing. Although it is not always easy to understand but even today in some cases the extent of defects on newly installed sports floor is such that products had to be partly / fully reinstalled / replaced.

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Role of Integrated Information Systems in Wood Processing Companies

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ABSTRACT

It is important to emphasize that Integrated Information Systems (IIS) play an important role in the radical and continuous change of business and production systems, both for small and large-size companies. The aim of this paper is to identify a key factors involved in IIS implementation and post implementation phase in case of wood processing companies, and how they contribute to the implementation outcome. A survey research was conducted on the sample of wood processing companies in Republic of Croatia.

Key words: implementation process, integrated information systems, survey, wood processing companies

1. INTRODUCTION

Technologies of the Fourth Industrial Revolution are blurring the lines between the physical, digital and biological spheres of global production systems. The current pace of technological development is exerting profound changes on the way people live and work. It is impacts all disciplines, economies and industries. Exciting advances in the internet of things, artificial intelligence, advanced robotics, wearables and 3D printing are transforming what, where and how products are designed, manufactured, assembled, distributed, consumed, serviced after purchase, discarded and even reused. They affect and alter all end-to-end steps of the production process and, as a result, transform the products that consumers demand, the factory processes and footprints, and the management of global supply chains, in addition to industry pecking orders and countries' access to global value chains (WEF, 2017). In line with above mentioned, the development of communication and information technologies, had impact on parallel development of the modern conception of production, with application of various new strategies and methods of managing business and production processes. In addition, ever growing globalisation, businesses need to create an effective strategy to help to help them succeed in a highly competitive market (Hitka *et al.*, 2018; Kampf *et al.*, 2017).

Due to global tendencies, nowadays almost all companies in the industry are using some kind of information technology for their business. Considering wood processing industry as a predominantly production-oriented industry, the requirements on information systems go beyond increasing productivity, achieved through better logistical and informatical support. Establishing company-wide and high-quality information systems is one of the key prerequisites for companies preparing to enter international markets and play an active role in globalisation processes. This holds true especially for small- and medium-sized companies which operate within the supply chain involving bigger companies (Perić *et al.* 2019).

As a branch of processing industry, wood processing industry is an essential part of Croatian economy. Fundamentally impacts economic structure at global, regional, national and local levels, affecting the level and nature of employment, and today is inextricable from environmental and sustainability concerns, considerations and initiatives (Klarić *et al.*, 2016; Perić *et al.*, 2019). Collectively, the sector of wood processing production has been the source of economic growth in developed and developing nations alike, a major source of employment for a rapidly evolving and increasingly skilled workforce, and continues to be the dominant focus of innovation and development efforts in most countries (Basarac Sertić *et al.,* 2018; Kropivšek *et al.*, 2019; Perić *et al.*, 2019; Pirc *et al.*, 2010; Sujová *et al.*, 2015).

Designed as integrated application platforms for company's business organization, management and supervision, IIS are commonly referred to as Enterprise Resource Planning systems (ERP). Generally speaking, an ERP platform unites information, collected from all departments and functions across a company, into a single system that caters to the unique and varied needs of different departments (human resources, finances, supplies, etc.), while at the same time enabling all departments to access any other relevant business information (Perić *et al.*, 2017; Perić *et al.*, 2019).

One of the problems of companies face to is the segregation of the business functions. Thus, the business experienced to implement ERP systems for solving this problem. In contrast, the ERP projects have not been effective enough and hence have been unable to achieve all the results envisaged. Therefore, an in depth understanding about the benefits of ERP implementation is needed to ensure the successful system implementation (Sadrzadehrafiei *et al.*, 2013). The aim of this paper was to identify a key factor involved in IIS implementation and post implementation phase in case of wood processing companies, and how they contributed to the implementation outcome. A survey research was conducted on the sample of wood processing companies in Republic of Croatia.

2. MATERILAS AND METHOD

The framework of the present study was tested with the use of developed questionnaire on a sample of Croatian wood processing companies. The initial target population was taken from the Register of Business Entities supervised by official statistical databases Bisnode. The sample on which the survey was conducted consisted of business entities classified according to the 2007 National Classification of Activities (NKD, 2007), Official Gazette 58/17 as *C 16 - wood processing* and *C 31 - furniture manufacturing* compnies. Data on the usage of IIS in Croatian wood processing industry was collected via Survs - online questionnaire. Open questions and five- point Likert scale was used for some of measurement of included variables (1 = "strongly disagree" to 5 = "strongly agree") or (1 ="very unimportant" to 5 =" very important"). A total of 226 companies were asked to participate in the survey by filling out the questionnaire. 73 companies responded, 47 surveys were not fully completed and therefore were not considered for further processing and after performing all necessary controls, 26 were kept for data analysis. Data were analysed using descriptive statistics methods with the use of the statistical packages IBM SPSS Statistics Desktop for Trial (IBM, 2017).

3. RESULTS

In our study, 26 wood processing companies were included. Considering the first part of questionnaire related to the general characteristics of companies 61.5 % are wood processing companies (C 16) and 38.5 % furniture manufacturing companies (C 31). According to the number of employee's, small and large companies represent in equal percentage shares (34.6 %), while 23.1 % of respondents stated that they belong to the medium-size companies. Further, in equal percentage companies claimed to have single production and small-batch production (26.9 %). Just 11.6 % of the respondents, or 5 companies responded to have large batch production.

In this research, only wood processing companies that claimed to use IIS solutions were considered. The results showed that 26.9 % of the surveyed companies have been using IIS solutions from 1 to 3 years. Further, 26.6 % used them for more than 7 years, while 23.1 % implemented them from 3 to 5 years.

It is interesting to note that, despite IIS platforms like MAPICS and QAD having evolved directly from MRP II packages, the majority of the surveyed companies opted for IIS systems tailored to their specific needs, with 50 % of them declaring to use customised integrated information systems. Major ERP providers like Oracle and PANTHEON™ share together only 11.5 %, Navision 19.02 %, while 3.8 % respondents declared to use Syspro i Lawson of the IIS market in the analysed industry.

Companies usually prefer industry-specific solutions which contain features addressing their specific challenges. Our survey results indicate an average use of the seven groups of modalities queried in the questionnaire (Table 1). The most frequently used module were Finance and Accounting, Purchasing and Sales at a rate of 84.6 %, followed by Inventory Management at 80.8 % and Human Resource Management 73.1 %. Production Cost Management and Production Management modules share together 65.4 % of usage. At the other end of the spectrum lie Project Management modules and Quality Management, with an implementation rate of only 38.5 % and 26.9 %.

Table 1. IIS groups of modalities (n=26)

Module Groups	N	(%)
Finance & Accounting	22	84.6
Quality Management	7	26.9
Purchasing	22	84.6
Sales	22	84.6
Production Management	17	65.4
Inventory Management	21	80.8
Production Cost Management	17	65.4
Project Management	10	38.5
Human Resource Management, Payroll	19	73.1

One of the research goals was to analyse the degree of implementation of information and business systems within an enterprise. It is found that in more than half of the surveyed companies (53.8 % more specifically) have IIS solution in the operational phase. Furthermore, 15.6 % of respondents stated that they have IIS solution in the project preparation phase, while 11.5 % in the phase of collecting business requirements and business process documentation - so that they can start implementing business systems within their companies.

As already mentioned, IIS platforms provide a broad range of solutions covering many aspects of business organization. In order to analyse motives relating the desired process and business improvements in pre-implementation phase a formative scale was built, presented in Table 2, where the variables were partly adapted to the present investigation from several previous sources (Mabert, *et al.* 2003; Petroni, 2002; Soja, 2006). The results showed that the getting the real-time data, real-time support for customers (M=4.46), monitoring internal control compliance (M=4.36), and increasing employee productivity (M=4.43), were the major reasons for implementing IIS solution. On another hand, the least important reason were recommendations from earlier users (M=3.43).

Table 2 Motives for IIS implementation (n=26)

Variables	M	SD
Increasing the quality and productivity of different business processes	4.25	1.14
Increasing employee productivity	4.43	0.79
Get Real-Time Data	4.46	0.58
Real-time support for customers	4.46	0.64
Monitoring internal control compliance	4.36	0.62
Integration of all business activities in the company	4.11	0.83
Standardization of working procedures	4.14	0.71
Recommendations from earlier users and their good experiences with using ERP	3.43	1.00

Table 3 summarizes the areas benefiting the most from IIS. Results showed that financial management, availability of information are the areas the most positively impacted. The areas benefiting the least are the costs of information technology, supplier management/procurement and personnel management.

Table 3 Areas benefiting from IIS implementation (n=26)

Variables	M	SD
Availability of information	4.57	0.59
Integration of business operations/processes	4.13	0.76
Quality of information	4.35	0.65
Inventory management	4.26	0.81
Financial management	4.70	0.47
Customer responsiveness/flexibility	3.96	0.88
Supplier management/procurement	3.91	0.85
Personnel management	3.91	0.73
Decreased information technology costs	3.70	1.10

Without financial indicators, in order to provide insight into the impacts of IIS implementation on company business process performance in post-implementation phase, non-financial performance measures were used. This approach has already been used by Pertoni (2003), who noted that benefits associated with the implementation of IIS could also be measured in terms of enhanced performance and user satisfaction. Getting a measure of success and contribution for an IIS implementation is difficult, given the scope, complexity and timing of this type of project. Research in this study showed that some of these systems have been implemented only recently so it may be too early to judge the full impact of an IIS solution at this stage. Table 4 summarizes the impact of ERP systems on the performance measures of key operating areas. The results show that improvements after the introduction of software in companies are in reduced direct operating costs and quicker response times for information. There are also improvements in financial close cycles and cash management. The least improvements are in delivery time, interaction with suppliers and inventory levels.

Table 4 Performance measures for key operating area (n=26)

Variables	M	SD
Reduced direct operating costs	4.22	1.12
Increased interaction across the companie	3.91	0.80
Improved order management/order cycle	3.96	0.69
Quickened information response time	4.13	0.69
Improved cash management	4.04	0.70
Lowered inventory levels	3.83	0.85
Decreased fnancial close cycle	4.04	0.79
Improved interaction with suppliers	3.87	1.00
Improved on-time delivery	3.78	1.15
Improved interaction with customers	3.91	0.79

4. CONCLUSION

This study provides some insights (role) into the implementation and use of ERP systems in wood processing companies in Croatia. According to the number of employees small and large companies in equal percentage share were dominantly represented in this research. The study shows that surveyed companies generally implement custom ERP systems for a period from 1 to 3 years and more than 7 years, where half of them declare to use customised integrated information systems. With the wide range of modules that offer ERP vendors in market, research results indicate partial use of the IIS moduluality, most frequently used module were Finance and Accounting, Purchase and Sales. According to the Shatat (2015), practice have shown that companies only used between 50 and 75 % of the ERP system functionalities or modules, comparing that with our case study, results are similar. Exploring the motives relating the desired process and business improvements in pre-implementation phase, results show that getting the real-time data, real-time support for customers monitoring internal control compliance and increasing employee productivity were the major reasons for implementing IIS solutions. Further, the key question of this study was addressed to explore the impact of IIS solution on the performance measures of key operating areas. Results showed that financial management and availability of information are the areas the most positively impacted. All in all, it can be concluded that introducing an IIS solutions into wood processing companies had positive impact on utilization of technological processes, thus providing a better insight into the availability of materials and improving the level of business of the company to a step higher.
The authors will continue this research, comparing similar projects in other companies in Croatia and abroad, in order to secure credible results and comparisons on a large sample size.

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Stiffness of Case Furniture Made of Layered Cellular Boards with an Auxetic Core - Numerical Approach

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ABSTRACT

Auxetics are materials and structures characterized by anomalous shrinkage properties during compression and swelling during stretching. They are called negative materials due to their negative Poisson's ratio. Such materials have not yet found applications in industrial practice. Therefore, in this study it was decided to demonstrate the influence of sandwich honeycomb panels with the auxetic core on stiffness and strength of cabinet furniture. The research was carried out using the finite element method in the Abaqus program. The calculation results were compared with the data obtained for furniture made of conventional particle boards. It has been shown that auxetic cellular panels have a positive effect on mechanical properties of furniture subjected to torsion and bending.

Key words: auxetic, FEM, furniture, honeycomb, stiffness

1. INTRODUCTION

Honeycomb panels are innovative structural materials in many technologically advanced branches of industry. They are characterised by low weight, high strength parameters and rational utilisation of natural resources (Petras, 1998; Librescu and Hause, 2000; Barboutis and Vassiliou, 2005; Nordvik and Broman, 2005; Ozyhar *et al.,* 2012; Shalbafan *et al.*, 2012; Feifel *et al.,* 2013; Keenan *et al.*, 2015; Smardzewski, 2015; Smardzewski *et al.,* 2017). Their particular advantage is connected with an attractive ratio of stiffness and strength to their density (Petras and Sutchiffe, 1999; Smardzewski *et al.*, 2014, 2015; Smardzewski and Prekrat 2018).

To date mechanical properties of honeycomb panels subjected to bending were analysed in terms of the applicability in case furniture (Barbutis and Vassiliou, 2005; Smardzewski, 2013). The effect of the shape and type of auxetic core cells on torsional stiffness was also investigated (Smardzewski and Prekrat 2018). In contrast, practically no analyses have been conducted on stiffness of case furniture subjected to torsion depending on the type of used honeycomb panels, especially those with auxetic cores.

The aim of this study was to determine to what extent the type of wood-based honeycomb panels, the manner of door installation and furniture support methods influence stiffness of single-chamber case furniture. It was decided particularly to specify whether auxetic properties of the honeycomb panel core affect furniture stiffness.

2. MATERIALS AND METHODS

2.1. Structure and geometry of cabinet furniture

Tests were conducted on case furniture items with dimensions as specified in Fig. 1. Two design variants were applied. One of them was furniture with concealed hinges. In contrast, in the other variant the furniture had no door. The door was recessed in the case interior so that a gap of 5 mm in width was obtained over the entire circumference. All the furniture body elements were manufactured applying an identical technology and the same materials. The materials included particleboards (PB), honeycomb sandwich panels with an auxetic core with elliptical cells (EL), honeycomb sandwich panels with prismatic single (S) or double cores (D).

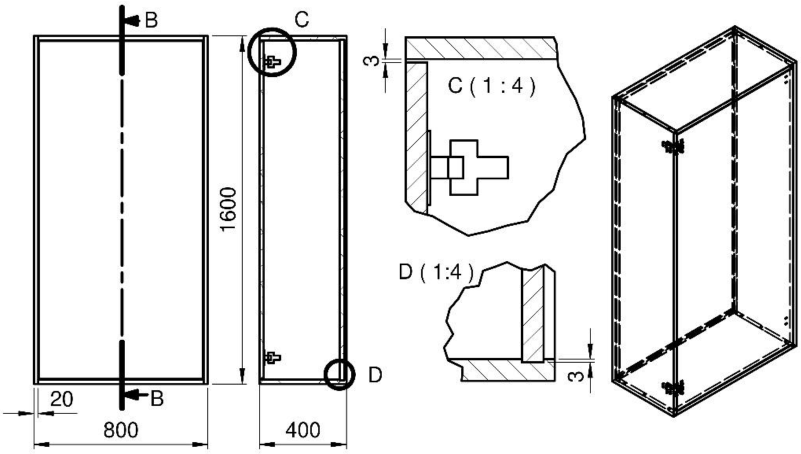

***Figure 1**. Case furniture used in the tests*

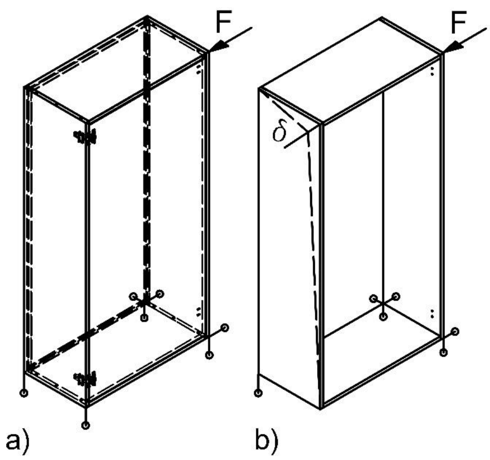

Figure 2. Furniture support method: a) in four corners, b) in three corners

Tests were executed according to the diagram presented in Fig. 2. The furniture bodies were supported in four (Fig.2a) or three corners (Fig. 2b) and loaded with a horizontal force *F* (N) in the right upper corner. The value of the loading force was selected so that deflection δ (mm) was 50 mm, irrespective of the type of structural design or used material. In view of two types of support, two types of furniture structural design and four types of furniture panels a total of sixteen calculation models were constructed.

2.2. Mechanical properties of boards

Particleboards (PB) were treated as isotropic material with commonly known mechanical properties (Smardzewski, 2015). Honeycomb sandwich panels in terms of their structural complexity and mechanical properties were considered to be orthotropic materials. Figure 3 presents the shape and proportions of used honeycomb panels with the following core types: double (D) (Fig. 3a), single (S) (Fig. 3b) and auxetic core with elliptical cells (EL) (Fig. 3c). Dimensions of individual honeycomb panel layers are given in Table 1 and in Fig. 4.

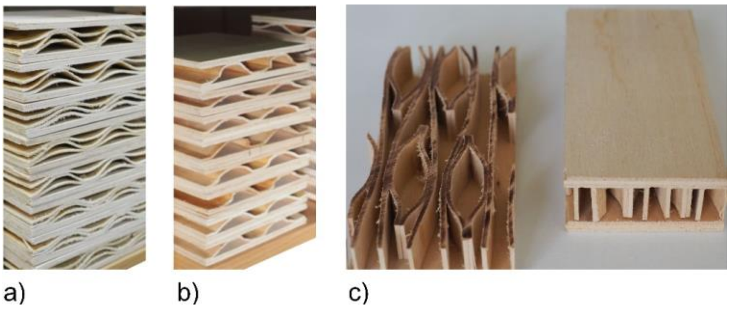

Figure 3. Honeycomb panels with the following core types: a) double (D), b) single (S), c) elliptical (EL)

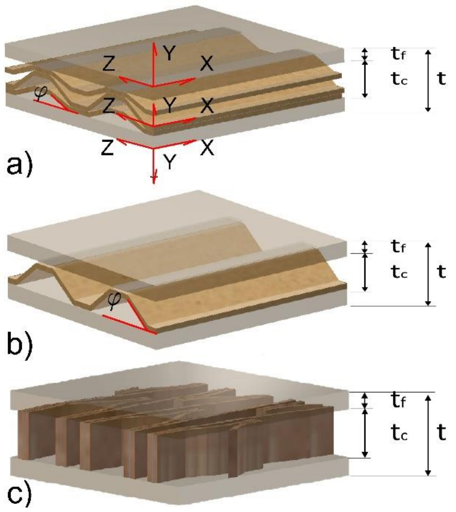

Figure 4. Shape and dimensions of samples used in testing: a, double (D), b) single (S), c) elliptical: t_f – facing thickness, t_c – core thickness, t – panel thickness

Table 1. Dimensions and selected physical properties of honeycomb panels used in testing. Standard deviations are given in parentheses

Type of core	Dimensions			Density	Moisture content
	t	t_f	t_c		
		mm		kg/m^3	%
D	16.86	4.4	8.06	423 (24)	6.10 (0.10)
S	19.89	4.4	11.09	399 (28)	6.20 (0.10)
EL	20.05	4.4	11.25	392 (28)	6.12 (0.05)

Veneer of beech wood (*Fagus sylvatica* L.) was used to manufacture facings and cores of honeycomb panels. Veneers were glued into plywood plies (Fig. 5) using urea-formaldehyde UF resin commercially available as Jowat 950.20 at 100 g/m^2 (Jowat Polska, Sady, Poland). Plywood facings were bound with honeycomb panel cores applying PVAc Jowacoll 103.30, D3 at 80 g/m^2 (Jowat Polska, Sady, Poland). Properties of tested materials were determined in (Smardzewski, 2015; Smardzewski *et al.* 2017) and summarised in Table 2.

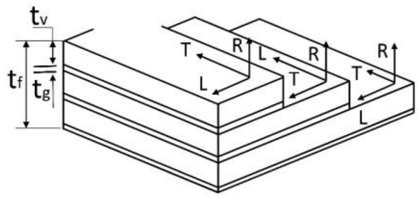

Figure 5. Plywood as facing of honeycomb panel

Table 2. Mechanical properties of tested materials

Material	$E_{L(X)}$	$E_{R(Y)}$	$E_{T(Z)}$	G_{XY}	G_{XZ}	G_{YZ}	υ_{XY}	υ_{XZ}	υ_{YZ}
	MPa							(-)	
Beech	14100	2280	1160	1645	1082	471	0.45	0.51	0.75
PB		3500			-			0.30	
ALU		$70 \cdot 10^3$			-			0.29	
PVAc		460			-			0.30	
UF		720			-			0.30	

2.3. Elastic properties of cores in multi-layered sandwich panels

It was assumed that in the further part of the study elastic constants of selected wood-based materials subjected to homogenisation would be used in numerical calculations. For this reason elastic properties of honeycomb panel cores were determined. Double prismatic cores (D), single prismatic cores (S) and elliptical cores (EL) were subjected to uniaxial compression with strain measured in the direction of loading and in the directions perpendicular to this loading (Fig. 6). Results of these calculations are given in Table 3. It shows that cores with elliptical cells (EL) exhibit auxetic properties due to negative values of Poisson's ratio. The other cores were conventional structures with positive values of Poisson's ratio. At the same time analysed cores exhibit strong orthotropy of mechanical properties. For this reason in further modelling it was assumed that greater values of moduli of linear elasticity were oriented along the longer edge of elements.

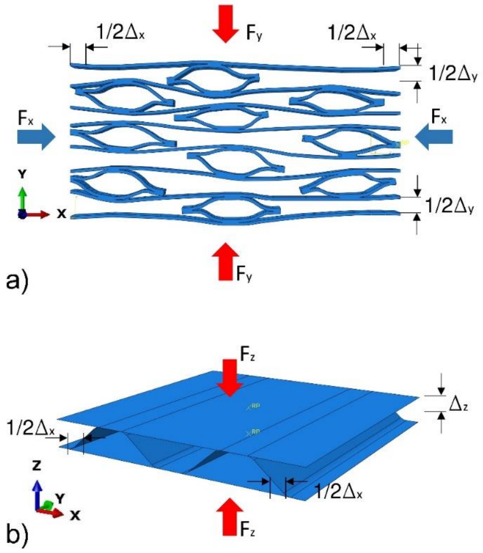

Figure 6. A diagram of uniaxial compression of cellular cores: a) elliptical (EL), b) single (S)

Table 3. Properties of core materials

Material	E_X	E_Y	G_{XY}	υ_{XY}	υ_{YX}	υ_{ZX}	υ_{ZY}
	MPa			(-)			
EL	79	$7.96 \cdot 10^{-6}$	3	-6.429	-0.011	-	-
S	240	116	20	-	-	0.041	0.341
D	180	106	19	-	-	0.042	0.341

2.4. FEM models

Figure 7 presents an example model for numerical calculations of the furniture body. All the furniture elements were modelled using 10–node finite tetrahedral C3D8R elements. Glue lines of facings and the core were modelled applying a cohesive element COH3D8 and a 0.1 mm layer thickness. The furniture body elements were joined by modelling rigid beech dowels of 8 mm in diameter. Between the narrow planes of the body elements surface-to-surface contact interactions were introduced with the friction coefficient of 0.3. The back wall was connected with the furniture body by housing and the contact interaction between all the surfaces of the back wall and the furniture body. In the case of furniture with doors additionally aluminium hinges were modelled, providing rigid connections with the side and the doors.

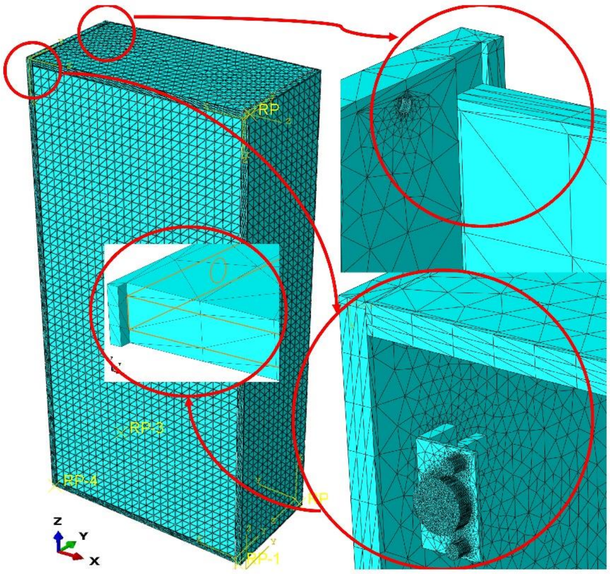

Figure 7. A grid of finite elements on furniture models

Elastic properties of veneers and adhesive, from which facings were formed, are presented in Table 2. Elastic properties of homogenised cores are given in Table 3. Numerical calculations provided values of forces causing deformation of the furniture body and values of deflections in the direction of these forces. In order to calculate stiffness of case furniture the theory of torsion of flat prismatic rods may be applied (Smardzewski, 2015). The dihedral angle of a single panel may be determined from the following equation:

$$\varphi_i = 2(1+\vartheta)\frac{F_i(l_1 l_2)_i}{\beta E_i t^3 l_{2i}} = \frac{dF_i}{l_{2i}} \quad (1)$$

where: F_i – internal force, $dF_i = \delta$ – internal deflection, $(l_1 l_2)_i$ – dimensions of i-th board, t – thickness of i-th board, β – factor dependent on the $(l_2/t)_i$ ratio, for $(l_2/t)_i > 10$, β = 1/3, E_i – Young's modulus of i-th board.

In the case of the analysed structure, work of external force F on external deflection δ is equal to the sum of works of internal forces F_i on internal deflections dF_i of deformed elements:

$$FdF = \sum_{i=1}^{n} F_i dF_i \tag{2}$$

Solving the system of Eqs. (1 and 2) an expression was obtained linking external deflections $dF = \delta$ with internal deflections dF_i:

$$FdF = \sum_{i=1}^{n} \frac{E_i t^3}{6(1+\vartheta)(l_1 l_2)_i} dF_i \tag{3}$$

From the geometry of deformations of the case and from the assumption on the perfect stiffness of board elements in their plane we obtain specific relationships between deflection $dF = \delta$ of vertical external board elements and deflection dF_{ic} of horizontal elements and dF_{ib} of the back wall:

$$dF_{ic} = \frac{a}{c} dF,\ dF_{ib} = \frac{a}{b} dF \tag{4}$$

where: a, b, c, denote width, deep and height of furniture, respectively. Defining deflection of the i-th board in the general form as:

$$dF_i = \alpha_i dF \tag{5}$$

and applying Eqs. (3 and 4), stiffness of a furniture unit subjected to torsion was expressed in the following form:

$$K = \sum_{i=1}^{n} \frac{E_i t^3}{6(1+\vartheta)(l_1 l_2)_i} \alpha_i = \frac{F}{\delta} \text{ (N/mm)} \tag{6}$$

In order to determine the effect of the type of material, furniture structural design and the manner of its support on the stiffness of the furniture body the respective stiffness coefficients were determined using equation (6).

The numerical calculations were performed using the Abaqus v.6.16 programme (Dassault Systemes Simulia Corp., Waltham, Ma, USA) at the Poznań Supercomputing and Networking Centre in the Eagle cluster.

3. RESULTS

Figure 8 presents example deformations calculated for furniture bodies and example values of resultant deflections of the front, left and upper corners. It shows that the greatest deflection $\delta = 132\ mm$ (thus the lowest stiffness) is observed in furniture items without doors supported in three corners (Fig. 8a). Support of the same furniture body in four corners reduces deflections almost 2-fold, to $\delta = 68\ mm$ (Fig. 8b). When the doors are recessed within the furniture body the resulting deflections are additionally decreased and the stiffness of the structure is increased (Fig. 8 c,d). It needs to be stressed here that deflections for furniture bodies supported in three and four corners differ only slightly at $\delta = 16.2\ mm$ vs. $\delta = 13.6\ mm$. Thus the application of doors mounted within the furniture body had a decisive effect.

Figure 9 presents dependencies between loading and deflection for all analysed furniture design structures. Continuous lines mark structures supported in three corners, while broken lines denote structures supported in four corners. For the structure without doors (Fig. 9a) the regularity presented above is confirmed, showing that support of furniture items in four corners increases design loads for the same deflection values. It may also be stated that the application of honeycomb panels only slightly reduces stiffness of furniture bodies in comparison to that of furniture manufactured from reference particleboards. Similar regularities are found in the case of furniture items equipped with doors (Fig. 9b). However, in furniture bodies having no doors we observe a markedly greater stiffness of furniture items supported in three corners. These dependencies are presented more precisely in the form of stiffness coefficients K in Fig. 10.

