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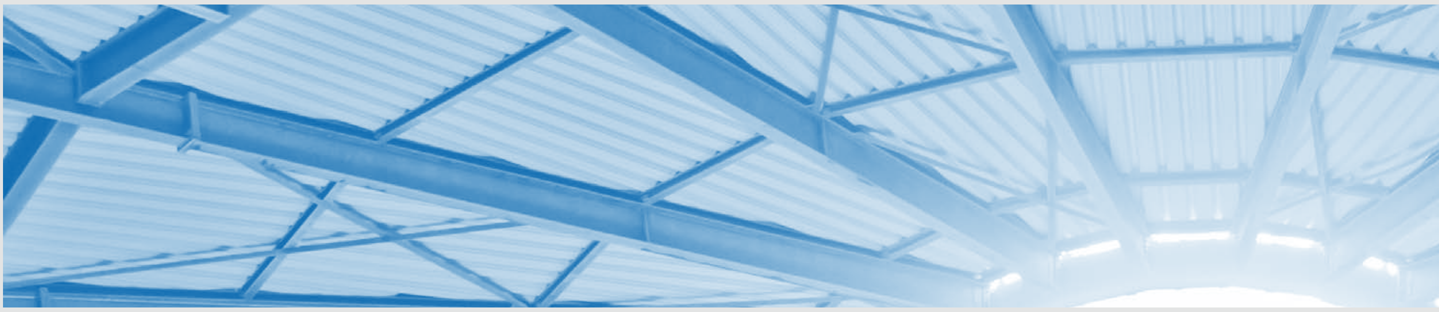
Activity Report



2015 – 2018

vdz.

Activity Report 2015–2018

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The VDZ activity report summarises the activities of the German Cement Works Association and its Research Institute in the reporting period.

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Dear readers of our Activity Report,

VDZ produces an Activity Report at regular intervals to describe the work performed in the preceding years. As a globally recognised competence centre, VDZ again supported the cement industry and undertook a wide range of activities to help promote concrete construction in the 2015 to 2018 period under review. The findings obtained by VDZ through its involvement in numerous national and international research projects, in particular as a founding member of the European Cement Research Academy (ECRA), have made a significant contribution to sustainable cement production and use. They result from the joint efforts of the German cement industry and reflect more than 140 years of success to date.

Concrete and cement are the construction materials a modern society needs for bridges, roads, schools, hospitals, sports halls, stadiums, offices and residential buildings. Forecasts for the worldwide demand for concrete and cement indicate a continuing increase – not least due to the enormous infrastructure investments required in view of the population growth in many countries. In the light of this development, the continued high level of building activity and the worldwide availability of the raw materials required for cement production, such as limestone and clay, there is still no other construction material which could adequately replace cement and concrete. All the more so because concretes produced with cement offer extremely robust and durable solutions for practical applications. The cement industry is nevertheless facing some major challenges. The great demand for cement-bound building materials makes it necessary to further optimise power consumption and resource utilisation together with the associated CO_2 emissions. As no binder is likely to be available in the near future which could even come close to replacing the established cements in terms of properties and quantity, the aim must be to further improve today's systems based on Portland cement clinker and to make the production of these as environmentally sound as possible. With this aim in mind, the cement industry is working together on a number of future issues such as the further reduction of emissions, climate protection and also digitisation along the cement and concrete value chain.

The structure of the VDZ Group of companies has continued to evolve in recent years so that it is well equipped to deal with the many different challenges of the future. A particularly important development is the new VDZ building close to Duesseldorf University, scheduled for completion in 2019. After around 60 years in the Tannenstrasse in Duesseldorf, VDZ will thus be moving to a new and modern home offering plenty of potential for VDZ to carry on expanding its activities.

On behalf of VDZ, I hope that you will join me in looking confidently into the future and that you will find the report a source of inspiration.

Duesseldorf, September 2018

Dr Martin Schneider
German Cement Works Association
Chief Executive

1

VDZ – Tradition and Innovation

1.1 Tasks, activities and structures of VDZ

1.1.1 German Cement Works Association

The German Cement Works Association (VDZ) is the joint organisation of the German cement manufacturers. For more than 140 years the association has been representing the interests of its member companies and pursuing the aims of environmentally compatible cement production and high-quality concrete construction. The association has always been dedicated to the promotion of science and technology, including pre-competitive research and development in the field of hydraulic binders. For this purpose, VDZ runs the Research Institute of the Cement Industry, a unique competence centre for cement and concrete research. VDZ represents cement manufacturers at regional and national level in both Berlin and Brussels on economic, raw material, climate and energy policy issues.

Membership in VDZ

Full membership is open to any natural person or legal entity engaged in the production of cements and cement-type binders which are standardised or officially approved in the Federal Republic of Germany. Cement manufacturers outside Germany and other organisations allied to the cement industry can join as VDZ associate members without voting rights. The 18 VDZ member companies (figure for 2018) together operate 46 cement plants in Germany, employing a workforce of more than 7 500 and generating an annual turnover of a good 2 billion Euro. Five German companies and 22 businesses in other countries are also associate members of VDZ.

VDZ gGmbH is a non-profit organisation which coordinates the joint activities of the German cement manufacturers with a view to promoting science and technology, as well as research and development for the production and use of hydraulic binders. Drawing on more than 140 years of research experience in this field of work, VDZ gathers and produces new findings for the purpose of:

- Ensuring the performance of cement and concrete – in particular durability
- Opening up new areas of application for cement-bound building materials
- Tackling problems relating to the production and use of cement and cement-bound building materials
- Using alternative fuels and constituents for cement and concrete production
- Improving the operating characteristics of kiln plants and grinding plants
- Reducing energy consumption in cement production
- Reducing the emissions of carbon dioxide (CO_2) and other substances of relevance to the climate and the environment in cement production
- Ecological assessment of cement-bound building materials
- BIM-assisted condition assessment and repair planning for concrete constructions

Scientists from VDZ are also responsible for presenting these findings to the VDZ member companies, authorities, universities and the public. Of particular importance are questions relating to standardisation and quality assurance. At the same time, VDZ experts work on ways of improving in-plant environmental protection and promoting industrial safety measures. The VDZ development programme also offers extensive further training in the form of seminars, workshops, online courses and multi-week

Fig. 1.1.1-1 VDZ CEO Dr Martin Schneider

courses for the pit & quarry industry. The work of VDZ involves providing services in the areas of environmental and plant engineering, chemistry and mineralogy as well as concrete and concrete constituents.

VDZ works in association with FIZ GmbH, which coordinates activities relating to independent testing, inspection and certification services. FIZ GmbH operates the following competence centres for this purpose:

Testing, Inspection and Certification Body (PÜZ)

The testing, inspection and certification of cements and cement-type binders have always been central areas of VDZ expertise. With these activities, VDZ has been helping to meet the safety objectives of the European Construction Products Regulation and of the Federal State Building Codes for many decades. The PÜZ is an accredited body for the certification of products in accordance with DIN EN ISO/IEC 17065 and certifies cements, concrete constituents and mortars.

Environmental Measuring Body

For more than 40 years, the environmental measuring body has been taking environmental measurements as part of the official inspection procedure for plants requiring a licence. In addition to dust and gaseous emissions, the environmental measuring body also examines the environmental impact in the vicinity of cement plants and carries out noise and vibration measurements to satisfy official requirements. The environmental measuring body also checks the proper installation and functioning of continuously operating measuring devices and performs the necessary calibration work. Since the early 1980s it has been recognised as an independent testing agency as per §29b of the Federal Pollution Control Act and offers its services for plants covered by the 13th and 17th Ordinance on waste incineration and co-incineration as well as the Technical Instructions on Air Quality Control. It is also accredited in accordance with DIN EN ISO/IEC 17025.

FIZ GmbH Certification Body (FIZ-Zert)

The certification body of FIZ GmbH (FIZ-Zert) is accredited by the German Accreditation Authority (DAkkS) in accordance with DIN EN ISO/IEC 17021 and DIN EN ISO 14065 for the certification of management systems and the verification of greenhouse gas emission reports. Since 2017, FIZ GmbH has also been recognised by the Concrete Sustainability Council (CSC) as a testing body for the performance of CSC certification at concrete manufacturers (see section 2.5 CSC certification).

Christian Knell new president of the German Cement Works Association

Fig. 1.1.1-2 VDZ President Christian Knell

On 27.04.2017, the VDZ members elected Christian Knell, General Manager of HeidelbergCement in Germany, as their new president. He succeeded the long-standing president Gerhard Hirth, who had been at the VDZ helm for twelve years.

With Christian Knell in charge, VDZ remains in the hands of an experienced representative of the cement industry. Knell had been VDZ vice-president since 2012 and has been working in the cement industry for more than 25 years. Following his election by VDZ members, Christian Knell stressed that he was taking over a well-run organisation from Gerhard Hirth and that he was looking forward to making his contribution to the future development of VDZ to the benefit of the cement manufacturers. During his tenure as president he intends to focus particularly on environmental and climate protection, as well as on research in the fields of cement and concrete. 'With regard to environmental protection, German plants are amongst the best in the world – but we are going to get even better,' explains the new president. To comply with the highly ambitious environmental legislation targets, the German producers are currently investing around 400 million Euro in state-of-the-art exhaust gas cleaning technology. 'This represents a strong commitment to the industry here on the part of domestic cement manufacturers,' says Knell.

Following his election as the new VDZ president, Christian Knell paid tribute to the achievments of his predecessor Gerhard Hirth. Under Gerhard Hirth, VDZ developed into an independent and professional organisation which is without doubt the only one of its kind anywhere in the world. VDZ has deep roots in the cement industry and represents the interests of the industry with respect to crucial environmental and economic policy issues. It also provides its member companies and customers throughout the world with a unique range of services. Out of gratitude and recognition for his work as VDZ president, the General Assembly appointed Gerhard Hirth as Honorary Board Member. He will thus remain available to VDZ in an advisory capacity.

The challenges facing the cement industry in the coming years are plain to see. Christian Knell placed particular emphasis on the paramount importance of climate protection, for example. Given the fact that the raw material-induced process emissions restrict the potential for reducing CO_2 in cement production, the new president would however welcome moderation in policy-making for the future. 'Particularly with regard to energy and environmental policy, we need realistic political decisions that will secure the future of competitive cement production in Germany.'

1.1.2 Boards and committees

Concrete Technology Committee

The Concrete Technology Committee deals with current issues regarding the production and use of concrete. It accompanies the corresponding VDZ research activities in the context of the proper and quality-conscious use of cement and concrete in practice.

For this purpose the Concrete Technology Committee has set up working groups on traffic engineering, regulations and durability as well as the ad-hoc task group on concrete durability classes.

Energy Committee

The Energy Committee deals with current issues regarding German and European energy and climate policy. These include greenhouse gas emissions trading in Europe, the German energy transition process, the taxation of power and sources of energy, as well as the German renewable energies act and the development of power grid fees. The Committee gathers topics of interest from all German cement manufacturers in this field

Environment and Process Technology Committee

Alongside current issues concerning thermal and mechanical process technology, the Committee focuses on safety, environmental and energy-related topics. The Committee supervises and initiates projects as part of the extensive VDZ research programme.

To perform its work, the Environment and Process Technology Committee has set up working groups on safety at work, abatement of emissions, monolithic materials, NOx reduction and comminution.

Cement Chemistry Committee

The work of this Committee focuses on current analytical issues, product-related industrial health and safety provisions and ongoing research projects in the field of cement chemistry, in particular on the use of cements with several main constituents and cements with a low clinker content.

For this purpose the Cement Chemistry Committee employs working groups on analytical chemistry, the performance of cement constituents, cement and admixtures, as well as the task group on product-related health and safety provisions.

Specialist Committee to the Quality Surveillance Organisation

The VDZ Specialist Committee to the Quality Surveillance Organisation monitors the objective and impartial implementation of the quality inspection work carried out by the testing, inspection and certification body (PÜZ). In particular, it checks the prerequisites for the awarding and withdrawal of certificates in the areas of product certification and the certification of factory production control. In this context, the Committee intensively studies the current and future course of legal, official and normative regulations and the influence of these on the production and use of construction products.

Certification Advisory Board

The Certification Advisory Board acts as a steering committee for both the certification body FIZ-Zert and for the testing, inspection and certification body (PÜZ) and checks observance of the self-set standards and the independence demanded. Alongside representatives of FIZ GmbH, the meetings of the board are attended by other interested bodies such as the Federal Institute for Materials Research and Testing, as well as representatives from German cement manufacturers.

Technical and Scientific Advisory Board

The Technical and Scientific Advisory Board is responsible for management of the VDZ research activities. The VDZ committees report to the Advisory Board on their current activities, research projects and areas of future action. The Advisory Board coordinates the tasks of the individual committees and adapts these to existing and future challenges and the interests of the VDZ member companies.

External boards

VDZ has also participated in more than 300 national and international boards of other organisations on behalf of the German cement manufacturers. Examples include standards committees of the German Institute for Standardisation (DIN) or the European Committee for Standardisation, work with allied associations such as the German Ready-Mixed Concrete Association (BTB), the German Concrete and Construction Technology Association (DBV), the German Aggregates Federation (MIRO), the German Association for Construction Chemicals (DBC), the German Concrete Association for Roads, Landscaping and Garden Construction (SLG), the German Institute for Building Technology (DIBt), the German Committee for Structural Concrete (DAfStb), the Road and Transportation Research Association (FGSV) and political representation on boards of the Federation of German Industries (BDI) or the European Cement Association CEMBUREAU.

1.1.3 Membership, initiatives and investments

VDZ and its research institute work closely together with authorities, universities, material testing agencies and numerous professional associations, standards committees and organisations of allied industries in a variety of fields at national, European and international level. This cooperation usually involves employees representing the institute or member companies on the boards of these organisations.

Federation of Industrial Cooperative Research Associations (AiF)

The AiF, of which VDZ was a founding member, uses funds from the Federal Ministry of Economic Affairs and Energy to promote industrial collective research (ICR). One of the conditions for funding is that the research associations themselves have to make their own financial contribution in addition to the funds provided. In the past few years VDZ has regularly received AiF funds for several major research projects. The AiF and the Federal Economics Ministry are to be thanked for their support.

Initiative for Sustainability in the German Cement Industry

With their initiative for sustainability, the social partners in the German cement industry have been promoting the sustainable development of their sector since 2002. Alongside VDZ the initiative is supported by the socio-political working group of the German cement industry (SPADZ) as well as the trade unions Industrial Union for Building-Agriculture-Environment (IG BAU) and Industrial Union for the Mining, Chemical and Energy industries (IG BCE). In the period under review covered by this Activity Report, the social partners jointly published a study on the supply of raw materials and resource productivity in the German cement industry conducted by the Wuppertal Institute for Climate, Environment and Energy (see Box in section 1.2.2). In 2018 two studies will be completed:

- a study on the high quality use of waste in the German cement industry, conducted by the Institute for Energy and Environmental Research Heidelberg (ifeu)
- an analysis of the status quo and the potentials of Industry 4.0 in the German cement industry, conducted by the RWTH Aachen University.

Concrete Information Centre (IZB)

The Concrete Information Centre (IZB) was founded by the German cement industry back in 1972. The aim was to provide a single comprehensive platform to satisfy the demand for information about cement-bound building materials. The merger of BetonMarketing Deutschland and the regional BetonMarketing companies led to the reorganisation of the IZB in 2015. The Concrete Information Centre functions as a central hub, employing the well-established concrete network with contact and consultation offices in Beckum, Erkrath, Hanover and Ostfildern. As a platform for producers and motivator for the industry, the IZB provides a network for all players in the construction sector. Its core activities include market expansion, market consolidation and image promotion for cement-bound construction methods. New areas of application for cement-bound building materials are specifically promoted, as is the use of innovative products and methods. An essential aspect of this is the provision of technical consultation for building owners, builders, architects and engineers. The IZB focuses not just on building construction but also on engineering work and road construction, as well as on garden construction and landscaping and construction in the agricultural sector. The specific services are geared to current construction activities: The emphasis is on concretes and methods which permit reliable technical solutions, leave room for architectural design flexibility and help ensure economical, high-quality and sustainable construction.

Normensand

The Normensand company was founded in Beckum in 1954 by 23 Westphalian cement plants. Its main area of business is the production of test sands. These are treated sands of specific particle sizes and mineralogical composition used for the monitoring and quality inspection of cements and other binders. Normensand supplies test sands to producers, institutes and testing laboratories in over 90 countries. Being one of the largest purchasers of test sands in Germany, VDZ acquired a large share in Normensand in 2013.

Universities

VDZ has always been involved in promoting university activities in the field of construction research and building technology. In the period under review, VDZ again provided funds for research work at university institutes. Together with the Federal Association of the German Lime Industry, VDZ sponsors a professorship at Clausthal University of Technology to support the faculty of 'Binders and Construction Materials'. In addition, employees from the research institute work as lecturers at various technical universities and other institutes of higher education.

1.1.4 International cooperation

CEMBUREAU

CEMBUREAU is the umbrella association of the European cement industry in which 31 national cement associations work together across borders. VDZ has been contributing technical and scientific expertise to this joint project for many years. In the period under review, top priority topics were environmental protection, CO_2 reduction and sustainable construction. Joint European efforts were also continued to establish the possible effects on human health of working with cement.

NANOCEM

VDZ has been part of the European research and training consortium NANOCEM since it was established in 2004. NANOCEM is made up of 34 partner organisations, including universities, national research institutions and industrial partners. More than 120 researchers work together in NANOCEM. The aim is to find out more about the nanostructures and microstructures of hardened cement paste to gain a better understanding of the macroscopic properties of cement-bound building materials.

European Cement Research Academy (ECRA)

VDZ was one of the founding members of the European Cement Research Academy (ECRA) which celebrates 15 years of joint activities in 2018. ECRA now has more than 45 members, including cement manufacturers and cement associations as well as companies which work for the cement manufacturers in a variety of capacities. Seminars and workshops are held on various topics relating to the production and use of cement. In most cases these take place on site at the plants of ECRA members. VDZ scientists regularly support ECRA in these efforts with their expertise.

One topic on which ECRA concentrates is the capture and recovery (CCS/CCU – Carbon Capture and Storage/Utilisation) of carbon dioxide from the exhaust gas of rotary kiln plants at cement plants. Since 2007, ECRA has conducted extensive research work on this topic and has been supported in a variety of ways by VDZ in doing so. Whereas the first project phases involved theoretical studies, laboratory scale tests and simulation work, the oxyfuel process is now to be subjected to real-scale testing (see Box in section 1.3.1). The planning of a demonstration project at two European cement plants got under way in 2017.

A further focal point of ECRA activities is research into new grinding techniques as part of the 'Future Grinding Technologies' research project started in 2014. This is considering how grinding processes are likely to develop in the future and whether there are any innovative processes which are not yet in use at cement plants. In this context the first step was to set up a database containing more than 120 different grinding processes from a wide variety of applications. This compilation is now being analysed to determine whether it is possible to apply certain aspects to grinding processes commonly used in the cement industry. ECRA is working in close cooperation with the Institute for Particle Technology in Brunswick on this topic under the leadership of Professor Kwade. The work involves not just modelling the various grinding processes, but also verifying them in laboratory-scale tests.

Fig. 1.1.5-1 VDZ CEO Dr Martin Schneider at the 2017 Annual Cement Conference

1.1.5 Congresses and conferences

VDZ organises various events with a view to putting the findings from VDZ research projects into a practical context. The VDZ Annual Cement Conference has become a permanent fixture on this agenda and was held in September 2015, 2016 and 2017. Around 400 experts from the cement and concrete industry and from allied branches met up in each of these years to discuss matters of common interest at the traditional gathering.

On the occasion of the 2016 VDZ Annual Cement Conference, the Klaus-Dyckerhoff Prize was awarded for the fifth time with Professor Dr Siegbert Sprung being honoured for his life's work (see Box).

The VDZ specialist conferences provide a platform for information exchange and the advancement of research and technology. In the period under review, experts from the industry gathered at the VDZ specialist conferences on cement chemistry in 2015 and 2017. A successful VDZ specialist conference on process technology was held in 2016, and more than 140 experts attended the VDZ specialist conference on concrete technology in March 2018.

Klaus-Dyckerhoff Prize awarded to Prof. Dr Sprung

On the occasion of the 2016 VDZ Annual Cement Conference on 27 September 2016 in Duesseldorf, Germany, Professor Dr Siegbert Sprung was awarded the fifth Klaus-Dyckerhoff Prize for his life's work. The Drs. Edith und Klaus Dyckerhoff-Foundation awarded the prize in recognition of Professor Sprung's outstanding achievements in the field of cement properties as well as the production and use of cement and concrete.

In the course of his remarkable professional career, Professor Sprung worked and performed research at VDZ in Duesseldorf from 1961 to 1999. Having started out as senior engineer, he then became head of the Department of Cement Chemistry and deputy head of the Cement Technology division. In 1988 he was appointed director of the Cement Technology division and managing director of VDZ. From 1998 until he left in 2000 he was Spokesman of the Executive Management of VDZ and Director of the Research Institute.

Evidence of his extensive knowledge and the wealth of his professional experience are contained in innumerable lectures and publications, above all in his post-doctoral thesis 'Technological Problems during the Burning of Cement Clinker, Causes and Solutions' from 1982. As a lecturer at RWTH Aachen University he consequently made a great contribution towards establishing the excellent reputation of VDZ as a centre of research and competence and that of cement research in Germany in general. In 1987 Siegbert Sprung was appointed associate professor at RWTH Aachen University. Throughout his career, it was always particularly important to Professor Sprung to promote young scientists and to arouse their enthusiasm for research into and the advancement of cement and concrete.

Fig. 1.1.5-2 The benefactor, Dr Edith Dyckerhoff with the prize-winner, Professor Dr Siegbert Sprung

Bild 1.1.5-3 Honorary Chairman Gerhard Hirth in conversation with prize-winner Prof. Dr Siegbert Sprung

In his speech at the awards ceremony, VDZ CEO Dr Martin Schneider emphasised the outstanding significance of Siegbert Sprung's efforts: 'We have his work to thank for a lot of what we know today about cement and its properties.'

The Dyckerhoff prize is awarded every two years by the Drs. Edith und Klaus Dyckerhoff-Foundation in recognition of particular achievements in the field of cement production and use. With prize money of 30000 Euro, it is one of the most prestigious international awards in this field. The prize honours ground-breaking research work or professional achievements in the development of (new) methods of application and/or manufacture in the area of hydraulic binders. The award is aimed at European universities and the research departments of scientific institutes in the construction and building materials industry, as well as the research departments of companies in the construction and building materials sector. The prize was awarded for the fifth time in 2016.

Since 1994, the Drs. Edith und Klaus Dyckerhoff-Foundation has been promoting the young generation of scientists and exceptional achievements in the key technologies for cement-based building sciences and technologies in the Association of Benefactors for German Science. As stated in the announcement of the Klaus Dyckerhoff Prize, 'liveable homes and workplaces in an intact environment require economic and ecological efficiency through intelligent use of the available material and energy resources'. In keeping with this philosophy, the intention is to assess manufacturing and usage technologies, already existing and not yet studied, for cement-based construction methods with regard to building planning and erection, usage and disposal, and to provide an innovative impetus to promote these.

1.1.6 Construction of new research institute building

VDZ is currently housed in a building dating back to the 1950s which falls a long way short of present-day technical standards and cannot provide the necessary conditions for modern, efficient working in terms of the space available, room design, infrastructure and fittings. On the basis of an in-depth analysis it was decided, for economic reasons, not to pursue the idea of modernising the substance of the existing old buildings in the Tannenstrasse any further. A suitable plot was accordingly purchased in 2013 in the Toulouser Allee in Duesseldorf – not far from the current location. The new building will lay the foundation for the solid long-term development of VDZ and its associated companies.

The new building

Construction of the building, designed by the Barkow Leibinger architects' office and with further planning performed by the pbr Planungsbüro Rohling AG architects' office, commenced in April 2017 and is scheduled for completion by the end of 2019. A block-shaped structure with five above-ground, in part horizontally offset, storeys is to be erected on the plot in the Toulouser Allee. This will not just give the new building a dynamic appearance, it will also be of advantage in various other ways. For example, it will create a roof over the working area with its delivery entrance on the north side and main access on the south side.

In addition to test rooms and working areas, the ground floor will also accommodate differently sized training and conference rooms which can be partitioned off to allow flexible use. The first and second floors are intended primarily for laboratories and working areas, whereas the third and fourth storeys will house office facilities.

Showcasing the construction material

Fair-faced concrete will be the predominant design feature of the foyer with its bright, open atmosphere. Horizontal facade elements, made of precast concrete components, will characterise the outward appearance, highlighting concrete as a future-proof, modern material. These will alternate with large-area strip windows to divide up the building within the storeys and as a contrast to the deliberately massive impression made by the fair-faced concrete.

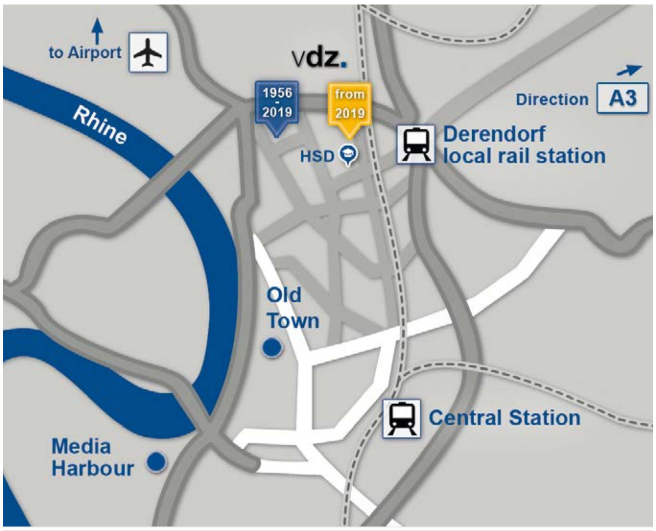


Fig. 1.1.6-2 After more than 60 years on Tannenstrasse, VDZ is moving to new premises and from the end of 2019 can be reached at the following address: Toulouser Allee 71, 40476 Duesseldorf, Germany. The new building is conveniently located near the Derendorf S railway station and is in the immediate vicinity of the Duesseldorf University of Applied Sciences (HSD).

Science centre

With two new universities in the immediate vicinity of the new address, the development of a science centre is on the horizon. Together with the engineering faculties and institutes of the universities the aim is to provide new impetus for joint research activities and to intensify networking with university research.

Fig. 1.1.6-1 New VDZ building, viewed from the south, graphic: pbr Duesseldorf

1.1.7 Statistics, compliance and data protection ■

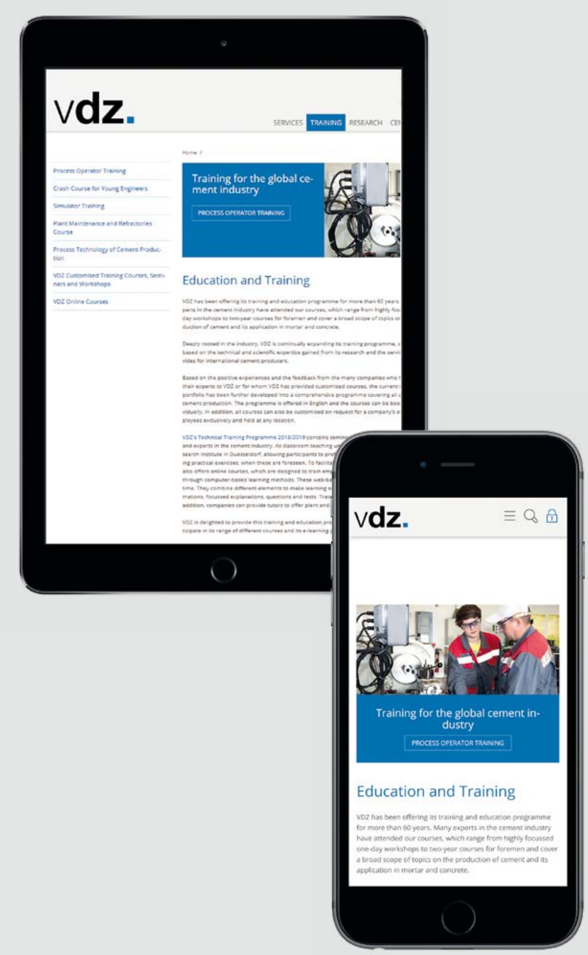
To perform its wide-ranging research tasks and to keep its members informed, VDZ collects and analyses both market and environment-related data. For example this includes domestic cement deliveries, raw material and fuel usage and electrical energy input, as well as dust and NO_x emissions.

The requirements for non-identifying information are satisfied in relation to data publication on the website or in VDZ publications. It is thus not possible to derive the identity of an individual company or cement plant from any particular data. VDZ has also incorporated further safeguards, for instance data on domestic cement deliveries are only published with a six-month time lag. In addition, a compliance officer at VDZ monitors these and other processes and recommends improvements where applicable. Many different instruments thus ensure that VDZ satisfies the requirements of competition law with regard to market information systems and the corresponding association statistics.

Alongside industry data, the handling of personal data is also becoming an ever more important topic. VDZ takes the protection of this information and the employees and business partners to whom it relates very seriously in its day-to-day work. Not least the EU General Data Protection Regulation, which came into force in May 2018, provides important guidance in this respect.

VDZ launches new website

In the period under review, VDZ launched a completely re-designed website. The re-launched VDZ website www.vdz-online.de has a new, modern appearance and is available in several languages, with more extensive content and functionalities for VDZ members, partners and customers. The intention is to provide even better access to the broad scope of information and statistics on the industry. Alongside the position of the German cement industry on matters of environmental and economic policy, the website presents the wide range of services, training courses and research projects of VDZ in a modern, clear format. As an internationally operating technical and scientific organisation for the cement and building materials industry, VDZ covers all aspects of cement, concrete and environmental protection – from testing to consulting and complex expert reports. The new website presents information on the broad spectrum of services in the fields of the environment and plant technology, chemistry and mineralogy, concrete and mortar, certification, environmental measurements and training in a more clearly arranged format.



For more than 60 years, VDZ has been successfully offering its training and education programme to the cement industry, from basic technical training to courses imparting specialist knowledge and development programmes for management personnel. To meet the increased international demand for services and training, the VDZ website is now available in German, English and Russian. With regard to design, particular emphasis was placed on mobile presentation on smartphones and tablet PCs (responsive design).

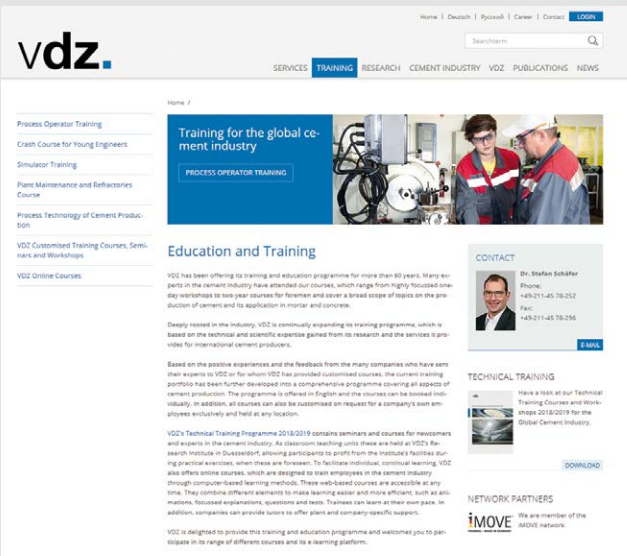


Fig. 1.1.6-2 New VDZ website with extensive range of international services and development programmes

1.2 Cement industry in Germany and Europe

1.2.1 Cement market in Germany

Whereas the cement market in Germany was relatively stable in the period between 2008 and 2015 – with an average annual consumption of 26.6 million tonnes – there have been signs of a moderate upswing since 2016 (**Fig. 1.2.1-1**).

The most important customers of the German cement industry are domestic producers of ready-mixed concrete. Over the past 10 years, this sector accounted for 56 % of domestic cement deliveries on average. During the same period, an average of 23 % of deliveries went to producers of concrete and precast components. The rest was accounted for by deliveries of other silo cement (approx. 14 %) and bagged cement (approx. 7 %). There was very little shift in the proportion of deliveries to each of the groups of producers and with regard to the form delivered over the course of this time. Merely the use of bagged cement has declined in recent years.

Differentiated according to cement types, a significant trend has been apparent for domestic cement deliveries since the end of the 1990s. It shows that the German cement industry has been making increased use of Portland composite cements (CEM II) and blast furnace cements (CEM III) in order to reduce the amount of clinker and consequently CO_2 emissions. This is in contrast with a significant reduction in deliveries of Portland cements (CEM I), the share of which has dropped by more than half from above 60 % at the end of the 1990s to around 28 % of domestic cement deliveries in 2017.

In the period between 2008 and 2017, the German cement industry exported an average of 6.5 million tonnes of cement per annum. Exports thus accounted for an average share of around 20 % of total German cement deliveries over the past ten years. The most important trading partners include the Netherlands, France and Belgium. Cement imports in the period between 2008 and 2017 totalled 1.3 million tonnes p.a. on average. Calculated on the basis of cement consumption in Germany, this yields an average import share of 5 %.

Germany is currently the largest market for cement within the European Union. In the period between 2008 and 2017, Europe's largest economy accounted for an average of around 16 % of total cement consumption in the EU. On a global scale the share is around 0.7 %. By far the largest cement market in the world is the People's Republic of China with a cement consumption of 2.3 billion tonnes – corresponding to around 57 % of the global total.

In terms of per capita cement consumption, Germany has recently ranked in a middle position on both a European and a global scale. In 2016, the average figure was around 334 kg of cement per head of the country's population. The frontrunner in Europe is Luxembourg, with approximately 1100 kg of cement per capita in 2016. The Emirate of Qatar exhibits the highest figures in the world, with approx. 3000 kg of cement for each of the 2.6 million inhabitants in 2016 (**Fig. 1.2.1-2**).

Demand for cement and the building industry

The building industry, which alongside the actual building and interior works trade also includes upstream and downstream industry sectors such as the building materials industry, is of great

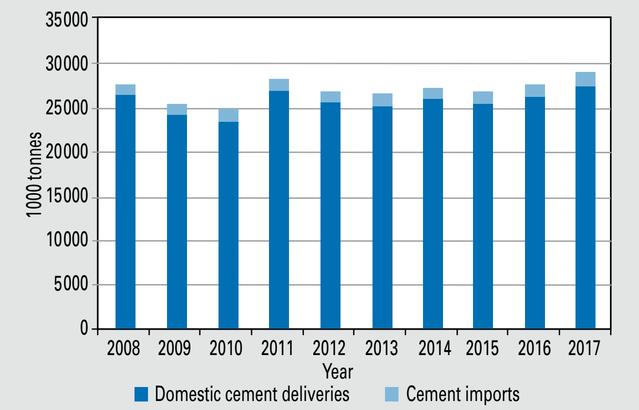


Fig. 1.2.1-1 Domestic cement consumption Source: VDZ

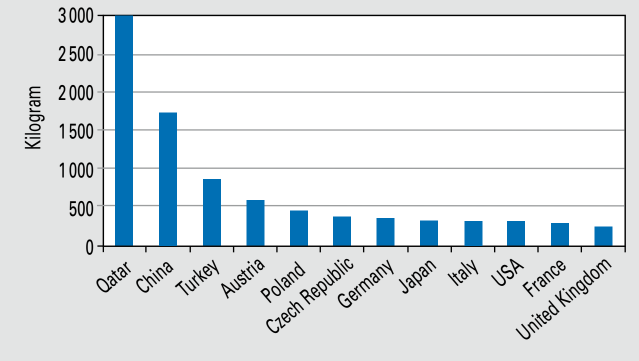


Fig. 1.2.1-2 Per capita cement consumption of selected countries in 2016 Source: Cemnet

importance to the German economy. In 2016, a total of approximately 3 million people were employed in this area, making a substantial contribution to Germany's economic performance.

The use of concrete – and thus also of cement – has steadily gained in significance over the last ten years in Germany. According to the German Federal Statistical Office, concrete was used as building material in 27 % of the multiple dwelling construction projects completed in 2016, for example. This represents an almost three-fold increase in the share of concrete as the most widely used construction material in this segment since 2000. With a figure of 55 % (2000: 42 %), this share is even greater again for non-residential buildings completed.

Building construction is the predominant market segment for the German cement industry. In 2017, around 19.1 million tonnes of cement were used in this sector, which corresponds to a share of 66 % of overall German cement consumption. Civil engineering accounted for 9.7 million tonnes or 34 % of cement consumption (**Fig. 1.2.1-3**).

Housing

With regard to medium-term market expectations, VDZ is anticipating impetus for the economy from the building industry. The housing sector in particular is likely to continue promoting growth on the German cement market, albeit possibly at a somewhat slower rate. In view of the high capacity utilisation level in the building trade, a growing number of projects with planning

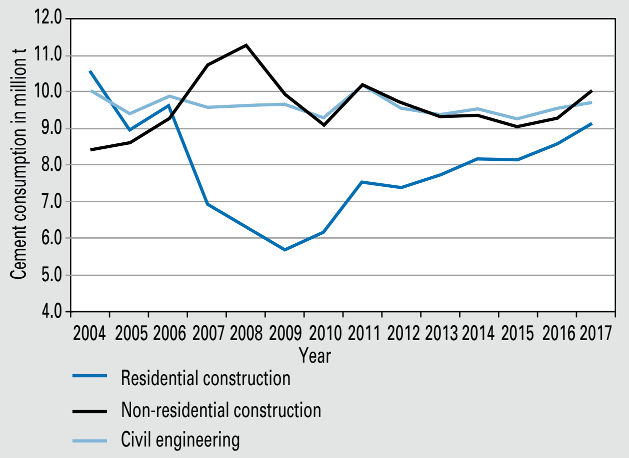


Fig. 1.2.1-3 Cement consumption according to construction sector
Source: VDZ

permission but not completed and the recent stagnation in permits for the construction of new buildings, it can be assumed that the number of new residential buildings completed will increase at a slower rate than in the recent past and could settle at a level of around 350 000 residential units per year.

At the same time the demand for housing remains high, particularly in urban areas. In the coalition agreement signed in March 2018, the parties forming the German government therefore declared their intention to construct 1.5 million new homes by 2021. The new Federal Government also wants to make more building land available for the construction of affordable housing. The introduction of an earnings-related building grant for families is also intended to help people purchase their own homes. It remains to be seen whether the planned package of measures will be sufficient to effectively satisfy the demand, above all for more affordable housing.

Civil engineering and transport infrastructure

Civil engineering in the public sector might be further strengthened by the significant increase in federal investment resources. In recent years, the Federal Government has successively increased the funds available for the federal transport infrastructure (roads, railways, inland waterways) to around 14 billion Euro p.a. and, according to the coalition agreement, intends to maintain the figure at this high level. In order to be able to implement, or at least make a start on, the projects contained in the new Federal Transport Infrastructure Plan with a total volume of approx. 270 billion Euro by 2030, the Federal Government would have to make around 18 billion Euro available every year for roads, railways and inland waterways.

To partially relieve the financial burden on the federal infrastructure budget, the Federal Government has increased the scope of user charges for federal trunk roads over the past few years. For instance, the truck toll system has been extended in several stages to cover a larger network of roads and more vehicle classes. According to the German Transport Infrastructure Financing Company (VIFG), the estimated toll revenue for 2018 will amount to 5.6 billion Euro. The funds remaining following deduction of the system costs are to be spent directly on the federal roads. In March 2017 the German parliament also decided to introduce an infrastructure charge for passenger vehicles, but this is yet to be implemented. The majority of experts are of the opinion that the introduction of this charge will not create any considerable revenue for the federal budget.

In addition to funding at a national level, discussions in recent years have increasingly centred on the topic of how local authorities, and in particular those in a difficult financial situation, can be assisted with the financing of infrastructure projects. In its 2017 Municipal Panel Study, the Reconstruction and Loan Corporation (KfW) comes to the conclusion that an investment of 34.4 billion Euro would be required to catch up with the backlog and to replace old roads and transport infrastructure at a local and regional administrative level. A gap of 32.8 billion Euro has also opened up in the school and adult education sector. In their coalition agreement, the parties forming the government have set out various possible solutions, for example restrictions on cooperation between federal and regional authorities to pave the way for increased national investments in the education infrastructure could be eased. Existing municipal supportive schemes are also to be continued at the current level of 2 billion Euro p.a., for urban development measures for instance.

Non-residential building construction

The development of cement consumption in the non-residential building construction sector has stagnated over the past few years. In relative terms, the building sector has thus lost in significance (33.8 % in 2016 as opposed to a share of 41.4 % in 2008). This is somewhat surprising, given that the development of the segment is linked to the economic situation of the country, and this has been both positive and extremely robust in recent years. On top of this, experts have - in the light of the low cost of financing building projects, the high level of capacity utilisation and the exceptionally good ifo Business Climate Index in manufacturing industry constantly witnessed over the last few years - been predicting a significant increase in investments in new commercial buildings, which has however not come about. The conditions for non-residential building construction are likely to remain positive in the coming years as well. From the point of view of investors there are signs of a slight worsening of the situation with regard to interest rates, as the European Central Bank (ECB) could well be going to follow the example of the US central bank and pursue a less expansive monetary policy. The expectations for the overall economic development of Germany nevertheless remain highly positive – the Federal Government for example is expecting 2.3 % real growth in GDP for 2018.

During the past years Germany has been experiencing an increasing construction demand based on a variety of different factors, for example a high demand for housing in urban areas, a backlog in investments in the transport and public infrastructure and more funds available for public spending. The increase in building activity is automatically associated with greater capacity utilisation both in the building industry and from the point of designers and approval authorities. According to the ifo institute, the orders in hand both in the building construction and civil engineering sector and for freelance architects have risen well above the long-term average. Factors standing in the way of rapidly increasing capacities are uncertainty about how long the building boom might continue, a shortage of skilled workers in particular. The new government's coalition agreement includes a law to accelerate building and planning procedures in an attempt to remedy the situation. In addition the intention is to set up an infrastructure company by 2021 to bundle the financing and implementation responsibilities for federal road construction on one level with the aim of enabling projects to be completed more quickly.

Table 1.2.1-1 Facts and figures

The German cement industry	2014	2015	2016	2017
Number of companies	23	23	23	23
Number of cement plants	53	53	53	53
Number of employees (per September 30th)[1]	7 933	7 810	7 901	8 037
Turnover (without value-added tax) in million Euro[1]	2 506	2 488	2 537	2 729
Cement deliveries in 1 000 t				
Total cement deliveries[2]	31 598	31 596	32 271	33 455
Domestic cement deliveries[3]	25 850	25 334	26 178	27 265
Cement exports[2]	5 748	6 262	6 093	6 190
Clinker exports[2]	420	366	439	437
Cement imports[2]	1 325	1 308	1 320	1 561
Clinker imports[2]	45	44	75	96
Domestic cement consumption[2]	27 175	26 642	27 505	28 826
Per capita cement consumption in kg[2]	333.6	326.1	333.6	348.3
Clinker production	23 871	23 355	23 423	24 802
Cement production	32 099	31 160	32 674	33 991
Domestic cement deliveries by type in %[4]				
CEM I: Portland cement	29.8	30.4	28.6	27.6
CEM II/S, CEM II/P, CEM II/V: Portland-slag cement, Portland pozzolanic cement, Portland-fly ash cement	17.7	18.0	19.1	18.9
CEM II/T, CEM II/LL: Portland-burnt shale cement, Portland-limestone cement, Portland-composite cement	29.1	27.7	27.7	27.7
CEM III: Blastfurnace cement	22.4	22.7	23.9	25.4
CEM IV, CEM V: Pozzolanic cement, Composite cement	< 0.1	0.1	0.1	< 0.1
Other cement	1.0	1.1	0.5	0.4
Domestic cement deliveries	100.0	100.0	100.0	100.0
Domestic cement deliveries by type of delivery in %[4]				
Ready-mixed concrete manufacturer	55.2	58.3	56.8	61.6
Concrete and precast component manufacturer	24.4	24.4	22.5	21.6
Other silo cement	13.5	10.4	14.2	10.5
Bagged cement	6.9	6.9	6.5	6.3
Kiln capacity				
Number of kilns (per January 1st)	53	53	53	53
Capacity in tonnes per day	107 160	107 160	107 460	107 460
Fuel energy consumption in million GJ/a				
Fossil fuels	33.9	31.7	32.1	33.9
Alternative fuels	58.6	57.8	59.1	63.0
Total thermal energy consumption	92.5	89.5	91.2	96.8
Total electrical power consumption in million MWh/a	3.57	3.50	3.62	3.77

[1] Data for plants of companies with 20 and more employees
[2] Data for 2017 are preliminary
[3] partially estimated
[4] Data rely on VDZ members

Sources: VDZ, Federal Statistical Office Germany (Destatis), DEHSt

Table 1.2.2-1 Use of raw materials in the German cement industry

Raw materials input in 1 000 tonnes		2015	2016	2017
Group	Raw material			
Ca	Limestone, Marl, Chalk	36 858	37 194	39 391
	Others[1)]	81	70	81
Si	Sand	1 096	1 122	1 174
	Used foundry sand	178	160	182
Si-Al	Clay	1 150	1 305	1 184
	Bentonite, Kaolinite	26	22	16
Fe	Iron ore	115	128	149
	Other input materials from the iron and steel industries[2)]	95	92	93
Si-Al-Ca	Granulated blastfurnace slag	6 821	7 244	7 896
	Fly ash	341	283	243
	Oil shale	113	136	123
	Trass	32	32	38
	Others[3)]	58	49	23
S	Natural gypsum	734	714	781
	Natural anhydrite	533	628	667
	Gypsum from flue gas desulpherisation	301	325	290
Al	Input materials from the metal industry[4)]	28	44	37

[1)] Lime sludge from drinking water and sewage treatment, hydrated lime, foam concrete granulates, calcium fluoride
[2)] Roasted pyrite, contaminated ore, iron oxide/fly ash blends, dusts from steel plants, mill scale
[3)] Paper residuals, ashes from incineration processes, mineral residuals (e.g. soil contaminated by oil)
[4)] Residues from reprocessing salt slag, aluminium hydroxide

Source: VDZ

Outlook

Irrespective of the question of capacity, the medium-term prospects for the German cement market are predominantly good. Construction activity is expected to remain on a high level in the coming years. Nevertheless, a further significant expansion is unlikely due to the existing capacity restrictions. The housing sector will probably become somewhat less dynamic, but this could well be made up for by public sector civil engineering as a new source of additional demand for cement. It remains to be seen how much impetus may come from the non-residential building construction segment. It also depends on economic and foreign policy-related uncertainties. The available figures do however indicate a growing demand for office buildings and educational institutions.

1.2.2 Use of raw materials and raw materials policy ■

Locally available raw materials form the basis for the production of cement and are an essential part of industrial value chains in Germany. The most important starting materials for cement include limestone, clay or the naturally occurring mixture of the two, lime marl. From a geological point of view, around 90 % of the quarried limestone comes from the Mesozoic era and is thus between 65 and 250 million years old.

Use of raw materials

In 2017, the German cement industry used around 52.4 million tonnes of raw materials for the production of approximately 34.0 million tonnes of cement (**Table 1.2.2-1**). 8.8 million tonnes alone were accounted for by alternative raw materials, which thus covered about 17 % of the total raw materials required. For instance, the raw materials employed in the burning process for cement clinker production include sewage sludge from drinking water treatment, waste foundry sand from metalworking and fly ash from coal-fired power stations. In cement grinding considerable use is also made of blast furnace slag, which occurs as a by-product in iron making. The utilisation of these alternative raw materials makes it possible to save more than 11 million tonnes of limestone per year. In view of the overall demand for raw materials for cement production, the industry will however continue to depend on a reliable supply of primary raw materials in the long term as well.

Use of fuels

In addition to primary and alternative raw materials, the production of cement also requires large quantities of fuel, mainly for the production of cement clinker, but also for drying raw materials. Nowadays fossil fuels only play a secondary role. For the most part, the thermal energy demand is covered by alternative fuels (65.0 % in 2017). These include used tyres, waste oil, commercial and municipal waste or scrap wood (**Table 1.2.2-2**).

In the case of cement production, the alternative waste-derived fuels used not only yield energy, the material is also recycled. Whereas the organic content is a substitute for the fossil energy sources, the inorganic constituents (ashes) become part of the actual product (so-called co-processing). The use of alternative fuels accordingly does great justice to the aims of resource-efficient waste management and climate protection. Due to various changes to the laws on waste in 2017 (e.g. Waste Management Act, Commercial Waste Ordinance), it is not impossible that in the future more extensive verification may be required for the use of alternative fuels with regard to the quality of utilisation.

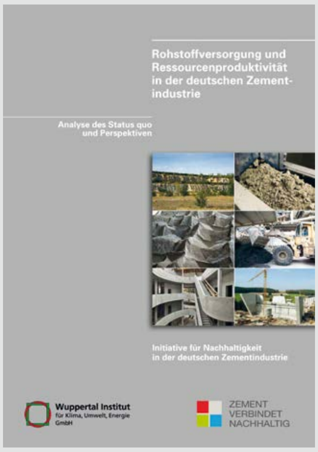
Land use and biodiversity

As the German cement industry extracts most of the primary raw materials it requires itself, it is dependent on securing valuable deposits over the long term. Not least for ecological and economic reasons, the majority of the plants in the country are located in

Study on the supply of raw materials and resource productivity in the German cement industry

As part of their sustainability initiative, the social partners of the German cement industry presented a study on the supply of raw materials and resource productivity along the value chain for cement to the Federal Ministry for the Environment in Berlin in November 2015 (**Fig. 1.2.2-1**). The around 50-page report described how scientists from the Wuppertal Institute for Climate, Environment and Energy investigated the ways in which the cement industry, including the downstream concrete industry, already contributes to the preservation of resources and the prospects which today appear to exist for increasing resource productivity still further and for providing the industry with a sustainable supply of primary and alternative raw materials.

Crucial to an increase in resource productivity are technological and organisational measures along the value chain for cement and concrete. The production of cement takes place in processes and plants which have already undergone a long process of optimisation. Although the majority of the plants used for the production of cement and cement clinker have already been in operation for many years and larger, in some cases more modern installations are basically available, existing technologies offer relatively little efficiency potential and economic exploitation of this is scarcely possible. The situation is similar with regard to making even greater use of the alternative raw materials employed so far. On the contrary, assuming that cement production remains constant, it is questionable whether alternative raw materials such as fly ash, blast furnace slag or waste foundry sand will still be available to the same extent in the light of the ongoing structural change in the energy sector and in industrial production. This means not least that the cement industry will continue to be dependent on a reliable supply of primary raw materials in the long-term.



The production of alternative cements and binders which are currently still at the development stage is considered to hold further potential. A particularly crucial aspect with regard to the further development of these is a reliable constant supply of raw materials. The authors also see opportunities for further resource preservation with regard to concrete constituents. For example it can be anticipated that larger quantities of waste mineral building materials will be available in future for the production of recycled aggregates. More development and research work will however be necessary to obtain high-quality products. Further potential for increasing raw material productivity exists in the industrial prefabrication of concrete components and, as a future prospect, in the use of ultra high-strength concretes. Ideally it will be possible to combine both.

Further information: https://vdz.info/owoo3

Fig. 1.2.2-1 The social partners of the cement industry while handing over the study to the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

the direct vicinity of the appropriate limestone or marl excavation sites so that the most important raw material can be processed to form clinker and cement on the spot. Together, all the authorised excavation sites operated by the cement industry cover an area of approx. 5 600 ha. In terms of the total excavation area for the extraction of near-surface raw materials in Germany, this corresponds to a share of approx. 3 to 4 %.

In contrast to other forms of utilisation, such as traffic and settlement areas, areas for the extraction of near-surface raw materials are only used for a limited period of time. Recultivation and renaturalisation measures both during extraction operations and following closure largely compensate for the consequences of the excavation work. From the point of view of biodiversity, the limestone quarries of the cement industry are highly significant. The great biodiversity found at both active and disused excavation sites is the result of the many different types of biotope in these areas, which have become rare in Germany's cultivated countryside. These are generally areas with extreme local conditions, offering primary habitats for highly specialised species and biotic communities. For example, steep faces in quarries often provide suitable biotopes for cliff-nesting birds.

A planned biodiversity database is to record, document and evaluate the contribution made by the pit & quarry industry to biological diversity in Germany. VDZ and six other building material associations will be helping to finance and set up the database.

1.2.3 Energy input and energy policy ■

As an energy-intensive sector, the German cement industry is particularly dependent on a competitive and stable energy policy framework. With an energy cost proportion of more than 50 % of the gross value added, the production of cement is one of the most fuel and power-intensive production processes in manufacturing industry. Alongside competitiveness, the reliability of the power supply is of utmost importance.

In 2017, the 53 cement plants in Germany used a total of 96.8 million GJ of fuel energy. Alternative fuels supplied around 65.0 % of the thermal energy input. In the same period, the power consumption of the German plants amounted to approximately 3.77 TWh (**Fig. 1.2.3-1**). This corresponds to an electrical energy input of 110.0 kWh per tonne of cement. The annual power costs for the industry as a whole are around 250 million Euro or roughly 25 % of the gross value added.

This makes energy one of the most expensive production factors for the industry. It has therefore always been in the interests of cement companies to improve energy efficiency. Consequently, any potential for making operations less energy-intensive has been systematically exploited in the past, which has led not least to a significant reduction in CO_2 emissions. Over the course of the past few years, a conflict of aims has meanwhile become ever more apparent between political demands for energy efficiency and requirements set down with regard to environmental policy, which for technical reasons is automatically associated with higher power consumption.

In this context, current energy and climate policy developments are of major significance for the industry. It is in particular foreseeable that the direct and indirect costs resulting from the energy transition will continue to rise and make themselves felt in consumer electricity prices in the form of the EEG levy (renewable energy act) and power grid fees. Even now it is apparent that the Special Equalisation Scheme of the EEG will further gain in significance in the future, as it is becoming established as a prerequisite for relief in other regulatory areas as well. In the meantime, the coalition agreement for the new legislative period until 2021 contains plans for a fundamental reform of power grid fees. The background to this is the political desire for a flexibilisation of electricity demand, in industry for example, to minimise the need for further expansion by utilising the existing power grids as efficiently as possible. Particularly in this sector, the legislators must however always be aware of the need to maintain the competitiveness of energy-intensive industry in Germany.

With regard to taxes on energy and electricity, the eco tax peak equalisation scheme will, alongside relief for mineralogical processes, continue to be of great significance for the cement industry. To date, this tax relief has been linked to the introduction of certified energy management systems at the companies and to collective efficiency improvement on the part of German industry. So far, the annual targets set down in 2012 have always been met.

1.2.4 Climate protection and climate policy ■

In December 2015, the UN Paris climate agreement paved the way for global efforts to combat climate change until 2050. Germany's reaction to this came as early as November 2016 with the presentation of the 2050 Climate Protection Plan, making it one of the first countries to submit the long-term strategy demanded in Paris. This plan confirms the existing climate targets and clarifies certain details. The intention is accordingly to reduce CO_2 by 80 to 95 % at national level as compared to 1990.

The German cement industry is fully aware of its responsibility and has been committed to climate protection for many years. On the basis of the climate protection agreement between the Federal Government and German industry in the year 2000, it has for example proved possible to reduce the specific energy-related CO_2 emissions associated with cement production (resulting from fuel and power consumption) by around 52 % between the base year 1990 and 2015. Producers are also increasingly switching to alternative raw materials, such as blast furnace slag, fly ash, natural pozzolanas and burnt oil shale. This has successfully reduced the average clinker content of cement in Germany by around 14 % over the course of the last 20 years. A further increase of clinker efficiency is determined by factors such as both the standardised quality requirements for cement as end product and the availability of alternative constituents, which are often by-products of other industrial sectors, such as iron making or coal-fired power generation.

As a subsequent regulation to the climate protection agreement, German industry concluded an agreement with the Federal Government in August 2012 to increase energy efficiency as an important means of reducing CO_2 emissions as well. According to the corresponding verification report for the year 2016, manufacturing industry cut its specific energy consumption by 13.8 % as compared to the base period 2007 to 2012, thus clearly surpassing the reduction target of 5.25 %.

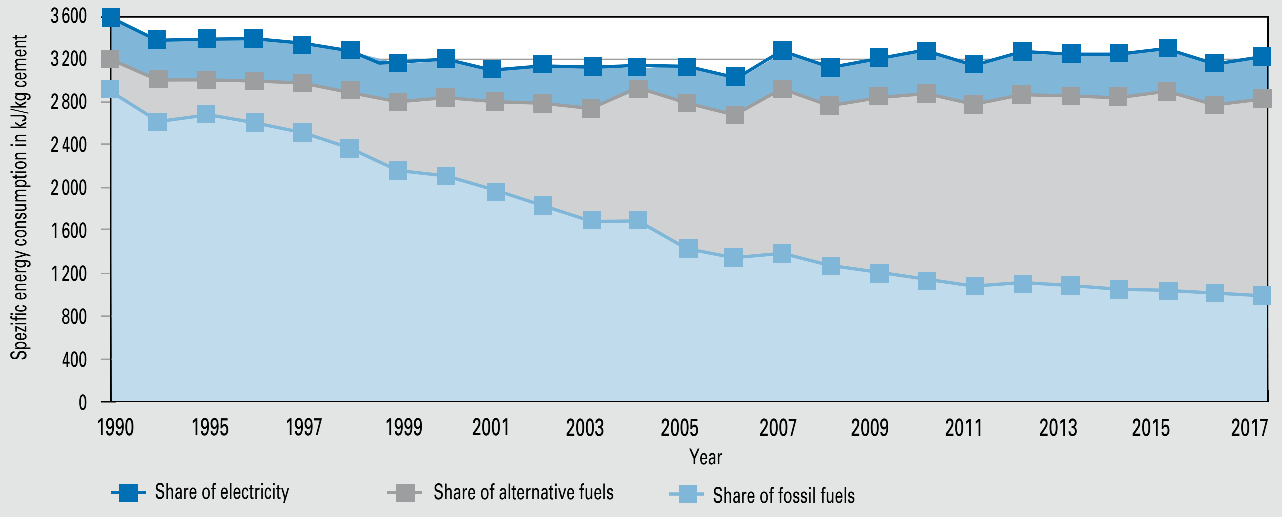


Fig. 1.2.3-1 Development of specific energy input Source: VDZ

European emissions trading system

The EU Emissions Trading System (EU ETS), which has been in place since 2005, is the central European climate protection policy instrument aimed at effectively restricting CO_2 emissions in European industry and the energy sector. The basic principle involves the awarding or auctioning of a limited number of emissions certificates to the operators of relevant plants. If a plant exceeds its greenhouse gas emission allowance, the company has to purchase further rights to comply with its annual surrender obligation. By contrast, companies in possession of more rights than they need can sell these to other companies. This creates a financial incentive to reduce greenhouse gases. To achieve the emission reduction target of 21 % by 2020 (base: 2005) for the sectors covered by the EU ETS, the number of available certificates in the current third trading period (2012 to 2020) is being reduced by 1.74 % each year. In this way, European industry is making an above-average contribution towards the reduction of greenhouse gases as compared to other sectors such as transport, buildings and agriculture (non-ETS sectors: 14 % by 2020).

At the start of the third trading period, the full auctioning of CO_2 certificates (EUAs) was introduced in principle for the energy sector. Since then, industry has also had to acquire some of its certificates by auction or purchase. Sectors verifiably facing carbon leakage, i.e. the relocation of production or emissions to countries outside Europe, are provided with a basic allocation of EUAs free of charge on the basis of demanding benchmarks. As regards the European cement industry facing carbon leakage, individual benchmarks apply to grey cement clinker (766 kg CO_2/t) and white cement clinker (987 kg CO_2/t). The average emissions of the best 10 % of plants in the EU were used as the basis for calculation. A so-called cross-sectoral correction factor does however mean that the benchmark allocation for all industrial installations will be cut by around 12 % on average, so that even particularly efficient plants will be burdened by additional costs from emissions trading.

After lengthy negotiations, a revised emissions trading directive was passed at the start of 2018 for the fourth trading period from 2021 to 2030. Accordingly, the new emission reduction target for ETS sectors is 43 % as compared to the base year 2005 (non-ETS sectors: 30 %). To this end, the number of certificates is to be reduced by 2.2 % each year as of 2021 (instead of by 1.74 % to date). In addition, the Market Stability Reserve (MSR), which was made more stringent as part of the ETS reform, will already come into force as of January 2019. The aim of the MSR is to retroactively withdraw some of the emissions certificates from the market, which in the past were issued but were not required to be surrendered by the plant operators.

Benchmark allocations for industries facing carbon leakage have also been retained for the fourth trading period. As of 2021, up to 43.9 % of the total number of certificates will be available to the industry. By contrast, there will be a significant reduction in the benchmarks which form an important basis for allocation calculation. Whereas the benchmarks applied to date were set solely on the basis of empirical data, an average annual reduction rate is to be determined in future which will then be subject to linear progression – irrespective of actual technical developments. This method represents a departure from the benchmark principle, as in future even the most efficient plants in a sector will only reach the benchmark in exceptional cases.

Climate protection policy at national level

In parallel with EU emissions trading, the German Federal Government is, at national level also pursuing the internationally binding goal of reducing greenhouse gas emissions by at least 55 % by 2030 as compared to 1990. According to the government's coalition agreement drawn up in the spring of 2018, national climate protection legislation is to be passed for this purpose and a commission set up to gradually cut back on coal-fired power generation. By the middle of the century, the 2050 climate protection plan aims to reduce greenhouse gas emissions by 80 to 95 %. Industry is not just making an important contribution to reducing CO_2 in Germany in the context of the EU emissions trading system. In 2014, 18 industrial associations and organisations signed up to a voluntary agreement to introduce 500 energy efficiency networks by 2020. Together with companies from other building material industries, the cement industry is also involved in networks at federal and regional level.

1.3 Environmental protection and sustainability

1.3.1 Climate protection in the German cement industry ■

The global warming potential (GWP) of emissions in the cement industry can be almost entirely attributed to carbon dioxide. The CO_2 emissions occurring in cement production arise from limestone calcination (raw material-related emissions) and from both thermal and electrical energy input (energy-related emissions). Other greenhouse gases (e.g. N_2O or CH_4) specified in the Kyoto protocol either do not occur at all or only in extremely small quantities in cement production.

Raw material-related CO_2 emissions

CO_2 is released in the calcination of limestone ($CaCO_3$), the most important raw material for the production of clinker. The emission of raw material-related CO_2 per tonne of clinker produced depends on the composition of the raw material. The crucial factor in this respect is the carbon content of the raw materials. This does however only vary minimally from plant to plant. Raw material-related CO_2 emissions – referenced to a tonne of cement – can only be reduced to a limited extent by increasingly going over to producing cements with several main constituents. Virtually no reduction is possible referenced to a tonne of clinker. Development work on new construction materials indicates potential for CO_2-efficient binders in future, but at the current level of research and development these would appear to have only limited areas of application. The efficient utilisation of clinker in cements will therefore continue to play a crucial role in the limitation of raw material-related CO_2 emissions.

Fuel-derived CO_2 emissions

In the clinker burning process, fuel-specific CO_2 emissions arise on the one hand from the conversion of fuel energy to generate process heat in the rotary kilns. In addition, fuel energy is employed for the drying of other main cement constituents such as blast furnace slag. Roughly 65 % of the fuel energy required in Germany is provided by alternative fuels. These are full substitutes for traditional and purely fossil fuels. As the waste material would otherwise release its carbon content in the form of CO_2 or other greenhouse gases at some other point, the use of alternative fuels in the clinker burning process leads all-in-all to a reduction in CO_2 emissions.

There is a systematic difference between this evaluation of alternative fuels and the reporting method employed in the context of the European Emissions Trading System (EU ETS). All fossil fuels and the fossil content of alternative fuels are included in emissions trading. In the calculations, an emission factor of zero is only applied to the emissions of the biogenic content of the fuels. Replacement of the traditional fossil fuels lignite and hard coal with other fuels with lower specific CO_2 emissions such as natural gas is not possible on account of the cost. As fuel costs are a significant factor in the cost of cement production, continuing efforts are being made in the cement industry to replace fossil fuels with alternative fuels derived from waste materials. The use of biogenic waste-derived fuels and fuels of this type with biogenic content is becoming increasingly important in this respect. The high energy yield obtained from these and the full utilisation of the inert material additionally contribute to energy and resource efficiency in the context of waste management.

Electrical energy-related CO_2 emissions

Electrical energy accounts for about 14 % of the total energy input in German cement plants. Approximately 46 % of the electrical energy input is accounted for by cement grinding and roughly 25 % by raw material processing. Around 24 % of the electrical energy goes into the burning and cooling processes. Packing plants and shipping use about 5 % of the electrical energy required. To date, the German cement industry has scarcely generated any power of its own.

In summary, **Table 1.3.1-1** shows the direct CO_2 emissions of the German cement industry and indirect CO_2 emissions from the use of electrical energy for the period 2005 to 2016. It proved possible to further reduce the specific CO_2 emissions between 2014 and 2016. In 2016, the direct and indirect CO_2 emissions amounted to 19.3 Mt CO_2 or 0.651 t CO_2/t cement. One reason for the further reduction in CO_2 emissions is the increased use of alternative raw materials and fuels in the clinker burning process.

Greenhouse gas accounting and reporting

In the context of the EU ETS, companies in the cement industry are required to produce an annual report on their direct CO_2 emissions from raw materials and fuels in clinker production. In addition to the correspondingspecifications for reporting, a further tool available to the cement industry is the Cement CO_2 and Energy Protocol (CSI Protocol) of the Cement Sustainability Initiative (CSI), which is employed throughout the world on a voluntary basis. The CSI Protocol takes into account not just the direct, but also the indirect CO_2 emissions arising from the power used and clinker purchased. In addition to the direct CO_2 emissions from the clinker production process, it further includes smaller sources of direct CO_2 emissions as well, for instance from mobile sources on the site of the plant and in the quarry. In 2016, a European standard was published for the determination of greenhouse gas (GHG) emissions from energy-intensive industries which gives particular consideration to the specific conditions in the cement production industry. Information on the relevant material flows in a cement plant, the usage and production quantities and the applicable material parameters, such as calorific value and emission factor, forms the foundation for all methods.

CO_2 reporting in the EU ETS

The main instrument employed by the EU to reduce greenhouse gas emissions, the EU ETS, is currently in its third trading period (2013 to 2020). Power plant operators and companies in energy-intensive branches of industry (e.g. steel, cement, lime, chemicals, glass, paper) and in aviation from a total of 31 countries (EU 28, Iceland, Lichtenstein and Norway) are participating. Since 2013, the annual CO_2 emission reports have to be produced on the basis of the European monitoring regulation (MRR) and the latest guidelines of the EU and the German emissions trading authority (DEHSt). The plant-specific determination methods are set down in a monitoring plan (MP). This is created online in a Form Management System (FMS) and has to be approved by the DEHSt. A central aspect of this procedure is the stipulation of and compliance with the required accuracy for the determination of the CO_2 emissions of individual material flows. A record must be kept of the regular checking and adjustment of process scales to ensure that the accuracy of the measuring instruments complies with the specifications of the MRR and the monitoring plan. Accredited laboratories are normally called in to perform analytic determination of the fuel parameters calorific value and emission factor. The monitoring of process emissions is of particular importance for the cement industry. The emission factor of clinker (and dusts) is analytically determined at regular intervals. Since 2013,

Table 1.3.1-1 CO_2 emissions of the German cement industry

Year	Direct CO_2 emissions [Mt CO_2]	Indirect CO_2 emissions [Mt CO_2]	Total CO_2 emissions [Mt CO_2]	Specific CO_2 emissions [t CO_2/t cement]
2005	20.1	2.0	22.0	0.711
2006	20.4	2.1	22.5	0.669
2007	22.0	2.1	24.1	0.723
2008	20.4	2.0	22.4	0.668
2009	18.8	1.8	20.6	0.675
2010	18.6	1.9	20.5	0.684
2011	20.0	2.2	22.1	0.660
2012	19.9	2.1	22.0	0.677
2013	19.0	2.0	21.0	0.672
2014	19.6	2.0	21.6	0.673
2015	19.1	1.9	21.0	0.674
2016	19.3	1.9	21.3	0.651

Sources: VDZ, DEHSt, UBA

CO_2 emissions from organic carbon (TOC) in the raw meal and the minimum combustion emissions of fuels used in emergency generators have also had to be included. This however only adds very slightly to the scope of CO_2 emissions reported. On average, there has thus been hardly any change in recent years in the specific emissions, totalling 0.8 t CO_2 per tonne of cement clinker, as compared to the 2nd trading period (2008 to 2012).

The future framework conditions and regulations in the 4th EU ETS trading period from 2021 to 2030, in particular for the upper limit of the available emissions certificates and the free allocation of these, were set down in a so-called trilogue procedure (see Section 1.2.4)

Cement CO_2 and Energy Protocol

The CSI Protocol provides guidance on the production of inventories for CO_2 emissions from and energy input in cement production at both plant and corporate level. It was developed by the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD) with the involvement of its member companies and VDZ. It consists of the following three elements:

- Guidance document: CO_2 and Energy Accounting and Reporting Standard for the Cement Industry – The Cement CO_2 and Energy Protocol
- Detailed web-based guide (Internet Manual: www.cement-co2-protocol.org) and
- Calculation mask in Excel format as central tool (CSI Protocol Spread Sheet, 2013 updated version 3.1).
- Within the cement industry, the CSI Protocol

is the definitive instrument employed throughout the world for CO_2 accounting and reporting. The data obtained on the basis of the CSI Protocol is gathered for the purpose of further developing an international CO_2 and energy information system for the cement industry. The most important specific emission data (key performance indicators, KPI) from more than 930 plants is summarised according to regions and published in anonymised form in a database of the CSI Getting the Numbers Right project (GNR data up to 2015: www.wbcsdcement.org/GNR-2015).

European standard published in 2016

The European standard series EN 19694-1 to -6 for the determination of greenhouse gas emissions from five energy-intensive industries was published in 2016. Part 3 (EN 19694-3) deals with specific cement industry methods, which were developed with major contributions by VDZ and ECRA. In addition to the part specific to cement, other individual parts of the standard deal with general aspects and four further energy-intensive industries (steel, aluminium, lime and ferro-alloys).

In contrast to the EU ETS, the standard covers not only direct, but also indirect CO_2 emissions from power and heat input and output. The methods for the cement industry include stationary CO_2 sources throughout the entire cement production process chain. The CSI Protocol provides the procedural foundation, in particular for description of the mass balance methods for the determination of process-related CO_2 emissions from calcination in the clinker production process. European cement plants which proceed in accordance with the CSI Protocol now have the advantage that the methods they already employ will also satisfy the EN standard, which is likely to meet with greater international recognition.

An internationally valid ISO standard is currently to be produced within three years on the basis of the EN 19694 standard series. Work on this commenced in 2018. The Joint Working Group (JWG) from ISO/TC 2017/SC 7 and ISO/TC 146/SC 1 is concentrating on the general aspects. The standardisation group ISO/TC 146/SC 1/WG 30 bears overall responsibility for work on the sector-specific standards.

CO_2 capture and storage/utilisation

To meet the long-term political climate targets of the EU and Germany, not only the energy sector, but energy-intensive industries in particular will be required to significantly reduce their greenhouse gas emissions.

For process technology reasons and to suit market requirements, the CO_2 reduction potential offered by traditional measures in the clinker burning process (e.g. reduction of the clinker content of the cement, enhancement of energy efficiency, increase in the proportion of alternative fuels with biogenic content) has already been largely exploited. For this reason, research into new methods of CO_2 capture has been going on for some time now and has to some extent been tested on a pilot scale. Possible approaches and the measures required to attain the ambitious climate targets are described in so-called road maps which have been produced in recent years by organisations such as the International Energy Agency (IEA) and the Global CCS Institute for various industrial sectors, including the cement industry. The updated and supplemented CSI/ECRA Technology Papers 2017 (www.wbcsdcement.org/technology) were produced with the important participation of experts from ECRA, VDZ and the research institute. CSI and IEA created a new Cement Technology Roadmap on this basis in 2018. According to this, the use of carbon capture methods would have to achieve 40 to 60 % of the required reduction in CO_2 in the year 2050.