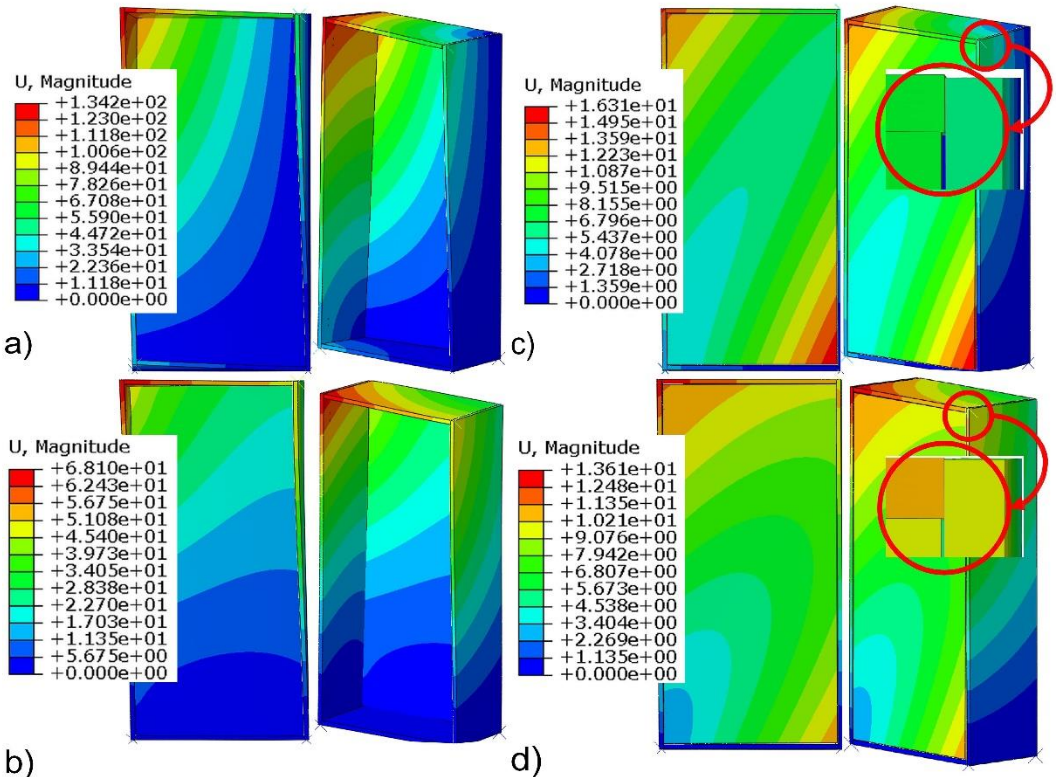

Figure 8. Deformation of furniture (deflection in mm): a,b) without doors, c,d) with doors, supported in three corners (a,c) and in four corners (b.d)

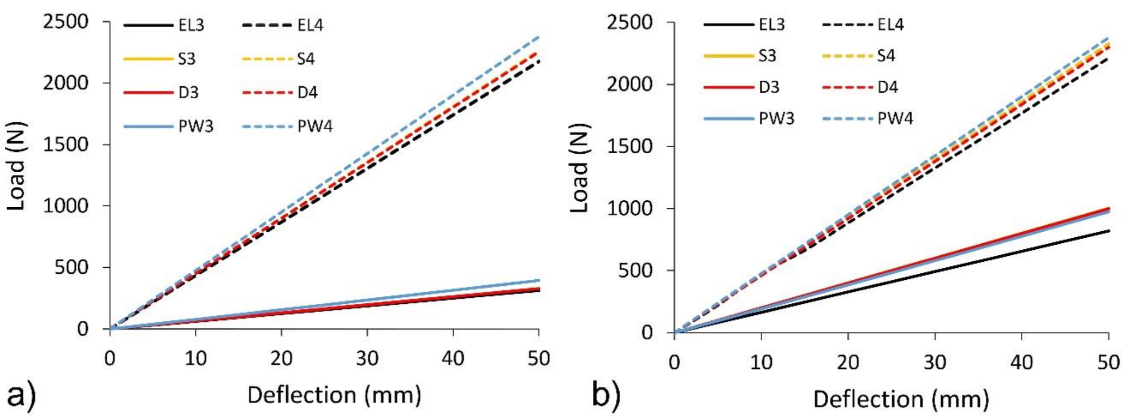

Figure 9. The dependence of force on deflection for furniture items: a) without doors supported in three and four corners, b) with doors supported in three and four corners

It results from Fig. 10a that stiffness coefficient K (N/mm) for furniture bodies supported in three corners ranges from 6.3 N/mm to 7.9 N/mm. The highest values were recorded for furniture manufactured from particleboards, while they were lowest for furniture made from honeycomb panels with an auxetic core. This difference amounts to 20.2 %. In turn, stiffness of furniture supported in four corners is 6- to 7-fold greater compared to that of furniture bodies supported in three corners. Support of furniture items in four corners results in additional stiffening of their base. As a consequence, the bottom element, in contrast to the other structural elements, is not subjected to torsion and it considerably improves furniture stiffness. The use of doors (Fig. 10b) increased values of stiffness coefficients K (N/mm), particularly in those furniture items, which were supported in three corners. Their stiffness compared to that of furniture not equipped with doors increased 2.6- to 3-fold. Also in this case it may be observed that furniture made from particleboards exhibits stiffness by 15.9 % greater than that of furniture made from honeycomb panels (EL). In the case of structures equipped with doors, supported in four corners, their stiffness ranges from 44 N/mm to 47.5 N/mm. The lowest stiffness is found in furniture made from auxetic boards (EL). In comparison to furniture manufactured from particleboard this difference amounts to 7.4 %. In panels with a prismatic core, both double (D) and single (S), stiffness K (N/mm) is reduced by as little as 3.2 %.

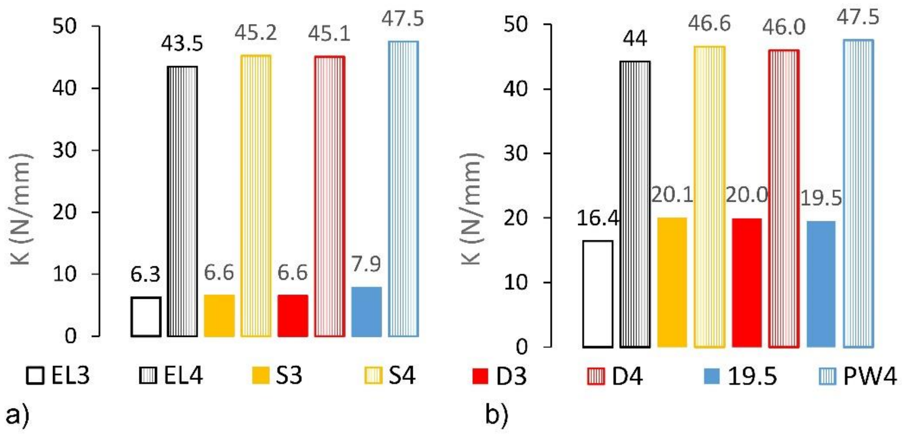

Figure 10. Stiffness coefficient of furniture: a) without doors supported in three and four corners, b) with doors supported in three and four corners

4. CONCLUSIONS

Results obtained based on numerical calculations and their analysis gave grounds for the following conclusions and remarks:

1. Honeycomb panels are very good substitutes for particleboard used when designing case furniture.
2. Stiffness of furniture manufactured from honeycomb panels with density of approx. 400 kg/m^3 compared to furniture made from particleboard with density of 630 kg/m^3 is highly satisfactory. For furniture bodies supported in three corners this difference is min. 20.2 %, while for support in four corners it is 7.4 %.
3. The auxetic character of the core has no positive effect on stiffness of case furniture. This is caused by the torsional character of furniture deformation.
4. Doors mounted as recessed into the furniture body have a considerable effect on furniture stiffness. This effect is comparable to the effect of furniture support in four corners.

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FEM Analysis of Deformations and Stresses of an Upholstered Furniture Frame with OSB Side Plates

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ABSTRACT

A linear static analysis (FEA) of frame 3D model for one-seat upholstered furniture was carried out with a CAD/CAE system by the method of finite elements (FEM) simulating light-service loading of the frame. The orthotropic material characteristics of pine solid wood (*Pinus sylvestris* L.) for the rails and OSB for the side plates were considered in the analysis. Two variants of corner joints in the frame (model A – staples and PVAC; model B - staples, PVAC and strengthening elements under rails of the seat) were considered. FEA was performed with regard to laboratory determined and calculated coefficients of rotational stiffness of used staple corner joints. As results, the distribution of displacements (linear and nodal) and principal stresses in the 3D discrete model of upholstered furniture frame with staple corner joints are presented and analysed. Under light-service load, the most loading construction part of the considered furniture frame is the rear rail of the seat and its joints with the side plates of OSB, where the maximum values of linear displacements, nodal rotations and stresses are received due to the nature of the applied force. The strengthening of the seat rails to side plate joints with solid wood components influences the deformability and strength of the considered furniture frame with side plates of OSB – the linear displacements are reduced with 29 %, nodal rotations with 25 %, tension stresses are reduced with 20 %, compression stresses with 18 %. The deformation and strength behaviour of side plates of OSB is considerably improved – the linear displacements and nodal rotations are reduced approximately with 45 %, tension stresses – 23 %, compression stresses - more significantly with 64 %.

Key words: deformations and stresses, FEM, OSB, *Pinus sylvestris* L., staple corner joints, upholstered furniture frame

1. INTRODUCTION

The skeleton of upholstered furniture is usually wood and/or wood-based products. Although the wood composites are commonly used in box type furniture, their utilization in the frame type furniture is not widespread. It is recommended that wood composites could be used in the production of the frame type furniture, especially in the upholstered furniture frames, but, in this case, it is important according to material type used that the additional reinforcing details and giving a decision about its place (Kasal, 2006).

There is limited number of references concerning the deformation behaviour of upholstered frames constructed with structure elements of OSB, although OSB panels are increasingly used in the construction of upholstered furniture frames latterly.

Wang (2007a) has investigated a three-seat sofa frame made entirely of 18 mm thick OSB plates. With software SAP 2000 author have created 3D linear models by beam finite elements of three different constructions of a sofa frame with two types of connections – rigid and semi-rigid and two types of connectors: 1) screws and metal plates, and 2) staples and metal plates. Nonlinear static analysis has been performed simulating three loads: light-, medium- and heavy-service. Wang has established the most appropriate configuration of the sofa frame of OSB under investigated loads and has concluded that the type of connectors does not change the joint displacements remarkably.

Erdil *et al.* (2008) have investigated the behaviour of three-seat upholstered furniture frames constructed with 3/4-inch thick OSB (EN 300, 1997) and joining elements – yellow birch dowels and aliphatic resin glue (PVAC) using the simplified methods of structural analysis in the engineering of such frames. They have concluded that OSB may be used in construction of upholstered furniture frames to meet specific design loads.

Kasal (2006) has investigated the strength properties of glued-dowel joined sofa frames constructed of solid wood and wood based composite materials by using the finite beam elements by CAE. Considering wood materials as isotropic, author has established that the OSB (18 mm thick) has lowest load bearing capacity. The failure of OSB sofa frame has been the pull-out of dowels from the member with some core wood particles attached to the dowel and some splits have occurred at the edge of the butt members in the sofa frames.

More information concerning the strength characteristics of upholstered furniture joints made of OSB is available: Jivkov *et al.* (2003) have established the ultimate bending strength under compression of end corner joints of 18 mm thick OSB with different connectors – screws, dowels, "Confirmat"; Wang *et al.* (2007b, 2007c) have investigated T-shape corner gusset-plate joints with staples and with/without PVAC glue of details of 18 mm thick OSB panels under static bending, torsion and fatigue load. They have concluded that the static bending strength increases with 27 % when the reinforcing elements are glued. They have established that both stapled and glued stapled joints had similar static-to-fatigue moment capacity ratios.

Data about strength characteristics of other joints of OSB for upholstered furniture in tension, shear, bending and cyclic loads are given by Erdil *et al.* (2008) in the result of previous researches for dowel joints of different construction elements (front rail to stump, top rail to back post and back post to top rail joints of 4-inch thick OSB); Zhang *et al.* (2001a, 2002) for dowel joints; Wang *et al.* (2007d, 2008) for metal-plate connected joints; Zang *et al.* (2001b) for gusset-plate joints; Dai *et al.* (2008) for glued face-to face and end-to-face joints.

The literature study revealed a limited number of publications on frame strength studies of upholstered furniture with staple joints and side plates made of OSB.

The aim of this study was to define and analyse the displacements and stresses of one-seat frame of upholstered furniture with staple joints and side plates of OSB by CAD/CAE using the method of finite elements (FEM).

2. MATERIALS AND METHODS

3D model of one-seat upholstered furniture frame with length 600 mm, width 725 mm and height 650 mm was created with Autodesk Inventor Pro® (Educational product) (Fig. 1). The used rails are with cross section 25×50 mm.

A linear static analysis of each 3D modelled frame was carried out with CAD/CAE system Autodesk Simulation Mechanical® by the Finite Elements Method (FEM). Two discrete models were created – *model A* without and *model B* with strengthening details under the rails of the seat with a shape of triangle prism (70,7×70,7×25 mm) and two design scenarios were performed (Fig. 1). The generated Midplane mesh has 5130 orthotropic plate finite elements and 33616 DOF's for *model A* and 5230 orthotropic plate finite elements and 34096 DOF's for *model B*.

Orthotropic materials type was used for construction elements of the skeleton models:

Scots pine (*Pinus sylvestris* L.) for rails and strengthening details with measured density 430 kg/m³ according to BDS EN 323:2001 and elastic characteristics: $E_z = E_L = 9000 \times 10^6$ N/m^2,

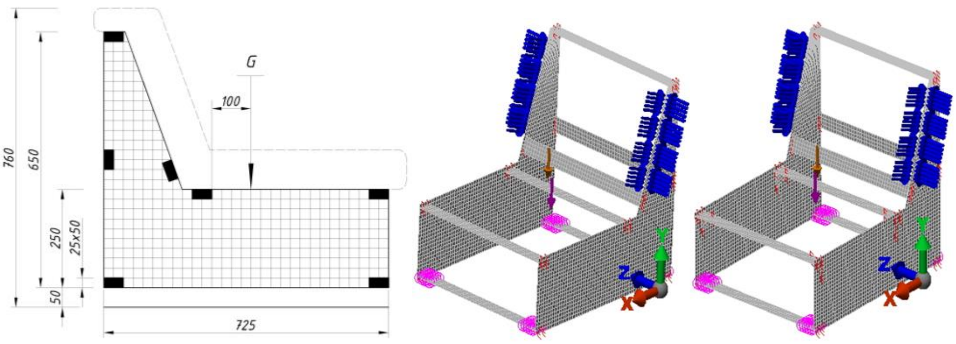

Figure 1. 3D frame models A and B and loading

$E_x = E_T = 593 \times 10^6$ N/m², $G_{LT} = 554 \times 10^6$ N/m², $\nu_{LT} = 0.027$, $\nu_{LR} = 0.03$, $\nu_{TL} = 0.41$, $\nu_{RL} = 0.49$.

Oriented strandboard (OSB), type EGGER OSB2 EN 300 E1 CE, designed for load-bearing structures for use in a dry environment with thickness 15 mm and technical requirements according to BDS EN 13986:2004+A1:2015 were used for side plates. The physical and mechanical characteristics of the OSB panels are: density 596 kg/m³, measured according to BDS EN 323:2001; modulus of elasticity in bending (major axis) – $E_x = E_{/\!/} = 3500 \times 10^6$ N/m²; modulus of elasticity in bending (minor axis) – $E_y = E_{\perp} = 1400 \times 10^6$ N/m²; Poisson ratios ν_{xy}=0,30 according to Thomas (2003) and ν_{yx}=0,24, calculated according to Bodig and Jayne (1982) by the equation:

$$\frac{\nu_{xy}}{E_x} = \frac{\nu_{yx}}{E_y} \quad (1)$$

Support boundary conditions were set: bottom front rail – no translation on *y* direction and bottom rear rail no translation on *x*-, *y*- and *z* direction (Fig. 1).

In order to simulate semi-rigid connections between rails and side plates of the frame, two actions were performed: First – narrow zones were created in the place of joints in the discrete model with established via tests by FEM lower modulus of elasticity of the used materials perpendicular to the common edge of the corner joint; Second – the laboratory determined by Hrisodorova (2019) coefficients of rotational stiffness of the corner joints with two staples (type M1) and PVAC glue, loading under compression were introduced in the nodes of the respective corner joints – case butt joints (*c*=767 Nm/rad) and end to face butt joints (*c*=510 Nm/rad).

The both discrete skeleton models were loaded with a total load of 800 N, distributed as follows (Fig. 1): *Seat:* 80 % were set as a remote force, distributed between upper rails of the seat with application point of 100 mm in front of the upper rear rail, simulating upholstery base made of zig-zag springs; *Backrest:* 16 % were set as equal nodal forces, distributed on the edges of the two sides of the backrest simulating elastic belts.

The validity of this approach has been proven and discussed in author's previous publication (Staneva *et al.*, 2018).

3. RESULTS AND DISCUSSION

The results for linear displacements *u*, nodal rotations θ, and principal stresses for both *models A* and *B* are shown in Table 1, Table 2 and in Fig. 2 to Fig. 9 for the upholstery frame and for the side plates of the frame respectively. The visualizations of the deformed model are shown with a scale factor 3 % of model size for the frame, and with a scale factor 5 % of model size for the side plates.

In Fig. 2 the distribution of resultant displacements is presented. The maximal resultant displacements of 2.73 mm for *model A* and 1.93 mm for *model B* are received in the middle of the rear rail of the seat, on the inside of the rails and are determined mainly by the *y*-displacements (u_y) (Table 1). The resultant displacement is 1.4 times greater in *model A* than the same in *model B.*

The maximal resultant nodal rotations θ_{res}=1.86° for *model A* and θ_{res}=1.39° for *model B* are located in the rear rail for both models (Fig. 4) and they are determined mainly by rotations about *z*-axis (Table 1). The resultant nodal rotations of *model A* are approximately 1.3 times greater than the same in *model B.*

Table 1. Maximal values of displacements of the frame

Parameter	Location	Frame A	Frame B
u_x×10^{-3} [m]	side plates	0,04	0,05
u_y×10^{-3} [m]	front rail rear rail	-1.41 -2.73	-1.02 -1.93
u_z×10^{-3} [m]	side plates	0.20	0.48
θ_x [°]	rear rail	0.80	0.55
θ_y [°]	side plates	0.15	0.15
θ_z [°]	front rail rear rail	1.80 -1.86	1.33 -1.39

Table 2. Maximal values of displacements of the side plates

Parameter	Location	Side plates A	Side plates B
u_x×10^{-3} [m]	front rail rear rail backrest	-0.063 0.034 0.019	0.040 0.032 0.038
u_y×10^{-3} [m]	front rail rear rail	0.172 -0.175	0.033 -0.076
u_z×10^{-3} [m]	base rear rail backrest	0.204 -0.143 -0.129	0.476 -0.075 -0.152
θ_x [°]	front rail rear rail	-0.32 -0.62	-0.184 -0.371
θ_y [°]	rear rail	-0.147	-0.148
θ_z [°]	front rail rear rail	0.416 -0.209	0.112 -0.051

In the side plates the maximum values of the resultant displacement for both models are received in the places of the base where dissolution of the side plates is observed (Fig. 2 and Fig. 3).

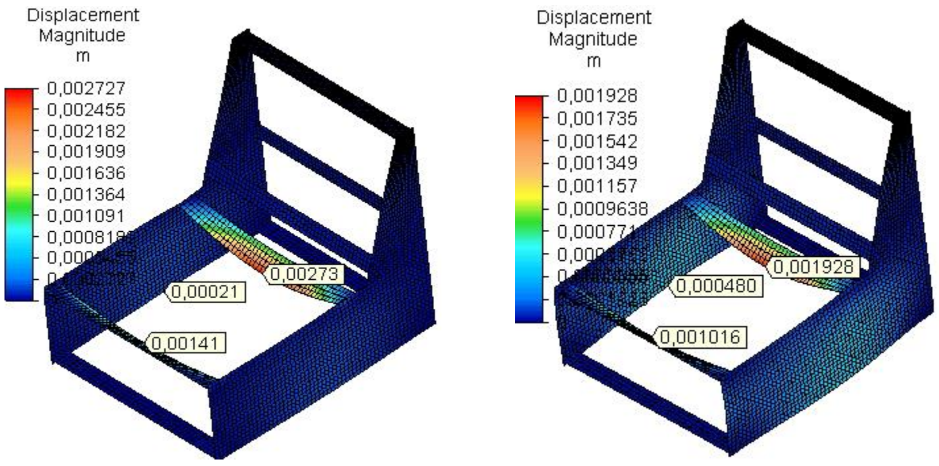

Figure 2. Distribution of resultant displacements for model A and model B

This is due to the fact that the resultant displacements are determined mainly by *z*-displacements (u_z) (Table 2). The resultant displacement in the base of *model B* are 2.3 times greater that this of *model A* because of rearrangement of displacements due to the strengthening details. In *model B* in the field of the rear rail of the seat the resultant displacement is reduced 1.8 times and 2 times in the field of front rail of the seat.

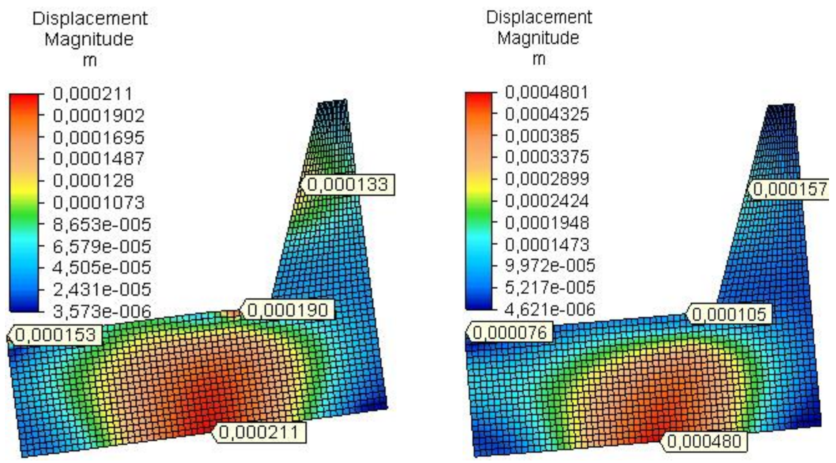

Figure 3. Distribution of resultant displacements in the side plates for model A and model B

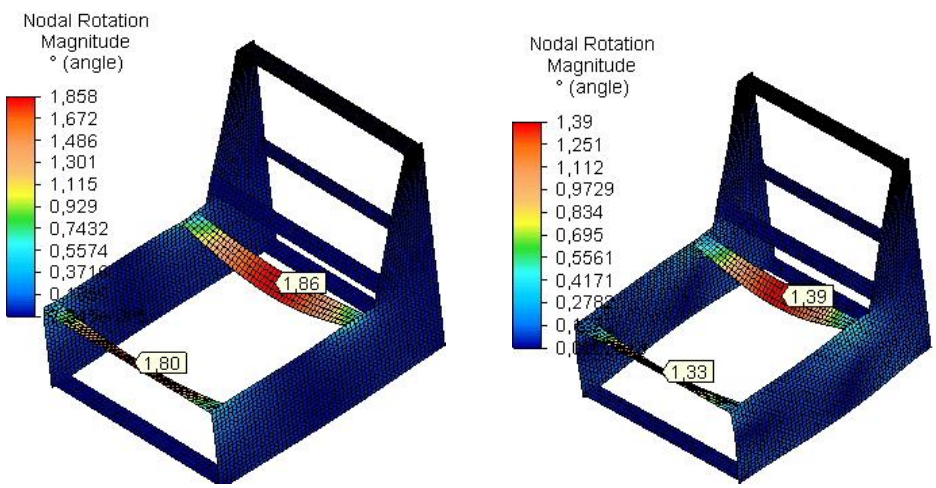

Figure 4. Distribution of resultant rotational displacements for model A and model B

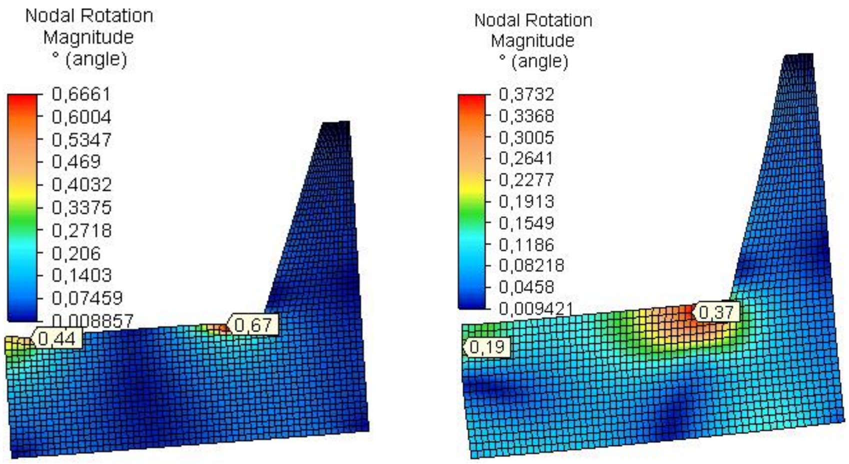

Figure 5. Distribution of resultant rotational displacements in the side plates for model A and model B

Maximal values of resultant nodal rotation in the side plates are received in the contact field with the rear rail for both models (Fig. 5). The resultant nodal rotations in the side plates of *model A* are 1.8 times greater in the field of rear rail and 2 times in the field of front rail than the same in *model B.*

The results for maximum principal stresses – tension stresses and minimum principal stresses – compression stresses for both *models A* and *B* are shown in Fig. 6 to Fig. 9 for the frame and for the side plates of the frame respectively.

For *model A* the maximum principal stresses (tension (+)) and the minimum principal stresses (compression (-)) have maximal values located in the rear rail of the seat at the bottom and on the top respectively (Fig. 6 and Fig. 7). For *model B* maximal values of the tension and compression stresses are located in the strengthening details of the rear rail of the seat.

The tension and compression stresses in the rear and in the front rail of the seat decrease approximately 1.25 times and 1.1 times respectively in the *model B*, comparing to the same in *model A.*

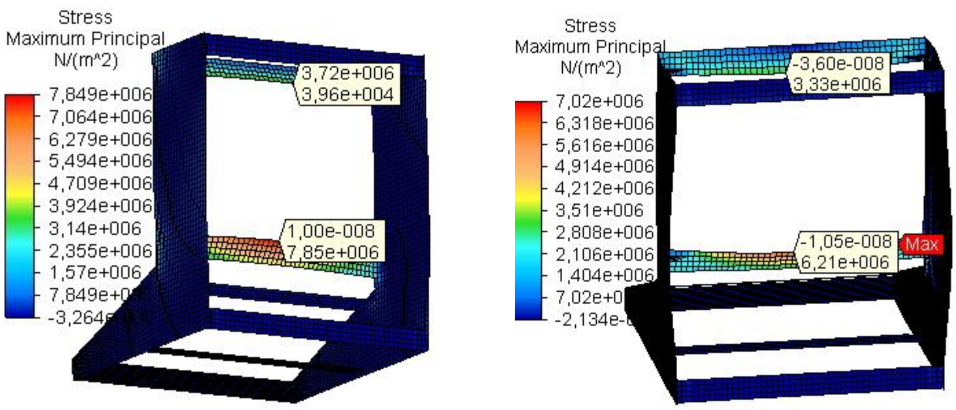

Figure 6. Distribution of maximum principal stresses for model A and model B

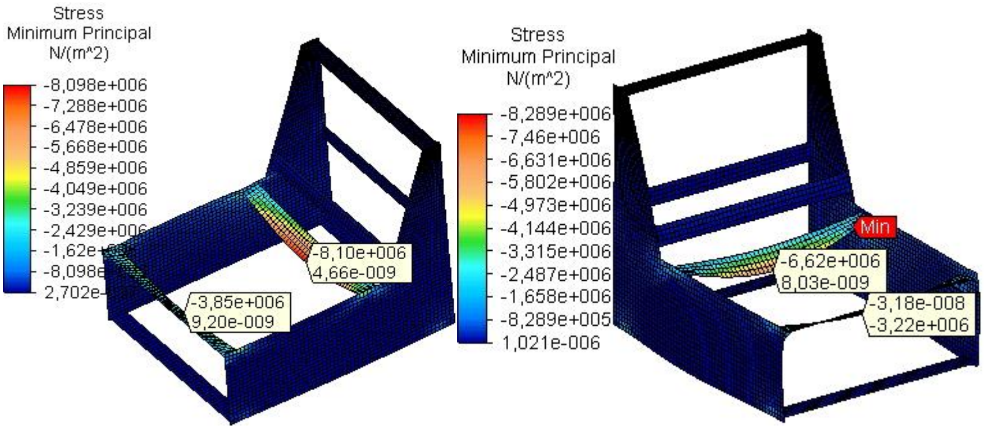

Figure 7. Distribution of minimum principal stresses for model A and model B

In the side plates of OSB the maximal values of tension stresses are located in the field of front rail for *model A* and in the field of rear rail for *model B* (Fig. 8). The maximal values of compression stresses in the side plates are located in the field of rear rail for both models (Fig. 9). It was established a reduction of the maximal values of tension stresses almost 1.3 times and reduction of the maximal values of compression stresses approximately 2.8 times in the side plates of the frame for *model B* comparing to the same in *model A.*

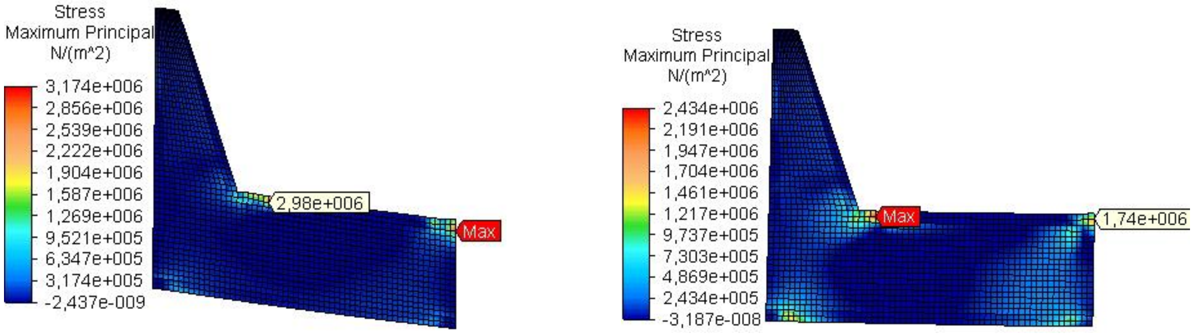

Figure 8. Distribution of maximum principal stresses in the side plates for model A and model B

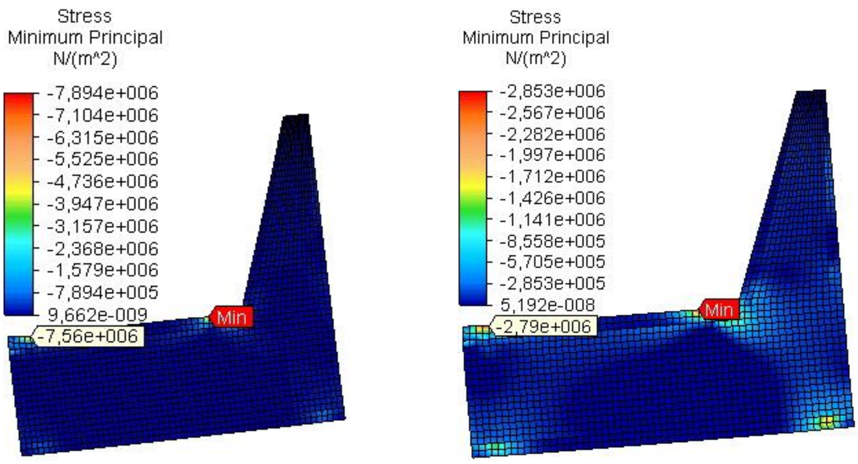

Figure 9. Distribution of minimum principal stresses in the side plates for model A and model B

4. CONCLUSIONS

From the results of this study by FEM on the deformations and stresses of one-seat upholstered furniture frame with staples and glue joints made of Scots pine and OSB side plates several conclusions can be derived:

Under the light-service load, the most loading construction part of the skeleton with side plates of OSB is the rear rail of the seat where the maximum values of linear displacements, nodal rotations and stresses are received due to the nature of the applied force.

The strengthening with solid wood components of the rails of the seat to side plates joints influences the deformability of the skeleton with side plates of OSB – the linear displacements reduce with 29 % and nodal rotations reduce with 25 %. The strengthened frame with side plates of OSB has greater stiffness.

The reinforcement of the rails of the seat to side plate joints with solid wood components improves the strength behaviour of the skeleton with side plates of OSB – the tension stresses are reduced with 20 %, compression stresses with 18 %. The strength behaviour of the side plates is also improved after reinforcement – tension stresses are reduced with 23 %, compression stresses – more significantly with 64 %.

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Effect of Material Characteristics on the Displacements and Stresses of Upholstery Furniture Frame with Staple Corner Joints

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ABSTRACT

A linear static analysis of a frame 3D model for one-seat upholstered furniture was carried out with a CAD/CAE system by the method of finite elements (FEM) simulating light-service loading of the frame. Two FEM models were analyzed for two material characteristics of the construction elements - isotropic and orthotropic of pine solid wood *(Pinus sylvestris* L.) for the rails and PB for the side plates and two design scenarios were performed. Corner joints in the frame – staples and PVAc were considered. FEA was performed with regard to laboratory determined and calculated coefficients of rotational stiffness of used staple corner joints. As results the distribution of displacements (linear and nodal) and principal stresses in both 3D discrete models of upholstered furniture frame with staple corner joints isotropic and orthotropic are presented and analyzed. It was established that displacements and stresses of the orthotropic model are greater than the same of isotropic model with 16 % for linear displacements, 102 % for the nodal rotations and 22 % for tension and compression stresses in the rear rail of the seat that is way the orthotropic characteristics must be taken into account in the FEM analyses of upholstered furniture frames.

Key words: deformations and stresses, FEM, isotropic and orthotropic, staple corner joints, upholstered furniture frame

1. INTRODUCTION

Strength and deformation characteristics of upholstered frames are very important to ensure optimal design of upholstered furniture. In our days deformation and strength design of furniture constructions can be accomplished by 3D solid modeling and structural analysis software based on Finite Element Method (FEM). The more important factors impact the furniture structure’s behavior are the material characteristics of the construction elements and joints between them. The literature study revealed a limited number of publications on deformation and strength studies of upholstered furniture frames by FEM taking into account the orthotropic characteristics of used materials.

In Bulgaria first attempt to study by FEM with computer program SAP 90 of wooden chair frame has made by Marinova and Kyuchukov (1999) using the developed by Marinova (1996) methodology of stress and strain furniture structure analysis of case furniture. The methodology considered the *orthotropic* characteristics of used materials and it is adapted according to specific characteristics of furniture structure by taken into account of the pliability of furniture corner joints under loading – test established spring constants of elastic fixation have been imported in the program.

First attempts of numerical investigation of construction frame of upholstered furniture were undertaken by Smardzewski (2001): he has carried out finite element analysis of the skeleton of one-seat armchair that resulted in lower material consumption and assures optimal strength of the construction using Algor® CAE program, but he has modeled the materials of the construction elements (birch wood and chipboards) as *isotropic* brick finite elements, that is unjustified.

Yang *et al*. (2002) have proposed a modified structural design by two-dimentional system of the FEM for wooden school desk and chairs and wood is treated as *orthotropic* material.

Further Smardzewski and Papuga (2004) have used Algor® package for analysis of structural strength of a chair subjected to real loads considering the *orthotropic* characteristics of beech wood.

Kasal (2006) has investigated the strength properties of glued-dowel joined sofa frames constructed of solid wood and wood based composite materials by using RISA 3D finite element analysis software. Considering wood materials as *isotropic*, he has established that the OSB has lowest load bearing capacity. Kasal has not compared numerical and experimental results.

Further Smardzewski and Prekrat (2009) have used Algor® CAE for optimization of dimensions of the main construction elements of 2-seat sofa frame modeled with brick *orthotropic* finite elements (HDF boards for seat and backrest, particle boards for side elements and pine and beech wood for beam elements). Although authors do not considered the real behavior of the corner joints of the sofa construction elements they have established differences ranged from 2 % to 14 % comparing numerical and laboratory results for deflections and stresses.

Wang (2007) has carried out nonlinear static analysis using finite element software SAP 2000 of three configurations of 3-seat sofa skeleton made entirely of OSB. The sofa frame is modeled by 3D linear frame-type (beam) *orthotropic* elements with two types of connections (screws with metal-plates and staples with metal-plates). Wang has used rigid and semi-rigid types of links in the models and has established the most appropriate configuration of the sofa frame of OSB under investigated loads and has concluded that the type of connectors does not change the joint displacements remarkably.

Derikvand *et al.* (2015) have investigated the semi-rigid behavior of different joints for a chair under a bending load by ANSYS and considered the *orthotropic* characteristics of Pine wood. They have estabished differences between the FEM and experimental results for the stiffness values that are ranged from 2.90 to 31.77 %.

Yildirim *et al.* (2015) investigated the fatigue behaviour of M&T joined armchair frames constructed of Scots Pine with *isotropic* characteristics by ANSYS Workbench software. Authors have established that there are close convergence between experimental study and FEM results - the consistency level was 81.25 %.

Langova *et al.* (2019) have taken into account the *orthotropic* characteristics of wood-based lamella in the FEM analysis of flexible chairs under different ultimate loads, forming from different weight gain of a population.

Tankut *et al.* (2014) have made an review of the FEM applied in the analysis of furniture products constructed with wood, but have not discussed the impact of the material characteristics on the obtained results.

Hajdarević and Busuladžić (2015) are the first that have compared the results obtained on the stiffness of a *isotropic* and *orthotropic* frame of wooden furniture frame. Three 3D FEM numerical examples of chair's side-frame were analysed using Catia software: orthotropic with joints, orthotropic without joints and isotropic. Examples are given for chair's side-frame of maple wood. The analysis of the orthotropic model (with and without joints) and isotropic model revealed that a maximum stiffness has the isotropic model of frame. The effects of the orthotropic properties of wood and joints on the frame's stiffness are evident – minimum stiffness or a maximum deformation has an orthotropic model of frame with joints as a result of the interaction between elements of the joints, following from the orthotropic model without joints and isotropic model. Authors have estabished that the difference between the results obtained for isotropic model and orthotropic model with joints is largest: 35 %-40 %. Authors have not discussed the stresses in the models.

The aim of this study was to define and to compare the displacements and principal stresses of one-seat upholstered furniture frame with staple joints and side plates of PB taking into account the isotropic and orthotropic material’s characteristics of the construction elements by the method of finite elements (FEM) using a CAD/CAE program.

2. MATERIALS AND METHODS

3D model of one-seat upholstered furniture frame with folowing dimentions - length 600 mm, width 725 mm and height 650 mm was created with Autodesk Inventor Pro® (Educational product) – Fig.1. The used rails are with cross section 25×50 mm. A linear static analysis of each 3D modeled frame was carried out with CAD/CAE system Autodesk Simulation Mechanical® by the Finite Elements Method (FEM).

Two discrete models were created – *isothropic* and *orthotropic*. The generated Midplane mesh has 5130 plate finite elements and 33616 DOF's for each model. Two design scenarios were performed.

Isotrhropic and Orthotropic materials type was used for construction elements of the frame models:

Scots pine (*Pinus sylvestris* L.) for rails and strengthening details with measured density 430 kg/m³ according to BDS EN 323:2001, and elastic characteristics:

Isothropic: $E_z = E_L = 9000 \times 10^6$ N/m^2 and $\nu_{LT} = 0.027$.

Orthotropic: $E_z = E_L = 9000 \times 10^6$ N/m^2, $E_x = E_T = 593 \times 10^6$ N/m^2, $G_{zx} = G_{LT} = 554 \times 10^6$ N/m^2, $\nu_{LT} = 0.027$, $\nu_{TL} = 0.41$.

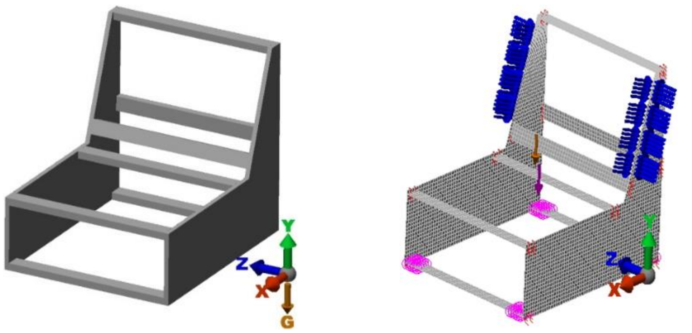

Figure 1. 3D frame model and loading

Particleboard (PB) for side plates with thickness 16 mm and measured density 678 kg/m³ according to BDS EN 323:2001:

Isothropic: modulus of elasticity in bending $E_y = E_\perp = 2700 \times 10^6$ N/m^2 and Poisson ratios $\nu_{yx} = 0.30$.

Orthotropic: modulus of elasticity in bending $E_y = E_\perp = 2700 \times 10^6$ N/m^2 and $E_x = E_{/\!/} = 1600 \times 10^6$ N/m^2; Poisson ratios $\nu_{xy} = 0.18$ and $\nu_{yx} = 0.30$ according to Bodig J. and B. Jayne (1982).

Support boundary conditions were set: bottom front rail – no translation on *y* direction and bottom rear rail no translation on *x*-, *y*- and *z* direction (Fig.1).

In order to simulate semi-rigid connections between rails and side plates of the frame two actions were performed:

First – narrow zones were created in the place of joints in the discrete model with established via tests by FEM lower modules of elasticity of the used materials perpendicular to the common edge of the corner joint. This idea was proposed first from Cai and Wang (1993) for case furniture.

Second – the laboratory determined by Hristodorova (2019) coefficients of rotational stiffness of the corner joints with 2 staples (type M1) and PVA’c glue, loading under compression were introduced in the nodes of the respective corner joints - case butt joints (c=1018 Nm/rad) and end to face butt joints (c=767 Nm/rad).

The both discrete frame models were loaded with a total load of 800 N, distributed as follows (Fig. 1):

Seat: 80 % were set as a remote force, distributed between upper rails of the seat with application point of 100 mm in front of the rear rail of the seat, simulating upholstery base made of zig-zag springs;

Backrest: 16 % were set as equal nodal forces, distributed on the edges of the two sides of the backrest simulating elastic belts.

The validity of this approach has been proven and described in our previous publication – Staneva *et al.* (2018).

3. RESULTS AND DISCUSSION

The results for linear displacements, nodal rotations and principal stresses for both *models isotropic* and *orthotropic* are shown in Fig.2 to Fig.9 for the upholstery frame and for the side plates of the frame, respectively. The visualizations of the deformed model are shown with a scale factor 3 % of model size for the frame and with a scale factor 5 % of model size for the side plates.

In Fig.2 the distribution of resultant displacement is presented. The maximal resultant displacement of 2.30 mm for *isotropic model* and 2.68 mm for *orthotropic model* are received in the same place of both models – in the middle of the rear rail of the seat. The maximal resultant displacement is 1.2 times greater in *orthotropic model* than the same in *isotropic model* in the rear rail of the seat and 1.4 times in the front rail.

In the base of the side plates the resultant displacement is 1.4 times greater in *orthotropic model* (Fig.2 and Fig.3). In the field of connection of rear and front rail of the seat it is reduced 1.2 times and 1.5 times in *orthotropic model*, respectively. In the field of the backrest resultant displacement is almost the same in both models (Fig. 3).

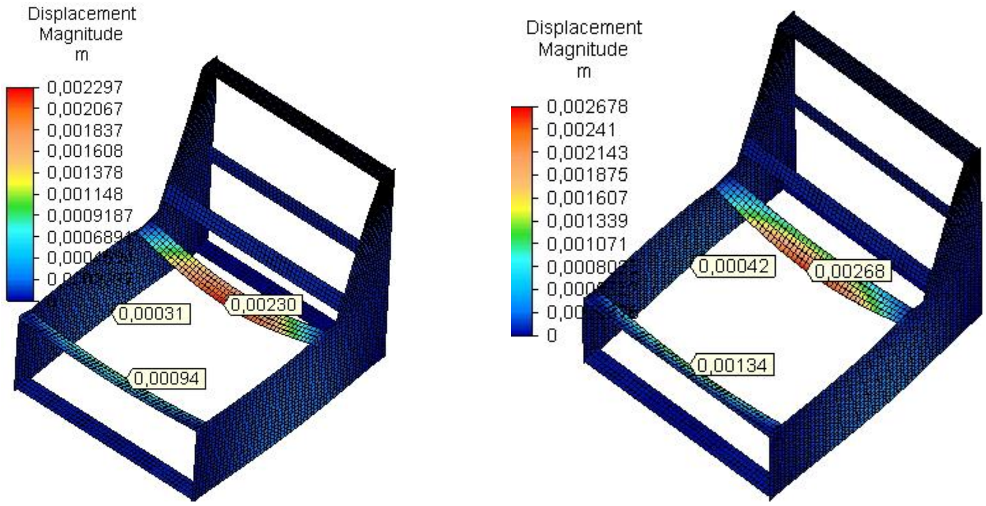

Figure 2. Distribution of resultant displacements for isothropic and orthotropic model

The maximal resultant nodal rotations are obtained in the rear rail of the seat in both models, but in different field (Fig.4) and are 2,8 times greater in *orthotropic model* than the same in *isotropic model.* In the front rail of the seat in both models maximal resultant nodal rotation is obtained in the middle of the rail and is 2 times greater in *orthotropic model.*

In the side plates, in the field of rear and front rails of the seat maximal resultant nodal rotations are aproximately 1.2 and 1.3 times greater for *orthotropic model* – Fig. 5.

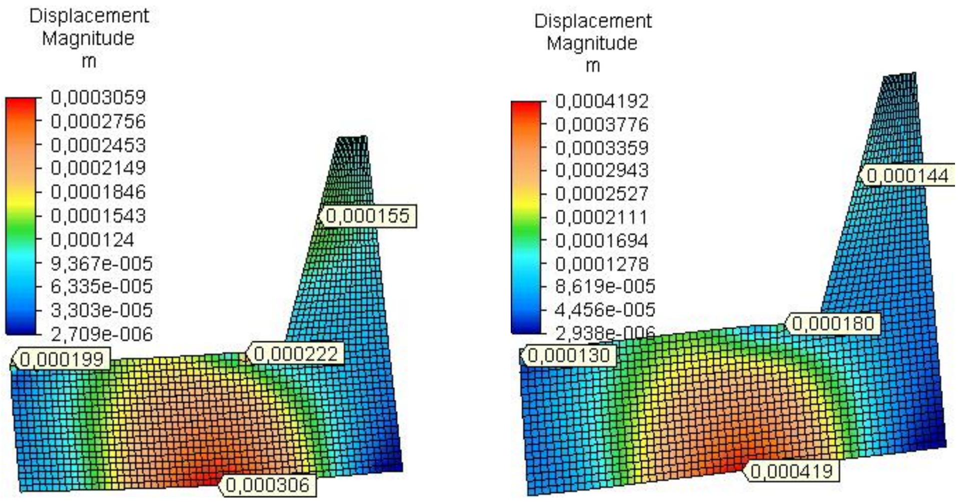

Figure 3. Distribution of resultant displacements for isothropic and orthotropic model in side plates

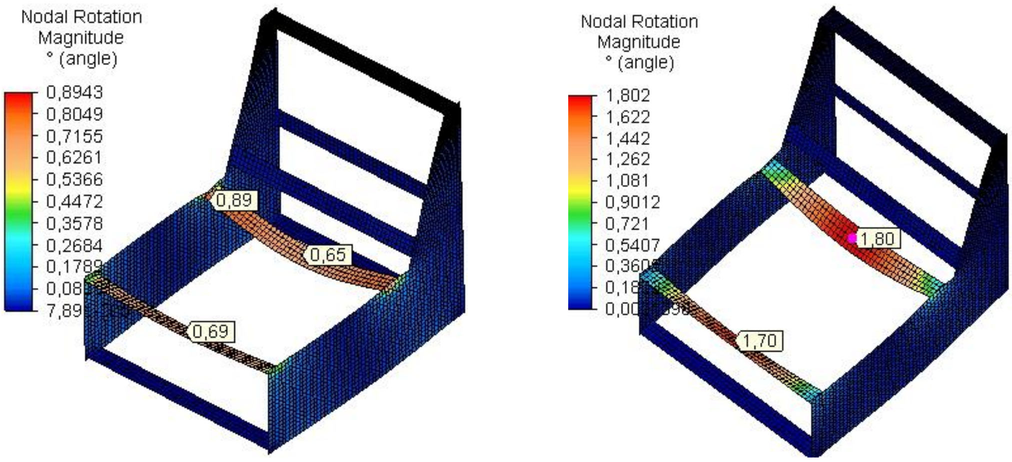

Figure 4. Distribution of nodal rotations for isothropic and orthotropic model

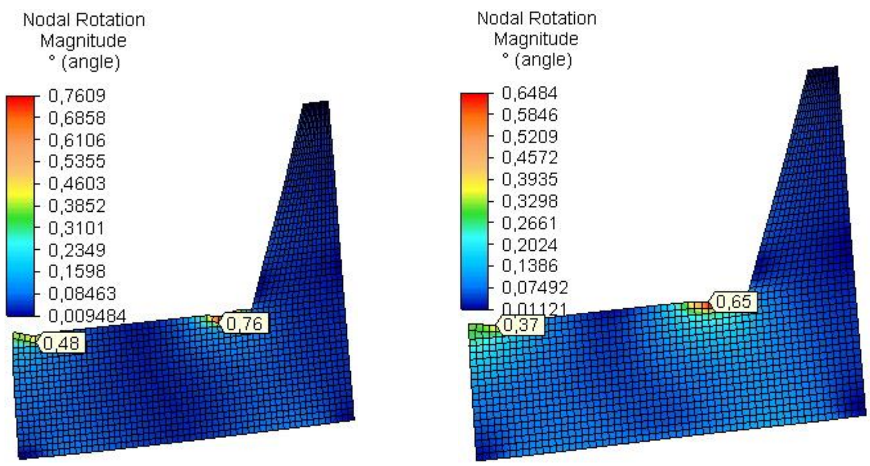

Figure 5. Distribution of nodal rotations in side plates for isothropic and orthotropic model

The results for maximum principal stresses (tension stresses) and minimum principal stresses (compression stresses) for both *models isotropic* and *orthotropic* are shown in Fig. 6 to Fig. 9 for the frame and for the side plates of the frame respectively.

The maximum value of tension stress in the model was obtained in the middle of the rear rail of the seat and is 1.2 times greater in *orthotropic model – Fig. 6.*

In the side plates the maximum value of tension stresses was obtained in the field of connection of rear rail of the seat and is 9 times greater in *orthotropic model* than the same in *isotropic model* – Fig. 7. In the field of connection of front rail of the seat tenssion stresses are almost the same for both models.

The maximal value of compression stress has received in the middle of the rear rail of the seat for both models (Fig. 8) and is 1.2 times greater in *orthotropic model*.

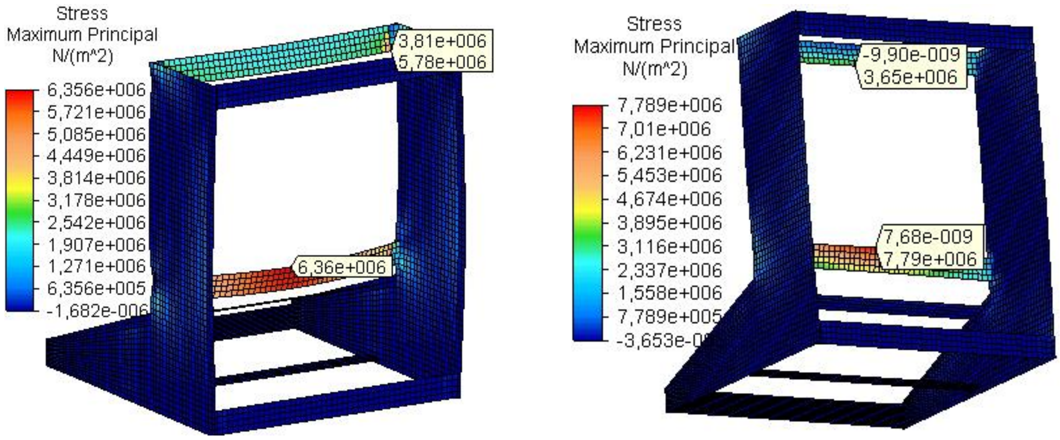

Figure 6. Distribution of maximum principal stresses for isothropic and orthotropic model

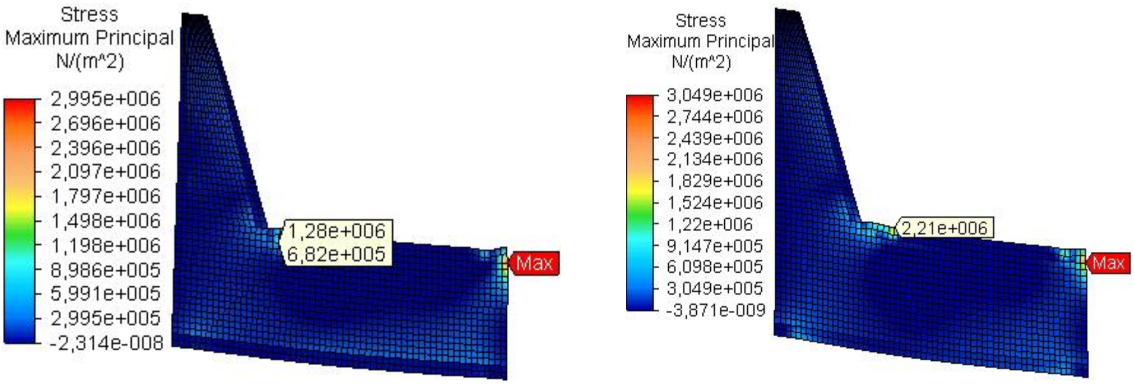

Figure 7. Distribution of maximum principal stresses in the side plates for isothropic and orthotropic model

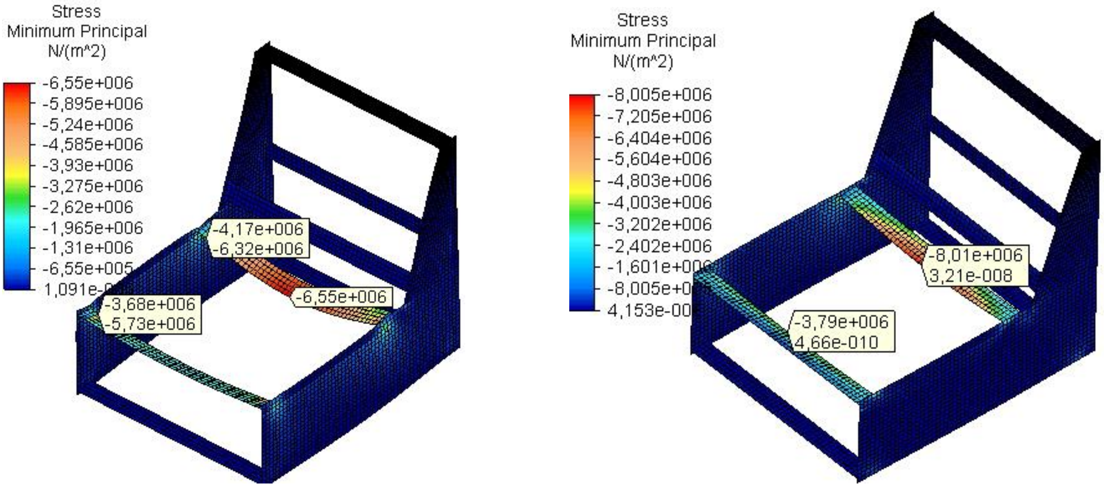

Figure 8. Distribution of minimum principal stresses for isothropic and orthotropic model

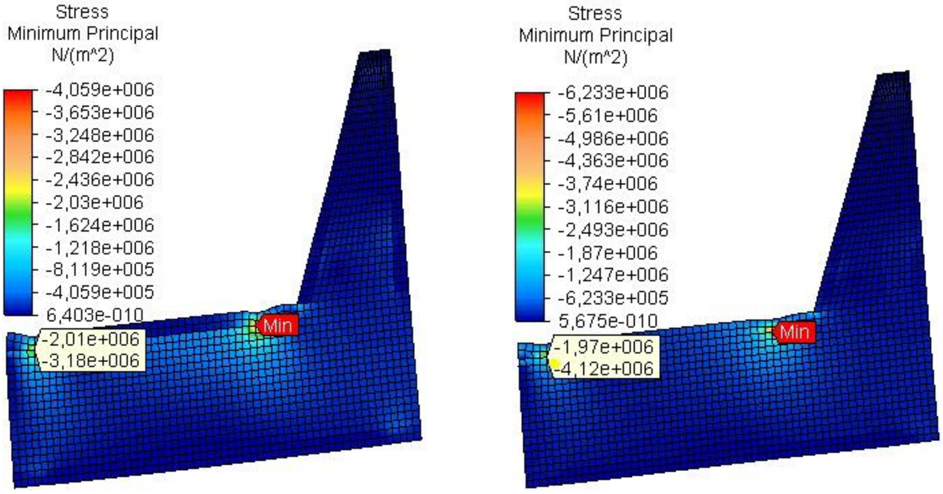

Figure 9. Distribution of minimum principal stresses in the side plates for isothropic and orthotropic model

In the side plates the maximal value of compression stress is located in the field of connection with the rear rail for both models (Fig. 9) and it was established an increasing of almost 1.5 times in *orthotropic model*. In the field of connection of front rail of the seat the maximal value of commpression stress is 2 times greater in *orthotropic model.*

4. CONCLUSIONS

From the results of this study by FEM on the deformations and stresses of one-seat upholstered furniture frame with staples and glue joints made of Scots pine and PB side plates under light-service load and taking into account isotropic and orthotropic characteristics of used materials several conclusions can be derived:

It was established that maximal resultant displacements of the orthotropic model are greater than the same of isotropic model with 16 % for linear displacement and 102 % for the nodal rotation in the rear rail of the seat.

It was established that both maximal tension and compression stresses in the rear rail of the seat of orthotropic model are greater than the same of isotropic model with 22 %.

In the side plates of orthotropic model maximal linear displacement in the field of connection with rear rail of the seat is greater with 19 % while the maximal nodal rotation is reduced with 14 %. The maximal compression stress in the fild of connection of rear rail of the seat is greater with 53 % for orthotropic model while the maximal tension stress is almost the same for both models.

The orthotropic upholstered furniture frame has greater displacements (less stiffness) and greater principal stresses (tension and compression), that is way the orthotropic characteristics must be taken into account in the FEM analysis in order to receive more real results.

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Internationalization of Small and Medium-Sized Wood Industry Businesses

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ABSTRACT

Small and medium-sized enterprises (SMEs) are the key driver of economic development. They have a significant share in GDP, job creation, exports, and so on. In the EU, over 99 % of the total number of enterprises belongs to small and medium-sized enterprises. The number of small and medium-sized businesses has significantly increased in recent years and they make up over 99 % of the total number of enterprises in the Republic of North Macedonia. Internationalization is one of the essential elements of globalization. It is a way to expand the horizons of SMEs, to expand production on the international market, increase demand and customer numbers, make activities of the enterprise to be responsibility not only its managers, but also agents, distributors, managers who will work in the field of international business. Furthermore, by employing local workers, reduce costs, and to create positive relationships with the foreign country, to present domestic brand in foreign markets, and over time to become a brand in other countries, and so on. Internationalization is increasingly important for the competitiveness of small and medium-sized businesses. It provides opportunities for revenue growth, knowledge sharing and capacity building, thereby enhancing long-term competitiveness. Expanding your business outside your home country has many benefits. According to surveys done in the EU, only one in eight companies cooperated with partners abroad. The situation in our country is similar. Previous researches and statistics can be concluded that the most useful way for entering foreign markets is exports.

Key words: internationalization, small and medium - sized businesses, wood industry, competitiveness

1. INTRODUCTION

SMEs in developed market economies represent a significant economic force contributing to employment, income generation and growth, flexibility of the economy and adaptation to rapid technological and market changes, and greater efficiency of economic development.

It is known that small and medium-sized enterprises in EU countries make up about 99 % of the economic entities and provide 60-70 % of the jobs. They are at the core of the dynamics of the development of modern economies. Given their importance, the number of SMEs has increased significantly in the last few years where their share is over 99 % of the total number of enterprises in the Republic of North Macedonia. Enterprises in the wood industry as part of the processing sector are characterized by the same situation.

Today, all businesses are affected by globalization, so there is a need to internationalize the operations of small and medium-sized businesses in order to emerge on the global market and ensure competitiveness. The internationalization process itself is a big challenge. If an enterprise does not have sufficient resources, sufficient human resources, information, capital, technology, knowledge of the international market, it will be very difficult for it to rise internationally and survive. Unless it goes through all the phases, observes all the regulations, laws and barriers to international market place, it will not be able to join it.

Introducing internationalization standards is an important element that all small and medium business owners should have, as it is vital to their operations. The goal of every entrepreneur is to be the best, the most competitive and to have the best products. Effort, good strategy and determination must be made in taking the risk of investing in international markets. Our companies do not take this step so often. There are numerous reasons why this is so: ignorance of the international market, cultural differences, barriers to entry and exit, lack of information, and so on.

The purpose of our research, therefore, is to try to explain what a company needs to operate globally and succeed. What is the prospect of our companies and how much they use state programs and assistance to place their products on the international market. In fact, the main purpose of the research will be to find out why SMEs do not appear in foreign markets, and to make recommendations to encourage the internationalization of our businesses.

2. THE IMPORTANCE OF SMALL AND MEDIUM BUSINESSES FOR ECONOMIC DEVELOPMENT

According to the European definition of enterprises, small and medium-sized enterprises are those employing up to 250 people, the annual balance sheet not exceeding EUR 43 million and the annual turnover not exceeding EUR 50 million. The Commission recommends the adoption of four criteria for identifying these companies: 1. Number of employees; 2. Turnover; 3. Overall balance sheet and independence; 4. The threshold of 50 and 250 employees for small and medium-sized enterprises is a determining framework for the size and structure of human resources management.

Small and medium-sized businesses can be characterized by the following characteristics: immediacy, flexibility, one-person management, entrepreneurial spirit, limited management skills, limited financial means, independence, competing market activity, high failure rate, low cost, personal satisfaction, specialization of certain products and services, pursuit of community interests, profit-oriented, small tax contribution, and easy entry and exit from business (Shuklev, 2011).

The importance of small and medium-sized businesses for economic development can be seen through:

First - they affect unemployment. In fact, they increase employment and increase market competitiveness.

Second - they play a role in GDP creation and value added.

Third - they play a major role in innovation, technology development and entrepreneurship. Small and medium businesses are rapidly connecting and adapting to new technologies and high creativity. In fact, it fosters the spirit of innovation and thus the overall economic development of a country. The development of small and medium-sized enterprises means strengthening the competitiveness and entrepreneurship, which directly affects the improvement of efficiency, productivity and the degree of innovation in a country's economy.

Fourth - they balance the micro and macro levels. They stimulate competition and reduce the power of monopolies. They adapt very quickly and are flexible to market changes and communicate well with the community. To encourage the growth of small and medium-sized businesses a quality business environment is needed.

From the above, it can be said that the development of small and medium-sized businesses is a particularly important part of a country's economic policy. Therefore, in order for a country's economy to thrive, small and medium-sized businesses also need to grow and improve.

3. INTERNATIONALIZATION – ENLARGEMENT PROCESS OF BUSINESS ACTIVITIES OF SMALL AND MEDIUM – SIZED ENTERPRISES

Internationalization is one of the essential elements of globalization, which in addition to spreading economic activities encompasses the functional integration of such internationally dislocated activities, which is reflected first and foremost by qualitative changes in the organization of economic activities (Dicken, 2003). It is an economic challenge for small and medium-sized businesses, and is a complex process that requires additional skills and knowledge to enable more companies to compete in international markets.

The internationalization of business brings many advantages and disadvantages. When it comes to the advantages and disadvantages of internationalization, a US SME marketing expert (Gaille, 2015) has done research and identified six advantages and disadvantages of internationalization. According to him, the advantages of internationalization are:

1. It is a way to broaden your horizons,
2. The visibility of the business brand will increase,
3. Sales will typically increase when more customers are exposed to a business,
4. There is actually less overall competition,
5. You do not have to do all of the work yourself,
6. The business becomes less vulnerable to changing trends.

And the disadvantages of internationalization are:

1. It creates timing issues,
2. Language can become a tremendous barrier,
3. Currency fluctuations can completely eliminate profits,
4. There no possible way to ignore local politics,
5. International businesses are going to have timing issues,
6. You can not do business somewhere when you do not know the market.

Given that internationalization has long affirmed the need to operate internationally, it is necessary for small and medium-sized businesses or managers to create a development strategy for internationalization (Mihailovic *et al.*, 2008).

Internationalization of business occurs gradually through several stages: first, the initiative to approach the foreign market, secondly, identifying foreign markets and thirdly, the internationalization of business. It follows that the formulation of the strategy and its implementation must be adapted to the objectives and characteristics of the foreign market.