The term carbon capture refers to the separation of CO_2 from the exhaust gas and its long-term storage (CCS) or re-use (CCU). Given the uncertain national legal situation with regard to the underground storage of CO_2, the focus of attention is on the use of CO_2 as a raw material for marketable products such as methane or methanol. In the cement clinker burning process, particularly the following areas of technology lend themselves to the capture of CO_2 from the process:

- Post combustion: Post-combustion capture using sorbents
- Oxyfuel: Combustion with pure oxygen and increase in CO2 concentration in the process

The cement industry is promoting further research and testing of technologies for CO_2 capture in cement plants. Since 2007 the ECRA CCS project has been researching into the technical feasibility of capture technologies, with particular emphasis on oxyfuel technology (https://ecra-online.org/research/ccs/). Based on the results of the preceding phases, concepts were developed for two pilot plants and two suitable plant locations were identified for these. The cement companies are currently preparing for a possible demonstration project at these two locations. Given appropriate financing, large-scale industrial testing of oxyfuel technology could start in 2019 to 2021.

Prototype testing of oxyfuel technology and in-depth technological and economic analysis of CO_2 capture methods were performed in the European research project CEMCAP with important contributions by VDZ (see Box and section 3.2.1). The Norcem company has tested various post-combustion methods on a pilot scale at its Brevik plant (Norway). A subsequent project on the application of the post-combustion method (amine scrubbing) at the Brevik cement plant was proposed in Norway. Two further European research projects studied methods of CO_2 capture: the so-called calcium looping method and direct CO_2 capture during calcination (direct separation) in the CLEANKER (www.cleanker.eu) and LEILAC (www.project-leilac.eu) research projects, again with the participation of the research institute. VDZ is accompanying discussions on CO_2 storage technologies in the German research project CLUSTER.

So far, the costs of capture have been estimated at 40 to 110 Euro/t CO_2. The production costs per tonne of cement would thus rise significantly by around 30 to 70 Euro/t. In this case, effective legislation to prevent carbon leakage would be imperative. This would have to go well beyond the regulations contained to date in the EU ETS. In addition, a reduction in costs can only be achieved through trials and further development of the technologies. The road maps also forecast that 40 to 60 % of all the cement plants in Europe would have to be equipped with carbon capture technologies in 2050. It will only be possible to continue pursuing this course if the technologies are demonstrated in the near future.

1.3.2 Energy demand and energy efficiency ■

Production capacity and kiln plants

In the period up to the year 2017, the approved production capacity of the kiln plants in the German cement industry was 107460 t/d. 53 kiln plants had operating licences. One less kiln with cyclone preheater was registered on 1.1.2018, so that the daily capacity accordingly dropped to 106310 t. The overwhelming majority of the kilns are operated using the dry and semi-dry process. In addition, there are eight licensed shaft kilns (**Table 1.3.2-1**). The average capacity of rotary kilns has changed only slightly, with the current figure being 2389 t/d. 98.9 % of the approved total capacity is accounted for by plants with cyclone and grate preheaters. The share of cyclone preheater plants has remained constant at approx. 94 % (referenced to capacity). Of the twelve precalcining plants installed, nine are provided with tertiary air ducting. On account of their comparatively higher kiln capacity, precalcining plants represent more than a quarter of the installed and approved clinker capacity of German cement plants.

Utilisation of the kiln plants increased in the reporting period and is determined by the permitted and technical capacity as well as the availability during the year.

Fuel energy demand

Most of the fuel energy used in cement production is required for burning the cement clinker. Only a small amount of thermal energy is employed for drying other main cement constituents such as blast furnace slag. The principal raw materials are limestone marl and clay. The raw materials are fired at temperatures of between 1400 and 1450 °C for the production of cement clinker with its characteristic properties. Due to the fact that a high-temperature process is necessary to satisfy the product requirements, the cement industry is one of the most energy-intensive branches. The cement industry has always made efforts to reduce its energy demand with a view to lessening the environmental impact and cutting the high fuel energy costs involved. This is reflected by the way in which the fuel energy input per tonne of cement developed between 1987 and 2017 (**Fig. 1.3.2-1**). Process technology optimisation has led to the specific thermal energy demand with reference to cement remaining virtually constant since 1999 (**Fig. 1.3.2-2**).

All-in-all fuel energy input has dropped since 1987 from 119.9 to 96.8 million GJ in 2017, partly on account of the decline in production (**Fig. 1.3.2-3**). This corresponds to a reduction of 19.3 %.

Fuel mix

The share of alternative fuels in the fuel mix has increased steadily since 1999 from 23 % to 65 % in 2017. Whereas the alternative fuels are primarily used as a substitute for lignite, the consumption of other fossil fuels (light distillate oil, heavy fuel oil and natural gas) has increased slightly. The figures for these are however at an overall very low level and they are generally employed for the start-up of kiln plants. Only a minor shift was observed in

First cement clinker produced using oxyfuel cooler

In the EU research project CEMCAP, the project partners IKN, HeidelbergCement and VDZ succeeded in producing cement clinker using innovative oxyfuel cooler technology. The prototype oxyfuel cooler constructed for this purpose was put into operation at the HeidelbergCement plant in Hanover in 2016 as part of the research project. Several experiments were performed in 2017 to set the gas composition for the oxyfuel process and to test the clinker quality and operation of the cooler. The CEMCAP project is intended to create the prerequisites for the large-scale use of CO_2 capture technologies at cement plants and so allow for subsequent storage or utilisation of the CO_2 (CCS, CCU).

The aim is to advance the CO_2 capture technologies for the cement industry to a higher technological readiness level (TRL) and thus bring them closer to practical use. The prototype of the oxyfuel clinker cooler is based on theoretical concepts which were developed in the ECRA CCS project phase III (https://ecra-online.org/research/ccs/). It attained a throughput rate of 47 t of clinker/day. The experimental work on the prototype served to test the oxyfuel cooler in an industrial environment and to reliably obtain a sufficient cooling rate (efficiency) and clinker quality.

Fig. 1.3.1-1 Prototype oxyfuel clinker cooler undergoing practical testing

A particularly challenging task when designing the prototype was the extraction of hot clinker from the kiln line with operation in progress. This was achieved through the development of an innovative clinker discharge system by IKN. The test process parameters were continuously plotted. Exhaust gas flows were recorded and analysed by VDZ to assess the efficiency of the air seal to prevent false air ingress. For the purposes of analysis, clinker samples were regularly taken upstream and downstream of the oxyfuel clinker cooler and examined in the VDZ laboratory. In spite of numerous technical challenges, CO_2 concentration levels of more than 70 vol. % were repeatedly attained in the cooling medium.

Findings obtained from operation of the prototype oxyfuel clinker cooler reveal that the transition zones such as the cold clinker discharge system require particular attention with regard to minimisation of the ingress of false air. This also applies to the implementation of projects on an industrial scale. No leakage of CO_2-rich gas was found during the experiment. The gas itself had no influence on the clinker quality. Unexpected alite decomposition up to a maximum of 4 mass % occurred in certain clinker samples. VDZ is currently investigating the combined effect of water and CO_2 on this. A second study is also in progress with a view to being able to rule out or narrow down the influence of the slight alite decomposition observed on cement strength. The results of the experimental work and laboratory scale tests will allow estimation of how the condenser to be fitted in a future oxyfuel kiln plant for dehumidification of the recirculated gas should be designed with regard to its dimensions and operation. These results will be presented in the CEMCAP research project and in scientific publications (https://www.sintef.no/projectweb/cemcap/).

The involvement of VDZ in the research project as a whole is described in Section 3.2.4. The experimental work at the cement plant has also been documented in a short film (https://www.vdz-online.de/en/research/current-projects/cemcap/).

CEMCAP is a research project financed through the European Union HORIZON 2020 research and innovation programme within the scope of grant agreement no. 641185.

Table 1.3.2-1 Number and capacity of kilns with an operating licence in Germany

	As of 01.01.2016			As of 01.01.2017			As of 01.01.2018		
	Number	Capacity		Number	Capacity		Number	Capacity	
		t/d	%		t/d	%		t/d	%
Kilns with cyclone preheaters	39	100 760	93.8	39	100 760	93.8	38	99 610	93.7
Kilns with grate preheaters	6	5 500	5.1	6	5 500	5.1	6	5 500	5.2
Shaft kilns	8	1 200	1.1	8	1 200	1.1	8	1 200	1.1
Total	53	107 460	100	53	107 460	100	52	106 310	100
Average kiln capacity in t/d – Rotary kilns	2 361			2 361			2 389		
Average kiln capacity in t/d – Shaft kilns	150			150			150		

Source: VDZ

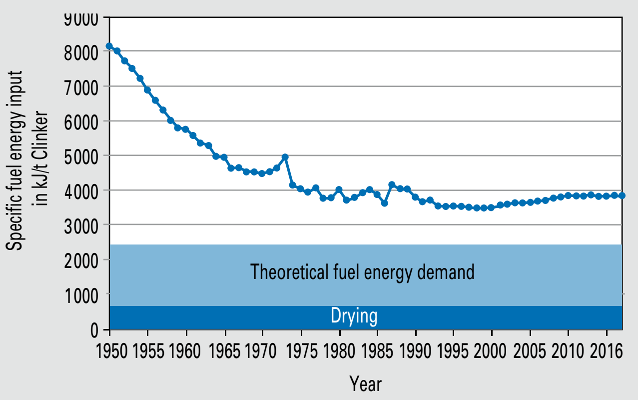


Fig. 1.3.2-1 Specific fuel energy input of German cement plants (up to 1987 old West German states, then Germany as a whole)

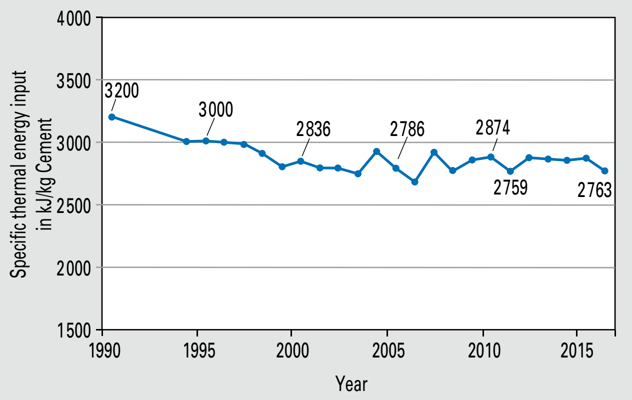


Fig. 1.3.2-2 Specific thermal energy input of the German cement industry Source: VDZ

Table 1.3.2-2 Use of alternative fuels in the German cement industry

Alternative fuel in 1 000 t/a	2015	2016	2017
Waste tyres	221	201	202
Waste oil	24	66	68
Fractions of industrial and commercial waste:			
- Pulp, paper and cardboard	93	81	87
- Plastics	654	640	680
- Packaging	–	–	–
- Wastes from the textile industry	–	7	–
- Others	1 127	1 163	1 089
Meat and bone meal and animal fat	149	145	150
Mixed fractions of municipal waste	317	283	440
Waste wood	< 1	< 1	< 1
Solvents	145	145	130
Fuller's earth	–	–	–
Sewage sludge	382	463	587
Others, such as: - Oil sludge - Organic destillation residues	65	58	156

Source: VDZ

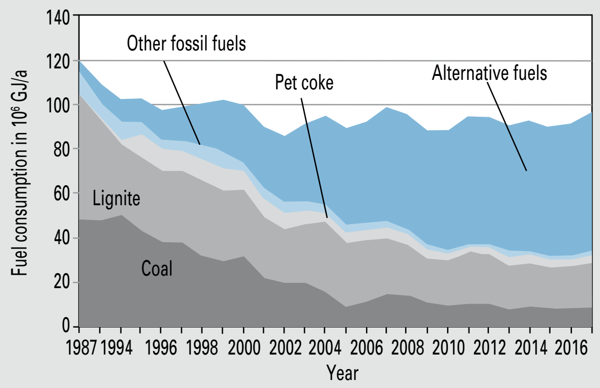


Fig. 1.3.2-3 Fuel input of the German cement industry
Source: VDZ

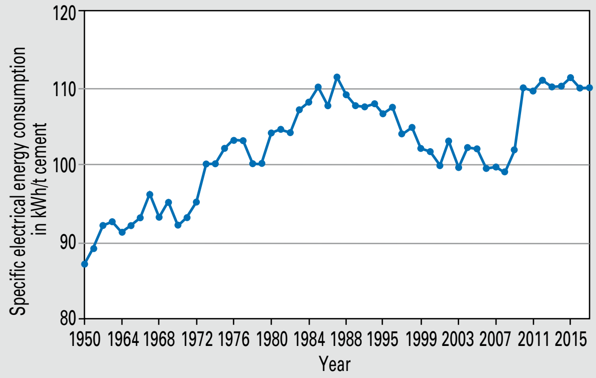


Fig. 1.3.2-4 Specific electrical energy input of the German cement industry (up to 1987 old West German states, then Germany as a whole)
Source: VDZ

the proportions of the various fuels in the period 2015 to 2017 (**Table 1.3.2-2**). There has been a rise in the use of sewage sludge and treated fractions from municipal waste, for example. This is in contrast to a slight drop in the volume of used tyres employed (from 221 000 t in 2015 to 202 000 t in 2017).

Electrical energy demand

In cement production, electrical energy is primarily used for raw material processing (about 20 %), for burning and cooling the clinker (about 25 %) and for cement grinding (about 45 %). Up until 1987, the development of the specific electrical energy input in the German cement industry was characterised by a long-term increase to values of around 110 kWh/t of cement (**Fig. 1.3.2-4**). Following the reunification of Germany, this trend was initially reversed until 2008. After that, power consumption rose again and since 2010 has settled at approx. 110 kWh/t of cement. One of the reasons for the increase has probably been the greater demand for finely ground high-performance cements in the building materials industry. The more intensive use of other main constituents in addition to clinker does however generally also require a higher grinding energy input, as blast furnace slag is more difficult to grind than clinker for example, or has to be more finely ground to achieve the same cement quality. On the other hand, the replacement of clinker makes it possible to save the amount of electrical energy which would have been required for its production (raw material processing, burning process). Energy-efficient mill types in combination with high-pressure grinding rolls and vertical roller mills have been successfully introduced for the grinding of raw materials and cement in new plants. The working properties of the cements from these mills often do not however correspond to regional market requirements, with the result that ball mill grinding is still performed in many cases. Quality requirements are increasingly being implemented by separately grinding the main constituents followed by mixing in mixing plants. Within the scope of usual possibilites this does not lead to a significant reduction of the electricity demand.

VDZ evaluation matrix for assessment of fuel energy demand

The production of cement clinker in modern cement plants is one of the most efficient industrial processes altogether. In addition, the fuel ashes occurring are fully recycled. This combination of co-incineration and material recycling ('co-processing') thus makes a significant contribution to resource efficiency and circular economy.

The fuel energy demand is an important factor in the energy-efficiency assessment of a plant in general. Other aspects such as waste heat utilisation, material recycling and fuel quality also have to be taken into consideration.

For many years, VDZ has been conducting technical audits at cement plants around the world, often focussing on the thermal and electrical energy efficiency of the plants. To take into account the complexity of the plants, the research institute has refined its evaluation matrix for thermal energy efficiency.

An extended evaluation matrix was developed on the basis of earlier model calculations for the fuel energy demand of the clinker burning process [1] and the energy efficiency of cement production [2], as well as the BAT range stated in the European BAT reference document (BREF) for the energy demand of the clinker burning process, namely 2 900 to 3 300 kJ/kg of clinker (**Fig. 1.3.2-1**). The energy demand given in the BREF is to be viewed as an optimum value which can be attained in a performance test. According to the BREF, the annual energy demand may be 160 to 320 kJ/kg of clinker higher on account of start-up and shut-down operations or kiln stoppages, for example. Assuming a BAT value of 3 000 kJ/kg of clinker, this results in an annual BAT level of 3 160 to 3 320 kJ/kg of clinker for the precalcining plant taken as a basis in the BREF with a kiln capacity of 3 000 tonnes per day. With the inclusion of the publicly available data of the Cement Sustainability Initiative (CSI), the influences of kiln capacity and the use of alternative fuels were integrated into the evaluation matrix – on the basis of a complex fuel mix.

VDZ thus now has a tool permitting the assessment of the fuel energy demand of kiln plants even under complex operating conditions. As shown in **Fig. 1.3.2-5**, data determined in audits fits into this matrix very well.

Energy demand and utilisation

The energy demand for the clinker production process depends on a variety of parameters, including above all the plant design

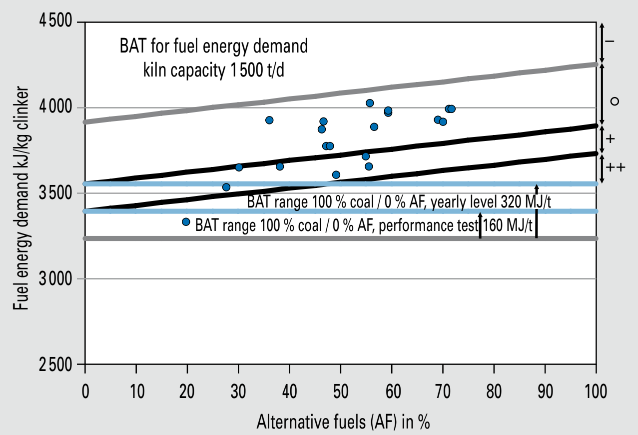


Fig. 1.3.2-5 Evaluation matrix for fuel energy demand (kiln capacity 1500 t/d)

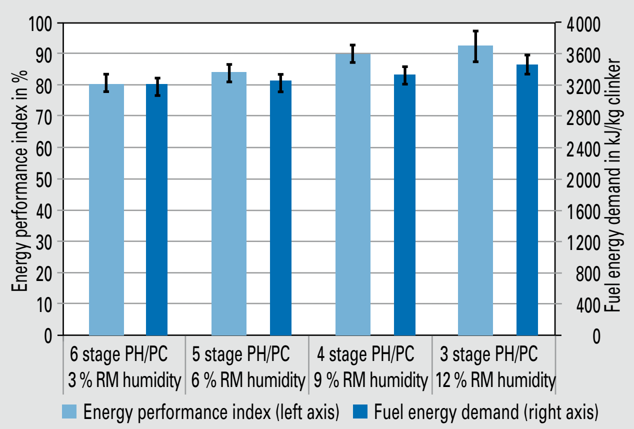


Fig. 1.3.2-6 Energy performance index and clinker-specific energy demand for optimised BAT model plants (3000 t/d, 100 % coal) with different raw material moisture contents

and moisture of the raw materials to be dried. It does not however provide any indication of the energy efficiency of a plant. Cement plants are usually designed for the drying of locally available raw materials by utilising the heat of the rotary kiln exhaust gases. Plants working with relatively moist raw materials thus have a higher clinker-specific energy demand than those using less moist raw materials. This does not however have any negative effect on energy utilisation and thus on the energy efficiency of the process. In addition, the calorific content of the rotary kiln exhaust gases and the cooler exhaust air is often used for drying other main cement constituents (primarily blast furnace slag), as is that of coal, petroleum coke and increasingly also alternative fuels. So far, waste heat-derived power generation is only employed in a few plants in Europe. Such measures have no influence on the fuel energy demand of the plant, but they do increase their efficiency.

Requirements for alternative fuels

Depending on their physical and chemical properties, an increase in the use of alternative fuels may increase the fuel energy demand, but in most cases it also provides greater potential for additional thermal efficiency.

The fuel ash occurring is fully incorporated into the clinker and so ultimately becomes part of the cement. This combination of co-incineration and material recycling is a unique feature of the clinker production process. It must however be ensured that the fuel ash is of additional benefit to the production process. Furthermore, the fuel mix must satisfy the basic requirements for the burning process. Qualitatively high-grade, pre-treated alternative fuels are a prerequisite for very high substitution rates in relation to fossil primary fuels.

Assessment of energy utilisation

To fully elaborate the benefits of co-processing, VDZ developed guidelines for ECRA for the assessment of the energy utilisation of cement plants and worked out an energy performance index as a measure of energy utilisation, taking into account the specific requirements of the production process. According to this, the energy performance index is between 70 and 80 % depending on the framework conditions applied. The European data of the CSI-GNR database for 2014 served as a basis. For more extensive assessment, various scenarios were studied for optimised BAT model plants from the above-mentioned VDZ model calculations on the influence of the fuel quality employed and the raw materials to be dried (**Fig. 1.3.2-6**). Standard alternative fuels were also characterised on the basis of their properties and classified in terms of their energy utilisation taking into account possible pre-treatment measures.

Circular economy

In 2016, around 24 % of municipal waste in the EU was landfilled. This figure varies greatly between the member states. The conclusion drawn from this by the EU Commission is that no overcapacities currently exist in the area of waste incinerators and co-incineration plants. There should accordingly be sufficient suitable materials available for co-incineration in the EU. An increase in the proportion of material co-incinerated at cement plants would make a major contribution towards avoiding CO_2 emissions, reducing the volume of waste landfilled and at the same time preserving natural resources by incorporating the fuel ash into the product. This would however mean the process, the fuels and ultimately the product having to satisfy exacting demands. Only then will co-processing be able to continue making an appreciable contribution towards sustainable and progressive circular economy in Europe in the future.

1.3.3 Protection from ambient pollution and abatement of emissions

Environmental data

VDZ has been publishing the 'Environmental data of the German cement industry' every year since 1998 (www.vdz-online.de/Publikationen/Umweltdaten). Amongst other things, this contains a comprehensive collection of the environmentally relevant emissions of all clinker-producing plants in Germany. In this way, VDZ keeps a record of the results of both continuous emission monitoring and individual measurements of trace elements and organic exhaust gas compounds in German cement plants.

Amendment of the Technical Instructions on Air Quality Control

The last new version of the Technical Instructions on Air Quality Control was produced in 2002; a major amendment process has been in progress since the beginning of 2015.

The Technical Instructions on Air Quality Control form part of the general standard-specifying administrative provisions issued on the basis of § 48 of the Federal Pollution Control Act. They set down legal requirements in the environmental sector and guarantee uniform enforcement by the authorities in the context of licensing procedures. The immissions section of the Technical Instructions on Air Quality Control (chapter 4) specifies general requirements for protection against harmful environmental effects. The Emissions section (chapter 5) contains general and plant-specific requirements (chapter 5.4) to prevent harmful environmental effects. The most important emission limits for cement plants using alternative fuels were set down in the already amended 17th BImSchV (Ordinance on waste incineration and co-incineration) Above and beyond this, the Technical Instructions on Air Quality Control regulate other generally applicable limit values and major aspects of licensing procedures, inspections based on environmental legislation (e.g. stack height calculation and dispersion calculation) and emission monitoring.

The reasons for the amendment process include adaptation of the regulations to progress in the state of the art, the implementation of existing BAT (Best Available Techniques) conclusions on the Industrial Emissions Directive, the inclusion of new plant types and adaptation to the Air Quality Directive and the 39th BImSchV (Ordinance on air quality standards and emissions ceilings)

The first three work packages of the Federal Ministry for the Environment (BMU) were published in summer 2015 and the first official ministerial draft bill including justification in September 2016. The considerable number of regulations contained therein some of which had been greatly tightened up and/or were new such as more extensive measurement and verification obligations, tighter emission and ambient air limit values and newly introduced nature conservation regulations, led to severe criticism on the part of the industry. The official association hearing on the Technical Instructions on Air Quality Control Amendment took place in December 2016; numerous talks were also held on individual aspects between the industry, the Federal Ministry for the Environment and the Federal Office for the Environment (UBA). The much-expected official second draft ministerial bill including justification was then finally published in April 2017.

Plant-specific section – regulations for cement plants

The draft sets down an annual measurement obligation for total dust at sources with an exit gas volume flowrate > 10 000 m³/h for kilns, mills, dryers, coolers and crushers. This is associated with considerably greater outlay for crusher plants as compared to the current status. The 5 mg/m³ emission value for formaldehyde is still defined as limit value and not – as demanded by the industry – as a target value. Only if it is not possible to comply with the emission values with reasonable outlay is it admissible to limit emissions in keeping with the emission minimisation principle on a case-to-case basis. There is also no change to the tightening of the emission limit value for benzene (3 mg/m³ rather than 5 mg/m³), which may well be problematic for certain plants in future on account of raw material-induced emissions.

In July 2018 the BMU published an updated version of the ministerial draft bill as the basis of the interdepartmental coordination. VDZ will alos comment on this new version. According to the planning of the BMU the amendments will be adopted by the end of 2018.

Amendment of the Environmental Impact Assessment

A new version of the Environmental Impact Assessment Act (UVPG) was produced at the end of July 2017. It was based on the 2014 European Environmental Impact Assessment (EIA) amending directive. According to §§ 19, 20 of the new UVPG, certain application-related documents, such as EIA reports, now have to be submitted electronically in an internet portal. The 16 Federal States have jointly developed a central internet information portal (in German): https://www.uvp-verbund.de/startseite. The internet publication obligation applies to all projects for which applications have been submitted since 16.05.2017. Sensitive company data in reports should therefore be marked as company and business secrets in future and excluded from publication.

Reduction of mercury emissions

The Minamata convention, a binding global treaty aimed at cutting worldwide anthropogenic mercury emissions, came into force in August 2017. After being opened for signature in October 2013, the milestone of 50 ratifications was passed in May 2017 (out of 128 signatory states as of February 2018).

Amongst other things, the import, export and production of mercury-containing products are to be prohibited by 2020 and emissions from small-scale gold mining curbed through the use of mercury-free alternative techniques. Emissions from industrial processes such as coal-fired power stations, waste incinerators and cement plants are to be minimised by employing the best available techniques (BAT) and the best environment practice (BEP).

As ECRA representative and in cooperation with the Cement Sustainability Initiative (CSI), VDZ actively contributed its expertise to the production of the BAT/BEP guidelines of the CSI and the United Nations Environment Programme (UNEP), which were compiled at international level and published in 2016. These are expected to be incorporated into the upcoming revisions of the European BAT documents for the cement, lime and magnesium industry, as was already the case in the new version of the BAT reference document for large power plants which appeared in 2017.

The CSI and UNEP guidelines can be obtained via the corresponding website:

- CSI: https://vdz.info/sdelg
- UNEP: https://vdz.info/ct9dg

In the context of these global efforts, the German cement industry already has proven techniques available to contribute to a reduction in mercury emissions. New technologies and measures are also currently being further investigated with a view to achieving even greater reduction.

NO_x abatement measures

In Germany the NO_x limit values for cement plants are to be lowered to 200 mg/m³ with effect from 1 January 2019. An emission limit value for NH_3 of 30 mg/m³ has also already been in force since 1 January 2016 if use is made of SNCR or SCR processes. In the light of this, the German cement manufacturers have extensively optimised or renewed their NO_x abatement systems in recent years.

Precalcining plants offer favourable conditions for the SNCR process, as the kiln exhaust gas residence times in the appropriate temperature window are sufficiently long. The situation is however different in the case of conventional kiln plants with cyclone preheater, where it is often not possible to comply with the NH_3 limit value in particular.

As a consequence of this development, German companies are investing in the latest SNCR and SCR systems for the various kiln lines. For the most part, the high-dust SCR process is employed for catalytic exhaust gas cleaning, but a further tail-end system also went into operation in 2016. More SCR systems are to follow in 2018 and 2019.

The start-up of a first DeCONOx system at a German cement plant is also planned for 2018. This is a combination of a low-dust SCR system and RTO (Regenerative Thermal Oxidiser), i.e. a considerable reduction in total carbon and carbon monoxide emissions is to be expected in addition to lower NO_x and NH_3 emissions. An Austrian cement plant has already gained corresponding operating experience. As in this case the process is intended to be used in conjunction with a special fuel concept, it is to be subjected to further trials in a publicly funded demonstration project. In the course of an extensive measurement program with the participation of VDZ, not just the $DeCONO_x$ process but also other emission abatement measures are to be systematically studied.

Major investments have also been made at two cement plants in southern Germany, where new kiln lines with calciner were constructed. It is planned to put the installations into operation in 2018/2019. Alongside staged combustion in the calciner, the SNCR process is to be employed as a secondary NO_x abatement measure.

The current volume of investments aimed at further cutting NO_x emissions has reached the hundred million mark. The German cement industry is at the forefront of world developments in the field of NO_x abatement and is also helping to ensure compliance with the national emission ceilings (NEC) for the components NO_x and NH_3 in Germany.

Environmental measuring technology

Developments in mercury measuring techniques

In the light of extremely low limit values for mercury emissions, highly verifiable and reliable analytical methods are essential to furnish proof of compliance with the limit values. The detection limit should generally be max. 10 % of the limit value for the result to be used for assessment of conformity. The term detection limit refers to the concentration as of which qualitative verification of a substance is possible. For a limit value of 30 µg/m³, the detection limit must therefore not be higher than 3.0 µg/m³. The European reference method in accordance with DIN EN 13211 sets down a detection limit of 2.6 µg/m³, which means that this condition is only just satisfied. Further developments and possibly new methods will be required in order to increase the reliability of the results and to be able to verify compliance with limit values which may be even lower in the future. A highly promising method based on sampling with mercury absorbers, so-called ‘sorbent traps’, is currently being investigated at VDZ as to its applicability, for example, in the cement industry.

In practice, mercury emissions are continuously monitored in the industry. This involves recording both elemental mercury Hg(0) and the oxidised form Hg(II). As the UV photometers available for continuous monitoring only detect mercury in its elemental form, a well-functioning reduction unit is required and has to be carefully checked at regular intervals. Calibration of these devices in accordance with DIN EN 14181 is performed using the European reference method as per DIN EN 13211. With this method, the mercury is collected in an oxidising absorption solution and then analysed by means of cold vapour AAS (atomic absorption spectrometry). As a relatively small partial volume of the absorption solution is analysed, very small absolute mercury contents have to be detected. Consequently, very low detection and determination limits are necessary to satisfy the above requirements. When using sorbent traps, the mercury is adsorbed onto iodised activated carbon. Sampling can be performed over short periods of 30 minutes, for example, but long-term sampling should also be possible with this method. The entire sample is then thermally desorbed and analysed directly in an AAS measurement cell. As analysis is performed not just on a sub-sample but on the sorbent as a whole, far lower detection limits of an order of magnitude of 0.02 µg/m³ are to be expected. The applicability of the method is currently being examined by way of comparison with the DIN EN 13211 reference method. Work is also being conducted at European level on a Technical Specification for the ‘sorbent trap’ method. This process is already employed in the USA as a reference method for mercury calibration (US EPA 30B) and as a quasi-continuous method for monitoring low emission limits (US EPA 12B).

The sorbent traps consist of at least two separate layers. The first layer serves to absorb the mercury to be measured. The purpose of the second layer is to verify that full sorption of the mercury has taken place in the first layer and there has been no breakthrough. As a means of quality control, use can be made of sorbent traps with a third layer containing a known concentration of mercury both to permit checking of the results of analytical determination and to rule out losses during sampling. Sampling is performed in parallel in two sorbent traps to obtain double determination. An example of this is shown in **Fig. 1.3.3-1**.

As the mercury analysis unit is mobile, the method can also be used ‘on site’ to obtain direct results, provided that continuous mercury measurement is not being performed. This also permits studies into process optimisation and its associated effects on mercury emissions.

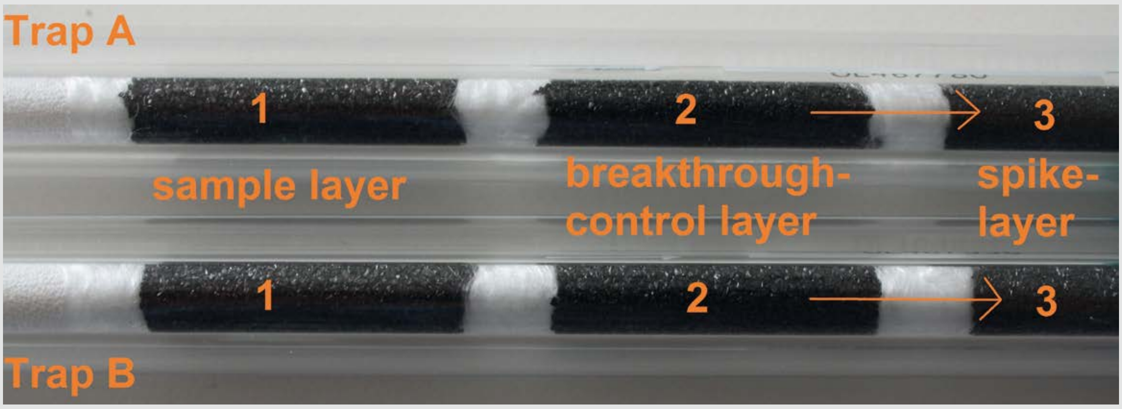


Fig. 1.3.3-1 Structure of sorbent traps

Initial results are already available from comparison of the reference method with the sorbent trap method and are shown in **Fig. 1.3.3-2**. The results of the two methods are of the same order of magnitude, but the number of comparison measurements is still very small so that results can only be viewed as a forecast. Further comparison measurements are currently being taken in order to obtain a reliable comparison of the methods.

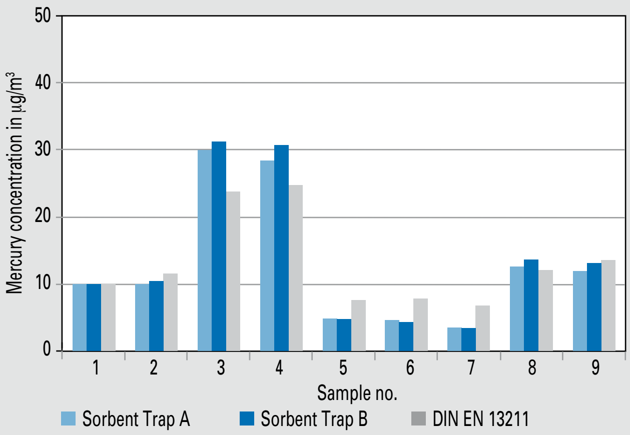


Fig. 1.3.3-2 Comparison of sorbent trap method with measurement results based on EN 13211

1.3.4 Utilisation of waste

Cement plants are reducing the consumption of natural raw materials and the combustion of fossil sources of energy such as oil and coal by substituting suitable alternative materials for natural raw materials and fuels.

In Germany, more than 65 % of the total fuel energy required was provided by suitable alternative fuels in 2016. The use of these alternative fuels meant that it was possible to avoid using the more than 2 million tonnes of coal that would have been necessary to obtain the equivalent calorific value for the production of the cement clinker required.

An average substitution rate of 41 % was attained for the cement industry in 2017. This figure does however vary considerably in the various European countries. Whereas countries such as Germany, Austria and the Czech Republic prove that it is possible to achieve annual average substitution rates of more than 60 %, the substitution rates in certain other EU member states are well below 30 % of the fuel energy required.

In 2017, CEMBUREAU commissioned a study to investigate the reasons for the differences in substitution rate. The study comes to the interesting conclusion that the substitution rate in the area of co-incineration is particularly low in countries where a disproportionate amount of waste is still dumped on tips. So it is a positive move on the part of the European Commission to undertake efforts to combat the still excessively high dumping rates in individual member states.

Particular mention should be made in this context of the action plan for waste management in Europe published by the Commission in December 2015. The EU Commission sets down ambitious targets here. For example, the plan is to re-use 65 % of municipal waste by 2030. At the same time, the aim is to recycle 75 % of all packaging waste by 2030. In addition, no more than 10 % of all waste occurring should be disposed of on tips by 2030.

In a memorandum on the importance of deriving energy from waste within the waste management system in January 2017, the European Commission acknowledged that the use of waste-derived energy in the clinker burning process is a particularly efficient and worthwhile form of waste utilisation. The European Cement Research Academy (ECRA) also produced a technical study for CEMBUREAU in 2017 which makes it possible to calculate the energy efficiency of individual plants. The ECRA study shows that the energy efficiency attained is of an order of magnitude of 70 % and above. This confirms the earlier findings of the European Commission.

From the point of view of the European cement industry it is also important that utilisation of fuel ash material is actually recognised as a form of recycling A current positive example of this is the derivation of energy from used tyres. With effect from 2018 the French government has acknowledged a recycling rate of 23.75 % for the utilisation of used tyres in clinker kilns. In view of the considerable significance attached to the recycling of waste in European waste disposal law, this approach should also be applied to other types of waste as well. For example, treated fractions from commercial and industrial waste with a high calorific value usually have an ash content of around 10 % which is also recycled. With other replacement fuels such as sewage sludge, recycling may even attain an order of magnitude of 40 % and above.

Fig. 1.3.4-1 Used tyres for use as alternative fuels and raw material

1.3.5 Sustainable construction

Sustainable development meets the needs of the current generation, without compromising the opportunities of future generations. For the construction sector, this principle means constructing functional low-cost structures with little impact on the environment for long-term use.

Standardisation for sustainable construction

Over the past few years, the technical committee CEN/TC 350 'Sustainability of structures' of the European Standardisation Organisation CEN has drawn up standards for the sustainability assessment of structures. VDZ was involved in the development of these standards in the form of international cooperation with CEMBUREAU.

An assessment of the sustainability of buildings according to the standards developed by CEN/TC 350 includes all three dimensions of sustainability (environmental, social and economic) and considers the entire life cycle of a building. In addition to the standards already published for the sustainability assessment of buildings, corresponding European regulations are currently also being developed for civil engineering works. A so-called 'framework document' for the sustainability assessment of civil engineering works was published with the standard EN 15643-5 in 2017.

An important standard drawn up by CEN/TC 350 is EN 15804. This standard contains rules for the development of life cycle assessments and environmental product declarations for construction products. As EN 15804 applies to all construction products, some of the regulations are of a somewhat general nature. Under the supervision of a representative from VDZ, a CEN/TC 51 ('Cement and building lime') task group therefore drew up the standard EN 16908 ('Cement and building lime – Product category rules complementary to EN 15804'), which was published in 2017. This standard supplements the rules of EN 15804 to include rules specific to construction materials for the life cycle assessment of cement and building lime. Similarly, a CEN/TC 104 ('Concrete and related products') and TC/229 ('Precast concrete products') task group drew up the standard EN 16757, which contains the product category rules for concrete and concrete elements. This standard was also published in 2017.

Environmental product declarations

Quantified environmental information on the construction products used is required in order to assess the environmental sustainability of a structure. The standardised format for the presentation of this information is the so-called Environmental Product Declaration (EPD). The above-mentioned standard EN 15804 applies to the development of EPDs. The aim is that producers should provide verifiable and consistent data determined on the basis of comparable rules for all construction products. The environmental product declarations are verified by independent third parties to ensure the credibility of the information contained in them.

As the validity of an EPD produced by VDZ for a cement with a composition corresponding to the mean composition of the cements produced in Germany expired at the beginning of 2017, an updated EPD, valid until the beginning of 2022, was produced on the basis of environment-related production data from member companies. The revised EPD is available for download at https://vdz.info/ta5ii

The environmental production declarations available for concretes of various strength classes (can be downloaded from the information platform of the InformationsZentrum Beton; in German only) are to be updated by VDZ in 2018 on behalf of the German Ready-Mixed Concrete Association (BTB) and the German Association for Precast Construction (fdb). The data required for this will be determined by the BTB and fdb and made available to VDZ. For calculation of the life cycle assessment of an average concrete for each compressive strength class under consideration, life cycle assessments are first to be produced for ready-mixed concrete and precast concrete for the corresponding strength class on the basis of the production data. The average will then be formed for each strength class, weighted according to the production volume of ready-mixed concrete and precast concrete.

Product environmental footprint

With the Product Environmental Footprint (PEF), the European Commission is aiming to establish a methodical approach intended to enable member states and the private sector to evaluate, present and ultimately also benchmark the environmental performance of products, services and companies on the basis of comprehensive assessment of the environmental impact over the entire life cycle. In an initial step more than 20 product groups have, in the course of a pilot phase, developed rules for the life cycle assessment of their products within the context of the PEF. The European cement industry was not involved in this pilot phase.

On the basis of a European Commission mandate, the standards developed in CEN/TC 350 are currently being revised to bring them into line with the rules of the PEF. In particular this includes the mandatory assessment of the environmental impact associated with the end of the life cycle of structures and construction products, in other words with demolition and possibly waste recovery, recycling or landfilling. In addition, fundamental rules are to be set down as a basis for the benchmarking of construction products to be performed at a later date.

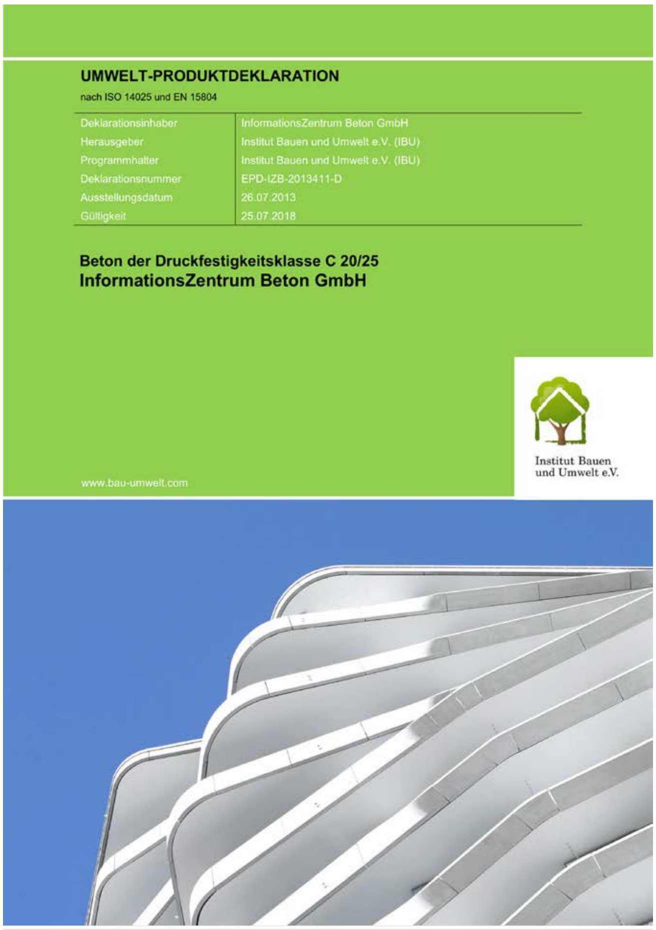


Fig. 1.3.5-1 EPD for concrete with compressive strength class C20/25 (in German)

Fig. 1.3.5-2 Brochure 'Explanatory notes on environmental product declarations for concrete' (in German)

The first step was to amend the standard EN 15804. In accordance with the mandate, the updated rules of this standard will in future require environmental product declarations to also include estimates for the end of the life cycle of building materials. A provision was made in the current draft standard for exempting intermediate products such as cement from this rule, so that only declaration of the 'cradle-to-gate' life cycle modules continues to be obligatory for cement. According to the draft standard it will be possible in future to declare the absorption of CO_2 through the carbonation of cement-bound building materials as negative global warming potential in environmental product declarations.

The CEN survey on the amendment of EN 15804 is scheduled for the second quarter of 2018, with publication currently planned for the start of 2019. Revision of other standards produced in CEN/TC 350 is also to take place in the coming months to follow the mandate of the European Commission and to bring the standards into line with the rules of the 'PEF'.

1.4 Health and safety at work

1.4.1 Safety at work ■

High safety standards

Improving safety at work at plants in the cement industry is one of the tasks defined in the VDZ statutes. For more than 55 years now, the 'Safety at work' working group has been making an important contribution towards this. Alongside the analysis of accident occurrence at the member plants and the recording of accident figures, its work involves drawing-up and recommending measures designed to ensure greater safety at work. These measures are implemented at the plants with the aid of safety codes of practice and check lists. The overall aim is to create safer workplaces and equipment, as well as to make the workforce constantly more aware of safety considerations. The way in which the Lost time injury frequency rate (= number of accidents per 1 million hours worked) has developed shows that the safety measures taken at the plants in conjunction with VDZ have brought about steady improvement over the years. The lowest rate since records have been kept was recorded for the year under review, 2015. **Fig. 1.4.1-1** shows the development of the Lost time injury frequency rate since 1970 as defined by the Professional Association of Raw Materials and Chemical Industry (BG RCI) and, as of 2007, also in accordance with the tighter assessment for the VDZ safety competition.

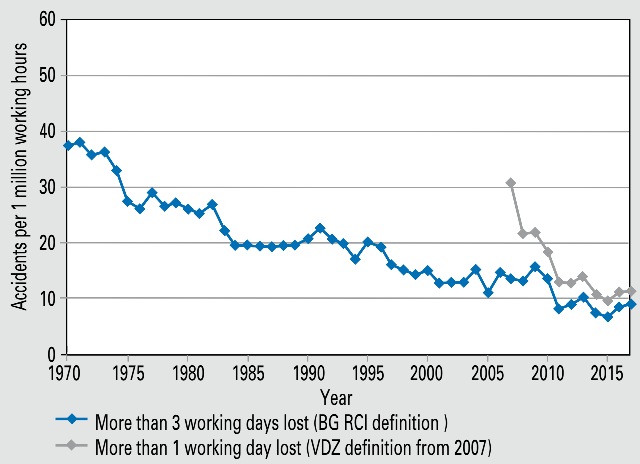


Fig. 1.4.1-1 Lost time injury frequency rate for notifiable accidents
Source: VDZ

VDZ accident statistics

Since 1965, the number of notifiable industrial and commuting accidents at VDZ member plants in Germany has been annually recorded, evaluated and collected in the accident statistics. The most important accident statistic results and figures for the years 2014 to 2017 are shown in **Table 1.4.1-1**. Up until 2008, a plant classed as being accident-free if no employee was absent from work for more than three working days on account of an accident. As of 2008 this criterion was tightened to also include accidents involving just one day of absence. This relates to the first working day or the first scheduled shift following occurrence of the accident and corresponds to the CSI definition of a 'Lost time incident' (LTI).

Since 2014 there has been a slight drop (-5.7 %) in the workforce registered at the plants. This is however partly explained by the fact that only 46 plants are now taken into consideration as opposed to 47. In 2015 the number of reported accidents declined from 94 in the previous year to 80, though it increased again in the following years, to 95 in 2016 and 92 in 2017.

The Lost time injury frequency rate has also developed accordingly. The lowest rate so far was obtained in 2015, with 9.45 accidents per 1 million working hours. This then rose to 11.3 in 2016 and remained virtually constant in 2017 with a figure of 11.17. Accidents recorded on the basis of the Professional Association criterion exhibit a similar pattern. The share of these in the total number of accidents however increased constantly from 70 to 80 %

Table 1.4.1-1 Accident figures for the workforce at VDZ member plants in the period 2014 to 2017

Year	2014	2015	2016	2017
Number of plants	47	46	46	46
Number of employees	5 562	5 315	5 276	5 263
Hours worked	8 883 495	8 464 771	8 410 590	8 233 417
Lost time injury (LTI – one or more working days lost)	94	80	95	92
Lost time injury with absence of three or more working days	66	57	72	75
LTI Lost time injury frequency rate (LTI FR – definition until 2007, accidents with three or more lost working days per 1 million working hours)	7.4	6.7	8.6	9.1
LTI Lost time injury frequency rate (LTI FR – definition from 2008, total industrial accidents per 1 million working hours)	10.6	9.5	11.3	11.2
Calendar days lost due to industrial accidents	2 419	2 367	2 260	2 577
Work days lost per employee	0.4	0.4	0.4	0.5
Calendar days lost per industrial accident	25.7	29.6	23.8	28.0
100-person ration (old definition, reportable accidents per 100 employees)	1.2	1.1	1.4	1.4
100-person ration (new definition, reportable accidents per 100 employees)	1.7	1.5	1.8	1.7

Source: VDZ

Fig. 1.4.1-2 Winners of the 2016 VDZ occupational health and safety competition

in the period 2014 to 2017. But this does not permit any conclusions to be drawn about a possible increase in accident severity.

The average number of calendar days lost per accident occurrence was between 23.8 and 29.6. This represents an increase of around 60 % as compared to the period 2004 to 2013. The economic significance of industrial accidents can be assessed on the basis of the annual loss of production. This figure indicates the calendar days lost due to industrial accidents referenced to the number of company employees. Since 2012, the average annual loss has settled at a value of around 0.45. A further criterion is the 100-person ration. This is the number of industrial accidents referenced to 100 company employees. Based on the new criteria, this rate dropped sharply in the period between 2011 and 2013 to roughly 2.1 accidents per 100 employees and then settled at about 1.7 from 2014 to 2017.

Fig. 1.4.1-2 shows the winners of the 2016 VDZ occupational health and safety competition at the awards ceremony in September 2017. The distinction for clinker plants, which has been awarded by VDZ for more than 30 years, takes the form of a plaque with the VDZ safety at work symbol and the wording 'VDZ work safety'. It acknowledges the efforts of the plant management and workforce to ensure health and safety at work. In 2017, nine clinker plants and eight grinding plants received an award for accident-free work.

VDZ safety codes of practice

To promote safety at work, three safety codes of practice are published each year containing information on particularly significant accidents or topics, as well as three check lists for safety devices and safety measures in various working areas. These documents are intended to provide practical help and are used by safety experts and plant supervisors. They are a means of constantly reminding employees about a whole range of hazards. In recent years, the topics have included safe conduct in ball mills, working at heights, platform collapse during separation work, eruption of meal and the risk of becoming trapped by conveyor belts. Code of practice no. 100 on securing loads has also been updated.

VISION ZERO

On the occasion of the 112th meeting of the VDZ Safety at Work working group on 26 April 2017, the new 'VISION ZERO. Zero accidents – health at work!' cooperation agreement was signed by the German Cement Works Association (VDZ) and the Professional Association of Raw Materials and Chemical Industry (BG RCI). The aim is to work together with the VDZ members to further enhance safety at work in the cement plants through additional prevention measures and thus to achieve the target of 'Zero accidents'.

Fig. 1.4.1-3 Helmut Ehnes (BG RCI, left) and Kai Wagner (Head of VDZ Safety at Work working group, right) after signing the Vision Zero cooperation agreement

VDZ can look back on many years of close cooperation in this context with the BG RCI. The way in which the accident figures have developed shows that continuous efforts are being made with regard to hazards and conduct at the workplace. The motivation of employees and in particular the management plays a crucial role in this respect. That is the reason why VDZ has regularly arranged seminars for supervisors and foremen in cooperation with the BG RCI since 1993. The seminars last two days and are organised and held by BG seminar managers for groups of 15 to 20 people at external locations.

Whereas in previous years the emphasis was on topics specific to cement, such as working with hot meal and the use of alternative fuels, new ideas were introduced as of 2015. The new subject matter is based on a training series offered by the German Aggregates Federation (MIRO). It concentrates on areas such as maintenance, sudden disruptions and the organisation of work. Further topics include back health and industrial medical services.

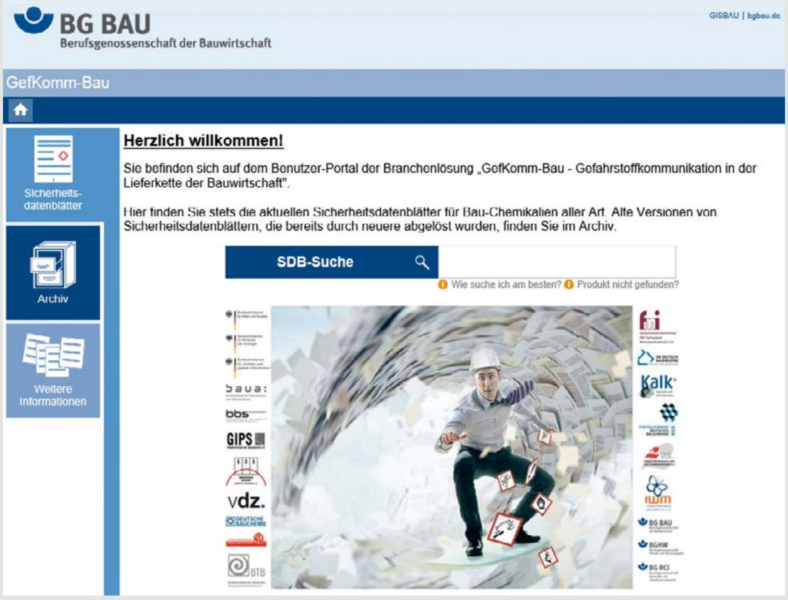


Fig. 1.4.2-1 Homepage of the user portal of the industry solution 'GefKomm-Bau – Gefahrstoffkommunikation in der Lieferkette der Bauwirtschaft' (in German)

1.4.2 Product-related health and safety provisions ■

Classification and labelling

Since 1 June 2015, all substances and mixtures have to be classified and labelled solely on the basis of the CLP (Classification, Labelling and Packaging) regulation. This was implemented for cements and other cementitious products in accordance with the specification coordinated at European level with the CEMBUREAU 'TF REACH, CLP & SDS' task force.

GefKomm Bau

A new procedure has been in place since the beginning of 2016 for hazardous substance communication in the supply chain of the building industry, in particular for the simple transmission of safety data sheets. A central sector-specific pool for safety data sheets for all construction materials containing hazardous substances is located at the Professional Association for the Building Sector (BG Bau) and provides constant access for all parties concerned, allowing them to specifically call up the information required at each particular company. The sector-specific pool affords valuable assistance for companies in the building industry, as the safety data sheets for the products used then no longer have to be kept on the company premises for ten years – as the law demands. VDZ and its member companies are actively involved in this sector-specific solution.

Reporting to poison information centres

Quick and uncomplicated emergency medical assistance is required in (suspected) cases of poisoning. It is then essential to know which substances are contained in a product. The purpose of the new Annex VIII to the CLP regulation, passed in 2017, was to standardise the required procedure throughout Europe and to simplify matters for the authorities and companies responsible. The new regulations will come into force as of 2020 and will apply to all mixtures which are classified as being hazardous on account of health-threatening or physical properties. They will accordingly also be applicable to cements and other cementitious products. Manufacturers will have to provide the central national bodies, in Germany the Federal Institute for Risk Assessment (BfR), with extensive information on their products. This includes much of the information contained in the safety data sheet and a relatively precise indication of the composition of the substance, as well as a so-called identification number, the UFI. However, even slight modifications to the composition make it necessary to renew the UFI and submit a new report to the BfR.

As cements, and even more so mortar and concretes, are subject to frequent changes in composition, implementation of the new regulation would create unnecessary bureaucracy in the industries concerned without achieving any tangible benefit. Together with other industries, the European cement industry is therefore appealing to the applicable committees in Brussels to simplify the necessary procedures before 2020.

Crystalline silica

The two-yearly reporting required by the 'Crystalline silica' European Social Dialogue Agreement took place in 2016 and 2018. The purpose of this is to improve health protection for workers who handle crystalline silica or products containing this. The reporting activities monitor implementation of the measures set down in the agreement within the companies. The level of participation by the European, and thus also the German, cement industry was exemplary.

The issue of crystalline silica is however also a concern to industries in which workers may come into contact with silica. Silica was incorporated into the European Carcinogens and Mutagens Directive (CMD) in the context of 'Work with exposure to crystalline silica produced in the working process' and with an associated occupational exposure limit value at the place of work of 0.1 mg/m³ for respirable crystalline silica. The EU member states have until the beginning of 2020 to implement the CMD in national law. It remains to be seen how high the limit value will be in Germany. The figure will presumably be based on the assessment criterion newly defined in 2016 for crystalline silica (0.05 mg/m³) and will thus be below the European limit value deemed to be the minimum value.

1.5 Personnel development and qualification

1.5.1 VDZ courses and training courses

Qualification and development programmes for employees are central aspects of VDZ activities. The programme ranges from basic technical training to courses imparting specialist knowledge and long-term development programmes for management personnel. The exchange of information within the VDZ personnel development working group and cooperation with the plants guarantee efficient, practice-oriented learning with topical subject matter.

Fig. 1.5.1-1 Participants in the 27th lime/cement plant supervisor training course

Fig. 1.5.1-2 Participants in the 23rd control room operator training course

Plant supervisor training course

For around 60 years now, VDZ has been providing a Lime/cement plant supervisor training course (IML) in Germany in conjunction with the Federal Association of the German Lime Industry. So far, a total of 643 supervisors have been trained in these courses. The 23 participants in the 27th training course, 21 from the cement industry and two from the lime industry, received their master craftsman's certificate in March 2017 after convincing the examination committee of the Duesseldorf Chamber of Commerce and Industry of their abilities (**Fig. 1.5.1-1**). The 28th plant supervisor training course started in March 2018 with 15 participants.

The prospective plant supervisors have to acquire all the theoretical knowledge they require for their future careers at cement or lime plants in a total of 28 subjects with approx. 860 hours of instruction. In the 18-month long training measure, the participants not only learn about the theoretical principles of lime and cement production. They also receive specific instruction on overarching topics such as human resource management and relations. Particular emphasis is placed on the ability of the trainees to function as a team and assist one another. The attendance phases initially concentrate on the fundamental subjects Mathematics, Physics, Chemistry and the principles of materials science. Following two 4-month and 6-month remote courses at their own plants, the trainees then receive specialist instruction in the specific subjects. Another focal point of training is safety at work and correct conduct. The recognised training measure is finally rounded off by acquisition of the trainer aptitude qualification (AEVO). After passing an examination, the supervisors are then entitled to train employees.

Control room operator training course

The increasing complexity of process engineering installations in combination with the demands of high standards of environmental control, safety at work and efficient operation also require an extremely high level of specialist knowledge and networked ways of thinking on the part of control room operators at clinker and grinding plants. To be able to satisfy the constantly increasing requirements, VDZ has been successfully staging so-called control room operator training courses (PSL) since the 1990s. By 2017, 453 people had been trained as cement control room operators in a total of 23 courses (**Fig. 1.5.1-2**). The course content includes a theoretical part, which is offered in the form of seven weeks of attendance instruction, and a practical part to be completed at the cement plant. The aim is to bring the control room personnel up to date with the latest level of knowledge relating to process and environmental technology in cement production as well as to teach them about requirements for efficient, safe and trouble-free operation. The participants acquire an in-depth understanding of materials science, burning technology, environmental technology, grinding technology, instrumentation and control topics, as well as of fundamental science subjects. Training with the Simulex® simulator helps to consolidate the knowledge acquired. It intensively prepares the participants for both normal and unscheduled operating situations at cement plants. The participants receive extensive instruction, starting with the commissioning of individual machines and the installation as a whole and progressing to diagnostic procedures for complex faults. Alongside the actual subject matter, further elements of the course include the practical exchange of information and working in a group.

Seminars and workshops

Since 1998 VDZ has been offering a variety of single and multi-day seminars as part of its training programme. In addition to subjects relating to process technology in cement production, chemical analysis, environmental protection and cement quality, seminars are held on aspects of concrete technology and how to use efficient the VDZ learning platform. The VDZ seminars are intended both for people new to the industry and for experienced employees from the pit & quarry and supply industries.

Since 2015, the VDZ training programme has provided an average of more than 20 seminars per year specialising in different topics. The number of participants has continued to develop well since 2015. The latest courses on offer are always presented in the form of a brochure and in the internet at www.vdz-online.de/en/training/. The website also provides the

Table 1.5.1-1 List of courses VDZ is conducting as part of its education and training activities in German speaking countries

Cement Production
Foundations of raw material extraction
Foundations of cement chemistry
Basics of cement production and its application
Installation of refractories
Maintenance management systems
Modern burning technologies
Update course for foremen and operators
Hands-on training on dosing and weighing
Wear mechanism of refractories
Cement and concrete basics for non-technicians
Cement production for young engineers
Comminution and grinding technology
Quality assurance
Quality control acc. to EN 196
Seminar for internal auditors
Light microscopy on cement and blast furnace slag
X-ray diffraction (XRD)
X-ray fluorescence spectroscopy (XRF)
Hands-on seminar on representative analysis results
Environmental protection
Emission abatement for operators
Basic and advanced training for immission control officers
Concrete technology
Durability of concrete
Grinding and product characteristics

Table 1.5.2-2 Overview of the topics of the VDZ online courses on concrete technology (currently only available in German)

No.	Topic
BE 0.1	Cement and concrete over the course of time
BE 0.2	Constituent materials for concrete
BE 0.3	Basic principles of concrete design
BE 0.4	Concrete design
BE 0.5	Aggregates
BE 0.6	Concrete curing
BE 1.1	Properties of fresh concrete and testing of fresh concrete
BE 1.2	Strength and deformation
BE 1.3	Concrete microstructure and impermeability
BE 1.4	Durability of concrete
BE 2.1	Standardization and constituents
BE 2.2	Cement properties / test methods
BE 2.3	Basic principles of cement chemistry
BE 3.1	Concrete plasticizer and superplasticizers
BE 3.2	Air-entraining agent
BE 4.1	SCC
BE 4.2	Fair-faced concrete
BE 4.3	Recycling in concrete construction

option of online registration, as well as of subscribing to a newsletter issued three to four times a year and containing information on upcoming VDZ seminars (**Table 1.5.1-1**).

In-house training

The VDZ training programme further offers tailor-made training units to be held on site by VDZ employees. They are an opportunity for participants to obtain individual qualifications and receive advanced training. The VDZ experts ensure the full spectrum of instruction, ranging from fundamental aspects of chemistry to process technology and plant optimisation. Each participant is given individual assistance to ensure successful training results.

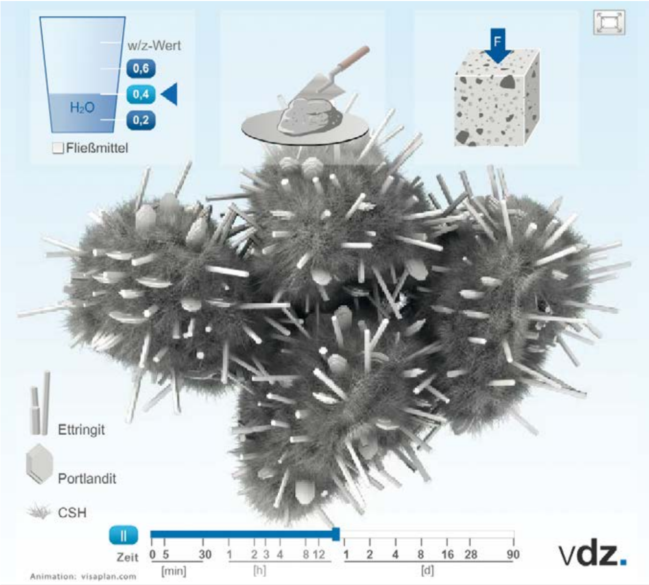


Fig. 1.5.2-1 Animated film on cement hydration from the VDZ concrete technology online courses (in German)

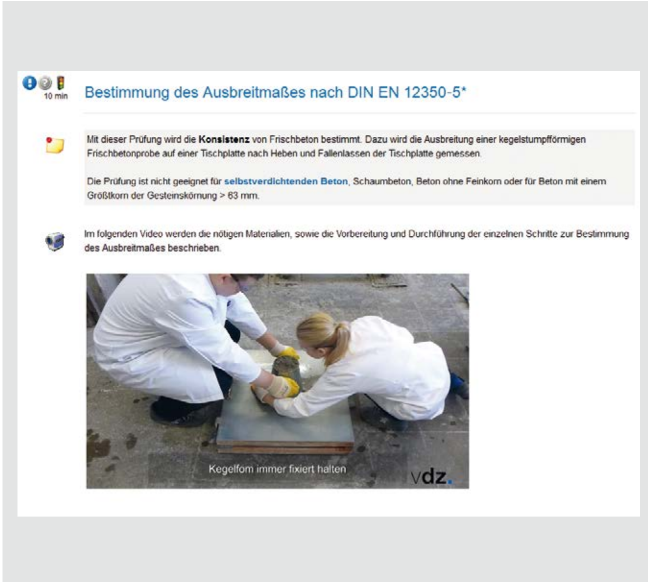


Fig. 1.5.2-2 Content page from the VDZ concrete technology online courses with a video on how to determine the slump (in German)

1.5.2 Learning and working with digital media ■

The online courses offered by VDZ since 2010 are an effective means of providing instruction for skilled, semi-skilled and non-skilled workers and management personnel in the cement industry, as well as for employees from other companies in the pit & quarry industry. Every year, in excess of 1 500 users around the world actively work with the VDZ course content. In more than 70 online courses with over 150 hours of instruction (in German; fewer in English and Russian), employees can obtain information on the fundamental production processes of cement right through to concrete applications (**Table 1.5.2-1** and **Table 1.5.2-2**).

Animated films (**Fig. 1.5.2-1**) and videos (**Fig. 1.5.2.-2**) provide employees with a better understanding of testing procedures and complex concepts, as well as helping them to operate installations more efficiently, more safely and more ecologically in practice. Employees can use the tests provided to check their progress on a computer. They automatically receive printable certificates to confirm the successful completion of tests.

By way of accompaniment, the VDZ training programme offers courses on how to make effective use of the VDZ online courses in everyday working life. In a tutor training course, experienced employees are taught to become in-plant learning assistants. In regular short classroom training units, the tutors then help colleagues to put the VDZ online courses to effective use in day-to-day practice.

The 'Knowledge Network Pit & Quarry' developed since 2011 also gives employees in the pit & quarry industry the opportunity to utilise modern forms of web-based knowledge acquisition to gain individual qualifications. Alongside the VDZ online courses

Fig. 1.5.2-3 In the online course 'BE 1.4 - Durability of Concrete' the exposure classes for concrete structures are explained through an animation (in German)

on cement production and concrete technology, the knowledge network offers a lot of extra useful functions and content, such as collaboration in working groups, or access to reference documents and VDZ codes of practice (Merkblatt). Thanks to cooperation with the lime and ready-mixed concrete industry, further information and qualification measures are also available as part of the knowledge network.

1.6 Quality surveillance and certification

1.6.1 Inspection and certification body ■

Construction products can have a direct effect on the strength and thus the safety of buildings and other structures. Which is why detailed requirements have long since existed for construction products and the inspection of these. The first standard for cement came into force in Germany right back in 1879, for example.

The inspection and certification of cement and cement-type binders have always been some of the central tasks of VDZ. In this way, the association contributes towards ensuring the protection intended by the applicable regulations for construction products. The inspection and certification body is responsible for these activities at VDZ. The results of third party inspection are discussed twice a year in the VDZ Specialist Committee to the Quality Surveillance Organisation.

Construction products according to the Construction Products Regulation (CPR) may only be marketed in the European Union (EU) if provided with a valid CE mark. In Germany, labelling with the Ü-mark is mandatory for many construction products which are not subject to the CPR. In certain other countries use is made of private-law marks, such as the BENOR mark in Belgium, the Dancert mark in Denmark, the KOMO mark in the Netherlands and the NF mark in France. The performance of so-called conformity assessment procedures, which are designed to ensure health and safety when using the products and the safety of the structures is prescribed in all these cases. For the majority of the construction products inspected by VDZ, the corresponding regulations set down initial testings, inspection of the manufacturing plant and of factory production control and assessment of the results of these tests and inspections. Regular audit-testing of the products and continuing surveillance, assessment and evaluation of factory production control by an independent inspection and certification body is subsequently required. This body issues the appropriate certificates if all requirements are satisfied.

Notification and accreditation

The VDZ inspection and certification body is accredited by the German Accreditation Authority (DAkkS) in accordance with DIN EN ISO/IEC 17025 (testing laboratory) and DIN EN ISO/IEC 17065 (certification body). It is also notified by the German Institute for Building Technology (DIBt) as responsible authority in accordance with the CPR and recognised at national level in accordance with the Federal State Building Code (LBO). The notification relates in particular to cements and cement-type binders further applies to concrete additions and admixtures, aggregates and cementitious mixtures (e.g. masonry mortar) for both standardised and officially approved products.

Third party inspection of cement in accordance with legal regulations

In 2017, the inspection and certification body certified 514 binders from 59 cement plants in Germany and other countries on the basis of legal regulations. This included 477 cements. Multiple certificates for identical cements with different addition properties were issued for 128 cements.

The number of binders and plants inspected has remained virtually constant over the past few years (**Fig. 1.6.1-1**). The average number of binders certified per plant increased until 2009 and has since been between 8.4 and 9 binders per plant (**Fig. 1.6.1-2**).

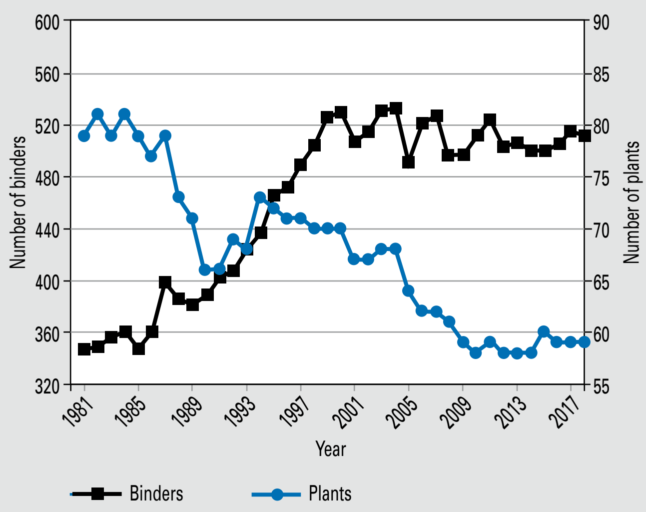


Fig. 1.6.1-1 Development of binders and plants subjected to third party inspection by the inspection and certification body
Source: VDZ

46 cements approved for use for concrete pavements, 15 masonry cements in accordance with EN 413-1 and 22 hydraulic road binders as per EN 13282-1 were also certified in 2017.

The number of certified cements of strength class 32,5 has decreased, whereas those of strength classes 42,5 and 52,5 have increased. The reason for this is that in recent years a number of cements of classes 32,5 R and 42,5 R have been reassigned to the next higher classes 42,5 N and 52,5 N.

Third party inspection of cement in accordance with voluntary regulations

Bilateral agreements on the mutual recognition of testing, inspection and certification activities have been in place for many years between the inspection and certification body of VDZ and the corresponding Belgian, Danish, French and Dutch bodies. This includes third party inspection in accordance with private-law national regulations beyond the requirements of EN 197. By agreement with the bodies in the other countries, the inspection and certification body carries out the required additional tests and inspections at German plants. This significantly reduces the extra outlay for the cement manufacturers.

In 2017, the inspection and certification body inspected 60 cements in accordance with Belgian regulations (BENOR), twelve cements in accordance with Danish regulations (Dancert), 48 cements in accordance with French regulations (NF) and 125 cements on the basis of Dutch assessment criteria (KOMO).

Further construction products

The testing, inspection and certification of cement and cementitious binders continue to form the focal point of the activities of the VDZ's inspection and certification body. However, the area of responsibility has constantly expanded in recent years and now covers many other construction products as well. One example is the inspection and certification of factory production control at various pigment producers in accordance with EN 12878. The inspection and certification body also certifies ground granulated blast furnace slag in accordance with EN 15167-1 and fly ash in accordance with EN 450-1.

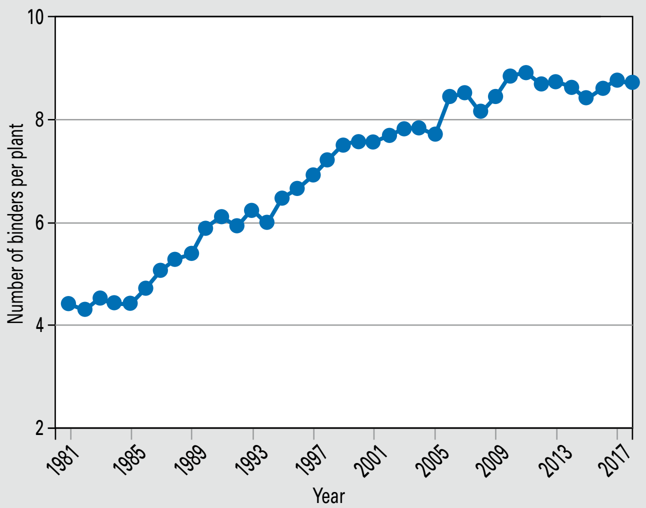


Fig. 1.6.1-2 Average number of certified binders per plant inspected by the inspection and certification body

Source: VDZ

Comparison tests

Accreditation of the VDZ testing laboratories in accordance with DIN EN ISO/IEC 17025 requires laboratories to take part in comparison tests. The inspection and certification body has been regularly participating in various round robin tests for many years. In particular, the standard tests for cement are compared nationally and internationally several times a year.

For instance, weekly comparison tests with a reference cement are organised by a Dutch body and evaluated every three months. The results are discussed at annual meetings of representatives of the third party inspection bodies involved. On top of this, the results of the weekly inspection of the reference cement are documented in a quality control chart to establish and be able to react quickly to any fluctuations.