Enterprises that have well-established production capacities in the domestic market require additional markets to take full advantage of their opportunities and achieve a large-scale economy. They need a good internationalization strategy. The internationalization strategy is the most dynamic development direction of growth and development of companies.

According to Porter (1980), an analytical framework for the formulation of international business strategy identifies the following strategies: ethnocentric, polycentric, region centric and geocentric.

Each of these strategies has its own characteristics (Dzordzevic, 2001):

Ethnocentric is acceptable for companies in the initial internationalization process. Access to a foreign market is conditional on access to a domestic market, hence the name of ethno-orientation. Costs of attending a foreign market using an ethnocentric orientation are minimal.

Polycentric - orientation towards global competition with a full line of products in order for the enterprise to compete worldwide. It is basically a polycentric orientation where the emphasis is on product differentiation and low costs as sources of competitive advantage. The focal point of companies is the local market. It involves researching and processing local markets, competition analysis and consumer research by companies. The costs are higher than the ethnocentric orientation, but the effects are high.

Region-centric - the company is looking for potential target markets among regional markets. The focal point is the regional market. The costs are small in the region and the effects are increasing.

Geocentric - applied by companies of a global nature in shaping international operations. The focus is on the world market. Management is centralized to increase operational and management efficiency. The company strives to be as equitable worldwide as possible.

International production requires partnerships of different types. If a company decides to enter the international market, it should decide which way or model of entry strategy it will choose. Choosing the right model will mean success for the company, but if they make a mistake they are unlikely to enter international markets.

As the basic entry models (strategies), SMEs can choose from: import and export, "turnkey", licensing, franchising, joint ventures and strategic alliances (Hil Chars, 2010).

Import - through this model strives to provide products and lack of the importing country, which are demanded in the market, importing country will use or sell. Although imports are thought to be the simplest model of internationalization, there is still a risk in doing so. Mostly raw materials, raw materials, fuels and the like are imported. High-skilled and trained labor or cheap and low-skilled labor are also imported, depending on the needs of the company and the business.

Export is the means of transporting a certain quantity of goods, goods and services produced by one country and exported abroad to other countries. This is the most used and basic way to enter international markets. Exports avoid the cost of building plants in the other country and only serve the foreign market, thus achieving economies of scale. The company achieves profitability, increased sales, reduced risk of operating in an unstable market and builds competitiveness and reputation in the domestic market. Exports are the transfer of products, services and capital from one country to another through their own direct networks or through distribution and marketing intermediaries. Export risk is not high because it does not require large investments and the company can easily control its operations.

The license can only be obtained through a contract between the two companies. The license agreement is binding in nature and is concluded according to certain rules established by law. Licensor grants certain rights to Licensee for a specified period of time and receives monetary compensation for that period. The license is attractive to companies that lack the means to open a representative office in another country or do not want to invest part of their funds in an unknown market. This model is characterized by low costs and low risk. The license is seen as an import of technology. Commonly licensed: equipment, patents, technical information, inventions, formulas, design, trademark, proprietary rights, etc. If the product is a brand with a well-known name and the company does not have sufficient funds to finance direct entry into the host country, this model is best used. The right holder benefits from the license being sold and increases his income. Most often a license is issued for a longer period of time and is more expensive for a longer period but it is in the interest of both the owner and the buyer and in practice the cooperation is long term. The licensor is obliged to service the product and provide technical support to the buyer, which reduces the risk of equipment failure due to malfunction or lack of spare parts. The licensing company assumes the risk of operating. The disadvantage of licensing is that the licensee has little control over production and marketing. It may happen that the licensor may ban the promotion of the product being promoted or restrict the market in which the product is marketed. Any restrictions must be written into the license agreement which is always in writing and both parties abide by it.

Franchising has been a very popular and successful business model in recent years especially in the United States. Similar to a license, buying a franchise means the right to use a particular name, brand, etc. The buyer pays an agreed amount to the franchisee and in return you get all the knowledge, all the techniques of the seller, the way of working and so on. and the buyer is obliged to give a certain percentage of the sales made. There are several types of franchise, such as: Product franchise - A feature of this business is that franchisees have the right to distribute the product and pay a fee; manufacturing franchise - has widespread use in industry, where the franchisor has the exclusive right to manufacture and distribute the product in a particular area; business franchising is the most popular form of franchise (75 % of all franchises in the US), where the franchisee offers a wide range of services and receives a fee for it.

Joint Ventures is a contract-based model between two or more companies to make joint ventures. Unlike strategic alliances, this model is not based on long-term cooperation but is time, financially and project-limited. A new contract is concluded for each subsequent project.

Strategic alliances are a model of linking enterprises in international trade for the purpose of acting together and making a profit. Two or more companies collaborate and exchange experiences, technologies, skills and the like. They are formed in environments that are less stable due to the entry-level markets. Most often these are transition states. They can be limited to the exchange of knowledge and information, joint marketing activities, exclusive and the like (Miceski, 2013). Strategic alliances gain relevance across a range of industries and services. Modern companies strategize with customers, suppliers and other partners. They replace the principle of working alone on strategies, with the principle of working together on strategies, ie by relying on partnership. Reliance on a partnership means encouraging the strengths of your business partner in order to create greater value and make more sales than any company that operates alone (Kotler, 1999).

3.1. Standards for the internationalization of small and medium businesses

Standards are written rules for regulating the activities of enterprises in the international economy. Implementing standards greatly helps in running businesses, enhancing the value of the business and helping them build partnerships with other companies more quickly and easily internationally. Standards can be barriers to entry due to different markets, but they are also legally binding.

At the European level, common standards have been developed for all types of products and services in a wide range of sectors such as chemical industry, construction, energy, food industry, health and safety, household appliances, information, technology, machinery, telecommunications and transportation. SMEs need to gather as much information as possible about the standards and organizations they offer.

Every standard is written and requires constant performance improvements and each has its own purpose. Standards play a particularly important role within the single European market (or European Economic Area), which includes all EU member states plus a number of neighboring countries. For the single market to function effectively, standards must be aligned so that products and services can be sold and purchased across borders. European standards have been identified by the EN code, and the target market of SMEs is the European market here, some of the European standards are explicated. Namely, European standards are recognized in all 33 European countries, where there is an obligation to withdraw any other national standard that is not in accordance with European standard. This means that any component, product or service that complies with relevant European standards should be accepted in all participating countries.

The most commonly used international standards are: ISO 9001 - quality management system standards, ISO 14001 - environmental management systems, ISO 17000 - systems for various assessment organizations, ISO 27000 - information security management systems, ISO 31000 - Risk Management Process, OHSAS 18001 - Occupational Safety and Health

Management System, HACCP - Hazard Analysis System and Critical Control Points, HALAL System, FSC - Supervisory Chain Control System, IFS - International Food Standard, (BIO) Organic Certificate, BRC Standard, GOST-R standard.

In addition to these standards are quite current FAIR TRADE standards. Fair trade is an alternative approach to trade based on a partnership between producers and traders, businesses and consumers. International Fair trade standards are made up of international organizations representing the largest trade system in the world. Fair trade standards are designed to tackle poverty and encourage producers in the poorest countries in the world. Standards apply to manufacturers and traders.

In this context it is necessary to state that the product conformity mark, the CE mark is an important condition for successful operation, although not standard. To ensure the free flow of goods and a high degree of protection of the public interest within the European Union (EU), products under the new laws must bear a CE mark, which is proof that they have been developed, designed, manufactured and tested in accordance with European regulations.

3.2. Barriers to access small and medium businesses to international market

Numerous studies have shown that many small and medium-sized businesses have failed to reach the foreign market. Due to many obstacles, they abandoned their purpose. Whether these are external, internal, political, economic, legal and other differences, the enterprise has one goal - to overcome them successfully. The European Commission has classified barriers to entry to international SME markets. According to the OECD, the barriers to entry into international SME markets are classified as INTERNAL and EXTERNAL.

Internal are: information barriers, lack of human resources, financial barriers, production barriers and barriers to distribution, logistics and promotion.

External are: procedural barriers, communication difficulties, slow payment, Government and legislative barriers, political instability, health standards.

While the European Commission in 2014 conducted a survey that ranked the top 10 barriers to internationalization of small and medium-sized enterprises. The survey was conducted according to the TOP TEN RANKING METHOD.

The most common barrier is the lack of capital and financial resources and ranks first. It is followed by problems in obtaining information on foreign markets, lack of time and a good management team to work internationally, difficulties in competitively pricing, transportation costs, communication and shipping problems.

3.3. The impact of internationalization of the small and medium businesses competitiveness

SMEs play a major role in the competitiveness of the economy itself as they adapt quickly to changing markets. A number of factors affect the competitiveness of an economy, and thus the competitiveness of small and medium-sized businesses.

According to OECD research, the key factors that determine the competitiveness of small enterprises are: the role of the owner / manager in the competitiveness of the small enterprise; the competitiveness of the enterprise is determined by its strategy which depends on the skills, responsibility, attitudes and behavior of the owner / manager; the ability to obtain and use scientific and technological information; the quality of the organization of the firm; investment in adequate technology; flexibility.

Competitiveness is rooted in both the internal and external perspectives of SMEs operations. To overcome all barriers and increase the competitiveness of SMEs that are oriented towards foreign markets, they should pay attention to the following:

- Making global differences in production conditions more efficiently exploited;
- Innovation skills and ability to develop and absorb new technologies;
- Knowing the markets they will be competing in;
- Access to capital.

4. INTERNALIZATION OF SMALL AND MEDIUM - SIZED BUSINESSES IN THE REPUBLIC OF NORTH MACEDONIA

In the Republic of North Macedonia there is no single definition of SMEs. Article 470 of the Companies Act 2004, in the section on trade books, annual accounts and financial statements, classifies large, medium, small and micro traders in terms of accounting. This definition is in line with the EU definition (EU Recommendation 2003/361) regarding staffing thresholds, but not with annual income and balance sheet thresholds. Also, different agencies have different criteria for their services. For example, the Law establishing the APPRM (the Law establishing the SMEs Agency of the Republic of Macedonia), identifies SMEs as independent enterprises with less than 50 employees, achieving a total annual turnover not exceeding 1.5 million EUR, expressed in MKD, and are at least 51 per cent privately owned (Article 3).

Regardless of the size of the enterprises, the micro, small and medium-sized enterprises (MSMEs) sector as a whole is dominant in the Macedonian economy. The latest data show that 99.8 % of all enterprises belong to this group. In 2013, 53,137 companies were MSMEs, down from 55,385 in 2009. Namely, according to the State Statistical Office data, the number of micro, small and medium enterprises has increased significantly in recent years. The following table shows the number of entities, ie micro, small, medium and large enterprises from 2014 to 2018.

Table 1. Active business entities by size and years, on December 31st

Year	Business entities				
	Micro	Small	Medium	Large	Total
2014	49659	19937	724	459	70659
2015	48611	20313	725	490	70139
2016	49364	20892	746	517	71519
2017	48577	21543	776	523	71419
2018	48778	22138	840	559	72315
Average	48998	20965	762	510	71210
(%)	68,9	29,3	1,1	0,7	100

According to data in the table 1, it can be said that the number of registered small and medium enterprises is growing year by year.

For the analyzed period (2014 - 2018), on average out of the total number of business entities (71210), small enterprises participate with 29.3 % or (20956), and the medium enterprises with 1.1 % respectively (762). The remaining 68.9 % or 48998 companies are micro, and 0.7 % or only 510 companies are large enterprises.

SMEs are also the largest employers, providing 76.6 % of all employment. In this respect, it is found that micro enterprises employ only one third of the total number of workers, while SMEs together employ 43.0 % of all workers. The few large enterprises in the country, with more than 250 employees, provide employment for 23.4 percent of the workforce. From a value-added standpoint, the contribution of micro-enterprises continues to decline. Regardless of their size, micro enterprises account for only 24.0 % of value added, while SMEs account for 43.0 %. Large enterprises are significantly larger value-added generators. Therefore, the key challenge is to help micro and small enterprises grow and contribute more to national employment and create added value (National strategy of SMEs 2018-2023).

The data of the structure of active business entities, according to the number of employees in the processing industry sector, including the enterprises in the wood industry, for the period 2014 - 2018 is presented in table 2.

Table 2. Number of active business entities by activity sectors according to NKD Rev. 2 and according to the number of employees, (manufacturing industry)

Year	Manufacturing industry						
	Total	0 employees or no data	1 - 9	10 - 19	20 - 49	50 - 249	250+
2014	7675	209	5915	656	472	363	60
2015	7639	572	5605	593	455	343	71
2016	7967	605	5889	594	469	340	70
2017	7885	568	5845	596	468	341	67
2018	8033	586	5984	571	492	331	69
Average	7840	508	5848	602	471	344	67
(%)	100	6,4	74,6	7,7	6,0	4,4	0,9

The data from the previous table show that the largest share in the total number of enterprises has the business entities with 1-9 employees (74,6 % on average). The following are the entities with 10-19 employees (7,7 % on average), followed by the unemployed (or those who did not present the employee data) with 6,4 % and the entities with 20-49 employees and the entities with 50-249 employees who participate on average with about 10 % in the analyzed period. The business entities with over 250 employees (on average 0,9 %) have the lowest share of the active entities. It can be said that, in the manufacturing sector, more than 99 % of the total number of business entities are small and medium-sized enterprises, while only 0,9 % are large enterprises.

On the territory of the Republic of North Macedonia, in the wood industry were registered an average of 1104 business entities for the period 2011-2015. The number of business entities in wood production and wood products is 477 on average, and in furniture production the number is higher (628) in the analyzed period. The share of the business entities in the wood industry in the number of business entities in the manufacturing industry is about 14 % on average for the given period (Stankevik Shumanska, *et al.,* 2017).

Of the total active business entities in the timber industry, micro-enterprises have the largest share of around 55 %, small enterprises participate with 30 %, and medium-sized enterprises with only 15 %. Regarding the number of medium-sized enterprises, the largest share (about 13 %) is of the enterprises with up to 100 employees (Stankevik Shumanska, 2014).

Expanding your business outside your home country has many benefits. According to research done by the EU, only one of eight companies worked with partners outside their home country. The situation in our country is similar. Previous researches and statistics in our country can be concluded that currently the most used way to enter the foreign markets is the export. In addition to exporting and franchising, it is often used as a way of accessing foreign markets, yet exporting takes first place.

The total trade in 2017 between Macedonia and EU countries amounted to 13,391,318 thousand US dollars (USD), 5, 6 billion USD belong to exports, while import balance amounts 7,7 billion USD. In 2016, the total trade exchange between the Republic of Macedonia and the

EU countries amounted to 8 billion USD, of which 3,82 billion USD belonged to exports, while the import balance amounted to 4.18 billion USD.

According to the State Statistical Office data, the total value of export from the Republic of North Macedonia in the period January-December 2017 was 308 341 881 thousand MKD denars, increasing by 15,6 % compared to the same period last year. Value of import in the period January-December 2017 was 420 245 581 thousand MKD denars, which is 11,7 % more than the same period of the previous year. The trade deficit in the period January-December 2017 was 111 903 700 thousand MKD denars, while the coverage of the import by export in the period January-December 2017 was 73,4 %.

Over the years, it can be seen that Germany is the most stable and largest trading partner of the country. In 2017, it remains the number one country of all countries with which Macedonia trades the most. In the period January-December, this European country traded 26,7 % of the total volume of foreign traded products, priced at 194 251 488 MKD denars, followed by the UK, Greece, Serbia, Bulgaria and Italy, but at a significantly smaller volume of trading.

The share of the average export of wood industry which is 105754000 USA ($) in the total average export of processing industry products with 4142287000 USA ($) for the period 2013-2016 equaled 2,6 %. The share of the average import of wood industry which is 71644000 USA ($) in the total average import of products from the processing industry with 6225040000 USA ($) for the period 2013-2016 is 1,2 % (Stankevik Shumanska, *et al.*, 2017).

International furniture trade in the Republic of Macedonia is not widespread in the world markets. Almost all trade for decades has been with neighboring countries. The reasons for such trade relations are due to the low transport costs, the good knowledge of the markets which is traditional, and of course the already established interconnections dating back a long time. It can be said that this trend continues (Meloska, *et al.*, 2018).

Unlike us, small and medium-sized enterprises (up to 249 employees) are considered to be the engine of the European Union (EU) economy, creating jobs and supporting economic growth. According to new data from Eurostat, however, they also contribute significantly to trade within the Union. SMEs have a number of export benefits, as a result of their export activity diversifying their operations and at the same time isolating themselves from periods of slow growth in the domestic economy, so export orientation is a key component of their development strategies. As a result of globalization processes, liberalization of trading conditions and the advantages of information technology, SMEs' participation in the international market is greater than ever.

4.1. Measures and programs to support the internationalization of small and medium-sized businesses

More measures have been taken to encourage Macedonian companies to exit the foreign market, but they are still insufficient.

In this context, the National Strategy for SME Development (2002-2013) has been adopted by the Ministry of Economy. Among the goals of the strategy is to "encourage the internationalization of small and medium-sized enterprises". The measures offered by this Program concern increasing the competitiveness of SMEs and their ability to export to the market. Assistance is provided in the promotion of the products through participation in fairs, informing our companies about distribution channels, foreign markets, demand also and so on. In addition to these measures, support is also provided through lending, insurance and export guarantees.

In addition to this Program of the Ministry of Economy, many other measures have been adopted to develop SMEs and support internationalization. Some are financial, some help in another way. Some are sponsored by the Government of the Republic of Macedonia and some by the European Union, which enables participation of all our companies that wish to receive benefits and support through these European programs. The following are the current policies and instruments to support internationalization, and the most widely used model of internationalization for export:

- Industrial Policy of the Republic of Macedonia 2009-2020,
- Export Promotion Strategy,
- Innovation Strategy of the Republic of Macedonia 2012-2020,
- Regional Development Strategy of the Republic of Macedonia 2009-2019,
- National Strategy for Sustainable Development in the Republic of Macedonia 2009-2030,
- Export Promotion Strategy of the Macedonian Industry and Information Services IPA Cross-Border Component,
- Programs for innovation, competitiveness and entrepreneurship,
- European SME Competitiveness Program - COSME
- HORIZON 2020 - Research and Innovation Framework Program (2014-2020)
- EU Competitiveness and Innovation Framework Program etc.

Export Promotion Strategy (2011) - The main goals of this strategy are: strengthening institutional capacity, working with the business community, promoting domestic products on international markets, building a good image and defining export goals.

SME Support Tool - This tool helps SMEs who have ideas and vision to create new products, processes and services and are ready to enter international markets. Only companies with innovative potential and a desire for internationalization are potential users of this tool. It has 3 billion euros for the period from 2014 to 2020. It covers three phases: first, feasibility assessment, innovative projects are created and commercialization of the project.

The COSME program is a continuation of the Competitiveness Framework Program for SMEs. This program is scheduled to run from 2014 to 2020. The budget set for all years and for all countries is 2,3 billion euros. Target groups are small and medium-sized enterprises, and many countries, including ours, have the right to participate. Cosme has 4 operational programs: access to finance, access to new markets, improvement of framework conditions and promotion of entrepreneurship. This Program is implemented by the Executive Agency for Small and Medium Enterprises. All SMEs have the right to participate in this Program and may apply electronically.

The Enterprise Europe Network is a network of business support organizations from over 50 countries. The Republic of Macedonia is also part of this network. This organization has data on the European market, including data on enterprises, business partners and so on. It provides assistance in finding an international partner, provides free consulting services, information on possible sources of funding, organizes training, offers business partner support, and more.

The latest is the National Strategy for Small and Medium Enterprises (2018-2013). The strategic goals of the strategy are:

1. Favorable Business Environment: Create a favorable business environment that encourages entrepreneurship and investment.

2. Increasing and Improving SME Growth Opportunity: To help SMEs become highly productive and competitive players in European and other international markets.

3. Dynamic Entrepreneurship and Innovation Ecosystem: To Foster Macedonia's Economic Competitiveness by Increasing SMEs' Entrepreneurial and Innovation Capacity.

In the area of increasing and improving the opportunity for SME growth, the program for facilitating internationalization is included. The government is establishing a strategic and institutional framework for export promotion aimed at improving the internationalization of the SME sector. To ensure that the SME sector is export-oriented and driven by new opportunities in the EU and the world, the Government will intensify its support in this area. A national assessment of SME opportunities, barriers and capacities for entry into emerging international markets will be commissioned. The results of this assessment will provide direct information on the revision of the national export strategy, which will be integrated into the development of SMEs. The government will provide more funding to the export promotion agency and improve monitoring and evaluation of export promotion services. This will include greater integration and coordination with APPRM and other relevant organizations. A portal will be created where all SMEs can access information and data on conditions, opportunities and constraints in foreign markets, which will facilitate their access to foreign markets (National Strategy of SMEs 2018-2023).

Internationalization is an important factor in achieving a higher rate of economic growth that would have an impact on increasing the competitiveness of the enterprise. The help our country aids the European Union is important to achieve this. For some companies, internationalization is only a few kilometers from where they work. The European Union is helping to develop a cross-border business with a market of over 500 million consumers. It creates a single European market where small and medium-sized enterprises will grow and thrive. But this aid is not always used, as according to European Union data 63 % of European SMEs are active in their home countries and only 6 % outside them. That is why small and medium-sized businesses need support, whether financial or advisory, yet it is a way to reach out to them to reap the benefits of the international market.

4.2. Measures and recommendations

SMEs still have limited access to foreign markets. In this regard, the measures to be taken in the future are:

- trainings that will enable the owners of small and medium-sized businesses to become more familiar with the international market,
- greater stimulation so that owners can decide to expand,
- promoting other models of foreign market presence, such as strategic alliances, joint ventures, franchises and licenses,
- programs available to all SMEs,
- assisting the Government and the Ministry of Economy to make the access to foreign markets of SMEs easier and more accessible to all,
- greater financial support as small and medium-sized enterprises finance their own operations,
- reduction of interest rates, taxes, duties,
- creation of credit funds to support internationalization,
- greater education of employees in small and medium-sized enterprises
- training in marketing for promotion of the company beyond the borders of our country,
- improving awareness of business expansion, improving the competitiveness of enterprises, promoting innovation and improving SME access to foreign markets,
- greater support by the SME Development Agency for export promotion,
- adopt legislation to encourage internationalization and access to foreign markets,
- adoption of measures to improve the competitiveness of small and medium-sized enterprises,
- strengthening the entrepreneurial spirit,
- assistance in the development of the financial market, labor market, creation of new strategies for appearing in foreign markets and stabilization of the political crisis in our country.

5. CONCLUSIONS

Internationalization affects everyone, not only large but also small and medium enterprises. Specifically, small and medium-sized enterprises face international competition and are forced to compete in international markets. States must develop their resources to improve their market position. The different models of appearing in foreign markets lead to the development of entrepreneurship outside of their own country. Small and medium-sized businesses, including companies in the wood industry, play a major role in our country's economy and are a key factor in economic development. Exports are the most common model for foreign markets. Macedonian SMEs use it to promote their products outside the country, for greater profit and cooperation with foreign companies. According to research done by the EU, only one of eight companies worked with partners outside their home country. The situation in our country is similar. In addition to exporting and franchising, it is often used as a way of accessing foreign markets, yet exporting takes first place.

According to the research, Macedonian small and medium businesses do not have sufficient support from the institutions regarding internationalization. They need to know more about the possibilities of expanding the company beyond the borders. Applying international standards will improve the quality of their products and services and achieve better competitive advantages. It is necessary to overcome the barriers that hinder company growth and conquer new markets. It is also necessary to deepen cooperation with foreign companies to enable the development of the economy and support of all models for foreign markets, export as the most used model and support of licenses, franchises, joint ventures and strategic alliances. The European Union works in the interest of expanding cooperation between states and the introduction of standards and the smooth development of small and medium-sized enterprises in the Republic of North Macedonia. Internationalization measures and programs need to be developed in order for Macedonian SMEs to take risks, invest funds and compete in foreign markets with one of the models of performance. Through different models of entry into foreign markets, small and medium-sized enterprises gain their place in foreign markets. Entering international markets offers great profit but also greater risk. However, by thinking reasonably and clearly throughout the process, you can take advantage and minimize the risks.

There is a need for greater support for internationalization of small and medium-sized enterprises. There are currently several key areas dealing with this problem such as: financial support for research and development of small and medium-sized enterprises, support for innovation, improvement of export conditions, reduce of export costs, investment in people and business, and getting acquainted with the conditions for entry into foreign markets. However, this is not enough. The European Union works to improve the innovation of companies and provides financial support. However, the conditions have not matured, most of the small and medium-sized enterprises in our country do not decide to invest in the international market.

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Main Characteristics of Larch Stems *(Larix gmelinii)* for the Production of Solid Wood Materials

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ABSTRACT

Larch is naturally distributed in large areas in Siberia, the Himalayas, the Alps and Carpathians, China, Japan, North America and northern Europe. Wood is widely used not only in the housing construction and production of furniture but also in many other areas where its high durability and stability, good physical and mechanical properties and aesthetic qualities are appreciated. Larch is a non-dominant coniferous tree species for the Republic of Bulgaria and it has been studied in terms of forestry science. The main purpose of this research is to determine the basic characteristics of larch stems (Larix gmelinii, Rupr.) and their variation from the base to the top of the stems. The following main characteristics were determined: average diameter, bark thickness, dimensions of heartwood and sapwood, density and moisture content of wood, hardness along and across the wood fibres. The results will be used to assess the rational use of wood of the stems for production of solid wood materials for various purposes.

Key words: larch *(Larix dahurica)*, characteristics of stems, solid wood materials

1. INTRODUCTION

Larch is a coniferous tree species and belongs to the family *Pinaceae*, genus *Larix Mill*. It is a native species to large areas in Siberia, the Himalayas, China, Japan, northwestern USA, southwestern parts of Canada, the Alps and the Carpathian Mountains. It forms single-species and mixed forests with other conifers. It is relatively easy to hybridize and change depending on the growth conditions. The genus *Larix* includes from 16 to 20 species (Buligin, 1991), but only about 10 species are of higher prevalence and importance. According to genetic characteristics and morphological features larch can be classified into two main groups within the genus: Eurasian species (*Larix sibirica*, *Larix gmelinii*, *Larix decidua*, *Larix kaempferi*, *etc.*) and North American species (*Larix laricina*, *Larix lyallii*, *Larix occidentalis)*. Larch forms powerful stems with a height from 20 to 60 m, in most species from 30 to 45 m. The diameter of the stems is from 0.8 to 1.0 m, but in some species it can reach up to 1.8 m. Larch is considered a fast-growing tree species with extremely vigorous growth, especially at young age. Under favourable soil and climatic conditions the annual height increase can reach 1.0-1.5 m.

Larch is a non-dominant coniferous tree species for the Republic of Bulgaria. It is naturally distributed in the high parts of the Rhodope Mountains, Balkan Mountains, Rila, Pirin, Belasitsa, Osogovo, etc. Due to the valuable characteristics of wood, stands with a 50-80 years of age from the species *Larix gmelinii (syn. Larix dahurica), Larix decidua* and insignificant quantities of *Larix sibirica* and *Larix kaempferi* have been introduced and established. The total stock of larch does not exceed 120 thou. m^{-3}, and the occupied area - 2500 ha (Forest Executive Agency, 2019).

Larch timber has been extensively used for centuries in various applications in the field of industry, construction, housing, household and urban landscaping. This widespread interest is provoked by its extremely useful characteristics – high mechanical and technological properties, beautiful texture and colour. One of the most valuable properties of larch wood is its durability and resistance to rot, moisture and other climatic and biological influences (Ross, 2010; Bergstedt, and Lyck, 2007 *et al.*).

Larch has been the subject of a number of studies, mainly from the point of view of forestry science – morphological characteristics, taxonomic data, silvicultural activities (Buligin, 1991; Peltola, 2006; Milev, 1996; Kharuk, 2019 *et al.*). The anatomical structure, physical and mechanical properties of larch have also been significantly studied (Borovikov and Ugolev 1989; Bergstedt and Lyck 2007; Ross, 2010; Topaloglu and Ay, (2010); Koizumi *et al.*, 2003). In the scientific literature there are also a number of studies on the physical and mechanical properties of larch wood products (Ross, 2010; Song *et al.* 2018; Georgiev, 1976). Ay, Topaloglu and Akpınar (2013) studied the variation of density, shrinkage and swelling of wood in height of the stem of European larch (Larix decidua Mill.). Trichkov and Koynov (2016) published results about the dimensional characteristics of stems, related to another tree species – Pinus silvestrys L. Partial data on the physical and mechanical characteristics of heartwood were determined by Ross, R. (2010), Borovikov and Ugolev (1989).

The production of finished wood products requires primary processing of round materials, obtained from delimbed tree stems. For this purpose, different cutting patterns and models are developed which require initial information about the wood dimensional characteristics (diameter and shape of the cross section, taperness, ovality, bends), physical and mechanical properties of wood from the base to the treetop, dimensions of heartwood and sapwood, location of knot zones, presence of wood defects typical for the respective tree species and shape of the stems. No data about similar studies related to larch wood have been found in the scientific literature.

The aim of this research is to develop a characteristic of larch stems harvested in the Republic of Bulgaria. It comprises results of the studies on the dimensional characteristics of the stem, physical and mechanical properties of wood and their variation in height of the stem.

2. MATERIALS AND METHODS

The experimental wood was harvested on the territory of the training and experimental forestry range at the University of Forestry, which is located in the Rhodope Mountains (the village of Yundola, Velingrad municipality). The area of stem harvesting is located at an altitude of 1400 m with a south-southeastern exposure. The soil is brown forest, clay-sandy and medium fertile. The forest is of a mixed type and is consisted of Scots pine, Dahurian larch and Douglas fir. Eight model stems were harvested and delimbed in accordance with the requirements of BDS ISO 4471: 1997, which were selected to be of approximately the same age, dimensions in height and diameter and without significant visible wood and stem defects and abnormalities (spiral growth, decay, bends, etc.). The experimental stems were allocated to the different aims of the study – to determine the dimensional characteristics and variation of physical and mechanical properties in height of the stem, to study quality zones inside the stem, to examine some exploitation properties at cutting and drying of wood and to study the adhesion processes and mechanical properties of construction materials made of larch. The stems for this study were cut into sections of 1.0 m length. Two mutually perpendicular diameters without bark d_1 and d_2 and with bark d_{1b} and d_{2b} were measured of each section. Discs with a thickness of 70 mm were obtained from each section. From 1 to 12 test pieces were obtained from each disc in accordance with standardized methodologies and the following properties were determined: density and moisture content of wood – ISO 13061-1:2014; static hardness of wood along the grain and across the grain according to the G. Janka hardness test - ST of SIV 2366:1980. The following variational and statistical indicators were calculated from the results of each disc: arithmetic mean, variance and standard, standard deviation and accuracy. For the purpose of this study, Pearson's linear correlation coefficients were calculated, using the formula (Vuchkov and Stoianov, 1986):

$$r_{x,y} = cov(x,y)/\sigma_x\sigma_y = \frac{1}{n}\sum_1^n(x_i-\bar{x})(y_i-\bar{y})/\sigma_x\sigma_y, \quad (1)$$

$r_{x,y}$ - Pearson linear correlation coefficient
$cov(x,y)$ - covariance between x and y
σ_x, σ_y - standards of x and y
n - number of elements in the sample.

The analysis of the results was performed using the arithmetic mean values of each sample. In the top sections, due to the small diameter and inability to obtain a large number of test pieces, the arithmetic mean value or the single value of the indicator was used for the analysis.

3. RESULTS AND ANALYSIS

The results of the variation of stem diameter, bark thickness and percentage of sapwood and heartwood of the model stem are presented in *Table 1*.