VDZ also takes part in the annual cement comparison test of the Association Technique de l'Industrie des Liants Hydrauliques (ATILH), in which nearly 200 testing laboratories from more than 30 countries regularly participate. In addition to these international round robin tests, comparison tests were performed at national level on cement and other construction materials such as fly ash.

Testing laboratory

In the context of third party inspection tests and associated commissioned and comparison tests, around 3800 binder samples are tested each year at the VDZ testing laboratories.

Given an average of twelve properties to be tested, that corresponds to more than 45 000 tests. Such a high sample throughput demands efficient procedures in the laboratories. At the same time a constant level of testing and high testing quality also have to be ensured. This is achieved through a high degree of standardisation of the processes and regular training. The competence of the testing laboratories is constantly verified by way of comparison tests and through accreditation.

1.6.2 Quality assurance for cement and binders

Common cements bearing the CE mark can be traded on the European single market without any restrictions. Such cements are assessed in accordance with the European harmonised standard EN 197-2 'Conformity evaluation'. Guidelines for the application of EN 197-2 are contained in the CEN report CEN/TR 14245. The European Sector Group SG 02 of the notified bodies has also drawn up various position papers providing additional information. The CEN report, published in German as DIN SPEC 18098 (formerly DIN technical report 197), and the position papers ensure uniform application of the monitoring standard for conformity evaluation by the notified bodies in Europe.

Assessment and verification of conformity in accordance with the EU Construction Products Regulation

The conformity evaluation procedures for the various construction products are set down by the EU Commission and formulated in harmonised standards by the European standardisation organisation CEN. Four systems of assessment and verification of constancy of performance are defined in the Construction Products Regulation (**Table 1.6.2-1**). With all these systems, manufacturers have to perform factory production control on their own responsibility. The systems differ in terms of the extent to which an independent external body is involved.

System 4 makes no provision for the participation of any notified body. In this case it is sufficient for the manufacturer to carry out assessment of the performance of the construction product (initial test) and to implement factory production control. With system 3, initial testing of the product has to be conducted by a testing body. The more stringent system 2+ is to be applied to hydraulic road binders, for example. In addition to initial inspection of the plant and factory production control, the notified body is also responsible in this case for the continuing surveillance, assessment and evaluation of factory production control. System 1+ specifies regular third party inspection tests for product certification. This is only required for a few construction materials, for example for common cements, cements with special properties and special binders, as these construction products are of particularly great significance for the safety and durability of structures.

In contrast to many other corresponding European directives and regulations, the Construction Products Regulation does not contain any direct product requirements. These are rather governed by European harmonised product standards and European technical assessments (ETAs), which set down the verification to be furnished by the manufacturer, including the tests to be performed as well as the testing frequency and procedures to be employed. The conformity of cement is evaluated in accordance with the standard EN 197-2. Having proven its worth, this standard was also taken as a basis for corresponding stipulations for concrete additions such as fly ash, silica fume and blast furnace slag.

Market surveillance

The European regulation on the specifications for accreditation and market surveillance requires the EU member states to organise a uniform system of market surveillance. The central element is the introduction of national market surveillance programmes. In Germany, the authorities of the federal states and the German Institute for Building Technology (DIBt) are responsible for the

Table 1.6.2-1 Systems of assessment and verification of constancy of performance in accordance with Annex V of the Construction Products Regulation

System	Tasks of the manufacturer	Tasks of the notified body	Construction products
1+	- Factory production control - Further testing of samples in accordance with the prescribed test plan	**Product certification** based on - Initial inspection of the manufacturing plant and of factory production control - Assessment of the performance of the construction product (initial testing) - Continuing surveillance, assessment and evaluation of factory production control - Audit-testing of samples	Cement[1] Masonry cement Ground granulated blast furnace slag Fly ash Silica fume
1		- as for system 1 + but without Audit-testing of samples	–
2+	- Assessment of the performance of the construction product (initial testing) - Factory production control - Further testing of samples in accordance with the prescribed test plan	**Certification of the factory production control** based on - Initial inspection of the manufacturing plant and of factory production control - Continuing surveillance, assessment and evaluation of factory production control	Admixtures Hydraulic road binder Aggregates[2] Pigments Building lime Masonry mortar[3]
3	- Factory production control	- Assessment of the performance of the construction product (initial testing)	
4	- Assessment of the performance of the construction product (initial testing) - Factory production control	–	Aggregates[2] Masonry mortar[3]

[1] Common cement according to EN 197-1, Very low heat special cement according to EN 14216, Calcium aluminate cement according to EN 14647, Supersulfated cement according to EN 15743
[2] System 2+ for high safety requirements, otherwise system 4
[3] System 2+ for designed masonry mortar, system 4 for masonry cement according to recipe

implementation of market surveillance. These bodies are entitled to perform tests not just on a cause-related, but also on a random sample basis. This usually first involves checking whether construction products satisfy the formal requirements (administrative verification with regard to labelling etc.). The products may also be subjected to physical and/or chemical tests if applicable.

Cooperation between notified bodies

In Europe there are several hundred notified bodies as defined by the Construction Products Regulation with a lot of different backgrounds in terms of traditions and experience. So it is important to ensure that the standards and regulations are interpreted and applied in the same manner. For this purpose, the Construction Products Regulation stipulates that notified bodies have to regularly engage in information exchange as an essential prerequisite for notification. In line with the specifications of the EU Commission, the notified bodies are themselves responsible for organising cooperation. Both horizontal and sector-related European committees exist. As there is a particularly large number of notified bodies in Germany, interaction takes place at a national level as well.

VDZ's inspection and certification body regularly takes part in information exchange within both the relevant European and national committees. For example, it made a decisive contribution to the position papers for cement, fly ash, silica fume and blast furnace slag.

1.7 Standards and regulations on cement and concrete

1.7.1 Evolution of standards on cement and other binders

Cement standard EN 197-1

Published in the year 2000, EN 197-1 'Cement – Part 1: Composition, specifications and conformity criteria for common cements' was the first harmonised European standard for a construction product. A revised version additionally regulating cements with a high sulphate resistance (so-called SR cements) and low early strength blast furnace cements (so-called L-cements) appeared in 2011. This standard was then also revised to incorporate formal changes required by the Construction Products Regulation (see Section 1.7.3). In the course of this revision, the applicable European Committee for Standardisation CEN/TC 51 'Cement and building lime' also took the decision to include further cement types in the standard. This concerns cements containing the established main constituents clinker, blast furnace slag, siliceous fly ash, natural pozzolana and limestone. Lower clinker contents than used to date are however to be made possible. The new cement types with at least 50 mass % clinker are referred to as Portland composite cements CEM II/C-M, those with less than 50 mass % clinker as composite cement CEM VI. For this reason, the existing composite cements CEM V are to be re-named 'Slag pozzolana cements'. **Table 1.7.1-1** provides a summary of the composition of the planned new cements.

Above and beyond this, the European Commission services are demanding that the next version of EN 197-1 should also contain rules on alkali content. In future, cement manufacturers should be able to declare the alkali content of cements in declarations of performance if this is of relevance for the cement concerned or its application. An extension of the cement designation (e.g. to include 'LA' for 'Low Alkali') is however not envisaged, as such a designation would be misleading on account of currently differing national alkali limit values.

The new rulings described were incorporated into a revised version of the mandate M/114. The new mandate has however not yet been approved by the EU Commission. Revision of the cement standard can therefore not yet be concluded either.

Cement conformity evaluation

The revised version of DIN EN 197-2 'Cement – Part 2: Conformity evaluation' was published in 2014. In this, no major changes were made to the content of the preceding version issued in 2000. It merely contained certain necessary clarifications. For instance, the standard now includes information on evaluation of the measurement uncertainty of test results and specification of the procedure in the event of non-conformity of factory production control. In parallel with revision of EN 197-2, the guidelines for application of the standard were also revised and published as European Technical Report CEN/TR 14245 (in Germany as DIN SPEC 18098:2014).

Hydraulic road binders

EN 13282-1 'Rapid hardening hydraulic road binders' appeared in June 2013. The content of the European standard largely corresponds to that of the earlier German standard DIN 18506, which it supersedes. EN 13282-3, which regulates conformity evaluation for hydraulic road binders, was published at the same time as the product standard.

EN 13282-2 'Normal hardening hydraulic road binders' was additionally published in 2015. The standard does however contain requirements not specified in the European mandate M/114. For this reason, the standard has not yet been published in the EU Official Journal and cannot be used as a basis for the certification of corresponding products.

Other binders

CEN/TC 51 has drawn up a series of standards for special cements and other binders. One example is EN 14647 for calcium aluminate cement, which can be used for instance for repair mortar. Other standardised binders are masonry cements, supersulphated cements and hydraulic binders for non-structural applications. **Table 1.7.1-2** provides a summary of the current state of the existing product standards for cements and other hydraulic binders.

Test methods

The test standards are also revised at regular intervals in parallel with the product standards. **Table 1.7.1-3** provides an overview of the current state of the test methods of the EN 196 series. This table does not include the performance test methods developed by CEN/TC 51 in conjunction with CEN/TC 104 'Concrete and related products' in the working group WG 12 'Additional performance criteria'.

Table 1.7.1-1 Composition of the new cements according to EN 197-1

Cement type			Clinker	Blastfurnace slag	Siliceous fly ash	Natural pozzolana	Limestone
			K	S	V	P	L/LL
Portland-composite cement	CEM II/C-M	S-L S-LL	50–64	16–44	–	–	6–20
		V-L V-LL		–	16–44	–	
		P-L P-LL		–	–	16–44	
		S-V		16–44	6–20	–	–
Composite cement	CEM VI	S-L S-LL	31–59	–	–	–	6–20
		S-V		–	6–20	–	–

Table 1.7.1-2 Product standards for cements and other hydraulic binders

Standard No.	Cement/binders	Cement/Binder type Number	Name	Strength class	Additional classes	State
EN 197-1	Common cement	27	CEM I CEM II CEM III CEM IV CEM V	32,5 L/N/R 42,5 L/N/R 52,5 L/N/R	SR, SR 0, SR 3, SR 5 LH (≤ 270 J/g)	2011, Revision initiated
EN 14216	Very low heat special cement	6	VLH III VLH IV VLH V	22,5	VLH (≤ 220 J/g)	2015
EN 14647	Calcium aluminate cement	1	CAC	40	–	2005/AC:2006, Revision initiated
EN 15743	Supersulfated cement	1	CSS	32,5 L/N 42,5 L/N 52,5 L/N	–	2015
EN 13282-1	Quick-hardening hydraulic road binder	1[1]	HRB	E 2 E 3 E 4 E 4-RS[2]	RS[2]	2013, Revision initiated
EN 13282-2	Normal-hardening hydraulic road binder	1[1]	HRB	N 1 N 2 N 3 N 4		2015, not published in the Official Journal of the EU
EN 413-1	Masonry cement	1	MC	5 12,5 22,5	12,5X and 22,5X (without air entraining agent)	2011, Revision initiated
EN 15368	Hydraulic binder for non-structural applications	1	HB	1,5 3	–	2008+A1:2010, Revision initiated
EN 459-1	Building lime	5	CL, DL, NHL, FL, HL	2 3,5 5	Q, S, S PL, S ML, A, B, C	2015, not published in the Offcial Journal of the EU

[1] Declaration of composition within given limits
[2] RS = rapid setting

Table 1.7.1-3 Test standards of the EN 196 series for cement

EN 196 part	Content	State
1	Strength	2016
2	Chemical analysis	2013
3	Solidifying, soundness	2016
(4) [1]	Composition	2007
5	Pozzolanicity	2011
6	Grinding fineness	2017 Draft
7	Sampling	2007
8	Heat of hydration – Solution method	2010
9	Heat of hydration – Semi-adiabatic method	2010
10	Water-soluble chromate	2016
11	Heat of hydration – Isothermal Conduction Calorimetry method	2017 Draft

[1] Published as CEN Technical Report CEN/TR 196-4

1.7.2 Standards on concrete construction

Evolution of the concrete construction quality chain in Germany

The requirements with regard to the design and the execution of concrete structures are just as diverse as the performance of concrete itself. This consequently makes the design and execution of complex civil engineering work a more elaborate procedure than is the case with usual building construction projects. It also means that the associated quality assurance measures have to satisfy the requirements for the structure concerned throughout all the design and construction phases. Such a differentiated approach is however currently not fully reflected by the standards applying to concrete construction. The concrete construction quality concept (BetonBauQualität BBQ) is intended to fill this gap. A first conceptual draft for a guideline has been produced and is being intensively discussed.

Initial situation

Differentiated requirements already exist today for special construction projects to ensure the quality chain with regard to the whole design, concrete technology and execution process. Examples of this are the DBV/VDZ code of practice for 'Fair-faced concrete' or the additional technical contractual conditions for hydraulic engineering. In these, the client formulates requirements for the design and execution of the structure. The requirements are then binding for all concerned and guarantee a quality chain appropriate to the construction project, which in such cases goes beyond the specifications of the concrete standards.

In this respect, the concrete standard DIN EN 206-1/DIN 1045-2 can be viewed as an established 'uniform basic standard'. The discussions about the evolution of this standard have shown that it would indeed make sense for the standards themselves to contain differentiation on the basis of the complexity of the construction work. This applies to the areas of responsibility of the designers, the manufacturers of the building materials and the contractors. The interaction of all concerned is then required to obtain the best solution for the construction project. The importance of this interaction is shown by the example of the assumptions made by designers with regard to the early tensile strength of the concrete. The concretes actually used in practice on account of the other concrete technology boundary conditions (durability, progress of construction work) then regularly failed to satisfy these requirements. A first draft of a German Committee for Structural Concrete (DAfStb) guideline has been presented with a view to dealing with these issues better than in the past. Conclusion of the work performed so far: The intensity of communication across boundaries will be a central distinguishing feature in the various application situations.

The concept

The intention is to subdivide the structures into three concrete construction quality classes:

- BBQ-N: Normal requirements
- BBQ-E: Higher requirements
- BBQ-S: Specially stipulated requirements

Table 1.7.2-1 shows the first draft of a decision-making scheme which could provide help with assignment to the three classes. The class depends for example on the service life, the construction method employed and the type of concrete.

Whereas, in general building construction (BBQ-N), success can usually be achieved without those concerned having to mutually exchange their information to any greater degree, BBQ-E and BBQ-S require exchange of the relevant information and coordination of the crucial decisions by way of

- A binding BBQ tender meeting or
- Binding BBQ execution meetings with a kick-off meeting and possibly several follow-up meetings

In addition to these elements, consideration is being given to extended initial tests on the concrete and descriptive specifications for the concrete composition, such as the paste content for example, on a case-to-case basis. The aim is to ensure the robustness of the fresh concrete properties under building site conditions.

Implementation

A DAfStb guideline offers the possibility of addressing the areas of design, concrete technology and execution on a cross-boundary basis. The complexity of the structure or its individual components, broken down according to design classes, concrete classes and execution classes, is relevant for assignment. The BBQ class is derived from the highest sub-class. In the case of water-impermeable concrete structures, for example, experience shows that success and failure tend to depend on design and execution rather than on the actual concrete.

Discussion status

Stipulation of the BBQ class is a design task. Assignment to the classes would be as shown in **Table 1.7.2-2**. Other cases would be classified accordingly. **Table 1.7.2-2** also provides an indication of the applicable performance phases for decisions and actions. Designers have certain reservations about having to take decisions and assume responsibility at a time when not all details of the construction work are known. They do however welcome the planned improvements in communication across boundaries and, like the other groups within the DAfStb, consider that the quality of concrete construction will benefit from the fact that the BBQ classes make it easier to convince clients of the different complexities of the construction procedure. This would meet a central demand of the joint analysis conducted by the German Concrete and Construction Technology Association (DBV) and VDZ.

Durability of concrete structures

To describe the performance of 'concrete' as a construction material, the current generation of concrete standards, DIN EN 206-1 and DIN 1045-2, contains a system of descriptive requirements (e.g. maximum permissible water-cement ratios and minimum cement content) and classes (e.g. exposure classes, consistency classes, minimum compressive strength classes). Today's complex five-component system 'concrete', consisting of aggregate, cement, water, additions and admixtures, can be used for a wide range of building activities. Despite the large number of possible combinations of cements, admixtures and additions, this system is basically robust and largely insusceptible to incorrect use. In terms of durability this system does however have its limits in certain cases:

- If a minimum service life >> 50 years has to be verified (e.g. ZTV-W).
- If new construction materials or construction materials for which there is no long-term experience are to be used (e.g. approval procedures).
- In the case of special ambient conditions/loads (e.g. ASR in concrete roads).

The requirements for the durability of concrete are one major reason why EN 206 has not been harmonised to this day. It has so far not been possible to establish a uniform European basis for evaluating the durability of concrete.

The requirements for the durability of concrete are defined in the existing European standard EN 206 by exposure classes ('standardised ambient conditions'), which are implemented in the form of national requirements for the concrete.

The possibility of describing durability in the form of so-called Exposure Resistance Classes is currently being discussed. These classes could be defined for structures on the basis of a maximum carbonation depth after 50 years under defined boundary condi-

Table 1.7.2-1 Possible assignment of applications to design, concrete, execution and concrete construction quality (BBQ) classes

Z	Reference	Application	Work phase (HOAI)[5)]	DC[2)]	CoC[2)]	EXC[2)]	BBQ
S	1	2	3	4	5	6	7
1	Component	Components in exposure class X0	3	1	1	1	N
2	Component	Interior components in exposure class XC1	3	1	1	1	N
3	Component	Components in exposure class XC3 or external components in exposure classes XC4/XF1/XA1/XD1/XS1	3	1	1	1	N
4	Component	Components in moisture classes WO or WF	3	1	1	1	N
5	Component	Foundation components in the exposure classes XC1/XC2	3	1	1	1	N
6	Component	Components with planned concreting openings and vibrating lanes adapted to the installation process	5	1	1	1	N
7	Component	Components with flatness requirements according to line 1 according to DIN 18202 or components without flatness requirements	?	1	1	1	N
8	Execution	Standard concrete for in-situ concrete with compressive strength class ≤ C25/30[1)]	5	1	1	1	N
9	Component	Components in exposure classes XF2/XF3, XD2/XD3, XS2/XS3, XA2, XM2	3	1	1 / 2	2	E
10	Design/ Con-crete	Concrete with artificially entrained air-voids, e.g. XF2/XF3/XF4	5	2	2	2	E
11	Component	Components in moisture class WA	3	1	2	1	E
12	Component	Exposed concrete classes SB1, SB2 or SB3	0	2	2	2	E
13	Component	Massive structural elements according to *DAfStb*-Guideline	3	2	2	2	E
14	Component	Components in special civil engineering (piles, diaphragm walls, etc.)	3	2	1	2	E
15	Design/Com-ponent	Waterproof concrete structures according to *DAfStb*-Guideline with use category B	0	2	1	2	E
16	Design/Com-ponent	Waterproof concrete structures according to *DAfStb*-Guideline with use category A	0	2	1	2	E
17	Design/Com-ponent	Waterproof concrete structures according to *DAfStb*-Guideline with use category A***	0	2	1	2	E
18	Design/Com-ponent	Vessels (fermenters, biogas plants, etc.)	0	2	2	2	E
19	Component	Components with prestressing (prestressed concrete)	2 or 3	2	2	2	E
20	Concrete	Fibre concrete without performance class	5	1	1	1	N
21	Concrete	Concrete with synthetic fibres for fire protection	3	2	2	2	E
22	Concrete	Fibre concrete with performance class (according to DAfStb-Guideline 'Stahlfaserbeton')	3	2	2	2	E
23	Component	Components with flatness requirements according to DIN 18202, Table 3, lines 2 or 3 and 5 or 6	?	1	1	2	E
24	Execution	Standard concrete ≥ C30/37 and ≤ C60/75	5	1	1	2	E
25	Design/ Concrete	Lightweight concrete ≤ LC35/38 for ≥ D1,6 up to D2,0	5	2	2	2	E
26	Design/ Concrete	Lightweight concrete ≤ LC25/28 for ≥ D1,0 up to D1,4	5	2	2	2	E
27	Design/ Concrete	Heavy concrete	0 or 3	2	2	2	E
28	Component	Increased requirements for limitation of deformation (e.g. deflection)	3	2	2	2	E
29	Concrete	Self-compacting concrete	5	1	2	2	E
30	Design	Reduction of the allowance on the reinforcement of the concrete cover (only in cases according to DIN EN 1992-1-1/NA, 4.4.1.3 (3))	3 or 5	2	1	2	E

Z	Reference	Application	Work phase (HOAI)[5]	DC[2]	CoC[2]	EXC[2]	BBQ
S	1	2	3	4	5	6	7
31	Component	*WHG* constructions (LAU) according to *DAfStb*-Guideline (WHG: German Water Resources Law, LAU: e.g. fuel oil tanks, diesel tank systems, gasoline separators etc.)	0	2	2	2	E
32	Component	Constructions with consequence class CC3	0	?	?	?	?
33	Component	Service life over 50 years (e.g. durability design for service life class 5)	0	3	1	1	S
34	Component	Traffic areas with maintenance plan to ensure durability (e.g. parking decks)	3	3	1	1	S
35	Component	Components in which the minimum reinforcement (compulsion) with reduced tensile strength is determined	3 or 5	3	1	2	S
36	Design	Particularly high reinforcement ($A_s \geq 9$ % for predominantly vertical components (including overlap joints) and $A_s \geq 4$ % for predominantly horizontal components)	3 or 5	3	1	2	S
37	Design	Components in which the arrangement of concreting openings or vibrating lanes is not possible and therefore the installation process has to be planned particularly	5	3	1	3	S
38	Component	Exposure classes XM3 and chemical attack XA3 or more	2 or 3	3	1	1	S
39	Component	Components that additionally require a coating or seal to ensure durability	3	3	1	1	S
40	Design/Concrete/ Execution	From 28 days different proof age for the compressive strength of concrete (MP: under the conditions of Annex C)[3]	5	1	2	2	E
41	Design/Concrete	Standard concrete ≥ C70/85 or ≥ LC40/44	5	1	2	2	E
42	Component	Flat components without formwork with systematical slope (e.g. > 5 %)	5	2	1	2	E
43	Component	Exposed concrete class SB4	0	3	3	3	S
44	Component	Components with flatness requirements according to DIN 18202, Table 3, lines 4 or 7	0, 1 or 2	1	1	3	S
45	Component	Tolerance class 2 according to DIN EN 13670	3	3	1	3	S
46	Component	*JGS* constructions (*JGS*: slurry, manure, silage effluent)	0	2	2	2	E
47	Concrete/Execution	Pumped concrete with transfer before pumping with the concrete pump [4]	acc. to 5	1	1	3	S
48	Concrete	Pumped concrete with transfer after pumping with the concrete pump	acc. to 5	1	1	1	N
49	Execution	Special conveying methods (e.g. transport of the concrete by pumping over longer distances or with bigger height differences or with small pipe diameters)[4]	acc. to 5	1	3	3	S
50	Execution	Slip-form method	3 or 5	3	3	3	S
51	Concrete	Concretes with flow classes F1 to F5 or compaction classes C0 to C4	acc. to 5	1	1	1	N
52	Execution	Installation under water (underwater concrete)	acc. to 5	1	2	2	E
53	Execution	Mechanical installation (e.g. paver, rolled concrete)	acc. to 5	1	1	2	E
54	Execution	Additional surface treatment (beyond scraping and peeling) and surfaces with special texture (e.g. broom finish)	acc. to 5	1	1	2	E
55	Execution	Concretes with slow and very slow strength development	3	1	2	2	E
56	Concrete	Concretes with flow class F6	acc. to 5	1	2	2	E
57	Component	Steel composite construction	3	2	2	2	E
58	Component	Top-down construction method	3	2	2	2	E

Z	Reference	Application	Work phase (HOAI)[5]	DC[2]	CoC[2]	EXC[2]	BBQ
S	1	2	3	4	5	6	7
59	Concrete	Special requirements for concrete constituents according to DIN EN 206, 6.2.3, indents 1 and 2[4]	0	3	3	3	S
60	Concrete/ Component	Other technical requirements (see DIN EN 206, 6.2.3, last indent), unless already included in this table	0	3	3	3	S

DC = Design class; CoC = Concrete class; EXC = Execution class, BBQ = Concrete construction quality class Requirements: N = Normal, E = Enhanced, S = particularly Specified
[1] Note: Comes from the surveillance classes in DIN 1045-3.
[2] Minimum class, depending on the application a higher class may be required.
[3] Note: Adopt GÜB quality assurance plan for execution in Guideline.
[4] Determinations are made in the BBQ tendering meetings/BBQ-execution meetings in Annex A, therefore CoC3/EXC3
[5] HOAI = Fee arrangement for architects and engineers.
A *** = Use category A *** = ‚Demanding use‘ acc. DBV guidelines ‚High quality use of basements‘ Deutscher Beton- und Bautechnik Verein e.V., Berlin

Source: German Committee for Structural Concrete (DAfStb) (March 2018)

Table 1.7.2-2 Exposure resistance classes – example to explain the principle

Resistance class	Carbonation RXC			Chloride RXSD			Freeze-thaw RXF	
	RXC20	RXC30	RXC40	RXSD45	RXSD60	RXSD75	RXF 1.0	RXF 0.5
Definition	50-years of exposure to **XC3 (RH 65 %)** with 10 %-probability of **carbonation front** exceeding (mm)			50-years of exposure to **XS2** with 10%-probability of **chloride concentration** exceeding **0.5 % at depth (mm)**			Assume XF1 and XF2 with DtS-rules and **XF3 and XF 4** with **scaling loss m_{56} in kg/m²** supplemented with DtS-rules	
Classification according to standard	20	30	40	45	60	75	1.0	0.5
	EN 12390-10[1]			EN 12390-11[1]			CEN/TS 12390-9	CEN/TC 12390-9

[1] Assuming that EN 12390-10 and EN 12390-11 can be used as a basis to develop them into suitable test standards
[2] DtS = Deemed to satisfy rules

Source: CEN/TC 104/SC 1/WG 1 N 72

tions for example (**Table 1.7.2-2**). The designer would specify the class and stipulate the minimum concrete cover accordingly. In the concrete standard EN 206, the applicable classes of concrete would have to be defined on the basis of a corresponding laboratory test procedure in a manner permitting national stipulation of the concrete cover with which the concrete can be used in exposure class XC3, for example, based on the declared performance (e.g. a carbonation rate in mm/$a^{0.5}$) and extrapolation over 50 years. What may well sound relatively straight forward is currently the object of intensive and controversial discussion, as it gives rise to a series of questions which will first have to be answered in the corresponding CEN task groups. For example, a design working life will have to be defined in the Eurocode. With regard to reinforcement corrosion, this can for example be the limit state 'Depassivation of the reinforcement by carbonation' or the limit state 'Attainment of a critical corrosion-inducing chloride content'. Representatives of the CEN committees for cement, concrete, precast components and design have jointly formulated the questions to be answered and drawn up a rough time schedule (**Table 1.7.2-3**).

1.7.3 European Construction Products Regulation ■

The Construction Products Regulation (CPR) was published in the EU Official Journal on 4 April 2011 and came into force 20 days later. With effect from 1 July 2013 it completely superseded the 1988 Construction Products Directive. The Regulation describes the duties of all the economic operators involved in the supply and distribution chain, i.e. producers, representatives and importers. The CPR also re-defined the requirements for notified bodies and contains stipulations with regard to European technical assessments and market surveillance.

According to the Regulation, construction products can only be traded on the European single market if they are suitable for the intended use and satisfy the following seven 'Basic requirements for structures':

- Mechanical resistance and stability
- Safety in case of fire
- Hygiene, health and the environment
- Safety and accessibility in use
- Protection against noise
- Energy economy and heat retention
- Sustainable use of natural resources

Table 1.7.2-3 Questions and time schedule for work on the implementation of the ERC (Exposure Resistance Classes) concept in European concrete construction standards

Item	Task	Proposed time schedule
1	Definition of what event marks the end of design working life	Fall 2018
2	a) Definition of ERC (Carbonation /Chloride) and level of reliability (ß-value)	Fall 2018
	b) Definition of ERC (Freeze/Thaw, Chemical Attack)	
3	Review/amend exposure classes	Spring 2019
4	Confirmation of model relating performance parameters of concrete (ERC) to design working life under given exposure classes for carbonation, chloride attack and freeze-thaw	Spring 2019
5	Specification of minimum concrete cover to reinforcing steel acc. to EN 10080 for durability as a function of ERC for exposure classes and design working life	Spring 2019
6	Additional provisions for minimum concrete cover for durability for prestressing steel and tendons with different protection levels	Spring 2020
7	Additional provisions for minimum concrete cover for durability for coated reinforcement, stainless steel, FRP reinforcement, other additional protection (membranes, etc.) or particular conditions	Spring 2020
8	Development of testing standards for durability testing providing sufficient data for classification into ERC for carbonation, chloride attack, freeze-thaw and chemical attack	
9	Checking ERC assumed in draft EN 1992-1-1 against data and experience of available concrete testing	Fall 2019
10	Checking of ERC and minimum concrete cover assumed in draft EN 1992-1-1 against current Deemed-to-Satisfy rules and experience	Fall 2019
11	Provisions how to classify a specific concrete mix into ERC based on (i) performance testing, and (ii) based on deemed- to-satisfy rules. Give provisions for initial type testing and FPC	End 2020
12	Checking of available experience on durability performance as a function of curing conditions	Summer 2021
13	Provisions for execution (curing, etc.) which ensure that ERC performance assumed in design is achieved in structure	Summer 2021

Source: CEN/TC 104/SC 1/WG 1 N 72

In contrast to other European regulations, the specifications for construction products are not formulated directly in the CPR. Rather, they are set down in European harmonised standards and European technical assessments (ETAs).

ECJ ruling against Germany

With its ruling dated 16.10.2014 (case C-100/13), the European Court of Justice (ECJ) condemned the Federal Republic of Germany on account of trade barriers for construction products. The court ruled that additional requirements set down in national regulations for construction products which conform to European harmonised standards represent impermissible trade barriers.

As a consequence of the ruling, the German building regulations were revised. The amended legal stipulations, which include the Model Administrative Provisions - Technical Building Rules (MVV TB), make a distinction between requirements for construction products and regulations for assembling construction products to form structural elements (construction techniques). This gives rise to changes in particular for construction products which until now have been subject to national additional requirements in the form of German standards, although they already conform to a harmonised standard. These include 'low-alkali cements' in accordance with DIN 1164-10. Such cements now have to be marketed as cements in accordance with EN 197-1. The additional German cement designation 'NA' is therefore no longer possible. Instead, VDZ has recommended that the standard designation be supplemented by the two lower-case letters 'na' in brackets, for example 'Portland cement EN 197-1 – CEM I 32,5 R (na)'. The 'low-alkali property' must be assured in a Manufacturer's Declaration and confirmed by an independent body, e.g. in the form of a private-law product certificate.

1.7.4 Environmental requirements for cement-bound building materials coming into contact with groundwater and soil

European activities

The European Commission demands that in future, new and revised harmonised European product standards must include stipulations on the release of dangerous substances. The generic horizontal test methods required for this are being worked out by the technical committee CEN/TC 351 'Construction products: Assessment of release of dangerous substances', which was set up in 2005. With regard to soil and groundwater, WG 1 of TC 351 has submitted draft versions for a 'Horizontal dynamic surface leaching test' for monolithic construction products and a 'Horizontal up-flow percolation test' for granular construction products.

Table 1.7.4-1 Comparison of no-effect levels for 2004 and 2016

Parameters	GFS 2004	GFS 2016
	[μg/L]	[μg/L]
Antimony (Sb)	5	5
Arsenic (As)	10	3.2
Barium (Ba)	340	175
Lead (Pb)	7	1.2
Boron (B)	740	180
Cadmium (Cd)	0.5	0.3
Chromium (Cr)	7	3.4
Cobalt (Co)	8	2
Copper (Cu)	14	5.4
Molybdenum (Mo)	35	35
Nickel (Ni)	14	7
Quicksilver (Hg)	0.2	0.1
Selenium (Se)	7	3
Thallium (Tl)	0.8	0.2
Vanadium (V)	4	4
Zinc (Zn)	58	60
Chloride (Cl^-)	250 [mg/L]	250 [mg/L]
Cyanide (CN^-)	5 (50)	10 (50)
Fluoride (F^-)	750	900
Sulfate (SO_4^{2-})	240 [mg/L]	250 [mg/L]

Following the corresponding robustness tests, the test method for monolithic construction products, which is largely identical to the method of the German Committee for Structural Concrete (DAfStb) employed in Germany, was published as DIN CEN/TS 16637-2 in November 2014. No agreement was initially reached with regard to the test method for granular construction products, as significant differences exist between the test conditions specified to date in various member states. For example, regulations in the Netherlands demand a general size reduction of the construction products to 100 mass % < 10 mm with a proportion of 90 mass % < 4 mm and a low flow rate of 150 mm/d. In Germany on the other hand, granular construction products have to be checked without size reduction in the state in which they are used and the flow rate is around 450 mm/d. Intensive discussions gave rise to the following compromise: The proportion of particle size < 4 mm must be at least 45 mass %, the maximum particle size is limited to 22.4 mm and the flow rate is to be 300 mm/d.

With this compromise, the draft standard was published in December 2016 as DIN CEN/TS 16637-2. The European round robin tests for the two Technical Specifications started in September 2017. This means that the final European test standards could be available by the end of 2018/beginning of 2019. With effect from this date, the European product committees will have to make reference to the above test standards when producing and revising the corresponding product standards.

National activities

A dossier of the European Concrete Platform (ECP) recommends the classification of concrete and concrete constituents in the European category 'Without Further Testing' (WFT).

The German Institute for Building Technology (DIBt) has studied the dossier and is not in agreement with the proposed general WFT classification. The DIBt considers there to be 'A need to revise standards for concrete and reinforced concrete components with regard to effects on soil and groundwater'.

The ECP dossier was produced under the direction of Hans van der Sloot – an internationally renowned Dutch expert on leaching tests. Leaching results gathered in an extremely comprehensive database on mortars and concretes produced throughout the world provided the basis for the dossier. After comparing these results to the requirements set down in Dutch law for the release of environmentally relevant parameters from construction products, the authors come to the conclusion that – apart from a few exceptions – general WFT classification is possible for concrete and concrete constituents, as the release levels deter-mined for many parameters are less than 10 % of the permissible release level.

Comparison of the existing leaching results with the environmental requirements of the DIBt in Germany however reveals that 23 % of the mortars and concretes investigated would not satisfy the requirements for vanadium release. This difference arises from the use of different evaluation concepts. Whereas in the Netherlands for example, risk assessment is performed, resulting in a permissible release of 320 mg/m² vanadium, the corresponding value for Germany is just 4.4 mg/m².

The existing, extremely low German no-effect levels (GFS) were updated in 2016 by the Working Group on Water Issues of the Federal States and the Federal Government (LAWA) and significantly lowered in many cases. **Table 1.7.4-1** lists the no-effect levels for inorganic parameters for the years 2004 and 2016. If the updated no-effect levels were to be used as a basis for the environmental evaluation of concrete and concrete constituents, the parameters for lead, cobalt and vanadium in particular could present obstacles to the use of concretes. In view of the more stringent no-effect levels, it remains to be clarified whether adaptation of the transfer model (from no-effect level to leaching test) is possible.

1.7.5 Hygiene requirements for cement-bound building materials coming into contact with drinking water

European activities

Based on the European Commission mandate M 136, WG 3 of CEN/TC 164 'Water supply' works out test methods for materials which come into contact with drinking water. Whereas the test standards DIN EN 14944-1 'Influence of factory-made cementitious products on organoleptic parameters' and DIN EN 14944-3 'Migration of substances from factory-made cementitious products' have existed since 2006 and 2007, the corresponding work on site-made products was stopped in 2005 due to the fact that too many regulatory issues were still unresolved.

After the European 'Acceptance scheme for construction products in contact with drinking water' had finally failed in 2006, the four EU member states Germany, France, the Netherlands and the United Kingdom (4MS group) agreed in 2007 to prepare a joint approach to product evaluation in order to implement the corresponding hygiene requirements in each of the member states. The 4MS group published the document 'Assessment of cement-bound products in contact with drinking water' in 2012 for this purpose. As this document also includes the necessary regulatory requirements, the working group for cement-bound products was reactivated. In the meantime, the existing parts 1 and 3 of the standard have been revised and drafts have been completed for parts 2 and 4 for site-made products. These moved to the working group survey stage in 2015. Unfortunately this survey failed on account of formal errors, resulting in the work item being retracted by CEN. In 2017, WG 3 decided to reactivate the work on the test methods with the corresponding project group under new leadership.

National activities

In Germany at present, cement-bound materials in contact with drinking water are regulated by the work sheet W 347 'Hygiene requirements for cement-bound materials intended for use in drinking water supply systems' of the German Association for Gas and Water (DVGW). Until now the German Environment Agency (UBA) has issued guidelines or recommendations for the assessment of materials and substances coming into contact with drinking water or made reference to applicable DVGW work sheets. The second amendment to the German Drinking Water Regulation (TVO) now assigns the UBA the task of working out hygiene-related bases for evaluation for metals, plastics, elastomers etc. and for cement-bound materials. These bases for evaluation will include the test regulations with the test parameters, test criteria and method specifications. They are also to contain the definitive lists of the raw materials or the materials and substances which can be used. These definitive lists are to be kept and revised when necessary by the UBA.

In contrast to the voluntarily applicable guidelines and recommendations, the bases for evaluation will become legally binding two years after being set down. This means that operators of water supply systems – including drinking water installations in buildings – will then only be allowed to use components containing materials and substances which correspond to the applicable basis for evaluation. It is intended that it will then be possible to verify conformity to the requirements by way of the test report of an accredited testing institute for example.

The German Environment Agency has set up technical committees to advise on elaboration of the bases for evaluation. Cement-bound materials are being dealt with in the UBA technical committee 'Plastics and other non-metallic materials in contact with drinking water (KTW-FG)' with the participation of VDZ. In 2013 the UBA presented the draft 'Bases for evaluation for cement-bound materials in contact with drinking water – cement – bases for evaluation (ZTW)'.

The ZTW draft is based on the established DVGW work sheet W 347. Accordingly, the draft reiterates the principle – also contained in the 4MS document mentioned above – that compliance with the specified trace element contents in cement obviates the need for leaching tests for these parameters. The content values currently listed in the DVGW work sheet W 347 are 100 ppm for arsenic, 10 ppm for cadmium and 500 ppm for lead, chromium and nickel. The UBA does however intend to specify additional content values for the elements antimony, cobalt, thallium and vanadium. The existing content values are also under scrutiny. The UBA is however prepared to accept the current values, which are satisfied by all German standard cements, if experimental proof is furnished of reliable compliance with the permissible leaching quantities. In coordination with the UBA, VDZ produced the mortar prisms required for the leaching tests. Use was made of cements with the highest possible trace element contents for this purpose. In the majority of cases, doping with the appropriate trace element was however required in order to be able to attain the above-mentioned content values at all. The leaching tests did confirm the content values for certain elements, but the tests were then held up for a whole range of different reasons. The aim is to test the remaining parameters again in 2018.

The German Environment Agency is assuming that development of the basis for evaluation for cement-bound materials will take some time yet. Until then, hygiene-related evaluation of cement-bound materials can continue to be conducted on the basis of the established DVGW work sheet W 347 (2006 edition).

1.7.6 ASR regulations in Germany and Europe

A deleterious alkali-silica reaction (ASR) in concrete can shorten the working life in addition to reducing its serviceability and, in rare cases, its load-bearing capacity. Concretes in accordance with EN 206-1 therefore have to exhibit sufficiently high ASR resistance over the working life of at least 50 years (working life category 4 as per DIN EN 1990). In Europe, the rules required for this have so far been set down at national level.

Situation in Europe

To date, at European level there are no uniform ASR-related exposure and moisture classes, procedures for testing the alkali-silica reactivity of aggregates or classes for their categorisation. A joint working group of the European standards committees for cement, aggregates and concrete (CEN/TC 51, 154 and 104) came to the conclusion that it has not been possible so far to set down ASR regulations in the harmonised product standards (DIN CEN/TR 16349) on account of their national orientation and diversity. It could be possible to define European ASR exposure classes in future. There is some degree of similarity between the existing national classes.

Due to the different national regulations, standardisation of 'low alkali' cements has so far not appeared to be possible. The European Commission is however insisting that at least the alkali content should be incorporated into the future European cement standard DIN EN 197-1 as an essential characteristic (see also Section 1.7.1). Cement manufacturers could then declare the alkali content of their cements if this is of relevance to the particular application of the cement. In future, national regulations on the avoidance of deleterious ASR, for example the German Alkali Guidelines, could make reference to the specifications of the manufacturers regarding the alkali content of the cements. The national definition of 'low alkali' cements would still be possible.

CEN/TC154 (aggregates) announced the intention to conclusively regulate the essential characteristic 'Alkali-silica reactivity' of aggregates in the harmonised DIN EN 12620 through declaration of the alkalis which can be released from aggregates. ASR prevention measures based on this information could be set down if applicable in EN 206 and the national application documents. This

Table 1.7.6-1 Technical regulations in Germany to mitigate damage by alkali-silica reactions in concrete structures

Scope	Moisture class *	Technical regulations
Concrete, reinforced concrete and pre-stressed concrete structures and engineering works according to the 'Additional Technical Terms of Contract and Guidelines for Civil Engineering Works' (ZTV-ING)	WO, WF, WA	- DIN EN 1992-1-1 + NA/DIN1045-2 - 'Alkali Guidelines' of the German Committee for Structural Concrete (DAfStb)
Hydraulic structures	WF, WA	- Decree WS 12/5257.6/2 for the business unit of the Federal Waterways and Shipping Administration - 'Alkali Guidelines' of the German Committee for Structural Concrete (DAfStb)
Railway sleeper	WA	- Deutsche Bahn standard 918 143 in combination with - 'Alkali Guidelines' of the German Committee for Structural Concrete (DAfStb)
Concrete road pavements according to the 'Additional technical conditions of contract and directives for the construction of base courses with hydraulic binders and concrete pavements' (ZTV Beton-StB 07)	WA	- Technical delivery terms for materials and material mixtures for base courses with hydraulic binders and concrete pavements (TL Beton-StB 07) in combination with - 'Alkali Guidelines' of the German Committee for Structural Concrete (DAfStb)
	WS	- Technical delivery terms for materials and material mixtures for base courses with hydraulic binders and concrete pavements (TL Beton-StB 07) - General Circular on Road Construction (ARS) No. 04/2013
Aviation area (runways)	similar to WS	- Specification are defind in tender documents, usually - Verification of a sufficiently high resistance against alkali-silica reaction of the concrete by an ASR-performance-test with an external alkali supply by solutions based on de-icing chemical

* Moisture classes:
WO: dry
WF: moist environment
WA: moist environment + external supply of alkalis
WS: Road pavements in load classes Bk1.8 to Bk100 in accordance with the Directive for standardising the paving of road pavement (RStO)

development is to be closely observed and monitored to ensure that European stipulations remain compatible with the regulations successfully applied for decades in Germany.

Structural elements made from reinforced concrete and prestressed concrete in accordance with DIN EN 206-1 and DIN 1045-2

With regard to structural elements made of reinforced and prestressed concrete in accordance with DIN EN 206-1/DIN 1045-2 in Germany, the 'Alkali Guidelines' of the German Committee for Structural Concrete (DAfStb) are to be applied to obtain a sufficiently high ASR resistance in structural elements and to avoid ASR damage. The Alkali Guidelines regulate methods of testing and the categorisation of aggregates into alkali reactivity classes. The ASR prevention methods contained in it also set down descriptive specifications for concrete compositions. The measures which may have to be taken depend on the environmental conditions of the concrete in terms of moisture class, the alkali reactivity class of the aggregate and the cement content of the concrete. The measures are as follows:

- Replacement of the alkali-reactive aggregate
- Reduction of the alkali content of the pore solution of the concrete by using a cement with a low effective alkali content (cement in accordance with DIN EN 197-1 with additional properties as per DIN 1164-10)

Concrete railway sleepers

On the topic of ASR, the DB Standard 918 143 (DBS), issued in May 2015, specifies testing of the sleeper concrete in addition to setting down requirements for the aggregate and the cement. Annex G of the DBS stipulates that a sufficiently low ASR potential has to be verified in an expert report for each sleeper concrete composition by way of an ASR performance test. The procedure and the methods are comparable to those for concrete road pavements. Annex G is initially of an informative nature and is to become normative in 2019 following further testing of sleeper concretes.

Hydraulic engineering structures

For the area of responsibility of the Federal Waterways and Shipping Administration (WSV), the Alkali Guidelines and the decree WS 13/5257.6/2 dated 19.06.2015 apply as supplementary provisions. With the decree, the Federal Ministry of Transport and Digital Infrastructure (BMVI) introduced its own measures for the waterways infrastructure. The preventive measures are more stringent than those in the Alkali Guidelines. In the case of aggregates of alkali reactivity class E III-S (alkali reactive), structural elements of moisture class WF (moist environment) and cement contents ≤ 350 kg/m³, for example, use has to be made of a cement with the additional property 'low effective alkali content' in accordance with DIN 1164-10.

Concrete road pavements

The General Circular on Road Construction (ARS) no. 04/2013 of the Federal Ministry of Transport, Building and Urban Affairs contains regulations specifically for the concrete road pavements of federal motorways to prevent ASR damage. Road pavements in load classes Bk1.8 to Bk100 in accordance with the Directives for the standardisation of the superstructures of trafficked surfaces (RStO) 12 are to be assigned to moisture class WS. Verification must be furnished of either a high ASR resistance of the concrete in the form of an expert report, generally by way of an ASR performance test (procedure V1), or of a low alkali-silica reactivity of the coarse aggregates with d ≥ 2 mm by way of a WS basic test (procedure V2). Both procedures take around 14 months. After successful testing, further verification has to be furnished as follows in accordance with procedure V3:

- Concrete mix evaluations through testing of the concrete constituents in the event of a successful ASR performance test
- WS confirmation tests on the coarse aggregate in the event of a successful WS basic test

Irrespective of procedures 1 to 3, simplified verification with procedure 4 is also possible in Bavaria (announcement IID9-43435-002/08 of the Supreme Building Authority in the Bavarian State Ministry of the Interior, for Building and Transport). This involves the producer having to declare that positive experience has already been gained with the aggregate concerned in road construction in Bavaria for moisture class WS. The aggregate must further be categorised into alkali reactivity class E I and be subjected once a year to petrographic examination and accelerated mortar bar testing in accordance with the Alkali Guidelines.

Airfields

Nowadays, it is often standard practice in Germany to conduct an ASR performance test with external alkali supply in the form of solutions containing de-icing agents on concrete for airfields (e.g. runways and taxiways) and precast concrete elements coming into contact with airport-specific de-icing agents.

1.7.7 Fire safety

Revision of the Eurocodes

Structural design in Europe is regulated by common standards, the so-called ‘Eurocodes’. This also applies to hot design, in other words to fire design.

In December 2014 the European Commission issued a ‘Mandate for amending existing Eurocodes and extending the scope of structural Eurocodes’ to the European standardisation organisation CEN. Publication of the Eurocodes being revised is planned for 2020.

To revise the Eurocodes on the design of reinforced concrete, the applicable standardisation committee CEN/TC 250/SC 2 has been organised to form several task groups to work on specific problems under the supervision of a coordinating working group (WG 1). The task group TG 5 is concentrating on revision of the Eurocode for the fire design of concrete. Within the context of European cooperation with the European Concrete Platform (ECP) and CEMBUREAU, the European Cement Research Academy (ECRA) is actively assisting with the work on the Eurocodes for the fire design of concrete in TG 5. In addition, the German mirror committee for TG 5 is headed by a VDZ employee.

Having been classified as being potentially unreliable, a column design method (Annex C of the standard) has been replaced by a new method in an amendment to EN 1992-1-2 in TG 5. In contrast to the column design methods previously available, the new design tables also permit fire design for cantilever columns. The amendment to the standard is to be published in 2018.

The following additional important modifications are to be made for the hot design of reinforced concrete (EN 1992-1-2):

- The regulations on the explosive spalling of concrete in case of fire are to be extended, as the results of recent research show that the current standard is too highly focused on the moisture content of concrete.
- The thermal conductivity of concrete is to be uniformly regulated in Europe.
- The regulations on the design of high-strength concretes are to be supplemented to take into account the latest findings on the strength development of such concretes at high temperatures.

1.7.8 Traffic route engineering

The regulation governing road bases with hydraulic binders and concrete road pavements consists of three parts

- TL Beton-StB 07: Technical Terms of Delivery for construction materials and material mixtures
- ZTV Beton-StB 07: Additional Technical Terms of Contract and Directives for Construction
- TP Beton-StB 10: Technical test regulations

and has been under revision in the relevant committees of the Road and Transport Research Association (FGSV) since the middle of 2014.

In future, the test regulations are to be collected in a loose-leaf booklet ‘Technical test regulations for traffic area pavements - concrete construction methods’. The advantage of this is that the corresponding test regulation can quickly be replaced if any changes are made. The tests so far contained in TP Beton are gradually being transferred to the loose-leaf booklet. In the case of test regulations which have not yet been dealt with, the loose-leaf booklet contains a reference to the section of TP Beton still applicable to this case.

Most progress has been made with the work on the ZTV. Work on the TL Beton started in 2017. The following requirements for road pavement cements are being discussed:

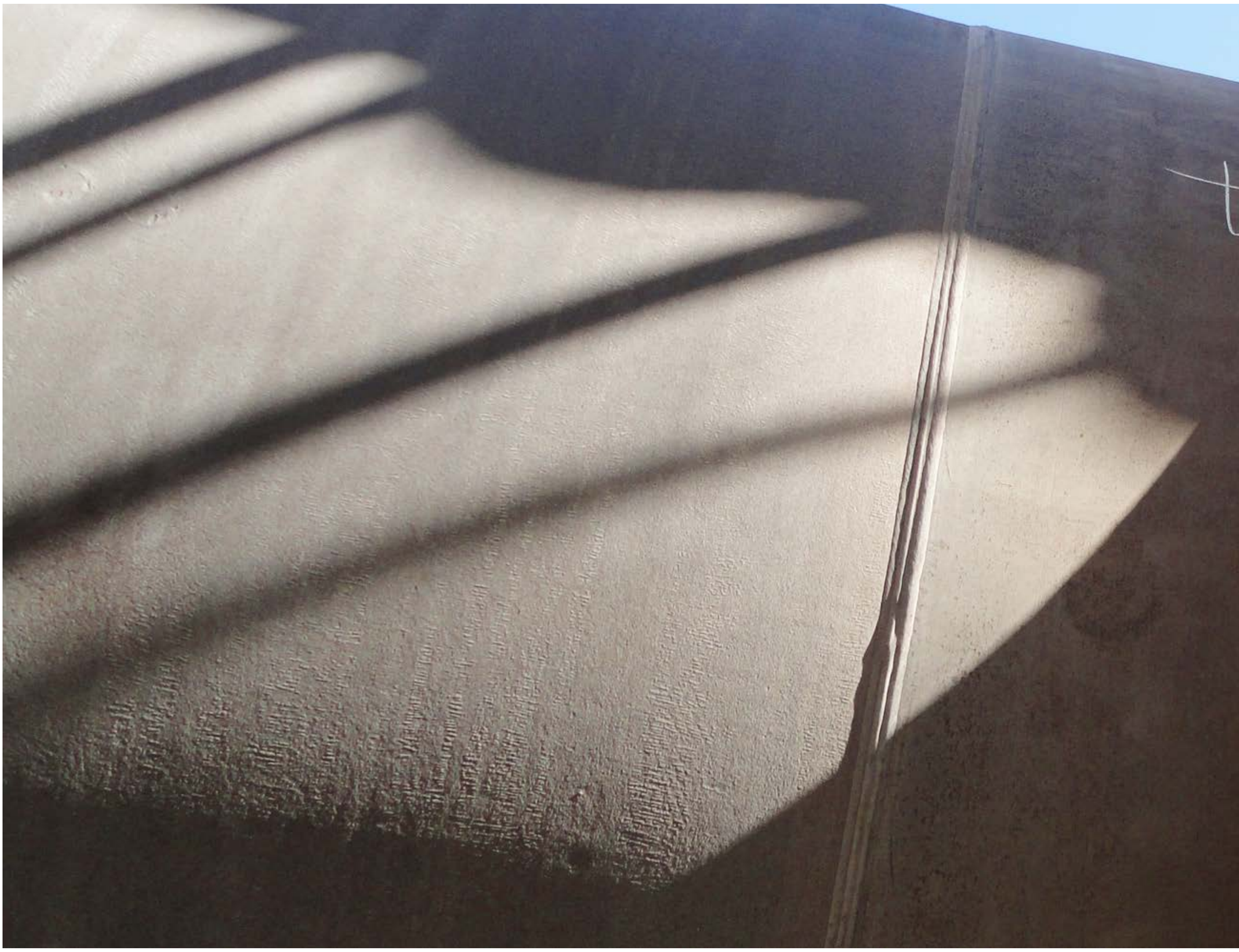
- For the production of pavements, use is generally to be made
- for the top course concrete of CEM I and CEM II/A-S
- for the base course concrete of CEM I, CEM II/A-S, CEM II/B-S, CEM II/A-T, CEM II/B-T, CEM II/A-LL and CEM III/A

(max. 50 mass % S) of strength class 42,5 in accordance with DIN 197-1. The top course and base course concrete cements must not be more than one strength class apart.

With the agreement of the client, use can also be made of the cements CEM II/B-S, CEM II/A-T, CEM II/B-T, CEM II/A-LL and CEM III/A (max. 50 mass % S) in accordance with DIN 197-1 for the top course concrete. In this case, the cement must exhibit a 2-day compressive strength of at least 20 N/mm^2 when tested in accordance with DIN 196-1.

2

VDZ Services



VDZ Services

With its roots in the cement industry and its comprehensive know-how, VDZ today is an internationally present technical/scientific service provider for the cement and building materials industry. From conducting well-founded analysis through offering competent consultation to preparing complex expert reports, VDZ offers all services along the entire cement and concrete value chain from a single source.

Environment and plant engineering

The VDZ range of services comprises all the testing and advisory services required in thermal and mechanical process technology. Its experienced experts optimise processes, improve the performance and efficiency of plants and assess the environmental compatibility and sustainability of production processes.

Chemistry and mineralogy

VDZ is a recognised specialist in the analysis and characterisation of inorganically mineral materials and in the optimising of laboratory work in the cement industry. VDZ staff advise on the choice of suitable input materials and fuels, and help to optimise cements and the cement bound construction products manufactured with them.

Concrete and initial constituents

The accredited VDZ concrete laboratory offers all the important tests on fresh and hardened concrete, and on concrete constituents. VDZ experts also perform approval tests, write complex damage appraisals and assess the environmental compatibility of your products.

Certification and verification

FIZ-Zert, the certification body of FIZ GmbH, certifies management systems according to ISO 9001, ISO 14001, ISO 50001 and OHSAS 18001 resp. ISO 45001 and verifies greenhouse gas emissions and tonne-kilometre reports according to EU regulation 600/2012. It also certifies companies according to the requirements of the Concrete Sustainability Council (CSC). FIZ GmbH is accredited by the German Accreditation Body according to ISO 17021 and ISO 14065.

Product certification

Traditionally, the monitoring and certification of cements and other construction products is one of VDZ's core areas of competence. The testing, inspection and certification body is accredited to ISO 17025 (Civil engineering and construction products) and EN 45011.

Measurements and analytics

FIZ GmbH is accredited by the German Accreditation Body according to ISO 17025 (Immission control). FIZ GmbH is also gazetted as an officially recognised, independent monitoring body according to Section 29b of the Federal Pollution Control Act, 13th and 17th protective decrees for immissions of the Federal Republic of Germany and the TA Luft (Technical Instructions on Air Quality Control). Qualified, reliable environmental measurements as well as the calibration and function testing of emission measurement devices form the core of the service spectrum.

Education and training

For over 60 years VDZ has supported businesses in the pit and quarry industry in the qualifying of their workforce. As well as the plant supervisor training course, VDZ can now offer numerous other training courses, seminars and online courses as well as customer-specific training in different languages worldwide.

2.1 Environment and Process Technology

In the field of environmental and plant engineering, the range of VDZ services encompasses all types of thermal and mechanical process technology analyses as well as studies into the causes of and ways of reducing emissions in cement plants. VDZ offers complete planning and organisation of factory trials as well as the implementation and evaluation of these, thus making it possible to find solutions for even complex aspects of environmental and process technology.

Technical audits and energy audits

In recent years VDZ has conducted a number of kiln and mill audits both in Germany and in other countries. Based on this experience it offers standardised audits with different depths of detail:

- A-level audit:
  Assessment based on information available in the plant
- B-level audit:
  Assessment based on information available in the plant and on-site inspection
- C-level audit:
  Complex measurements on site and analysis of results (mass flows, volume flows, emissions, particle size distribution etc.)

The audits cover issues and problems such as firing techniques for alternative fuels and the effects of these on kiln operation, the reduction of material cycles, primary and secondary emission abatement measures, the reduction of CO_2 emissions and the process technology modelling of kilns and grinding plants as well as plant engineering optimisation. These technical audits are adapted to the particular customer and plant requirements.

Environmental technology

The VDZ workforce has gained comprehensive experience over many years of permit management for plants in the cement and lime industry. With the latest cement-specific findings from science, consulting and research, this offers the ideal foundation for our consulting work in the field of environmental sustainability. Besides preparing environmental reports, VDZ also provides and reviews permitting applications for its customers and provides start-to-finish support and consulting in permitting procedures and all environmental questions. These services are all delivered based on the very latest level of knowledge thanks to continuous collaboration in current research projects and regular participation in training courses and working groups.

The customer is supported in the following areas:

- Support for licensing procedures under pollution control law
- Determination and assessment of a project's impact on emissions and immission pollution
- Determining the chemical and physical properties of the relevant constituents

In addition to the VDZ services the accredited environmental measuring body of FIZ GmbH also offers emission and immission pollution measurements (see chapter 2.6). In the field of climate protection/energy and resource efficiency, the range of VDZ services is complemented by the certification of environmental and other management systems and by the verification of CO_2 emission reports by the certification body for management systems of FIZ GmbH (FIZ-Zert) (see chapter 2.5).

Important issues in times of rising energy costs and tighter environmental standards include the reduction of emissions as well as both thermal and electrical energy savings. In this respect the range of VDZ services includes the following contract investigations:

- Plant engineering analyses and assessments as part of technical audits (state of the art/best available techniques, see above)
- Recommending measures to reduce emission and ambient pollution levels
- Emission and immission forecasts
- Requirements for discharge of emissions/calculation of stack height
- Environmental impact studies
- Complex dispersion calculations
- Assistance with authorisation procedures
- Soil analyses
- Measurement and forecasting of emissions and environmental impact with respect to noise and vibrations
- Studies, e.g. on the topics of environmental protection, climate protection, energy efficiency in cement manufacturing

Thermal process technology

The portfolio of VDZ services in the field of thermal process technology encompass a broad range, from high-temperature process measurements to consulting on process optimisation, product quality, energy efficiency and use of alternative fuels and raw materials to process technology modelling. VDZ's experienced measurement technicians and engineers have comprehensive knowledge that has been proven in practice, in the cement industry particularly, but also in other non-metallic minerals industries, e.g. the lime industry.

The VDZ regularly carries out projects on measurements and for optimising industrial plants (e.g. rotary kiln plants in the cement industry). As part of contracted research and publicly funded research projects in the cement industry, VDZ systematically works to improve our understanding of process technology and continuously advance our methods.

Maintaining and improving cost-effectiveness and competitiveness requires regular examination of production processes as. This reveals the extent to which long-term sustainable upgrades of a plant or the installation of new technologies may be necessary. VDZ services in the field of process optimisation include the following:

- Technical analysis of the clinker burning process or the entire rotary kiln plant
- Bottleneck analysis
- Chemical and physical analysis of all materials in collaboration with the chemistry and mineralogy department
- Testing and optimisation of clinker and cement quality
- Optimisation of primary and secondary measures for emissions reduction (e.g. NO_x emissions, mercury emissions, organic emissions, SO_2 emissions) and minimising CO_2 emissions
- Optimisation of kiln plant operation
- Diagnosis and consulting of build-up problems

Mechanical process technology

In the field of mechanical process technology, VDZ has always offered its customers a diverse range of services, from characterisation of solids in powder form to conducting complex grinding trials and classification testing to the optimisation of industrial plants. VDZ's laboratory staff and technicians have many years of experience with the sometimes highly sensitive measurement procedures employed in mechanical process technology. The key measurement procedures are accredited and subject to regular round robin tests and internal quality checks.

VDZ offers auditing and supplier-independent optimisation of industrial grinding plants, including all subsystems. VDZ specialists assess and optimise grinding plants for cement grinding, raw grinding, coal grinding and other dry grinding processes in other sectors of industry, and will if necessary offer the customer complete solutions which includes the chemistry and mineralogy of both raw material and product.

VDZ's most important optimisation services are:

- Reduction of specific energy demand/improvement of energy efficiency
- Capacity increases
- Changing fineness/particle size distribution
- Targeted modification of cement properties
- Use of grinding aids
- Reduction of wear/extension of service life
- Planning mechanical and process-technology maintenance
- Holistic examination of grinding and product portfolio
- Point-of-failure analysis
- Independent cost estimates
- Supporting investment projects

Maintenance

Preventive maintenance is essential to guarantee continuous production operations. It calls for regular precise and reliable inspections and surveys of rotary kilns and ball mills – the core aggregates of the plants. Specifically, VDZ's range of services covers the inspection and surveying of rotary kilns, rotary dryers, rotary coolers and ball mills, assessing the mechanics of rotary machinery as well as numerous other maintenance tasks around the mechanical parts of the mill (supervising assembly, crack testing, first-time commissioning and recommissioning).

VDZ works for clients in all sectors of industry where rotary machines are operated (e.g. cement/lime/gypsum, chemistry, fertilisers, timer, paper, foodstuffs, sugar or refineries). For every plant it offers a specific service portfolio from which individual services can be combined to meet the customer's needs. Alternatively a fully customised service can also be provided.

Inconsistencies in operation

During the continuous operation of rotary kilns numerous problems can crop up repeatedly which threaten the regular progress of production and so require maintenance work. They can include difficulties with the kiln lining or tyre fixation, tyre wobbling as well as out-of-roundness. An irregular contact pattern between tyre and supporting roller can also occur. Cracks or material fractures are also possible on tyres, supporting rollers, on the girth-gear, on the kiln/mill shell and on the mill head. Furthermore the main drive can have mechanical problems, indicated by high power consumption on the main motor, a ‘knocking’ sound on gear/pinion or unusual vibration around the main drive pier. Other problem areas include the irregular wear of supporting rollers or tyres, no ‘floating’ of the kiln on the support rollers/hydraulic thrust system, hot support roller bearings and a tyre lift up from the support roller. Deformation may also occur on the kiln shell (e.g., a ‘banana effect’) and a high shell eccentricity at the kiln feed and/or discharge section.

Technical audits in practice

Technical audits have great significance for the evaluation of cement plants. They can be tailored to meet the specific needs of the plant or the requirements of the customer. In recent years the focus has been increasingly on energy audits because cement plants worldwide see or have seen significant savings potential on both the thermal and on the electrical energy side. These audits have shown scope for savings potential in many cement plants. VDZ has been able to suggest appropriate optimisation measures, some of which plants could implement with no major investment meaning that such an energy audit soon pays for itself. A detailed report which is discussed in detail with the plant operator is prepared for all audits. The report will also include a plant-specific schedule of measures that should be implemented to be able to achieve the savings potential.

VDZ was able to identify a savings potential or around 2.50 Euro per tonne of cement during an energy audit conducted in one plant of a leading cement manufacturer. Of this, savings potential requiring no investment accounted for approx. 1.00 Euro while approx. 1.50 Euro of savings potential required reasonable investment. This shows that energy audits can quickly pay for themselves, even for small cement plants.

In one audited plant VDZ assessed and examined in detail each department individually step by step, from the quarry to the shipping department. The audit found that approx. 2/3 of the energy savings potential was on the fuel side and approx. 1/3 on the electricity side. The results were then discussed with the works management and possible measures for achieving the savings potentials were discussed and agreed.

In another plant audit the VDZ experts also identified energy optimisation measures which can be implemented as part of general routine maintenance. It is often damage to inlet seals or the steel casing of a heat exchanger which causes an increased heat demand, although operational shortcomings can have the same effect. Typical improvements can involve identifying sources of false air or the general mode of operation of the kiln/cooler, right down to optimising the quality of the kiln meal/hot meal. The sum of all individual optimisation measures will then result in significant savings of thermal and electrical energy.

Electrical energy can also be saved using targeted maintenance-related optimisation measures. This can optimise electrical controllers and regulators, e.g. through the correct shutdown of plant parts or the optimisation of pressure regulating circuits in kilns and grinding plants. Work which arises as a result of process optimisation, such as replacing mill linings or repairing partition or discharge walls, can also reduce power consumption.

In the course of a mill audit experts also found a mill with ‘coated’ internals which exposed both damage to the lining and a ‘blocked’ discharge wall (**Figs. 2.1-1** and **2.1-2**). These features of a poorly running mill may be trivial individually but concealed a complex problem which is illustrative of the optimisation of mills: Measurements in the mill showed that the mill temperature was too high due to the blocked mill and so caused the mill internals’ ‘coating’. The blocked discharge wall could not be explained right away however because the source of the scrap iron that was used was not clear. Suspicions pointed to a defective batch of grinding balls in which the balls burst during operation. As initial measures therefore the mill was first discharged, the scrap removed from the discharge wall and the ball charge replaced. However the mill ventilation was still too low after the ball charge was replaced so reducing the mill temperature was not entirely possible. The mill’s operating state was stabilised with further process-technical optimisation measures.

Fig. 2.1.3-1 Damage to the lining

Fig. 2.1-2 ‘Coated’ mill internals

Survey services of VDZ
For clients operating grinding plants VDZ conducts full plant-specific inspections and symptom-based targeted measurements. Very diverse services are provided according to requirements:

- Geometry of support stations
- Thermal profile of the mill shell/infrared profile
- Wobbling and out-of-roundness of tyres, mill flanges and girth gears
- Out-of-roundness of supporting rollers, journals and trunnions
- Temperature profile of girth-gear and pinion
- Root to tip clearance measurement between girth-gear and pinion
- Vibration and thermal measurements, e.g. on the mill drive (motor/gearbox)
- Wall thickness measurement on the mill shell/front wall
- Wall thickness measurement on other components up to 200 mm
- Hardness measurement of components for HB, HRB, HRC, HSD, HV
- Roughness measurements for Ra, Rz, Rq and Rt, e.g. on bearing shafts

Other services on rotary equipment
The data obtained from measurements and inspections can necessitate immediate action to prevent damage, and this is where the reliable and tailored service of VDZ comes into its own:

- Visual inspection of plant
- Survey and assessment of machinery mechanics
- Detailed analysis and reporting of the surveyed data, including appraising and recommendations for continued stable plant operation
- Adjusting the axis of rotation
- Checking and adjusting ‘roller skewing’
- Checking and adjusting the plant balance
- Checking and adjusting the contact patterns of girth-gear and pinion
- Machining the contact surfaces of girth-gear and pinion
- Inspecting girth-gear/pinion lubrication for correct operation, lubricant quantity and spray pattern
- Red/white crack testing
- Supporting supervision of assembly
- Support with the commissioning of new plant or recommissioning of existing plant following repairs
- Preparing plant-specific service checklists
- Training and induction

Practical example: Maintenance of a ball mill

VDZ’s maintenance experts occasionally come across true ‘long-distance runners’ during their regular inspections and surveys of rotary kilns and ball mills. One of these is the ball mill built by VEB Schwermaschinenbau Ernst Thälmann in Magdeburg, East Germany, way back in 1959. They may be a rarity but in some places they are still in use after nearly 60 years of operation (**Fig. 2.1-3**).

The ball mill’s performance data are formidable: With a 1 000 kW motor (19.7 r.p.m.) it delivers a capacity of 20 tonnes per hour with a length of 13 000 mm and a 2 600 mm diameter. If over its 58 years of operation such a mill ran for 300 days a year for 24 hours per day at 19.7 r.p.m. it would have produced around 8.4 million tonnes of cement. By now components such as neck journal bearings, mill body and front walls would have completed 450 million revolutions.

After such long periods of operation, maintenance work increasingly becomes an insoluble task. Whether the mill can still be operated and for how long however depends not only on the sourcing of spare parts. Rather, it is fundamental questions which come to the fore, for instance in terms of the mill’s capacity, its availability, energy efficiency and grinding quality.

Visit the VDZ website for further information about servicing and maintenance.

https://www.vdz-online.de/en/maintenance/

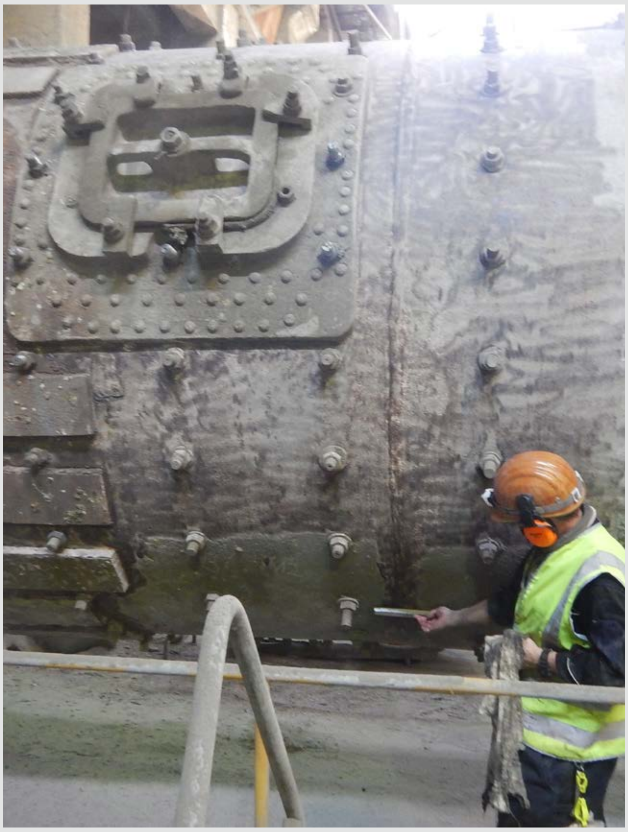


Fig. 2.1-3 Working on the ball mill built in 1959

2.2 Chemistry and mineralogy

VDZ maintains a high-performance, extensively equipped testing laboratory with a staff of qualified personnel and accredited in accordance with EN ISO/IEC 17025. As a result it can conduct tests and investigations to the latest state of the art. In the field of chemistry and mineralogy VDZ offers services that cover all major investigations on material characterisation as well as comprehensive consulting and complex advisory services.

Characterisation of materials

For years VDZ has been a leading specialist in the analysis and characterisation of inorganic mineral substances, of constituents and fuels for the non-metallic minerals and cement industry as well as of cements and the construction products made with these. The breadth of materials to be analysed with the aid of physical, chemical and mineralogical investigations comprises:

- Cement (main constituents: Portland cement clinker, blast furnace slag, pozzolanas, trass, fly ash, burnt shale, limestone, silica fume; minor additional constituents; sulphate agents: gypsum, anhydrite; additives), raw meal, kiln dust, other binders
- Mineral raw materials (e.g. clays, marl) and aggregates (quartz sand, gravel, crushed stone)
- Lime and lime products
- Admixtures and additives for concrete and mortar, pigments
- Mortar and concrete
- Fossil and alternative fuels

To analyse these substances, VDZ offers numerous physical, chemical and mineralogical tests capable of determining the parameters required by the relevant standards. The following methods which have earned close interest in recent years and in which VDZ possesses special expertise are listed below by way of example.

Determining hydration heat by means of isothermal heat flow calorimetry

Over recent years VDZ has made a major contribution to establishing isothermal heat flow calorimetry as a new reference method for determining the release of hydration heat of cements. Isothermal heat flow calorimetry offers two significant advantages over the standard method used previously solution calorimetry. First, it does not require the handling of hazardous acids, and second, in addition to the desired final value the method also offers the chronological progress of the release of heat.