Table 1. Experimental results of the studies on stem diameters, bark thickness and relative proportion of sapwood and heartwood of a Larix gmelinii *stem*

Distance from the base of the stem, m	Diameter of stem, cm						Ratio of the bark-free diameters	Change of diameter, cm/m	Average thickness of the bark, mm	Relative part of heartwood, %
	with bark			without bark						
	$d_{1(b)}$	$d_{2(b)}$	$d_{av(b)}$	d_1	d_2	d_{av}				
0	44.0	37.0	40.5	35.5	40.0	37.8	0.89		13.8	89.4
1,0	36.0	33.0	34.5	32.0	30.0	31.0	0.94		15.5	
2,0	33.0	31.0	32.0	30.5	28.0	29.3	0.92	4.25	13.8	89.7
3,0	32.5	29.5	31.0	29.5	27.5	28.5	0.93		12.5	
4,0	30.0	29.0	29.5	26.5	28.0	27.3	0.95	1.00	11.3	85.3
5,0	31.0	28.0	29.5	28.5	25.5	27.0	0.89		12.5	
6,0	29.0	28.0	28.5	27.5	25.5	26.5	0.93	0.38	10.0	82.6
7,0	27.5	26.5	26.5	26.0	25.0	25.5	0.96		7.6	
8,0	27.5	26.5	27.0	26.0	24.5	25.3	0.94	0.63	8.8	81.0
9,0	25.5	25.5	25.5	23.5	23.5	23.5	1.00		10.0	
10,0	25.0	24.5	24.8	23.5	22.5	23.0	0.96	1.13	8.8	74.8
11,0	24.0	23.5	23.8	22.5	21.5	22.0	0.96		8.8	
12,0	23.5	23.0	23.3	22.5	21.0	21.8	0.93	0.63	7.5	74.3
13,0	23.0	22.0	22.5	21.0	20.5	20.8	0.98		8.8	
14,0	22.0	22.0	22.0	19.6	19.8	19.7	0.99	1.03	11.5	74.6
15,0	22.0	21.5	21.8	20.0	19.5	19.8	0.98		10.0	
16,0	20.0	19.5	19.8	17.9	17.8	17.9	0.99	0.93	9.5	68.6
17,0	20.0	19.0	19.5	18.0	17.2	17.6	0.96		9.5	
18,0	17.0	17.0	17.0	16.0	15.5	15.8	0.97	1.05	6.3	65.7
19,0	16.0	15.5	15.8	16.0	15.0	15.5	0.94		4.3	
20,0	14.5	14.0	14.5	14.0	13.0	13.5	0.93	1.13	5.0	61.5
21,0	12.5	12.5	12.5	12.0	12.0	12.0	1.00		2.5	
22,0	11.0	10.5	10.8	10.5	10.5	10.5	1.00	1.50	5.0	52.4
23,0	10.5	10.5	10.0	9.5	9.5	9.5	1.00		5.0	

The studied model stem of *Larix gmelinii* had a height of 24.5 m. Its characteristics were studied up to 23 m due to the limitations of the European standards (BDS EN 1315) regarding the average diameter of round materials for mechanical processing.

From the obtained results it can be seen that the stem diameter without bark from the base to the top varies from 37.8 cm to 9.5 cm, respectively. The ratio between the two mutually perpendicular diameters is from 0.89 to 1.0, but the prevalent values are within the range from 0.97 to 1.0. The data indicate that larch forms stems with a cross section very similar to a circular section. Regarding the variation of diameters in height it can be seen that it is the highest in the ground section (4.25 cm/m) and in at top part of the stem – from 0.93 to 1.5 cm/m. In the middle part of the stem the variation of diameter is lower and ranges from 0.38 to 0.63. An important characteristic of larch stems should be noted, namely that in the ground section (from 0 to 4.0 m) there is a strong thickening. This fact was also determined in other stems which are not subject to analysis of the present paper.

In forest taxation stems are regarded as rotational geometric bodies, derived from the rotation of generatrix around the *x* axis of a Cartesian coordinate system *OXY*. Using the experimental data given in *Table 1*, equations of the generatrix of the circumferential surface were derived. They are as follows:

- generatrix equation of the stem with bark:

$$d_b = 0{,}0004h^4 - 0{,}0182h^3 + 0{,}402h^2 - 3{,}6439h + 39{,}058, \qquad R^2 = 0{,}992 \qquad (2)$$

- generatrix equation of the stem without bark:

$$d = 0{,}0003h^4 - 0{,}0182h^3 + 0{,}3402h^2 - 3{,}1483h + 35{,}689, \qquad R^2 = 0{,}986 \qquad (3)$$

d_b - diameter of the stem with bark in cm
d - diameter of the stem without bark in cm
h - distance from the base in m.

The above equations can be used to perform simulation calculations on the optimal cutting of stems.

The variation of bark thickness and the relative proportion of heartwood in the cross section of the stems is shown on *Figure* 1.

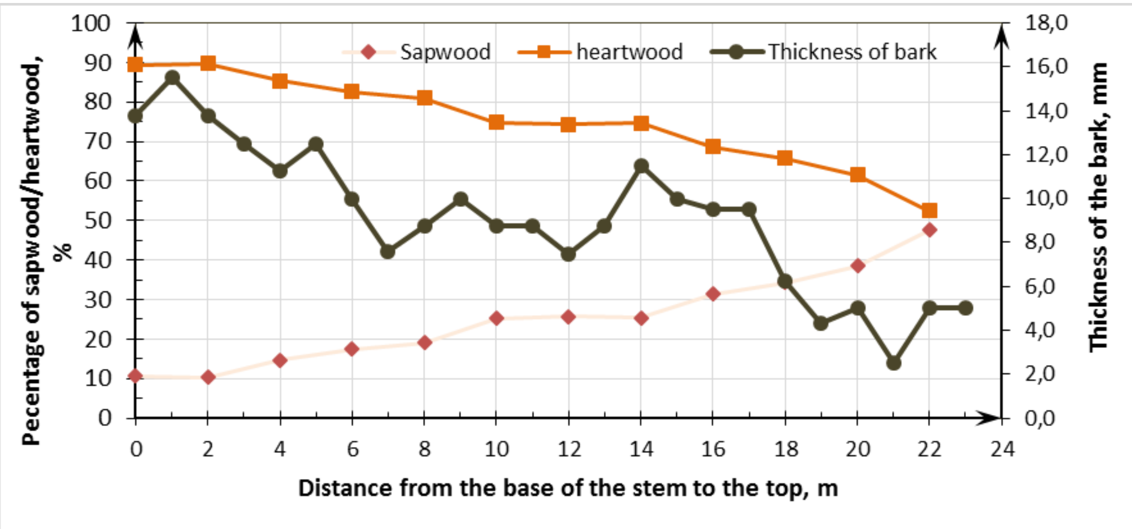

Figure 1. Variation of bark thickness and relative part of heartwood and sapwood in the model stem of Larix gmelinii

The bark thickness of the studied model stem varies from 5.0 to 15.5 mm. The thickest bark is determined in the ground section and it decreases with height. The bark thickness is not uniform in the cross section – areas with thickenings as well as areas with thinner bark are noticeable. No correlation between the bark thickness and north-south stem orientation was determined. In comparison with the bark thickness of the Scots pine (Trichkov and Koynov, 2016), the larch bark has a lesser thickness.

Larch is a heartwood tree species. The conducted experiments showed that the heartwood occupies a large part of the stem cross section, especially in the ground sections. Thus, at the lowest part of the stem (0 m, 2 m) the relative proportion of the heartwood exceeds 89 %. The lowest percentage of heartwood is determined in the top parts of the stem – 52.4 % (at 22 m).

The results of the studied physical and mechanical properties of larch wood are presented in *Table 2*. Graphical representation of the results is given on *Figures 2* and *3*.

Table 2. Results of the studied physical and mechanical properties of the model stem of Larix gmelinii

Distance from the base of the stem (H), m	Moisture content (W), %	Density (ρ), kg.m^{-3}		Hardness (Janka test), N			
		ρ_0, (W=0 %)	ρ_{12}, (W=12 %)	Straight of grain	Across the grain		
					Radially (R)	Tangentially (T)	Average between R and T
0	50.9	543.5	567.9	3250	2300	2360	2330
2,0	40.5	520.3	543.7	3100	2210	2270	2240
4,0	37.4	512.6	535.6	3080	2180	2250	2215
6,0	36.1	513.1	536.1	2900	2070	2170	2120
8,0	43.9	508.4	531.3	2800	2080	2090	2085
10,0	42.4	504.6	527.2	2850	1910	2100	2005
12,0	46.7	513.6	536.7	2660	1830	1850	1840
14,0	57.0	512.3	535.3	2600	1620	1720	1670
16,0	57.8	513.6	536.7	2480	1560*	1680*	1620*
18,0	63.4	512.3	535.3	2400	1520*	1620*	1570*
20,0	67.1	507.5	530.3	2430	1380*	1420*	1400*
22,0	64.6	501.7	524.2	2260	1310*	1400*	1355*

Note: Due to the small diameter of the stem, the number of test pieces is insufficient for statistically significant results. Indicator (*) indicates single values or average values of the test.

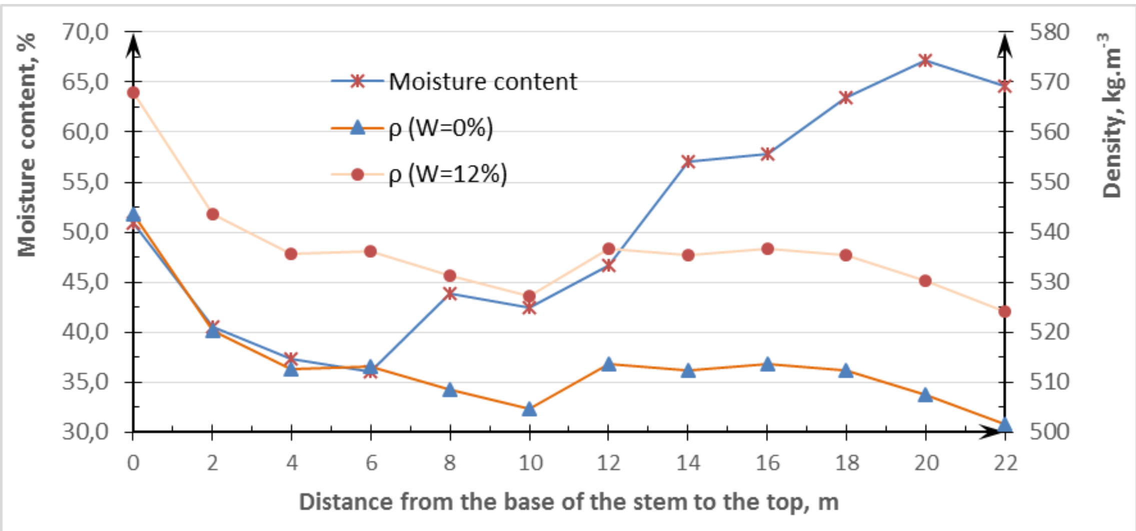

Figure 2. Variation of density and moisture content in the model stem of Larix gmelinii

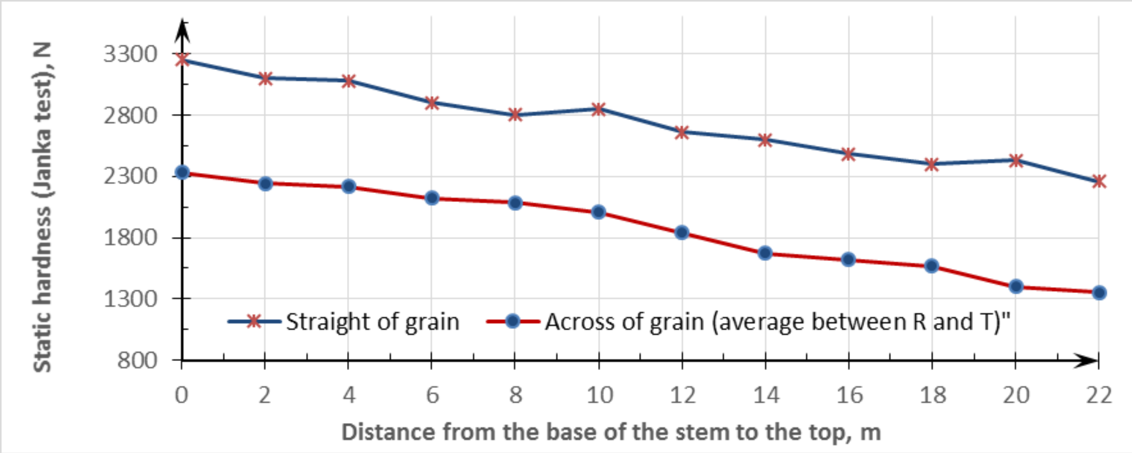

Figure 3. Variation of the hardness of larch wood (Larix gmelinii) *from the base to the top of the model stem*

From the results it can be concluded that the moisture content of wood increases from 50,9 % to 67,1 % with the increase of the stem height. The density of absolutely dry wood decreases and ranges from 543,5 kg.m^{-3} to 501,7 kg.m^{-3}. These results can be explained by the increased share of early wood in the composition of annual rings and the increased relative share of juvenile wood at the top. These conclusions are confirmed by the linear correlation coefficients (*Table 3*). Thus, the coefficient $r_{H,W}$ has a high positive value (+0,828422), and the linear correlation coefficient r_{H,ρ_0} is negative (-0,65957).

Table 3. Pearson correlation coefficients

Properties	Distance from base (h)	Density (ρ_0)	Hardness, along the grain (H_{II})
Distance from base (h)	1		
Moisture content (W)	+0.828422		
Density (ρ_0)	-0.65957	1	
Hardness, along the grain (H_{II})	-0.98768	+0.661569	1
Hardness, across the grain ($H_\perp$)	-0.98945	+0.582079	+0.973756

The hardness of wood, determined in the direction along the grain, has values of 2260 N at the top of the stem and 3250 N at the base. The radial hardness of wood at the base of the stem is 2300 N and is about 30 % lower than the one in longitudinal direction. The radial hardness of wood at the top is 1310 N and is approximately 42 % lower than the hardness in longitudinal direction. The trends of variation of tangential hardness are similar and it varies from 1400 to 2360 N. The greater difference in hardness along the grain and across the grain in the top parts of the stem is due probably to the greater relative share of sapwood. Due to the large diameter of heartwood and small diameter of the top parts of the stem it was not possible to study the hardness of heartwood and sapwood. The results of single test pieces showed that the hardness of heartwood is higher than the hardness of sapwood.

4. CONCLUSIONS

The following main conclusions can be drawn from the conducted experimental studies the analysis of the obtained results on model stems of *Larix gmelinii* (Rupr.):

- *Larix gmelinii* is characterized by straight stems with slight deviations in the longitudinal and cross sections. This creates favourable prerequisites for a smaller share of waste generated in the primary processing of stems and sections and greater utilization of wood.
- Larch has a relatively thin bark. It decreases from the base to the top and represents from 2,5 to 15,5 mm. In the volume of sections the bark represents from 8,1 to 17,9 %;
- Heartwood has a very high relative share and comprises more than 89 % of the stem cross section at the base and decreases to 52 % at the top parts of the stem.
- The density of absolutely dry wood varies from 501,7 kgm^{-3} to 543,5 kgm^{-3}. It decreases from the base of the stem, which is characterized by the highest share of heartwood, to the top of the stem, where early wood, juvenile wood and sapwood prevail. The moisture content of wood also varies depending on the stem height and increases from the base to the top within the range from 50,9 to 64,6 %.
- The hardness of wood along the grain ranges from 3250 N at the base of the stem to 2260 N at the top parts. The radial and tangential hardness are almost equal in value. They are from 30 to 40 % lower than the hardness in longitudinal direction.

The calculated linear correlation coefficients confirm the results of the analyzes and provide additional information on the magnitude of the interdependence of the studied indicators, namely:

- Changing the distance from the base to the top of the stem has a very high influence on the hardness of the wood ($r_{h,H_{II}} = -0{,}98768$; $r_{h,H_{\perp}} = -0{,}98768$). With a lower degree of correlation is on the content moisture ($r_{h,W} = +0{,}828422$). The lowest influence is on the density of the wood - $r_{h,\rho_0} = -0{,}65957$.
- The density of the wood has a lower influence on the hardness than the distance from the base to the top. The corresponding linear correlation coefficients are: $r_{\rho_0,H_{II}} = +0{,}661569$; $r_{\rho_0,H_{II}} = +0{,}582079$.
- A very high interdependence is found between longitudinal and cross hardness - $r_{H_{II0},H_{?}} = +0{,}973756$.

Besides, the observations made during the experimental studies have shown that the larch forms a crown of "living twigs" in the upper 1/3 of the stems. In this part, it is expected that there will be healthy rottenness-free knots. In the part from the base to the crown there are no twigs or single dried twigs have been found. Inside these parts, dry and rottenness knots can be expected. Their size and location are unknown. Therefore, further studies on longitudinal sections are needed to identify quality areas in the stems.

The conducted experimental studies on stems and wood of *Larix gmelinii* from relatively young stands show that larch is characterised by high physical and mechanical properties. With the increase of age of trees in the stand it can be expected that its mechanical properties will improve.

Larch is a fast-growing coniferous tree species and its rapid growth rate is another reason to pay more attention in order to improve the raw material balance of the country with qualitative wood.

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Determination of the Values of the Cutting Forces on a Wood Shaper with Lower Spindle Position

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ABSTRACT

In this paper a study of certain factors influencing the cutting forces of the individual blades of a woodworking shaper's cutting tool is presented. The reasons for the different values of cutting forces are specified and justified as well. The main reason is the different radius of cutting for each of the cutting edges of the tool. Also, the reasons leading to the difference in radius of the cutting edges are discussed and analysed. As such are distinguished: sharpening mistakes, radial runout of the spindle, looseness in the fitting between the spindle and cutting tool and precessional movement of the cutting tool. A reasonable hypothesis to define the value of each blade cutting forces regarding a tool with four blades with a theoretically calculated cutting force (momentary maximum) is proposed. The study results are applicable to conduct an extensive research in regard to the strength parameters, as well as the torsional vibration of the spindle caused by the cutting mechanism in the woodworking shaper machine.

Key words: woodworking shaper, cutting forces, cutting tool

1. INTRODUCTION

The issue related to the cutting forces in milling woodworking machines is particularly relevant, as they are the basis of the spindle's strength parameters, their torsional vibration, noise and other dynamic processes specific to them. They significantly affect the accuracy of processing and quality of the machined surfaces. This requires a targeted research to be conducted in which the cutting forces are examined in detail, taking into account a group of factors that have influence on them. This allows to study the actual dynamic processes which appear in the wood shaper machine during its operation.

The engineering practice confirms that the cutting force of the individual blade of the cutting tool varies greatly. The reason for this is the different radius of cutting for each of the cutting edges. As an example, the study on the cutting forces of a cutter tool with two blades in counter-milling, in which the radius of one of them is smaller by only 0.01 mm, can be shown. The results of the study show that the cutting force is more than two times smaller for the tooth with the smaller radius of cutting (Grigorov, 1985).

There are known studies explaining how the unbalance of the cutting tool impacts the accuracy of processing in wood shaper machines. From these, it was found that the centrifugal force causes the cutting tool to deflect – so that one cutting edge takes bigger chips than the opposite one (Strenkovsky, 1967). The machined surface with cutting tool having unbalance greater than $17 \cdot 10^{-5}$ kg·m is formed by one tooth whereupon the location of the unbalance and the blade forming the surface coincide. The opposite cutting edge takes part in the cutting process but does not participate in the formation of the processed surface.

Other studies regarding the influence of the unbalance of the cutting tool on the cutting power show that with its increase the cutting power decreases up to 25 % (Vlasev, 1990). It was found that this is due to the precessional movement of the cutting tool. The trajectory, which passes the geometrical center of rotation, is an ellipse. Therefore, the various cutting edges have different radius of cutting, which indicates that with the increase in imbalance, some of the cutting edges cut away smaller chips than the others. It can go even further, namely that the number of blades which take part in the cutting process decreases. All this confirms the conclusion that cutting forces on the individual blades vary considerably.

The explanation given above shows the importance to ascertain the values of the cutting forces acting on each of the individual edges of the cutting tool. However, there are no known methods for precise determination of these forces in the examined wood shaper machines or at least are not known to the authors.

The aim of the present study is to analyze the existing way of determining the cutting forces, and based on known scientific facts, to establish a more accurate model regarding the load on the cutting mechanism in a woodworking shaper machine. This model is based on the different values of the cutting forces of each individual blade of the cutting tool with four blades, as commonly used in practice. The study requires analysing the reasons for the difference of cutting forces – different radius of cutting of each individual cutting edge. At the same time, it is necessary to assess the impact of each of the factors leading to the formation of such a difference in radii of the cutting blades. Thus a hypothesis to determine the values of the cutting forces acting on individual blades of the cutting tool can be proposed.

2. THEORY AND DISCUSSION

The cutting force of cutting edge, as the momentary maximum force, is defined by the formula (Grigorov, 1985; Filipov *et al.*, 1983).

$$Fc_{max} = \frac{2\pi D}{zl} Fc_{ave} \quad (1)$$

Fc_{max} – the maximum instantaneous cutting force in N
Fc_{ave} – average tangential cutting force in N
D – diameter of the cutting tool in m
z – number of blades of the cutting tool
l – the arc length of the cutting path of individual blade in m

Figure 1 illustrates the change of the current maximum cutting force of each individual blade per revolution of a cutting tool with four blades, calculated based on the average tangential cutting force, where the angle α is the angle of rotation of the cutting tool (Filipov et al., 1983). According to the above-cited authors, strength calculations are performed using the force determined by the formula (1) and by assuming that the cutting forces of all blades are identical. However, in real conditions, as noted above, this is not true.

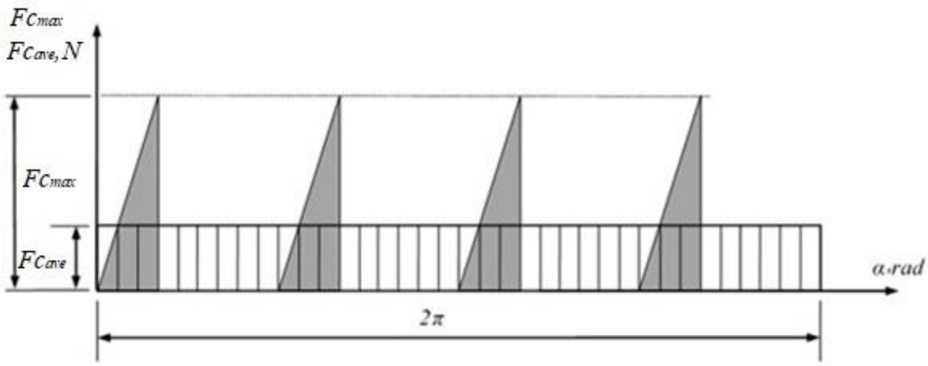

Figure 1. Cutting forces of each individual blade per revolution of the cutting tool

The conducted analysis regarding the reasons why a difference in the diameters of the cutting blades of the cutting tool may occur, allows those reasons to be divided into several groups. They are, as listed below:

1. The radial runout of the spindle. According to BDS 3780-84 it is permissible to be in the range of 0.02-0.04 mm;
2. Looseness in the fitting between the spindle and cutting tool. Obreshkov (1976) recommends two fittings - H7/h6 and H7/g6. For example, for a nominal diameter of 30 mm, the maximum allowable clearance fit would be 37 and 45 μm;
3. Mistakes made during sharpening. Obreshkov (1976) recommends the maximum admissible value of the radial runout of the blades to be within the range 0.02-0.05 mm;
4. The use of a sectional cutting tools, in which the height of the blades is adjusted with a screw;
5. Precessional movement of the cutting tool.

The first four of the above listed reasons are related to the geometrical characteristics of the spindle unit. As it can be seen, the first three independently have values greater than 0.01 mm and cannot be avoided so far. In case of the fourth, this accuracy is very difficult to be achieved in real working environment. These four reasons can directly affect the radius of cutting of each individual blade, even when they are within acceptable values.

Some of the reasons listed above, such as radial runout of the spindle and the looseness in the fitting between the spindle and the cutting tool, as well as the unbalance of the cutting tool, cause disbalance of the spindle unit (Vlasev, 2013). As a result, in idle and working mode a precessional movement of the cutting tool is obtained. A centrifugal force is formed, which operates in a radial direction, and is with the same frequency of rotation as the working tool. The value of the centrifugal force could be calculated as follows:

$$C = m \cdot r \cdot \omega^2 \qquad (2)$$

where

m – the value of the unbalanced mass in kg

r – the radius of rotation of the unbalanced mass in m

ω – the angular velocity of the working tool in $rad \cdot s^{-1}$

This force leads to additional dynamic loads of the spindle unit. In the formula (2) it is seen that with the increase of unbalance, the centrifugal forces acting on the cutting tool (on the spindle respectively) increase (Filipov, 1977; Obreshkov, 1997), and according to Chukov (1990), the radii of cutting of the individual cutting edges differ significantly.

Determining the size of the cutting forces on all individual blades is a difficult task, a solution for which has not yet been found. This is so because of two reasons. The first is due to the trajectory that describes the geometric center of rotation of the cutting tool, being an ellipse. Both diameters of this ellipse vary considerably, with a ratio of approximately 4:1 (Vlasev, 1990). Given that the deflection of the cutting tool from the geometric center of the rotation around the major axis exceeds 0.1 mm, it can be seen how big the difference only from the precession movement in cutting radius can be. The second reason is the orientation of the ellipse regarding the work piece. Its major axis can be directed towards the work piece, as well as perpendicular to it – parallel to the direction of feed. This is determined by many factors such as the geometric parameters of the spindle unit, stiffness of the system in a certain direction (Komarov, 1981), the belt tension direction (Vlasev, 1990) etc. This orientation can be determined only under laboratory conditions. The above shows that in case of a cutter with four blades, a difference in cutting radius greater than 0.01 mm is very likely to occur - and twice as big cutting force for the higher cutting edge (Grigorov, 1985).

In the data from the last literary source mentioned, the cutting forces of a cutting tool with two blades were studied. This paper analyses the cutting forces of a four-blades cutting tool. The question may arise here – are the study results of two-blades tool applicable to four-blades tool? For this reason, the gathered results from the study on the precessional movement of the cutting tool can be taken into consideration (Vlasev, 1990). In studies with a large unbalance (but within the allowable) of the cutting tool, it has been found that only two blades cut. For a brief description of the experiment, the blades will be labeled with numbers from 1 to 4 depending on the direction of rotation of the cutter. The unbalance was set on the side of the first blade, as a result of which the major axis of the ellipse was described only by this particular blade. The opposite blade No. 3 cuts with a smaller radius, as the spindle rotates curved in the direction of the first blade (It is necessary to pay attention to the fact that the work piece in this experiment is fed perpendicularly to the major axis of the ellipse). Consequently, this blade did not cut away a single chip. Blade No2 also does not remove chips because the first one has taken a very large one. This experiment shows that under certain conditions a tool with four blades can use only two of them. The latter has been found by testing the cutting power as a function of the unbalance of the cutting tool and confirmed by laying a coat of paint on all four blades. After making the cut it was reported from which cutting edges the paint had been removed and on which it had remained. Therefore, the results from the research conducted on a tool with two blades can be applied to a tool with four blades under certain operating conditions which are possible to happen in practice.

From the present analysis regarding the factors influencing the cutting forces and based on the above references, a certain ratio between the values of those forces can be accepted. For this purpose, the example above will be discussed but with four cutting edges. For this case, as for the previous one, the cutting force is the greatest for this blade, on which the unbalance is located (considered first), since it has the largest cutting radius. The opposite cutting edge - the third, has the smallest radius of cutting, since at that moment the cutting tool has already moved away from the processed material. The second blade cuts away a smaller chip than the first for two reasons: firstly, because it is farther away from the processed material due to its trajectory and secondly, because the first tooth has already cut away a larger chip at the expense of the second. The fourth blade cuts away a smaller chip than the first, but a larger one compared to the second and third (Vlasev, 1990). To determine the values of the cutting forces, it is taken into account that their sum within a complete rotation of the cutting tool must be constant, which is represented by the formula.

$$Fc_1 + Fc_2 + Fc_3 + Fc_4 = 4 \cdot Fc_{max} \tag{3}$$

Fc_i – the maximum instantaneous cutting force of each blade /i=1-4/

Another condition that arises from the presence of precessional movement must be borne in mind – i.e. the trajectory described by the geometric center of rotation of the cutting tool, which, as mentioned above, is an ellipse. Since the axes of this ellipse are different, then the different blades will cut away chips of different sizes. In the example given above, the second and fourth blade will cut away a smaller chip than the first one (as they are located on the minor axis of the ellipse) from which another condition follows, expressed by the inequality.

$$Fc_1 + Fc_3 > Fc_2 + Fc_4 \tag{4}$$

Therefore, in regard to a cutter with four blades, with theoretically calculated momentary maximum cutting power Fc_{max}, the corresponding can hypothetically be admitted as follows:

– for the first blade – $Fc_1 = 2 \cdot Fc_{max}$;

– for the second blade – $Fc_2 = 0.5 \cdot Fc_{max}$;

– for the third blade – $Fc_3 = 0.2 \cdot Fc_{max}$;
– for the fourth blade – $Fc_4 = 1.3 \cdot Fc_{max}$.

Figure 2 illustrates the change in the cutting forces of each individual cutting edge during one rotation of a cutting tool with four blades in real operating conditions, according to the formula (3), inequality (4) and previously mentioned ratios. Distributing the magnitude of the cutting forces, as mentioned above is hypothetical and it can be different from that, presented here. It should be noted that the largest force $Fc_1=2 \cdot Fc_{max}$ needs to remain the same when changing others.

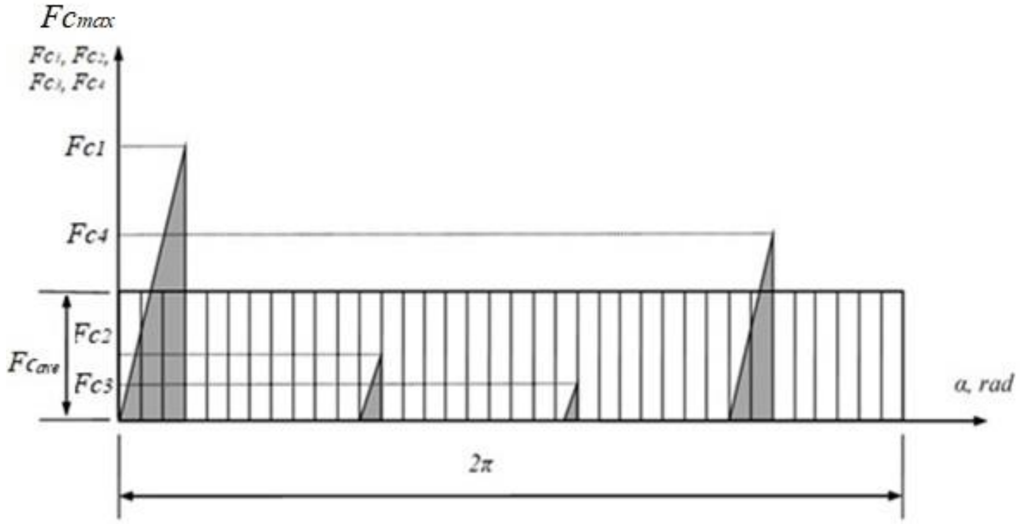

Figure 2. Cutting forces of each individual tooth per revolution of the cutting tool under real working conditions

Regarding the distribution of the cutting forces in Fig. 2, it is characteristic that each cutting force begins at an angle different from π/2 with regard to the maximum of the previous blade depending on the value and the maximum of each force for each blade is at an angle π/2 from the previous or the next.