Determining trace elements

Recent years have seen the use of increasingly demanding assessment criteria for the concentrations of so-called ‘trace elements’ in emissions, waste or construction products. The importance of inorganic trace analysis has also increased to this extent. Using the methods of ICP-MS (Inductively Coupled Plasma Mass Spectrometry) and AAS (Atom Absorption Spectrometry) VDZ is able to determine these with ever greater accuracy. However this assumes that matrix effects etc. are taken into consideration and that sample preparation does not result in subsequent contaminations.

New scanning electron microscope (SEM)

A new and powerful Zeiss GeminiSEM 300 scanning electron microscope (SEM) was commissioned by VDZ in early 2017 (**Figs. 2.2-1** and **2.2-2**). It replaced the existing ESEM which was decommissioned after around 20 years of service. The SEM also includes a new energy-dispersive EDAX Octane Elite X-ray spectrometer (EDX) in which the detector can be operated without liquid nitrogen. This new acquisition was made possible with the support of the Drs. Edith und Klaus Dyckerhoff-Foundation.

In high-vacuum mode the very highest resolutions can be achieved with the microscope’s in-lens SE detector even at relatively low electron energies. This is of great benefit particularly when imaging water-rich hydration phases which react sensitively to high electron energies. The powerful EDX detector means that far less time is needed to create elemental mapping images than with the old system. Phase mapping images can also be generated from the elemental mapping images with the appropriate software. In future these will be used more widely for a quantitative analysis of clinker, mortar and concrete samples.

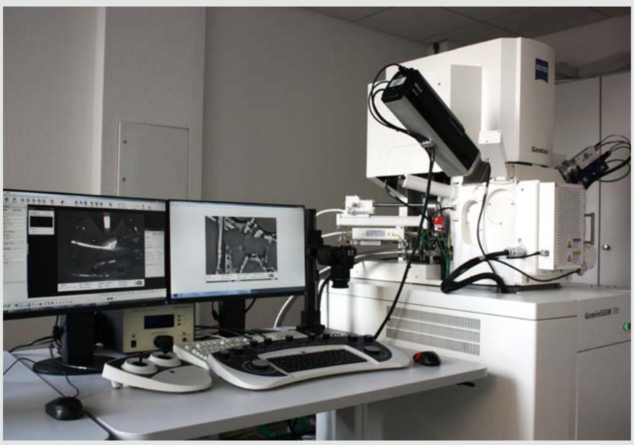


Fig. 2.2-1 Zeiss GeminiSEM 300 scanning electron microscope

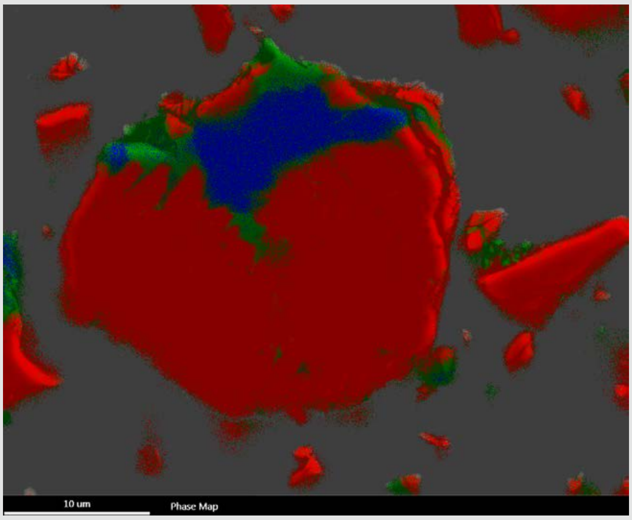


Bild 2.2-2 SEM photomicrograph with superimposed colour phase assignment using the example of cement particles; red: Ca-silicate; blue: Ca-aluminate; green: Ca-alumo ferrite

Quantitative X-ray diffractometry

The mineralogical composition of many substances is becoming increasingly important. Examples include the different modifications of clinker phases or the very complex composition of bypass dusts. Quantitative X-ray diffractometry using Rietveld analysis is gaining in importance as a result. VDZ has much experience and the expertise needed to be able to perform the Rietveld evaluation and analyse the results in a technically competent way.

Microscopic testing

Both light microscopy and scanning electron microscopy are tools which are used in particular with special problems or certain questions. Looking at the microstructure of clinkers, mortars and concretes can often help make a judgement which goes beyond what is possible with chemical methods. With its up-to-date technical resources and many years of experience with this method, VDZ can for example create element and clinker phase distribution images for its customers and help them interpret the results (see box 'New scanning electron microscope').

Consultation and product optimisation

VDZ advises customers on product optimisation aspects, supports companies with the determination and evaluation of the status quo at their plants and checks the influence of firing and cooling conditions as well as of raw materials and fuels on clinker properties. On its clients' instructions it will for example conduct tests on the sulphate resistance and performance of cements and cement constituents as well as the effectiveness of chromate reducers. VDZ experts audit plant laboratories, accompany the planning, implementation and evaluation of plant trials and perform preliminary trials for obtaining technical approvals. VDZ can also offer its customers many other tests as part of product and process optimisation:

- Characterisation of Portland cement clinker (impacts of burning and cooling conditions and alternative raw materials and fuels)
- Coating formation in cement or lime kilns
- Sulphate optimisation of cements (setting behaviour/strengths/interactions with admixtures)
- Effectiveness of chromate reducers
- Characterisation of new binders
- Performance of cements (e.g. sulphate resistance) and individual cement constituents
- Hydration behaviour of cementitious binders
- Effectiveness of concrete admixtures
- Hygienic properties of cement-bound building materials (e.g. in the drinking water sector)

VDZ also supports its customers in compliance tests to obtain technical approvals, for example for SR cement. In this context VDZ experts are also able to make predictions of the concrete's durability properties on the basis of parameters based for example on the degree of hydration. The planning, execution and evaluation of operational trials to obtain technical approvals, as well as supervising the practical introduction of the products into the construction industry are also parts of VDZ's services.

VDZ reference materials for laboratory practice

VDZ's reference materials offer laboratories the opportunity to test their analysis quality with the aid of known materials. Three reference cements for cement analysis, a reference material for determining the chlorine content and calorific value in alternative fuels, plus a reference cement for determining the water-soluble chromate content, and an ASR test cement, are currently available.

Fig. 2.2-3 VDZ reference cements

Reference cements VDZ100, VDZ200, VDZ300

Reference cements VDZ100 (CEM I), VDZ200 (CEM II/B-M (S-LL)) and VDZ300 (CEM III/B) were characterised in a round robin test carried out by VDZ's Cement Chemistry Committee and its subsidiary technical working groups. Each of these cements is available in units of approx. 200 g.

As well as the mean values, the comparative standard deviations of the round robin test and the reference value uncertainties derived from them are also provided. The following reference values are available:

- X-ray fluorescence analysis
- Wet chemical analyses according to EN 196-2
- Free lime content
- Trace elements
- Phase composition by means of X-ray diffraction and Rietveld analysis
- Particle size distribution
- Blaine surface area
- Density

Reference material for determining chlorine and calorific value

In a round robin test initiated by VDZ and the Association of Secondary Fuels and Recycling Timber (BGS e.V.) 43 test laboratories determined the chlorine content and gross calorific value of a particular plastic material. The material was a polymer to which a defined quantity of chlorine was homogeneously proportioned by the precise addition of PVC. The mean chlorine content of the reference material is approx. 0.8 mass %, the mean gross calorific value is 39200 kJ/kg. This material is available in units of approx. 180 g.

Reference cement for determining water-soluble chromate

The VDZ working group 'Analytical Chemistry' initiated a round robin test involving 20 cement laboratories in order to define a reference cement with regard to its water-soluble chromate content. The material selected is a Portland cement without minor constituents and without chromate reducer. The cement is stored under air-tight conditions and its chromate content is regularly determined. The mean water-soluble chromate content of the reference cement according to EN 196-10 is approx. 6.8 ppm.

ASR test cement according to the Alkali Directive

ASR test cement with a high alkali content must be used for tests to determine the alkali reactivity of aggregates according to the Alkali Directive of the German Committee for Structural Concrete (DAfStb), Annex B and C. All laboratories conducting these tests should use the same cement so as to reduce variations between them. VDZ therefore supplies a uniform ASR test cement with information about its properties and guidance on its usage (**Fig. 2.2-3**).

Information about the reference materials can be found on the VDZ website at https://vdz.info/wbdmx.

Practical example: Audit of X-ray analysis in the plant laboratory

Precise analysis in the cement plant laboratory is essential to keep the plant's production at a high quality level. Through regular reviews of analysis methods VDZ experts help businesses identify further optimisation potential in their laboratory practices.

Regular reviews of RFA and RBA

Chemical and mineralogical analyses are carried out on raw materials as well as on intermediate and end products so as to manage the material flows in cement production. Automated measurement methods such as X-ray fluorescence analysis (XRF) or X-ray diffraction analysis (XRD) are used for this purpose.

However it is not just the care and maintenance of the measuring instruments which is essential for accurate analysis results using XRF and XRD, the regular checking and adjusting of calibration and evaluation routines is also very important. On customer's behalf VDZ examines and optimises these routines in plant laboratories. VDZ experts identify inappropriate calibrations and XRD evaluation files and provide support for new set ups.

VDZ's experience from numerous projects shows that sources of error can creep in with routine analyses, and so the laboratory staff must be sensitised in particular to issues of correct sampling and sample treatment and of analysis. By way of example, **Fig. 2.2-4** shows the significant improvement in the precision of a plant laboratory following a review by VDZ experts. The regular preparation and determining of the lime standard of a reference sample of raw meal using XRF were optimised as a result of the findings.

Supporting plant laboratories

For many years now VDZ has successfully supported very different types of plant laboratories in optimising their processes and methods of analysis. XRF and XRD laboratories are a new focal point at VDZ in this context. Special consideration is given both to the path taken by samples from production to the measuring device, and to the routines deployed for calibrating and evaluating data. Working together with the laboratories, VDZ uses comparison trials among other means to identify customer-specific improvement potential in the sampling process or in analysis, and trains laboratory staff.

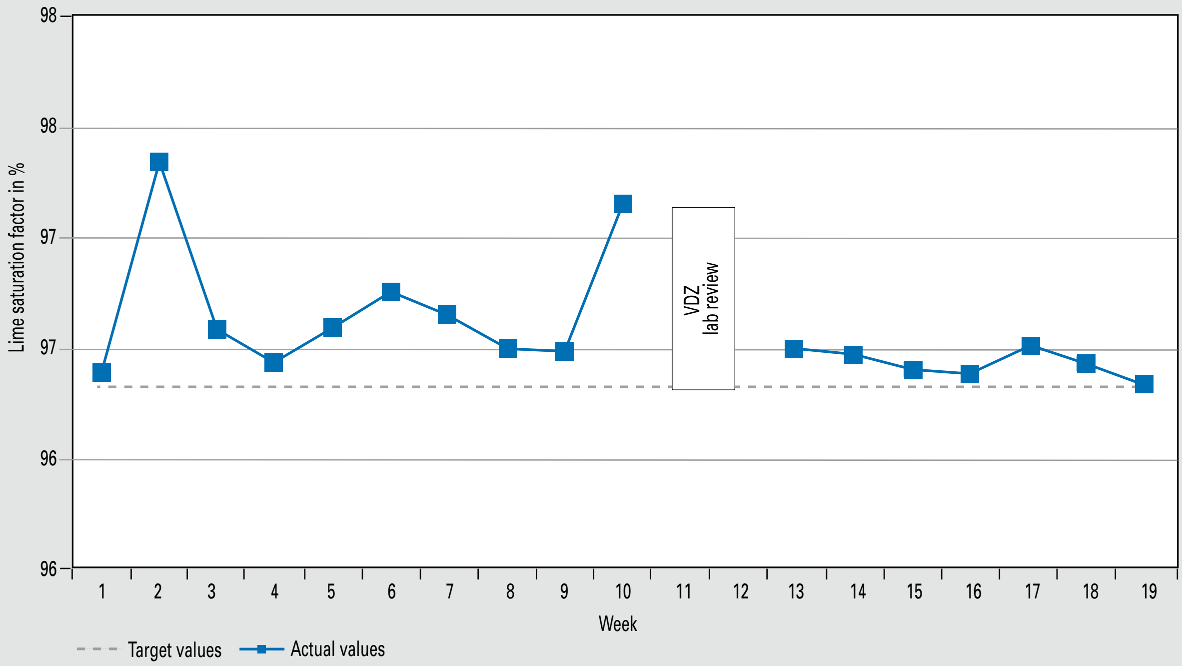


Fig. 2.2-4 Comparison of the precision of the weekly XRF measurement of the lime standard (LSF) of raw meal before and after a laboratory review by VDZ

2.3 Concrete and concrete constituents

When it comes to concrete and concrete constituents, the interdisciplinary team of VDZ can answer any questions on the production and processing of concrete and mortar and on their properties and performance in a structure. The services offered by VDZ include conducting all major material tests and giving advice to clients on optimising their products, also preparing complex expert reports on damage avoidance or investigating the causes of damage. Clients can task VDZ with the preparation of site audits as well as expert planning and design in line with the repair and maintenance guidelines of the German Committee for Structural Concrete (DAfStb). Specifically, the services of VDZ comprise:

- Testing of concrete constituents
- Testing of fresh concrete and fresh mortar
- Testing of hardened concrete and hardened mortar
- Durability tests, performance tests and computational durability forecasting (service life assessment)
- Testing alkali-silica reaction (ASR) and preparing expert reports on the results
- Construction product approval procedures
- Supporting and monitoring the casting of concrete, site audits
- BIM-assisted damage surveying and repair planning, damage assessment, expert reports
- Digitising of existing structures
- Life cycle assessment and sustainability assessment
- Holding training courses, VDZ online courses in concrete technology

VDZ services are oriented towards the requirements published by national, European and international organisations. These include: German Institute for Standardisation (DIN), German Committee for Structural Concrete (DAfStb), Road and Transport Research Association (FGSV), Federal Highway Research Institute (BASt), Federal Waterways Engineering and Research Institute (BAW), European Committee for Standardisation (CEN), European Assessment Documents (EAD), International Organization for Standardization (ISO), American Society for Testing and Materials (ASTM), International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM), Association française de normalisation (AFNOR), International Federation for Structural Concrete (FIB).

Testing of concrete constituents

As a modern five-component system, concrete consists usually of cement, water, aggregate as well as additives and admixtures. Fibres and pigments can also be added depending on the application. The services offered by VDZ relating to the various different concrete constituents and their performance in the concrete cover all tests according to the relevant European and national standards:

- Chemical and physical tests on cement and mortar
- Hydration-based characteristic values for predicting concrete durability C-value determination of cement
- Properties of aggregates
- Tests on concrete admixtures
- Suitability testing of grout for prestressing tendons
- Testing of fly ash
- Testing of silica fume
- Testing of blast furnace slag meal
- Testing of steel fibres:
  - Tensile strength of steel fibres
  - Flexural tensile strength of steel fibre concrete beams for determining performance classes according to the German Committee for Structural Concrete Code of Practice ‘Stahlfaserbeton’ or EN 14651
  - Consistency of concrete (Vebé time)

Testing of fresh and hardened concrete

The concrete laboratory of VDZ is accredited according to EN ISO/IEC 17025 and has comprehensive technical equipment to facilitate all major testing of fresh concrete, hardened concrete and mortar. A range of tests according to ASTM standards can also be conducted, e.g.

- Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory (ASTM C940)
- Flow Table for Use in Tests of Hydraulic Cement (ASTM C230)
- Flow of Hydraulic Cement Mortar (ASTM C1437)
- Time of Setting of Hydraulic Cement by Vicat Needle (ASTM C191)
- Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression (ASTM C469)
- Creep of Concrete in Compression (ASTM C512)
- Length Change of Hardened Hydraulic-Cement Mortar and Concrete (ASTM C157 / C157M)
- Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage (ASTM C1581)

Testing of durability

Concrete’s durability is by tradition a main focal point of tests carried out at the VDZ laboratory. Current research projects form a basis for the practice-oriented assessment of results. Relevant variables here include

- Resistance to carbonation
- Resistance to chloride penetration
- Frost and freeze-thaw resistance with de-icing salt
- Alkali-silica reaction and
- Abrasion resistance

According to the General Circular on Road Construction (ARS No. 04/2013), VDZ is recognised by the Federal Ministry of Transport and Digital Infrastructure (BMVI) and the Federal Highway Research Institute (BASt) as an official expert for the assessment of aggregates and concrete compositions in regard to harmful alkali-silica reaction. It is on this basis that VDZ prepares expert reports on the suitability of aggregates and concrete compositions in regard to harmful alkali-silica reaction.

Consultancy, product optimising, approval, monitoring of building projects

On behalf of its client, VDZ conducts preliminary trials and the tests required to gain national technical approvals (abZ), European Technical Assessments (ETA) or KOMO approval with product certification pursuant to CUR 48.

The range of services includes all stages of the approval procedure, such as support with submitting the application, preparation and implementation of the experimental programme, the test report and an expert report on the suitability of the product. VDZ will if requested conduct site audits with the aim of supporting the contractor and guaranteeing a high quality of execution. At the customer’s request, concrete compositions can be optimised and

Table 2.3-1 VDZ durability tests

Service	Method
Testing of frost resistance and freeze-thaw resistance with de-icing salt:	
– Cube test	EAD 15001-00-0301
– CIF/CDF test	CEN/TS 12390-9, BAW Code of Practice ‘Freeze-Thaw Test’
– Slab test	CEN/TS 12390-9
– Beam test	CEN/TR 15177
Chloride migration coefficient	EAD 15001-00-0301, NT Build 492, BAW Code of Practice ‘Resistance to Chloride Penetration’
Chloride diffusion coefficient (profile grinding)	EAD 15001-00-0301, DIN SPEC 1176, CEN/TS 12390-11
Determining the electrical conductivity of concrete for early indication of its resistance to penetration of chloride ions	ASTM C1202
Carbonation depth	EAD 15001-00-0301, DAfStb Volume 422
Predicting the durability results of the following methods from characteristic values based on the degree of hydration:	
– Carbonation depth – Chloride migration coefficient – Cube test – CIF/CDF test	VDZ method (see concrete technology information entitled ‘Characteristic values for predicting the durability of concrete’)
Abrasion testing with the Böhme grinding wheel	DIN 52108, EN 13892-3
Testing for alkali-silica reaction / Testing of aggregates:	
– Rapid test method	DAfStb Alkali Guidelines
– Concrete test with fog chamber storage (40 °C)	DAfStb Alkali Guidelines
– Concrete prism test at 60 °C	DAfStb Alkali Guidelines, RILEM AAR-4.1
– WS basic testing of coarse aggregates	BMVI (previously BMVBS)/BASt/FGSV
Testing for alkali-silica reaction / Testing of concretes (ASR performance testing):	
– Concrete test at 60 °C without external alkali supply	AFNOR P 18-454, RILEM AAR-11 (draft)
– Concrete test at 60 °C with external alkali supply	VDZ method, TP B-StB, part 1.1.09 (draft), RILEM AAR-12 (draft)
– Concrete test at 60 °C on two drilled core halves (with or without alkali supply)	VDZ method
– Concrete test with fog chamber storage of drill cores at 40 °C	VDZ method
Analysis of damage resulting from a harmful alkali-silica reaction	Reflected light microscopy, transmitted light microscopy and scanning electron microscopy
Expert reports for the suitability of aggregates and concrete compositions	e.g. according to BMVI General Circulars on Road Construction (ARS) No. 04/2013 and for aviation areas
Testing the resistance of mortars to attack by sulphate and sea water	Civieltechnisch Centrum Uitvoering Research en Regelgeving Aanbeveling 48 (CUR 48)
Resistance of concrete to penetration by water-polluting substances (FD and FDE concrete)	DAfStb Guideline BUmwS

special test methods developed. VDZ supports its clients in all matters of concrete technology, including giving advice on developing concretes with special properties.

Life cycle assessment and sustainability assessment

On the issue of ‘sustainability’, the services offered by VDZ include the preparation of life cycle assessments and environmental product declarations according to EN ISO 14040 and EN 15804 for the cement and concrete sector. The rules developed by CEN/TC

Practical example: Developing concretes with a high modulus of elasticity

Initial situation
In the case shown here, VDZ was commissioned to develop a concrete with the highest possible modulus of elasticity (> 100 GPa) for special applications.

The modulus of elasticity of concrete is usually in the range of 20 to 40 GPa and depends largely on the modulus of elasticity of the aggregate that is used, the proportion of aggregate in the concrete, the maximum particle size of the aggregate and the strength of the hardened cement paste matrix. To achieve the described objective, VDZ had to develop a concrete with

- ceramic aggregate with a high modulus of elasticity
- a high packing density
- a low paste content and
- a high hardened cement paste strength.

Tests
Corundum (modulus of elasticity according to references 300 to 380 GPa) with a maximum particle size of 16 mm and sintered silicon carbide (modulus of elasticity according to references 300 to 600 GPa) with a maximum particle size of 3 mm was used as aggregate. Silicon carbide is not available on the market in coarser sizes. Portland cement CEM I 52,5 R and silica fume were used for the hardened cement paste matrix. The paste content was set at 240 or 210 l/m³ (not including ultra-fine particles of the aggregate) for an A/B16 grading curve. For an A16 grading curve, 240 l/m³ were required to be able to ensure the workability of the concrete.

Six cylinders with dimensions Ø = 150 mm and h = 300 mm were made for each concrete. The test specimens were initially stored for 24 hours in their moulds – protected from draughts and drying out – at an air temperature of (20 ± 2) °C. After 24 hours the test specimens were demoulded and stored under water at (20 ± 2) °C. After 28 days the dynamic modulus of elasticity was determined by resonance frequency measurement. The static modulus of elasticity was tested according to EN 12390-13, Method B on three cylinders per concrete, again after 28 days.

Results
Fig. 2.3-1 compares the results with the static modulus of elasticity of a regular concrete of strength class C30/37 calculated according to Eurocode 2 (**Table 3.1**). Compared with this concrete it was possible to significantly increase the static modulus of elasticity in all four cases. This shows that the modulus of elasticity largely depends on the aggregate that is used. A static modulus of elasticity of approx. 120 GPa was achieved using a mixture of silicon carbide and corundum. The dynamic modulus of elasticity was generally approx. 15 GPa higher than the static modulus of elasticity.

Summary
Concretes were developed based on ceramic aggregates with moduli of elasticity of approx. 120 GPa. The client is now considering whether these concretes meet its specific needs.

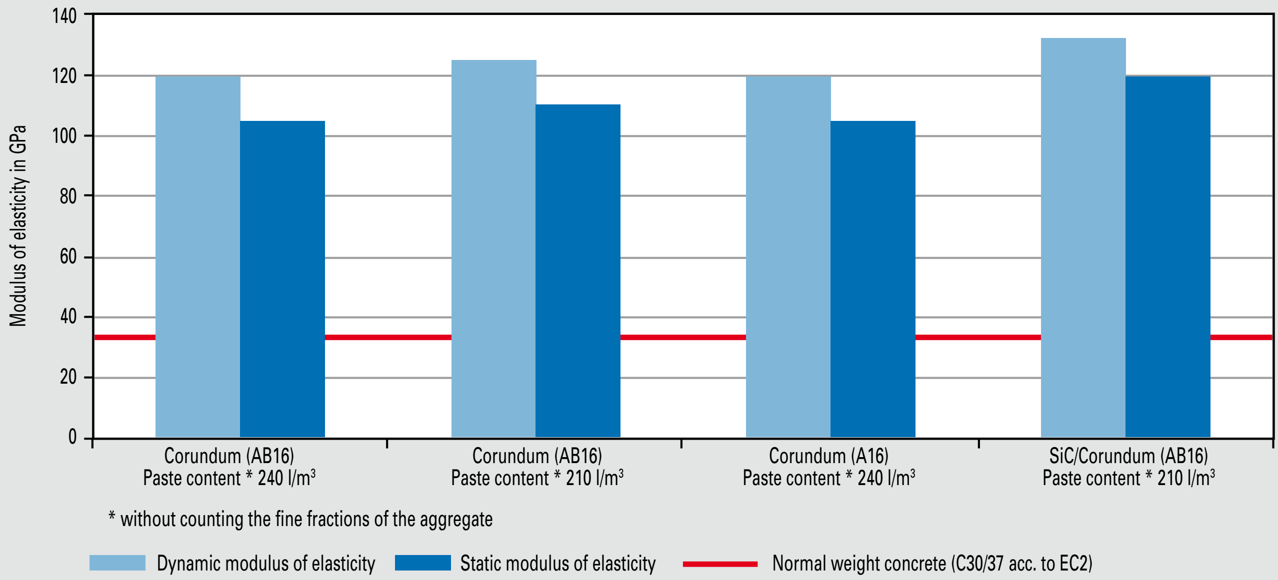


Fig. 2.3-1 Modulus of elasticity of the concrete

350 for the construction sector are applied. VDZ staff are trained as auditors according to the rules of the German Sustainable Building Council (DGNB) and provides certifications according to the Concrete Sustainability Council (CSC).

Building diagnostics

Building diagnostics involves investigating and documenting the condition of a reinforced concrete or prestressed concrete structure as part of an analysis of that structure. The VDZ team of experts will examine the structure using largely non-destructive measurement procedures in the course of a site visit. The investigation includes taking samples of building materials for in-depth laboratory tests.

The aim of building diagnostics is to be able to make a statement about the general state of the building. This will help when planning further measures for the building's repair and maintenance. If required, the results of the exercise are presented to the client in a 3D building model as so-called IFC files. Major steps of the diagnostics process include:

- Taking an inventory of damaged and undamaged parts of concrete constructions
- Identifying and assessing damage mechanisms, e.g. crack formation and softening
- Damage prediction, e.g. ASR residual expansion potential
- Finding the causes of efflorescence and discolouration
- Calculating the remaining working life of the structure
- Evaluating the structure's need for repair

Practical example: ASR damage assessment

A harmful alkali-silica reaction (ASR) is a major durability problem for concrete. All over the world ASR damages structures, such as dams, road pavements, airport runways, bridges, guide barriers and nuclear power plants, shortening their service lives and increasing their operating costs. To continue operating such structures, operators require information on the cause of the damage and the current state of the structure or component as regards durability, serviceability and structural safety.

In a typical case VDZ examined an ASR-damaged hydraulic engineering structure and assessed the extent of the damage, the state of the structure and the existing ASR residual expansion potential. In previous years the structure had undergone a series of remedial measures intended to extend its working life, and the effectiveness of these measures VDZ was also asked to assess.

Tests
Drill cores were taken from damaged and minimally damaged areas and from the repaired areas. The cause of the damage and the concrete microstructure were first examined on thin sections of the drill cores using light microscopy. Other drill cores were stored in the 40 °C fog chamber to determine the residual expansion potential. The bulk density, compressive strength, tensile splitting strength and static modulus of elasticity before and after storage in the 40 °C fog chamber were also determined.

Results
The tests showed that the concrete of the hydraulic structure had suffered extensive damage from an ASR. Many grains of gravel were cracked and displayed signs of disintegration along the cracks. The cracks continued in the hardened cement paste matrix and were filled with new mineral formations (**Fig. 2.3-2**).

The results of the fog chamber storage showed that the residual expansion potential had decreased over time compared with tests done twelve years previously (**Fig. 2.3-3**). The drill cores taken from previously repaired surfaces were expanded more than the drill cores taken from areas where no repair system was in place, pointing to a delay in the progress of the ASR in the repaired areas.

According to information supplied, the hydraulic engineering structure had been built using B225 and B300 concrete which with characteristic strengths of around 15 MPa and 20 MPa would today be equivalent to strength classes C12/15 and C20/25 respectively. According to EN 13791 with a characteristic compressive strength of 46.7 MPa, the current concrete

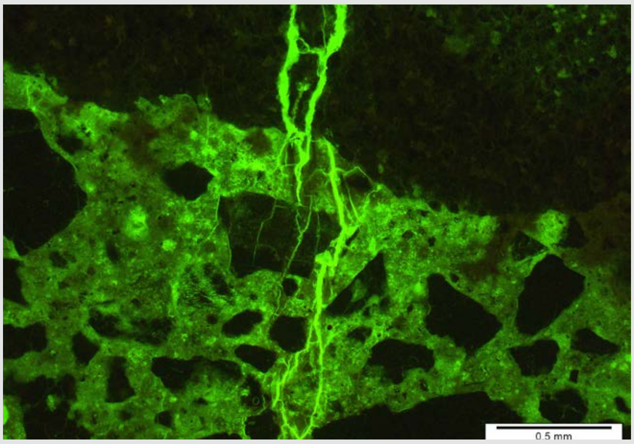


Fig. 2.3-2 Thin section of the concrete in ultraviolet light: Crack system partly with recrystallised gel starting from a sandstone grain

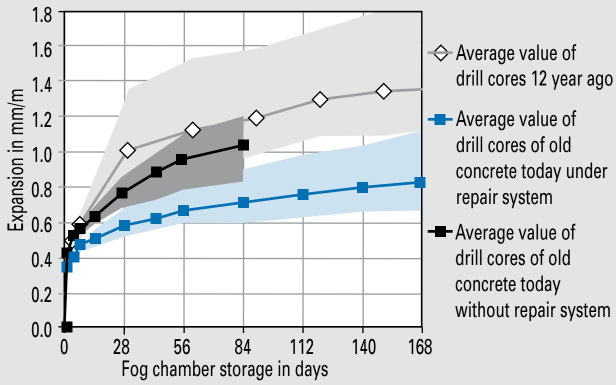


Fig. 2.3-3 Areas of expansion of drill cores in the fog chamber at 40 °C

compressive strength corresponds to compressive strength class C40/50 pursuant to EN 206-1.

The measured static modulus of elasticity was 16.6 GPa, significantly below what should have been expected according to EN 1992-1-1 – 35 GPa (E_{cm}) – for the C40/50 compressive strength class. The measured modulus of elasticity was also relatively low compared to the mean moduli of elasticity of 27 GPa and 29 GPa for the C12/15 and C20/25 strength classes. This is most probably due to the damage caused by the ASR as it also reduces the modulus of elasticity of the aggregate. The client was able to give further consideration to the management of the structure on the basis of these investigations.

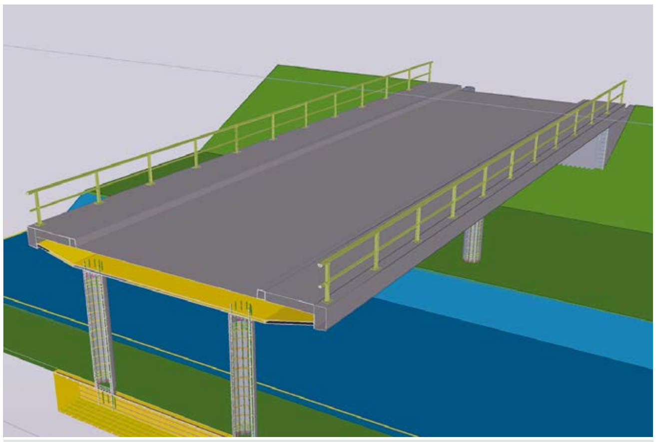


Fig. 2.3-4 Digital 3D model of a bridge with BIM

Fig. 2.3-5 Service life design of a concrete structure

Digitising of existing structures

A digitised structure inventory provides the client with a powerful and innovative tool for managing and maintaining an existing building. If required, VDZ can digitise existing structures as part of Building Information Modeling (BIM) projects. Operators of structures can use BIM models to view data in 3D on their computers and efficiently analyse them. The more complex and difficult a building's geometry is, the more valuable BIM becomes as a planning tool for clients and designers. For example, BIM can freely create sections in the models so that clashes between trades (including during repair work) can be clearly identified on the 3D model.

The results of structure diagnostics can also be stored as information in the 3D models as an additional benefit. This also applies to the results of a service life assessment and its updates from regular building inspections. Structures can be digitised to different degrees of detail, from LOD100 (concept design) through LOD300 (detailed design) to LOD500 (as-built). Once the structure has been digitised the 3D models can also be used for BIM-based repair scheduling.

Scheduling repairs using BIM

BIM can display the structure as a 3D model for repair scheduling purposes. The structure is modelled in a virtual space based on as-built drawings and the results of building diagnostics. The results of the diagnostics, such as test points, drill core removal sites, chloride profiles and results of the reinforcement scanner, all become part of the BIM model. The as-is state is digitally captured and a target/actual comparison is therefore possible. The material properties found on the structure are stored in the 3D model as component-specific information. Repairs are also scheduled using the 3D model. In the project, VDZ supplies its client with the structure's model as an IFC file. As a result, the client receives two services from a single source:

- Digitising the existing structure and
- Structure repair scheduling and monitoring with the aid of a 3D model.

Another advantage of the model-based approach using BIM is that the contractors doing the work can use the 3D model as a basis for their quantity surveys. BIM-based design and execution also ensures that potential clashes between trades are identified before work starts on site. BIM also provides for a high degree of transparency along the design and construction process. Execution is still carried out according to drawings but these can now be derived from the digital model. On site, the BIM 3D model provides additional information and a basis for discussion.

Service life assessment

The probability of the depassivation of the reinforcement, or the reaching of critical chloride content on the reinforcement due to carbonation of the concrete cover or the penetration of chlorides into the concrete, can be assessed with the aid of probabilistic design models according to the fib model code or ISO 16204. Related VDZ services include:

- Service life assessment for new reinforced concrete components
- Service life assessment for remedial measures (concrete replacement)
- Estimating the residual service life of existing reinforced concrete components
- Performance-related concrete design for specified service life and/or durability requirements

Typical applications for assessing service life include the use of new materials (concretes, concrete replacement systems) whose durability has to be established before they are used in the structure, or analysing the impact of irregularities or shortcomings during the construction phase on the structure's reliability. Service life assessment is also used for evaluating components which have to meet exceptional requirements for durability, and for verifying a sufficiently low corrosion risk for structures with a particularly long service life (> 50 years). Up to now this could not be guaranteed through the use of normal descriptive rules. Service life assessment must also be used when determining layer thicknesses for concrete replacement in the planning of maintenance, and when assessing the impact of altered effects (e.g. as a result of conversions or a change in environmental impacts) and when developing maintenance concepts based on these factors.

2.4 Product certification

Construction products according to the Construction Products Regulation (CPR) may only be marketed in the European Union (EU) if provided with a valid CE mark. Other marks are also used in various EU Member States. In Germany for example many construction products which do not comply with a harmonised European standard must carry the Ü-mark. In other countries private-law marks are used, such as the BENOR mark in Belgium, the Dancert mark in Denmark, the KOMO mark in the Netherlands and the NF mark in France.

The ability to use the CE mark or these other marks depends on the outcome of a conformity assessment procedure intended to guarantee safety and health protection when the products are used, and the safety of the structures that are built with them. Depending on the construction product and/or the underlying rules, the conformity assessment procedures can involve product testing, an inspection of the manufacturing plant and of the factory production control and an assessment of the results of these tests and inspections, and finally a regular audit-testing of the product and continuing surveillance, assessment and evaluation of the factory production control. A certification body then issues certificates if all requirements are met.

Surveillance and certification of construction products

Traditionally, the monitoring and certification of construction products is one of VDZ's core areas of competence, and the inspection and certification body was set up for this purpose. The body is accredited for product certification according to EN ISO/IEC 17065, notified by the competent authorities under EU's Construction Products Regulation (CPR) and recognised by the building inspectorate according to the Federal State Building Regulation.

The laboratories of VDZ's inspection and certification body are accredited according to EN ISO/IEC 17025.

The inspection and certification body offers its clients services in the following fields:

- Certification of cements and other binders
- Certification of concrete and mortar
- Certification of aggregates, particularly with regard to alkali reactive components
- Certification of concrete additions and concrete admixtures

Most of the construction products listed above are regulated by standards harmonised across Europe. However certain products may not come within the scope of an existing harmonised standard, or the harmonised standard may lack a suitable assessment procedure for at least one essential characteristic. In such cases a European Technical Assessment (ETA) can be issued for the construction product. Such products can also be inspected and certified by the VDZ's inspection and certification body (see Box).

VDZ Quality Seal

The quality inspection and development of quality standards have been one of VDZ's tasks for more than 140 years. Today, the certification body of VDZ monitors and certifies more than 500 binders in 59 cement plants. The 'VDZ hexagon' label has stood for the highest product quality standards for many decades and is affixed by VDZ members to construction products monitored by our certification body

Practical example:
European Technical Assessment (ETA)

An ETA is based on a European Assessment Document (EAD) in which the relevant test methods in particular are described. With new ETAs, both documents, i.e. EAD and ETA, are frequently generated at the same time. It is even possible for an ETA to be issued by the competent authority before the underlying EAD is published in the Official Journal of the European Union. In such cases the manufacturer could already start technically producing the corresponding binder. However certification bodies must first be accredited and notified for the relevant EAD and this is only possible after the EAD exists in its final wording and has been published in the Official Journal. The process of accreditation and certification can easily take six to twelve months. Prior to being notified, certification bodies may not issue certificates of constancy of performance for products according to the ETA, and the manufacturer may not market the product in the EU without this certificate.

According to EN 197-1 blast furnace cement CEM III/A is not classified as a cement with a high sulphate resistance, but in practice such cements often present a high sulphate resistance. This is why ETAs were issued for various different CEM III/A products with a high sulphate resistance under the legal framework of the former Construction Products Directive. However these 'old' ETAs could not be renewed and expired at the end of 2017/beginning of 2018. Various cement manufacturers have therefore applied for a new ETA for their corresponding cements according to the rules of the EU Construction Products Regulation (CPR). The underlying European Assessment Document EAD 150009-00-0301 'Blast Furnace Cement CEM III/A with assessment of sulphate resistance (SR) and optional with low effective alkali content (LA) and/or low heat of hydration (LH)' was only published in the Official Journal of the European Union on 10 November 2017 however. In the same month some manufacturers received the new ETAs for CEM III/A with a high sulphate resistance.

In the run-up to this development VDZ's certification body had already made very early contact with the German Accreditation Body (DAkkS) and the German Institute for Building Technology (DIBt) as the notifying authority. This early communication with all parties concerned resulted in VDZ's certification body being accredited for the new EAD on 19 December 2017 and notification already taking place on 30 January 2018 despite the intervening Christmas holiday period. The certification body was already issuing new certificates for CEM III/A with a high sulphate resistance in early February 2018, the first notified body in Germany to do so. This ensured that the cement manufacturers affected were able to meet the supply agreements made with their customers.

2.5 Certification and verification

The certification of management systems and the verification of greenhouse gas emission reports are combined in the management systems certification body (FIZ-Zert) operated by FIZ GmbH. By the end of 2017 FIZ-Zert was handling over 70 procedures relating to the certification of management systems. At the same time more than 50 reports are tested and verified each year as part of the European emissions trading scheme (EU ETS).

All FIZ-Zert auditors and verifiers have an in-depth knowledge of the production processes used in the cement and lime industry. FIZ GmbH is itself inspected each year by the accreditation authority. Regular witness audits also take place under the supervision of the accreditation authority. The formal competency of FIZ-Zert as an independent accredited testing body is continuously demonstrated by these processes.

Certification of management systems

As part of client projects, FIZ-Zert has for many years now been certifying quality management systems according to EN ISO 9001, environmental management systems according to EN ISO 14001, energy management systems according to EN ISO 50001 and health and safety management systems according to OHSAS 18001 for businesses in the pit and quarry industry and the construction products industry. Customers can engage the services of FIZ-Zert irrespective of their location, their membership of associations/organisations or other requirements. The certification of management systems involves FIZ-Zert providing the following services:

- Initial certification with stage 1 and stage 2 audits
- Conducting regular inspection audits on the client's premises
- Re-certification of the client's management system
- Matrix certification of the client's management systems

FIZ-Zert makes the most exacting demands of its own services and the technical qualification of its experts. This applies in particular to the aspects of independence, confidentiality and secrecy.

Verification of CO_2 emission reports

As a neutral and accredited inspection body, FIZ-Zert verifies more than 50 CO_2 emission reports each year in accordance with the applicable European and national laws and ordinances for submission to the respective supervisory authorities. The qualified experts of FIZ-Zert are officially recognised environmental verifiers or are approved as experts by the German Chamber of Commerce and Industry (IHK). FIZ-Zert is also represented on the national sector committee of the German Accreditation Body (DAkkS) as a verifier.

Customers from the various segments of the pit and quarry industry – particularly cement, lime and gypsum – and the corresponding related industrial sectors benefit from the in-depth knowledge of the industry and outstanding specialist competence offered by FIZ-Zert experts. For our customers who do not engage the services of these experts in connection with verification or drafting of emissions reports, we also offer consultation on greenhouse gas emissions trading.

Innovations in quality and environmental management systems and in energy management systems

Quality and environmental management systems
The relevant standard for quality management systems, EN ISO 9001, and its counterpart for environmental management systems, EN ISO 14001, were both amended in 2015. The amending of both these standards in 2015 means that from 15 September 2018 at the latest, certifications can only take place based on the new version of the standards.

Both standards have the same structure and address the same issues under identical standardisation points. The result is that documentation is greatly simplified, especially when businesses have access to integrated management systems (with the simultaneous display of the requirements of different standards). The standards have also developed further in terms of process orientation and so the customers of FIZ-Zert have greater degrees of freedom to implement the respective standard requirements individually and in a way that suits their particular structure.

EN ISO 9001 and EN ISO 14001 both impose tougher requirements as a result of dealing more intensively with the issue of handling risks and opportunities. At this point businesses are invited to define company-specific risks and opportunities more clearly and to explain how risks can be avoided and opportunities taken advantage of.

Energy management systems
In the field of energy management systems, ISO 50003 has now been introduced as a binding standard. It is directed in the first instance not at certified businesses but rather at accredited certification bodies like FIZ-Zert. Businesses themselves are indirectly affected however. For example, they are required to provide additional information for calculating the expenditure of time required for certification. As well as energy consumption, they must state their main energy consumers and energy sources, and must also name the EnMS effective personnel. Using this information, the amount of time needed for certification must then be estimated by binding specifications of the standard.

With immediate effect businesses must also regularly provide evidence of actual improvements in their energy-based services. This requires a far more accurate recording of performance indicators and if necessary a redefining of the energy starting point.

The requirements of the new ISO 50003 came into binding force in October 2017 which means that initial and recertifications by FIZ-Zert can now basically only be conducted on the basis of that standard.

CSC Certifications

The Concrete Sustainability Council (CSC) was established in November 2016 on the initiative of the international cement and concrete industry and the Cement Sustainability Initiative (CSI) (**Fig. 2.5-1**). The CSC's main objective is to present the concrete manufacturing process and its supply chains in a transparent way. The focus here is on describing the potential impact on the social and ecological environment, the aim being to make third parties more aware of the sustainability of concrete as a building material. Sustainable production processes in the concrete industry in particular should be promoted, and to this end the CSC has developed its own certification system. The CSC has recognised FIZ GmbH as one of four certification bodies in Germany. The very first CSC certification procedure in Germany was successfully concluded by FIZ-Zert jointly with a company in the ready-mixed concrete industry as early as the end of 2017.

FIZ-Zert provides the following services as part of CSC certification:

- Visiting the plant or various sites and examining the CSC report
- Inspecting and certifying suppliers as applicable
- Calculating the points attained
- Issuing certificates in bronze, silver, gold or platinum standards

Fig. 2.5-1 Logo of the Concrete Sustainability Council (CSC)

Fig. 2.5-2 Kick-off event of the CSC in April 2018 in Berlin: Johannes Kreißig, Managing Director of DGNB GmbH gave a lecture in Berlin on the topic of Greenbuilding and announced the approval of the CSC in the DGNB system (Photo: BTB/Edelbruch)

2.6 Environmental measuring body

For many years the environmental measuring body of FIZ GmbH has held a permit under Section 29b of the German Federal Pollution Control Act (BImSchG) and offers a comprehensive service portfolio in this legally regulated field. Customer-specific inspection concepts and accompanying measurements for process optimisation complete the service profile. The basis of these activities is an accreditation of the environmental test body according to EN ISO/IEC 17025 which places exacting demands on the quality of the work and the training of the workforce.

The environmental measuring body conducts measurements of the following exhaust gas compounds on instructions from its clients:

- Inorganic gases (for example carbon monoxide, sulphur dioxide, nitrogen oxides, hydrogen chloride, hydrogen fluoride, ammonia)
- Organic gases (dioxins and furans, benzene, toluene, xylenes, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, hexachlorobenzene, formaldehyde and many more)
- Dust and heavy metals (arsenic, lead, cobalt, chromium, nickel, vanadium, cadmium, thallium, mercury, manganese, tin, selenium, tellurium and many more)
- Greenhouse gas emissions (carbon dioxide, methane, N_2O)
- Gas components for process optimisation (e.g. sulphur trioxide)

The environmental measuring body also offers the following activities:

- Calibration and function testing of continuous emission measuring devices
- Advising customers on the choice of measuring instruments and the setting-up of measurement locations (**Fig. 2.6-1**)
- Production of installation certificates for continuous emission measuring instruments
- Planning and executing special measurements (e.g. determining dioxins and furans in the process)

Fig. 2.6-1 Giving targeted advice on the use of measurement concepts

Measurement and reduction of mercury emissions

Particular emphasis is placed on the measurement and reduction of mercury emissions due to mercury's high environmental relevance. The monitoring of mercury emissions is therefore required to meet the highest quality standards of the environmental test body. Over and above its work in areas regulated by law, the environmental test body also deals with the following individual assignments:

- Creating input/output balances for mercury in industrial installations
- Speciation measurements to determine the bonding form of the mercury
- Hiring out continuous mercury measuring devices for a limited period of time for dealing with process technology issues
- Long-term mercury measurements using solids adsorbers
- Monitoring mercury reduction trials
- Direct determination of mercury immediately following measurement for rapid results calculation and plant optimisation
- Measurement of mercury immissions

Fig. 2.6-2 Mercury measurement

Use of multi-component measuring devices for continuous emission monitoring

Today continuous emission monitoring is making increasing use of so-called multi-component measuring systems. These measuring systems make it possible to detect up to twelve components (including exhaust gas boundary conditions and total organic carbon) with a single sampling probe. The multi-component measuring devices currently available on the market operate as extractive hot gas measuring systems in which the whole sampling system must be heated up to at least 180 °C. Even exhaust gas components such as SO_2, NH_3, HCl and HF that are sensitive to condensation effects are reliably detected with very low detection limits. The implemented measuring methods are infrared spectroscopy (FTIR, bi-frequency/gas filter correlation method), flame ionization detection (FID) and measurement with chemical measuring cells (Zr_2O).

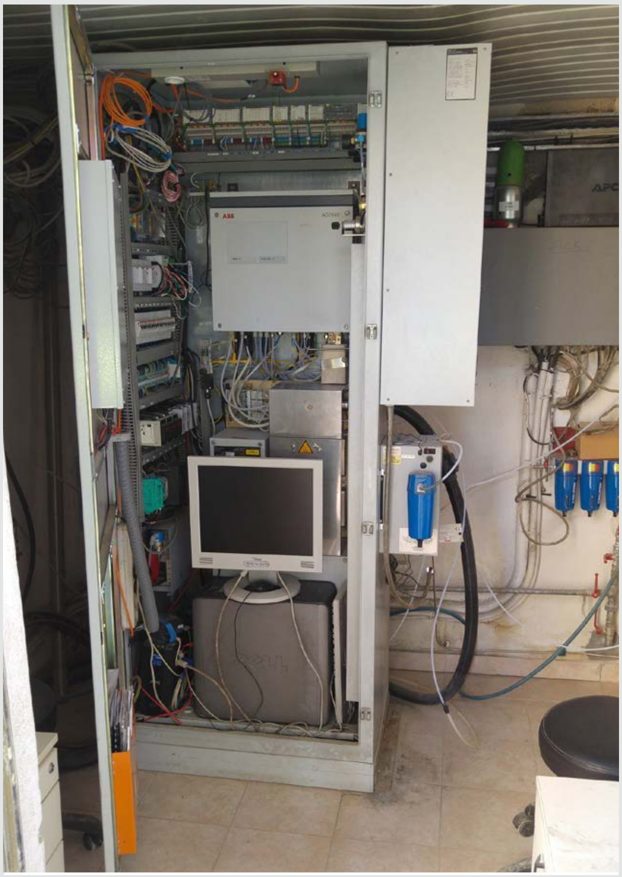


Fig. 2.6-3 Exemplary installation of a multi-component measuring device in a cement plant

The multi-component measuring systems are calibrated according to EN 14181. The standard reference methods applicable to the respective component are used and at least 15 comparison measurements are carried out to create the calibration function.

An important parameter determined in the course of calibration is the 'upper limit of the valid calibration range'. This is the highest value found during the calibration plus 10 % and it applies for the period until the next calibration (three years as a rule). If the upper limit of the calibration range is overrun during ongoing operation then the associated half-hour mean values are written into special classes S 9 or S 10 during classification. If too many overruns are counted in these two classes then a re-calibration will be necessary before the end of the 3-year period.

Close collaboration between the plant operator and the measurement institute is therefore essential in the run-up to a calibration. The first step should be to establish which emission bandwidths are normal and typical of the plant operation, for example by evaluating the classifications for the past 3 years. The plant's mode of operation must then be varied during the comparison measurements that run over 3 days so as to cover the concentration range which occurs for all components in normal operation mode.

This is a challenge not to be underestimated when the simultaneous calibration of a large number of emission parameters (e.g. NO_x, SO_2, CO, NH_3, HCl, HF, TOC) is involved. Intervention in the emission reduction equipment (e.g. SCR, SNCR, addition of slaked lime) is one option. This must not result in the applicable emission limitations being exceeded however. For parameters such as TOC or SO_2, in individual cases an attempt will be made to selectively achieve higher emission concentrations for short periods by adding sulphur powder or wood pellets. For components such as HCl or HF there is currently no possibility of influencing the emission level during a calibration.

2.7 Education and Training

For over 60 years VDZ has supported businesses in the cement industry and related industrial sectors in the qualification of their employees. As well as the annual open seminars and courses held by VDZ there is now a broad range of seminars and workshops tailored to specific customer requirements. With its decades of experience in staff training and access to over 70 international experts in the pit and quarry industry, VDZ is in a position to offer high-quality training measures on virtually every topic to do with cement and concrete and their respective sub-aspects (fuels, the environment, quality etc.). The course content, its duration and the degree of difficulty of the training is specified jointly by VDZ and its customer so that the seminar or course takes full account of the particular requirements. All seminars can be held either at VDZ in Duesseldorf or on the customer's site and offered in English or to an extent in Russian as well.

In-house training

The demand for customer-specific training in cement and concrete production has grown rapidly in the past three years, both in Germany and abroad. Besides training courses, VDZ has held many workshops lasting several weeks as well as one-day and multi-day seminars dealing with specific topics. Starting with seminars about environmental protection, process technology, energy efficiency, alternative fuels, benchmarking and product optimisation, seminars on optimising day-to-day laboratory work as well as on maintenance have also been offered. These courses have been held not only for production workers but also for middle management and executives, and with great success. A great many training courses lasting from one to four weeks have also been hosted in the plants for production workers and laboratory personnel, focusing on selected topics. As well as the basic theoretical knowledge, VDZ is always mindful of the need for practical application, so the courses often call upon the services of experienced experts from industry and practical exercises are conducted. Training courses culminate in a test and certification of the participant's personal success.

Open international courses

In addition to the customer-specific training measures mentioned above, VDZ's training organisation offers five to six open training courses a year in English which can be booked by employees in the cement and supply industry worldwide. These are courses for young engineers, foremen, control room operators, maintenance staff and laboratory personnel. Target groups are trained specifically according to their particular needs in these one-week modules. Here too, the emphasis is on the interplay between theory and practice. The courses incorporate the latest state of knowledge in the particular technical field as well as the essential basics. **Table 2.7-1** shows VDZ's open international seminars for 2018/2019.

More information about the seminars and courses can be found in the Training section of the VDZ website.

Table 2.7-1 Open international seminars 2018/2019

Title	Duration
Simulator Training with SIMULEX®	1 week
Process Technology of Cement Production Module 1: Raw Material Preparation and Grinding Technology	1 week
Process Technology of Cement Production Module 2: Clinker Production and Material Technology	1 week
Process Operator Training	3 weeks
Crash Course for Young Engineers	1 week
Plant Maintenance and Refractories Course	1 week

VDZ Online Courses

Since 2010 VDZ has offered online courses on the VDZ e-learning platform https://www.elearning-vdz.de/en/. Each year more than 1500 users worldwide take advantage of inexpensive training with the help of these online courses. There are over 60 German-language modules in which employees can learn about topics ranging from fundamental production processes to concrete applications. Engaging simulations help employees to better understand complex issues and to operate their plants more efficiently, more safely and more environmentally friendly in practice. Participants can use subsequent tests to check their progress on the computer. They are automatically issued with a certificate to confirm their successful completion of a test.

For some years now VDZ's online courses have been available in English and Russian. Currently there are a total of 38 English (**Table 2.7-2**) and 40 Russian process technology courses on offer. These online courses are used by many VDZ customers worldwide as part of training projects and internal company staff development strategies. The options for implementation range from hiring the VDZ learning platform to integrating the online courses in the customer's own intranet (see the practical example).

Fig. 2.7-1 Theoretical training in the client's classroom

Practical example: In-house training in the Middle East

A customer-specific seminar was given in English on a cement manufacturer's site in the Middle East. The main topics of this two-week training course were creating 'Energy balances and mass balances of kiln plants' and 'Optimising grinding plants'.

The target group consisted of experienced engineers. At the customer's request the course participants first took a written test to enable the attained learning effect to be quantified at the end of the seminar. Again at the customer's request, VDZ's training material was adapted to reflect the requirements of the plant and the conditions on site. The purpose of the seminar was to give the participants a better understanding of the plant's thermal and mechanical process technologies. The participants also learned how to correctly record and calculate the plant's optimisation potential both on the product side and as regards its energy needs. The theoretical course content was supplemented by practical exercises in the plant (**Figs. 2.7-1** and **2.7-2**).

In the first week VDZ's instructors taught the participants how to prepare an energy and mass balance according to VDZ-Merkblatt Vt10 and which process data are needed to create an energy balance (**Fig. 2.7-1**). A test schedule and a calculation tool specifically for the customer's kiln plant were jointly developed in a workshop with the participants. The way in which the individual parameters are measured and evaluated was then demonstrated in the plant (**Fig. 2.7-2**).

The focus in the second week of the seminar was on 'Optimising cement grinding plants'. The example of a mill audit was used to demonstrate which process parameters must be determined in order to improve efficiency.

At the end of the training course the participants took a final test which they all passed successfully. To quantify the learning success the results of the initial test were compared with those of the final test. All participants then received their attendance certificates. The feedback from both the participants and from management about the course was decidedly positive. The plant will take the content generated by the workshop into account in future calculations of energy and mass balances.

Fig. 2.7-1 Theoretical instruction in the customer's training room

Fig. 2.7-2 Site inspection with the trainer

Table 2.7-2 List of currently available online courses in English and Russian (in 2018)

VDZ Online Courses:	Онлайн-курсы VDZ:
LB 0 - Overview of cement production and use	LB 0 - Общие сведения: Производство цемента-применение бетона
Raw material extraction	Добыча сырья
LB 1.1 - Raw Material Extraction	LB 1.1 - Добыча сырья
LB 1.2 - Water Drainage Systems	LB 1.2 - Водоотливные установки
Raw material preparation	Подготовка сырья
LB 2.1 - Primary Comminution	LB 2.1 - Предварительное измельчение
LB 2.2 - Raw Materials, Blending Bed	LB 2.2 - Сырьё, усреднительный склад
LB 2.3 - Combined Drying and Grinding	LB 2.3 - Сушильно-помольные установки для сырьевых материалов
LB 2.4 - Raw Meal Homogenization Systems	LB 2.4 - Гомогенизация сырьевой муки
Clinker production	Производство клинкера
LB 3.0 - Rotary Kiln Plants	LB 3.0 - Линия производства клинкера
LB 3.1 - Rotary Kilns	LB 3.1 - Вращающаяся печь
LB 3.2 - Firing Systems	LB 3.2 - Горелочные устройства
LB 3.3 - Preheaters	LB 3.3 - Теплообменники
LB 3.4 - Calciner	LB 3.4 - Декарбонизатор
LB 3.5 - Bypass Systems	LB 3.5 - Байпасные системы
LB 3.6 - Clinker Coolers	LB 3.6 - Клинкерные холодильники
LB 3.7 - Fuels	LB 3.7 - Топли
LB 3.10 - Refractories	LB 3.10 - Огнеупорные материалы
Cement production	Производство цемента
LB 4.1 - Cement Grinding Plants	LB 4.1 - Установки для помола цемента
LB 4.2 - Ball Mills	LB 4.2 - Шаровые мельницы
LB 4.3 - Roller Mills	LB 4.3 - RШаровые мельницы
LB 4.4 - High Pressure Roller Mills	LB 4.4 - Валковые мельницы высокого давления
LB 4.5 - Classifiers	LB 4.5 - Сепараторы
LB 4.6 - Cement Raw Materials, Products	LB 4.6 - Сырьё для получения цемента, продукция
LB 4.7 - Cement Blending Systems	LB 4.7 - Цементно-смесительные установки
LB 4.8 - Cement Cooling	LB 4.8 - Охлаждение цемента
Packing plant and dispatch	Упаковка и отгрузка
LB 5.1 - Packing Machinery	LB 5.1 - Упаковочная линия
LB 5.2 - Palletizing Machines	LB 5.2 - Линия палетирования
LB 5.3 - Cement Storage	LB 5.3 - Хранение цемента
LB 5.4 - Loading Equipment	LB 5.4 - Отгрузочное оборудование
General plant equipment	Оборудование общезаводского хозяйства
LB 6.1 - Mechanical Continuous Conveyors	LB 6.1 - Механические конвейеры
LB 6.2 - Pneumatic Conveyors	LB 6.2 - Пневмотранспортные установки
LB 6.3 - Process Measurement Techniques	LB 6.3 - Измерительная техника
LB 6.4 - Metering Equipment	LB 6.4 - Дозирующие устройства
LB 6.5 - Drive Technology	LB 6.5 - Приводные устройства
LB 6.6 - Compressed Air Supply	LB 6.6 - Обеспечение сжатым воздухом
LB 6.7 - Cooling Water Supply	LB 6.7 - Обеспечение охлаждающей водой
Environmental protection	Защита окружающей среды
LB 7.2 - Dedusting Equipment	LB 7.2 - Обеспыливающие устройстваа
LB 7.3 - Reduction of Gas Emissions	LB 7.3 - Сокращение газообразных выбросов
	LB 7.8 - Измерительная техника контроля за выбросами
Quality assurance	Контроль качества
	LB 8.1 – Обеспечение качества/Управление качеством
	LB 8.2 - Оборудование для отбора проб
Courses from partners of VDZ:	Курсы партнеров VDZ:
RT 01 - Control technology	RT 01 - Теория автоматического управления

Practical example: e-learning worldwide

Since 2010 VDZ has offered its online courses at www.elearning-vdz.de/en/ as an internet-based training tool for the cement industry. The courses were initially in German but were subsequently translated into English and Russian in response to the significant level of international interest. There are now over 50 courses in German, with 38 online courses in English and 40 online courses in Russian. Over 1500 users worldwide take VDZ's online courses each year.

The initial situation
The customer had been using VDZ's German-language online courses at his German branches since 2010. Given the positive experience with the courses and the internally gauged worldwide demand for continuing education in the cement sector the decision was taken to roll out the courses in other countries as well. All workforces worldwide should have an opportunity to use the VDZ online courses to acquire the latest knowledge in cement production processes and review their existing knowledge (**Fig. 2.7-3**). Project management was with the customer's technical centre and their central HR department which was already running its own learning solution on the intranet and was looking to enrich it through the VDZ online courses.

The approach
VDZ set up a separate learning platform for the customer tailored to his internal requirements. As well as adopting the customer's corporate design, the learning platform was linked to the customer's intranet by means of a newly developed interface through which participants can access the VDZ online courses without entering login data (Single-Sign-On). A second interface was implemented to report user activities in the online courses. Once the customer's English-language users had started successfully with the new learning platform, the German-language users were also transferred to it after a while. For the customer's Russian-speaking users VDZ implemented its special solution for correctly reproducing Cyrillic fonts as well.

The results
Today, over 1000 employees a year use the online courses in three languages to broaden their technical knowledge of cement production. Thanks to the content of VDZ's courses and the tests which they contain the customer was able to ensure the existence worldwide of a broad knowledge base of cement production and the continuing expansion of existing knowledge. The VDZ online courses have an important role to play within the customer's global personnel development strategy.

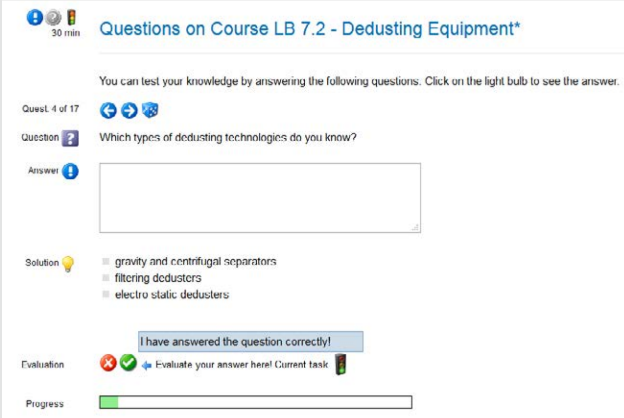


Fig. 2.7-3 Self-test questions in the VDZ online course LB 7.2 in English

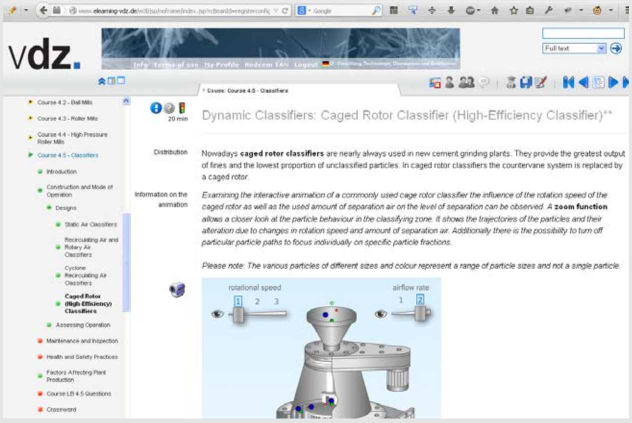


Fig. 2.7-4 Online course 'LB 4.5 - Classifier' in the VDZ Learning Platform

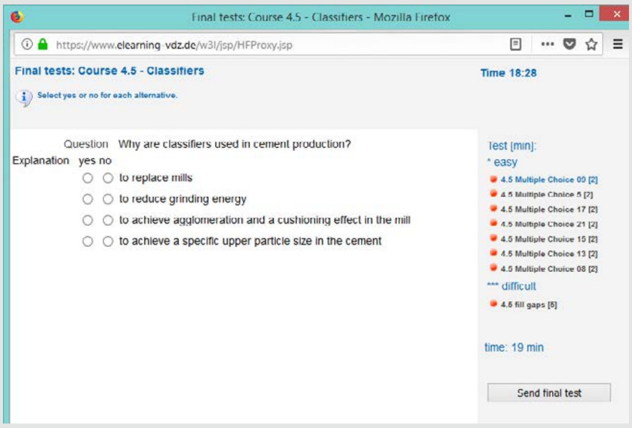


Fig. 2.7-5 Final test of course 'LB 4.5 - Classifier'

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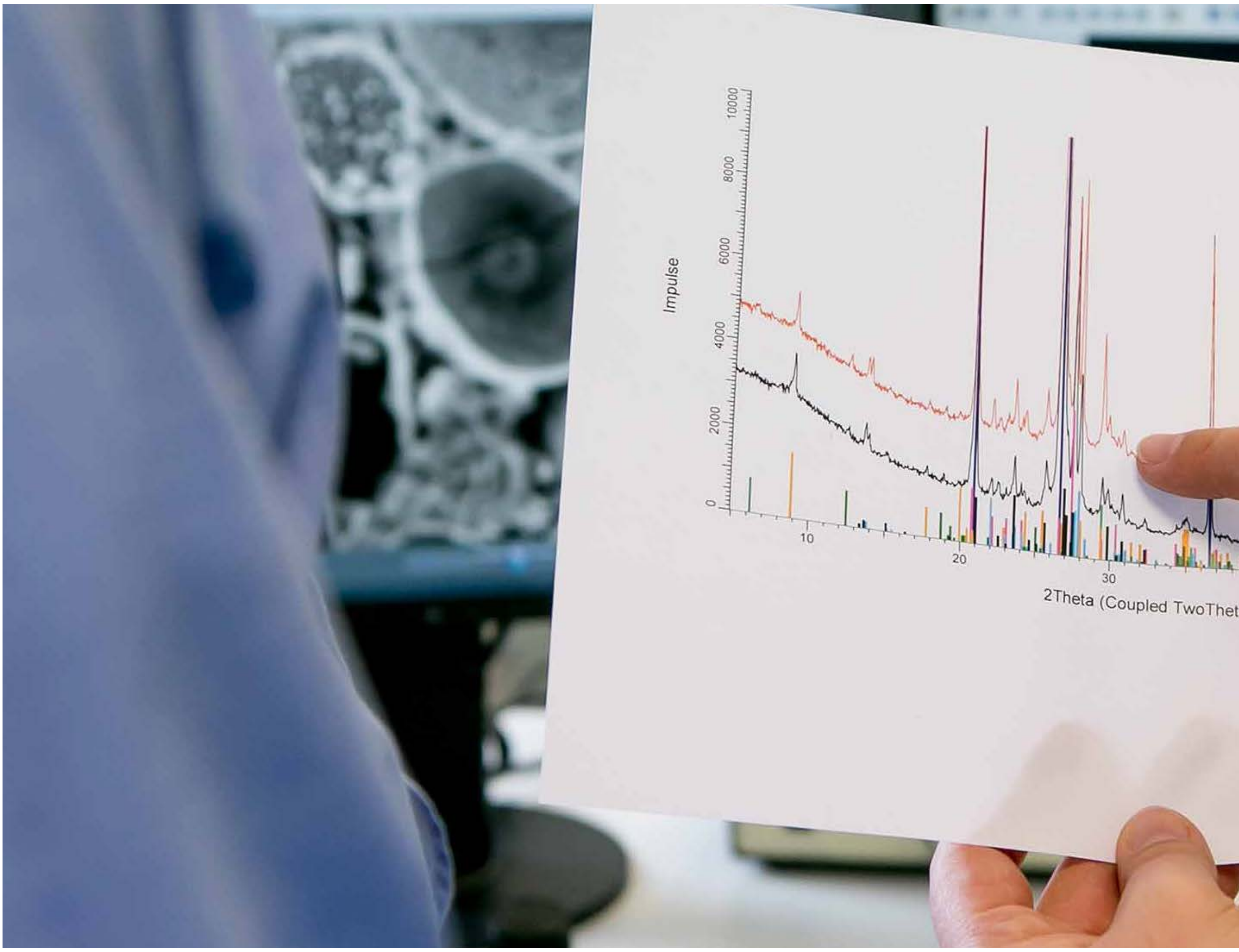
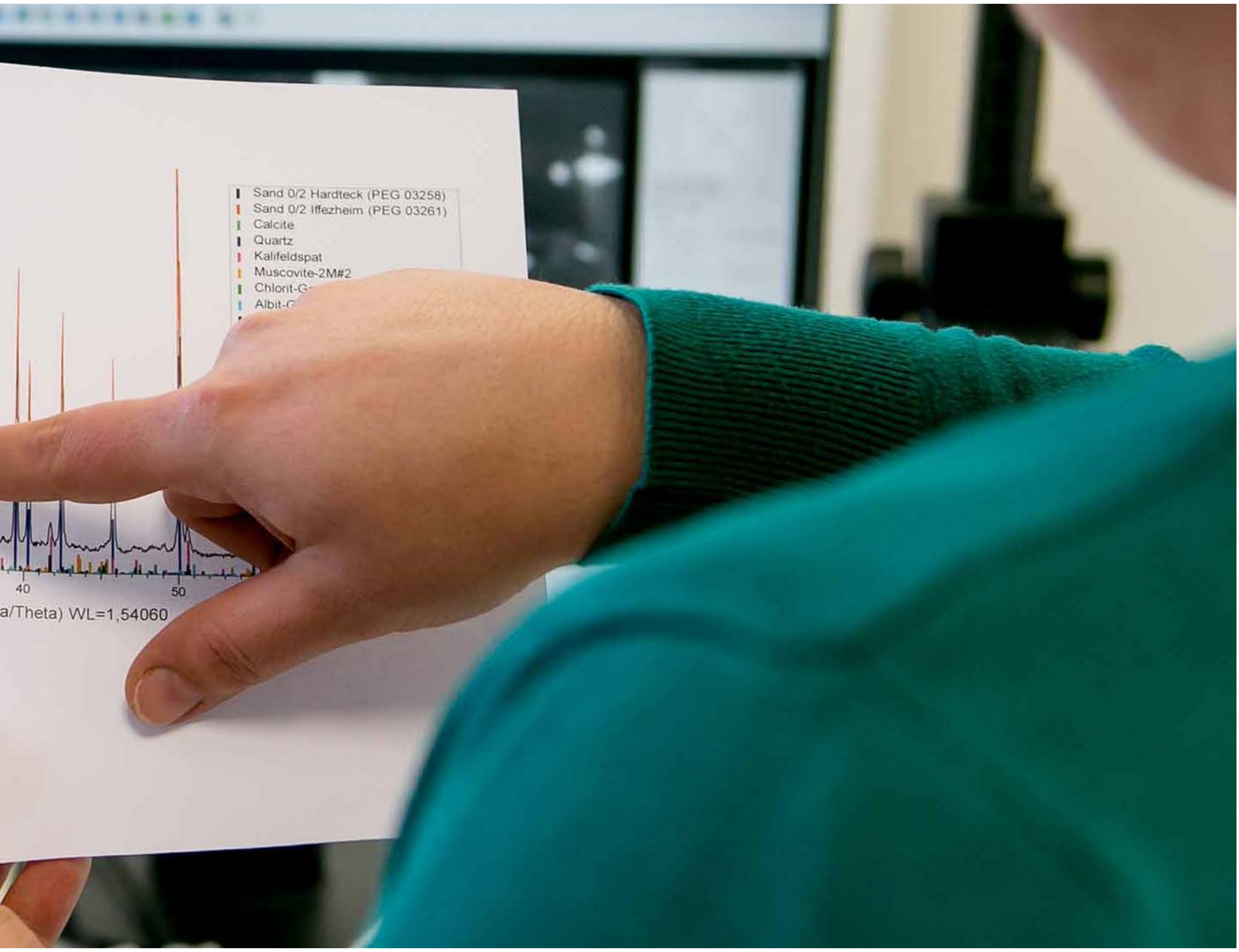
Research Projects of VDZ

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Application-oriented research of VDZ

Ever since it was founded more than 140 years ago, VDZ has been working within the framework of Industrial Collective Research (IGF) on both basic research and actual technical applications in the industry. This chapter presents a summary of the main aims and results of our research work for the period under review between 2015 and 2018. As in previous years, research focused on process technology, environmental protection in production and the application-related performance of cement in mortar and concrete. With research projects concerning the reduction of nitrogen oxides, the durability properties of concretes with high-volume blast furnace slag and fly ash cements, and the avoidance of a detrimental alkali-silica reaction (ASR) through the specific use of siliceous fly ash, for example, VDZ helps to promote competitive and ecological cement production and high-quality concrete construction methods. In recent years, VDZ education programmes and knowledge transfer projects have given rise to any number of improvements to the benefit of the employees in the cement industry and the innovative capacity of the branch as a whole.

As a founding member of the Federation of Industrial Cooperative Research Associations (AiF), VDZ has been part of the AiF research network since 1954. Functioning as a research centre for the cement industry, VDZ works together with German cement manufacturers to develop new ideas and approaches for innovative scientific projects. The research activities of VDZ have received recognition in the form of the 'Innovation through Research' quality seal awarded by the Association for the Promotion of German Science. Including projects currently in progress, more than 130 research projects have been supported and implemented by the AiF and the German Federal Ministry for Economic Affairs and Energy (BMWi) over the past 25 years at VDZ.

With its involvement in numerous international research projects, in particular as founding member of the European Cement Research Academy (ECRA), VDZ will continue to play a part in ensuring competitive, ecological and resource-conserving cement production in the future as well.