So far, the values of the cutting forces has been explained hypothetically, but as mentioned above there is a difference in the radii of cutting. This means that the latter will affect the torque. To what extent the different radii of cutting may affect the torque can be determined with a specific example. For a cutting force of 100 N and radius of cutting – 90 mm, with a difference in radii of cutting 0.02 mm for two teeth, the torques are respectively 9 Nm and 9.02 Nm. The example shows that such small changes in the radii of cutting would lead to a calculation error of 0.22 %, which for this analysis can be considered as a negligible value.

The analysis made it possible to draw some conclusions about the dimensioning of the spindles of the milling machines with such distribution of cutting forces. It is necessary to know the maximum tangential and radial cutting force as well as the maximum torque, which can be determined from this study. To calculate the torsional vibrations, it is necessary to know the torques for each of the blade, which regardless of being presented here only hypothetically, are described much more realistically than in previously known methods. Here it was found that not only does the torque vary for the different blades, but the maximum torque is also two times larger than the one traditionally calculated.

3. CONCLUSION

1. Factors influencing the different values of the cutting forces on the individual blade of the cutting tool have been identified. The reason for the difference in the values of cutting forces is stated and justified. The main reason is the different radius of cutting for each individual blade of the cutter.
2. A reasonable hypothesis to determine the values of the cutting forces at different edges of cutters with four blades with a theoretically calculated momentary maximum cutting force is proposed. These forces correspond to the actual working conditions of the machines.
3. The tangential and radial cutting forces and maximum torque are twice larger than the traditionally calculated regarding the strength parameters of the spindle in the shaper machines.
4. It was found that the torque varies for the different cutting edges, as well as that the maximum torque is two times larger than the traditionally calculated one, which would have a significant influence when calculating the torsional vibrations.

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Mechanism for Belt Sanding Machines with a Fixed Bearing of the Sanding Belt and Eccentric Tension

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ABSTRACT

A low-cost mechanism for sanding machine has been developed, consisting mainly of standard hot-rolled steel plates, made of structural steel. The construction is such that for most of the elements and nodes high processing accuracy is not required and can be made in small workshops and mechanical repair workshops. The mechanism is intended to be used by small and medium-sized companies, but can also be used by other woodworking companies. It is also suitable to be used as an additional mechanism for a single spindle moulder.

Key words: sanding, belt sanders, milling machine

1. INTRODUCTION

Wood sanding machines with fixed belt support are intended not only to improve the roughness of the surfaces but also to improve the form of the details. The fixed supports of this type of machines can be elastic or rigid. These machines are widespread uin the woodworking and furniture industry. The construction of these machines is characterized by the fact that there are two basic mechanisms. The first one is a band tensionerand he second one is a mechanism for adjusting the position of the band on the band pulleys.The first mechanism consists of an opening located in a suitable support element in which the carrier fork is located (Filipov, 1979). The fork is pushed by a spring and a screw mechanism which provide the band tension. The second mechanism, in most structures, consists of a fork on which one of the pulley is mounted. The pulley can be tilted using a screw mechanism. This is the easiest way to adjust the band.

The production of these machines is done in specialized metalworking enterprises. The cost of machines nedded for the production of wood sanding machines is high and is not available to some small and start-up companies with less financial resources. Most woodworking and furniture companies have mechanical repair shops or workshops, including small and new companies. They usually prepare the cutting tools for different machines. Factories with well-equipped workshops and highly quallified technical personnel, except for the preparation of cutting tools, can be used to produce a variety of gadgets and mechanisms for their needs at a relatively low cost.

The aim of this work is to create a simplified construction of a belt sanding mechanism with a fixed support of the belt, which can be made in non-specialized metalworking enterprises and at a low cost.

Figure 1. Sanding machine

2. MATERIAL AND METHODS

To create a mechanism that meets the aim in this article, it should be made mostly of standard elements and such which can easily be processed on a lathe and other widespread machines. For manufacture of the construction have been used primarily elementary operations such as cutting, welding, drilling holes, threading and more. Cutting can be done with a power hack-saw, but also with a grinder since most of the elements don’t have required for high precision.

Figure 3 shows a scheme of the proposed construction with explanations for the characteristics of some elements and knots.

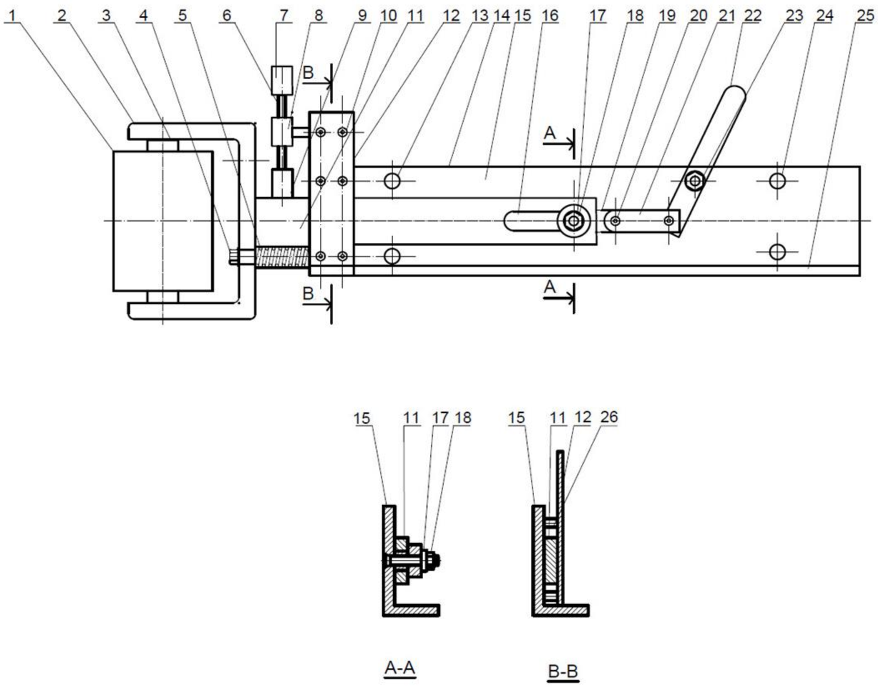

Figure 2. The scheme of proposed construction of implified construction of a belt sanding mechanism with a fixed support of the belt

The body (position No. 15) carries all mechanism elements. It is made of angular steel with dimensions 125×80×10 mm (БДС EN 10056-1:2017). Position No. 25 also shows the body of the machine. It indicates the small profile size, which is reduced to 50 mm and serves as a base. In some cases, the sanding belt reaches the base of the mechanism. The fork (position No. 2) is made of steel with dimensions 32×20 mm or 25×10 mm (БДС EN 10058 (2005)),from whichthe elements of suitable sizeare cut and welded in the shape of letter П. There must be enough space to assemble roll (postion No. 1) and axis (position No. 3).

The fork guide (position No.11) is made from hot-rolled steel with size 50×12.5 mm (БДС EN 10279 (2000)). At the end the longitudinal hole is drilled in the fork (position No. 16). It is used as a guide along the longitudinal axis of the mechanism.

Guiding is realized by bolt with a hidden head and bushing /section A - A/. The diameter of the bolt is smaller than the width of the longitudinal hole by 0.03 mm. The height of the bolt is greater than the thickness of the fork driver by 0.05 mm. On the bush are mounted washer with large diameter (position No. 17) and nut (position No. 18). This gap provides easy guidance along the longitudinal axis and the washer restricts the driver horizontal movement. The fixed support under the sanding belt is joined to the body through the openings (position No. 24). On the left side of the driver /on the side of the fork/ is welded a piece perpendicular to its longitudinal axis, which is used to attach to the fork by bolts. Free distance in the bolted joints can be used to adjust the parallel of the washer to the driver. Restriction of the driver in the horizontal direction is carried out by the restraint piece (position No. 12). It is connected to the body of the mechanism with four bolts, bushings (position No. 26) (section B - B) and nuts (position No. 10). The sanding belt is tensioned by an eccentrically located spring (position No. 5), which is attached to the fork by bolt (position No. 4). The spring rests on the body (position No. 15) and restraint piece (position No. 12). The fork tilts simultaneously with the working of the spring and the cylindrical clammer (position No. 9). The cylindrical clammer is made of polyamide or teflon and is connected to the lower end of the screw (position No. 6). The last is wind up in a nut (position No. 8) which is connected to the restraint piece (position No. 12) by the handle (position No. 7). Tilting is carried out under the pressure of the spring and the moment created by it. The moment seeks to move the fork forward and upward at the same time due to its eccentric position relative to the driver. When lifted up, the guide (position No. 11) rests on a height-adjustable cylindrical clammer (position No. 9). The handle (position No. 22) is used to pull the fork when inserting the band.

The band pulley (position No. 1) is mounted in two radial single row ball bearings. For the assembly of the inner bearing tolerance band h5 / H6 was used and for the outer bearing ring H6 / h5. It is necessary to use a labyrinth seal for both bearings because of the high dustiness (Sokolovski, 2007; 2014). The second band pulley is mounted on the motor shaft (not shown in the figure) or on a specially designed shaft.

This mechanism can be used in a independent sanding machine construction, as well as an additional mechanism for the single spindle moulder. For the second aim, the mechanism can be mounted on the wood shaper work table or with an additional drive pulley on the the working shaft. The diameter of the pulley depends on the treated surfaces.

Normal belt speed should be between (15 - 25) m/s. The belt speed (v) can be calculated by the formula (Filipov, 1983).

$$v = D \cdot \pi \cdot n \qquad (1)$$

where D –is the diameter of drive pulley or spacer bushes and n is the rotational frequency of the working shaft.

This mechanism was made in Department of Woodworking Machines at the University of Forestry by Assoc. Prof. PhD Vasil Vlasev Vasilev. The developed mechanism has been used for 8 years in a furniture manufacturing company and has shown excellent work.

3. RESULTS AND DISCUSSION

A cheap belt sanding mechanism with a fixed support of the belt has been created that can be made in mechanical repair shops or workshops that are not specialized in the field of machinery construction. It mainly uses standard hot-rolled structural steel profiles. The mechanism is intended for use by small factory and those with limited financial resources, but can also be used by any company in the field of woodworking. Also It can be used as an additional part for the single spindle moulder.

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Spatial Vibrations of a Single Spindle Moulder Caused by the Unbalance of Drive Electric Motor's Rotor

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ABSTRACT

Proposed study investigates the forced spatial vibrations of a single spindle moulder, caused by the unbalance of its drive electric motor's rotor. The investigations are done on the base of an original mechanic-mathematical model targeted to study of the forced spatial vibrations of single spindle moulders, developed by the authors. In this model the machine, the spindle and the electric motor's rotor are regarded as rigid bodies, which are connected by elastic and damping elements with each other and with the motionless floor. The model takes into account the needed mass, inertia, elastic and damping properties of the elements of the considered system. It includes also the force disturbances and all necessary geometric parameters of this system. A system of matrix differential equations is compiled and analytical solutions are derived. Numerical calculations are carried out by using the developed model and modern computer programs. The calculations use the parameters of a machine used in the practice. As a result of the whole study, the forced spatial vibrations of a single spindle moulder caused by rotor's unbalance of drive electric motor are obtained and illustrated. These results allow clarifying the influence of the considered unbalance on the work of the main elements of this machine.

Key words: forced spatial vibrations, single spindle moulder

1. INTRODUCTION

The effective maintenance of single spindle moulder is directly related to the reliable operation of their cutting mechanisms (Keturakis and Juodeikiene, 2007; Prakasvudhisarn et al., 2009; Rousek et al., 2010). The modern development of technical diagnostics and in particular of vibration and acoustic diagnostics is a prerequisite for improving the reliability of these mechanisms. A number of companies offer a variety of equipment for vibration and acoustic diagnostics of machines and equipment with corresponding specialized software products. The device as a general rule gives the opportunity for observation of a large number of parameters; moreover, the explored signals are processed and analyzed. However, obtaining reliable results from diagnostic information requires prior identification of characteristic symptoms of specific technical defects for the mechanism under consideration (Amirouche, 2006; Beljo-Lučić and Goglia, 2001; Orlowski et al., 2007). This study is a continuation of the previous authors' studies (Atanasov et al., 2018; Gochev and Vukov, 2017; Vukov et al., 2018).

2. MATERIALS AND METHODS

The analysis of theconstruction of single spindle mouldershows the strong influence of the spindle and the drive motor on the operation of the whole machine, which can be seen from the Figure 1 and Figure 2. In the figure 2. the machine's body is marked with *1*, *2* is the drive electric motor, *3* – the belt drive, *4* – the vibration isolators between the machine and the floor, *5* – the spindle with the bearings, *6* – the tool.

Figure 1. Single spindle moulder – general view

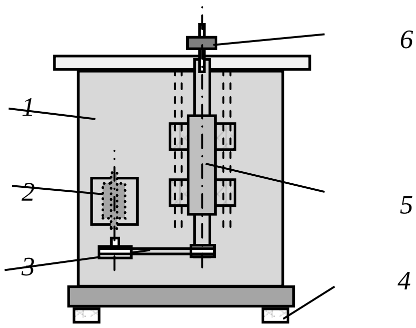

Figure 2. Scheme of a single spindle moulder

The model of a single spindle moulder built for the study of forced vibrations is shown in Figure 3.

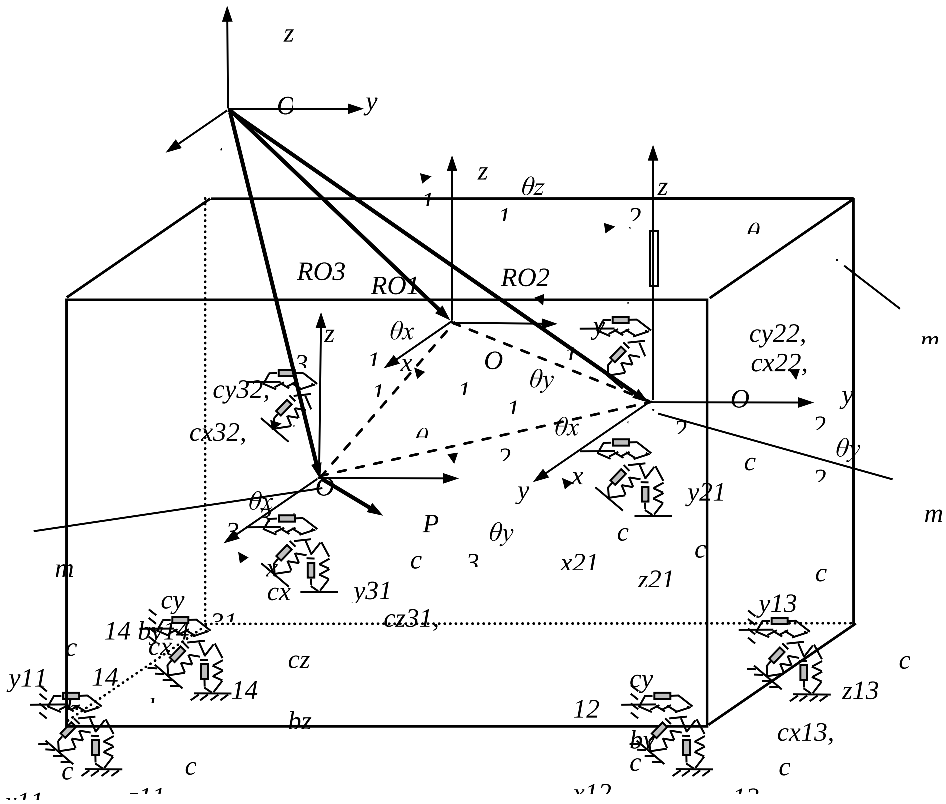

Figure 3. Mechanic-mathematical model of the wood shaper

The following symbols are used:

m_1, m_2, m_3 – mass of the woodworking shaper, the spindle and the rotor of the driving electric motor;

$\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$ – inertia moment tensors of the woodworking shaper, the spindle and the rotor of the driving electric motor;

c_{x1i}, c_{y1i}, c_{z1i} , $i = 1, 2, 3, 4$– elastic coefficients of the vibroisolators between the machine and the floor;

b_{x1i}, b_{y1i}, b_{z1i} , $i = 1, 2, 3, 4$– damping coefficients of the vibroisolators between the machine and the floor;

c_{x2i}, c_{y2i}, c_{z2i} , $i = 1, 2$– elastic coefficients between the body of the machine and the spindle;

b_{x2i}, b_{y2i}, b_{z2i} , $i = 1, 2,$ – damping coefficients between the body of the machine and the spindle;

c_{x3i}, c_{y3i}, c_{z3i} , $i = 1, 2$– elastic coefficients between the body of the machine and the rotor of the driving electric motor;

b_{x3i}, b_{y3i}, b_{z3i} , $i = 1, 2,$ – damping coefficients between the body of the machine and the rotor of the driving electric motor.

The three bodies of the mechanical system perform spatial vibrations - three small translations and three small rotations relative to the axes of the rectangular local coordinate systems that are fixedly connected to the bodies. It is assumed that the axes of the local coordinate systems are parallel to the axes of the reference coordinate system.

The position of the mechanical system in space is defined by the vector of the generalized coordinates, which is

$$\mathbf{q} = \left[x_1\ y_1\ z_1\ \theta_{x1}\ \theta_{y1}\ \theta_{z1}\ x_2\ y_2\ z_2\ \theta_{x_2}\ \theta_{y_2}\ \theta_{z_2}\ x_3\ y_3\ z_3\ \theta_{x3}\ \theta_{y3}\ \theta_{z3} \right]^{\mathrm{T}} \tag{1}$$

The mechanical system has 18 degrees of freedom. The details of the proposed model and the response to free vibrations are given in greater detail in Vukov et al., 2019. In this work, the model is further developed for the study of forced vibrations, caused by rtheunbalance of a drive electric motor’s rotor.

The differential equations of the forced spatial vibrations are derived by using the Lagrange’s method

$$\frac{d}{dt}\left(\frac{\partial E_K}{\partial \dot{q}}\right) - \left(\frac{\partial E_K}{\partial q}\right) + \frac{\partial F_b}{\partial \dot{q}} + \frac{\partial E_P}{\partial q} = \mathbf{Q} \tag{2}$$

where E_K and E_P are respectively the kinetic and the potential energy of the systems, and F_b is the dissipation energy or dissipative function. **Q** is the vector of generalized forces.

The obtained system of differential equations, which describes the forced spatial vibrations of the mechanical system, is

$$\mathbf{M}_{18\times18}.\ddot{\mathbf{q}}_{18\times1} + \mathbf{B}_{18\times18}.\dot{\mathbf{q}}_{18\times1} + \mathbf{C}_{18\times18}.\mathbf{q}_{18\times1} = \mathbf{Q}_{18\times1} \tag{3}$$

The matrix in these equations which characterizes the mass-inertial properties of the mechanical system is **M,B** is the matrix that characterizes the damping properties of this system and **C** characterizes the elastic properties.

The kinetic energy of the mechanical system is

$$E_K = \sum_{i=1}^{3} E_{K\,i}\,, \tag{4}$$

where $E_{Ki} = \frac{1}{2}.\left(m_{RR}^{i}.V_{Ci}^{0\,T}.V_{Ci}^{0} + \Omega_i^{i\,T}.I_{\Theta\Theta}^{i}.\Omega_i^{i} \right),$

and $\mathrm{m}_{RR}^{i} = \int_{V_i} \rho_i\,.\mathbf{I}\,.dV_i = m_i\,.\mathrm{I}$.

The elements of the matrix **M** of mass-inertial properties are defined by the expression

$$m_{i,j} = \frac{\partial^2 E_K}{\partial \dot{q}_i\,.\partial \dot{q}_j} \tag{5}$$

Potential energy is defined by

$$E_P = E_{PK}(q)_m + E_{PG}(q)_i \tag{6}$$

where $E_{PK}(q)_m = \sum_{m=1}^{8} \frac{1}{2}.\mathrm{q}^T.\mathrm{C}(q).\mathrm{q}$,

$E_{PG}(q)_i = \sum_{i=1}^{3} -m_i.\mathrm{g}^T.\mathrm{R}_{Ci}^{0}$,

$\mathrm{C}(q)$ is a matrix of elastic properties;

$\mathrm{g} = \begin{bmatrix} 0 & 0 & g & 0 \end{bmatrix}^{\mathrm{T}}$ – vector of gravitational acceleration,

m is the number of the elastic element between two bodies of the mechanical system

The elements of the matrix **C** of elastic properties are determined by the expression

$$c_{m,n} = \frac{\partial^2 E_{PK}(q)_{ij}}{\partial q_n.\partial q_m} \tag{7}$$

Dissipate function is calculated by the formula

$$F_b = \sum \frac{1}{2}.b_k.\left(\boldsymbol{\delta}\dot{\mathbf{r}}_{\mathbf{k}}\right)^2 \tag{8}$$

where $\boldsymbol{\delta}\dot{\mathbf{r}}_{\mathbf{k}}$ is the deformation velocity of the elastic elements

The elements of matrix B are obtained by replacing the elements of matrix C – $c_{i,j}$ with $b_{i,j}$.

The presence of static unbalance (i.e., the axis of rotation is not a main inertia axis) of the motor's rotor generates polyharmonic vibrations in radial direction. The main harmonic has rotational speed ω and it has the greatest amplitude. There are also odd harmonics with frequencies 3ω, 5ω, 7ω... . Their amplitudes are smaller, but under certain conditions they may increase sharply. The reason for appearance of static or dynamic unbalance of the rotor may be damage or wear of its bearing units or deformation of its axis (Stevens, 2007; Veits et al., 1971). Another reason is cracked or broken rotor wires or short - circuit rings, bad connection between them and others. The disturbing force P_r on the rotor (Figure 3) is represented by the first three harmonics, in this study.

The vector of the generalized external forces has the form

where

$$\mathbf{Q} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{Q}_{\mathbf{F}(3\times1)}^{\mathrm{T}} & \mathbf{Q}_{\mathbf{Q}(3\times1)}^{\mathrm{T}} \end{bmatrix}^{\mathrm{T}} \tag{9}$$

$$\mathbf{Q}_{\mathbf{F}} = \begin{bmatrix} P_{rx3} \\ P_{ry3} \\ 0 \end{bmatrix}, \tag{10}$$

$$\begin{aligned} P_{rx3} &= P_1.\cos(\omega t) + P_2.\cos(3\omega t) + P_3.\cos(5\omega t) \\ P_{ry3} &= P_1.\sin(\omega t) + P_2.\sin(3\omega t) + P_3.\sin(5\omega t) \end{aligned},$$

$$\mathbf{Q_Q}\left(F\right)=\mathbf{U_i^{\Omega 0 T}}.\left(\tilde{\mathbf{r}}_{\mathbf{Pi}}^{\mathbf{0}\,\mathrm{T}}.\mathbf{Q_F}\right), \tag{11}$$

$$\mathbf{U_i^{\Omega 0\,T}}=\begin{bmatrix}1 & 0 & \theta_{y1}\\ 0 & 1 & -\theta_{x1}\\ 0 & \theta_{x1} & 1\end{bmatrix}^{\mathrm{T}} \tag{12}$$

$$\tilde{\mathbf{r}}_{\mathbf{Pi}}^{\mathbf{0}\,\mathrm{T}}=\begin{bmatrix}0 & l_{Piz}^0 & -l_{Piy}^0\\ -l_{Piz}^0 & 0 & l_{Pix}^0\\ l_{Piy}^0 & -l_{Pix}^0 & 0\end{bmatrix} \tag{13}$$

Obtaining the common solutions of the system (3) is related to the determination of the initial conditions of movement $q\left(0\right)$ and $\dot{q}\left(0\right)$.

The general solutions of the system of differential equations in matrix form, with initial conditions $t=0,\ q(0)=q_0,\ \dot{q}(0)=\dot{q}_0$, are

$$\begin{aligned}q(t)=&\sum_{r=1}^{18}\frac{2}{g_r^2+h_r^2}[\mathbf{G}_r.\mathbf{M}.\dot{q}(0)+(-\alpha_r.\mathbf{G}_r.\mathbf{M}+\beta_r.\mathbf{H}_r.\mathbf{M}\quad+\mathbf{G}_r.\mathbf{B}).q(0)].e^{-\alpha_r t}.\cos\beta_r t+\\ &+\sum_{r=1}^{18}\frac{2}{g_r^2+h_r^2}[\mathbf{H}_r.\mathbf{M}.\dot{q}(0)+(-\alpha_r.\mathbf{H}_r.\mathbf{M}-\beta_r.\mathbf{G}_r.\mathbf{M}+\mathbf{H}_r.\mathbf{B}).q(0)].e^{-\alpha_r t}.\sin\beta_r t+\\ &+\mathrm{Re}\{\sum_{k=0}^{n}\sum_{r=1}^{18}\frac{2}{g_r^2+h_r^2}.\frac{\alpha_r.\mathbf{G}_r+\beta_r.\mathbf{H}_r+i.k.\Omega.\mathbf{G}_r}{\omega_r^2-k^2.\Omega^2+i.2.k.\sigma_r.\omega_r.\Omega}\mathbf{Q}.e^{ik\Omega t}\}\end{aligned} \tag{14}$$

where

$$\begin{aligned}&g_r=-2.\alpha_r\left(\mathbf{V}_r^{\mathrm{T}}.\mathbf{M}.\mathbf{V}_r-\mathbf{W}_r^{\mathrm{T}}.\mathbf{M}.\mathbf{W}_r\right)-4.\beta_r.\mathbf{V}_r^{\mathrm{T}}.\mathbf{M}.\mathbf{W}_r+\mathbf{V}_r^{\mathrm{T}}.\mathbf{B}.\mathbf{V}_r-\mathbf{W}_r^{\mathrm{T}}.\mathbf{B}.\mathbf{W}_r;\\ &h_r=2.\beta_r\left(\mathbf{V}_r^{\mathrm{T}}.\mathbf{M}.\mathbf{V}_r-\mathbf{W}_r^{\mathrm{T}}.\mathbf{M}.\mathbf{W}_r\right)-4.\alpha_r.\mathbf{V}_r^{\mathrm{T}}.\mathbf{M}.\mathbf{W}_r+2.\mathbf{V}_r^{\mathrm{T}}.\mathbf{B}.\mathbf{W}_r;\\ &\mathbf{G}_r=g_r.\mathbf{L}_r+h_r.\mathbf{R}_r;\quad \mathbf{L}_r=\mathbf{V}_r.\mathbf{V}_r^{\mathrm{T}}-\mathbf{W}_r.\mathbf{W}_r^{\mathrm{T}};\\ &\mathbf{H}_r=h_r.\mathbf{L}_r-g_r.\mathbf{R}_r;\quad \mathbf{R}_r=\mathbf{V}_r.\mathbf{W}_r^{\mathrm{T}}+\mathbf{W}_r.\mathbf{V}_r^{\mathrm{T}}.\end{aligned} \tag{15}$$

The whole machine and the three bodies are modelled with software Solid Works. These models are shown respectively in Figure 4, Figure 5, Figure 6 and Figure 7. Figure 4 shows the local coordinate systems and the reference coordinate system that coincides with the coordinate system of the body 1 and in which all the vectors are projected. It is assumed that the axes of the local coordinate systems are parallel to the axes of the reference coordinate system. The elastic-damping elements are marked with points 1 to 8. The application point of the disturbing force P_r, which coincides with the mass center of body 3, is marked by point 9.

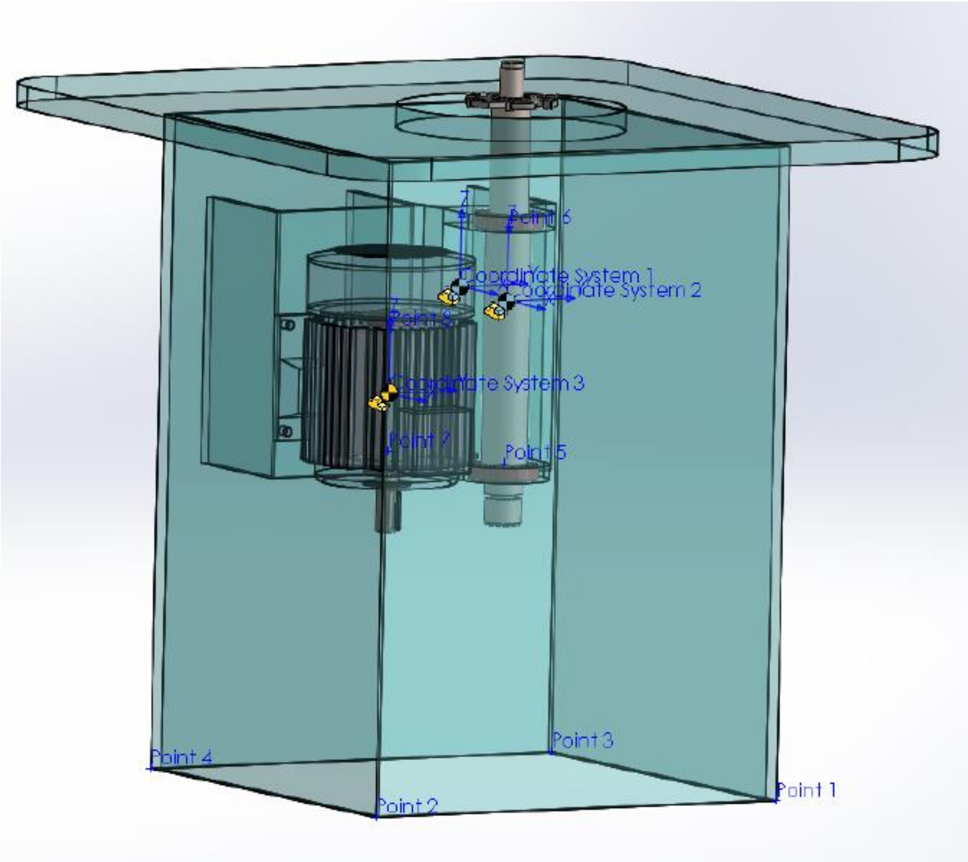

Figure 4. Model of the whole machine

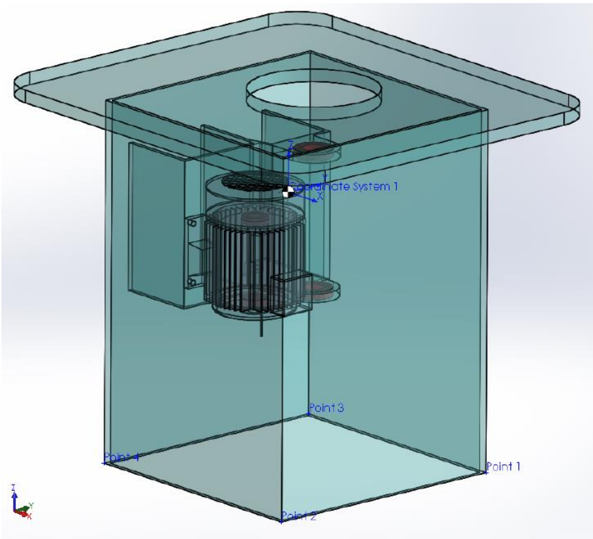

Figure 5. Model of body1

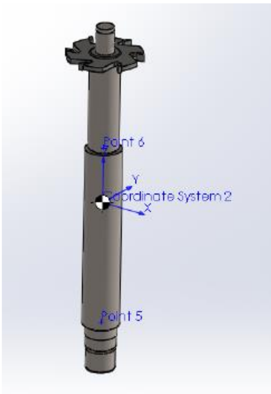

Figure 6. Model of body2

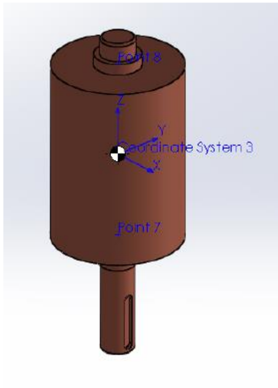

Figure 7. Model of body3

The data used for calculation are presented in Table1 and are based on the measurements made on the single spindle moulder model FD-3, which is produced in ZDM – Plovdiv .

Table 1. Technical characteristics of the single spindle moulder FD-*3*

Body No	*Mass, kg*	Mass inertia moments, *kg.m²*						Coordinates of the mass centers, *m*		
	m	J_{xx}	J_{yy}	J_{zz}	J_{xy}	J_{yz}	J_{xz}	l_{Cx}	l_{Cy}	l_{Cz}
1	391.52	49.2672	52.0000	47.9480	0.0395	0.4405	0.2525	0	0	0
2	11.123	0.2937	0.2937	0.0052	0	0	0	0.009	0.066	-0.020
3	14.378	0.0516	0.0516	0.0206	0	0	0	0.019	-0.115	-0.134

Coordinates of the supporting points of the elastic elements

In the coordinate system of the body 1				In the coordinate system of the body 2			
т.	l_{xi}, m	l_{yi}, m	l_{zi}, m	т.	l_{xi}, m	l_{yi}, m	l_{zi}, m
1	0.309	0.316	-0.654	5	0	0	-0.214
2	0.309	-0.284	-0.654	6	0	0	0.096
3	-0.291	0.316	-0.654				
4	-0.291	-0.284	-0.654				
In the coordinate system of the body 3				**In the coordinate system of the body 1**			
т.	l_{xi}, m	l_{yi}, m	l_{zi}, m	т.	l_{xi}, m	l_{yi}, m	l_{zi}, m
7	0	0	-0.076	5	0.009	0.066	-0.234
8	0	0	0.084	6	0.009	0.066	0.076
				7	0.019	-0.015	-0.210
				8	0.019	-0.015	-0.050

Damping coefficients

Between Bodies	b_{xi}, (N.s)/m	b_{yi}, (N.s)/m	b_{zi}, (N.s)/m
0 and 1	980	670	470
1 and 2	980	670	470
1 and 3	980	670	470

Elasticity coefficients

Between Bodies	c_{xi}, N/m	c_{yi}, N/m	c_{zi}, N/m
0 and 1	1000000	1000000	1500000
1 and 2	2250000	2250000	2250000
1 and 3	2250000	2250000	2250000

Disturbing force: F_H = 300 N

Angular speed: 100 s^{-1} = 15,9 Hz

3. RESULTS AND DISCUSSION

The vibrations on all 18 generalized coordinates of this mechanical system are obtained as a result of the simulation with given parameters. Due to the limited volume of the article, only a few of them are illustrated here. The linear vibrations on the three coordinates of the machine's body, the rotor of the electric motor and the spindle are presented. The results are given at angular speed 100 s^{-1} and disturbing force 300 N. The amplitudes of the considered coordinates are q_1 – 0,21 mm; q_2 – 0,12 mm; q_3 – 0,10 mm; q_7 – 0,32 mm; q_8 – 0,025 mm; q_9 – 0,43 mm; q_{13} – 0,55 mm; q_{14} – 2,00 mm; q_{15} – 0,16 mm.

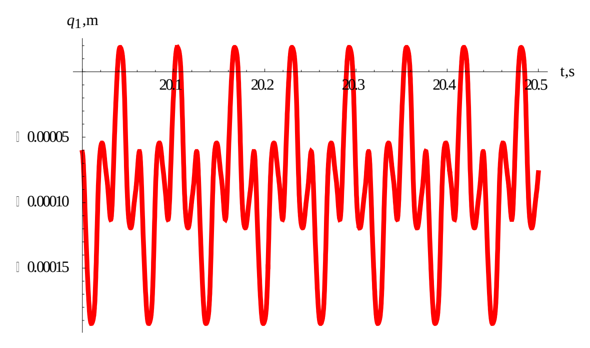

Figure 8. – Graph of $q_1(x_1)$

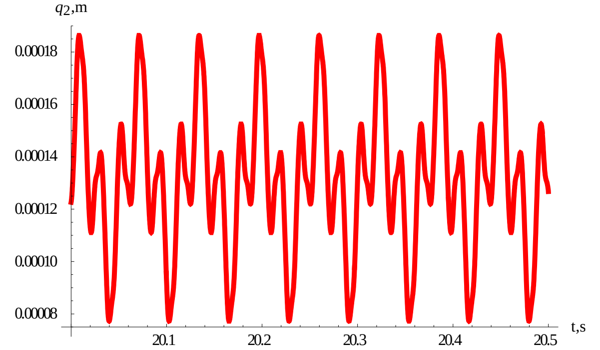

Figure 9. – Graph of $q_2(y_1)$

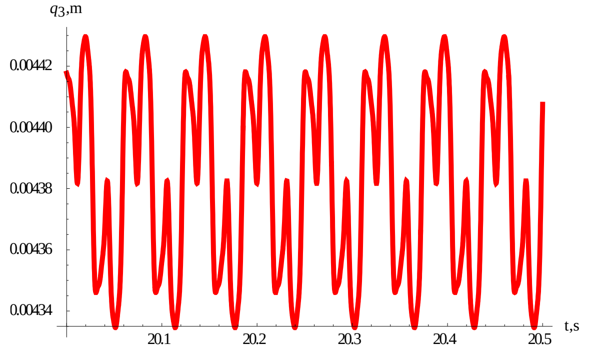

Figure 10. – Graph of $q_3(z_1)$

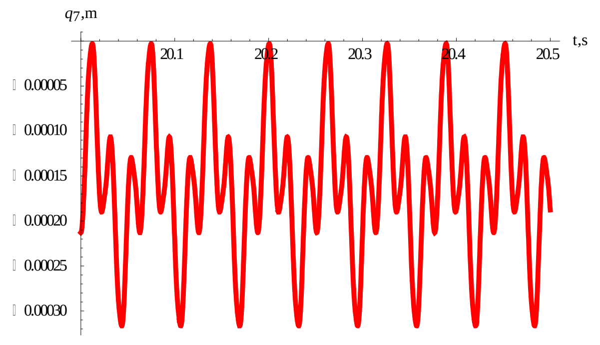

Figure 11. – Graph of $q_7(x_2)$

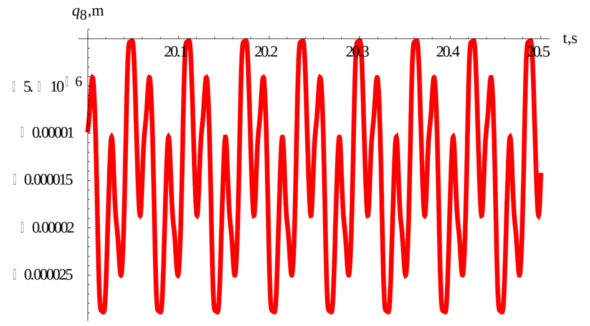

Figure 12. – Graph of $q_8(y_2)$

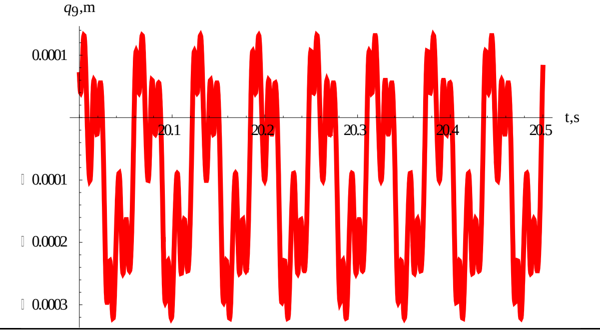

Figure 13. – Graph of $q_9(z_2)$

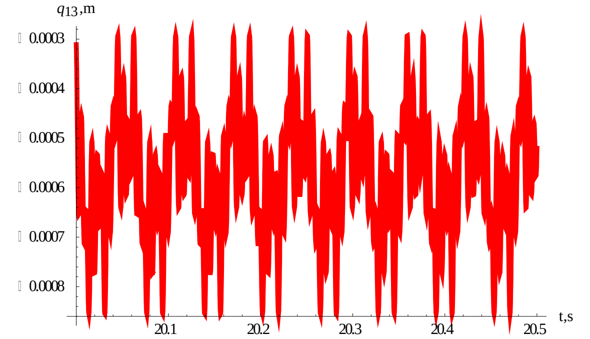

Figure 14. – Graph of $q_{13}(x_3)$

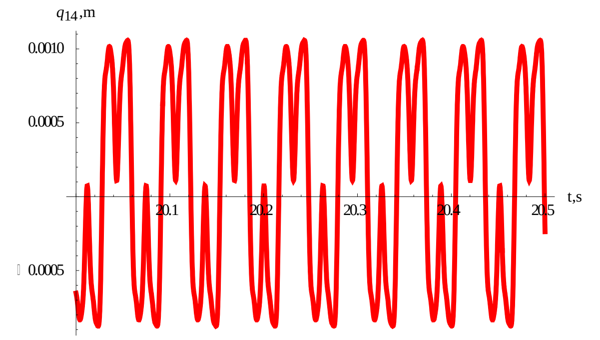

Figure 15. – Graph of $q_{14}(y_3)$

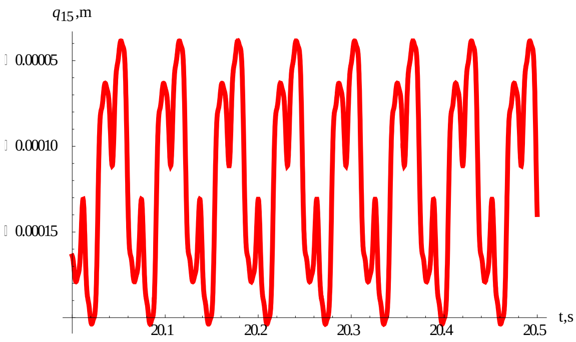

Figure 16. – Graph of $q_{15}(z_3)$

Some conclusions can be drawn from the presented graphs. The amplitudes of the machine's body vibrations on the three coordinates are relatively small. The amplitude of the spindle vibration on coordinate y is small, but the amplitudes on coordinates x and z increase considerably. These vibrations disrupt the interaction between the cutting tool and the material being processed. This, on the one hand, leads to a violation of the quality and accuracy of the production. On the other hand, there is inevitably increased loading of the cutting tool, its faster dulling and wear-out. The amplitudes of the vibrations of the motor rotor at the considered unbalance by the x and y coordinates are the largest and reach unacceptable values for the normal machine operation.

4. CONCLUSIONS

The paper presents a study of the forced spatial vibrations of a woodworking shaper. These vibrations are caused by an unbalance of the rotor of its drive motor. Some numerical calculations are carried out with the help of a developed model and modern computer programs. The calculations use the parameters of a woodworking machine used in the practice. The vibrations of the mechanical system on all the 18 generalized coordinates are obtained as a result of these investigations. Due to the limited volume in the article, only the linear vibrations on the three coordinates of the machine's body, the motor's rotor and the spindle are presented and illustrated. The results are analyzed and conclusions are drawn for the vibrations amplitudes by the individual coordinates for each of these bodies at the considered unbalance. As a result of the study, the impact of the drive motor's rotor unbalance on the operation of the main elements of the machine is clarified. Thus, it is possible to determine the effect of this malfunction on the accuracy and quality of the production. Along with this, it is possible to analyze the dulling and wear-out of the cutting tool.

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Sustainable Supply Chain of Softwood Raw Material

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ABSTRACT

A sustainable supply chain is the result of the challenges that entrepreneurs face in terms of material flow. It is a requirement that is becoming a standard as a result of the introduced legislation and more and more conscious and demanding attitude of customers. Considering the economic aspect of each project, it is necessary to take into account how much interference it will have with the environment and what social needs it will enable to satisfy.

From the point of view of the process of planning and implementation of economically effective and sustainable flows, transport is important. In the case of trade in wood raw materials, the requirements for transport, in particular the optimal use of available forms of transport, must take into account transport routes, vehicle loads and the need to taking a load from unpaved forest areas.

The aim of this work is to show the way softwood's flow from forests to selected groups of customers, such as sawmills, also to identify problems occurring in particular phases of the flow and to present solutions that could improve this process.

Key words: transport, wood raw material, sustainability

1. INTRODUCTION

The supply chain means a network of companies, suppliers and customers who cooperate to manufacture and sell products. It shows the flow of raw and other materials and final products through different stages and includes waste recycling as a part of reverse logistics (Sosa *et al*. 2015; Logistic 2/2013). The purpose of any action performed within the sustainable supply chain is to optimize the use of primary raw materials.

The cooperation across different links of the supply chain is crucial for the smooth flow of commodity, and contributes to management improvements, which result in expanding the business potential. Also, it has a considerable impact on how the company is perceived by potential customers (Palander and Väätäinen, 2005; Wieruszewski and Mydlarz, 2010; Ghaffariyan *et al*., 2013).

The role of a properly functioning sustainable supply chain is to maintain a balance between economic, environmental and social aspects. All these issues must complement each other and form a kind of integral whole. All logistical measures must therefore be comprehensive in their approach to the issues identified. In the wood industry, the certification of primary raw materials is a matter of importance from the perspective of a supply chain managed in accordance with sustainability principles. The certificates are often the only chance of selling products abroad. The basic requirements include the FSC (Forest Stewardship Council) certification of proper use of forestry resources and reduced adverse environmental impact. It enables the holders to use the FSC international trade mark and to enter their company to the international FSC holders base. It guarantees that the company implements an environmental policy and meets the defined standards (https://controlunion.pl/drewno-i-papier/fsc/). Another significant certificate for timber producers is PEFC (*Program for the*

Endorsement of Forest Certification Schemes). It enables tracing the origin of wood at each processing and flow stage (https://controlunion.pl/drewno-i-papier/pefc/). Also, both certificates enable tracing the origin of products across all processing stages, from lumber harvesting to the delivery of final products. They guarantee that each production stage meets the standards for production quality and safety.

In addition to those referred to above, companies also hold quality certificates (9000 series), environmental certificates (14001 series) and occupational safety certificates (18000 series) which supplement and confirm the steps taken towards sustainable development in the timber industry.

Also in the area of forest management, FSC and PEFC certificates held by the State Forests guarantee a properly conducted raw material policy in the field of timber harvesting.

An important aspect of wood harvesting is to maintain a balance and comply with sustainable development principles. This means, first of all, harvesting wood in such quantities to meet the needs of the wood industry while guaranteeing the sustainability of the social and environment function of forests. The underlying principle is to harvest less timber than is grown. In order for the logistics chain to operate in accordance with sustainable development assumptions, all of its participants must abide by these rules.

When observing the evolution in the supply chain of roundwood in Poland, the conclusion is that it tends to become shorter over the years. The process of seeking solutions that contribute to cost reduction, quality improvements and acceleration of processes accessory to customer supplies have resulted in concentrated efforts to optimize timber salvage. As another consequence, timber salvage has been taken over by subcontractors and final customers (Forsberg *et al.*, 2005; Gingras *et al.*, 2006). Any actions involved in planning and organizing the process of harvesting and transporting timber to the customer are a complicated issue. It consists in making the deliveries compliant with customer requirements while maintaining cost efficiency and safety conditions and minimizing the total logistics costs and environmental damage (Swaminathan *et al*., 1993; Sessions *et al*., 2003; Marciniec and Szkoda, 2013).

2. RESEARCH METHODOLOGY

The research presented is this paper focused on the supply of raw pine wood originating from selected Regional Directorates of National Forests in Poland. Timber was supplied to 10 medium-sized sawmills located in northwest of the country (with a total annual capacity of roundwood processing ranging from 30,000 m^3 to 60,000 m^3). The rationale behind their location is the availability of raw materials in the adjacent forest districts which ensure wood supplies. This case study focuses on large-size timber transported in the form of sawlogs and logs. This is because the type of raw material is determinant for the vehicle loading and unloading routine and for how its loading capacity is used. Roundwood was delivered by external transport companies who operate specialized vehicles. Depending on vehicle type and construction, the maximum allowed volume of wood that can be transported in Poland is 25 to 30 m^3, and the maximum total vehicle weight is 40 t. The above figures result from the size and density of wood (the density of pine wood is 740 kg/m^3, as provided for in the Regulation of the Minister of the Environment and the Minister of the Economy of May 2nd, 2012 on determining the density of wood). Unit transport costs and distances traveled by the vehicles were taken into account when analyzing the data.

Timber transport is highly specific for various reasons, including: the size and weight of timber; weather conditions; and the fact that the frequency of timber harvesting varies throughout the year (Kubiak, 1998). Therefore, a transport problem which is defined with more than one objective function usually requires a separate solution for the criterion used (in this case, the selected type of coniferous wood). Afterwards, a compromise solution needs to be sought to justify the selection of a specific form of transport (Forsberg, 2003a, 2003b; Greulich, 2003, Chung and Contreras, 2011). When solving such transport problems, researchers often rely on heuristic methods. Although they might not lead to the optimum solution, they are highly efficient and capable of solving complex problems with multiple objective functions (Fleischmann *et al.*, 1997, Martel *et al.*, 1998, Sessions *et al.*, 2003, Olsson and Lohmander, 2005, Contreras *et al.*, 2008).

The flow of wood raw material starts at the harvesting location. From that point, wood transport takes place in two stages: the first one is extraction which means the delivery of wood to a storage place; the next one means delivering wood from where it was stored to sawmills. Depending on the timber harvesting system, finished timber types may be produced either locally or after transporting the materials to the delivery area at the final customer's premises. Widely used timber harvesting systems are as follows:

– cut-to-length (CTL) logging,
– long wood system (LWS) (Laurow, 1999, Rönnqvist, 2003).

CTL is the most widely used method in both Polish and European forestry sectors; in this case, the finished marketable product (specific timber type) is produced at the place where timber is harvested. This system is believed to be the optimum solution for the Polish forestry, primarily because of its environmental friendliness and state-of-the-art technological equipment dedicated to coniferous timber harvesting.

When it comes to optimum handling of raw materials, LWS offers a much better performance. In this case, sawlogs are transported to the timber terminal, and timber types are produced upon prior inspection by qualified quality controllers. LWS enables a much more accurate quality analysis and offers greater precision in producing specific timber types than CTL in the case of which handling is often limited to sawing timber into logs (Gilmore and Gomory, 1961, Ballaun 1999, Muchowski 1999). The long wood system is used in Northern America and in less developed countries. In this harvesting method, all sawlogs are transported to the timber terminal where further handling takes place. LWS can be concluded to offer the following advantages: high labor efficiency; low processing costs; and the fact that no additional efforts are required to prepare logged areas for replanting (Favreau 1999).

Timber is harvested all year round, though at a varying intensity. The trend which suggests that greater volumes of raw material are harvested in the fall and winter (from November to March) is a reasonable pattern. However, the rationale depends on a much wider spectrum of factors than just a slowdown in the plants' physiological processes and a lower risk of deterioration in the quality of raw materials (Błuszkowska and Nurek, 2010). Another factor of importance is the uneven distribution of demand for wood raw materials, driven by the seasonality of operations of roundwood processors. Therefore, this study covered all-year-round supplies of roundwood raw materials in 2018 and 2019. The following was determined as a result of the study:

– the volume of pine wood supplies,
– the structure of wood supplies, taking their numbers and locations into account,
– the real cost of raw material transports,
– the impact of the distance on the unit cost of wood supplies,
– the average distance traveled to the sawmill,
– the average cost of transporting timber to the sawmill.

The verification of raw material supplies and transport costs provided a basis for calculating the raw material purchase cost per unit for each delivery to the processing plants covered by this study. The proportion of timber volumes transported over specific distances was also calculated. The full transport cycle starts when the vehicle leaves the depot to pick timber, and ends upon unloading the timber in the company's depot. The analysis covered a selection of 5616 full transport cycles carried out from August 2018 to July 2019. The study period was 12 full months during which vehicles made deliveries to the selected sawmills. The transport figures were averaged due to limitations resulting from stops and traffic restrictions for heavy vehicles applicable during holiday periods. For each processing plant, the average delivery distance for the selected pine wood was calculated as the ratio of kilometers traveled to the volume and market value of raw materials delivered.

3. RESULTS OF THE STUDY

The study on a sustainable supply chain of pine raw materials included analyzing the transport roads in terms of distance traveled and delivery volumes. According to the findings, ca. 92 % of all deliveries involve traveling a distance of up to 60 km. In some of the sawmills surveyed, the average distance (for an average delivery) was 45 km which represents 18 % of the maximum transport distance for the deliveries of pine raw materials covered by these observations.

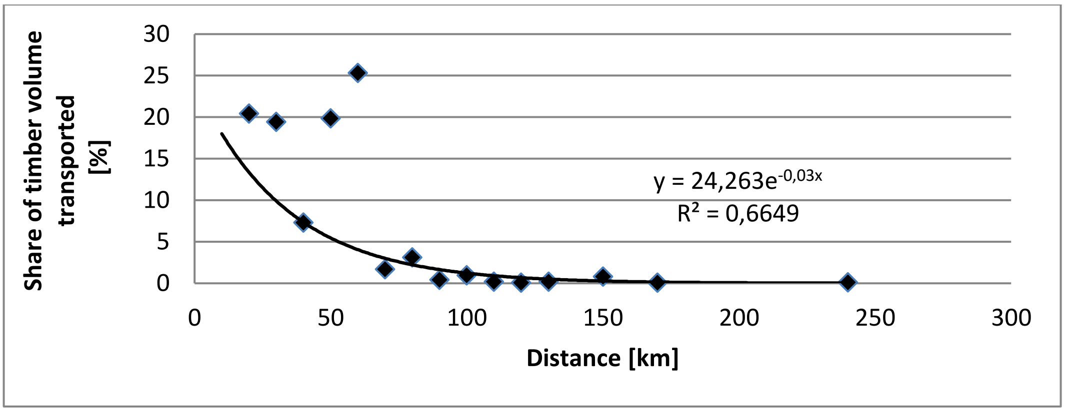

Figure 1. Analysis of the quantities of raw materials transported depending on the distance traveled.

The summary of shares of deliveries, as presented in Figure 1, provided a basis for calculating the value ratios and transport costs for raw materials purchased, as presented in Figure 2. Purchasing costs and delivery costs of raw materials (which depend on the distance traveled by vehicles) are highly variable. As shown in Figure 2, the highest purchasing costs of raw materials, increased with transport costs which represent up to 30 % of the wood price, were found especially in the case of large distances. In turn, a considerable increase in transport cost per cubic meter of roundwood purchased can be noticed in the case of deliveries at a distance of 71-150 km.

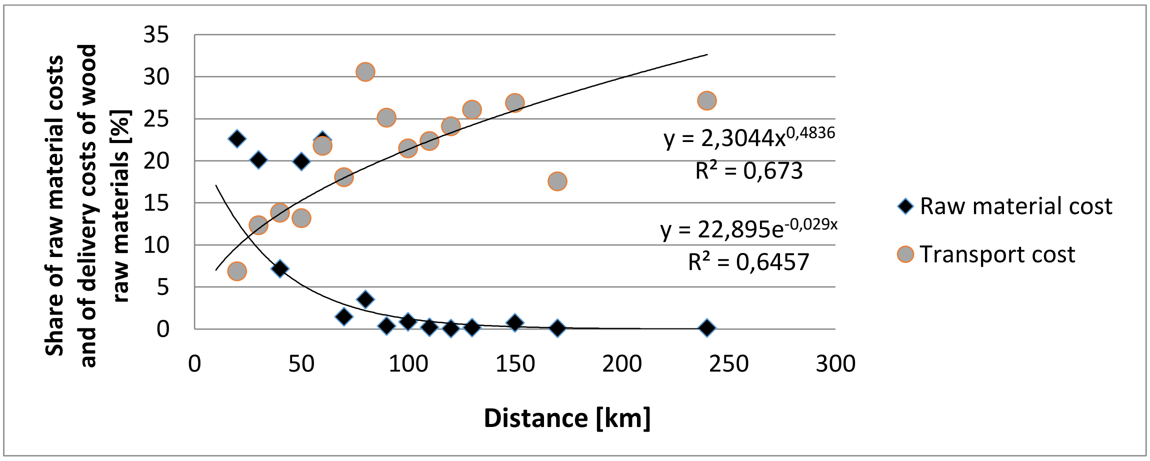

Figure 2. Relationship between wood raw materials and delivery costs, on one side, and the distance traveled, on the other.

Figure 3 shows the unit costs of raw material delivery for different distances gradually incremented by 10 km. In the study period (2018–2019), the real transport cost per cubic meter of roundwood fluctuated from PLN 20 to PLN 90 (VAT excl.), reaching the peak value for a distance of 61-80 km.

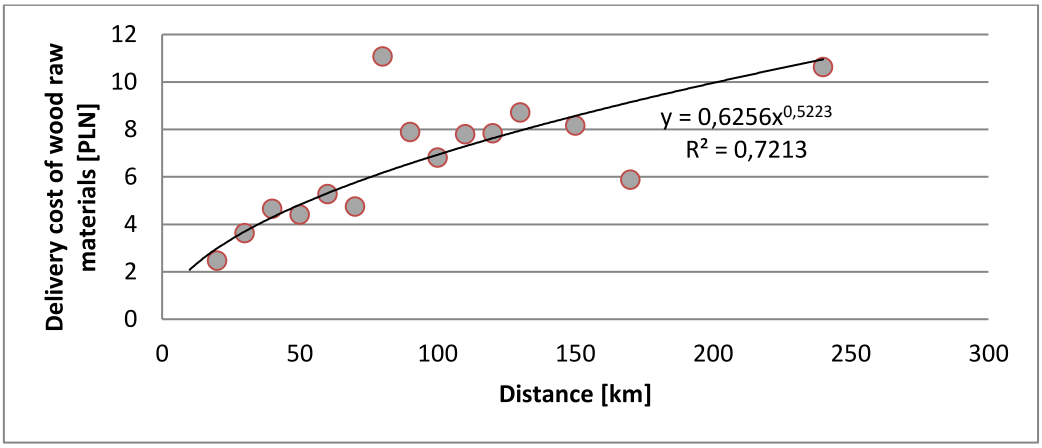

Figure 3. Transport costs per cubic meter of pine wood depending on the distance traveled.

The above findings on the distance of pine wood deliveries to sawmills suggest that the sawmills make efforts to source raw materials from establishments that harvest sawlogs in an area located closest to their premises. As shown in Figures 1–4, in the transport cycle (from loading to unloading raw materials to/from the vehicle), deliveries from a depot located 80–150 km away from the sawmill are the most cost-intensive. In this case study, they accounted for barely 5.8 % of the volume of raw materials delivered. In a vast majority (92 %) of deliveries covered by this study, the distance traveled was up to 60 km. Conversely, raw material costs clearly decrease as the wood delivery distance increases to 100 km. At longer distances, raw materials were more expensive; this is a consequence of the timber selling policy adopted by the Regional Directorates of National Forests. It takes into account the distance, the purchasing price proposed and the history of previous timber purchases (Regulation No. 46 of October 24, 2016).

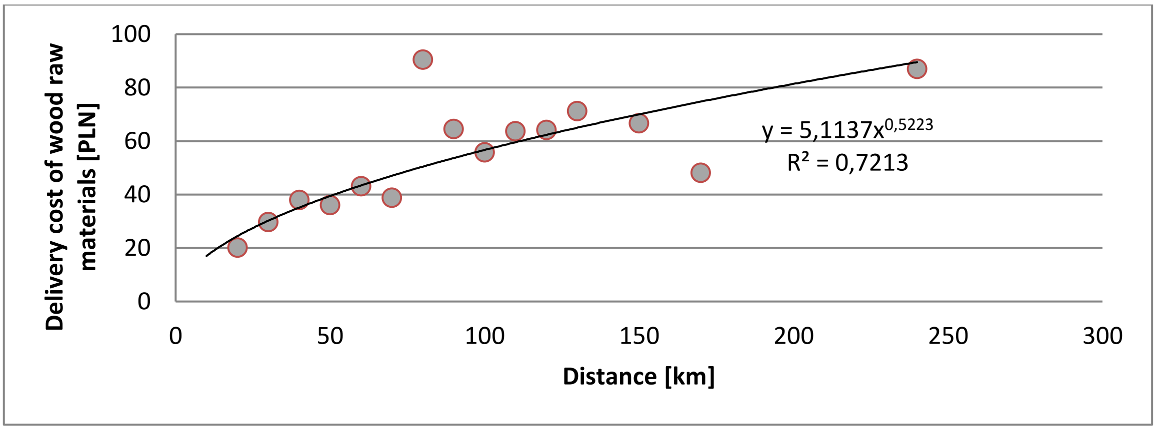

Figure 4. Per-cubic-meter cost of pine wood depending on the delivery distance.

4. DISCUSSION

The transport of wood raw materials plays a major role in the broadly defined timber industry. In Poland, the volume of raw materials harvested has fluctuated around 42 million m^3 in recent years (Leśnictwo (Forestry), 2018). Nearly 90 % of wood is delivered using road transport (Wieruszewski *et al.* 2018). The sustainability of the supply chain of wood raw materials depends on a series of factors. In many countries, this includes the restricted loading capacity of vehicles (Permissible, 2010, Lukason *et al.*, 2011) which in Poland is also limited under statutory provisions (Act of June 20, 1997; Directive of July 25, 1996; Act of September 6, 2001; Regulation of 2012) and under economic assumptions resulting from the rules of sales adopted by the State Forests National Forest Holding (Decision No. 137 of 2018, Decision No. 164 of 2018, Regulation No. 66 of 2018).

The economic aspect plays a decisive role in the research on the volatility of selected areas of wood raw material supply to final customers (in this case study, mechanical wood processing establishments). Of importance too is the accessibility of raw material sources and the loading capacity (Trzciński, 2011, Tomczak and Jelonek, 2014, Tomczak *et al.*, 2016). As regards pine raw materials, the extensive pine forest areas in western Poland contribute to improvements in quantitative ratios while reducing transport costs. Efficient wood transport operations depend on the proper functioning of the logistic process. This largely depends on the organization of timber salvage, on the accessibility of raw materials and on how timber is prepared for transport in terms of form and quality. These activities are the responsibility of State Forests National Forest Holding. The condition of forest roads, and the location and dispersion of raw material storage places have an additional impact on the efficiency of that process. Another factor of importance is the availability and technical condition of loading and unloading equipment in transport companies and processing plants, and the experience of operators.

Planned uses of timber (which depend on market factors) are decisive for the economic viability of timber processing, and therefore define the price thresholds for timber harvesting. The developing market of wood raw material customers can be expected to seek the most efficient ways of securing its existence, e.g. by developing the demand for specific product groups. The availability of raw material sources and the growing economic and social costs of timber harvesting and transport faced by European countries will be determined by the cost-efficiency of the decision-making process. The observed variation in customer demand for timber types of different quality mostly impacts the price level of different timber types. What matters in this context is the impact of the current location (including access to road infrastructures) of processing plants in a given phase of the production cycle, and the processing performance defined by the volume of raw materials processed, organizational capacities and a greater flexibility of stocks resulting from daily demand.

An attempt was made to determine the scope of market impacts on the raw material supply chain, and confirmed that a dominant factor is a level of the structure of reasonable wood management. That level allows to determine the rationale behind the supplies based on a simplified methodology of overall cost accounting at optimal efficiency level of lumber processing. These aspects can be referred to as the drivers of change in the future structure of the market of timber supplied for mechanical processing.