3.1 Cement production process technology

3.1.1 Investigation of separate superfine grinding of cements as a means of improving energy efficiency and cement properties ■

IGF project 18853 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Period: 10/2015 – 09/2017

Background and aims

The past 10 years have seen a continual increase in the fineness of cements in Germany. Consequently, today's cements contain a relatively high percentage of fine particles which largely determine the cement properties. From the point of view of quantity, the fine range only accounts for a small part of the cement, but it is of crucial importance with regard to quality, for example the early strength of the cement. In industrial grinding operations it is scarcely possible to control the quantity of fine particles (less than 8 µm), and they hardly occur at all when employing energy-efficient grinding processes. With intergrinding, however, the proportion of fine fractions can only be increased by exposing all the grain fractions to the grinding process. This frequently results in overgrinding of the product.

Whereas the ball mills most commonly used in Germany basically produce sufficient fine fractions, more energy-efficient high-pressure comminution plants such as vertical roller mills and high-pressure grinding rolls can only do so to a limited degree, depending on the mode of operation. With a view to making better use of the energy-efficiency advantages of these mills, this project investigated the possibility of producing the desired fine fractions in the particle size distribution through separate superfine grinding.

The separate superfine grinding of cements has not been implemented to date in the cement industry. In theory, multi-stage, adapted size reduction ought to make it possible to reduce the energy demand. Strength development and water demand can also be controlled by actively influencing the particle size distribution. A further aspect is that small fine-grinding units are less capital-intensive than grinding plants with standard production capacities. The mixing of extremely fine-ground fractions obtained from separate superfine grinding with coarse intermediate products could take place directly in existing mixing installations.

Approach

The object of the investigation was to establish how the fine fractions required could be produced by separate grinding in a special fine grinding mill (based on the example of a rapid-rotation stirred media mill, **Fig. 3.1.1-1**), and what effect this production process would have on cement quality. Two clinkers of different chemical and mineralogical composition were used for this purpose. The majority of the desired end product was made in a small-scale vertical roller mill (**Fig. 3.1.1-2**), accordingly supplemented by separate superfine grinding and mixing to obtain the required final fineness. There is very little experience to draw on in the cement industry with regard to the specific characterisation of the superfine fractions (< 8 µm) produced. The suitability of the laser diffraction method already established and widely used in practice to determine particle size distribution was therefore investigated specifically for the characterisation of dry superfine fractions. This formed the basis for the development of a model to identify the most energy-efficient mixture of the various intermediate products of primary and superfine grinding to simulate a pre-defined particle size distribution from a ball mill, for example. The model makes it possible to keep on optimising the separately ground constituents of the mixture until the deviation from the desired particle size distribution is minimal.

To explore the influence on cement quality, 32 cements were produced and analysed with regard to their properties in mortar tests. This also included the product of reference grinding in a semi-industrial closed-circuit grinding plant with ball mill. Amongst the factors measured were strength development and water demand.

Results

At the start of the project, a basic assessment was made of the suitability of superfine grinding for the main cement constituents clinker, blast furnace slag, fly ash and limestone. As expected, this revealed that fine grinding mills are able to produce a far higher proportion of fine fractions than the standard plants used in the cement industry. The grindability of the main cement constituents investigated was determined for further characterisation. Despite their differing chemical and mineralogical composition, the two

Fig. 3.1.1-1 Stirred media mill for separate superfine grinding

Fig. 3.1.1-2 Mill chamber of the small-scale vertical roller mill

clinkers used exhibited comparable grindability. In the further course of the project, this made it possible to examine the effects of the reactivity of the clinkers on separate superfine grinding given the same comminution history.

The suitability of laser granulometry for the characterisation of cement superfine fractions was also analysed. This revealed that the diffraction theory applied and the concentration of the sample in the dispersing agent have a crucial influence on the measurement result. The Fraunhofer approximation offers an appropriate means of describing the overall product. The Rosin, Rammler, Sperling and Bennet (RRSB) distribution frequently used for evaluation is able to describe the superfine fractions produced without any restrictions. Particularly pronounced multimodality of the particle size distributions was not found for any of the mixtures examined.

Working on this basis, the maximum finenesses attainable in a dry stirred media mill were determined in iterative test series. Given RRSB position parameters, maximum finenesses between 6 and 10 µm can be achieved with this method. Great dependence on the feed particle size was found for the mill used. The superfine grinding method produced only poor comminution of coarse particles.

A model was developed to allow separately superfine-ground materials to be specifically combined with other intermediate products to obtain a desired particle size distribution. This permits calculation of the best possible composition of the mixture with particle size distributions from different grinding plants on the basis of various boundary conditions. The deviation from a reference particle size distribution is determined as an indicator of the quality of the mixture. This can then be compared to the specific energy demand for grinding the necessary components of the mixture.

A wide range of particle size distributions with greatly differing finenesses and distribution widths can be obtained with the given intermediate products. Consequently, cements of various strength classes can be produced from just a few intermediate products. Within the boundaries of the intermediate products available it is also possible to adjust the distribution widths of the particle size distributions.

Assessment of separate superfine grinding involved checking its influence on the most important cement properties. For this purpose, strength development, water demand and setting behaviour were determined for 32 samples. In cases in which there was a sufficiently high proportion of fine fractions, no significant differences were found in relation to cements ground in ball mills. By way of example, **Fig. 3.1.1-3** shows a comparison of the strength development of cements obtained from separate superfine grinding and from ball mill grinding. With regard to the development of the heat of hydration, no significant differences were apparent between the mixtures and the ball mill reference grinding process. The tendency of the model to produce somewhat broader particle size distributions on account of the intermediate products used enabled the water demand of the mixtures to be reduced in comparison with the reference from the ball mill.

In the tests performed, the required standard strengths were obtained without any problem in many cases. Consequently, the mixtures do not have to exactly replicate the particle size distribution of the reference cements in order to satisfy the strength requirements. A relatively broad tolerance is therefore possible as regards the design of the mixtures. Higher or lower strength values may however be obtained in certain cases. This depends on the particle size distribution and the chemical and mineralogical composition. In such cases, use must be made of tighter tolerances and the distribution has to be adjusted, particularly in the superfine range. If the target strengths are significantly exceeded, the proportion of fine fractions can be reduced as a means of further reducing the specific energy demand in production. As a general rule, the desired particle size distributions should be designed to be robust enough to ensure attainment of the target strengths in spite of the process-related fluctuations encountered in large-scale plants.

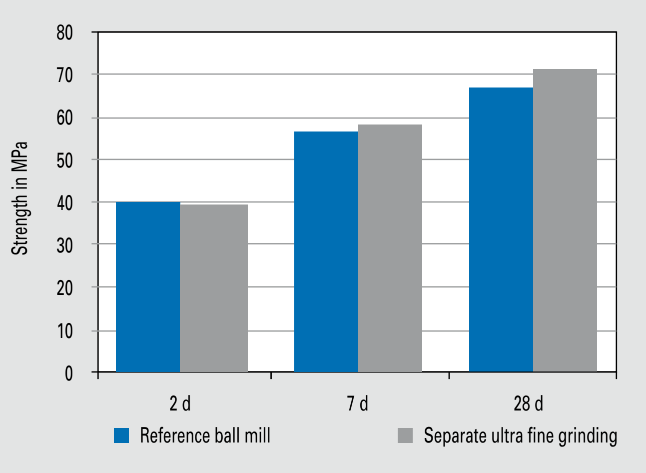

Fig. 3.1.1-3 Comparison of the strength development of cements from separate superfine grinding and ball mill grinding

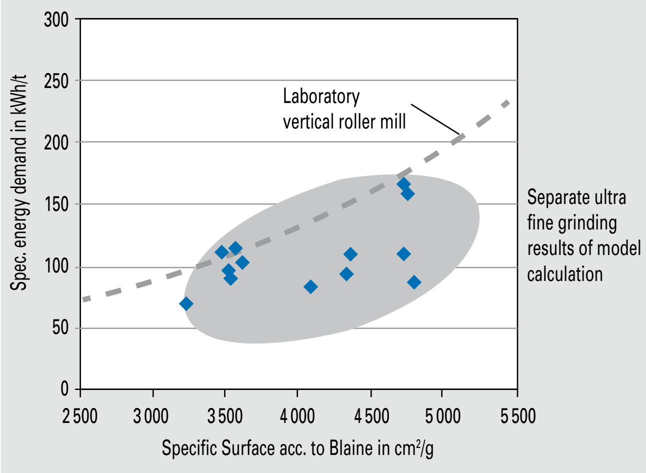

Fig. 3.1.1-4 Specific energy demand of a vertical roller mill in comparison with separate superfine grinding

In this context it has become apparent that the superfine range between 8 and 3 µm is of particular significance for the cement properties. The proportion of this fraction has a crucial influence on early strength and water demand. When assessing mixtures, it is therefore advisable to attach particular importance to this range.

Fig. 3.1.1-4 shows a comparison of the specific energy demand of a small-scale vertical roller mill and the calculated specific energy demand of the mixtures produced by way of separate superfine grinding. It should be noted that, on a laboratory scale, the vertical mill exhibits an exceptionally high specific energy demand. With high target finenesses in particular, the mixtures benefit from coarse intermediate products from the vertical roller mill, mixed with high proportions of secondary-ground product. This is not to be expected in large-scale applications. On an industrial scale, vertical roller mills and high-pressure grinding rolls operate far more efficiently than ball mills. It would therefore be possible to achieve a favourable energy demand for the mixtures even with energy-intensive superfine grinding. Separate superfine grinding is technically feasible and is able to yield equivalent or better product properties. The technology thus basically has the potential for use in cement production.

Further industrial-scale investigations are however necessary in the next step, as, on account of their particular characteristics, the energy demand of laboratory set-ups can only be scaled to an industrial level to a certain extent. Of particular interest is the influence of various large-scale superfine grinding mills on energy demand, the particle size distributions produced and the maximum attainable fineness. To be able to reach a final conclusion with regard to the total energy consumption for separate superfine grinding, there is a need to perform further investigations on continuously operating superfine grinding mills with good scalability.

3.1.2 Investigation of measures aimed at increasing the use of alternative fuels in the main firing system of rotary cement kilns

IGF project 18862 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partners: Department of Energy Plant Technology (LEAT), Ruhr University in Bochum, Chair of Environmental Process Engineering and Plant Design (LUAT), University of Duisburg/Essen
Project period: 10/2015 – 03/2018

Background and aims

Most of the thermal energy used in cement production is required for burning the cement clinker in rotary kiln plants. As energy costs represent a large proportion of the overall production costs, the cement industry has always been keen to reduce and optimise the amount of fuel used. These efforts mainly focus on the use of alternative fuels as a replacement for fossil fuels. The attainable alternative fuel rates are determined not only by the properties of the fuel, but also by the design of the plant and burner, the method of supplying cold primary air and hot secondary air in the burner/kiln hood area, and the fuel supply. A negative effect on the clinker properties is always to be avoided. In the project, the sensitivities and relationships of the various influence quantities were determined in a generally applicable form for all types of plant with the aid of CFD (Computational Fluid Dynamics) simulation and operational measurements.

Approach

The first phase of the project was concerned with defining target variables for the CFD models on the basis of typical characteristic quantities for rotary kiln plants. The second project phase involved conducting numerical simulation calculations for the combustion of alternative fuels in rotary kiln plants. The project partner LUAT determined the flow profiles of the secondary air from simulations of the clinker cooler and kiln hood geometry, and the project partner LEAT used these as a boundary condition for simulation of the firing in the rotary kiln. As a basis for calculation, in-depth analysis of the combustion properties of the fuels was performed.

Measurement data from a pilot centre experimental kiln and from full-scale operational trials in rotary kiln plants were used to validate the CFD simulations. As a means of systematically investigating the relationships of the various influence quantities, the operating parameters (fuel supply, substitution rate and fineness of alternative fuels, etc.) were specifically varied in the course of the full-scale operational trial. Sensitivity analyses were also performed with different clinker cooler, kiln hood and burner geometries. This was done on the basis of CFD simulation calculations, which permit the relatively unrestricted stipulation of geometries and boundary conditions (based on real plants). Finally, the object of the third project phase was to gather the findings in a manual for plant operators and plant manufacturers. It also involved drawing up best practice rules for the performance of simulation calculations.

Full-scale operational trials

Following the completion of all the preparatory work concerned with model formation and target variable definition, VDZ conducted full-scale operational trials in two kiln plants, making use of light-weight fractions of industrial and commercial waste (fluff). In the first kiln plant, a gradual increase in the alternative fuel rate in the main firing system resulted in an increase in the free lime content of the clinker, narrowing and lengthening of the flame, and an associated increase in temperature at the kiln inlet (**Fig. 3.1.2-1**). Furthermore, optical flame analysis performed using a thermographic camera revealed cooling of the flame and delayed fuel ignition. Microscopy of the clinkers pointed towards a slightly lower cooling rate and an extension of the precooling zone. Similar effects on the flame and clinker were observed when using a comparatively coarse fuel. Moving the main burner 30 cm into the kiln significantly improved fuel ignition, but at the same time resulted in narrowing and lengthening of the flame. Both these phenomena can probably be attributed to alteration of the secondary air flow to the flame. The free lime content remained unchanged. All-in-all, the measurement data from the first full-scale operational trial provided a sound basis for validation of the flow, combustion and clinker burning conditions in the CFD simulations.

CFD simulation

The first simulation calculations revealed good qualitative correspondence between the model calculation and the measurement data (pilot centre experimental kiln). For conducting sensitivity analyses on the basis of CFD simulation, the geometries of a reference kiln plant were then specified, computational grids were produced for the cooler, kiln hood and rotary kiln, and variation calculations were performed. In addition to testing different turbulence models, various primary air settings, secondary air temperatures and points of fuel addition were also simulated.

For the kiln plant used for the first full-scale operational trial, the computational grid was produced, and initial simulation calculations were performed and compared to the provisional results of the sensitivity analyses. It was noticeable that the degree of particle conversion in the gas phase (prior to contact with the kiln wall/kiln charge) was far higher than in the sensitivity analyses. Initial evaluation indicates that the secondary air flow from the kiln hood has a relatively great influence on the trajectory of the fuel particles

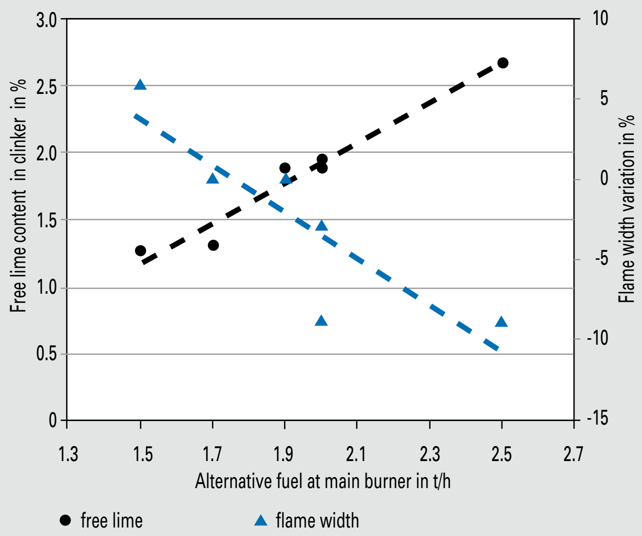

Fig. 3.1.2-1 Free lime content and flame width with significantly increasing alternative fuel rate. Results of full-scale operational trials in a rotary kiln plant.

and the length of time they remain in the hot flame. Production of the report on the results of the second full-scale operational trial and further simulation calculations concluded the project work.

3.1.3 Increasing energy efficiency and the substitution rate in the clinker burning process through the drying and grinding of alternative fuels

IGF project 18589 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 07/2016 – 06/2018

Background and aims

The use of alternative fuels in clinker production presupposes that these are of uniform quality. Moisture content and particle size should only fluctuate within certain ranges, for example. There is however only a limited supply of such high-grade alternative fuels. Inferior quality alternative fuels with a both high and greatly fluctuating moisture content and/or a high proportion of coarse particles are by contrast more readily available on the market. These include certain high and medium calorific value light-weight fractions of industrial and commercial waste (fluff) as well as mechanically dewatered sewage sludge.

Discussions are increasingly focusing on the extent to which it is technically and economically feasible to pre-treat such lower-grade alternative fuels on site at the cement works by way of suitable external drying, comminution and blending prior to infeed into the kiln. This treatment can take place either separately in drying or grinding plants or jointly in combined drying and grinding plants. One advantage of drying prior to the clinker burning process is that use can be made of surplus waste heat from the process for this purpose. The extent to which the energy efficiency of the clinker burning process can be enhanced in comparison with 'internal' drying in the rotary kiln, coupled with a possible further increase in the alternative fuel rate, is to be examined within the context of the research project.

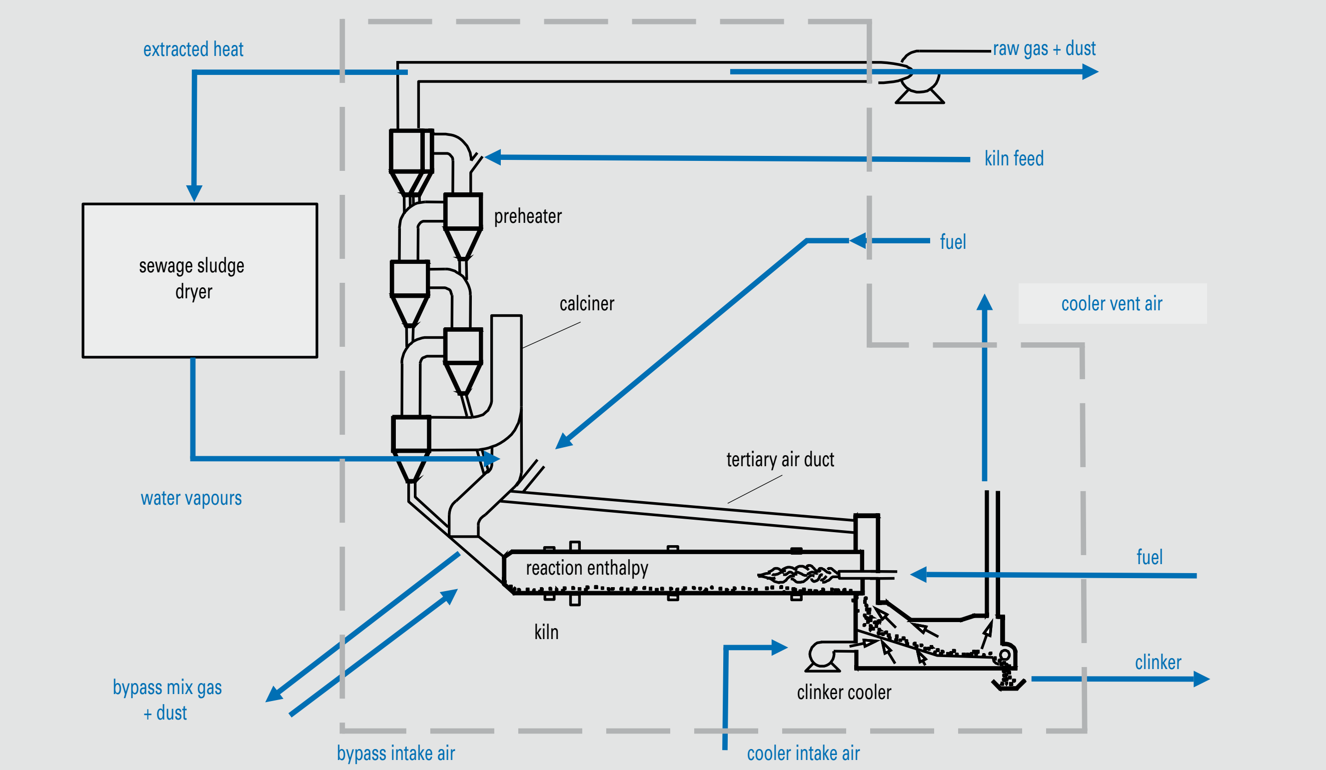

Fig. 3.1.3-1 Enthalpy flows determined within the scope of an energy balance for a kiln plant with sewage sludge dryer (operational measurement)

Fig. 3.1.3-2 Operational measurement of hot gas temperature

Approach

The first step was to determine the extent to which relatively inhomogeneous, non-pretreated alternative fuels can be fed into the kiln, and the effect of this on kiln operation. The study then looked into the question of how technically and economically feasible it would be to make these fuels suitable for use by employing an external fuel dryer or a fuel mill in the cement works. This involved producing an analysis of the benefits of the plants concerned versus the corresponding expense. The plan was to conduct full-scale operational trials in cement works and to compile a cost-effectiveness study.

In the course of the full-scale operational trials, complete energy balances were drawn up for the kiln plants to be able to compare operation with and without external drying from the point of view of energy efficiency. Trials were also performed with different operating settings in a kiln plant with fuel mill to study the effects on kiln operation and the clinker properties. The final step was to compile recommendations for action by the operators on the basis of the results obtained.

Results/current status of the work

Several full-scale operational trials were conducted and energy balances were drawn up for different operating settings. To produce these balances, the temperature, the volumetric flow rate and the mass flow were measured for all incoming and outgoing gas, liquid and solid flows, and the figures obtained were used to calculate the enthalpy involved. **Figs. 3.1.3-1** and **3.1.3-2** show the enthalpy flows determined in the course of the full-scale operational trial and a temperature measurement in the hot gas by way of example. Solid samples were additionally taken to determine the enthalpies of reaction. The wall temperatures were also measured for calculation of the energy loss by the kiln shell.

The first measurements taken in a kiln plant with sewage sludge dryer revealed that there was a comparatively small balance difference on completion of the energy balances. The experiments concentrated on the direct use of mechanically dewatered sewage sludge in the kiln plant, as well as the use of sewage sludge which had been dried down beforehand in the dryer to a residual moisture content of approx. 5 mass %.

A value of 2.8 kWh/t clinker was determined as power requirement for operation of the sewage sludge dryer (not including the power required for the sludge pumps). The additional power requirement resulting from the increased blower output of the heat exchanger was between 1.5 and 2.7 kWh/t clinker. Approx. 240 kJ of heat per kg of clinker was tapped from the raw gas for the drying process. Roughly 5 % of this was returned to the kiln plant by way of infeeding the vapour from the sewage sludge dryer.

The exhaust gas losses of the kiln plant through the raw gas were around 90 MJ/t clinker higher if exclusive use was made of dried sewage sludge instead of mechanically dewatered sewage sludge. This was primarily due to an increase in the raw gas volumetric flow rate and the raw gas temperature. On the one hand, the higher volumetric flow rate was a consequence of the higher water input into the kiln system through the vapours, as altogether far more dried sewage sludge was able to be used in the plant than mechanically dewatered sewage sludge (7.2 % as opposed to 2.8 % of the overall heat output of the firing system). In addition, a higher excess air quantity was found in the kiln plant in the case of operation with dried sewage sludge. Potential probably still remains for optimising the use of sewage sludge in the main firing system to obtain better combustion with reduced excess air quantity and exhaust gas losses. The combined utilisation of dried and mechanically dewatered sewage sludge led to a further increase in raw gas losses by an extra 90 MJ/t clinker. In comparison with the exclusive use of mechanically dewatered sewage sludge, this thus resulted in a greater energy loss (180 MJ/t clinker higher) via the raw gas. This energy loss can primarily be attributed to the use of more sewage sludge (10.3 % of the overall heat output of the firing system) and the associated higher input of water into the kiln system. The energy loss is in contrast with the extraction of useful heat for operation of the dryer, amounting to approx. 235 MJ/t clinker. The use of sewage sludge was not found to have any significant effects with regard to the clinker quality.

3.1.4 Development of a process for the utilisation of waste incinerator bottom ash (IBA) as raw material component in cement production ■

IGF project 18533 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partner: University of Duisburg/Essen
Project period: 06/2016 – 05/2018

Background and aims

Approximately 4.8 million tonnes of IBA are obtained as a waste product of incineration every year in Germany. This is mainly used in landfills. The aim of the research project was to develop a cost-effective process for separating heavy metals from the fine fraction of the waste IBA to such an extent that the mineral fraction can be used as raw meal substitute for cement production. These heavy metals include copper and gold for example. They occur in waste IBA in concentrations similar to those found today in low-grade geogenic ores.

Approach

The waste IBA was first broken up and ground, and then sieved and magnetically separated. The non-ferrous metals were removed in eddy current separation and washing processes to render the remaining mineral fraction suitable for use in the cement industry. Given the current level of expertise and today's metal prices, the recycling of metals from waste IBA would not be cost-effective if the fine-ground residual fraction could only be used as landfill.

As the remaining mineral fraction of the waste IBA primarily consists of the main constituents employed for cement production, it would basically be possible to make use of it in the clinker burning process. In view of the fact that the mineral ash constituents originate from a high-temperature process and are thus already calcined, this could help to further reduce CO_2 emissions in cement works. Another aspect is that the use of alternative raw materials in cement production would save on natural resources.

Assessment of the ash composition was primarily based on fine ash with particle sizes of 0 to 6 mm. As described above, further treatment consisted of breaking up and grinding the ash and dividing it into three fractions < 125 µm, 125 µm to 1 mm and > 1 mm. The next step involved magnetic separation, as well as eddy current separation of the non-magnetic material obtained from magnetic separation, in the above-mentioned three fractions in each case. The mineral material obtained from the preceding treatment step was then washed with various acids, bases and complexing agents to further reduce interfering constituents. Subsequently, the results of the chemical analyses of the washed mineral material were compared to the starting material after sieving. It was thus possible to track the treatment progress in each of the fractions.

At the same time, the mathematical VDZ process model was applied to determine the kiln meal substitution rate that could be achieved through the use of the treated mineral ash constituents. Clinker and emission predictions were made for the purpose of forecasting the heavy metals and trace elements which would be measurable in the clinker and in the clean gas if use were to be made of the kiln meal/ash mixture. Finally, clinker burning was performed with the calculated kiln meal/ash mixtures to preclude impairment of the clinker quality.

Current status of the work

In the course of the project, ash from three waste IBA processors was examined and treated. The treatment steps outlined above made it possible to reduce the concentrations of heavy metals such as chromium, copper, manganese and lead by approximately 30 to 60 % referenced to the initial concentration.

A 3000 tonnes per day reference kiln plant with 5-stage cyclone heat exchanger, precalciner and grate cooler was defined for mathematical process modelling. The fuel used in the first stage was coal dust. Modelling was based on an 'average' German kiln meal (reference kiln meal). The next stage involved the determination of an average composition of unwashed ash (**Fig. 3.1.4-1**) in the fraction of relevance to the cement production process (< 125 µm) as a basis for establishing the ash substitution rate for kiln meal. Consideration was given to the compositions of ash from different suppliers. In an initial approximation, a substitution rate of 4.3 %

treated waste incinerator ash was calculated. Roughly 16 % lime has to be added to the kiln meal/ash mixture obtained to largely restore the oxide composition to that of the reference kiln meal.

The first model results indicated minimal alteration of the phase composition of the clinker burned with the kiln meal/ash mixture (**Table 3.1.4-1**).

The heavy metal emission predictions with coal as fuel reveal that even with a theoretical 10 % ash substitution rate it is possible to satisfy the limit values of the 17th Protective Decree for Immissions of the Federal Republic of Germany (BImSchV) for heavy metals. The clinker predictions did however show a distinct increase in the heavy metals copper, lead, cadmium and chromium in the clinker as a result of adding the treated ash fraction.

In the next step, the model-based studies were continued with washed ash, which exhibits lower (however not yet available) contents of heavy metal. A further aspect to be considered was the use of alternative fuels.

The final step involved assessment of the composition and suitability of the clinkers burned with the addition of completely treated and washed ash in the laboratory.

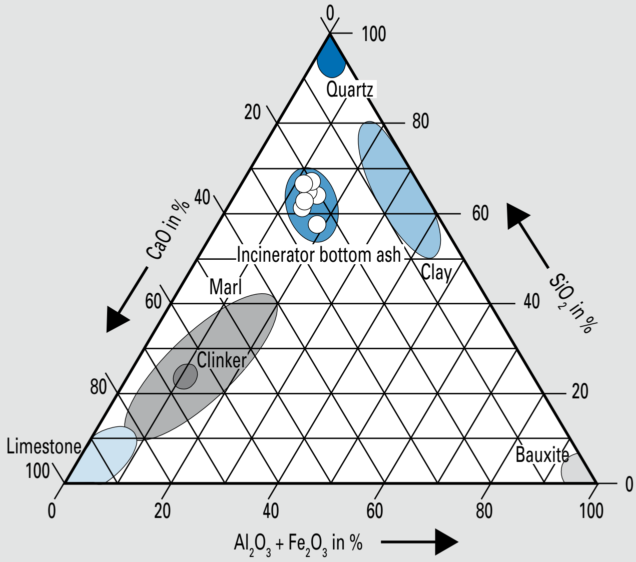

Fig. 3.1.4-1 Ternary diagram

Table 3.1.4-1 Comparison of calculated clinker phase compositions (figures in mass %)

Phase	With reference meal	With 4.3 % ash
C_3S	64.3	64.5
C_2A	14.0	14.7
C_3A	10.0	9.6
C_4AF	8.5	8.6

3.2 Environmentally compatible cement production

3.2.1 Reduction of Hg loads in rotary cement kilns through the use of sorbents – abatement of emissions whilst maintaining product quality

IGF project 18023 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 01/2014 – 06/2016

Background and aims

In the context of ever more, and international, discussions about the significance of mercury (Hg) and the associated risks for humans and nature, the German cement industry is making efforts to further reduce mercury loads in the cement production process in future. An essential prerequisite for sustainable cement production is an ecologically and economically acceptable method of cutting mercury emissions - without any effect on products and processes.

The main aim of the research project was to investigate the extent to which the mercury loads in rotary cement kilns can be effectively reduced through sorbent-assisted dust removal in mill-off operation. A further aspect studied was the question of whether binding the sorbent/dust mixture into the product can ensure reliable and environmentally compatible immobilisation of the mercury and whether it can be washed out of the bag dust by way of simple selective separation. Possible influences on product quality were also investigated.

Approach

The mercury separating efficiency of six different commercially available sorbents was examined on a laboratory scale: Lignite coke dust, activated coke (with 5 mass % H_2SO_4), brominated activated carbon (with 5 mass % HBr), two mixed adsorbents made up of 90 mass % calcium hydroxide and 10 mass % activated coke or 65 mass % calcium hydroxide and 35 mass % activated coke, and trass. The study focused on the influence of different temperatures (160 °C, 130 °C) and varying gas concentrations (SO_2, NO, CO) on the reduction effect of the sorbents and with regard to mercury speciation (Hg(0), Hg(II)).

Lignite coke dust, brominated activated carbon, mixed adsorbent (35 mass % activated coke, 65 mass % calcium hydroxide) and trass were then investigated in ten full-scale operational trials to assess the separation characteristics in the real exhaust gas of a rotary cement kiln. The binding of Hg into the exhaust gas dust without injection served as reference. The experiments yielded information on how the injection of sorbents affects mercury separating efficiency in the exhaust gas pipe. The mercury content of the dust was also determined at various locations in the raw gas cross-section upstream of the filter.

The aim of a third step was to examine the properties of the bag dust samples taken during the full-scale operational trials and the influence of these on the product characteristics of cement, mortar and concrete. This included examining the possibility of separating sorbent and bag dust by simple washing with deionised water, hydrochloric acid and hydrobromic acid, supplemented by leaching tests over a period of 24 hours in the form of a shaking test with deionised water in accordance with DIN EN 12457-4.

Taking a CEM I cement as a basis, cements, and mortars and concretes made from these, were produced using the bag dusts and examined as to their product properties (colour characteristics of the cements and cast mortar slabs, mortar tensile and compressive strengths, bulk densities and flow diameters). As a final step, the leaching characteristics were examined on concrete cubes in a long-term study over a period of 64 days in the form of a tank test in accordance with CEN/TS 16637-2.

Results

With regard to the fundamental aim of decreasing the mercury load in the exhaust gas pipe, temperature reduction in combination with dust removal in mill-off operation initially remains the most effective method. In relation to the reference condition (> 150 °C, no use of sorbent), a distinct reduction of approx. 60 % was achieved in this way. There are however limits to which the temperature can be lowered, as the evaporative cooler dust conveyors could be damaged by excessively moist material and the risk of corrosion in the exhaust gas pipe could be increased by the temperature dropping below the dew point.

The injection of sorbents can raise the effectiveness of separation following temperature reduction (135 °C) by a further 10 to 30 % (**Fig. 3.2.1-1**). The highest separation rates were achieved with sorbents containing coke/carbon. During the full-scale operational trials, raw gas dust samples were taken upstream of the filter with different trial settings. The sorbent dust samples taken from the gas flow revealed significant differences in terms of their mercury concentrations, depending on the position at which they were removed from the gas flow. In addition, mercury separation took place for the most part in the suspension flow upstream of the filter. The possibilities of optimising sorbent-assisted dust removal with respect to the distribution of dust and sorbent in the gas flow should therefore be examined in greater detail.

Where sorbents were employed to reduce the mercury load and the bag dust removed was used to set specific product properties, the studies revealed that no significant effects on the strength characteristics are to be expected and reliable inclusion of the mercury separated via the bag dust can be assumed. In the case of sorbents containing coke/carbon, there is however a possibility of the product colour being affected, which may be undesirable and have

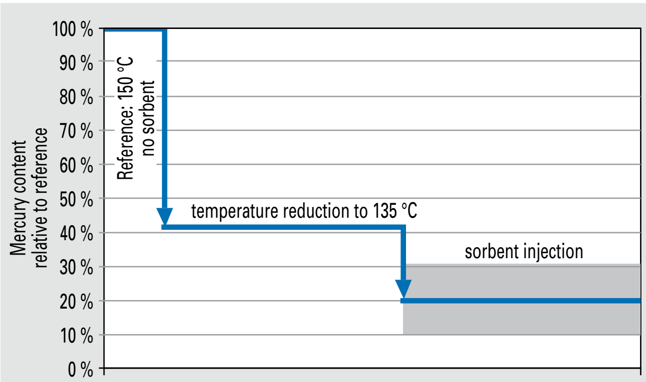

Fig. 3.2.1-1 Effects of temperature reduction and sorbent injection on the content of mercury and its compounds in the exhaust gas (100 % reference Hg content at 150 °C without use of sorbent)

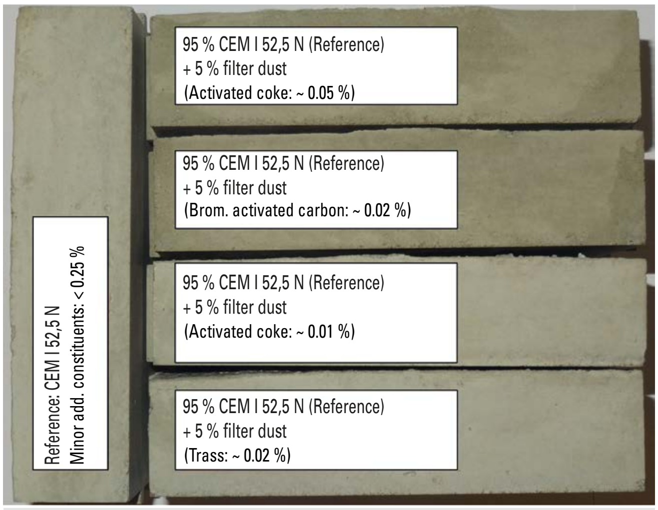

Fig. 3.2.1-2 Possible effects of bag dusts containing sorbent on colour

to be avoided in certain areas of application (**Fig. 3.2.1-2**). The recommendation at this point is to extend the studies performed on the influencing of product properties with specific setting of the (coke/carbon-containing) sorbent concentration in the product to also include other cement types with different strength classes.

To summarize, the project showed that specifically assisting dust removal in off-mill operation through the injection of sorbents into the exhaust gas pipe is a technically feasible means of further reducing the mercury load in the exhaust gas pipe of rotary cement kilns if necessary. Process technology limits and product quality requirements do however have to be taken into account.

3.2.2 Reduction of emissions in the non-metallic minerals industry through model-based process optimisation (EMREDPRO) ■

The research project with the Sketch No. KLIMA-907-011 is supported by the German Federal Ministry of Education and Research (BMBF)/Project Management Agency: DLR (KMU-innovativ)
Partners: KIMA Echtzeitsysteme GmbH, KIMA Automatisierung GmbH, DI MATTEO Förderanlagen GmbH & Co. KG
Period: 01/2017 – 12/2019

Background and aims

The process emissions of the cement industry include not only dust, nitrogen oxides and raw material-induced compounds, but also and above all CO_2 from combustion, from the raw materials and, indirectly, from power consumption. In the light of the high proportion of energy costs of more than 50 % in relation to the gross value added in the cement industry, continuous optimisation of the energy input is thus a major factor in achieving efficient and sustainable production processes. Just what effect modified process parameters or new, more efficient plant components will have on manufacturing in general in the cement works is however often difficult to predict. It means having to be able to assess the entire complex, interlinked overall process as a whole.

Although excellent models already exist today for certain aspects of cement production, there are as yet no suitable tools which permit model-based consideration of the complete process. The aim of the EMREDPRO project is therefore to develop a dynamic software model for mapping the installations and processes in the cement industry in their entirety. This should allow new plant components to be virtually integrated into a given production environment and permit examination of the associated effects. To be able to do so, the software must in particular be capable of determining the specific thermal energy requirement and the power consumption, and thus the direct and indirect CO_2 emissions. In this way it would be possible to identify and evaluate potential for saving energy in the process chain, as well as for reducing emissions. Over the course of the project, a basic model is to be developed and directly validated through the use of real process data. This method should ensure the practical suitability of the models.

Approach

The cement production process is made up of a number of individual chemical and physical processes. These include material and gas transport, heat transfer, combustion, chemical reactions, comminution and the interaction of these with the drives and the manipulated variables in the plants, for example. From the point of view of simulation, these complex processes represent a major challenge and therefore require a suitable form of abstraction. Whereas excessive simplification reduces the prediction quality, too detailed a representation would give rise to long calculation times and make handling impossible. Use is therefore first made of simple models, to which details are then gradually added. The wealth of theoretical and empirical data gathered from other research projects is also incorporated into this. In addition, the partial models are validated with real plant data at an early stage of the project.

The model has a modular structure to permit simple extension and adaptation at any time. Provision is also made for coupling the process model with a real control system.

Current status of the work

A modular model approach was developed in the Matlab/Simulink software on the basis of an in-depth system analysis. The individual components, such as the mill, the classifier, the silos, the kiln and the cooler were linked via a data structure permitting the exchange of relevant process and model data. The data structure containing all the necessary information on the media gas, dust and solids was designed to allow the unrestricted implementation of more complex model approaches as well in the future. As shown in **Fig. 3.2.2-1**, individual plant components can then be subsequently assembled into a cement works layout in a graphical environment.

Ways of linking the physical and chemical models to manipulated variables of the plant components were also studied. In this context, the acquisition of virtual measurement data, formatting and transfer to a higher-ranking control system are just as important as implementation of the effect of control actions on the process. Real-time capability plays a particularly significant role with regard to the use of control systems.

Alongside basic functions such as heat transfer and mixing, the first phase of the project concentrated above all on the transport processes. In addition to forced transport processes in conveying systems or silos, this also included potential-driven

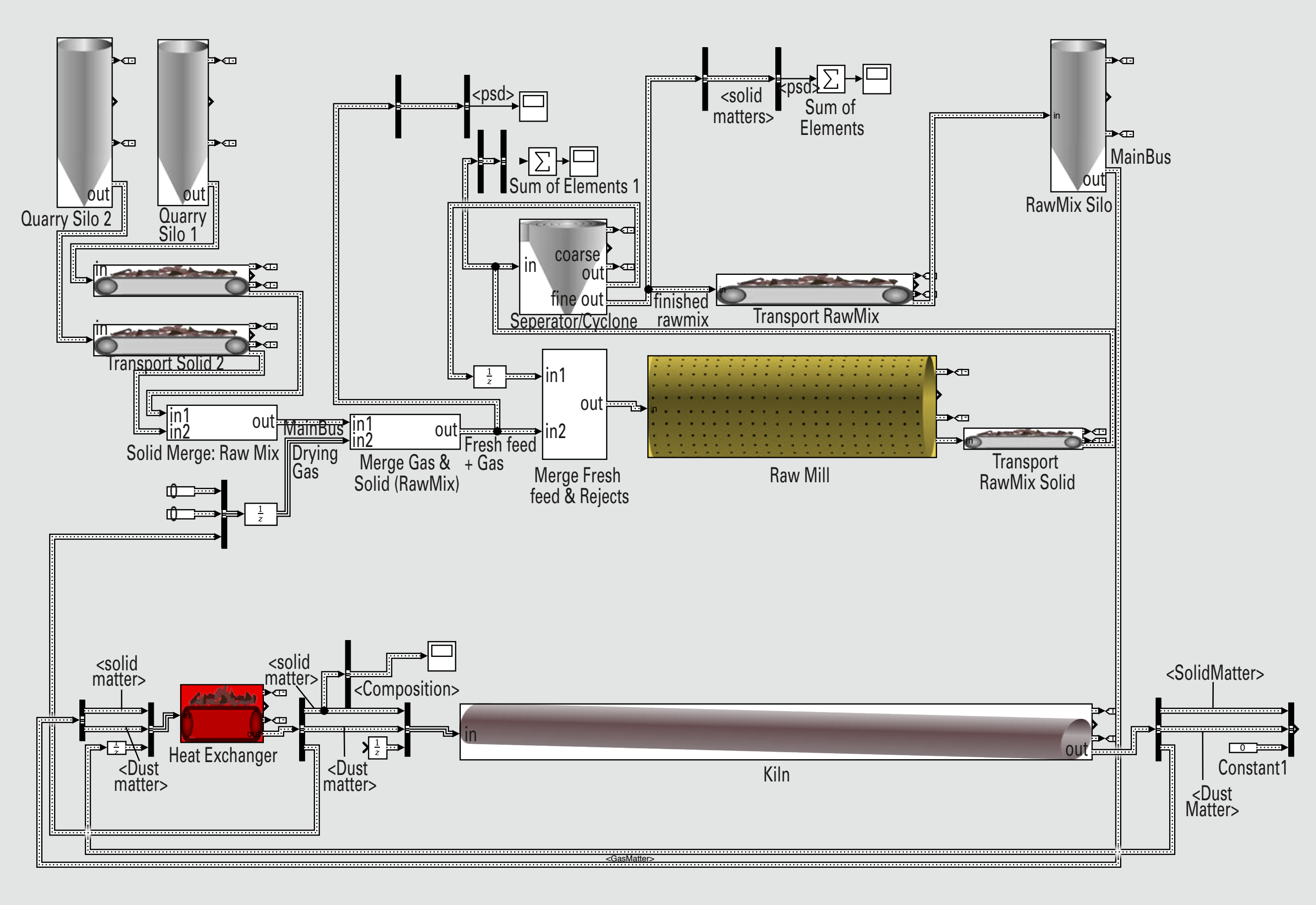

Fig. 3.2.2-1 Graphical development environment in which a plant can be assembled from individual components

transport-processes, such as those found in the grinding chamber of a ball mill. Consideration was also given to the influence of the mill chamber interior elements, in particular the transfer and discharge walls. Firstly, one-dimensional discretisation was performed for the mill by way of the series connection of ideal stirred vessel segments. The model parameters were adjusted on the basis of real plant data to guarantee realistic mill filling characteristics. **Fig. 3.2.2-2** shows the results of such parameter variation studies by way of example. The diagram illustrates the influence on the material filling level in the mill. This results from the transport characteristics in the mill, which are essentially governed by the flowability of the material, the permeability of the discharge wall and material passage in the wall. The corresponding simple 1st order size reduction model describes comminution as a function of energy input and material filling level. By decoupling material passage and comminution it is also possible to describe non-steady states in spite of the simple model structure. Thanks to the modular structure, the partial models can be extended whenever required. The next steps involve the implementation of gas and dust transport, classification, heat transfer and enthalpy balancing to ultimately be able to implement the components of the thermal process. Parameterisation of the high-temperature processes is considered to be a particular challenge in this context.

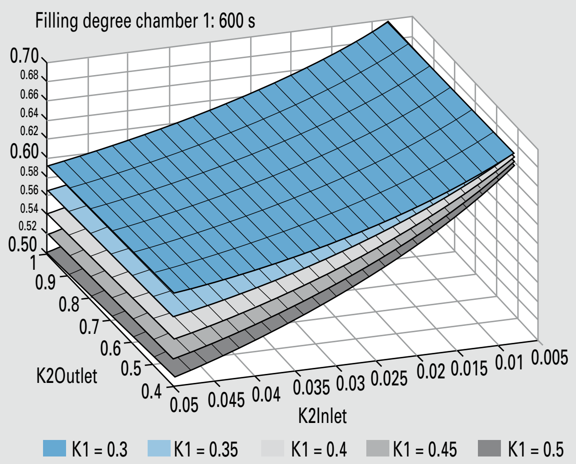

Fig. 3.2.2-2 Results of parameter variation studies for the transport characteristics in a ball mill depending on the material properties and the discharge wall

3.2.3 Synchronised and energy-adaptive production technology for flexible orientation of industrial processes towards a fluctuating power supply (SynErgie)

The collaborative Kopernikus SynErgie project is supported by the German Federal Ministry of Education and Research (BMBF) within the scope of research for sustainable development (FONA).
Grant number 03SFK3K0
Project partners: VDZ, Rohrdorfer Group, TU Darmstadt (consortium leader)[1)]
Project period: 09/2016 – 08/2019

Background and aims

In the course of this research project, an industry cross-sectoral method was developed to permit exploration of the potential for highly flexible utilisation of electrical energy. Particular consideration was given to the requirements of the basic materials industry. This is because the processes in the basic materials sector require a great amount of thermal energy and at the same time the product quality is extremely dependent on the nature of the process. With regard to the processes in the basic materials sector, it is therefore particularly important to identify flexibility potential which is compatible with the processes and does not have any negative consequences for the production volume or production quality. A conflict also exists between the aims of making a process either as flexible as possible or as efficient as possible. A distinction was made between currently available flexibility potential and prospects for flexibility which could be exploited in the future through the use of new technologies, the overcoming of obstacles or a change in boundary conditions.

Approach

In the cement industry, the greatest potential for demand side management is to be found in the area of material comminution through a shift in power consumption times. This applies in particular to cement grinding. The greatest amount of electrical energy is used in raw and cement grinding (**Fig. 3.2.3-1**). For the purpose of identifying technical flexibility potential, VDZ evaluated mill data statistics and presented these in a model for an integrated cement plant and a cement grinding station with average production capacities for Germany. The production and storage capacities and the seasonal course of production were assessed in the model application. Investigation into the prerequisites, obstacles and future prospects for flexible power utilisation was based in particular on the results of expert discussions with representatives of the industry. The project involved producing a description of the general requirements for flexible power utilisation with short-term (15 min), medium-term (several hours) and long-term (5 days) profile, which then served as a basis for the expert discussions. These also covered topics such as economic aspects, internal company organisation (order planning, shift planning, etc.) and the market situation (customer relations, supply capacity).

Results/current status of the work

The essential boundary conditions of the production processes being considered for flexibilisation in the cement industry were outlined in an industry summary. It is true to say that the cement industry has long since been exhibiting flexibility by carefully planning mill operating times to make use of off-peak power (demand-side management).

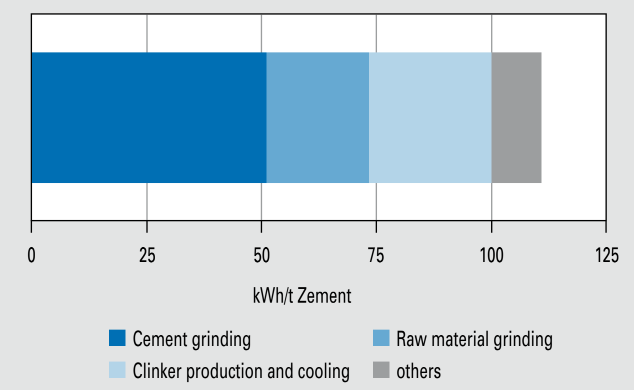

Fig. 3.2.3-1 Specific electrical energy use in the cement industry in kWh/t cement

The technical potential determined by the VDZ model for an integrated cement plant with average production capacity is a flexible capacity of up to 11 megawatts (MW) for load reduction (cement mills and raw mill) and up to 8 MW for load increase (without raw mill). Assuming flexible operation of one large mill (approx. 3 MW, **Table 3.2.3-1**) in every cement plant in Germany, this would yield a total flexible load of 172 MW as a maximum estimation including cement grinding stations. This is however only partially usable according to local load management requirements. The estimate of the technical potential is subject to restrictions in the form of numerous practical, organisational and economic prerequisites and obstacles. In the final analysis these can only be assessed specifically for each location.

The high quality requirements for standardised products (DIN EN 197-1) generally demand continuous production processes. Short to medium-term load reduction would therefore appear to be easier to implement than meeting the requirements for a short-term load increase. The high product quality standards required together with the stable production conditions needed to achieve these, would in any case still remain a prerequisite. Another task is to specify the amount of additional personnel, technical effort and wear associated with flexibilisation and ultimately to provide economic compensation for this.

The great seasonal fluctuation in production capacity utilisation in the cement industry requires particular consideration with regard to flexible energy input and estimation of the technical potential. This especially applies to cement production (**Fig. 3.2.3-2**), where phases of seasonal production capacity utilisation exceeding 90 % in the summer may completely restrict the potential for the flexible use of power in a cement plant. The duration of load adjustment also greatly depends on demand, current product stocks and the possibility of making up for production stoppages. The maximum duration for load reduction may be between several hours and a few days. It is estimated that a continuous production time of at least four hours is necessary for a load increase for additional mill operation for example in the middle of the day with a high level of renewable energy being fed into the power grid. With flexibility, it would then be possible to make use of particularly low or even negative electricity prices on the power exchange for load increase. A long-term load reduction, for five days for example

[1)] A list of all project partners is available at https://vdz.info/6ye7k

Table 3.2.3-1 Estimated technical potential for flexible energy input in raw and cement grinding with flexible operation of a large mill

Notification and duration of load adjustment	Potential for load reduction	Potential for load increase
Short term, 15 min. to 2 hours	Approx. 3 MW, followed by 4 hours guaranteed operation	Generally no short-term availability
Medium term, 4 to 12 hours	Seasonal, approx. 3 MW, load shift by 1 to 3 days	Seasonal, approx. 3 MW, 4 hours guaranteed operation

to overcome possible winter power shortages (absence of solar and wind energy) would only appear to be possible in the area of cement grinding and given particularly favourable conditions with sufficiently large product stocks. Investments aimed at increasing mill production or silo capacities to be able to make more flexible use of electrical energy would not appear to be cost-effective at present. In fact, today's standard power supply contracts for the industrial sector in Germany are associated with certain economic risks (e.g. for peak loads) rather than offering an incentive for more flexible power utilisation.

The results of this modelling and the expert discussions were analysed in the VDZ comminution working group and published in a report produced together with the project partners from the other basic materials industries in 2018 (https://vdz.info/6ye7k)[1]. In the further course of the research project, flexibility potential and obstacles are to be examined in greater detail on the basis of concrete time series in association with the Rohrdorfer Group and other project partners. The potential for flexibility when employing separate superfine grinding will also be considered with a view to a possible demonstration of this technology.

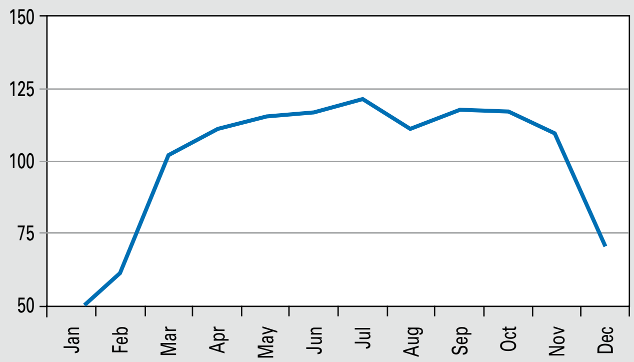

Fig. 3.2.3-2 Seasonal index of cement production in Germany 2010 to 2017, average = 100

3.2.4 CEMCAP – CO_2 capture in cement production ■

CEMCAP is a research project financed through the European Union Horizon 2020 research and innovation programme within the scope of grant agreement no. 641185.
Partners: GE Carbon Capture, GE Power Sweden, CSIC, Italcementi, European Cement Research Academy (ECRA), ETH Zurich, HeidelbergCement AG, IKN GmbH, NORCEM AS, Politecnico di Milano, SINTEF Energy (Coordination), thyssenkrupp Industrial Solutions AG, TNO, University of Stuttgart
Period: 05/2015 – 12/2018

Background and aims

The aim of the EU research project CEMCAP is to create the prerequisites for the utilisation of CO_2 capture technologies in cement plants. These could prevent CO_2 emissions in the cement industry and instead permit subsequent storage (CCS) or utilisation (CCU) of the CO_2. Particularly with regard to the reduction targets set down in the Paris Climate Agreement and the reduction of process-related CO_2 emissions in the cement industry, oxyfuel technology or other processes for capturing CO_2 from the exhaust gas (post-combustion technologies) could make an important long-term contribution to climate protection. Questions surrounding their technical and economic feasibility will also form part of this research project.

Technologies developed for CO_2 capture in power plants, many of which have a technological readiness level (TRL) of 7-8, require adaptation for retrofitting in cement plants. Capture technologies typically employed in the cement sector have a TRL of 4-5 or below. The CEMCAP research project was set up with a view to raising the technologies for the cement industry to a higher TRL to make them better suited to practical use. The primary aim of CEMCAP is to create the technological prerequisites for extensive implementation of CO_2 capture in the European cement industry. To achieve this, CEMCAP is pursuing the following sub-goals:

- Technological advancement to TRL 6 for oxy-fuel capture technology in cement plants and for three fundamentally different technologies for carbon dioxide capture in combustion processes (all with a target capture rate of 90 %).
- Identification of CO_2 capture technologies which can be retrofitted in a cost and resource-efficient manner in existing cement plants and which satisfy product quality and environ-mental compatibility requirements.
- Formulation of a technical and economic decision-making basis for CO_2 capture in the cement industry in order to reduce the current uncertainty about the costs of CO_2 capture technologies by at least 50 %.

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[1] Ruppert, Johannes; Treiber, Kevin: Statusbericht 'Flexibilitätsoptionen in der Grundstoffindustrie': Ausblick für die Zementindustrie. In: Schüttgut 2018 (3), pp. 52-56.

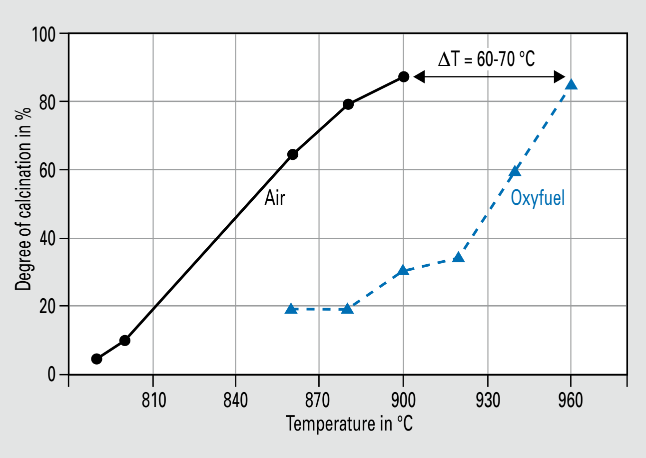

Fig. 3.2.4-1 Calcination of raw meal in air with 20 vol. % CO_2 and in an oxyfuel atmosphere with 80 vol. % CO_2 in a reactor of the University of Stuttgart

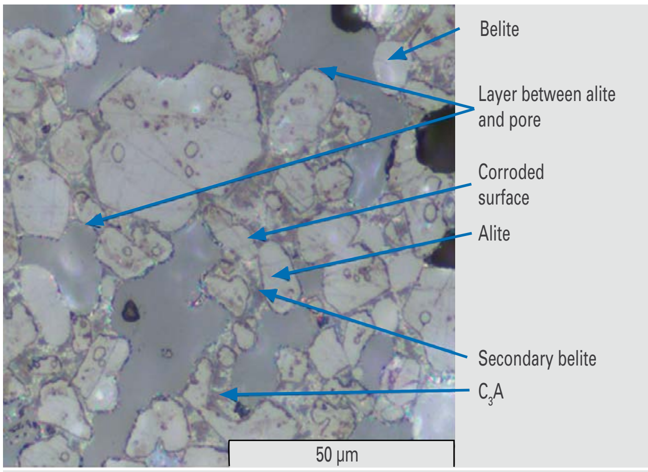

Fig. 3.2.4-2 Analysis of the first clinker samples from the pilot system of the oxyfuel cooler in the VDZ laboratory

Fig. 3.2.4-3 VDZ measurements taken during trials of the oxyfuel clinker cooler prototype in a cement plant as part of the CEMCAP research project[3)]

Approach

With a view to achieving the above-mentioned goals, VDZ and IKN together tested an oxyfuel clinker cooler prototype between September 2016 and March 2017 at the HeidelbergCement plant in Hanover (see Chapter 1.3.1). Results from a total of three experimental work packages on the oxyfuel process (calciner, burner, cooler) were inte-grated and analysed with the VDZ process model. The possibilities for optimisation, as well as the effects on energy demand and the CO_2 capture rate were investigated. As a final step, VDZ drew up a summary of the findings regarding the retrofitting of CO_2 capture technologies in cement plants. All the research results and conclusions are to be presented and discussed[1)] at a total of three workshops with representatives from industry, science and international organisations, and published both on the CECMCAP project website and in technical publications. The VDZ project website is available at https://vdz.info/th0di.

Results/current status of the work

A reference document with technical data for a typical cement plants in Europe was produced for the research project as a whole under the leadership of VDZ and based on concepts from ECRA-CCS project phase III (CEMCAP Framework Document, D3.2).[2)] This provides the basis for the experimental work, process modelling and technical/economic comparison of the various CO_2 capture technologies.

Laboratory investigations conducted as part of the ECRA-CCS project had revealed that a higher reaction temperature was required for the calcination of raw meal with a high CO_2 concentration. For the CEMCAP project, corresponding tests were performed in conjunction with the University of Stuttgart in a 2.5 m long suspension flow reactor and under oxyfuel process conditions. These confirmed the 60 to 70 Kelvin increase in temperature observed for calcination in the oxyfuel process with 80 vol. % CO_2 (**Fig. 3.2.4-1**). Variations in the reaction time and particle size also reinforced the decisive nature of the higher reaction temperature. The effective particle temperature is estimated to be lower than the absolute temperature measured in the electrically heated reactor. Regardless of this, the relative temperature increase indicates that a greater coating formation in the area of the calciner outlet has to be taken into account. Technically this can be counteracted by slightly reducing the maximum degree of raw meal calcination in the calciner.

The findings obtained from operation of the oxy-fuel clinker cooler prototype show that particular attention must be paid to the boundary zone of the cold clinker discharge system in order to minimize the ingress of false air. Unexpected alite decomposition of up to 4 percent by mass at pore boundaries was found in certain clinker samples (**Fig. 3.2.4-2**). This observation was initially attributed to a particularly high gas moisture level on account of the experimental conditions (**Fig. 3.2.4-3**). The clinker samples were further examined in the VDZ laboratory. The results emphasise that the condenser to be used in the gas recirculation circuit for the purpose of water vapour separation demands particular attention when designing the oxyfuel process in order to avoid impairment of the product.

[1)] cf. https://vdz.info/ht5l8 (external link)
[2)] CEMCAP Framework Document, D3.2, cf. https://vdz.info/y52pd (external link)
[3)] cf. https://vdz.info/8uyay (external link)

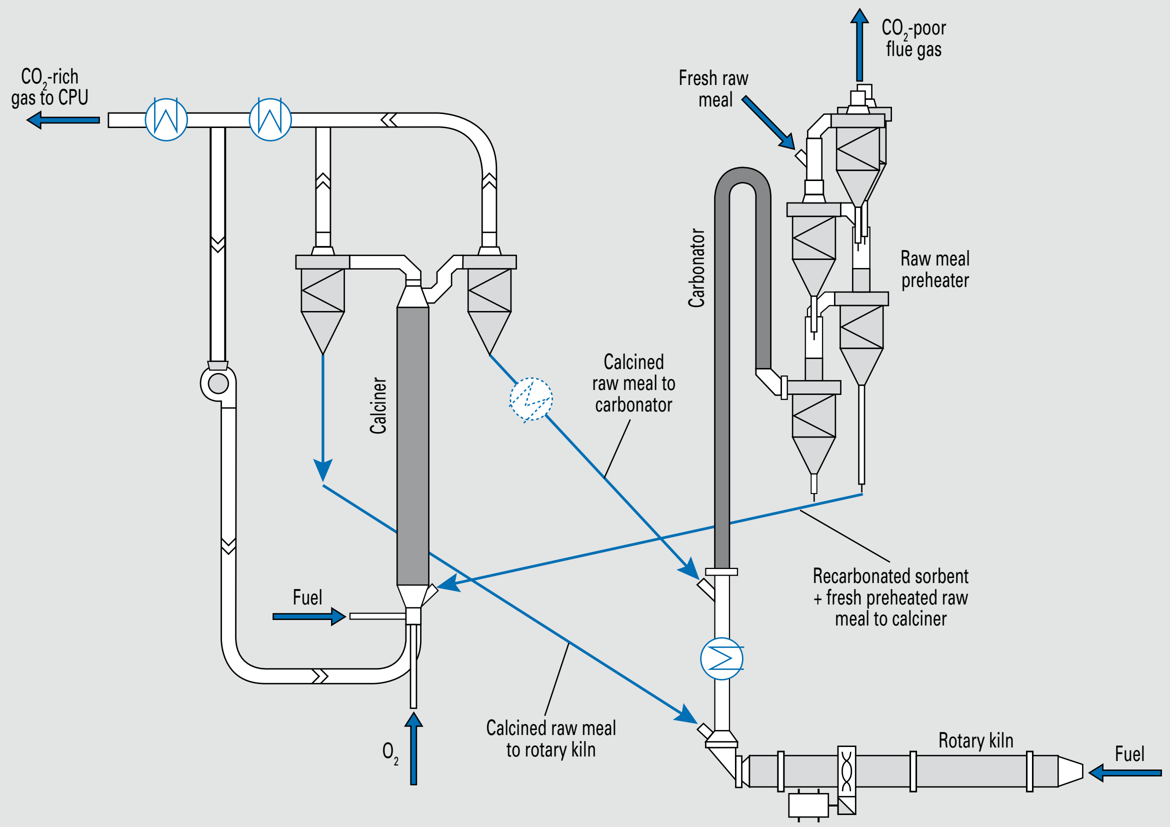

Fig. 3.2.5-1 Operating principle of the integrated calcium looping process (source: IKN)

Source: IKN

The results of the oxyfuel process modelling indicate potential for energy-efficient optimisation in combination with heat recovery (Organic Rankine Cycle, ORC) from the gas recirculation circuit, as well as showing little dependence of the electrical energy demand (+13 %) with respect to the potential ingress of false air in a low range between 4 and 8 %. Following further optimisation, the model results will be incorporated into the technical and economic assessment of various technologies investigated in the CEMCAP project for CO_2 capture from the clinker production process.

3.2.5 CLEANKER: Integrated calcium looping process for CO_2 capture

The CLEANKER project is financed through the European Union Horizon 2020 research and innovation programme within the scope of grant agreement no. 764816.
Commissioned by: European Union
Partners: LEAP (Italy), Buzzi Unicem (Italy), CSIC (Spain), Italcementi-HeidelbergCement Group (Italy), IKN (Germany), Lappeenranta University of Technology (Finland), Politecnico di Milano (Italy), Quantis (Switzerland), Tallinn University of Technology (Estonia), Tsinghua University (China), University of Stuttgart (Germany), ADT (Italy)
Project period: 10/2017 – 09/2021

Background and aims

A promising method of CO_2 capture from cement works exhaust gases is process integration of a calcium looping process, which up until now has only been viewed as a system for the downstream capture of CO_2 from the exhaust gas. This technology is considered to offer potential for the cement industry in particular, as quick lime is used as sorbent for CO_2. The resultant $CaCO_3$ can be directly utilised as a raw material component.

In detail, the concept involves the use of a so-called carbonator, which is intended to capture CO_2 from the kiln exhaust gas through the carbonation of CaO, and an oxyfuel-driven calciner to generate the purest possible flow of CO_2. The $CaO/CaCO_3$ is then exchanged between these units and/or partly circulated (**Fig. 3.2.5-1**). Once it has been cooled for heat recovery, the CO_2-enriched exhaust gas flow is transferred to a processing installation. This makes it possible to capture the CO_2 emissions arising from both the fuel and the material.

Approach

The aim of the CLEANKER (CLEAN clinKER) project is to perform large-scale testing of this technology as an integrated method (Technology Readiness Level 7). It is planned to treat 4000 m^3/h exhaust gas in a demonstration plant to be connected to an existing kiln line at the Buzzi Unicem works in Vernasca in Italy. In the course of the test campaign, various raw materials are also to be studied with regard to their suitability for use as CO_2 sorbents. The intention is thus to check the feasibility of the integrated calcium looping concept and the maintenance of constant product quality. VDZ is providing measurement technology, analytical services and cement expertise to support the project. Following demonstration of the technology, a technical and economic study will be performed for existing cement works based on scaling-up of the results and modelling of this process.

Use will also be made for this purpose of the process technology model developed by VDZ, which will be expanded for the specific application by incorporating the experimental results obtained.

The following ambitious targets have been set for integration of the method into the clinker burning process:

- CO_2 capture > 90 %
- Increase in electrical energy demand < 20 %
- Specific primary fuel requirement for CO_2 capture (SPECCA) < 2 $MJLHV/kg_{CO2}$
- Costs of CO_2 capture < 30 $€/t_{CO2}$
- Increase in cement production costs < 25 $€/t_{cement}$

Above and beyond the demonstration of CO_2 capture, the project is also intended to test CO_2 storage by means of the mineralisation of waste materials.

Current status of the work

The project is currently in the design and development phase.

3.2.6 ECo – Methanation for the utilisation of captured CO_2 and storage of renewable energy

The ECo project is financed through the European Union Horizon 2020 research and innovation programme, represented by the European Commission's Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU), within the scope of grant agreement no. 699892 – Eco.
Partners: Danmarks Tekniske Universitet (Dtu),
Commissariat A L Energie Atomique Et Aux Energies Alternatives (Cea), Eifer European Institute for Energy Research Edf-Kit Ewiv (Eifer),
Ecole Polytechnique Federale De Lausanne (Epfl),
Fundacio Institut De Recerca De L'energia De Catalunya (Irec), Htceramix Sa(Htc), Belgisch Laboratorium Van De Elektriciteitsindustrie (Engie), Enagas S.A.(Enagas)
Project period: 06/2016 – 05/2019

Background

Even though progress is constantly being made with the development of CO_2 capture technologies, the question of the final storage of CO_2 is yet to be resolved on account of social, legal and ecological considerations. It is thus all the more important to find ways of recycling CO_2 into hydrocarbon products. But this is an energy-intensive process. Combining the CO_2 from industrial sources using surplus renewable energy does however create synergies. The synthesis of methane could be a particularly promising solution, as the natural gas network already provides the necessary infrastructure and storage facilities (**Fig. 3.2.6-1** shows the process as a whole).

Aims of the project

The EU-supported ECo project (Efficient Co-Electrolyser for Efficient Renewable Energy Storage) is concerned with the development of highly efficient systems, so-called SOEC (Solid Oxide Electrolysis Cells), for the simultaneous electrolysis of steam and CO_2 to produce methane. The cells operate at low temperatures and high pressures and are to be studied with regard to their efficiency and durability.

In the further course of the project, the intention is to design an SOEC installation which will operate efficiently with a fluctuating energy supply and employing CO_2 from various sources. Investigations will be conducted into the purity of the CO_2 required for this system. The system must also be able to produce methane of the quality requirements demanded by the natural gas network. In a final step, a technical/economic study will be performed to assess the system in comparison with other electrolysis technologies.

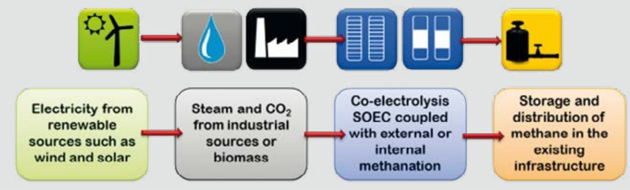

Fig. 3.2.6-1 Project concept Source: DTU

Current status of the work

Success has already been achieved with the first improved cells, although their performance does not yet match that obtained with pure steam electrolysis. Numerical tools were produced on the basis of long-term trials to gain a better understanding of the decomposition mechanisms. In an initial bibliographic study with the participation of VDZ, CO_2 sources from various industries, such as the cement industry, were characterised with regard to the CO_2 quantities, concentrations and fluctuations of these to be expected. The industries suitable for this technology were brought to light, e.g. the cement industry and biomass gasification and upgrading. A case study relating to a cement works with partial CO_2 capture and methane or syngas synthesis was conducted on this basis for the purpose of analysing potential (**Fig. 3.2.6-2**). The capture method selected was amine scrubbing, as this is the most advanced in terms of technological development. It was to be operated solely with waste heat. The combustible syngas or methane produced is to be returned to the process as fuel. A detailed balance of all the media occurring does however still have to be drawn up for this procedure. The results obtained should then be incorporated into the concluding technical/economic assessment. VDZ will be assisting the consortium with the study in an advisory capacity. It will be necessary to explore the conditions (costs, CO_2 footprint etc.) under which this type of system could be interesting for the cement industry.

3.2.7 Energy-efficient dry CO_2 capture from exhaust gas based on the example of the cement industry

IGF project 17796 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partner: TU Dortmund (Technical Chemistry B, Department of Chemical Engineering)
Project period: 2/2013 – 02/2016

Background and aims

CO_2 capture in the clinker burning process is basically possible with the use of so-called post-combustion methods. The advantage of these is that such systems are installed at the end of the process chain and thus do not interfere with the actual production process.

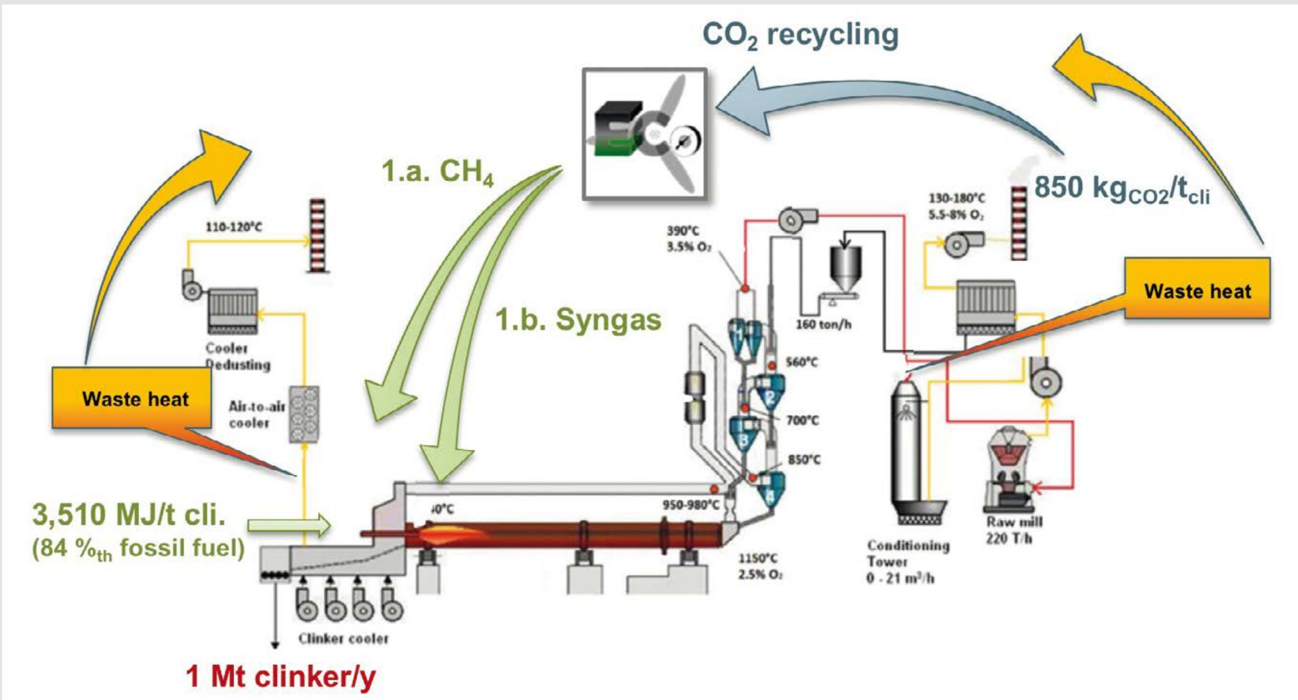

Fig. 3.2.6-2 Concept of a cement works with SOEC Source: DTU

As an alternative to the already relatively advanced amine scrubbing technique (wet method), a chemical absorption process with an extremely high energy demand for regeneration of the sorbent, it is possible to employ dry CO_2 adsorption. This involves using a solid adsorbent to bind the CO_2, which is then liberated again in highly enriched form in a regeneration operation.