5. CONCLUSIONS

1. In the Polish market conditions, the optimum transport distance of pine raw materials to sawmills is 60 km, which reflects the efforts made to use the closest resources. A near-optimal distance was observed in over 90 % of the transport cycles surveyed.

2. The variation in raw material purchasing costs results from local sales arrangements. No correlation exists between raw material costs and planned transport costs. The latter are determined only by the labor intensity of loading operations and by the distance to the source of raw materials. The difficulties in establishing integrated transport systems for roundwood result from frequent differences in transport specifications and in rules for roundwood purchasing.
3. In the full-year period covered by this analysis, the level of supplies resulted from a steady increase in both transport costs and raw material costs. The shorter the distance between the processing plant and the source of raw materials, the more reasonable it is to increase the volume of materials sourced from it.
4. The rationale behind implementing simple systems for vehicle transport of wood is impacted by the relation between loading and unloading costs, on one side, and the planned transport route, on the other. The duration and, as a consequence, the cost of these operations largely depend on the form of timber (logs or sawlogs) and on its density defined by how the wood is laid and arranged.

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Confocal Laser Scanning Microscopy to Study Variations in Wood Quality

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ABSTRACT

Wood quality depends on its anatomy that varies between and within trees and also between and within growth layers. In Mediterranean and Tropical environments, it is difficult to define annual growth layers and the boundaries between them. Such growth layers normally contain anomalies like intra-annual density fluctuations (IADFs). To better evaluate such anomalies and their effect on wood quality, we search for methodologies which enable fast observation (without time-consuming specimen preparation) and analyses of minute structures. In this context, we used Confocal Laser Scanning Microscope (CLSM) Olympus LEXT OLS5000 (Olympus Corporation Tokyo 163-0914, Japan) and OLS5000 image analyses software to identify the growth layers and to study the anomalies in wood anatomy on polished cross-sections of selected temperate, Mediterranean and (Sub)Tropical species. In temperate *Fagus sylvatica*, CLSM was used to define vessel parameters and distribution in exceptionally narrow rings, helping to evaluate which stressful parameter caused the anomaly. In Mediterranean *Pinus halepensis* and (Sub)Tropical *Pinus oocarp*a CLSM enabled observations and measurements of tracheids within the same radial row to define IADFs and demarcation of growth layers. In (Sub)Tropical *Swietenia macrophylla* and *Cedrela odorata* CLSM helped to clearly define the anatomy of marginal bands of axial parenchyma demarcating growth layers.

Key words: wood anatomy, tree rings, tree-ring boundaries, confocal laser scanning microscopy (CSML), image analysis, wood quality.

Thermal Degradation of Bonding Strength of Aspen Plywood

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ABSTRACT

The objective of this research was to study the effect of exposure time on the bonding strength of aspen plywood at elevated temperatures. The plywood samples were manufactured under laboratory conditions using two types of adhesive: urea-formaldehyde (UF) and phenol-formaldehyde (PF). The plywood samples were tested after exposure to three different temperatures (150 °C, 200 °C and 250 °C) and three exposure time levels (1, 2 and 3 hours) at each temperature. Additionally, a set of control samples was tested at room temperature. The quality of bonding was assessed by shear strength test in compliance with the requirements of the standard EN 314-1. The mass and density losses as well as colour changes of the plywood samples were also determined. The findings of this study indicated that exposure of plywood panels to elevated temperature caused significant degradation of their bonding strength. PF plywood samples lost 63.2 % of their initial strength after 3 h of exposure at 250 °C, while UF samples lost 65.9 % of their initial strength already after 3 h of exposure at the temperature 200 °C. Statistical regression-based models were also developed for predicting the loss of plywood bonding strength as functions of mass and density losses and total colour difference. As the mass/density losses or total colour difference of panels increased, the losses in bonding strength increased too.

Key words: plywood; heat treatment; bonding strength; mass loss; density loss, colour change

Evaluation of Torrefied Short Rotation Shrub Willow as Value-Added Fillers for Wood Plastic Composites

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ABSTRACT

Wood species growing on the marginal land (reclaimed mine land and agricultural land) can represent an important bio-based material that can be turned into value-added products. The NewBio project (Northeast Woody/Warm-season Biomass Consortium) investigated the production of short rotation woody crops for potential bioenergy and bioproducts. As part of this project, the goal of this research effort was to investigate how different short-rotation willow species can be modified and used to create value-added materials. Specifically, the project prepared torrefied short rotation shrub willow *(Salix × dasyclados)* and used the materials in wood/torrefied wood/polypropylene composites. Three different willow varieties (Millbrook, Fabius, and Fish Creek) were torrefied in a tube furnace at both 225 °C and 300 °C. The torrefied material was then ground and mixed with un-torrefied willow, polypropylene and lubricant in different ratios. The materials of differing ratios were blended using a Thermo 16TE twin extruder and then processed into pellets for further specimen preparation. In total 19 different batches were produced. The blended material was then molded into tension, bending, and water absorption samples in a hot press. The influence on torrefied willow percent, type, and level on tensile, flexural, water absorption, and thermal properties will be presented.

Key words: wood-plastic composite, torrefied wood, short rotation willow

Suitability and Thermal Comfort of Different Desktop Materials

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ABSTRACT

In design, tactile interaction between the human and elements in their environment, such as furniture, is often underappreciated. It has been suggested that materials and their finishing can influence user perceptions of thermal comfort and consequently affect well-being. The purpose of this research was to evaluate the thermal comfort of different materials used for desktops and their suitability for everyday tasks. The study involved 16 participants who randomly tested ten materials (untreated spruce, oil spruce, lacquered spruce, untreated oak, oiled oak, lacquered oak, veneer, oak imitation, glass, Kerrock®). Desktop and forearm temperature were measured before and after 15 minutes of use. Additionally, the participants performed a writing task and answered four questions regarding the suitability of the material. Materials with lower thermal conductivity (wooden fibres and oak veneered particleboard) obtained higher temperatures after 15 minutes of use and were rated as more haptically suitable and more likable for everyday use. The participants most appreciated the natural appearance of oiled and untreated oak and the oak veneered particleboard. Based on the results obtained, the choice of natural, wooden material could be the most suitable for desktop production, with the appropriate choice of surface treatment of the material, in our case lacquer, being crucial.

Key words: ergonomics, thermal conductivity, wood.

Impact of the European Union (26) Imports on Development of Wood Flooring Production in the Western Balkans

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ABSTRACT

The Western Balkan countries represent significant producers and exporters of wood flooring in Europe. In 2018, 9.4 % of Europe's wood flooring production originated from this region. The region is a net exporter of wood flooring since it exports over 50 % of total production. The most important market for the export of wood flooring is the European Union with participation of over 60 % in total exports. Trends in this market are important for manufacturers and exporters from the region. Therefore, the analysis of impact of the European Union (26) imports on wood flooring production in the Western Balkans region was conducted by application of econometric modeling. In addition to these results, the paper contains analysis of the competitiveness of wood flooring export from the region measured by appropriate competitiveness indices. The aim of this analysis was to quantify the level of their price and non-price competitiveness on the European Union market (26).

Changes in Customer Preferences for Wooden Furniture in Slovenia from 2010 to 2019

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ABSTRACT

In the last decade, the Slovenian furniture industry market has experienced a number of changes, especially with the arrival of new retailers on the market. Situation is such that furniture manufacturers and retailers are still trying to determine the best ways to adjust to new customer demands. Well known thing is that customer satisfaction is the key component for the success of the business. In order for companies to be more successful, it is important to have customers' insight into needs and wants. In line with this the purpose of this study, which was conducted in 2010 and 2019, was to observe and analyse changes in the preferences of customers for furniture: materials, attributes, and styles when deciding on new furniture in Slovenia. The results of the conducted research showed that respondents differ in their preferences for furniture materials, as well as the factors that influence their purchase decisions when buying interior and exterior furniture. It was found that wood was widely preferred as a furniture material among the respondents.

Key words: wooden furniture, customer preferences, survey, Slovenian market

Comparison of Wood Moisture Determination in Wood Particles by Rapid Field Method and Laboratory Method

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ABSTRACT

Nowadays, use and production of biomass as a renewable energy source is a way of reducing the production and use of fossil fuels and mitigating climate change. Wood biomass moisture is of great importance for its transportation and storage, and various measuring devices are being introduced on the market that make it easy to determine the wood biomass moisture. The paper analyzes the reliability of the wood moisture estimation with the EVO BIO PC device, which, without laboratory conditions and in a simple and fast way, can estimate the water content of chopped wood in the measuring range from 5 to 60 % of wood moisure, depending on the granulation of the wood particles. The results of the measurements performed with the EVO BIO PC were compared with the wood moisture of the wood particles determined by the gravimetric method. Measurements were made on fir wood particles (sawdust, shavings and wood chips) and two types of fir pellets. The differences in the wood moisture obtained by the two methods ranged from 0.4 to 2.3 % depending on the sample analyzed and the sampling site. Based on the statistical comparison of the measurement results, it can be stated that the EVO BIO PC is reliable for determining the wood moisture of fir wood particle and fir pellets, and given the speed and simplicity of estimating the wood moisture, it can serve as an alternative method for estimating the wood moisture of wood particles in woodworking plants and storage of wood particle material.

Key words: biomass, wood particles, sawdust, wood particle content, gravimetric method, EVO BIO PC

Improving Manufacturing Data Quality with Data Fusion and Advanced Algorithms for Improved Total Data Quality Management

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ABSTRACT

The advent of artificial intelligence, data mining, robotics, etc., has become a standard for successful business endeavours and is known as the 'Fourth Industrial Revolution' or 'Industry 4.0'. Data quality is a key issue in the sustainable biomaterials industry. Untreated data from multiple databases are generally not in the right structure to perform advanced analytics. Some inherent problems of data from sensors that are stored in data warehouses at millisecond intervals include missing values, duplicate records, sensor failure data (data out of feasible range), outliers, etc. This data science focused research was to create a continuous real-time software algorithm for data cleaning that automatically aligns, fuses, and assesses data quality for missing fields and potential outliers. The program automatically reduces the variable size, imputes missing values, and predicts the destructive test data for every record in a database. The impact of outliers and missing data were tested on a dataset with 201 variations of outlier percentages and missing data percentages ranging from 0-50 %. The software program was also validated on a real dataset from the wood composites industry. Overall, the data cleaning software program significantly decreased the NRMSEP ranging from 64 % to 12 % in accurately predicting quality control variables.

Key words: interactions effects, medium density fibreboard, regression trees

Digital Development of the Slovenian Wood Industry

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ABSTRACT

The research examined the digital development of the Slovenian wood industry, especially the implementation of the concept of Industry 4.0 into practice. Within this, the implementation of specific technological pillars was studied, with the emphasis on smart factories and smart, innovative products. In the empirical part of the research, we prepared a survey and interviewed selected managers and entrepreneurs. We compared answers regarding sub-sectors, the size of the companies and the level of digitalization. The general results show that around half of the surveyed companies are already implementing the Industry 4.0 concept into their businesses, while the rest are beginners when speaking about digitalization. The biggest obstacles to the implementation of the concept are the high investments needed in the equipment and the lack of financial support from the state. The lack of digital competencies, which is especially prevalent among older workers, is another major barrier that businesses face. Only 30 % of the surveyed companies are engaged in the production of smart products. We can conclude that digitalization in the Slovenian wood industry is still at a relatively low level, but with the latest strategic orientations at both the state and business levels, this situation will certainly improve in the near future.

Numerical Modelling of Stiffness of RTA Furniture with New Externally Invisible and Dismountable Joints

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ABSTRACT

The distribution of furniture sold in the form of flat packages requires the use of appropriate design solutions. These include joints, which need to facilitate self-assembly with no need to use tools. Such joints should be functional, aesthetically attractive, durable and safe to use. It was decided in this study to manufacture prototypes of innovative furniture joints and evaluate quality of furniture assembled using this joints. For this purpose, the finite element method and the Abaqus program were used. Joints were modelled as objects made of PLA. Surface to surface contact and assembly forces resulting from the construction of joints were introduced between the elements of the joint. The furniture case was subjected to torsional loads. The rigidity of furniture and stress distribution in joints were calculated. On the basis of numerical calculations the joints were positively validated.

Performance of Model Glulam Beams after Two Years of Outdoor Exposure

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ABSTRACT

The service life of the composites is influenced by the service life of input raw wood material and used adhesives. The aim of the study is to assess the performance of glulam beams exposed in an outdoor application. Glulam beams (83 mm × 68 mm × 1100 mm), made of three layers of Norway spruce (*Picea abies*) with PUR adhesives used are exposed in use class 3.2 in a horizontal position since 4th November 2016. Part of the specimens is equipped with MC sensors. Every year the degradation was evaluated visually (EN 252). The dynamic MoE was determined by longitudinal vibration, and the static MoE using a 4-point bending test (EN 408). On the smaller specimens, cut from glulam's, compressive strength (DIN 52185), delamination (EN 14080), and shear strength (EN 14080) of the adhesive bonds were determined. The results after two years of exposure indicate that the performance of the glulams is determined by the wood modification, the adhesive used and surface coatings applied.

Key words: degradation, glulam, mechanical testing, performance, service life, wood

Development of Optimal Surface Preparation for Anatomy Research of Invasive Wood Species by Scanning Electron Microscopy

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ABSTRACT

Research was done to develop the optimal method of wood surface preparation for scanning electron microscopy (SEM). Since 2018, environmental scanning electron microscope (ESEM™) FEI Quanta 250 has been installed at Department of Wood Science and Technology in Ljubljana. We tested several methods for the pre-preparation and cutting of wood surfaces for SEM analyses. The samples had been either dried, soaked in water and frozen, impregnated with paraffin or simply moistened before cutting. We analysed wood surfaces obtained by splitting, sawing, planning, grinding and cutting on a sliding microtome with different blades. The effect of gold coating on the SEM image quality was also evaluated. Best results were obtained by cutting a pre-moistened surface on a sliding microtome with a low profile replaceable blade and gold coated afterwards. Determined methodology is technically less demanding, not time consuming and obtains results that satisfy needs for wood anatomy research at magnifications up to 12.000x. Guidelines for the optimal preparation of samples were prepared and theoretical and practical basis for investigations of wood anatomy using SEM were provided. Method was afterwards used in analyses of invasive alien plant species – investigating their anatomical structure in the frame of the AlienPLAntSpEcies - APPLAUSE project. It was demonstrated that the use of the SEM opened new scope in detailed investigations of the wood structure and properties.

The Influence of Wood Modification on the Transfer Function of the Violin Bridge

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ABSTRACT

The violin bridge is an important component of the violin as it transmits the excitation forces from the string to the violin body. Depending on its structure, at certain frequency spectrum the bridge acts as a damper or amplifier of excitation forces, which depends on its transfer function. In the study the transfer functions in the range from 400 Hz to 7000 Hz in vertical directions of 3 bridges were measured, where the bridges were made from maple wood and distributed from different manufacturers. The bridges were then thermally modified, and measured the transfer functions again. To determine the influence of thermal modification on material properties, together with the bridges a sample of maple wood was also modified, where the modulus of elasticity and shear modulus before and after the modification were measured. Using Ansys software, a bridge was modelled with the finite element method, where natural frequencies and transfer functions before and after the modification were calculated. It can be confirmed from the research that the wood modification influences the bridge transfer function and that the finite element method can be used to determine the dynamic properties of the bridge by knowing the wood material properties and as such predetermine the transfer function of the violin bridge before its production.

Key words: violin bridge, excitation, transfer function, finite element method, Ansys, wood modification

Wood Surface Finishing of Selected Invasive Tree Species

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ABSTRACT

Due to their strong renewal power the invasive tree species are spreading rapidly, especially in abandoned agricultural and forest areas and along the traffic routes and water courses. One way of their restriction is promotion of their use. In our research we investigated surface finishing of wood of five selected invasive species in Slovenia, Box elder (*Acer negundo* L.), Black locust (*Robinia pseudoacacia* L.), Horse-chestnut (*Aesculus hippocastanum* L.), Honey locust (*Gleditsia triacanthos* L.) and Chinese sumac (*Ailanthus altissima* (Mill.) Swingle), and compared it with finishing of the European beech (*Fagus sylvatica* L.) wood. For coatings, we selected one component waterborne finish on acrylate-polyurethane basis, one component solventborne finish on polyurethane basis and Tung oil, as a natural finish. Several surface properties were investigated. We proved that coating hardness, resistance to scratching and adhesion are very much related to interactions between the coating and the substrate, while resistance to cold liquids was depended only on the type of the finish. It was also shown that in general woods of selected invasive tree species are not problematic for finishing. The only exception was Black locust wood on which Tung oil cured very slowly.

Key words: coating, finishing, invasive tree species, oil, wood

Determining of the Drying Characteristics of Invasive Wood Species Growing in Specific Environments

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ABSTRACT

Varying shapes and tree habitus are the reasons that from natural environments more and more tree species are spreading through non-native habitats, mostly in parks and gardens. Trees are subject of specific cultivation and pruning methods and in many cases their growth becomes uncontrolled and invasive. Due to the characteristic growth conditions and human actions, the structure of the wood is very heterogeneous and deviates from that which is typical in natural stands: the proportion of juvenile wood is higher; more discolored wood is formatted and more knots and fiber deviations are found. The drastic increase of tyloses, more infected wood with poor mechanical properties makes drying process problematic. A method of half adjusting drying time was introduced for evaluating the drying curves of three invasive wood species (*Robinia pseudoacacia*, *Acer negundo* and *Aesculus hippocastanum*), of three thicknesses and at two temperature levels. Drying quality was checked by determining the moisture content gradient, measuring the drying stresses and detecting typical drying defects. Due to the high risk of collapse, careful drying of fresh *Acer negundo* is essential. We confirmed the proper use of half adjusting drying method for comparative evaluation of drying characteristic of different wood species.

Key words: kiln-drying, invasive wood species, drying time, drying quality

Wood Sector Media Budget Allocation: Comparison of Republic of North Macedonia and some Balkan countries

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ABSTRACT

Promotion as one of the four marketing mix elements (product, price, place and promotion) is equally important for creating a relevant and differentiated value for the target group. It is the one of the essential marketing tools for increasing sales, number of customers, and providing long term profitable growth of the company itself. Wood industry, especially the furniture companies are using promotion for creating products' awareness, to increase sales with sales promotions, and the most important for building the brand image for long-term customer relationships.
This paper analysis and compares the official media reports published in Republic of North (RN) Macedonia and several other countries in Balkans as Croatia, Bosnia, Serbia, and Bulgaria. According to the official results from Nielsen Arianna, IPSOS, and Alma Quattro, Macedonian furniture companies' media budget allocation is mainly on television channels with budget of EUR 4.786.710, that is 6,7 times lower then Croatian furniture companies' media budget allocation on the same channel (EUR32.223.506). The conclusion is that the media budget of Macedonian furniture companies is on a very low level, compared to other Balkan countries, mainly because 74 % from total furniture companies are micro companies with up to ten employees, which influence on the media budget.

Key words: advertising, furniture, media budget allocation, promotion, wood industry.

Production and Applications of Nanofibrillated Cellulose

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ABSTRACT

Nanofibrillated cellulose (NFC) is a renewable, sustainable, biodegradable and light-weight material with excellent mechanical properties and is therefore suitable to be used as a reinforcing, packaging, medicinal material or even in printed and flexible electronics. Despite all the great potential such as high surface area, unique morphology, low coefficient of thermal expansion and good mechanical properties the main challenge in formulation of composite is the uniform dispersion of nanofibrils in biocomposites. The aim of this presentation is to review research work which was done in recent years at Department of Wood Science and Technology of the University of Ljubljana in the field of nanocellulose production and its use in biocomposites. The first part of the work was devoted to the production/isolation of NFC from wood biomass. Versatile biomass raw materials have been used for the isolation of cellulosic nanofibrils, among them wood of most important domestic hardwoods and softwoods, bleached and unbleached TGW and industrial Kraft pulps. NFC production encompasses mechanical disintegration of the biomass, purification, chemical pre-treatment and fibrillation. The developed processes and characterization of three different NFC products, TEMPO NFC, maleic ester of NFC and anionic NFC which were obtained by TEMPO mediated oxidation, maleic anhydride esterification and peracetic acid pulping, respectively, will be discussed. Second part of the research was focused on the development of biodegradable nanocomposites, based on polylactic acid (PLA) reinforced with neat and acetylated NFC. Selected properties of unmodified and acetylated NFC as well as biocomposites will be demonstrated.

Key words: nanofibrillated cellulose, production, properties, modification, composites, polymer

Engineering the Properties of Eco-Friendly Medium Density Fibreboards

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ABSTRACT

Free formaldehyde emissions from wood-based panels, especially in indoor applications, pose serious risks to human health at certain concentrations. Prolonged exposure to formaldehyde can cause adverse health effects including eye, nose and throat irritation, other respiratory symptoms and cancer. As a consequence, new formaldehyde emission limits for composite wood products were established in Europe, USA and Japan. This, together with the stricter environmental legislation are the main driving factors for shifting the scientific and industrial interest from the traditional formaldehyde-based synthetic resins to the new bio-based adhesives for production of eco-friendly wood-based panels. The lignin-based products are one of the most prospective ecological alternatives of the traditional formaldehyde resins. The main interest in lignin is due to its phenolic structure with several favourable properties for formulation of wood adhesives such as high hydrophobicity and low polydispersity.

The present article is aimed at studying the possibilities for using lignosulfonate as an adhesive for the production of eco-friendly MDF. Regression models describing the impact of lignosulfonate concentration and hot pressing temperature on the exploitation properties of MDF panels were developed. The individual and combined impact of both factors was analyzed in order to determine the optimal exploitation properties of the panels.

Key words: eco-friendly MDF; lignosulfonate; exploitation properties; bio-based adhesives; wood-based panels

Properties of Beech Cell Wall: Micropillar Compression, Nanoindentation Mapping and FE Analysis

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ABSTRACT

Wood, as a hierarchical material, exhibits very different behavior and properties at different scales. At the cell wall level, common nanoindentation provides important insight into the material, but it has limitations because it does not imply uniaxial stress and provides data from single spots. Therefore, our work aims to present mechanical properties of beech cell wall obtained by two state-of-the-art techniques: micropillar compression (MCo) tests and nanoindentation mapping (NIP). MCo represents uniaxial compression and provides elastic modulus (E) and strength. NIP brings full-field information on E at a broad region of interest. Our results show that average strength of beech cell wall is about 275.6 MPa, which is higher than in most cited literature. E obtained from MCo is about 7.95 GPa, which is lower than values obtained on a macrolevel and about 61 % of the value obtained from NIP. NIP also showed that cell wall around middle lamella is about 64 % of the value at the location attributed to S2 layer. To examine the effect of sinking of micropillar into wood substrate below it, we used finite element analysis (FEA). The FEA showed the sinking effect may reduce measured *E* to 40 %.

Key words: beech, cell wall, micropillar compression, nanoindentation, finite element analysis

Physical Properties of Juvenile Wood from two Paulownia Hybrids

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ABSTRACT

There is a growing trend in the world of planting fast growing species of timber (rotations 5 to 10 years). Their primary purpose is the production of wood fibers and biomass, but they certainly represent the potential in making solid wood products as well. One of the fast-growing species is *Paulownia*, a species of extremely fast growing wood. Plantation breeding of *Paulownia* in Croatia is increasing, although there is a little knowledge about the technical properties of *Paulownia* wood and its end use is questionable. This paper presents preliminary results of some physical properties of two Paulownia hybrids juvenile wood planted in the area near town Glina in Croatia. One hybrid is 9501 ((*Paulownia fortunei* × *Paulownia elongata*) × (*Paulownia fortunei* × *Paulownia tomentosa*)) and the other hybrid is Shan Tong (*Paulownia fortunei* × *Paulownia tomentosa*). The aim of this study was to investigate physical properties of Paulownia hybrids juvenile wood from one site in the Republic of Croatia; to determine differences in physical properties of wood between two hybrids and to evaluate correlation between density and shrinkages of each hybrid. Significant differences in oven dry density, basic density and density at maximum MC, between two hybrids were determined. There is no statistically significant difference in longitudinal, radial, tangential and volumetric shrinkages between two hybrids.

Key words: hybrid 9501, hybrid Shan Tong, juvenile wood, Paulownia wood, physical properties

Characterisation and Modelling of Drying Kinetics of Thin Ash and Oak Wood Lamellas Dried with Infrared Radiation and Hot Air

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ABSTRACT

Infrared and hot air drying characteristics of thin ash (*Fraxinus excelsior* L.) and oak (*Quercus robur* L.) wood lamellas were experimentally determined using an infrared and hot air laboratory device. Drying curves of 2 mm thin lamellas were established in temperature range between 60 °C and 90 °C, and fitted by Fick's diffusion model. Drying efficiency, drying rate and effective diffusivity have been estimated and compared between used drying techniques. Moisture ratio exponentially decayed with duration of the process at all used temperatures. Effective diffusivity was greater at ash than oak wood, and not influenced significantly by drying technique. The increased bound water diffusivity with increased drying temperature was confirmed at both wood species, and caused shortening of drying process. Similar activation energy was determined at both wood species, lower at the IR drying technique.

Key words: drying kinetics, hot air drying, infrared drying, moisture diffusion, wood.

Qualitative Analysis and Implications of Wood Products Perception on the Social Media

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ABSTRACT

The article presents the results of the qualitative research of the social media, managed by the Institute of the Civil Society, University of Ss. Cyril and Methodius in Trnava, with the cooperation of the Slovak University of Technology in Bratislava. The aim of the research was to analyse different areas of the current managerial challenges and their perception on the selected social networks. The research concentrated on the presentation of the selected manufactures from the automotive industry and furniture industry on the social media. The content analysis was based on the VADER (Valence Aware Dictionary and sEntiment Reasoner) lexicon that was specifically attuned to sentiments expressed in social media and QDA software.

Key words: automotive industry, qualitative analysis, sentiment analysis, social media wood industry

Influence of Some Factors on the General Vibrations Generated by Woodworking Spindle Moulder Machine

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ABSTRACT

The current study investigates the general dynamic behavior of a woodworking milling machine with a lower working shaft location, determined by the mean square value of the vibration speed (v, mm.s-1 (r.m.s)) measured on the shaft bearings.
The results show that the mounting of a cutting tool increases the overall vibration of the machine in idling. Among the measured factors, the cutting speed (Vc) has the greatest influence on the vibration intensity, followed by the feed rate (Vf) and the thickness of the cut-out layer (h). Based on the presented graphical relationships, the optimal values of the studied factors can be determined in order to reduce the overall vibration of the machine, which is an important prerequisite for the good work of the cutting tool and for improving the quality of the machined surfaces.

Enhanced Abrasion Resistance of Coated Particleboard Treated with Atmospheric Plasma

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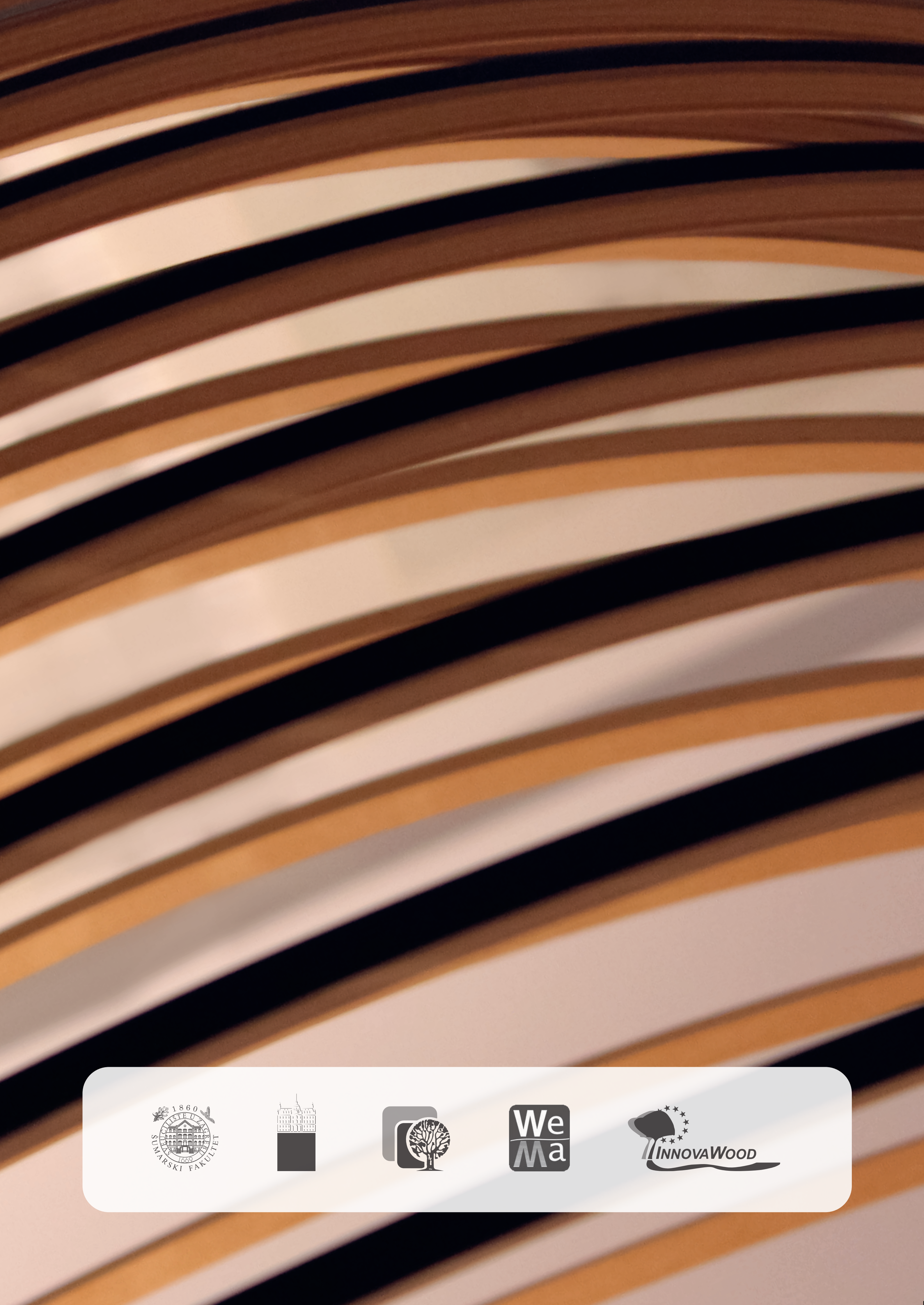
ABSTRACT

This study aims to investigate the influence of atmospheric plasma treatment on the abrasion resistance of particleboards, as an example of a wood-based material, coated with a waterborne finish. Treatment of the substrate prior to coating application using a floating-electrode dielectric barrier discharge (FE-DBD) plasma resulted in an enhanced abrasion resistance of the coated particleboards in comparison to the untreated ones during the abrasion test with a duration of 200 revolutions. This finding was related to lower contact angles of water and a coating after treatment with plasma and greater hardness of the coating on the treated substrates. The micrographs of the sample cross sections recorded with scanning electron microscope showed differences in the amounts of remained coating on the abraded areas. Investigation with attenuated total reflection Fourier transform infrared spectroscopy revealed that treatment of the substrate with plasma did not affect the chemical composition nor the curing and structure of the later applied coating. Further studies with investigations to determine the resistance properties of such surface systems to other impacts should be performed.

Key words: abrasion, coating, particleboard, plasma

NOTES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