Approach

To investigate this method, a research project supported by the AiF was conducted with the cooperation of the IUTA (Institute of Energy and Environmental Technology, Duisburg) and the TU Dortmund. In the course of the project between the end of 2013 and the start of 2016, fundamental studies were performed in the laboratory and in a pilot centre, then in a Westphalian cement works. The work focused on both the development of new adsorbents and the testing of commercially available adsorbents, including trials under real conditions in a cement works. In a further step, these findings were used as a basis for modelling to map the mass and heat transfer phenomena, as well as to produce a feasibility study on the integration of the adsorption unit into the overall cement clinker production process.

The tests at the cement works were performed using a triple cyclically operated pressure-temperature swing adsorption (P-T-SA) fixed bed system, suitable for handling 11 m^3/h gas (**Fig. 3.2.7-1**). The adsorbent used was a styrene-divinylbenzene copolymer with aminomethylene groups in free base form. The utilisation of such amine-functionalised adsorbents for capturing CO_2 from process gases has already been the subject of numerous studies, which however to date have primarily concentrated on thermogravimetric analyses or experiments on a laboratory scale, and to a lesser extent on a pilot centre scale, and generally only involved a few adsorption/desorption cycles. By contrast, the investigations conducted here focused on the suitability of the method for practical use.

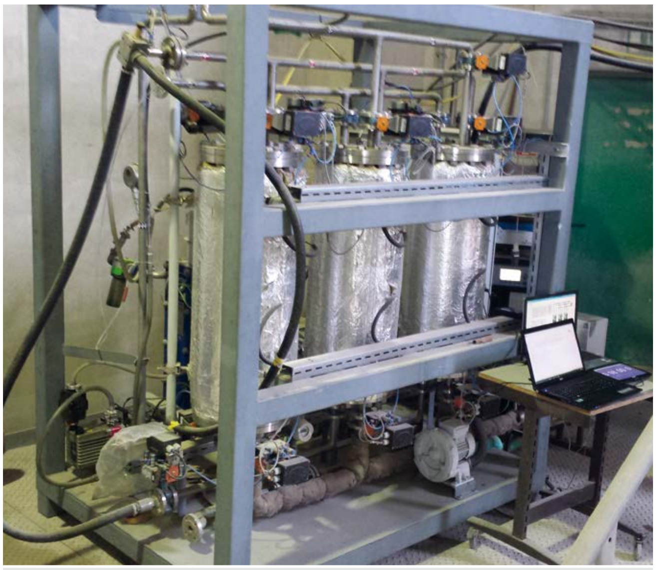

Fig. 3.2.7-1 Mobile apparatus for binding CO_2 at a Westphalian cement works

Results

In the course of the several weeks of experimentation with the real exhaust gas of a cement works, with an average CO_2 clean gas concentration of 13 to 15 vol. %, it proved possible to achieve stable plant operation. Adsorption brought about a reduction in the CO_2 concentration of the exhaust gas to a residual content of 0.6 to 1.5 vol. % (**Fig. 3.2.7-2**; the higher concentrations at the end of the adsorption phase are the result of opening valves on switchover). As with the pilot centre experiments conducted previously, these tests however again revealed only incomplete CO_2 desorption on sorbent regeneration, i.e. only up to one third

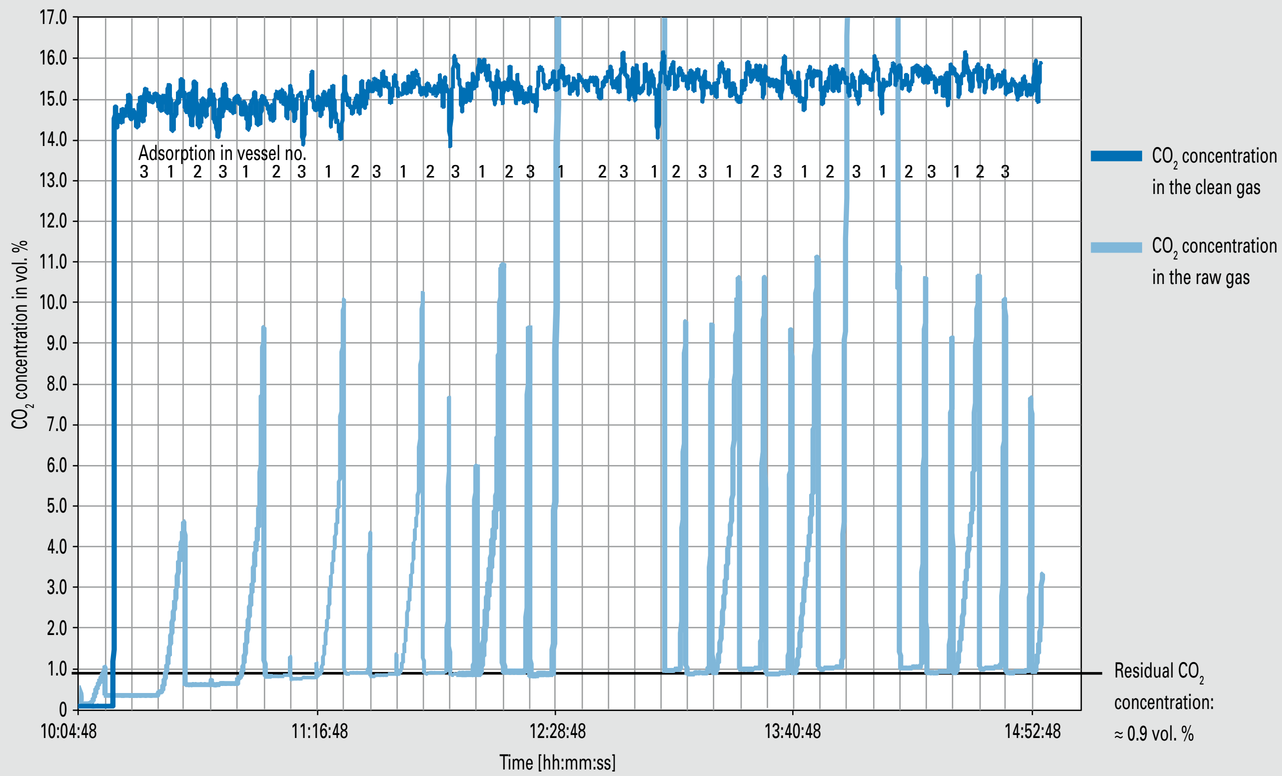

Fig. 3.2.7-2 CO_2 concentration in the ‚raw gas+ (upper curve) and in the ‚clean gas+ (lower curve) of the adsorption vessels

of the bound CO_2 was liberated. A CO_2 purity of up to 79 vol. % was obtained in the gas flow extracted with a vacuum pump. The majority of the remaining CO_2 was only released from the adsorbent and discharged when flushed with air. With cyclical operation of the reaction vessels, the loading capacity achieved with desorption and subsequent flushing permitted cycle times of up to eight minutes without CO_2 adsorption breakthrough. A welcome aspect for the adsorbent used was the low level of unwanted co-adsorption of water from the exhaust gas saturated with water vapour. Another positive finding was the absence of degradation of the adsorbent even after several months of trial operation with more than 1 000 adsorption/desorption cycles with real flue gas.

As a final step, studies into the energy demand for regeneration of the adsorbent and the total energy demand of the plant were taken as a basis for calculating the cost-effectiveness of the method examined and for initial assessment of dry adsorption in comparison with alternative methods. It became evident that, so far, the specific capture costs are far higher than for other CO_2 capture processes. This can be attributed to the as yet inadequate desorption, for example.

The method-based process modelling revealed that it would be no problem to incorporate dry adsorption at the end of the clinker burning process (post-combustion process). With single-stage adsorption it would not however be possible to achieve sufficient CO_2 reduction – more or less complete CO_2 capture would only be feasible with three-stage adsorption. The models for a BAT (Best Available Techniques) plant further revealed that, with an assumed raw material moisture level of 2 %, the entire heat of regeneration could be supplied by the clinker burning process.

It also became apparent that the incorporation of dry adsorption would have scarcely any effect on the actual clinker burning process, so that retrofitting in existing plants would basically be possible. Extensive further studies would however have to be performed beforehand, with better adsorbents for example.

3.3 Performance of cement

Chemical composition of standard cements

The chemical composition of the cements produced by the VDZ member companies is checked at regular intervals by means of X-ray fluorescence analysis. **Table 3.3-1** lists the mean values, maximum values and minimum values of Portland cements of various strength classes in accordance with DIN EN 197. No systematic changes are apparent in the data in comparison with earlier surveys.

The shift in market share towards cements with several main constituents has continued, particularly in the lower strength classes. There has however been no further increase in the Portland composite cement segment ('type M cements'). The chemical composition of the most important CEM II cement types is shown in **Table 3.3-2**. In addition, use is also made of oil shale, fly ash or silica fume as main constituents for CEM II cements at certain production sites.

Table 3.3-3 provides a summary of the chemical composition of the blast furnace cements currently in production (CEM III/A and CEM III/B). Cement types CEM III/C, CEM IV and CEM V continue to be of lesser importance.

For all cement types, a trend towards higher strength classes is evident amongst the cements submitted for surveillance. The usual method employed to ensure that cements exhibit adequate early strength even with a reduced clinker factor is to increase the fineness of grinding. This does however often also lead to higher standard strengths, which may mean that the cement has to be assigned to a higher strength class.

Table 3.3-1 Chemical composition of portland cement of different strength classes, values in mass % including LOI

	CEM I														
Strength class	32,5 R			42,5 N			42,5 R			52,5 N			52,5 R		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
SiO_2	19.34	20.47	22.35	19.08	20.80	22.96	18.41	20.34	22.84	19.40	20.99	23.03	18.55	20.59	22.77
Al_2O_3	3.95	5.05	5.94	2.97	4.67	5.74	3.50	4.87	6.52	3.06	4.60	5.73	3.57	4.74	5.58
TiO_2	0.22	0.30	0.38	0.17	0.25	0.36	0.13	0.26	0.41	0.13	0.25	0.38	0.13	0.25	0.36
Fe_2O_3	2.09	3.34	6.57	1.36	2.83	6.70	0.08	3.07	6.81	0.22	2.79	6.60	0.23	2.48	3.91
Mn_2O_3	0.05	0.07	0.09	0.04	0.07	0.20	0.03	0.14	2.99	0.03	0.07	0.16	0.03	0.07	0.25
P_2O_5	0.12	0.21	0.39	0.07	0.21	0.46	0.00	0.19	0.47	0.04	0.20	0.43	0.04	0.20	0.48
CaO	60.80	62.36	63.72	61.10	63.95	65.86	59.90	63.25	66.12	61.03	64.19	66.05	61.66	64.24	66.02
MgO	0.80	1.86	3.20	0.77	1.42	3.69	0.66	1.60	3.61	0.66	1.40	3.31	0.66	1.39	2.86
SO_3	2.43	2.94	3.18	2.18	2.81	3.24	2.02	3.01	3.59	2.23	2.90	3.65	0.70	3.18	3.74
K_2O	0.70	1.01	1.48	0.33	0.75	1.42	0.33	0.89	1.43	0.33	0.70	1.25	0.33	0.77	1.48
Na_2O	0.12	0.20	0.26	0.08	0.18	0.30	0.08	0.19	0.34	0.07	0.18	0.30	0.07	0.18	0.30
$Na_2O_{equ.}$	0.65	0.87	1.20	0.33	0.67	1.21	0.43	0.78	1.15	0.30	0.64	1.03	0.31	0.69	1.11
LOI	1.41	2.14	2.98	0.30	2.04	3.41	0.28	2.12	4.29	0.53	1.68	3.72	0.69	1.88	3.53

Table 3.3-2 Chemical composition of CEM II-cements. values in mass % including LOI

	CEM II														
Cement type	CEM II/A-LL			CEM II/A-S			CEM II/B-S			CEM II/B-M (S-LL)			CEM II/B-P		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
SiO_2	17.32	18.87	22.01	20.71	22.23	24.77	23.32	24.72	26.34	19.18	21.74	26.74	27.90	30.11	33.33
Al_2O_3	2.96	4.46	5.37	4.45	5.68	6.52	5.72	6.49	7.42	4.83	5.51	5.93	6.92	7.91	8.77
TiO_2	0.17	0.24	0.30	0.24	0.47	4.01	0.31	0.40	0.50	0.27	0.31	0.35	0.34	0.41	0.51
Fe_2O_3	1.16	2.50	3.89	1.66	2.38	3.12	1.07	2.08	3.22	1.74	2.27	2.70	2.51	3.41	3.83
Mn_2O_3	0.03	0.07	0.26	0.06	0.12	0.34	0.06	0.15	0.53	0.06	0.12	0.20	0.06	0.10	0.14
P_2O_5	0.07	0.18	0.39	0.07	0.19	0.42	0.06	0.13	0.21	0.07	0.24	0.38	0.10	0.20	0.39
CaO	59.16	61.90	64.35	55.90	60.37	62.70	54.16	57.38	60.52	55.23	58.29	60.15	44.93	47.75	49.75
MgO	0.62	1.57	3.83	1.24	2.34	4.19	1.71	2.91	5.31	1.60	2.47	3.14	1.13	1.64	2.39
SO_3	2.14	2.94	3.63	2.17	3.12	3.64	2.03	2.91	4.12	2.58	2.96	3.48	1.61	2.72	3.31
K_2O	0.30	0.79	1.45	0.38	0.88	1.33	0.42	0.75	1.28	0.64	0.96	1.25	0.73	1.72	2.52
Na_2O	0.07	0.16	0.30	0.13	0.22	0.33	0.17	0.24	0.33	0.17	0.21	0.31	0.62	0.87	1.20
$Na_2O_{equ.}$	0.27	0.69	1.11	0.51	0.80	1.11	0.48	0.73	1.05	0.60	0.85	1.03	1.11	2.00	2.70
S^{2-}	–	0.07	0.10	0.06	0.20	0.36	0.14	0.34	0.56	0.11	0.19	0.37	–	–	–
LOI	3.56	6.26	9.59	0.39	1.85	2.79	0.25	1.68	2.74	1.52	4.80	7.71	1.60	3.11	4.29

Table 3.3-3 Chemical composition of blast furnace cements, figures in mass %, including loss on ignition

Cement type	CEM III					
	CEM III/A			CEM III/B		
	Min.	Mean	Max.	Min.	Mean	Max.
SiO_2	25.09	27.78	31.84	29.22	31.16	33.08
Al_2O_3	6.28	7.64	9.57	8.19	8.86	10.09
TiO_2	0.37	0.50	0.67	0.45	0.64	0.83
Fe_2O_3	0.85	1.59	2.80	0.67	1.05	1.41
Mn_2O_3	0.08	0.21	0.90	0.11	0.24	0.34
P_2O_5	0.03	0.11	0.26	0.03	0.06	0.15
CaO	46.66	52.59	56.52	46.26	48.33	49.70
MgO	2.75	3.90	6.56	3.85	4.69	5.70
SO_3	1.07	2.99	12.49	1.03	2.34	3.87
K_2O	0.34	0.72	1.19	0.47	0.66	0.89
Na_2O	0.14	0.26	0.44	0.19	0.27	0.40
$Na_2O_{equ.}$	0.32	0.73	1.04	0.51	0.70	0.92
S^{2-}	0.30	0.59	0.99	0.55	0.85	1.09
LOI	0.39	1.65	3.50	0.46	1.30	3.19

3.3.1 Influence of the lowering of the melting point and viscosity of the clinker melt by ashes of alternative fuels on sintering reactions and coating formation ■

IGF project 19221 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partner: Forschungsgemeinschaft Feuerfest e.V. (FGF)
Project period: 10/2016 – 03/2019

Background and aims

Fuel ashes can reduce the viscosity of the clinker melt. The aim of this research project is to investigate what effect this has on sintering reactions and the refractory lining in rotary kilns. A particularly important aspect is the question as to whether the minor oxides typical of alternative fuel ashes allow an adequate degree of sintering to be achieved at lower process temperatures. The study will specifically be concerned with the influences on the chemistry and mineralogy of clinkers, as well as on cement quality and the refractory material.

A database will be compiled as a means of enabling cement manufacturers to optimise melt phase formation with an appropriate choice of alternative fuels. On this basis, the manufacturers of refractory products will be able to extend their knowledge regarding the influence of alternative fuel ashes and a reduced operating temperature on coating formation and the stability of their products in rotary kilns.

Approach

Mixtures of raw meal and ash were produced for the investigations. Research was also conducted into various methods of determining the amount of melt and the melt formation temperature. Laboratory clinkers made from several mixtures doped with different ashes were produced in static and dynamic burning processes. This procedure was intended to permit determination of the influence of the burning process on melt formation. In addition, the quality of the laboratory clinkers was to be assessed. To be able to estimate the effects of the changes in melt formation on the refractory lining of the rotary kiln, coating formation and refractory corrosion will be analysed in a laboratory rotary drum installation.

Current status of the work

All the mixtures of raw meal and ash in this re-search project are based on the model systems of the completed research project IGF 16905 N (see VDZ Activity Report 2012-2015). The ashes were synthetically created compositions of chemically pure substances. Two raw meals were produced with different alumina ratios (1.2 and 1.7) and the same lime standard (93) and silica ratio (2.0). Alternative fuels in the form of light-weight fractions of industrial and commercial waste as well as sewage sludge were taken as a basis. In keeping with standard practice the major oxides from the ashes of these were counted as raw meal, so that the cement chemistry parameters of the raw meal remained unaltered. The minor oxides, which vary depending on the type of ash, were also added to the raw meals.

Determination of the melt formation temperature of the mixtures of raw meal and ash is of great significance. No routine method as yet exists for assessing the actual reduction in melt formation temperature brought about by fuel ash in clinker systems. Studies are being conducted into the suitability of simultaneous thermal analysis (STA) and high-temperature X-ray diffraction and, at the Forschungsgemeinschaft Feuerfest e.V., into the 'Method of Monotonic Heating' (MMH). At the same time, four relevant firing temperatures for burning the modified mixtures of raw meal and ash to form clinker are to be specified on the basis of the results from the above-mentioned methods. This procedure is intended to monitor the progress of clinker formation by means of in-depth clinker analysis.

In addition to studying the clinker quality, research is also to be performed into the influence of the fuel ash-induced reduction in melt temperature on the stability of the coating layer in rotary kilns. This will involve clinker burning in a laboratory rotary drum. Various refractory materials will be fitted in the test set-up and tested for coating formation in conjunction with different mixtures of raw meal and ash. The aim of the systematic studies performed by the Forschungsgemeinschaft Feuerfest e.V. is to check whether a clinker melt with appropriate adhesion properties, allowing effective coating formation even at lower process temperatures, is still obtained with the reduction in melt temperature brought about by fuel ash.

3.3.2 High-performance clinker for blast furnace cements ■

IGF project 18935 N supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 11/2015 – 04/2018

Background and aims

One of the methods employed in the cement industry to reduce specific CO_2 emissions is to produce cements with several main constituents. Together with Portland cement clinker, blast furnace slag is the most commonly used main cement constituent. In the building industry there is a widespread demand for blast furnace cements with high early strengths. The early strength development of a blast furnace cement is decisively influenced by the properties of its two main constituents, namely clinker and blast furnace slag.

Table 3.3.2-1 Composition of the laboratory clinkers and 2-day compressive strengths of CEM I and CEM III/A with 60 mass % blast furnace slag 1 (ggbs1).

Parameter		Unit	RK	K1	K2	K3	K4	K5	K6	K9	K8	K12[1]	K13[2]	K14[3]	K15[4]
C_3S			68.7	58.7	73.2	70.7	69.1	67.8	63.8	62.1	74.9	70.6	70.9	68.6	68.1
C_2S			13.8	24.1	10.1	13.7	12.6	11.4	14.2	19	9.2	12.7	10.8	15.2	14.2
C_3A_{cub}			2.4	3.7	7.8	2.0	8.0	14.5	0.8	8.9	1.3	4.1	3.9	5.8	6.2
C_3A_{orth}			7.6	4.5	1.6	1.8	5.6	3.8	12.0	4.2	3.9	1.4	4.8	0.5	0.4
C_3A_{total}		mass %	10	8.2	9.4	3.8	13.6	18.3	12.8	13.2	5.1	5.5	8.7	6.3	6.6
C_4AF			6.6	8	6.7	11.0	4	1.4	5.6	4.4	9.6	10.8	8.4	9.2	9.9
F^-			–	–	–	–	–	–	–	–	–	0.33	0.16	0.2	0.27
2-day compressive strength	CEM I[5]		39.8	33.3	42.9	36.7	46.8	39.6	39.9	42.2	39.3	39.5	42.9	42.2	39.2
	CEM III/A with ggbs 1	MPa	15.7	13.5	18.2	14.9	16.5	17.3	14.2	15.2	18.0	14.2	14.9	14.6	13.0

[1] Addition of 1 mass % CaF_2
[2] Addition of 0.5 mass % CaF_2
[3] Addition of 0.5 mass % CaF_2 and 2.5 mass % $CaSO_4 \cdot 2\,H_2O$
[4] Addition of 0.7 mass % CaF_2 and 2.0 mass % $CaSO_4 \cdot 2\,H_2O$
[5] On prisms (1.5 cm · 1.5 cm · 6 cm)

The aim of the research project was to improve the performance of blast furnace cements by adjusting the clinker phase composition (or through the addition of mineralisers in clinker production) and thus to enhance the 2-day compressive strengths of the corresponding cements. The optimum mineralogical composition of the clinker with regard to the reactivity of the blast furnace slag concerned was systematically determined.

Approach

The amounts of the four clinker phases (C_3S, C_2S, C_3A and C_4AF) and the C_3A modifications were systematically varied in 13 laboratory clinkers and the interaction of these clinkers with two different blast furnace slags was examined (**Table 3.3.2-1**). The way in which four differently mineralised clinkers (C12-C15) influence the early strength development of blast furnace cements was also investigated. Sulphate agent optimisation was performed, both in relation to the clinker produced and to sulphate activation of the blast furnace slags through the addition of anhydrite. To establish the effects of the various clinkers on the properties of the blast furnace cements, and in particular on early strength, prisms conforming to DIN EN 196-1 were produced using laboratory cements and then used to determine the one-day, two-day and 28-day compressive strength.

Results/current status of the work

Alongside a reference clinker (RC), twelve further clinkers were produced in the laboratory (**Table 3.3.2-1**). The C_3S, C_2S and C_3A contents of clinkers C1 to C9 were systematically varied in relation to the reference clinker. For clinkers C6 and C9, the C_3A modifications (cubic/orthorhombic) were varied. Laboratory cements (CEM I) were produced by grinding to 4 500 cm^2/g according to Blaine and mixing with a specified sulphate agent. Mini-prisms (1.5 cm x 1.5 cm x 6 cm) were made from these cements and used to determine the two-day compressive strength (**Table 3.3.2-1**). The investigations reveal that the composition of the Portland cement clinker has a significant influence on the compressive strength development of the CEM I cement. The Portland cements with clinkers C2 and C4 exhibited the greatest 2-day compressive strengths. The addition of 0.5 mass % CaF_2 also improved the 2-day compressive strength of the CEM I.

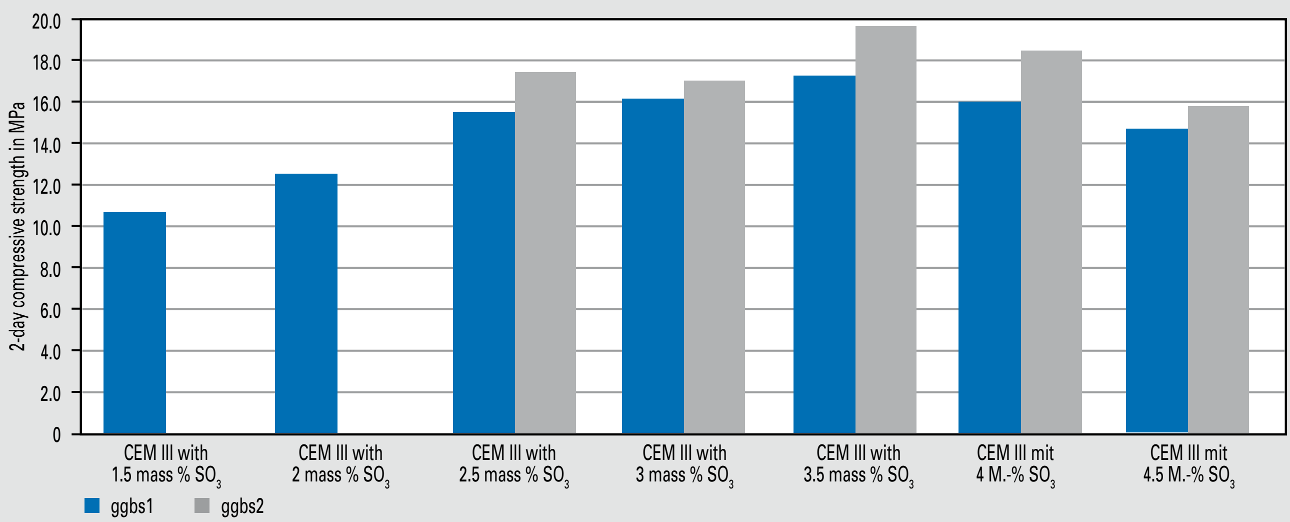

Fig. 3.3.2-1 2-day compressive strengths of mortar prisms with CEM III/A with 60 mass % blast furnace slag 1 (ggbs1) and blast furnace slag 2 (ggbs2)

The sulphatisation of blast furnace slags through the addition of anhydrite was studied as a secondary aspect. The aim was to achieve optimum sulphate activation of the blast furnace slags. For this purpose, CEM III/A cements (60 mass % blast furnace slag) with differing amounts of anhydrite were produced from Portland cement with optimised sulphate agents and two blast furnace slags and subsequently hydrated (w/c = 0.5). The amount of anhydrite added was varied for the blast furnace slag between 0 mass % (total SO_3 content 1.5 mass %) and 3.0 mass % (total SO_3 content 4.5 mass %). The maximum sulphate activation was established by assessing the two-day strength development of the CEM III/A cements (**Fig. 3.3.2-1**). With sulphate blast furnace slag activation, additional ettringite forms from the aluminate liberated from the blast furnace slag. This ettringite and the calcium silicate hydrates occurring at the same time make an additional contribution to early strength. This was equally apparent with blast furnace slags 1 (BS 1) and 2 (BS 2) with 3.5 mass % total SO_3 (2.0 mass % SO_3 addition as anhydrite). Increases of up to around 8 MPa (ggbs2) in early strength were attained here.

The influence of the different Portland cement clinker compositions on the early strength development of the blast furnace cements is shown by **Table 3.2.2-1**. An increase in both the C3S and the C_3A content as compared to the reference clinker has a positive effect on the 2-day compressive strength. This accordingly indicates that the optimum 2-day compressive strength with increasing C_3A content is obtained at around 13 to 18 %. A high C_3S content of the clinker also has a positive influence on the rate of reaction of the blast furnace slag, primarily on account of the greater $Ca(OH)_2$ development. Increasing the C_3S content of clinkers C2 and C8 for instance led to higher 2-day compressive strengths in comparison with the reference clinker.

Mineralisation of the clinkers (C12-C15) did not yield any significant improvement in the 2-day compressive strengths of the CEM III/A cements.

3.3.3 Assessment of Portland cement clinker employing microscopic and X-ray analysis to evaluate the clinker burning process ■

IGF project 18776 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 07/2015 – 03/2018

Background and aims

Clinker microscopy provides a good means of analysing the clinker burning process. It is however an elaborate procedure. A method was therefore developed which can be used to show correlations between clinker properties determined by microscopic/X-ray analysis and the firing conditions. This makes it possible to more quickly derive information on the firing conditions in the rotary kiln from the clinker properties. The process parameters for the firing conditions can then be optimised to ensure a constantly high clinker quality.

Approach

The effects of individual firing conditions on specific clinker properties were first analysed by way of light microscopy on a laboratory scale and compared to bibliographic data. The next stage involved checking the extent to which the relationships between clinker properties and firing conditions found in laboratory tests can also be applied to works clinkers produced with the fuel typically employed in Germany. The final step was to examine the way in which the clinker properties determined by way of elaborate light microscopy analyses are reflected in the properties revealed by X-ray analysis.

The light microscopy observations are based on Ono's method, which represents a combination of transmitted and reflected light examination techniques. In this process, semi-quantitative analysis is performed for four fundamental burning parameters (heating rate, maximum temperature, sintering time and cooling rate) on the basis of microscopic parameters (alite size, alite birefringence, belite size and belite colour). For detailed X-ray assessment, three diffractograms were evaluated for each sample (on the original sample, on the residue following methanol/salicylic acid decomposition and on the residue following KOH sucrose decomposition).

Results

Evaluation of the studies conducted on the laboratory clinkers using Ono's method revealed a relationship with the applicable clinker properties (belite size and belite colour), in particular for the sintering time and cooling rate burning parameters. Assessment of the maximum temperature and heating rate firing conditions did not reveal any systematic correlations with the alite-related parameters (alite birefringence and alite size). One possible reason for this could be the absence of dynamics in laboratory kiln burning operations in contrast to clinker production in a rotary kiln. In comparison with works clinkers, the alite crystals from laboratory clinker burning tended to be somewhat finer (approx. 10 to 12 µm).

Five works trials were performed with different flame shapes and lengths. The changes to the flame were brought about solely by regulating the air ratios at the main burner. Ono's method was largely verified by the works clinkers. The alite birefringence microscopic parameter increased on lengthening the flame, as the longer flame led to a drop in the maximum temperature in the sintering zone. Lengthening of the flame was accompanied by an increase in the size of the alite and belite crystals. There was a correlation between the alite size and a shorter heating rate, as well as between the belite size and a longer sintering time with lengthening of the flame. Assessment of the cooling rate with Ono's method did not yield any significant findings.

With regard to X-ray parameters, a linear relationship was established between the PO (Preferred Orientation) structure parameter and the alite size microscopic parameter. The PO is an evaluation parameter used in Rietveld analysis and is essentially influenced by sample preparation. When a powder sample is subjected to pressure, the crystals tend to become aligned in parallel with the surface depending on their size and in accordance with their main propagation directions. **Fig. 3.3.3-1** shows that the alite size decreases with an increasing PO value. This means that small alite crystals exhibit less of a preferred orientation after preparation.

There would appear to be a further correlation between the CS (Crystallite Size) structure parameter and the cooling rate. The CS is an indication of the size of ideally formed areas within a crystal. The size of the CS structure parameter of the dominant phase in the matrix (measured on the residue after methanol/salicylic acid decomposition) permits conclusions to be drawn about the cooling rate. The faster the clinker was cooled (comparison between planetary cooler and grate cooler), the smaller the C_3A and C_4AF crystals that could be detected with the microscope and the lower the corresponding CS value of this crystalline phase.

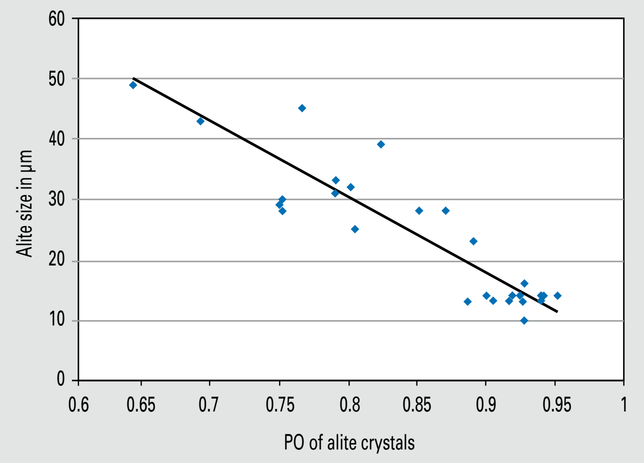

Fig. 3.3.3-1 Relationship between PO (Preferred Orientation) and alite size

3.3.4 Suitability of dolomite-rich carbonate rocks as main cement constituent

IGF project 18936 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 01/2016 – 06/2018

Background and aims

In accordance with EN 197-1, limestone for use as main cement constituent must have a calcium carbonate content (calculated from the CaO content) of at least 75 mass %, for example. This requirement is also satisfied by dolomitic carbonate rocks with a dolomite content of up to 54 mass %. Carbonate rocks with a higher dolomite content can therefore not be used as main cement constituent and only to a limited extent as raw meal component.

The aim of the research project is thus to investigate whether dolomite-rich carbonate rocks are also suitable as main cement constituent. This involved conducting tests on both cement and concrete. With regard to the carbonate rocks, another task was to analyse the influence of the rock-specific parameters and the role of the dolomite in cement hydration.

Approach

Five dolomite-rich carbonate rocks of differing geological origin with a dolomite content of between 61 and 98 mass % - four of which came from the quarries of cement works - were selected for the production of dolomite-rich cements. These were used in combination with four different Portland cements (two CEM I 42,5 and two CEM I 52,5) to produce 25 CEM II/B and 5 CEM II/A cements (with 30 and 20 mass % carbonate rock respectively). In addition, corresponding CEM II cements based on purely calcitic limestone were incorporated into the experimental programme as reference samples. Cement studies were performed on standard mortars to establish the setting behaviour, water demand and compressive strength. Based on the results, three of the five dolomites were then to be selected for the concrete tests. In combination with three of the four original Portland cements, around 50 concretes were produced on the basis of four concrete formulations and tested. The aspects studied were the fresh concrete properties, compressive strengths, freeze-thaw resistance (cube test), freeze-thaw resistance with de-icing salt (CDF test), carbonation depth and resistance to chloride penetration.

Results/current status of the work

The use of the various dolomitic carbonate rocks only resulted in slight differences of little significance, both among the samples and between these and the reference limestone. By contrast, the different Portland cements had a far greater influence on the cement properties. The compressive strengths after 7-day hydration were around 30 and 45 MPa and after 28-day hydra-

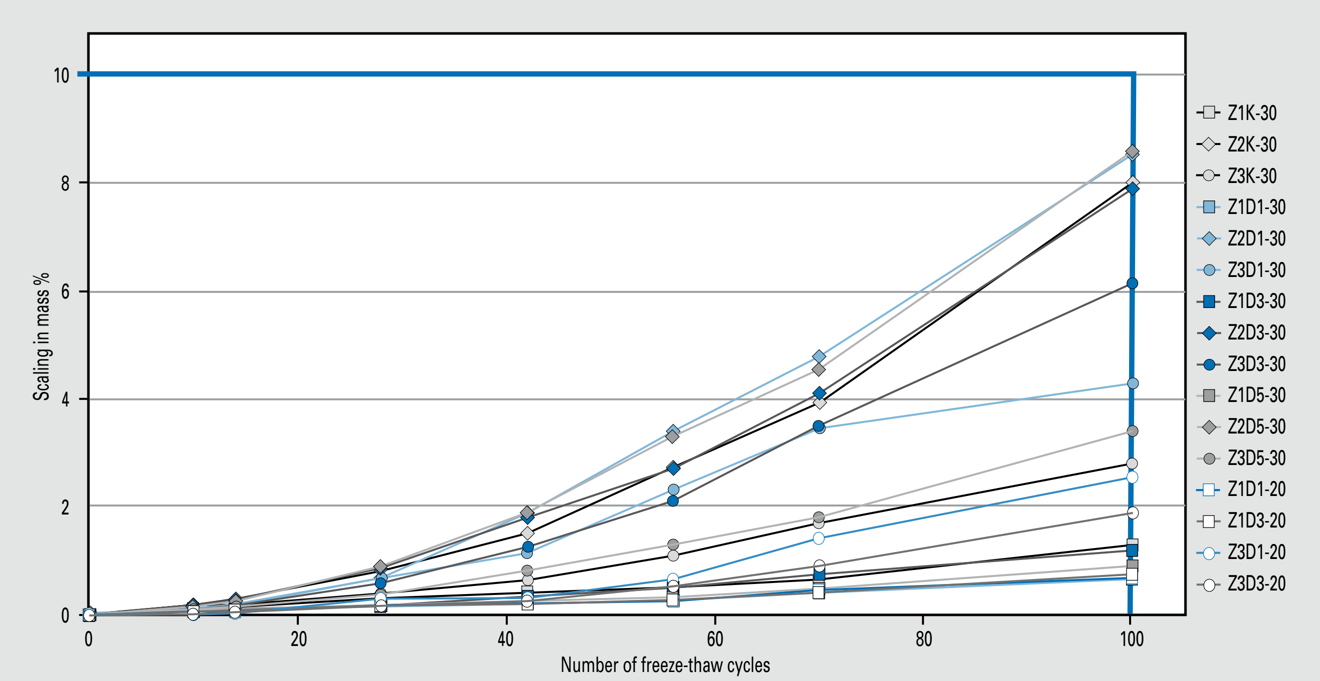

Fig. 3.3.4-1 Scaling (mass loss) of the concrete test specimens depending on freeze-thaw cycle storage (cube test)
Cements: Z1-Z3; Dolomites: D1, D3, D5; Reference limestone: K; Dolomite content: 30, 20, in mass %

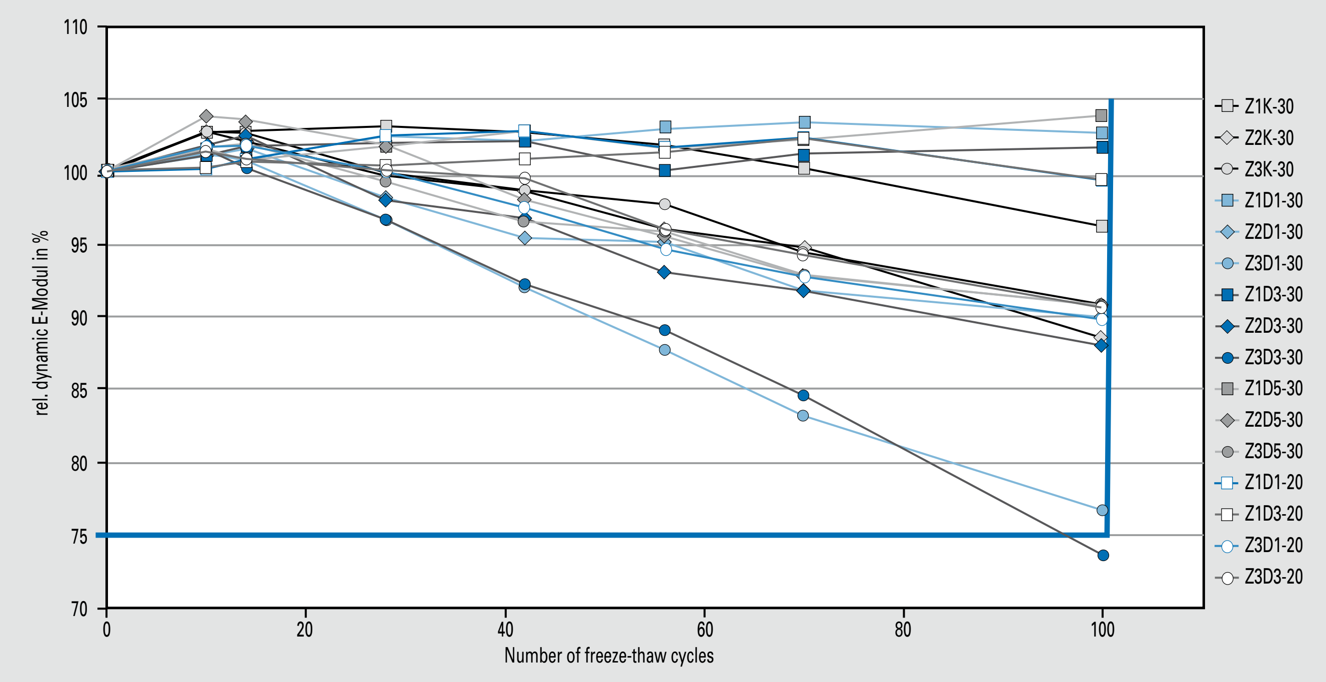

Fig. 3.3.4-2 Relative dynamic modulus of elasticity of the concrete test specimens depending on freeze-thaw cycle storage (cube test)
Cements: Z1-Z3; Dolomites: D1, D3, D5; Reference limestone: K; Dolomite content: 30, 20, in mass %

tion around 38 and 50 MPa for the CEM II/B cements based on a CEM I 42,5 and CEM I 52,5.

In the concrete tests performed so far, the dolomite-rich cements used also exhibited behaviour comparable to that of the cements based on the reference limestone. The studies conducted on fine concretes to investigate carbonation resistance after a preliminary storage time of 7/28 days revealed that the limit values defined by the German Institute for Building Technology (DIBt) were satisfied in all cases. After 140 days, the carbonation depths were less than 4 or less than 2 mm.

The 10 mass % limit value for scaling was never exceeded in the cube test (**Fig. 3.3.4-1**). With just one exception, the 75 % limit value for the relative dynamic modulus of elasticity was also satisfied (**Fig. 3.3.4-2**). (The concrete tests for freeze-thaw resistance with de-icing salt and for resistance to chloride penetration were still in progress at the editorial deadline).

3.3.5 Influences of temperature on interactions between superplasticizers and cements with several main constituents ■

IGF project 18642 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 04/2015 – 09/2017

Background and aims

To date, interactions between cements and superplasticizers have generally only been investigated at a standard temperature of around 20 °C. This was done to obtain defined conditions for specific analyses focusing on the influences of different superplasticizers and different cement constituents. Interactions between cements and superplasticizers are however temperature-dependent. Exact knowledge of the influences of temperature on such interactions is therefore of the utmost importance in order to be able to prevent unwanted reactions in concrete and so accommodate the increasing trend towards all-year-round concrete construction work.

The aim of the project was to determine the interactions between cements with several main constituents and superplasticizers in a temperature range between 5 °C (cold weather concreting) and 30 °C (hot weather concreting). These temperatures represent the minimum and maximum temperatures for the placement of

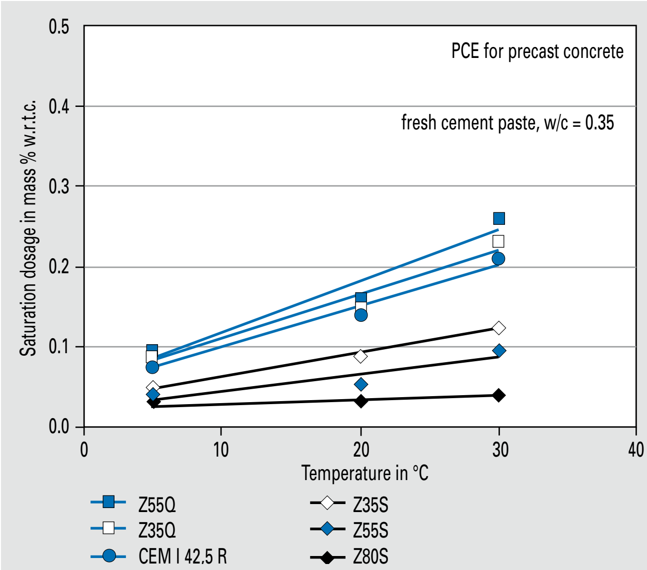

Fig. 3.3.5-1 Saturation dosage of cement paste with polycarboxylate ether (PCE) as a function of temperature and the proportion of calcined clay (Q) or blast furnace slag (S) of 35, 55 or 80 mass % in the cement

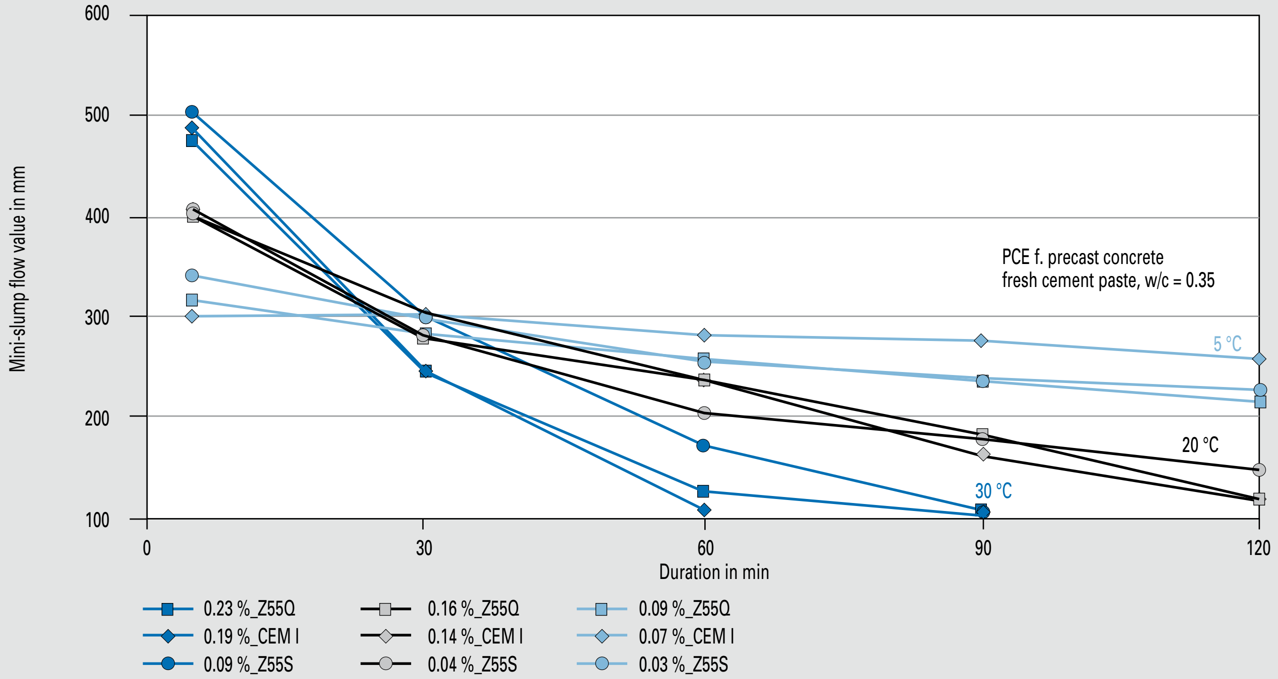

Fig. 3.3.5-2 Plasticising effect of polycarboxylate ether (PCE, see key for active agent dosage) and plasticisation time as a function of the cement and temperature

fresh concrete which are permissible without further measures in accordance with DIN 1045-3.

Approach

Interactions between ten cements and three commercially available superplasticizers were determined in a temperature chamber at 5, 20 and 30 °C. One superplasticizer was based on naphthalene sulfonate and two on polycarboxylate ether (PCE). The PCEs differed in terms of their areas of application (ready-mixed concrete and concrete for precast components). The cements had the same clinker and sulphate component, as well as up to 35 mass % limestone, up to 55 mass % calcined clay or siliceous fly ash or up to 80 mass % blast furnace slag. The sorption and plasticising effect of the superplasticizers, as well as the cement paste plasticisation time were established by way of TOC analyses and rheological measurements. The effective amount of charge of the superplasticizers, the ionic composition of the pore solution and the zeta potential were also determined. The findings were checked in concrete tests.

Results

The superplasticizer dosage required to plasticise the reference samples with Portland cement CEM I 42,5 R (saturation dosage) dropped on reducing the temperature from 30 °C to 5 °C. This can be attributed to the decreasing reactivity/hydration of the cement associated with reducing the temperature. Consequently a larger proportion of the water added was available for fluidification. At the same time fewer hydrate phases were to cover with active agent.

The influence of temperature decreased with increasing replacement of the clinker (reactive, temperature-dependent component) in the cement. Responsible for this were the other cement main constituents, which are still inactive in the early phase of hydration and are so less influenced by different temperatures. The properties of these then increasingly defined the saturation dosage of the superplasticizer in the cement paste or concrete. Higher proportions of limestone, fly ash or blast furnace slag in cement resulted in a decrease in the saturation dosage on account of their small specific surface areas. The cement samples with 55 or 80 mass % blast furnace slag, for example, exhibited hence low saturation dosages that were comparatively independent of the temperature (**Fig. 3.3.5-1**). An increasing proportion of constituents with a far larger specific surface area (e.g. calcined clay or limestone with higher clay mineral content) in the cement may increase the saturation dosage and make more superplasticizer necessary to achieve the same plasticisation. Expansive clay minerals in limestone, in calcined clay or in the fine fractions of the aggregate may distinctly reduce the effectiveness of PCE. The effectiveness of naphthalene sulfonate was also always inferior to that of the two PCEs at 5 °C and 30 °C.

The PCE for ready-mixed concrete achieved the desired moderate plasticisation of cement paste or concrete with comparatively little dependence on the cement and relatively little dependence on temperature. The plasticisation time was, as expected, very distinctive. It increased slightly with decreasing temperature; there was no unwanted late plasticisation. By contrast, the molecule-specific effect of the PCE for precast concrete (high degree of plasticisation, short plasticisation time) diminished appreciably with decreasing temperature, irrespective of the cement. The action of this PCE at 5 °C was not as expected, more like that of a PCE for ready-mixed concrete: the plasticisation was only moderate and hardly diminished over the course of the experiment (**Fig. 3.3.5-2**). The naphthalene sulfonate exhibited the expected effect for the tested combinations of cement and temperature (moderate plasticisation, short plasticisation time). This became slightly longer with decreasing temperature and in particular at 30 °C with increasing replacement of the clinker in the cement.

Table 3.3.6-1 Requirements for cement with a low effective alkali content in accordance with DIN 1164-10

Cement type	Blastfurnace slag in mass %	Na_2O-equivalent in mass %
CEM I to CEM V	–	≤ 0.60
CEM II/B-S	≥ 21	≤ 0.70
CEM III/A	≤ 49	≤ 0.95
	≥ 50	≤ 1.10
CEM III/B	–	≤ 2.00
CEM III/C	–	≤ 2.00

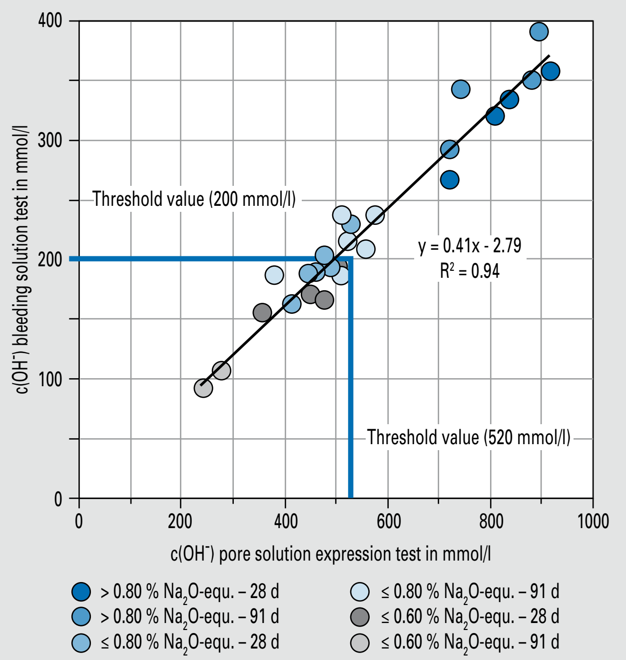

Fig. 3.3.6-1 Hydroxide ion concentration of different Portland cements with the expression method (water-cement ratio = 0.50) and the solution method (water-cement ratio = 1.00; testing of supernatant solution), after 28 and 91 days

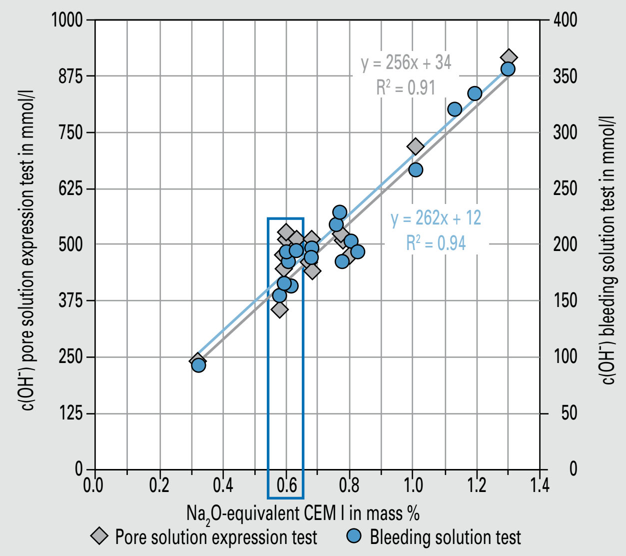

Fig. 3.3.6-2 Hydroxide ion concentration of different Portland cements with the expression method (water-cement ratio = 0.50) and the solution method (water-cement ratio = 1.00; testing of supernatant solution) after 28 days as a function of the Na_2O equivalent

3.3.6 Testing and assessment of effective alkali content in cements

IGF project 19295 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 01/2017 06/2019

Background and aims

For concrete constructions in which use is made of alkali-reactive aggregates, it is, in certain cases, only possible to achieve sufficient resistance to deleterious alkali-silica reaction (ASR) by employing cements with low effective alkali content (low-alkali cement).

DIN 1164-10 defines the property 'low effective alkali content' on the basis of the total alkali content and, if applicable, the slag content (**Table 3.3.6-1**). The influence of different blast furnace slags and other main cement constituents such as limestone (LL) on the effective alkali content of a cement has so far not, or not fully, been taken into account in the simplified method of determining the total alkali content. The aim of the project is to develop a testing and evaluation concept for the effective alkali content of cements to give closer consideration to the material properties of the cements.

It could then also be possible to derive assessment criteria for cement to avoid ASR damage with the use of moderately alkali-reactive aggregates. This refers to aggregates belonging to a previously non-defined alkali reactivity class E II-S. The new class would come about if the existing alkali reactivity class E III-S for alkali-reactive aggregates were to be divided up into the two new classes E II-S (moderately alkali-reactive) and E III-S* (alkali-reactive). A first proposal for the definition of this class has already been made in an earlier VDZ project. On this basis it might then be possible to make even more efficient use of the material resources in certain regions of Germany in the future.

Approach

CEM I low-alkali cements, road pavement cements and laboratory cements of different composition are to be examined by means of the expression method and the solution method. For the expression method, hardened cement pastes with a water-cement ratio of 0.50 are produced, and the pore solution extracted from these by means of expression at high pressure. The water-cement ratio for the solution method is 1.00. Supernatant water forms over the hardened cement paste. This is in equilibrium with the pore solution and can be extracted for analysis. There is no need for an elaborate expression process. Both methods involve examination of the hydroxide ion concentration of the solution as a basis for evaluating the effective alkali content of cements. The hydroxide ion concentrations determined will be compared to the results of concrete tests conducted in the laboratory (ASR performance tests) and to the results of concrete tests with outdoor exposure storage performed over the last forty years. This will provide a basis for deriving assessment criteria for the effective alkali content of low-alkali cements in accordance with DIN 1164-10 and of road pavement cements in accordance with the Technical terms of delivery for construction materials and material mixtures for base courses with hydraulic binders and concrete surfacing (TL Beton-StB 07).

Results/Current status of the work

The following results have been obtained so far with Portland cements:

- Good correlation exists between the hydroxide ion concentrations from the expression method and the solution method (**Fig. 3.3.6-1**).
- To derive threshold values for low-alkali cements, various Portland cements with an Na_2O equivalent between 0.58 mass % and 0.61 mass % were initially examined alongside cements with several main constituents. The Portland cements with an Na_2O equivalent ≤ 0.60 mass % exhibit hydroxide ion concentrations ≤ 520 mmol/l (pH value 13.72) with the expression method and hydroxide ion concentrations ≤ 200 mmol/l (pH value 13.29) with the solution method (**Fig. 3.3.6-1**). A condition for the threshold values was that Portland cements with an Na_2O equivalent of ≤ 0.60 mass % can still be assessed as being low-alkali cements if at all possible.
- **Fig. 3.3.6-2** shows that the hydroxide ion concentrations of Portland cements with a comparable Na_2O equivalent of around 0.60 mass % (blue border) differ clearly with the expression and the solution method. As different cements contribute different amounts of alkali to the pore solution, the hydroxide ion concentrations of cements with an Na_2O equivalent of greater than 0.60 mass % may in some cases also be below the threshold values shown in **Fig. 3.3.6-1**. The clinker composition of the cements is to be additionally investigated with a view to clarifying the cause of the moderate correlation between the Na_2O equivalent and the hydroxide ion concentrations.

3.3.7 Modified sulphate resistance testing procedure

IGF project 18024 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 01/2014 – 06/2016

Background and aims

In practice, all CEM I-SR and CEM III/B-SR cements exhibit a high sulphate resistance. This property, which has been known for decades, is however not always reflected in the testing procedure for determining sulphate resistance (SVA method) required by the expert committee of the German Institute for Building Technology (DIBt). The intention is to identify the cause of this and to modify the testing procedure to make it possible to obtain clear-cut test results for standardised cements known to have a high or low sulphate resistance. It should then also be possible to reliably assess the sulphate resistance of cements with several main constituents (in particular those containing fly ash or natural pozzolana). The aim of the research project was thus to develop a new, robust and more realistic testing procedure for determining the sulphate resistance of cements.

Approach

Ten CEM I-SR cements, in other words the entire range of SR Portland cements produced in Germany, as well as various CEM III/B-SR cements and ordinary Portland cements were tested. This was done both by means of the existing SVA method and the new variation of this proposed by the expert committee. In both variants relative changes in the length of flat mortar prisms were determined following storage in test and reference solution. There were differences in the sulphate concentration of the test solution (30 and 3 g/l) and in the storage duration (182 days and 2 years).

Further modifications of the testing procedure were also studied. In addition to the lower sulphate concentration of 3 g/l, these related to the water-cement ratio (w/c, 0.60 instead of 0.50), the test specimen geometry (cylinders as opposed to flat prisms), the nature and duration of preliminary storage and the composition of the test solution (mixture of calcium, sodium and magnesium sulphate instead of just sodium sulphate). The best version proved to be the one in which mortar cylinders with a w/c ratio of 0.60 were produced and placed in preliminary storage for one day in the mould at 20 °C and for nine days at 40 °C; with subsequent testing over the course of 180 days in sulphate solution (2 125 mg $CaSO_4$, 1 035 mg Na_2SO_4, 1 000 mg $MgSO_4$ per litre). This modified procedure was then used at the end of the project to also test the sulphate resistance of cements with several main constituents, in particular cements containing pozzolana and blast furnace slag.

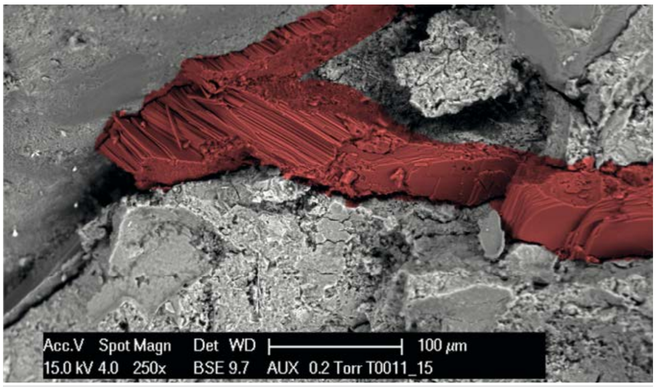

Fig. 3.3.7-1 SEM photomicrograph, secondary gypsum formation in a CEM I-SR mortar test specimen

Results

As already described in the VDZ Activity Report 2012-2015 (see chapter 2.3.6), it was not possible to obtain clear differentiation between SR and non-SR Portland cements using the standard existing SVA flat prism method. This was due to the fact that the majority of SR cements exhibited greater changes in length than the values stipulated in the test criteria. Investigation of the mortar microstructure revealed that the relatively great changes in length of the CEM I-SR cements can be primarily attributed to the formation of secondary gypsum (**Fig. 3.3.7-1**).

By contrast, the new version of the SVA method defined by the DIBt expert committee made it possible to achieve far better differentiation between SR and non-SR cements. A test duration of at least roughly one year is however necessary for this.

The best differentiation between SR and non-SR cements was obtained with an unchanged test duration of 182 days employing the new modified testing procedure described above, assuming a limit of 0.6 mm/m for the relative change in length (**Table 3.3.7-1**). CEM I-SR cements exhibited virtually no unexpectedly great changes in length, and the experiments performed so far with cements with several main constituents also produced results which correspond to practical experiences (**Fig. 3.3.7-2**).

The results are to be presented to the DIBt expert committee. This could adopt the modified test method as a procedure for SR approval testing. The test method is also to be presented to the European standardisation group CEN TC51/WG12/TG1, which is currently working on a European testing procedure for SR cements. In the medium to long term, the results of the research project could therefore contribute towards the definition of a European testing procedure for SR cements.

Table 3.3.7-1 Overview of sulphate resistance test methods

	SVA method	Alternative SVA method	Modified test method
Test specimen	Mortar flat prisms 1 cm x 4 cm x 16 cm	Mortar flat prisms 1 cm x 4 cm x 16 cm	Mortar cylinder Ø 2 cm x 16 cm
w/c ratio	0.50	0.60	0.60
Preliminary storage	14 d, 20 °C, 2 d in the mould, rest in calcium hydroxide solution	28 d, 20 °C, 2 d in the mould, rest in calcium hydroxide solution	1 d at 20 °C, of which the first 6 h rotating, 9 d at 40 °C, sealed
Sulphate solution	29 800 mg sulphate (Na_2SO_4)	3 000 mg sulphate (Na_2SO_4)	3 000 mg sulphate (2 125 mg $CaSO_4$, 1 035 mg Na_2SO_4, 1 000 mg $MgSO_4$)
Storage temperature	5 °C, 20 °C	5 °C, 20 °C	5 °C, 20 °C
Test duration	182 d	≥ 365 d	182 d
Examinations	Change in length, dynamic modulus of elasticity	Change in length, dynamic modulus of elasticity	Change in length, dynamic modulus of elasticity, Flexural strength

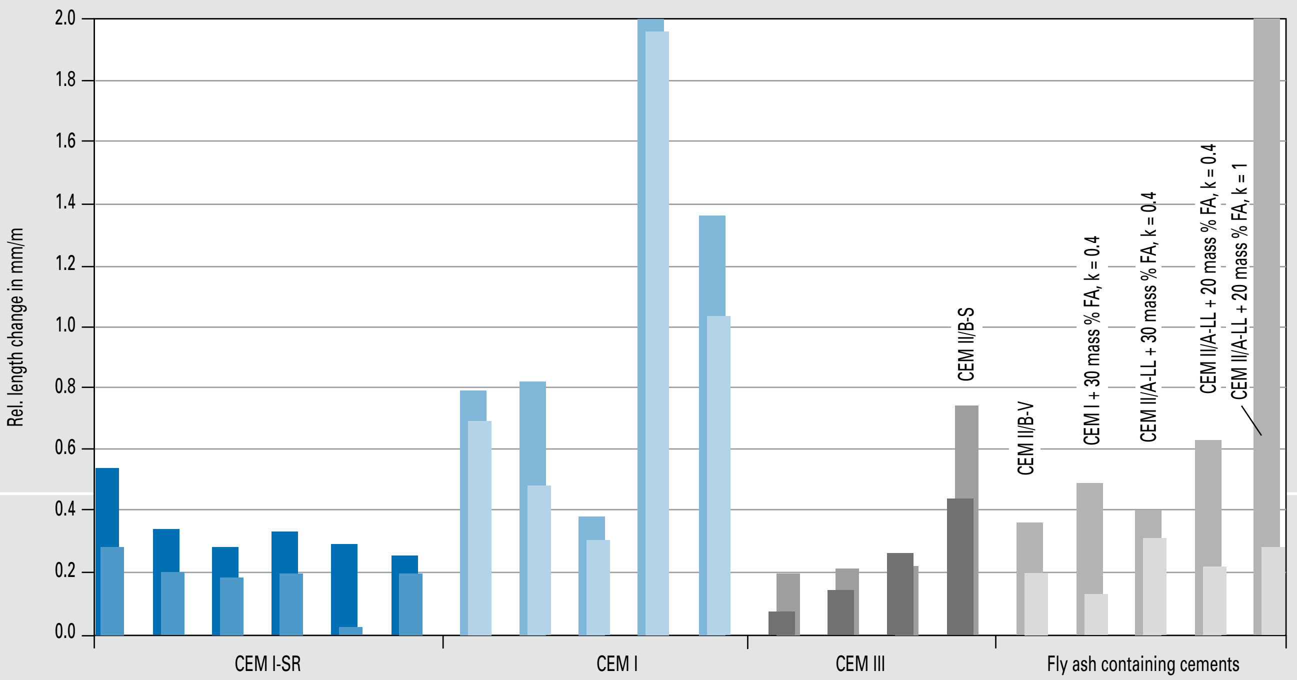

Fig. 3.3.7-2 Relative change in the length of the mortar test specimens after 182 days storage in sulphate solution (at 5 °C: dark colours, at 20 °C: light colours)

3.4 Performance of concrete

3.4.1 ASR damage potential for concrete pavements on roads and in bus traffic and parking areas in the municipal sector ■

IGF project 18775 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 07/2015 – 12/2017

Background and aims

Damage to concrete pavements on German motorways caused by alkali-silica reactions (ASR) gave rise to the development of ASR performance testing procedures. The General Circular on Road Construction (ARS) No. 04/2013 on the topic of alkali reactivity and corresponding testing procedures was published with a view to avoiding damage on motorways and trunk roads. In this, the moisture classes WA (concrete which is often moist, or moist for lengthy periods, and is often exposed, or exposed for lengthy periods, to an external supply of alkali in the course of use) and WS (concrete, which in addition to the exposure associated with class WA is subject to a high dynamic load level) are assigned on the basis of the construction or load class derived from the Guidelines for the Standardisation of Surfaces of Road Traffic Areas (RStO) (**Table 3.4.1-1**). The suitability of aggregates or concretes for class WS can be verified by subjecting the concrete to a WS aggregate test or an ASR performance test. Many traffic areas in the municipal sector are assigned to load classes Bk1.8 to Bk100 and thus, by analogy, to moisture class WS in accordance with the circular. These include bus stops, parking areas and many types of urban road, for example. The WS classification was defined for motorways (external alkali supply and high dynamic load). On account of the lower speeds involved, the dynamic traffic load is probably not as high in municipal areas. In addition, gritting agents tend to be used rather than thawing agents, thus reducing the alkali supply and the risk of damaging ASR. Moisture class WA or a comparable classification may therefore be sufficient. The stipulations of the Alkali Directive of the German Committee for Structural Concrete (DAfStb) would be applicable to moisture class WA.

Many applications in the field of municipal road construction involve smaller construction jobs than in the case of motorways and so do not warrant setting up an on-site mixing plant. The concrete therefore tends to be supplied by ready-mixed concrete companies. Practical experience since the introduction of the ARS has shown that problems are encountered with smaller building projects in particular, because moisture class WS is now demanded on the basis of the load class. As neither WS aggregate tests nor performance tests are available in many regions, it is often not possible to use concrete construction methods in urban areas. Ready-mixed concrete with the necessary verification cannot be supplied. The aim of the research project was to provide the municipal traffic area sector with findings as a basis for practicable moisture class assignment and corresponding evaluation of the concrete by way of performance tests, for example.

Approach

The research project was conducted in three work packages. The first step was to study concrete sections from the municipal sector or comparable applications where good practical experience had been gained. A prerequisite was a service life of at least 10 years without any evidence of damaging ASR. The surfaces were visually inspected for ASR-specific damage characteristics and the following data were recorded where available: Starting materials (cement type, alkali content, aggregates), concrete composition and other boundary conditions (year of construction, surface, use of thawing agents). In order to establish the behaviour of the concretes in laboratory tests, the second step involved taking drill core samples from the pavements and examining them with the testing procedures developed by VDZ for the moisture classes WA and WS. Chloride profiles were also determined for selected concrete pavements and compared to the results from motorways. Finally, selected concretes were replicated in the laboratory. WS and WA performance testing was conducted on the basis of the information from the original initial test, and fog chamber testing of the aggregates (crushed stone and gravel) was performed in accordance with the alkali directive.

Table 3.4.1-1 Assessment of moisture classes of Federal roads and suggestion for areas in the municipal road construction

RStO 01 Design relevant load B[1)]	RStO 12 Dimensioning relevant load B[1)]	RStO 01 Construction class	RStO 12 [7] Load class	Moisture class: Highways acc. ARS	Moisture class: Areas in municipal road construction (suggestion VDZ)
> 32		SV	Bk100	WS = Moisture class WS	WS = Moisture class WS
10 to 32		I	Bk32		
3 to 10	3.2 to 10	II	Bk10		WA = Moisture class WA Extension up to Bk10
0.8 to 3	1.8 to 3.2	III	Bk3,2		
	1.0 to 1.8		Bk1,8		
0.3 to 0.8	0.3 to 1.0	IV	Bk1,0	WA = Moisture class WA	
0.1 to 0.3	< 0.3	V	Bk0,3		
to 0.1		VI			

[1)] Equivalent 10 t single axis load in million

Test results

In the 60 °C concrete test with external alkali supply, all but one of the drill cores exhibited expansion below the assessment criterion for moisture class WA (**Fig. 3.4.1-1** left). Expansion above the assessment criterion was found in one instance (section no. 8). According to the sample provider, the section is 10 years old and undamaged. On account of the assignment of the aggregate to class E III-S on the basis of fog chamber testing, the concrete would not correspond to the alkali directive in moisture class WA. In the case of section no. 3 from the hard shoulder of a motorway, the crushed stone would be likewise assignable to E III-S, which means that according to the alkali directive it should not be used in moisture class WA with a cement content > 350 kg/m^3. With a cement content up to 350 kg/m^3 the aggregate could be used with low-alkali cement. For the concrete of section 3 the figure was 350 kg/m^3 and the cement used had low-alkali properties.

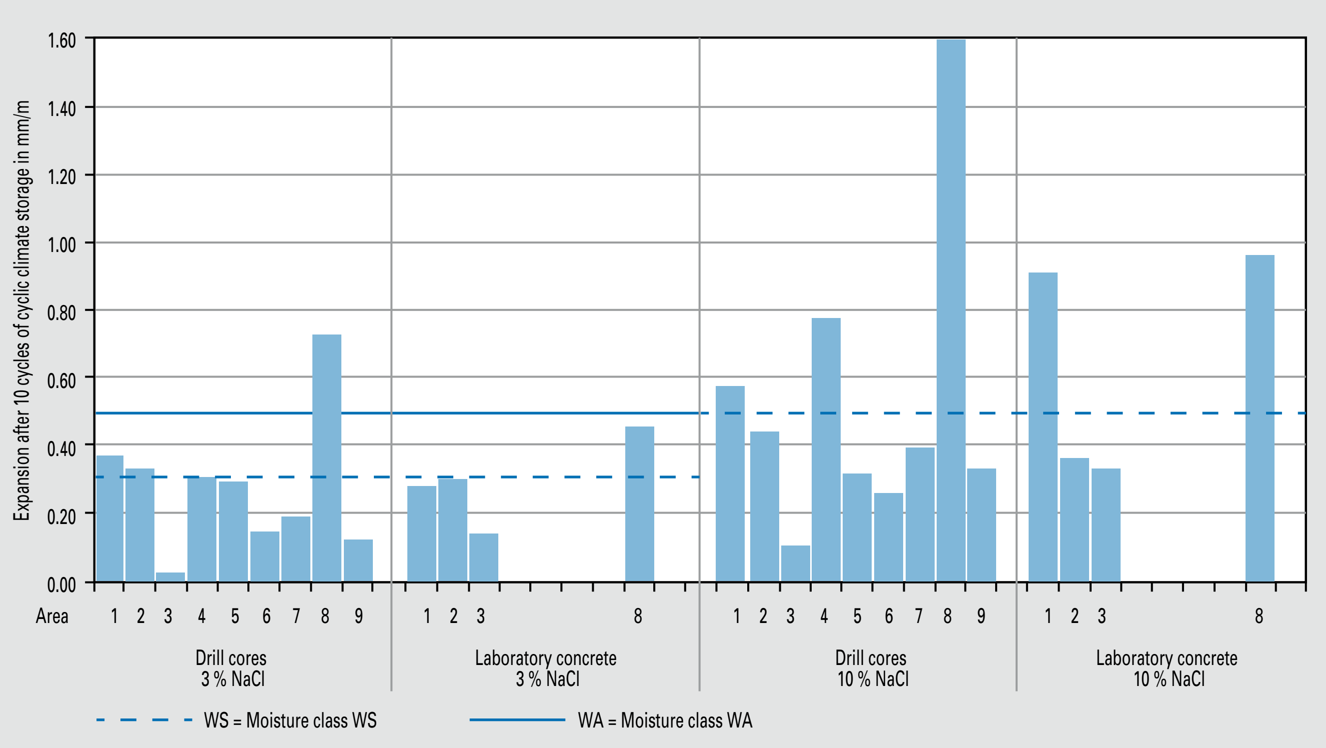

Figure 3.4.1-1 Expansion of drill core halves rsp. concrete beams after ten cycles of alternating storage in the 60 °C-concrete test with external alkali supply through a 3 % rsp. 10 % sodium chloride solution

All four of the laboratory concretes exhibited expansion below the assessment criterion for moisture class WA. Five out of nine drill cores also satisfied the assessment criteria for moisture class WS. This likewise applied to two laboratory concretes.

In the cases examined, application of the stipulations of the alkali directive for moisture class WA appears to be appropriate for road pavements. For concrete road pavements in the municipal sector up to and including load class Bk10, the recommendation is to base measures to prevent ASR on moisture class WA in the future (**Table 3.4.1-1**, right-hand column). The concrete compositions and the starting materials must conform to the requirements of the alkali directive. The requirements for cements in accordance with TL Beton-StB (Technical terms of delivery for construction materials and material mixtures for base courses with hydraulic binders and concrete surfacing) would remain applicable irrespective of the moisture class if the invitation to tender makes reference to the TL Beton-StB. In the event of classification in moisture class WA, the cement may additionally be subject to the requirements of DIN 1164-10 (low-alkali cement) in certain cases. Performance tests would then have to be conducted in the cases defined in the alkali directive or in case of doubt.

3.4.2 Behaviour of different types of rock under accelerated conditions in ASR testing procedures ■

IGF project 19077 BG, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partners: TU Munich (Centre for Building Materials (cbm)), Bauhaus Universität Weimar (F. A. Finger Institute of Building Materials Science (FIB))
Project period: 03/2016 – 02/2019

Background and aims

With the General Circular on Road Construction (ARS) No. 04/2013, the German Federal Ministry of Transport, Building and Urban Affairs introduced a range of measures which also include testing procedures for the avoidance of damage due to alkali-silica reaction (ASR) in newly constructed concrete road pavements for trunk roads (moisture class WS). The procedure described in ARS No. 04/2013 (ASR performance test and WS aggregate test) has become successfully established in practice in regions which are known for reactive aggregates and the frequent occurrence of damage. With the introduction of ARS No. 04/2013, this procedure is now also to be applied in regions in which there would appear to have been hardly any ASR-related problems to date. There are however certain indications that the tests do not always produce results that coincide with the knowledge currently available from practical experience. In the light of this, the purpose of the IGF project 19077 BG is to obtain fundamental findings about the behaviour of different types of rock under the accelerated conditions of the ASR testing procedures. The results of the research should help to create a basis for both reliable and practicable assessment of aggregates for use in concretes of moisture class WS. The aim is to ensure that the existing level of assurance is maintained, without however ruling out locally available aggregates and concretes which would be suitable for use.

Approach

Seven types of crushed stone and four quartz sands were selected for study. These differed in terms of their reactivity and had in some cases exhibited anomalous behaviour in earlier tests. Following basic chemical and mineralogical characterisation of the aggregates, use was made of different crushed stone and quartz sand combinations to produce a total of twelve concrete formulae, the behaviour of which was studied in the 60 °C

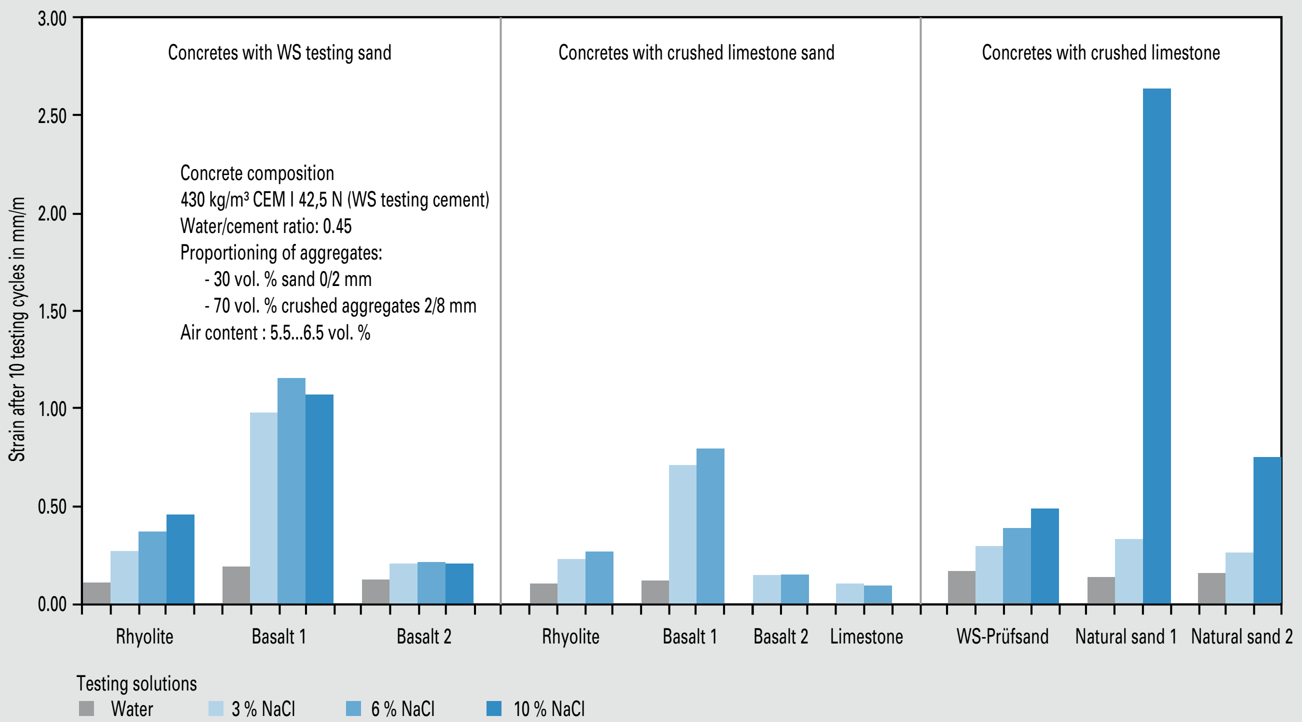

Fig. 3.4.2-1 Expansion of different concretes after ten test cycles in the 60 °C concrete test with alkali supply employing different test solutions and with water as test solution

concrete test with alkali supply (research locations VDZ and cbm) and, in some cases, in cyclic climate storage (research location FIB). The composition of the concretes was chosen on the basis of the specifications of ARS No. 04/2013 for top layer concrete in WS aggregate tests. In certain mix formulations, use was made of an inert crushed limestone sand or of two natural sands with different reactivity, instead of the WS test sand specified by ARS No. 04/2013. The influence of the sands on the test result is to be investigated with these aggregate combinations. By specifically varying the concentration of the storage solution in the 60 °C concrete test with external alkali supply, it will be possible to establish the influences of the accelerated testing conditions. In addition to the 3 % NaCl and 10 % NaCl test solutions normally used, 6 % NaCl dosing is also to be employed. The study will also involve storage in water without NaCl dosing.

On completion of the concrete tests, all the test batches will be examined for any microstructural changes by performing polarised light microscopy on thin sections and accordingly subjected to petrographic and microanalytical characterisation. The chemical composition of any ASR products formed will be determined on selected samples by means of SEM / EDX.

The solution behaviour of the individual aggregates is to be investigated in artificial pore solutions. The storage solutions will take the form of an artificial pore solution ($KOH + Ca(OH)_2$), in some cases with additional dosing of 3 % and 10 % NaCl on the basis of the concrete tests. After a storage time of 28, 91, 180 and 365 days, the storage solution will be removed and analysed. The aim of the solution tests is to study the influences of accelerated testing conditions (temperature, solution concentrations) on each of the aggregates irrespective of the concrete microstructure.

Current status of the work

As was to be expected, the results obtained so far from the 60 °C concrete tests with alkali supply and with water as test solution show that in nearly all cases greater expansion is found the higher the amount of NaCl in the test solution (**Fig. 3.4.2-1**). An exception to this behaviour is exhibited by the concrete with WS test sand and basalt 1, where greater expansion was found with alkali supply in the form of a 6 % NaCl solution than with a 10 % NaCl solution.

The expansion of all the concretes with the inert crushed limestone sand is less than that of the corresponding concretes with WS test sand. In some cases, the concretes with different quartz sands in combination with the inert crushed limestone sand exhibit great expansion, in particular with alkali supply from a 10 % NaCl solution. From these intermediate results it is possible to conclude that the quartz sand can have a significant influence on the expansion of the concrete, which is used as assessment criterion for ASR resistance.

In the further course of the project, thin sections from the concrete test specimens will be examined for microstructural changes and possible crack formation by way of transmitted light microscopy. The microscopic studies and the solution tests (neither of which had been completed at the time of publication) should together contribute towards a better understanding of the reaction mechanisms under accelerated testing conditions.

3.4.3 Carbon Concrete Composite – C³

C³ Carbon Concrete Composite is the largest building research project currently in progress in Germany. Even before its completion, the C3 project received the 2015 German Sustainability Award in the Research category and the 2016 German Future Prize. More than 130 partners from science, industry and various associations are involved in the ambitious project, researching into carbon concrete and helping it to become established as a new construction material. VDZ is participating in three sub-projects. The C³-Carbon Concrete Composite research project is supported by the German Federal Ministry of Education and Research (BMBF), as part of the 'Twenty20 Partnership for Innovation+ programme.

3.4.3.1 Sub-project 1: Proofs and testing concepts for standards and approvals

Project partners: TU Dresden: Institute of Concrete Structures (project coordinator) and others[1)]
Project period: 12/2015 – 03/2018

Background and aims

One of the aims of the project is to lay down clear-cut regulations with a view to eliminating market obstacles. Together with the German Committee for Structural Concrete (DAfStb), the German Society for Concrete and Construction Technology, renowned universities and other partners from the industry, VDZ is helping to create a foundation for regulation. This would apply to the use of carbon concrete for both reinforcement purposes and new components. Based on the results of the research project it will then be possible to draw up regulations aimed at enabling carbon concrete to become established in practice.

Approach

Work on the regulatory foundations was organised on the basis of the following subject areas: 'Design', 'Carbon reinforcement', 'Concrete matrix' and 'Execution of work'. VDZ is responsible for coordination of the 'Concrete matrix' task group. The first step was to compare the information already available on concretes which can be used in combination with carbon reinforcement with existing national and European regulations. In particular, these are EN 206-1, DIN 1045-2 and the DAfStb guidelines 'Strengthening of concrete components with adhesively bonded reinforcement' and 'Production and use of dry concrete and dry mortar'.

Carbon reinforcement primarily takes the form of rovings, some of which have far smaller mesh sizes than steel mats (e.g. 38 mm). This gives rise to the use of aggregate grading curves with a maximum particle size of around 13 mm. So far, reference concretes with a maximum particle size of 8 mm for normal-weight concretes and 5 mm or 2 mm for high-strength concretes have been employed for research purposes. The small maximum particle size results in a low packing density of the aggregate and hence a high paste requirement, as well as a powder content in excess of the currently standardised maximum permissible content. The powder content of the concrete influences various fresh concrete and hardened concrete properties, such as workability, shrinkage, creep, modulus of elasticity and freeze-thaw resistance.

There was thus a need to establish whether the relationships between the various hardened concrete properties applied to date

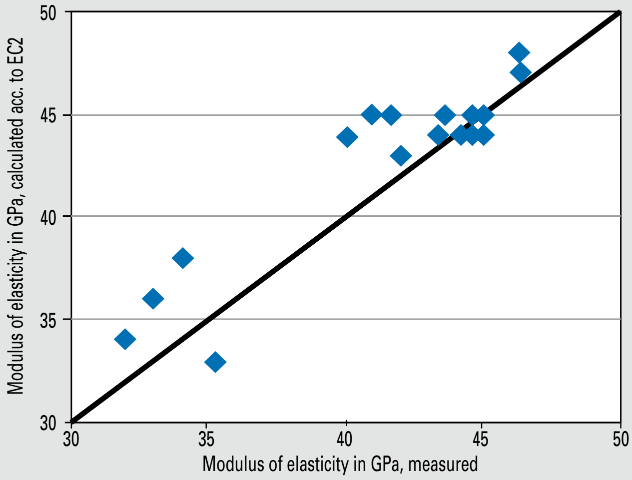

Fig. 3.4.3.1-1 Comparison between measured and calculated elastic modulus (EC2)

are still valid for concretes with a non-standard composition. In the design phase for example, both the elastic modulus and the tensile strength of the concrete were derived from the concrete compressive strength. The following relationships are defined in accordance with Eurocode 2 ('EC2'), Table 3.1:

Formula 1 (elastic modulus)
$E_{cm} = 22 \cdot (f_{cm}/10)^{0.3}$

Formula 2 (mean tensile strength according to Heilmann)
$f_{ctm} = 0.30 \cdot f_{ck}^{2/3}$; ($\leq$ C50/60)

Formula 3 (mean tensile strength according to Remmel)
$f_{ctm} = 2.12 \cdot \ln\,[1+ (f_{cm}/10)]$ (> C50/60)

A comparison of measured elastic moduli and elastic moduli calculated in accordance with Formula 1 is shown in **Fig. 3.4.3.1-1**. The calculated elastic moduli are reflected in the correct order of magnitude by the relationship in Formula 1, but are up to 10 % higher than the measured values. Talks are held with the 'Design' task group to discuss whether this deviation can be tolerated for design purposes or whether adaptation of Formula 1 is required, for example in the form of a linear shift.

As regards the relationship between compressive strength and tensile strength, Eurocode 2 contains two formulae which apply in different strength ranges. The relationship between the measured compressive and tensile strength is shown in **Fig. 3.4.3.1-2** together with the calculated values. It becomes apparent that Formula 2 reflects the measured values better than Formula 3 for greater compressive strengths as well. The database will have to be extended before more precise statements can be made. Virtually all the values currently available are within a 5 % quantile of Formula 2. Talks are held with the 'Concrete matrix' and 'Design' task groups to discuss whether Formula 2 could be applied to the relationship between compressive strength and tensile strength for all strength ranges of concretes for use in carbon concrete.

To investigate the influence of higher powder contents on shrinkage and creep, shrinkage and creep were modelled in accordance with Eurocode 2 and compared to measured values for

[1)] A list of all project partners can be found at: https://vdz.info/efd38

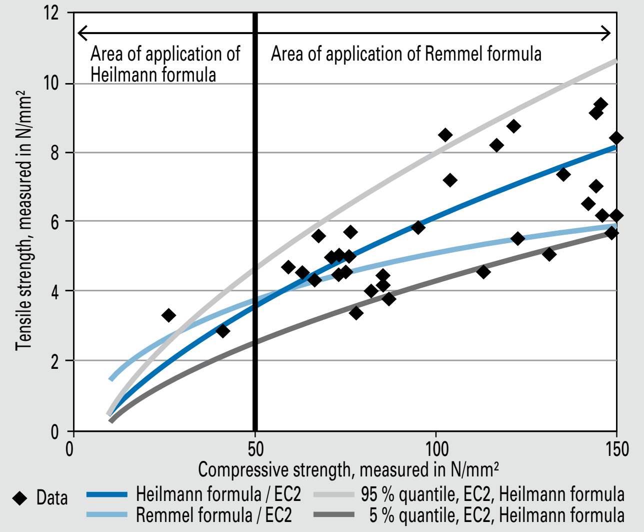

Fig. 3.4.3.1-2 Relationship between compressive strength and tensile strength

fine-grained concretes. Both shrinkage and creep are reflected in the correct order of magnitude by the models. For high-strength, fine-grained concretes with a maximum particle size of 2 mm, the measured shrinkage is around 0.15 mm/m higher than the calculated shrinkage.

Results

Based on the knowledge currently available, the concretes suitable for use in carbon concrete differ from the concretes widely used today in terms of their aggregate grading curve and powder content. The resultant changes in hardened concrete properties can be represented in the correct order of magnitude with familiar models. To reliably attain the designed fresh concrete and hardened concrete properties in carbon concretes under practical conditions as well, use is made of concretes with a relatively high paste content (volume of grains in cement + additives + fine proportion of aggregate + water). It may be necessary to specify a minimum paste content in the regulations to ensure the robustness of the concrete properties in practice.

3.4.3.2 Sub-project 2: Acceleration of standardisation and approval procedures in the context of test-based design and performance testing for C³ products (CarbonSpeed)

Project partners: TU Dresden, German Committee for Structural Concrete
Project period: 07/2017 – 06/2018

Background and aims

It generally takes several years for new technologies to come onto the market in the building sector, not just on account of the development work and performance verification procedures required, but also because of the legal aspects to be considered.

The aim of the C³ CarbonSpeed project is to create a guideline to complement the existing verification procedures of the building authorities (approval in individual cases, national technical approval) with a view to shortening the time required for the introduction of solutions with carbon concrete.

Approach and current status of the work

Performance-related approaches for the assessment of new product developments are being discussed in European standardisation committees working on updated versions of the Eurocodes and standards for concrete technology. Similar approaches are being considered by the building authorities (German Institute for Building Technology, DIBt) and the European Organisation for Technical Assessment (EOTA). In the course of the project, these approaches are to be applied to carbon concrete and the feasibility of their implementation discussed with the decision-makers of the building authorities.

Evaluation of the results of the sub-project described in section 3.4.3.1 revealed that in certain cases the concretes studied or used for C³ deviate from the currently applicable standards DIN EN 206-1/DIN 1045-2 in the following respects:

- Use of a cement type not yet subject to standardisation: CEM II/C-M (S-LL)
- Increased fines content
- Maximum particle size of the aggregate between 2 and max. 8 mm
- In some cases minimum cement content too low or water-cement ratio too high for the exposure class under consideration

These are in contrast with the cases defined so far in the approval procedures of the DIBt:

I Binder for concrete in accordance with DIN EN 206-1/DIN 1045-2
II Addition for use in accordance with DIN EN 206-1/DIN 1045-2, Section 5.2.5.3
III Concrete for use as concrete in accordance with DIN EN 206-1/DIN 1045-2

Approval in accordance with case I would be necessary if the above-mentioned CEM II/C-M (S-LL) were to be used in carbon concrete. This however applies irrespective of use in carbon concrete.

Deviation from the minimum cement content or maximum water-cement ratio (non-conformity with standard table F.2.2) would require approval in accordance with case III.

In an interview with the DIBt, the question was raised as to which verifications would be necessary if there were only deviations in terms of the fines content or the maximum particle size. If use has to be made of a small maximum particle size (e.g. 2 mm), the fines content has to be increased on due to the workability characteristics required. The fines content essentially influences properties such as the modulus of elasticity, the shrinkage and creep, the freeze-thaw resistance and the freeze-thaw resistance with de-icing salt, and possibly also the resistance to abrasion (XM). If, in connection with C³, verification has been furnished that there is no detrimental effect on these properties, this is not viewed as being critical. Separate approvals would then not be necessary. Conclusive discussions should be held in the committees of the DIBt once an adequate database is available.

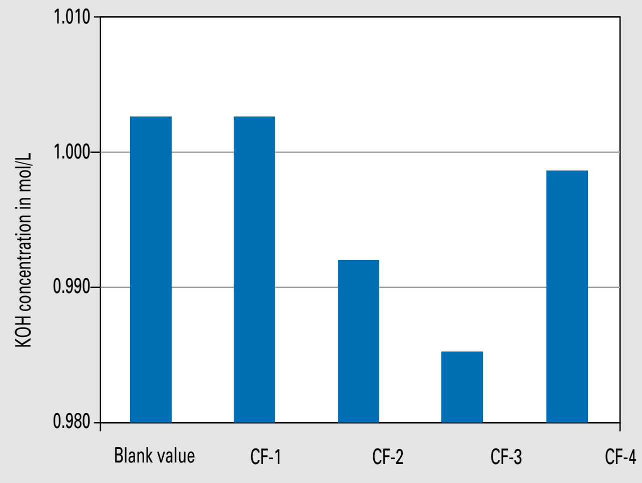

Fig. 3.4.3.3-1 Hydrolysis of carbon fibres CF-1 to CF-4

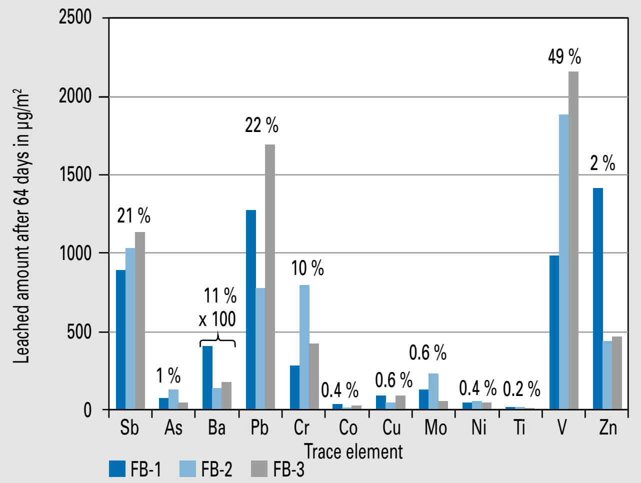

Fig. 3.4.3.3-2 Mean values of trace element leaching for the non-reinforced fine concretes FB-1 to FB-3

3.4.3.3 Sub-project 3: Characterisation and leaching tests to determine the environmental compatibility of C³ Carbon Concrete Composite

Project partners: RWTH Aachen University, Institute of Building Research; Hentschke Bau GmbH
Project period: 03/2017 – 02/2019

Background and aims

Alongside building technology properties, the environmental compatibility of construction products is becoming an ever more important aspect. In Germany it is currently assumed that standardised construction products and those approved by the supervisory authorities satisfy all environmental compatibility requirements. The environmental safety of new, unknown products may have to be verified in accordance with the 'Principles for assessing the effects of construction products on soil and groundwater' of the Centre of Competence for Construction (DIBt) (c.f. Model Administrative Provisions, Technical Building Rules, 2017/1 issue; Annex 10 'Requirements for physical structures regarding effects on soil and water (ABuG): 2017-07').

The aim of the research project is to perform corresponding leaching and irrigation tests (laboratory and field) on carbon concrete test specimens to compile a broad, scientifically verified database for assessment of the environmental compatibility of the new carbon concrete composite construction material. On this basis it may then be possible to classify carbon concretes such that no further environmental testing is required.

Approach

A polymer-based impregnation agent used to bond the carbon fibres employed for the production of carbon concrete. As the impregnation agent may contain small-molecule organic constituents, or these may dissociate from the impregnation agent to a slight extent in the highly alkaline concrete environment (hydrolysis), a study was made into the possible leaching of these substances from carbon concretes. This involved conducting the European long-term tank leaching test (DSLT) in accordance with CEN/TS 16637-2 for constant water contact, as well as laboratory and field irrigation tests for intermittent watering. As the material concentration in the pore water influences the rate of diffusion and thus also the leaching, the release of both organic substances and trace elements was investigated. It was assumed that the leaching behaviour of the trace elements may also be influenced by any small-molecule organic compounds. In addition to faster diffusion along the reinforcement, complexation of the trace elements by the small-molecule organic compounds and an associated improvement in the solubility of the trace elements in the pore water of the hardened cement paste are also conceivable.

Results/current status of the work

The characterisation tests on carbon fibres, ready-mixed products, cements and cementitious binders, as well as on fillers, for specifying the carbon fibres and the fine concrete for further studies have been completed. This involved using infrared spectroscopy and scanning electron microscopy to examine four carbon fibres. The trace element content, TOC release and hydrolytic stability of the fibres were also determined. The trace element content of a total of seven ready-mixed products, cements/binders and fillers was analysed. Three fine concrete mixtures were then specified on this basis, and the test specimens (fine concrete slabs 150 mm x 150 mm x 20 mm) for DSLT leaching were produced and eluted.

Examination of the carbon fibres revealed that the fibre CF-3 exhibits the highest TOC release and the lowest hydrolytic stability (**Fig. 3.4.3.3-1**). For this reason, the project partners decided that this fibre should be used for the further leaching and irrigation tests with the carbon fibre-reinforced fine concrete test specimens. DSLT leaching of the three non-reinforced fine concretes showed that these exhibit very similar leaching behaviour. **Fig. 3.4.3.3-2** presents the 64-day mean values of triple determination of the trace element leaching for the fine concretes FB-1 to FB-3. Cadmium and mercury do not appear in this figure, as all the measured values were below the determination limit. The percentages above the bars indicate the maximum amounts released in relation to the permissible DIBt limit values (c.f. ABuG: 2017-07 – Annex A; Table A-6 and A-8). It can be seen that only up to around 10 % of the permissible leached amounts is obtained for most of the elements. Only the elements antimony, lead and vanadium exhibit larger release amounts, with vanadium attaining about 50 % of the limit value. On account of the high, uniform and easily measurable release of barium, the project partners took the decision to use the fine concrete FB-1 for the further leaching and irrigation tests with the carbon fibre-reinforced fine concrete test specimens.

3.4.4 Durability properties of concretes with cements containing high contents of blast furnace slag and fly ash

IGF project 18228, N supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partner: FEhS – Building Materials Research Institute
Project period: 07/2014 – 12/2016

Background and aims

The research project is based on the findings of the IGF project 16148 N. This investigated the potential and performance limits of cements with both standardised and non-standardised compositions of Portland cement clinker, blast furnace slag and siliceous fly ash. It concentrated primarily on the standard properties of the cements. Particular emphasis was placed on statistical evaluation of the effects on compressive strength. For a wide range of the compositions studied it proved possible to produce cements with a standard compressive strength corresponding to strength class 42,5 MPa. Following on from this, VDZ and the FEhS Building Materials Research Institute have now investigated the concrete properties of relevance to durability.

The composition of the cements tested ranged from the familiar CEM II cements to the CEM II/C and CEM VI cements to be standardised in the future. Employing statistical methods, a test schedule was drawn up for 40 cements with five different cement compositions.

Approach

Five cement compositions were selected on the basis of the results of the parameter study. Three cements were included to take the updated version of DIN EN 197-1 (introduction of CEM II/C and CEM VI cement) into account. Two compositions above and beyond this were selected to estimate the potential offered by cements with a high blast furnace slag and fly ash content (**Table 3.4.4-1**).

In addition, two industrially produced blast furnace cements CEM III/A 42,5 N were used as reference cements.

The parameters of relevance to durability (methods and criteria) required in Germany (approval procedures of the German Institute for Building Technology, DIBt) were selected as a means of assessing durability. The procedures employed have been incorporated into the European Assessment Document EAD 150001-00-0301 and the CEN/TR 16563 procedural principles, Annex B.

Results

Testing of the carbonation behaviour of fine concretes in accordance with the European Assessment Document EAD 150001-00-0301, Procedure No. 15, C_{dcr} method, revealed that the preliminary storage time, which varied between 7 and 28 days, has a significant influence. Depending on the testing age, the carbonation depths found in the fine concretes using cement with 45 mass % clinker, 43 mass % blast furnace slag and 12 mass % fly ash were in the same range as those of the reference fine concretes with CEM III/A. By contrast, all the other fine concretes exhibited greater carbonation depths and were outside the assessment framework according to CEN TR 16563, Annex B, Figs. B.3 and B.4 and EAD 150001-00-0301, Annex D. The cements contained in these fine concretes would probably not pass the approval testing in the XC exposure classes in Germany.

Table 3.4.4-1 Composition of the test cements (data without sulphate agent)

Cement	Clinker	Ggbs	Fly ash
	Mass %		
a)	30	40	30
b)	30	64	6
c)	35	45	20
d)	50	30	20
e)	45	43	12

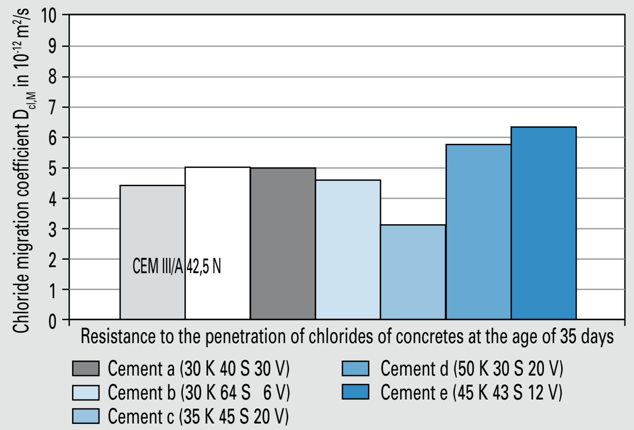

Fig. 3.4.4-1 Chloride migration coefficients of concretes made with test cements and reference cements CEM III/A 42,5 N in rapid test, concretes with c = 320 kg/m³, w/c = 0.50, testing age 35 days

In the DIBt approval procedures, the assessment criterion applicable to the chloride migration coefficient (Dmig method as per Procedure No. 16 EAD 150001-00-0301) is $25 \cdot 10^{-12}$ m²/s at a testing age of 35 days. All concretes (c = 320 kg/m³, w/c = 0.50) satisfied the criterion by a considerable margin. In accordance with the code of practice 'Resistance to chloride penetration of concrete' issued by the Federal Waterways Engineering and Research Institute (BAW), the assessment criterion for the chloride migration coefficient is $10 \cdot 10^{-12}$ m²/s for the exposure classes XS1/XD1 and XS2/XD2 and $5 \cdot 10^{-12}$ m²/s for the exposure classes XS3/XD3. Some of the values were within the range of the assessment criterion for exposure class XS3/XD3 (**Fig. 3.4.4-1**). The cements would therefore be suitable for use in both general concrete construction (DIBt) and in waterways engineering (BAW).

The assessment criterion applied in the DIBt approval tests for sulphate resistance (S_{FPM} method in accordance with Procedure No. 14 EAD 150001-00-0301) was also satisfied in all cases.

In the cube test method (FT_{cube} method in accordance with Procedure No. 17 EAD 150001-00-0301), scaling of the concretes with the test cements a, b, c, d and e was < 10 mass % after 100 freeze-thaw cycles, thus satisfying the criterion in approval tests. These would therefore be suitable for approval in Germany in exposure classes XF1 and XF3 in accordance with DIN EN 206-1/ DIN 1045-2 (**Fig. 3.4.4-2**).

The internal microstructural damage was investigated on the basis of the relative dynamic elastic modulus (RDM) of the concretes in the CIF test (Capillary suction, Internal damage and Freeze-thaw test/FT_{CF} method in accordance with Procedure No. 17 EAD 150001-00-0301). After 28 freeze-thaw cycles, three concretes

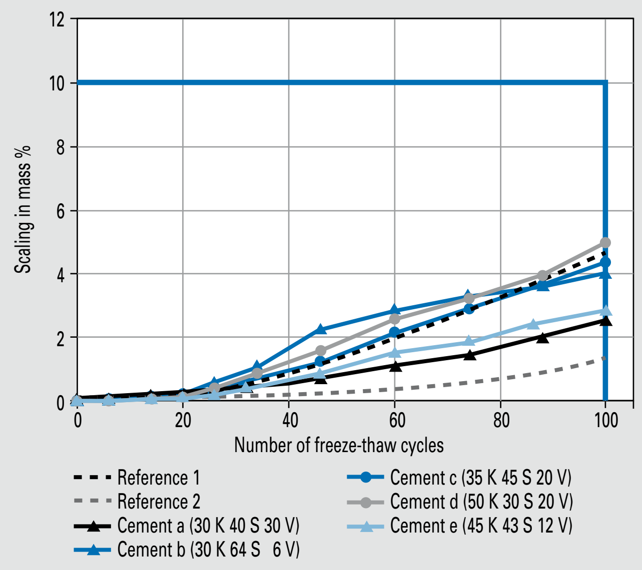

Fig. 3.4.4-2 Scaling of concretes made with test cements and reference cements CEM III/A 42,5 N in the cube test method as a function of the number of freeze-thaw cycles, concretes with c = 300 kg/m³, w/c = 0.60

satisfied the assessment criterion (RDM after 28 FTC > 75 %). The cements that complied with the assessment criterion were of compositions a, b and e. They would thus also be suitable for use in waterways engineering.

The freeze-thaw resistance with de-icing salt of the air-entrained concretes (FTSCDF method in accordance with Procedure No. 18 EAD 150001-00-0301) was examined in the CDF test. The assessment criterion, namely 1.5 kg/m² scaling after 28 freeze-thaw cycles, was satisfied by two concretes. Successful results were obtained when using the cements of composition d (50 mass % clinker) and composition e (45 mass % clinker). In Germany, these cements would therefore be suitable for approval in exposure classes XF2 and XF4 in accordance with DIN EN 206-1 and DIN 1045-2. The concretes using cements a, b and c (30 and 35 mass % clinker) failed the test.

As a supplement to laboratory testing of the concretes, characteristic value calculations were applied on the basis of the degree of hydration of hardened cement paste and the porosity of standard mortars. According to previous experience from IGF No. 17123 N, these would appear to be a suitable means of predicting the results of the cube test method and the CDF test. The hardened cement paste and mortar properties provided a good basis for estimation of the freeze-thaw resistance and freeze-thaw resistance with de-icing salt of the concretes of a composition eligible for approval (see chapter 3.4.5).

3.4.5 DURAFOR – Prediction of the durability of concretes with new clinker-based cements

IGF project 187 EN, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF Project partners: CRIC (Belgium), Smart minerals (Austria). Project period: 02/2017 01/2019

Background and aims

On account of differing climatic conditions and building traditions, the European concrete standard EN 206 has so far not been harmonised. Consequently, different rules apply in the member states to the use of various concrete constituents, such as cement in concrete. Different procedures apply throughout Europe with regard to the approval of cements previously not admissible for use in a particular member state. An obvious suggestion would be to verify the durability of concretes with these cements in laboratory tests. To date, the European concrete standards do not provide a consistent concept for furnishing such verification. At European level, the 'European Technical Assessment' (ETA) would be a possible alternative. A corresponding test schedule (European Assessment Document, EAD) containing testing procedures has been published for calcium sulphoaluminate cement. Some of the test methods were taken from previously domestic, and in particular German, approval procedures for cements based on Portland cement clinker.

In the light of the development of new, clinker-efficient cements, it would be useful to have easy to handle methods of predicting the durability of concretes with such cements. The project partners CRIC (Belgium), smart minerals (Austria) and VDZ (Germany) have pooled their resources in a CORNET (Collective Research Networking) research project, with VDZ as the head of the consortium, to determine characteristic values on cement and mortar samples and to compare, and where possible correlate, these values with the results of durability tests.

Approach/current status of the work

The characteristic values to be determined can supplement testing ahead of approval procedures, in addition to indicating the potential for and limits of development.

Such characteristic values could also be employed for the ongoing verification of the constancy of performance, as both bibliographical references and the earlier research project conducted on a national basis show that the compressive strength of concrete does not usually provide adequate correlation with the durability properties of the concrete. Discussions are currently in progress as to whether the European concrete standard EN 206 should in future contain a classification of the durability potential of the concretes above and beyond the national descriptive rules, based on testing for example. If such so-called resistance classes were to be introduced, the characteristic values obtained from hardened cement paste and mortar might already be enough to permit identification of possible class assignment.

The tests were preceded by the evaluation of European surveys and reports to obtain information on national approval procedures, testing procedures and assessment methods.

Table 3.4.5-1 Cements for the production of concrete in accordance with **Table 3.4.5-2**

	CRIC	Smart Minerals (SMG)	VDZ
1	CEM I 52,5 R	CEM I 52,5 R	CEM I 52,5 R
2	CEM II/C-M (S-LL) (A)	CEM VI (B)	CEM VI (A)
3	CEM II/C-M (V-LL) (B)	CEM II/C-M (V-LL) (A)	CEM II/C-M (S-LL) (B)
4	CEM II/C-M (S-V) (B)	CEM II/C-M (S-V) (B)	CEM II/B-M (S-LL) (A)
5	CEM II/B-M (LL-S-V) (B)	CEM II/B-M (LL-S-V) (A)	CEM II/B-LL (A)
6	CEM II/B-M (V-LL) (B)	CEM II/B-M (S-LL) (B)	CEM II/A-S (B)
7	CEM II/B-LL (B)	CEM II/B-M (V-LL) (A)	CEM III/B (A)

(A): CRIC: clinker fine; S, LL, V fine, SMG: clinker constant; S, LL, V fine, VDZ: clinker fine; S, LL, V constant
(B): CRIC: clinker coarse; S, LL, V coarse, SMG: clinker constant; S, LL, V coarse, VDZ: clinker coarse; S, LL, V constant

Table 3.4.5-2 Concretes and testing procedures

	Cement content in kg/m³	w/c	Air content in %	Origin	Testing acc. to
1	350	0.50	-	EAD	Carbonation: EN 13295 with 1 % CO_2
					Sulfate resistance: SIA 262, annex D
					Chloride diffusion: EN 12390-11
					Chloride migration: NT Build 492
					Freeze-thaw resistance: CIF (CEN/TS 12390-9 in combination with CEN/TR 15177)
2	260	0.65	-	CEN/TR: Germany	Carbonation: EN 13295 with 1 % CO_2
3	300	0.55	-	CEN/TR: Austria	Sulfate resistance: SIA 262, annex D
					Chloride diffusion: EN 12390-11
					Chloride migration: NT Build 492
4	340	0.45	5 ± 2	CEN/TR: most frequently used	Freeze-thaw resistance with de-icing salts: slab test acc. to CEN/TS 12390-9
5	300	0.55	5 ± 2	CEN/TR: UK	Freeze-thaw resistance with de-icing salts: slab test acc. to CEN/TS 12390-9

CEN/TR: CEN/TR 15868:2009 'Survey of national requirements used in conjunction with EN 206-1:2000'
EAD: EAD 15001-00-0301 for Calcium Sulphoaluminate based cement

Selection of cements
To select the cements, twelve cements were produced with two modifications in each case at each research location and examined with respect to their standard properties, in addition to three reference cements to be examined at each of the research locations concerned. Particular consideration was given to cements with compositions corresponding to CEM II/B-M in conformity with the currently valid EN 197-1, as well as CEM II/C-M and CEM VI cements in accordance with the latest draft of EN 197-1. From these 75 cements, one Portland cement was chosen as reference, and six other cements were selected per research location (**Table 3.4.5-1**). The concretes shown in **Table 3.4.5-2** are to be produced with these cements and tested with the methods stated.

Concrete compositions
The concrete compositions (c.f. **Table 3.4.5-2**) correspond to the Technical Report CEN/TR 15868:2009 'Survey of national requirements used in conjunction with EN 206-1:2000' and the European Assessment Document EAD 15001-00-0301 for calcium sulphoaluminate cements. The EAD concrete indicated in **Table 3.4.5-2** was chosen as reference concrete for all tests with the exception of determination of the freeze-thaw resistance with de-icing salt. Air-entrained concretes were employed for this purpose. For each durability test, the concrete with the lowest cement content and the highest water-cement ratio for the exposure class concerned according to CEN/TR was also selected. This makes it possible to investigate not just a large number of different cements, but also a wide range of standard European concretes.

Further tests
In addition to the tests shown in **Table 3.4.5-2**, the flow value or slump and the fresh concrete air content will be determined for each concrete using the pressure method. Compressive strengths will be tested after 2, 28 and 91 days.

In keeping with the completed national research project (IGF 17123 N, c.f. VDZ Activity Report 2012-2015), the development of the degree of hydration over time, the amount of chemically bound water and the pore radius distribution of the corresponding mortars will be tested for each of the selected cements. The chemically bound water will be determined comparatively by means of thermogravimetry (CRIC) and using a carbon and hydrogen moisture analyser.

Characteristic value determination
Parameters from the pore radius distribution and the amount of chemically bound water at various testing times will be collated to form empirical characteristic values and compared, and (where possible) correlated, with the results of the durability tests. The results will be available on completion of the research project in January 2019.

3.4.6 Influence of concrete technology parameters on moisture storage and moisture transfer in concretes and cement screeds and on the resultant moisture content under different exposure conditions

IGF project 17928 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 01/2014 – 12/2016

Background and aims

Two questions currently arising in connection with the planning of concrete components and the application of cement screeds make it necessary to study moisture storage and moisture transfer in cement-bound building materials in greater depth:

1. Drying behaviour of cement screed
There have been various reports indicating that the drying behaviour of screeds with CEM II cements (Portland composite cements) and CEM III cements (blast furnace cements) differs from that of screeds with Portland cements and that drying until ready for the application of floor coverings sometimes takes longer than in the case of screeds with Portland cement. Screed installers therefore still tend to avoid using CEM II and CEM III cements and opt for Portland cements instead. The aim of this research project is to systematically examine the influence of the cement type on the drying behaviour of cement-bound screeds.

2. Fire spalling of components
If concrete components are exposed to high temperatures in a fire, this can result in the spalling of fragments of concrete. Of particular significance is so-called explosive spalling, in which concrete fragments abruptly break away from the components concerned and fly off with a loud noise like an explosion. Attention has started to focus on this topic, both because of the use of high-strength concretes and on account of the regulations in DIN EN 1992-1-2 regarding structural fire design. The standard states that explosive concrete spalling is unlikely to occur 'if the moisture content of the concrete is less than k % by weight' where k is to be defined on a national level.

So far, no systematic studies have been conducted on the influence of different concrete compositions and ambient conditions on moisture content and moisture distribution in concrete components. For this reason, the research project investigated the moisture contents and distributions typically found in concretes of various compositions under standard exposure conditions. A further objective was to examine the possible influence of the concrete composition and moisture content on the occurrence of spalling when concrete is heated.

Approach

To study the drying behaviour of cement screeds, test specimens were produced with two compositions and five cement types in each case. The moisture of each of the screeds was measured 7, 14, 28, 56 and 168 days after their production to permit documentation of the development of the drying process over time. The moisture was measured in two ways on representative sub-samples:

- CM measurement (calcium carbide method)
- Weighing and oven drying at 105 °C to a constant mass.

To determine the moisture distribution in concrete components, computer-aided simulation of typical ambient conditions was performed and the resultant moisture content in the concrete was calculated with appropriate software. For simulation, the following input variables

- Moisture storage function/sorption isotherm
- Vapour permeability
- Water absorption coefficient

were experimentally determined for concretes of different compositions.

To study the behaviour of the concretes on heating and possible explosive spalling, use was made of a test set-up first described by Kalifa[1)] and subsequently employed by many scientists. This involves heating the surface of a 30 cm x 30 cm x 12 cm concrete member with electric radiant heaters. Some sources refer to the method as 'PTM test' as it measures the change in pore pressure, temperature and mass.

Results

The investigations into the drying behaviour of cement screeds and hardened cement paste revealed the following:

- After being stored for up to six months at 20 °C with 65 % relative humidity, screed mortars with blast furnace cements exhibited a higher moisture content (CM moisture and weight percent of the moisture content determined with oven drying at 105 °C) than screeds with other cement types.
- When stored at 20 °C with 65 % relative humidity, as well as at 40 °C with 30 % relative humidity, hardened cement pastes with blast furnace and Portland slag cements exhibited far less substantial mass losses, and constant mass was already attained after just a few weeks at 20 °C with 65 % relative humidity, i.e. no further material moisture was emitted to the environment.

Given the usual relative humidity levels, the equilibrium moisture content of screeds with blast furnace cement is higher than that of screeds with Portland cement. It may therefore not be possible to attain a moisture content below a maximum value defined on the basis of the drying behaviour of screeds with Portland cement, e.g. when using a blast furnace cement. The level of moisture loss, which is ultimately decisive for the possible occurrence of damage in floor structures, tends to be lower when using blast furnace cements than with Portland cement screeds. The reservations about blast furnace cements and certain Portland composite cements in relation to their drying behaviour would thus appear to be unfounded.

Calculation of the coupled heat and moisture transfer showed that, after several years, the relative humidity inside concrete components settles at a largely constant level corresponding to the prevailing mean relative humidity in the surrounding area. Only the moisture in the outer approx. 2.5 to 5 cm of a concrete component is decisively influenced by fluctuations in climatic conditions over the course of the year. The denser the concrete, the smaller the outer zone affected by climatic fluctuations.

[1)] Kalifa, P. et al.. Spalling and pore pressure in HPC at high temperatures. Cement and Concrete Research 2000, 30, pp. 1915-1927

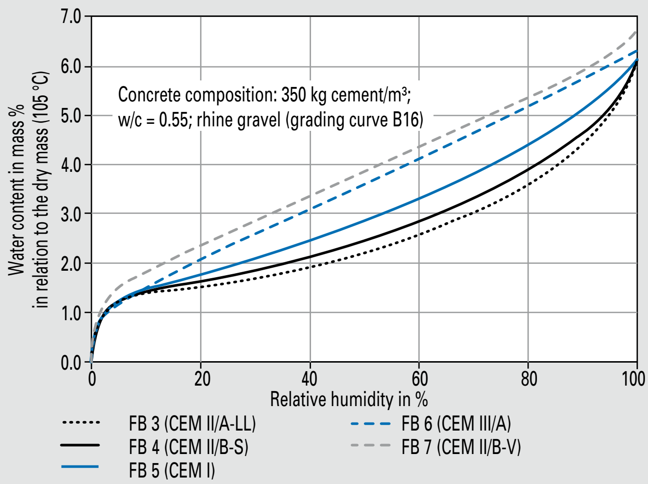

Fig. 3.4.6-1 Examples of desorption isotherms of concrete

Fig. 3.4.6-2 Surface of a test specimen after spalling

The relative humidity inside components settles at the following levels

- Around 50 % for interior components under typical indoor climatic conditions
- Around 75 to 80 % for non-insulated components under typical outdoor climatic conditions in Germany, and higher still if the components are exposed to rain

Using the sorption isotherms of the concretes determined in the project (examples in **Fig. 3.4.6-1**), it was possible to assign the corresponding moisture content in % by weight to the relative moisture contents by way of the component thickness. This permits checking of whether k % by weight is exceeded under the prevailing climatic conditions and thus of whether explosive spalling in accordance with DIN EN 1992-1-2 is likely to occur.

The tests performed on the explosive spalling of concrete in a fire yielded the following results:

- In this research project, high pore pressures were not the primary cause of the explosive spalling of concrete.
- Whereas other scientists did not find any spalling on performing the ‚PTM test+, modification of the method in this research project (application of a compressive load) led to the observation of explosive spalling in several cases (**Fig. 3.4.6-2**). It can thus be concluded that the application of compressive loads is crucial to the occurrence of spalling in the PTM test.
- Explosive spalling occurred in high-strength concretes, as well as in normal-strength concretes with blast furnace cement (CEM III/A) and Portland fly ash cement (CEM II/B-V). In comparison with other concretes in the experimental programme, the hardened cement paste of these concretes exhibits a smaller proportion of capillary pores and a higher proportion of gel pores.

Hypotheses were formed on the basis of own observations and findings from bibliographic sources as to the cause of explosive spalling in the research project. These hypotheses and the relative contribution to spalling made by the assumed phenomena are to be investigated in the course of a subsequent research project.

3.4.7 Retroactive determination of concrete composition ■

Research project T218/24815/2013 supported by the Drs. Edith und Klaus Dyckerhoff-Foundation
Project period: 01/2013 – 12/2016
and
IGF project 17829 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 06/2013 – 12/2015

Background and aims

Knowledge of the concrete composition is extremely important, not just with regard to the revitalisation and conversion of buildings with cement-bound building materials, but also when dealing with defects and damage. The original documentation from the time of construction is often no longer available. So there is a need for precise retroactive determination of the cement content and cement type, as well as the content of additions and aggregate in the hardened concrete. This is however not possible with the analytical methods available to date, or only to an unsatisfactory degree.

In the course of the projects, methods were developed to provide a reliable means of determining the cement content and cement type, or addition content, in hardened concrete. This primarily involved the use of cements containing other main cement constituents alongside clinker.

Approach

In order to be able to develop and validate the testing procedures, cements were first made from single main cement constituents (including blast furnace slag, limestone, trass and calcined clay). Concretes were then produced using these cements, so that the proportions of the cement and concrete constituents in the concretes were precisely known, and the efficiency of the testing procedures could be assessed. The testing procedures employed in the projects were essentially based on two fundamentally different approaches. Firstly, wet chemical methods were optimised on the basis of DIN 52170 and CEN/TR 196-4 so as to permit the determination of a variety of parameters with the maximum possible accuracy. The second approach involved the use of image analysis techniques, with images being obtained from element mappings employing micro-XRF (X-ray fluorescence analysis) and a scanning electron

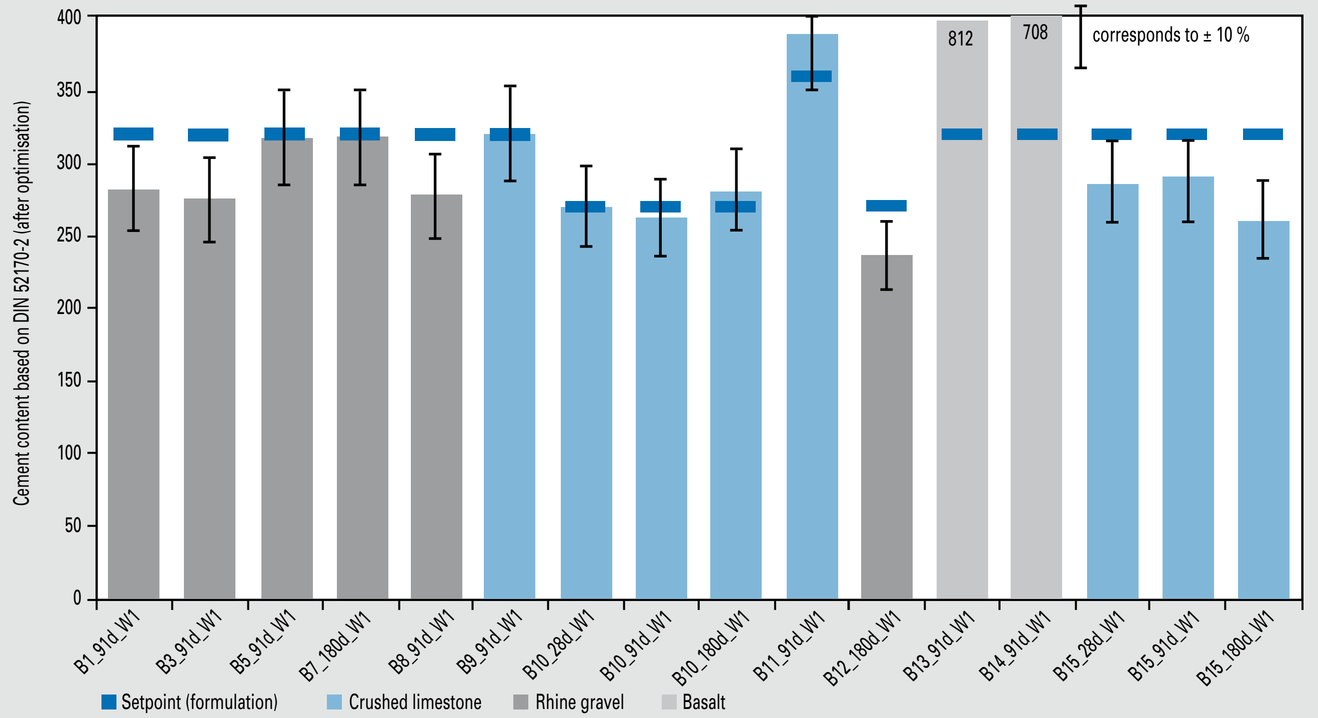

Fig. 3.4.7-1 Cement content based on DIN 52170-2

microscope (SEM) in combination with energy-dispersive X-ray microanalysis (EDX). These methods were validated on various concretes. This involved examining the influences of cement and addition content, concrete age and different cement types and aggregates on the applicability/accuracy of the procedures.

Results

With the method according to DIN 52170 2, cement content determination often yielded results with errors greater than specified in the standard. This could be attributed to process-related, systematic and random errors. For example, DIN 52170-2 assumes the presence of limestone in the aggregate of the concrete if the CO_2 content is > 0.75 %. In such cases, this limestone content is arithmetically assigned to the aggregate. When using Portland limestone cements or Portland composite cements, this assumption can however lead to significant underdetermination of the cement content, as the limestone forms part of the cement and not of the aggregate. Underdetermination of the cement content was also to be expected for pozzolanic cements (e.g. with trass or fly ash), as these pozzolans tend to behave like aggregates in the analytical process. Some of the results can be seen in **Fig. 3.4.7-1**. These are results from optimisation trials in accordance with DIN 52170-2. Optimisation essentially concentrated on determination of the insoluble residue and consideration of the CO_2 content of the concrete. Accurate determination of the cement content was possible in some cases, but considerable errors occurred with other concretes. In the case of B13 and B14 concretes, the cement content was greatly overdetermined, as these concretes contained a partly acid-soluble aggregate (basalt).

As an alternative to wet chemical determination of the cement content, an image analysis method based on µ-XRF mappings was developed. This involved preparing a cross section of the concrete and analysing at least two 10 cm x 10 cm areas. In the analysis, the elementary composition of the concrete was determined every 50 µm by means of µ-XRF to make it possible to differentiate between hardened cement paste and aggregate. Image analysis techniques were then employed to establish the proportion of the area made up by cement and aggregate. Use was made of the free software ImageJ for image analysis. Segmentation into hardened cement paste and aggregate was performed using the threshold value algorithms implemented. This made it possible to achieve largely user-independent segmentation. The contents were then converted into weight percents on the basis of the densities and volume ratios. The results show this to be a promising method, as quantification was possible for all the aggregate and cement types used. Before this procedure can be used in practice, it will however be necessary to study certain boundary parameters, such as the influence of stone dusts or different water-cement ratios. A corresponding follow-up project is already in progress.

A selective solution method based on CEN/TR 196-4 was employed for wet chemical estimation of the slag content of the concrete. This works on the principle that blast furnace slag is largely insoluble in ethylene diamine tetra-acetic acid (EDTA) and can be dissolved in HNO3. By performing both solution steps it is thus possible to estimate the slag content of the systems from the difference between the insoluble residues. Allowance must however be made for the change in solution behaviour due to hydration. This change was estimated on the basis of bibliographic information and own laboratory experiments. The results show that it is basically possible to estimate the slag content with this method. To achieve reliable analysis it is however also necessary to take the solution behaviour of the aggregate into account, as this usually constitutes the largest weight percent in the concrete. A retention sample of the aggregate is required for this purpose. A follow-up project is studying the question of whether the aggregate can be extracted from the concrete in a manner allowing determination of its solubility. This would obviate the need for retention samples.

As an alternative to wet chemical estimation of the slag content, an image analysis method was developed on the basis of element mappings using a scanning electron microscope (SEM) in combination with energy-dispersive X-ray analysis (EDX). At least eight mappings were produced for each of the concretes with 500x magnification. The first step was to identify the aggregate and assign the remaining share of the area to the hardened cement paste and pores. This proportion of the area was then converted into a cement content. It was subsequently possible to establish the proportions of blast furnace slag, fly ash, trass and calcined clay and reference these to the cement content. The results prove that an initial estimation of the proportions of the cement constituents can be obtained with this method. For more precise analysis, a greater number of mappings is however advisable – particularly if the constituents are of different sizes. One possible constraint with this method is particle size, as the mean compositions yielded by EDX for extremely fine particles cannot always be assigned to a constituent. In the course of this project, good estimations of the proportions were nevertheless obtained for all the given constituents.

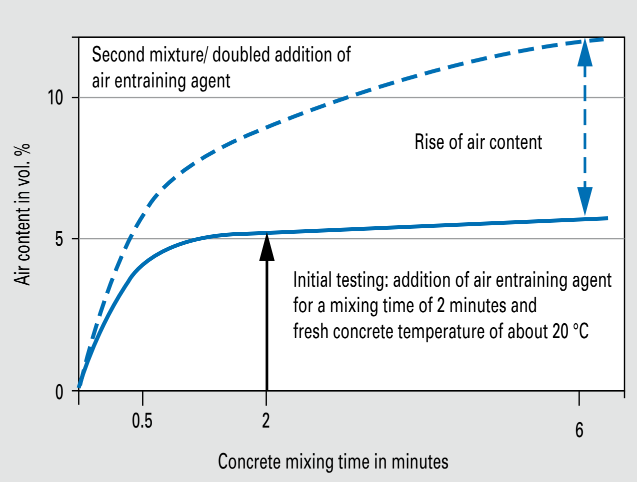

Fig. 3.4.8-1 Testing of the potential for later activation of a concrete composition in the initial test in the laboratory

3.4.8 Extended initial test for air-entrained concrete with superplasticizer under consideration of practical construction conditions

IGF project 18854 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 01/2016 – 12/2017

Background and aims

Increasing use is being made of concrete construction methods in urban areas as well, for roundabouts and bus lanes, for example. Air-entrained concrete is produced at ready-mixed concrete plant, transported to the spreading site in truck mixers and then generally placed manually or using light placing equipment. The softer consistency required for placement is set by adding superplasticizer. Interaction between air entraining admixture and superplasticizer, as well as the fluctuations in water content and temperature encountered in practice, increase the risk of a negative influence on air entrainment and the stability of the fresh concrete. The reasons for this include the later activation of the air entraining agent in the truck mixer during transportation and a non-uniform sequence of adding air entraining agent and superplasticizer.

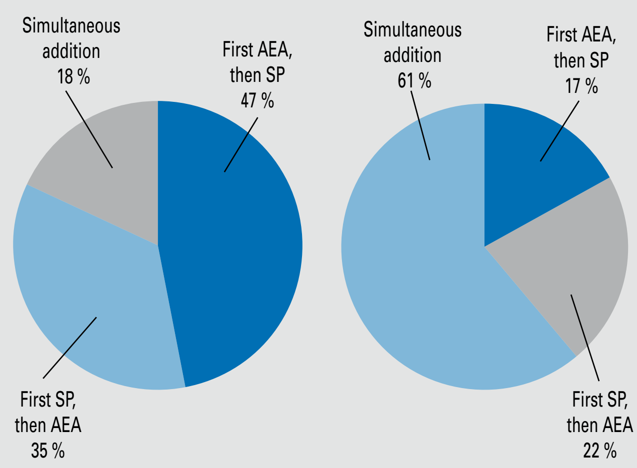

Fig. 3.4.8-2 Sequence of adding air entraining agent and superplasticizer in the initial test (left) and at the mixing plant (right)

The potential for later activation can be estimated as part of an extended initial test. This involves performing an additional test (**Fig. 3.4.8-1**), in which the amount of air entraining agent established in the initial test is doubled and the air content of the mixtures with the two added amounts is determined after a short mixing time of 30 seconds and after an extended mixing time of around four to six minutes. In the event of a significant increase in air content with the double added amount and extended mixing time, there is a risk of a subsequent rise in the air content on execution of the building work. Systematic studies performed on stiff paving concretes without the use of plasticiser revealed that air entraining agents with a natural active agent exhibit little potential for later activation. This is due to the fact that the majority of the active agent precipitates in the pore solution. A considerable later increase in air content is to be expected with synthetic tensides.

The aim of the research project is to examine whether the relationships between mixing time, active agent and the amount of air entraining agent added and the potential for later activation found for air-entrained concretes without superplasticizer (stiff consistency) still apply to air-entrained concretes with superplasticizer. In particular, the influence of the sequence of adding air entraining agent and superplasticizer was studied in laboratory experiments. As yet, however, there has not been any recommendation for an extended initial test with the combined use of air entraining agent and superplasticizer.

Approach

Work on the development of a test specification in the laboratory and the establishment of its transferability to practical construction conditions was performed in five work packages. The first step involved the selection of three admixture combinations of air entraining agent and superplasticizer (work package 1) for the laboratory experiments and practical tests. Experience gained by the producers of air-entrained concrete was gathered in a questionnaire

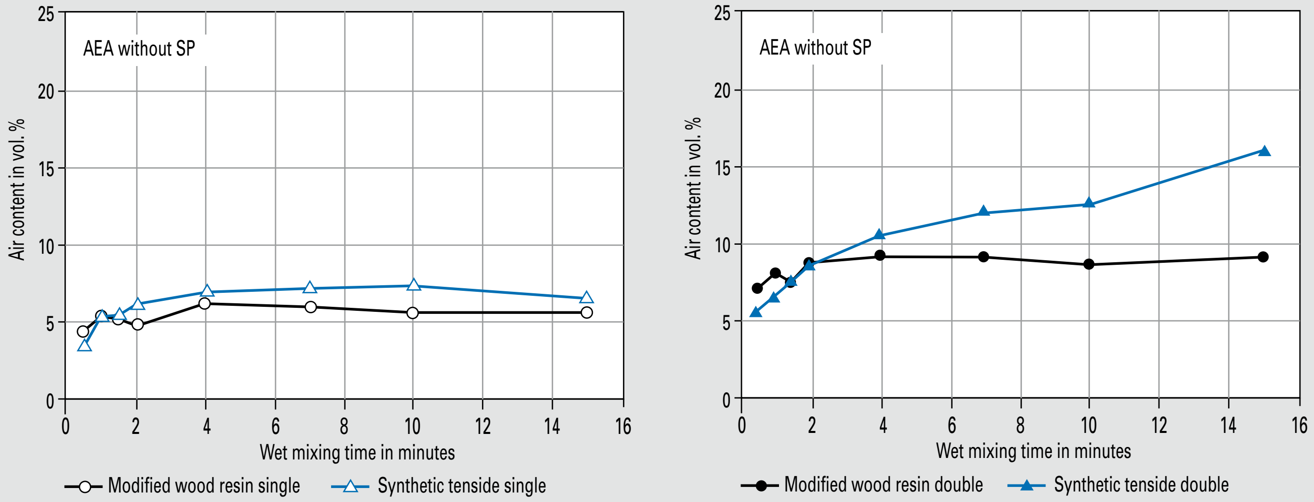

Fig. 3.4.8-3 a and b Air content of air-entrained concrete without plasticizer in relation to mixing time and type of air-entraining agent: left single and right double addition level of air-entraining agent

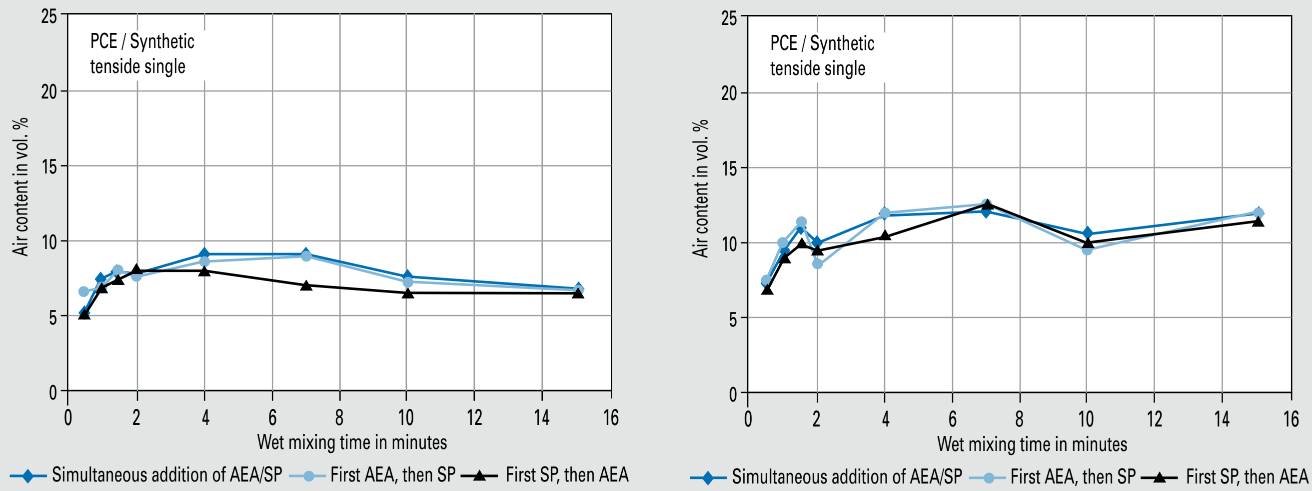

Fig. 3.4.8-4 a and b Air content in relation to mixing time and addition order with combination PCE/synthetic tenside: left single and right double addition level of air-entraining agentr

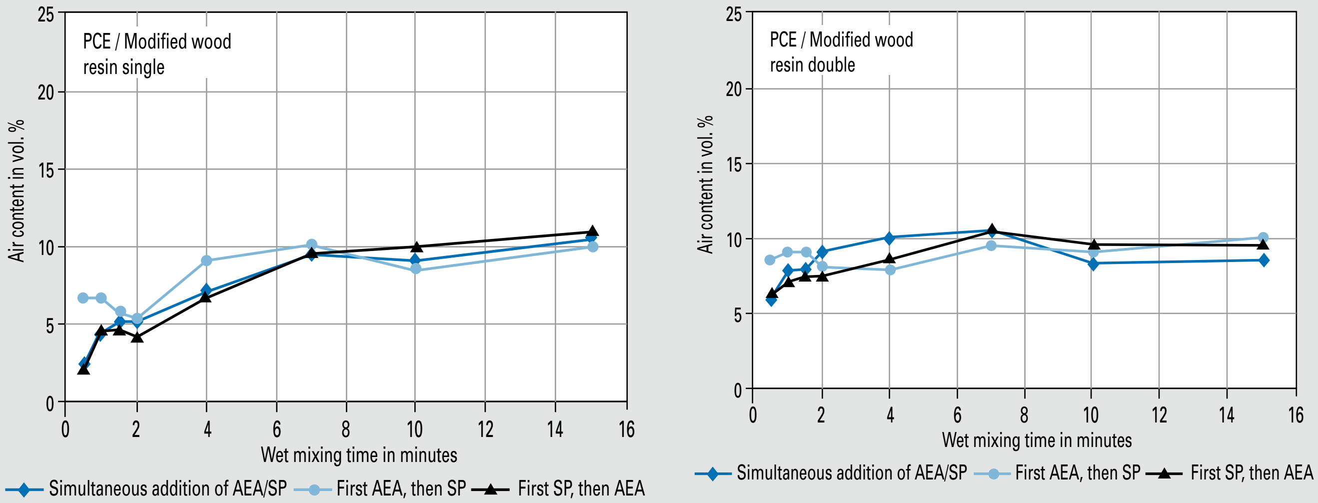

Fig. 3.4.8-5 a and b Air content in relation to mixing time and addition order with combination PCE/modified wood resin: left single and right double addition level of air-entraining agent

(work package 2). The next step was to find a ready-mixed concrete plant for the practical tests and to specify the starting materials, the concrete composition and the procedure for the practical tests (work package 3). Air entrainment in the fresh and hardened concrete was investigated in laboratory experiments with the cement used in the mixing plant (work package 4). Practical tests then had to be performed at the ready-mixed concrete plant (work package 5). Comparison of the test results permitted conclusions to be drawn about the transferability of laboratory experiments to practical construction conditions. Finally, recommendations were drawn up for an extended initial test with the combined use of air entraining agent and superplasticizer with the aim of ensuring the required air entrainment in practice.

Results

Two air entraining agents (not concentrates) with natural (modified wood resin) and synthetic (alkyl sulphate) active agent with low and high potential for later activation, and two superplasticizers (PCE, polycarboxylate ether, as used in ready-mixed concrete, and a combined product made of naphthalene sulfonate/melamine sulfonate) from one producer were selected and used in different combinations of superplasticizer/air entraining agent: PCE/synthetic tenside, PCE/modified wood resin and combined product/modified wood resin. The questionnaire relating to the sequence of adding the air entraining agent and superplasticizer at the time of the initial test in the laboratory yielded the following results: In 47 % of cases, the air entraining agent was added first in the initial test and then the superplasticizer (**Fig. 3.4.8-2**). The reverse applied in 35 % of cases. 18 % of those asked named the alternative 'simultaneous addition of air entraining agent and superplasticizer'. In the case of practical production at the mixing plant, 61 % of the answers named the simultaneous addition of air entraining agent and superplasticizer. The air entraining agent was added first, and then the superplasticizer, in 17 % of cases, and the superplasticizer first, and then the air entraining agent, in 22 %. This showed that the sequence of addition is different in practice than in the initial test. The main group of answers shifted from 'Air entraining agent first, then superplasticizer' (initial test) to 'Simultaneous addition of air entraining agent and superplasticizer' in practice. This is probably due to the associated shorter mixing time, permitting a higher mixing plant throughput.

The influence of the type and addition sequence of the admixtures and of the mixing time on air entrainment was investigated with a standard mixture in laboratory experiments. The fresh concretes were produced in line with a specified mixing scheme in such a way that they exhibited an air content of 5.5 (± 0.5 vol. %) and a flow value of 40 cm to 45 cm 45 minutes after the end of the mixing time. It became apparent that considerably smaller quantities of air entraining agent were required for the superplasticizer concretes than for the stiff concretes without superplasticizer. Based on the mixing time, air entrainment with single and double added amount was then determined in relation to the admixture combination and the sequence of addition. The evaluation also included the concretes without superplasticizer (**Figs. 3.4.8-3 a** and **b**). It became clear that the sequence of addition had no influence on air entrainment based on the mixing time (**Figs. 3.4.8-4** and **3.4.8-5 a** and **b**). There is virtually no evidence of the potential for later activation typical of stiff concretes without superplasticizer with synthetic air entraining agents. This is probably due to the fact that far less air entraining agent is added with soft air entrained concretes. The experiments showed that the test specification is also applicable to air entrained concretes with superplasticizer and is appropriate to practical conditions as well.

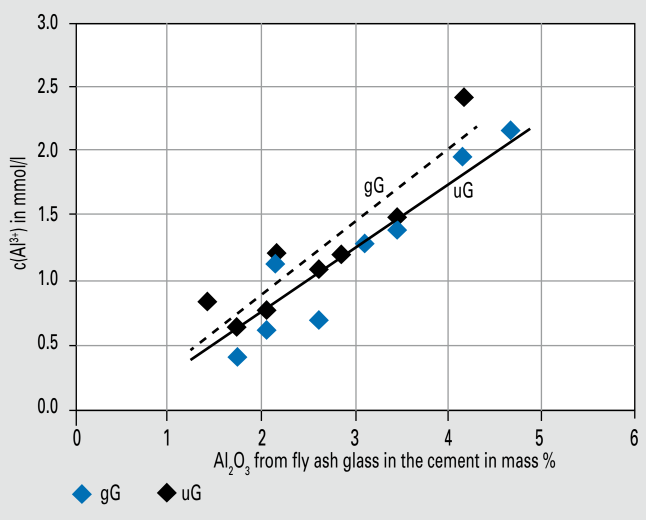

Fig. 3.4.9-1 Al concentration in pore solutions as a function of the reactive Al from fly ash in the laboratory cement; uG: fly ash in original state; gG: processed fly ash; age: 365 d

3.4.9 Prevention of deleterious ASR through the use of Portland fly ash cement – operating mechanisms in concrete

IGF project 19112 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 04/2016 – 09/2018

Background and aims

This research project follows on from the project 'Prevention of a damaging alkali-silica reaction through the specific use of siliceous fly ash as main cement constituent' (IGF 17249N; see Activity Report 2012-2015, P. 124) and has two objectives. The first aim was to study how the properties of fly ash cements affect the release of aluminium into the pore solution, which appears to have a distinct influence on the solubility of silicates and thus on the course of an alkali-silica reaction (ASR). The results will round off the extensive findings on the operating mechanisms of fly ash and fly ash cements with regard to the prevention of ASR. In a second step, concrete tests were to be performed with specifically selected fly ash laboratory cements to show what contribution is made by which mechanisms towards the prevention of deleterious ASR.

Approach

The project activities included the production of laboratory cements with 20, 30 or 40 mass % fly ash by mixing one Portland cement with six different siliceous fly ashes. The fly ashes were used in their original state (uG) and, in some cases, in processed form (gG: coarse fraction > 45 µm screened, ground and mixed with fine fraction < 45 µm). The gG state replicated the result of the typical treatment of fly ash for cement production.

The laboratory cements were hydrated with a water-cement ratio of 0.50 for up to 365 days at 20 °C. Pore solutions were then pressed out of the hardened cement pastes. The aluminium content in the solutions was determined by way of photometry.

Laboratory cements with 20 and 30 mass % fly ash were employed for the laboratory tests. To be able to distinguish between the effects of the various operating mechanisms, use was made of fly ashes with a high and low alkali content and a high and low reactive Al_2O_3 content, as well as of fly ashes in different processing states (uG, gG). The 60 °C concrete test with and without external alkali supply was employed for the studies.

Results/current status of the work

After 365 days of hydration, 0.4 to 2.4 mmol/l aluminium (Al) was found in the pore solutions. Evaluation of the results revealed that the Al concentration in the pore solution was essentially governed by the amount of Al_2O_3 introduced into the laboratory cement as 'reactive aluminium', i.e. as a constituent of the fly ash glass (**Fig. 3.4.9-1**). The amount of dissolved Al increased with an increasing proportion of reactive Al_2O_3 in the fly ash and with an increasing proportion of fly ash in the laboratory cement. Somewhat more favourable results are obtained for fly ash processed in the typical manner for cement. It became apparent that the release of Al into the pore solution can be controlled by way of the specific use of fly ash as main cement constituent, thus optimising the effect of the cement in terms of ASR prevention.

The concrete tests are long-term experiments. Final results on the influence of the various operating mechanisms of fly ash for ASR prevention can therefore be expected at the end of the project period.

3.4.10 Damage mechanisms of concrete exposed to freeze-thaw attack: Influence of main cement constituents on internal microstructural damage ■

IGF project 18439 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Period: 01/2015 – 06/2017

Background and aims

This research project picked up on the findings of earlier studies, in which freeze-thaw attack in the CIF test (Capillary suction, Internal damage and Freeze-thaw test) according to the Technical Report CEN/TR 15177 caused considerable microstructural damage in the presence of silica fume. The sharp decrease in the relative dynamic elastic modulus during exposure to freeze-thaw attack was attributed to silica fume gel formation by way of alkali silicates. This gel formation led to critical saturation of the pores in the concrete with water at an early stage.

The aim of the research project was to characterise the bonding and the freezability of the water in relation to the cement type and to determine the influence on microstructural damage in the course of freeze-thaw attack.

Approach

Use was made of laboratory cements with clinker, blast furnace slag, limestone, fly ash and silica fume as main constituents. The bonding of the water in the hardened cement paste and the pore structure of the hardened cement paste were characterised by way of water vapour sorption isotherms and mercury intrusion porosimetry. The internal damage to the concrete exposed to freeze-thaw attack was studied in the CIF test. The saturation of the concrete was determined via the relative pore filling degree.

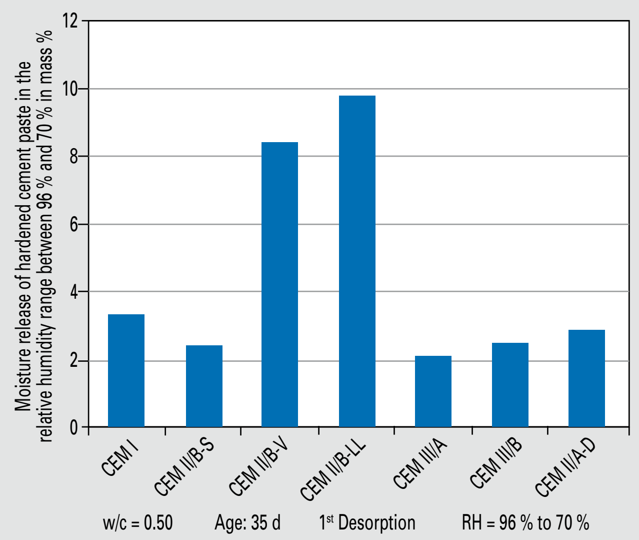

Fig. 3.4.10-1 Moisture release of hardened cement pastes with different cements during the first desorption in the relative humidity range between 96 % and 70 %

Results

In the sorption test, the equilibrium moisture content is determined for a defined relative humidity. Using the Kelvin equation, a pore radius from which the water desorbs in the hardened cement paste can be assigned for the relative humidity under consideration. By establishing a relationship between the relative humidity, the equilibrium moisture content of the hardened cement paste and the corresponding pore radius distribution it is possible to draw conclusions about the way in which the water is primarily bound in the hardened cement paste. For example, in the relative humidity range between 96 and 70 %, water desorbs from pores with a radius of between roughly 26.5 and 3.0 nm. This water was bound in particular by way of capillary condensation and multilayer adsorption. In the max. 20 % relative humidity range, chemisorbed or physisorbed water is desorbed from hardened cement paste pores with a far smaller radius up to max. 0.7 nm.

In the relative humidity range between 96 and 70 %, more water was seen to be desorbed from hardened cement pastes with Portland fly ash cement and Portland limestone cement than from hardened cement pastes with pure Portland cement, Portland silica fume cement, Portland slag cement and blast furnace cement (**Fig. 3.4.10-1**). Accordingly, more water is bound by way of capillary condensation and multilayer adsorption in hardened cement pastes with Portland limestone cement and Portland fly ash cement than in hardened cement pastes with Portland cement, Portland silica fume cement, Portland slag cement and blast furnace cement.

The results obtained from mercury intrusion porosimetry of the hardened cement pastes were compared to the water vapour sorption isotherms of these hardened cement pastes. For cements with a high capillary porosity (radii r ≥ 0.01 μm), a high level of moisture release was observed during desorption in the relative humidity range between 96 % and 70 %. In accordance with the Kelvin equation, water bonding accordingly takes place primarily by way of capillary condensation in the case of hardened cement pastes with high capillary porosity.

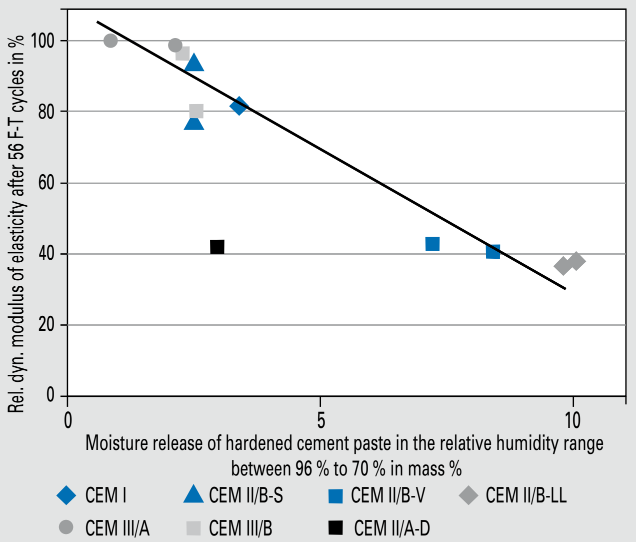

Fig. 3.4.10-2 Relationship between moisture release from hardened cement paste during desorption in the relative humidity range between 96 and 70 % and the relative dynamic elastic modulus of concrete in the CIF test after 56 freeze-thaw cycles (F-T cycles)

The water vapour sorption isotherms of the hardened cement pastes were compared to the results from the CIF test. The following relationship was observed for cements with blast furnace slag, fly ash and limestone as further main constituents: The greater the amount of moisture released during desorption in the relative humidity range between 96 and 70 %, the greater the drop in the relative dynamic elastic modulus after 56 freeze-thaw cycles in the CIF test. In this relative humidity range, the moisture was primarily released from the hardened cement paste pores with a radius of between 26.5 and 3.0 nm. This water was mainly bound by way of capillary condensation in the hardened cement paste (**Fig. 3.4.10-2**). Portland silica fume cement was the only type for which this relationship was not apparent. Despite the small amount of water bound in the hardened cement paste by way of capillary condensation, the concrete was severely damaged in the course of freeze-thaw attack in the CIF test. A possible explanation for this observation is yielded by the hypothesis from the earlier research project, that freezable water is bound in alkali silicates.

It thus became apparent that, when using various cement types, water is bound in different pore ranges of the hardened cement paste, either primarily via capillary condensation and multilayer adsorption or via physisorption and chemisorption. Severe microstructural damage when exposed to freeze-thaw attack in the CIF test was observed for concretes in which water is bound mainly via capillary condensation. In the case of concretes with cements containing silica fume, a sharp decrease in the relative dynamic elastic modulus was observed although only little water was bound by way of capillary condensation.

There is a correlation between the bonding of the water in the hardened cement paste and pore size characteristic values. With hardened cement pastes with a high proportion of capillary pores, water is mostly bound via capillary condensation in the hardened cement paste.

The results will contribute towards a more differentiated understanding of both the bonding of water in the hardened cement paste matrix and the behaviour of concretes in the CIF test.

3.4.11 Granulometry of main cement constituents – effects on the durability of concretes with limestone cements

IGF project 17853 BG supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partner: F. A. Finger Institute of Building Materials Science, Bauhaus University Weimar
Project period: 12/2013 – 11/2016

Background and aims

The project conducted together with the F. A. Finger Institute of Building Materials Science involved the production of limestone cements and research into the granulometric properties of the cements and their main constituents clinker, limestone, blast furnace slag and fly ash. The results of the studies were compared to the durability-related properties of concrete in laboratory experiments.

The aim of the research project was to draw up guidelines for the production of limestone cements with compositions in accordance with DIN EN 197-1, as well as with compositions not covered by the standard that satisfy the parameters relating to durability (procedures and criteria) required in Germany (approval procedures of the German Institute for Building Technology, DIBt). The methods employed have been incorporated into the European Assessment Document EAD 150001-00-0301 and the CEN TR 16563 procedural principles, Annex B. Systematic investigations were conducted into the influence of the granulometric properties (e.g. the particle size distribution) of the main cement constituents and of the packing density of the cements on the durability of the concretes produced with these. The cement properties were established in accordance with the definitions given in DIN EN 197-1. This means that the compressive strength was determined with a constant water-cement ratio (w/c), for example. The durability tests adhered to the principles of DIN EN 206-1/DIN 1045-2 and were thus conducted with constant mix formulations in compliance with the limit values. Consequently, no consideration was given to the possible reduction in water content associated with an improved packing density. The granulometrically defined cements were required to exhibit the performance level in concrete demanded in Germany. The basic performance characteristics for the durability of the concretes produced with these cements had to be within approval limits. The water-cement ratio was not adjusted (reduced) to achieve suitability for approval.

Approach

Cements with 35 mass % and 25 mass % limestone were produced together with 10 mass % blast furnace slag and 10 mass % fly ash. The vast majority of the experimental cements was made by grinding the main constituents separately and then mixing them with finely ground sulphate agent. Clinker, limestone and blast furnace slag were each used in two different finenesses as well as with broad and narrow particle size distribution. Fly ash was employed in its fine original state as well as in fully ground and selectively ground state. The material composition of each cement remained constant on varying the granulometric parameters.

Results

It became apparent that the packing density of the CEM II/B-LL and CEM II/B-M cements was influenced by the particle size distribution of their main constituents. As there are tight limits to the value range for the packing densities of flour-fine disperse systems,

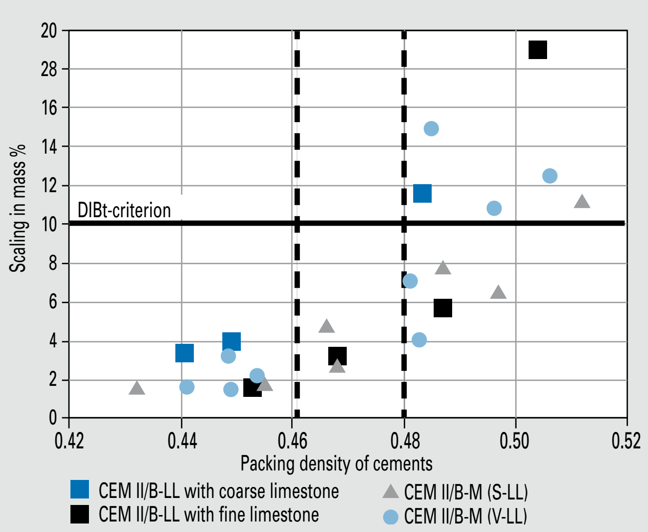

Fig. 3.4.11-1 Scaling of concretes after 100 freeze-thaw cycles in the cube test method (c = 300 kg/m³, w/c = 0.60) as a function of the packing density of the cements

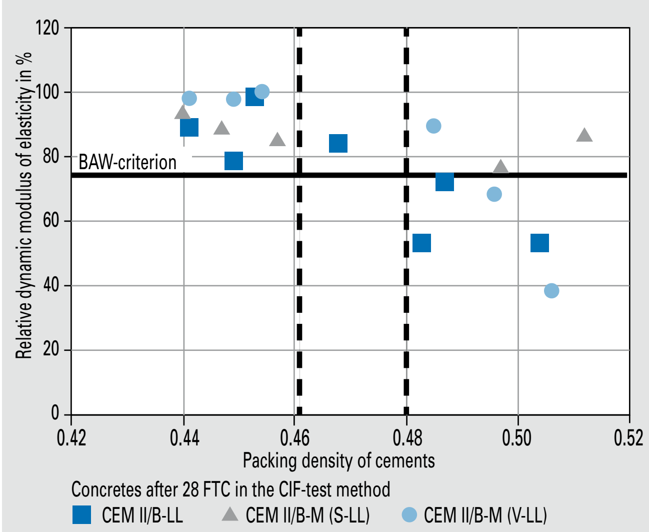

Fig. 3.4.11-2 Relative dynamic modulus of elasticity of the concretes after 28 freeze-thaw cycles in the CIF test (c = 320 kg/m³, w/c = 0.50) as a function of the packing density of the cements

the packing densities of the cements studied in this project were of an order of magnitude between 0.42 (low packing density) and 0.52 (high packing density). On using 65 mass % clinker of high fineness (approx. 5000 cm²/g according to Blaine) and narrow particle size distribution (n > 1.0 according to RRSB), for example, low packing densities (< 0.46) were obtained in the cements.

Cements with correspondingly different packing densities were selected for the studies performed on concretes, fine concretes and standard mortars. The durability was tested with a limit water-cement ratio in each case. The results show that comparatively low values for water demand in accordance with EN 196-3 and standard strengths (w/c = 0.50) as per EN 196-1 were found for cements with packing densities > 0.48. The values for water demand and standard strength increased significantly on reducing the packing density of the cements to < 0.46. The workability of the fresh concretes was also influenced accordingly. With w/c = 0.50, stiff consistencies were found in some cases on making use of cements with a low packing density.

Depending on the testing age fine concretes examined after a preliminary storage time of 7 days in accordance with the European Assessment Document EAD 150001-00-0301, Procedure No. 15, C_{dcr} method exhibited increasing carbonation depths with increasing packing density of the cements.

The studies conducted on concretes with w/c = 0.60 and air entrained concretes with w/c = 0.50 revealed that the freeze-thaw resistance (FT_{cube} method in accordance with Procedure No. 17 EAD 150001-00-0301) and the freeze-thaw resistance with de-icing salt (FTSCDF method in accordance with Procedure No. 18 EAD 15001-00-0301) increase appreciably in some cases with a decreasing packing density of the cements and that the corresponding assessment criteria (DIBt, Federal Waterways Engineering and Research Institute (BAW)) for scaling can be satisfied (**Fig. 3.4.11-1**). In addition, the relative dynamic elastic modulus of the concrete (w/c = 0.50) determined in the CIF test (Capillary suction, Internal damage and Freeze-thaw test/FT_{CF} method in accordance with Procedure No. 17 EAD 150001-00-0301) – which is used as a measure of internal damage – can also be influenced by the packing density of the cements and can achieve values corresponding to the assessment criteria for waterways engineering (BAW) (**Fig. 3.4.11-2**). The packing density of the cements examined here had no significant effect on the resistance to chloride penetration of the concretes (D_{mig} method in accordance with Procedure No. 16 EAD 150001-00-0301). When the main constituents blast furnace slag and fly ash were specifically pre-treated and used with a comparatively high degree of fineness and narrow particle size distribution, the chloride migration coefficients of the CEM II/B-M concretes (w/c = 0.50) attained values well below the approval criterion of the DIBt. The transferability and reproducibility of the results were confirmed by certain cements from other methods of manufacture and with other compositions. The findings obtained are to be checked in more extensive studies on concretes with constant workability and with adjusted water-cement ratios (w/c ≠ constant) using granulometrically optimised cements with a high packing density.

3.4.12 Serviceability limit state-related optimisation of concrete compositions: A step towards the further reduction of CO_2 emissions in the production of concrete? ■

Research project no. T218/24815/2013, supported by the Drs. Edith und Klaus Dyckerhoff-Foundation
Project period: 07/2013 – 06/2017

Background and aims

The aim of the research project was to determine durability-related material parameters for concretes with different compositions, using known and in some cases new cement types. The characteristic values of relevance to durability (e.g. carbonation

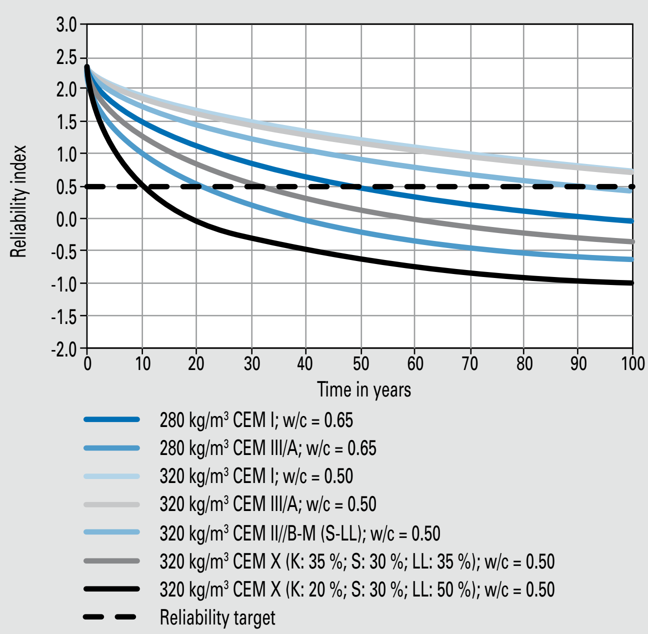

Fig. 3.4.12-1 Development of the reliability index for the carbonation limit state

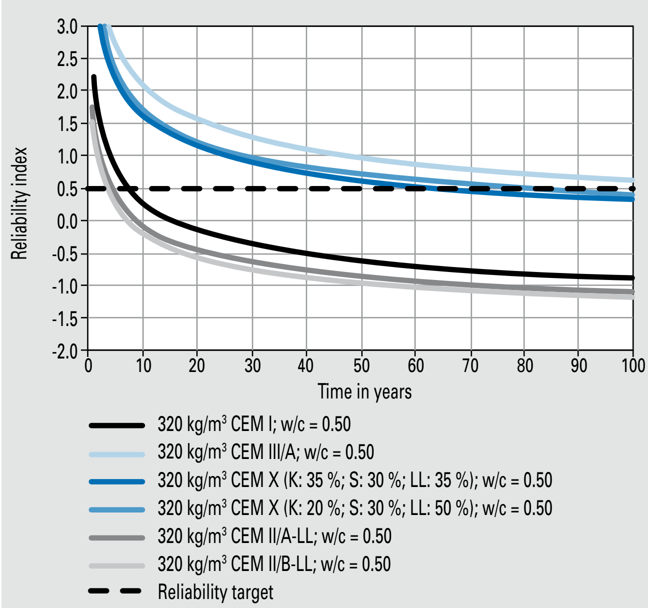

Fig. 3.4.12-2 Development of the reliability index for the chloride penetration limit state

rates) determined in laboratory tests formed the input variables for serviceability limit state studies based on the fib Model Code 'Service Life Design' and ISO 16204.

Approach

The experimental studies included investigations into carbonation behaviour and resistance to chloride penetration. Two concrete compositions were used: B0: Cement content (c) = 280 kg/m³, water-cement ratio (w/c) = 0.65; B1: c = 320 kg/m³, w/c = 0.50.

On the one hand, cements were employed that are approved for use in Germany for all exposure classes (CEM I, CEM II/A-LL, CEM III/A). In addition, use was made of new cements for which little or no practical experience exists with regard to carbonation and chloride penetration (CEM II/B-LL, CEM II/B-M (S-LL), CEM X).

The carbonation behaviour of the concretes was examined with various test methods, with both natural and increased CO_2 concentration. The resistance of the concretes to penetration by chlorides was studied in chloride migration and chloride diffusion tests, with variation of the age at the start of the test and the exposure time.

Taking the test results as a basis, serviceability limit state studies were performed to investigate the design performance of the concretes for use in reinforced concrete components under environmental conditions typical for Germany (exposure classes XC3, XD2). The corresponding development of the reliability index was determined over time until attainment of the applicable serviceability limit state for the serviceability limit states under consideration 'Depassivation of the reinforcement due to carbonation' (in brief: Carbonation limit state) and 'Attainment of the critical corrosion-inducing chloride content at the level of the reinforcement' (in brief: Chloride penetration limit state). This time period is referred to in the following as the design 'service life' and indicates the time until a minimum reliability index of $\beta = 0.5$ (reliability target) is no longer attained.

Results

The tests revealed that the cement type, the water-cement ratio and the cement content influence the carbonation behaviour. On varying the cement type for an identical concrete composition, the carbonation depths found with a natural CO_2 concentration increased with a decreasing clinker content of the cement. In some cases it was possible to compensate for these greater carbonation depths by using a concrete composition optimised in terms of w/c ratio and cement content (B1 instead of B0).

Two distinct groups of results were obtained from the chloride penetration tests. The concretes with the cement types CEM III/A and CEM X with 30 mass % blast furnace slag exhibited comparatively low chloride migration and chloride diffusion coefficients, whereas far higher values were found for the concretes with the cement types CEM I, CEM II/A-LL and CEM II/B-LL, irrespective of the w/c ratio and cement content.

The probabilistic serviceability limit state calculations on carbonation yielded a large value range for the design 'service life' of the concretes examined (**Fig. 3.4.12-1**). Long design 'service lives' in excess of 90 years were attained for the concrete composition B1 in combination with the cement types CEM I, CEM III/A and CEM II/B-M (S-LL). For the other concretes studied, the design 'service lives' were shorter than the minimum service life of 50 years generally applied to reinforced concrete structures.

The chloride penetration serviceability limit state studies revealed a direct relationship between the chloride migration coefficient and the design 'service life' (**Fig. 3.4.12-2**). Design 'service lives' well in excess of 50 years were established for concretes of composition B1 with cement type CEM X with 30 mass % blast furnace slag. When using CEM III/A with around 50 mass % blast furnace slag, a period of even more than 100 years was obtained. By contrast, the concretes with CEM I, CEM II/A-LL and CEM II/B-LL achieved design 'service lives' of less than ten years. This exemplifies the difference between the formulation of durability requirements based on an serviceability limit state as compared to the stipulations of the concrete standard DIN 1045-2. The stipulations of DIN 1045-2 prescribe a minimum 50-year service life without any macroscopically visible corrosion damage.

3.4.13 Resource-saving concrete – The next-generation material

The collaborative research project 'R concrete' stands for 'Resource-saving concrete - The next-generation material' and is concerned with the treatment and use of recycled aggregate (RC aggregate). The project encompasses the entire value chain and deals with all issues currently standing in the way of broad-based introduction of R concrete onto the market. The contribution made by VDZ took the form of a sub-project. One of the aims was to compile 'Guidelines for the use of crushed sands (fine RC aggregate) in the production of cement' – referred to in the project as 'R cement'. Ecological assessment in the form of an ecobalance with regard to cement and concrete production was a further objective of this sub-project. It also involved devising a practicable procedure for the reliable avoidance of alkali-silica reaction.

Collaborative research project 'R concrete – Resource-saving concrete – The next-generation material', funded by the German Federal Ministry of Education and Research (BMBF), funding scheme 'New materials for urban infrastructures – HighTechMatBau'
Project period: 11/2014 – 11/2017

3.4.13.1 Part 1: RC aggregate – Use in cement

Background and aims

Fine recycled aggregates, so-called crushed sands, are not defined as a main constituent in accordance with DIN EN 197-1, Section 5.2, and are therefore not allowed to be used in cement. Cements employing crushed sand as main constituent are subject to approval. With regard to environmental compatibility it would then probably also be necessary to comply with the maximum values stipulated in DIN 4226-101:2017-08 for the parameters relating to eluates and solids. Verification of both the cement properties demanded in DIN EN 196-1 and DIN EN 197-1 and the durability-related concrete properties would be required.

Approach

The Portland cements CEM I 42,5 R and 52,5 R formed the basis for the R cements (laboratory cements) produced in this project. The crushed sands differed in terms of their composition (origin), particle size and treatment method. Use was made of crushed sands obtained from the processing of sleepers (CTG), track ballast (UTG), crushed concrete (BTG) and masonry rubble (MTG). After delivery, the crushed sands were dried and ground to a fineness of approximately 4 000 cm²/g acc. to Blaine in an intermittently operating laboratory ball mill. The Portland cements were then mixed with the flour-fine crushed sands in the laboratory to form R cements. Proportions of 10 and 30 mass % crushed sand were set in the cement for production of the laboratory cements. In addition to this, large-scale operational trials were performed to produce R cement by way of joint grinding at a cement works. Proportions of 8 and 15 mass % crushed sand were set in the works cements.

Results

The crushed sands used in the VDZ laboratory experiments and full-scale operational trials complied with the environmental requirements of DIN 4226-101. The maximum values for the parameters relating to eluates and solids were satisfied. Depending on their material/granulometric composition, the R cements corresponded to strength classes 42,5 N to 52,5 R in accordance with DIN EN 197-1. Concretes were produced on the basis of selected R cements and tested. The compositions of the concretes were as follows: B1: Cement content (c) = 300 kg/m³, water-cement ratio (w/c) = 0.60; B2: c = 320 kg/m², w/c = 0.50. The cube test method was employed to determine the freeze-thaw resistance of the B1 concretes. These tests correspond to the standards applied to date by the German Institute for Building Technology (DIBt) for the approval of cements. The concretes were subjected to up

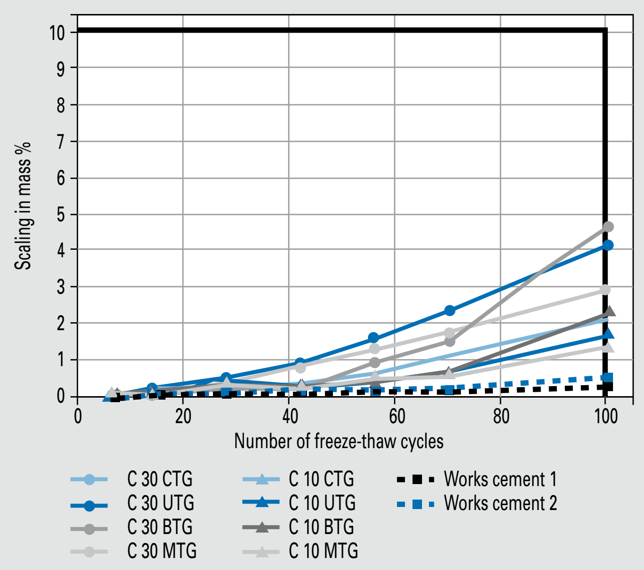

Fig. 3.4.13.1-1 Scaling of the B1 concretes made with laboratory and works cements in the cube test method as a function of the number of freeze-thaw cycles, concretes with c = 300 kg/m³, w/c = 0.60

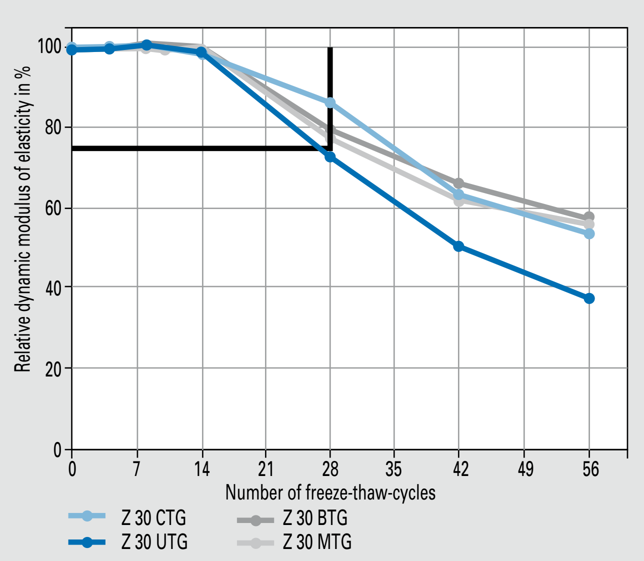

Fig. 3.4.13.1-2 Relative dynamic modulus of elasticity of the B2 concretes in the CIF test as a function of the number of freeze-thaw-cycles, concretes with c = 320 kg/m³, w/c = 0.50

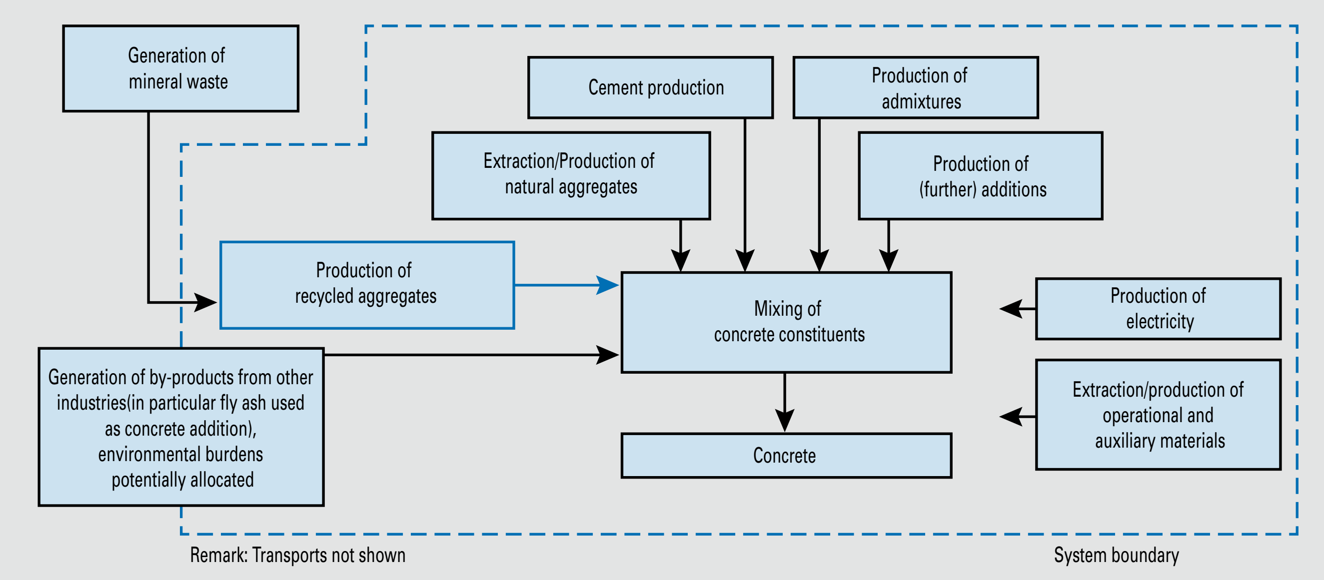

Fig. 3.4.13.1-3 System boundaries of life cycle assessment

to 100 freeze-thaw cycles (FTC) with one cycle per day. The scaling of the concretes differed only slightly depending on the type of crushed sands. **Fig. 3.4.13.1-1** shows that there was only a low level of scaling (max. 4.7 mass %) when using laboratory cements with up to 30 mass % crushed sand in combination with CEM I 42,5 R. The 10 mass % limit value for scaling after 100 freeze-thaw cycles employed in the DIBt approval tests was satisfied by a considerable margin. R cements with 30 mass % crushed sand in combination with CEM I 52,5 R and R cements with 10 mass % crushed sand in combination with CEM I 42,5 R were used to produce B2 concretes for examination of the internal microstructural damage (relative dynamic elastic modulus) in the CIF test (Capillary suction, Internal damage and Freeze-thaw test). The test specimens were made and analysed in accordance with the Technical Report CEN/TR 15177. Testing was conducted over the course of 56 freeze-thaw cycles. Taking the R cements with 30 mass % crushed sand in combination with CEM I 52,5 R as an example, **Fig. 3.4.13.1-2** illustrates the development of the relative dynamic elastic modulus of the concretes as a function of the number of freeze-thaw cycles. It can be seen that three out of the four concretes satisfied the assessment criterion for the CIF test in accordance with the code of practice 'Freeze-thaw testing of concrete' issued by the Federal Waterways Engineering and Research Institute (BAW) and attained a relative dynamic elastic modulus of > 75 % after 28 freeze-thaw cycles. The concrete produced with the R cement Z 30 UTG (track ballast) did not conform to the above-mentioned assessment criterion. An overall view of the results obtained for R cements in the project reveals that these cements, with up to 30 % crushed sand, could at least be used in interior component concretes. A continuous, uniform material flow of corresponding quality between the processing plant and the cement works would however be essential.

3.4.13.2 Part 2: RC aggregate – Life cycle assessment for cement and concrete production

Background and aims, current status of the work

The European standard EN 15804 sets down regulations for the life cycle assessment (LCA) of construction products. In 2017, VDZ published the LCAdata for the production of an average cement made in Germany in a revised environmental product declaration in accordance with EN 15804. This LCA was based on environment-related production data from German cement works.

The first topic to be dealt with in the 'Life cycle assessment' work package of the R concrete project was the influence of the use of crushed sand on the LCA of cement production. In particular, this involved giving consideration to the environmental impact associated with the processing of old concrete (crushing, sieving, etc.) and the use of these crushed sands in place of the raw materials currently used for cement production. A comparison between the data published by the association and the newly determined LCA parameters was intended to show the extent to which the use of RC fine material can help to reduce the environmental impact of cement production.

In a similar manner as for cement, consideration was also to be given to the possible effect of the use of RC aggregate on the LCA for the production of concrete. In 2018, VDZ will be producing updated LCA studies for concretes of six different strength classes, based on typical concrete formulae determined by the German Ready-Mixed Concrete Association (BTB) and the German Association for Precast Concrete Construction (FDB). These LCA studies, published in environmental product declarations, are intended to be used for comparison purposes. **Fig. 3.4.13-1** shows the system boundaries of the planned LCA, i.e. an overview of the concrete production processes for which the environmental influences are to be recorded and assessed.

3.4.13.3 Part 3: Assessment of the alkali reactivity of recycled aggregates

Background and aims

The alkali reactivity class has to be stated for aggregates for concrete in accordance with EN 206-1 and DIN 1045-2. If necessary, concrete manufacturers can take preventive action to avoid damage as a result of alkali-silica reaction (ASR). Prior to issuing of the 2010 DAfStb Specification Concrete with recycled aggregates, the measures for E III-O aggregates had to be taken for any recycled aggregates that could not be clearly assigned to a non-critical alkali reactivity class (**Table 3.4.13.3-1**). Since 2007 (in accordance with the alkali guideline) and 2010 (in accordance with the guidelineof the German Committee for Structural Concrete (DAfStb) on concrete with recycled aggregates), the recycled aggregates have had to be assigned to alkali reactivity class E III-S in such cases. This brought about a change in the preventive measures (**Table 3.4.13-1**). In the project 'R concrete – Resource-saving concrete – The next-generation material' (sub-project 5), this change was checked by conducting ASR performance tests on concretes.

Approach

To check the action marked (*) in **Table 3.4.13.3-1** for E III-S aggregates, concretes of unfavourable composition were produced with recycled aggregates. Unfavourable means that the prerequisites for detrimental ASR have been created in the form of alkali-reactive aggregates in the starting concrete and a high alkali content of the cement. The recycled aggregate of the concretes was obtained from concrete cubes which had been kept in the VDZ open-air store for many years for ASR test purposes (**Fig. 3.4.13.3-1**). At the time, the concretes were produced with a mixture of 15 mass % alkali-reactive gravel with opaline sandstone and flint 2/8 of alkali reactivity class E III-O – E III-OF and 85 mass % Rhenish gravelly sand of alkali reactivity class E I. Extensive studies performed by VDZ in the 1970s had identified this composition as being the least favourable type. For this reason, the aggregate mixture has in the past been used as reference aggregate for verifying the low effective alkali content of cements in accordance with DIN 1164-10 (low-alkali cement).

The ASR resistance of the concretes of moisture class WF (moist environment) was examined by performing the 60 °C concrete test without alkali supply. The test procedure corresponds to the 60 °C concrete test in accordance with the alkali guideline, Annex C. The method has been employed since 2004 in France (AFNOR P18-454) and in Switzerland (code of practice SIA 2042) to assess the alkali reactivity of concretes.

Results

The results show that the current (E III-S) measures are not always adequate for recycled aggregates (**Fig. 3.4.13.3-2**). The expansion of the two concretes in the 60 °C concrete test is well in excess of the limit value of 0.2 mm/m after 140 days employed in France and Switzerland and specified in AFNOR FD P 18-456.

DAfStb recommendation

On the basis of the results obtained, the DAfStb recommends that recycled aggregates should be treated, as was the case before 2007 and 2010, as aggregates of alkali reactivity class E III-O if these are used in the ice-age deposition region of Northern Germany, as specified in the alkali guideline, and verification of non-criticality is not possible or is not performed for the aggregate. In the rest of Germany, recycled aggregates for which verification of non-criticality is not possible or not performed can continue to be assigned to alkali reactivity class E III-S.

Table 3.4.13.3-1 Preventive measures to avoid detrimental alkali reaction in concrete in accordance with the alkali directive, 2013 issue

Alkali reactivity class	Cement content in kg/m³	Preventive measures for moisture class		
		WO (dry)	WF (moist)	WA (moist + external supply of alkalis)
E I, E I-O, E I-OF, E I-S	Not specified	None	None	
E II-O	≤ 330		None	Low alkali cement
E III-O			Low alkali cement	Replacement of aggregate
E II-OF	> 330		Low alkali cement	
E III-OF			Low alkali cement	Replacement of aggregate
E III-S	≤ 300		**None***	keine
	≤ 350			Low alkali cement or expert's report[1)]
	> 350		Low alkali cement or expert's report[1)]	Replacement of aggregate or expert's report[1)]

[1)] Specialist consultants are to be involved in the preparation of an expert's report.

Fig. 3.4.13.3-1 Concrete cubes and prisms in VDZ open-air store

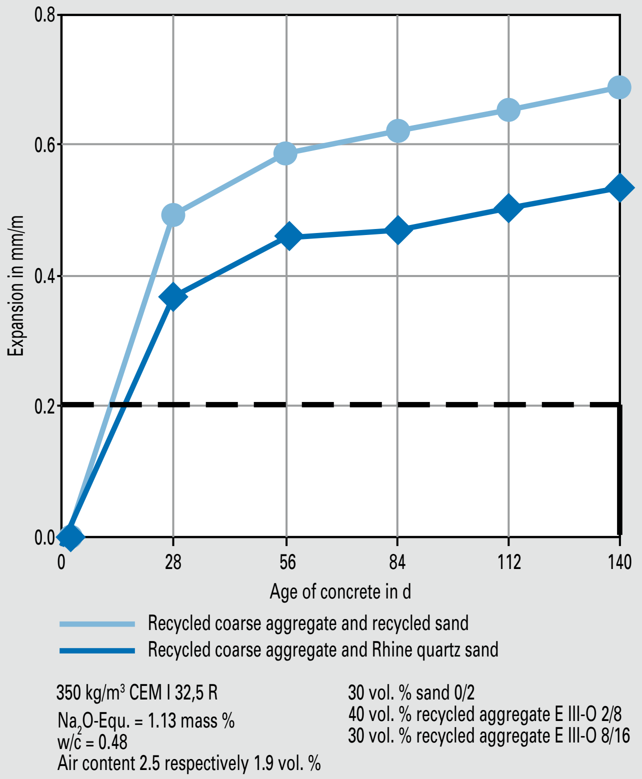

Fig. 3.4.13.3-2 Expansion of concrete prisms with recycled aggregate and cement with a high alkali content in the 60 °C concrete test (without external alkali supply)

3.4.14 Interactions between cements with several main constituents and methyl celluloses and the performance of these in modern mineral dry mortars

IGF project 17929 BG, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partner: F.A. Finger Institute for Building Material Engineering, Bauhaus-Universität Weimar
Project period: 01/2014 – 09/2016

Background and aims

Cements with several main constituents have been successfully used for decades both in concrete and in plastering and masonry mortar. For complex cementitious preparations (e.g. adhesives for tiles and slabs), which account for the majority of dry mortar, use is still primarily made of Portland cement. This is due to the fact that so far there has been a lack of knowledge about the performance of cements with several main constituents in these formulations and there were concerns about possible quality deficits in corresponding products.

The aim was therefore to determine the performance of cements with several main constituents in dry mortar. For this purpose, wetting capability, open time, slippage and tensile adhesion strength were determined on an application-oriented basis using a model formulation for tile adhesives. Interactions of the cements with cellulose ethers was determined in a fundamental study. Cellulose ethers provide a workable consistency and the necessary water retention of mortar, retard the microstructure development and increase porosity.

Approach

The dry mortar consisted of 30 mass % cement and 70 mass % quartz sand (0.5 mm maximum grain size). 0.35 mass % cellulose ether (CE) was added. Use was made of two commercially available methyl hydroxyethyl celluloses with degrees of substitution (DS) of 1.76 and 1.55. The CE with DS = 1.76 was modified either with 20 mass % starch ether or 5 mass % polyacrylamide. Portland cement CEM I 52,5 R was used as reference and to produce cements with 35 mass % limestone, blast furnace slag or fly ash and 55 mass % blast furnace slag or fly ash by mixing. The cements satisfied the requirements of EN 197-1.

Results

The CE modified with 5 mass % polyacrylamide resulted in (irrespective of the cement) stiffer mortar consistencies than the other CEs, for which there was no appreciable difference in effect. Water retention was not significantly influenced by the type of CE. For cements with several main constituents, less water had to be added to achieve the same consistency and water retention. A lower water content has the effect of accelerating strength development and improving durability.

As expected, the CEs retarded cement hydration and the microstructure development of the mortars. The retarding effect of the CEs increased for all cements with a decreasing DS. A greater retarding effect was obtained from modification with starch ether than with polyacrylamide. The effects of DS and starch ether on hydration and microstructure development known from Portland cement can therefore also be applied to cements with several main constituents. No further significant retardation was measured on replacing the Portland cement with cements with blast furnace slag or fly ash whilst maintaining a constant amount of CE.

As was to be expected, the mortars with CE exhibited greater porosities than the other mortars on account of the air-stabilising CE effect. The CEs produced a shift in the maximum pore volume distribution values from around 0.1 µm to around between 1 and 5 µm.

As compared to mortar with Portland cement, better wetting of the tiles and longer open times were achieved by the use of the cements containing fly ash or blast furnace slag. The use of ever larger tiles and slabs today makes minimal slippage a central requirement for adhesives. Modification with 20 mass % starch ether (CE-020SE) made it possible (irrespective of the cement) to reliably keep slippage below the limit value of EN 12004-1 (**Fig. 3.4.14-1**). As expected, greater slippage was found when using the non-modified CE, and the limit value was exceeded in two cases. It was possible to satisfy the tensile adhesion strength requirements after dry storage, water storage and freeze-thaw cycle storage with all cements when use was made of the non-modified CE. Starch ether modification produced lower values which, in combination with the slag containing cements, were below the limit value after dry storage (**Fig. 3.4.14-2**).

The results show that it is basically possible to use resource-saving cements with a clinker content significantly reduced by the use of further main constituents, and thus associated with considerably lower specific CO_2 emissions, in complex cementitious preparations such as tile adhesives as well. This is of particular interest from the point of view of sustainability. No evidence was found to confirm concerns that mortars containing such cements might exhibit far poorer performance. On the contrary, it became apparent that performance characteristics differing from those of Portland cement can be put to good use or adjusted through the use of admixtures.

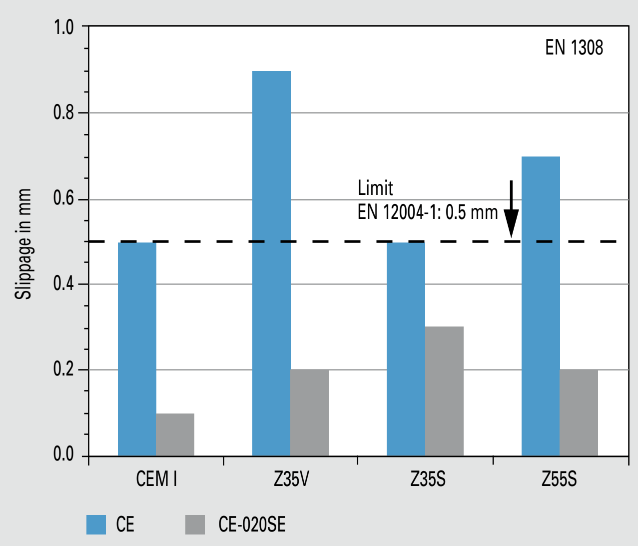

Fig. 3.4.14-1 Slippage of tiles in the mortar bed depending on the combination of cellulose ether and cement

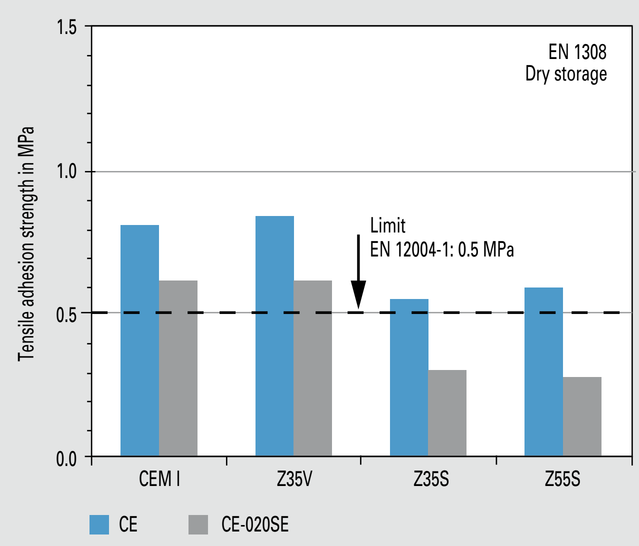

Fig. 3.4.14-2 Adhesive tensile strengths of mortar depending on the combination of cellulose ether and cement

3.4.15 Optimum compaction of highly robust high workability concretes

IGF project 19276 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project partner: TU Munich (Centre for Building Materials (cbm), Chair of Materials Science and Testing).
Project period: 11/2016 – 04/2019

Background and aims

High workability concretes (HWC) with flowable to highly flowable consistency (consistency classes F5 and F6) are extremely well suited to the production of components demanding high standards in terms of aesthetics and durability combined with a short construction time. The high degree of flowability makes it possible to reduce time-consuming processes to a minimum, for example concrete spreading in the formwork, compaction and reworking of the concrete surface following placement. For this purpose the concretes have to be adjusted such that little compaction energy is required for de-aeration.

A prerequisite for the successful use of HWCs on construction sites is appropriate compaction in combination with a robust concrete formula. The compaction energy required largely depends on the component geometry, the fresh concrete consistency and the concrete composition. As yet there are no adequate objective assessment criteria regarding the correct amount of compaction energy to be applied for HWCs. Over-compaction can lead to bleeding or sedimentation of the coarse aggregate. This can have a detrimental effect on the strength, deformation and durability properties of the hardened concrete.

The aim of the IGF project 19276 N is to obtain fundamental information on the practical assignment of the necessary working and compaction methods based on the fresh concrete properties.

Approach

For the purposes of the study, the consistency and rheological properties of concretes were specifically varied and the concretes were assigned to different workability classes on the basis of these characteristic quantities. The next step was to investigate the effect of various working and compaction methods on the fresh concrete properties (voids content, bleeding tendency, segregation resistance etc.) and hardened concrete properties (bulk density, compressive strength etc.). This permits the identification of concretes with robust fresh and hardened concrete properties, as well as the definition of appropriate working and compaction methods. The results are to be used to compile guidelines for the appropriate working and compaction of HWCs on construction sites. This should help to avoid incorrect application and so enhance the quality of this type of construction.

Current status of the work

With a view to applying the results obtained in the laboratory to practical use, a link was first established between laboratory compaction (vibrating table with adjustable frequency) and the compaction effect of practical methods (rodding, raking, internal vibrator). To check the comparability of the compaction effect, the air content of the fresh concrete and the concrete compressive strength were determined on the basis of different practical and laboratory compaction scenarios.

The consistency and viscosity of the concretes were specifically varied in order to define workability classes. The first step was to select three reference mix formulations for HWCs with different water/solids ratios and the same paste content. High workability concretes with high, medium and low viscosity were designed by using a low (w/c_{eq} = 0.30), a medium (w/c_{eq} = 0.46) and a high water/solids ratio (w/c_{eq} = 0.75). The consistency of the concretes was adjusted with a PCE (polycarboxylate ether) superplasticiser. The concretes were classified as HWCs with high flowability (flow value a = 68 ± 3 cm), HWCs with medium flowability (a = 62 ± 3 cm) and HWCs with low flowability (a = 56 ± 3 cm). To cover the range of potential HWC workability characteristics as comprehensively as possible, the cement type, as well as the type and quantity of the additions and the coarse aggregate (replacement of gravel with crushed stone) were also varied.

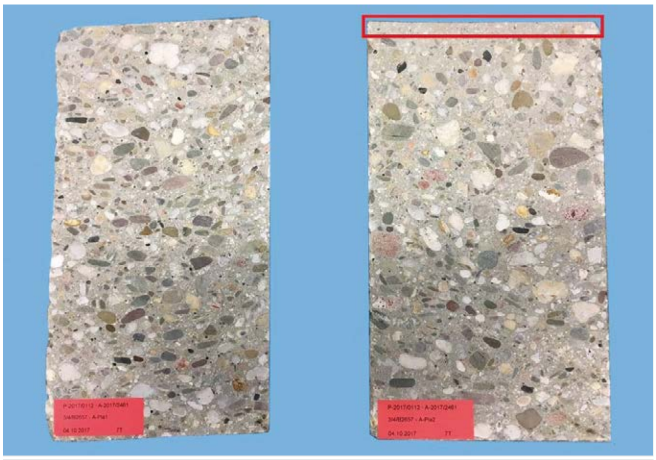

Fig. 3.4.15-1 Structure of concrete with high workability and mid-level viscosity after compaction through squeegeeing (left) and after compaction on a vibrating table (f = 50 Hz) in three layers, each layer vibrated for 20 s (right); framed area: visible segregation of coarse aggregates

Fig. 3.4.15-2 Structure of concrete with high workability and low viscosity after compaction through squeegeeing (left) and after compaction on a vibrating table (f = 50 Hz) in three layers, each layer vibrated for 20 s (right); framed areas: visible segregation of coarse aggregates

Another task was to quantify the relationships between exposure to compaction and the resultant fresh and hardened concrete properties of the HWCs on the basis of the workability classes. In the further course of the project (after the time of publication), fresh concrete is to be examined on the basis of various compaction scenarios to determine the air content, to establish bleeding with the bucket method and to determine the sedimentation of the coarse aggregates by performing a segregation test in accordance with the SCC (self-compacting concrete) directive. Tests will be conducted on hardened concrete to determine the compressive strength, the bulk density, water absorption and the sedimentation of the coarse aggregate on the basis of sectional views. By way of example, **Figs. 3.4.15-1** and **3.4.15-2** show the structure of a medium-viscosity HWC with medium flowability (320 kg/m^3 CEM I 42,5 N, 90 kg/m^3 siliceous fly ash, $w/c_{eq} = 0.46$, grading curve A/B 16) and of a low-viscosity HWC with high flowability (240 kg/m^3 CEM I 42,5 N, 67 kg/m^3 siliceous fly ash, $w/c_{eq} = 0.75$, grading curve A/B 16) according to various compaction scenarios. Comparison of the sectional views, in particular within the framed areas, reveals that, in terms of sedimentation of the coarse aggregate, the low-viscosity HWC reacts more sensitively to exposure to compaction than the medium-viscosity HWC, but by contrast exhibits less visible air entrainment on compaction by raking.

The final step will be to collate the results of the fresh and hardened concrete tests to determine appropriate compaction methods for each workability class. Limiting factors in the definition of appropriate compaction are the minimum amount of compaction energy required for de-aeration and the maximum amount that can be applied without causing bleeding or sedimentation of the coarse aggregates.

3.4.16 Concrete paving freeze-thaw resistance with de-icing salt Transferability to practical conditions of laboratory testing procedure results

IGF project 17996 N, supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF
Project period: 12/2013 – 11/2016
Project partner: University of Kassel

Background and aims

Since 2005, manufacturers have been required to verify freeze-thaw resistance with de-icing salt for concrete paving blocks by way of the modified slab test in accordance with DIN EN 1338 (referred to in the following as slab test for the sake of simplicity). Some clients in Germany prefer the CDF method (Capillary Suction, De-icing agent and Freeze-thaw test; DIN CEN/TS 12390-9), although there are sometimes discrepancies between laboratory test results and the behaviour of blocks laid in practice. In spite of passing the CDF test, the face concrete of the concrete paving stones was separated from the concrete after a few winters.

Approach

Concrete paving blocks from the large-scale production of various manufacturers with different finisher settings/different concrete composition were laid on an approximately 1 m^2 large bed of crushed stone and studied in frost chambers at low air temperatures, with sprinkler irrigation and with the application of de-icing salt. The temperature and humidity settings were based on climatic data recorded by the German Meteorological Office over several years in locations belonging to frost zones 1 to 3 in accordance with RStO2012 (Directives for the standardization of the superstructures of trafficked surfaces, 2012 issue). The freeze-thaw cycles in the frost chambers were implemented for around 83 % of the exposure time at between +20 and -6 °C and for around 17 % of the exposure time at between +20 and -15 °C. Two rainfall events per week were simulated with 1 litre of tap water per square metre of paving area. The amount of de-icing salt (sodium chloride) scattered was set at 130 g/m^2 per week on the basis of a manual test performed. In addition to factory-produced concrete paving blocks, blocks from a pilot plant were also incorporated into the study.

Table 3.4.16-1 Comparison of the results of tests performed on concrete paving blocks from large-scale production

Variety	Freezing chamber investigation		Slab-Test scaling in g/m²			CDF-Test scaling in g/m²			Accordance
	Damage (FTC)	UTT in µs min-max (mw)	LD	MD	HD	LD	MD	HD	SLT/CDF/FC
1	None (1 039)	n. d.[1)]	4.5	7.5	4.5	58	55	159	+
2	None (1 039)	n. d.[1)]	n. d.	7.0	n. d.	38	358	111	+
3	None[2)] (1 334)	30.9 ... 35.0 (33.0)	n. d.	27	n. d.	63	178	66	+
4	None[3)] (1 322)	31.8 ... 35.5 (33.0)	n. d.	6.8	n. d.	n. d.	46	n. d.	+
5	Cracks (958) edge spalling[4)] (1 334)	32.8 ... 123.0 (55.8)	n. d.	6.5	n. d.	168	88	60	-
6	Cracks, floe slabs (1 334)[5)]	31.8 ... 35.5 (33.3)[5)]	n. d.	8.0	n. d.	84	40	38	-

Abbreviations: USL – Ultrasonic Transit Time, SLT – Slab-Test, CDF – CDF-Test, FC – Freezing Chamber, LD/MD/HD Concrete paving stones with low / medium / high bulk density, n. d. – not determined, FEZ- Frost Exposure Zone

[1)] no damage to the facing concrete after 1 039 FTC (24/13/11 winter in FEZ 1/2/3) expanded for capacity reasons
[2)] no damage to the facing concrete after 1 334 FTC (31/17/15 winter in FEZ 1/2/3)
[3)] no damage to the facing concrete after 1 322 FTC (31/17/15 winter in FEZ 1/2/3)
[4)] first cracks after 958 FTC (30/17/15 Winter in FEZ 1/2/3) – spalling facing concrete after 1 334 FTC
[5)] first cracks at the corners / edges and beginning floe fracture of the facing concrete after 1 334 FTC

Results/conclusions

1. Concrete paving blocks from large-scale production
The face concretes of types 1 and 2 and 3 and 4 did not exhibit any visible scaling after 1039 and 1334 freeze-thaw cycles (FTC) in the frost chamber (**Table 3.4.16-1**). Ultrasonic transit time measurements taken over the surface of the various types of concrete paving block did not yield any indication of internal microstructural damage.

Cracks with fragmentary scaling occurred at the edges of individual concrete paving blocks in face concrete of type 6 after 1334 freeze-thaw cycles in frost chamber storage FC (**Fig. 3.4.16-1**).

By contrast, there was no appreciable scaling of the face concretes of concrete paving block type 6 in the slab test and with the CDF method. The results of the frost chamber studies and the slab test or the CDF method thus led to different assessments of the performance of concrete paving block type 6. There were isolated instances of initial cracking in the face concrete of type 5 after 958 FTC in the frost chamber, which in some cases resulted in detachment of the facing concrete after 1334 FTC (**Fig. 3.4.16-2**).

It was thus not possible to forecast the damage to the type 5 paving area laid in the frost chamber with either of the two laboratory freeze-thaw testing procedures.

2. Concrete paving blocks from a pilot plant – study of face concretes
Four laboratories studied the face concretes of four different types of concrete paving block from a pilot plant in a round robin test. One laboratory additionally tested the core concrete. The slab test performed on the face concrete of the crushed basalt concretes (types B8, B9) and of the gravel concrete type K11b yielded only marginal amounts of scaling, which closely coincided with the damage behaviour of the blocks in the frost chambers (**Table 3.4.16-2**).

After 326 freeze-thaw cycles in the frost chamber test, the concrete paving of gravel concrete type K10 exhibited cracks and bumps in the face concrete. By contrast, little scaling occurred in the face concrete in the slab test.

Very little scaling was generally also found in the face concrete of the paving blocks with crushed basalt (B8 and B9) when employing the CDF method. The face concretes of types K10 and K11b (gravel) on the other hand exhibited high degrees of scaling at all four laboratories. In roughly 25 % of cases, the results obtained from the CDF method coincided with the scaling behaviour in the frost chamber studies.

One laboratory also examined the core concretes of the paving blocks from the pilot plant. The slab test results for the core concrete corresponded to the results of the frost chamber studies in all cases. By contrast, testing of the core concretes with the CDF method only reflected the behaviour of the two-layer blocks in the frost chamber studies in half of the cases.

The greatest degree of consistency with the behaviour of two-layer concrete paving blocks in realistic frost chamber studies was found on examining both the face concrete and the core concrete with the modified slab test in accordance with EN 1338.

In addition to performing testing on the 'face concrete' area, testing of the central concrete for freeze-thaw resistance with de-icing salt is therefore also recommended. Use should be made of a robust concrete composition with an appropriate cement content in the central concrete as well. This reduces the risk of failure once the blocks have been laid. In the long term, testing of the core concrete with the slab test could be set down in DIN EN 1338. Until then, verification could be demanded in invitations to tender.

Fig. 3.4.16-1 Comparison of the results of tests performed on concrete paving blocks from large-scale production

Fig. 3.4.16-2 Fragmentary scaling as a result of face concrete damage at the edges of individual concrete paving blocks

Table 3.4.16-2 Comparison of the results of tests performed on concrete paving blocks from the pilot plant

Variety	Freezing chamber	Slab-Test					CDF-Test				
	Damage (FTC)	Test surface: facing concrete - scaling g/m^2									
		Lab1	Lab2	Lab3b	Lab4	Accordance FC/Slab	Lab1	Lab2	Lab3a	Lab4	Accordance FC/CDF
B8	None (401)	14	60	19[1]	20	+	334	840	2.113	131	-
B9	None (401)	14	113	8[1]	24	+	1 325	308	3 069	197	-
K10	Cracks, bulges (326)[b]	23	77	7[1]	25	-	1 829[3]	(197)[2]	1 842[4]	3 753	+
K11b	None (401)	26	140	7[1]	181	+	2 191	1 224[5]	6 070	5 804	-
	USL[a] in µs min-max (MW)	Test surface: core concrete - scaling in g/m^2									
B8	32.5 ... 37.0 (34.7)	75				+	360				+
B9	32.8 ... 36.9 (34.5)	736				+	1 951				-
K10	35 ... 109.4 (53.9)	10 222				+	83 340				+
K11b	33.6 ... 39.9 (35.6)	8				+	2 405				-

a) Ultrasonic transit time after 326 freeze-thaw cycles,
b) Uplifts, bulges at the edges, horizontal cracks in facing concrete (edges)
1) Thawing solution does not remain on the test surface
2) Results after 22 FTC – all specimens destroyed after another 4 FTC
3) Result of the last undestroyed paver, other 4 pavers already destroyed after 22 FTC
4) Value after 18 FTC - after 22 FTC 4 out of 5 stones destroyed (scaling degreased to 909 g/m^2)
5) One of five paving stones destroyed after 28 FTC

3.5 Knowledge transfer and media

3.5.1 BetonQuali – Information and qualification platform ■

This project is supported by the German Federal Ministry of Education and Research (BMBF) and the European Social Fund in Germany (ESF).

Partners: German Ready-Mixed Concrete Association (coordinator), Association for the Advancement of Vocational Training for Concrete and Precast Producers, Ready-Mixed Concrete Research Association, Research Institute for Vocational Education and Training (f-bb), S & P Consult GmbH
Project period: 04/2016 – 03/2019

Background and aims

The aim of the collaborative project 'BetonQuali Information and qualification platform' being conducted by VDZ and its project partners is to develop and trial a scheme for qualifying semi-skilled and unskilled workers in the concrete industry by 2019. It is intended to enable these groups of workers to prepare for the IHK (Chamber of Commerce and Industry) examination to qualify as process mechanics in the pit & quarry industry using digital media.

The concrete industry has a high proportion of employees from other fields. It is also often not possible to fill training vacancies. At the same time technological development is placing the workforce under pressure to acquire ever more qualifications, and it is hard to satisfy these requirements with the existing education and training programmes. The idea behind this project is therefore to create and try out a new approach to qualification measures for people already employed in the concrete industry. This will involve developing a digital information and qualification platform to enable qualifications to be obtained for the most part at the workplace and on the basis of practical work. It is also planned to develop tools to permit the identification and documentation of existing skills and to draw up individual qualification schemes on this basis.

The intention is that the participants should take a final state-recognised IHK examination to gain professional qualifications as a step towards qualifying for a higher position, as plant supervisor for example. The scheme is aimed primarily at employees in the following areas of the concrete industry: Plant control, scheduling, logistics, machine maintenance and materials testing.

The project is to serve as a best practice example for the integration of digital learning media into vocational development programmes and aims to establish a new training concept for the concrete industry which is also suitable for small and medium-sized enterprises (SME), as it does not involve long periods of absence from the workplace.

Approach

Online learning with the information and qualification platform is intended to support self-organised, flexible learning at the workplace. It will be combined with both practical training work within the company and traditional course elements at industrial training centres for example. The plans also include having instructors in the company to accompany the learning process of the platform users. The guiding principles of the scheme are to improve coordination of the learning and working processes for employees, to keep periods of absence from the workplace to a minimum and to promote the enthusiasm and motivation of the participants.

Table 3.5.1-1 Partial qualifications and sub-processes

Partial qualification 1: Concrete production
a) Preparation of the production process
b) Planning of concrete production operations
c) Production of concrete
Partial qualification 2: Concrete testing / Quality assurance
a) Testing of concrete constituents at the works
b) Testing of concrete
c) Testing of precast concrete products
d) Factory production control and conformity (quality assurance)
Partial qualification 3: Plant management and control
a) Set-up and operation of machinery and installations
b) Retrofitting of machines and installations
Partial qualification 4: Maintenance
a) Trouble-shooting and maintenance
b) Repair of machines and installations
Partial qualification 5: Commercial organisation and sales
a) Selling ready-mixed concrete and precast concrete products
b) Negotiations with institutes involved in the business

The integration of digital media makes it possible to accommodate the particular situation of individual companies (e.g. seasonal fluctuations) and of the participants (e.g. flexible time management, individual learning schedules, different means of access, acquisition of skills at the workplace). It should also help to reconcile the generally increasing need for better qualified employees in the industry with a shrinking workforce. The small and medium-sized enterprises typical of the industry should then be in a position to offer their workforce tailor-made qualification opportunities, even with limited human and financial resources. In the long term this ought to help make the companies more competitive.

Current status of the work

Within the framework of the project, the training regulations for the profession of Process mechanic in the non-metallic minerals industry with the specialist areas Ready-mixed concrete and Precast concrete products were analysed and split up into five so-called 'partial qualifications' with the corresponding sub-processes (**Table 3.5.1-1**). A set of skills is defined for each partial qualification.

In the project, these skills formed the basis for the development of teaching units which may contain various elements: Online courses, tests, practical work, revision exercises, seminars and digital media such as videos or animations. The teaching units are available on an information and qualification platform which can be accessed at www.BetonQuali.de.

The BetonQuali qualification scheme attaches particular importance to the so-called 'Learning process supervisor'. This is a person in the same company as the participant, who gets together with the participant to plan the qualification activities on the basis of a skills analysis (for example, the areas of the company in which the participant is to work in the course of the qualification process). The supervisor specifies the individual learning requirements of the participant (e.g. which partial qualifications already exist), regularly discusses the progress made and the next steps to be taken with the participant, and assesses the exercises and activities completed by the participant on www.BetonQuali.de.

BetonQuali is to be tried out in practice by selected companies in 2018, with the aim of introducing it on the widest possible scale in the concrete industry following completion of the project. Wherever feasible, successful elements of the qualification concept should then be extended to other sectors of the pit & quarry industry as well.

Fig. 3.5.2-1 Qualification course: Tours of the VDZ laboratory

3.5.2 Sustainable education for cement industry workers in Russia (BIRUZEM)

This project was supported by the German Federal Ministry of Education and Research (BMBF).
Project partners: Kima Echtzeitsysteme GmbH, Teutrine GmbH, Research Institute for Rationalisation (FIR) at Aachen University
Project period: 01/2013 – 12/2015

Background and aims

Germany is one of Russia's most important international trading partners. German products and services enjoy a good reputation in Russia by virtue of their quality and reliability. The anticipated building activity and the associated demand for top quality construction materials open up a whole range of opportunities for German manufacturers and service providers from this segment in Russia and on neighbouring markets.

Approach

At the request of VDZ members with business interests in Russian-speaking regions, VDZ therefore got together with other service providers and universities in early 2013 to start work on creating a platform for training courses in Russian in the field of cement production and utilisation. The idea was to offer not just traditional seminars, but also training courses for future cement industry managerial personnel and development programmes in the form of online courses for employees at cement works in Russian-speaking areas. In the project, VDZ was to take responsibility for subjects relating to process technology and the environment, Kima Echtzeitsysteme GmbH for instrumentation and control technology topics and Teutrine GmbH for the field of operative maintenance. The intention was also to approach further companies with a view to extending the range of subject areas available on the platform. The Research Institute for Industrial Rationalisation (FIR) at Aachen University assisted the project partners with creation of the platform and organisation of the services to be offered.

At the start of the project, partners were also found in the target country to help ensure successful implementation in cooperation with VDZ. In Russia, VDZ entered into contact with the cement manufacturers' association 'Soyuzcement', the organisers of the 'BusinessCem' trade conferences, the publishers of the renowned 'Journal of Cement and its Applications', the organisers of the 'PetroCem' conference and the 'Dmitry Mendeleev University of Chemical Technology of Russia', for example.

There were three main objectives of the project work:

- Cooperation within the association: Development of services and coordination of measures.
- Cooperation with the sub-contractors: Localisation of the seminars, training courses and online courses, development of an online learning platform in Russian based on the open-source platform 'ILIAS' (Integrated Learning, Information and Work Cooperation System), importing of subject matter onto the platform, printing of a range of presentation and promotional material in Russian.
- Cooperation with partners in the target country and cooperation with other partners: Establishment of networks and presentation of the training project, technical support for the translation and localisation of the online courses, testing of the online platform, consultation on development of the training concept, creation of organisational prerequisites.

Results/current status of the work

Several training courses in Russian have been developed and tried out within the framework of the project. These included an eight-week qualification course in Russian for plant foremen (**Fig. 3.5.2-1**) and future managerial personnel and a number of day seminars/weekly seminars on:

- Modern maintenance methods
- Blended cements
- Quality control in accordance with EN 196.

The qualification course in Russian for plant foremen and future managerial personnel was held twice whilst the project was still in progress. The course was well received by the participants. The seminar on 'Modern maintenance methods' was successfully conducted together with one of the project partners in the target country in June 2015 (**Fig. 3.5.2-2**).

Fig. 3.5.2-2 Seminar in St. Petersburg

Fig. 3.5.2-3 Seminar on blended cements, Ukraine

The training courses and seminars were held both in Germany and in the target country (**Figs. 3.5.2-1** to **3.5.2-3**).

Russian-speaking employees of VDZ and its partners are predominantly available for all specialist subjects. Meanwhile, the activities developed within the project have been incorporated into the VDZ training portfolio and are part of the standard services on offer. The registration procedure has been adapted for the Russian-speaking customers, the subject matter is updated at regular intervals and participation certificates are issued in English and Russian.

The following training services are currently meeting with the particular interest of customers in Russian-speaking countries:

- Blended cements
- Quality control in accordance with DIN EN 196
- Modern maintenance for cement works
- Wet chemical analyses

One of the results of the project work has been the creation of an online learning platform for courses in Russian. Access to this is provided by the website www.cementtraining.com specially developed in the course of the project. 40 online courses with various teaching media – illustrations, videos and animations – are available on the learning platform (**Fig. 3.5.2-4**). The content of an online course can easily be converted to a PDF file. Each online course ends with a test, with which participants can check their own work. The tutor can constantly monitor the progress of the participants. The concept has been broadly introduced within the Russian cement industry. Use of the online courses in Russian is meeting with increasing interest.

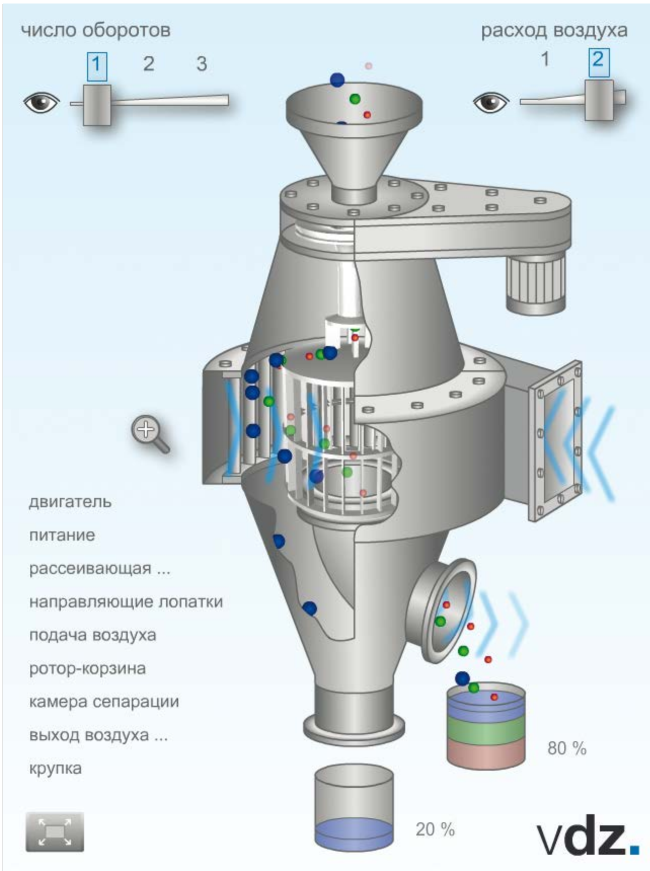

Fig. 3.5.2-4 Caged-rotor classifier (in Russian)

3.5.3 WiTraBau – Knowledge Transfer in the Construction Industry ■

This project is supported by the German Federal Ministry of Ed ucation and Research (BMBF).
Project partners: German Committee for Structural Concrete (DAfStb), German Society for Concrete and Construction Technology (DBV), Ready-Mixed Concrete Research Association (FTB), Road and Transport Research Association (FGSV), Fraunhofer Institute for Building Physics (IBP), Fraunhofer Information Centre for Regional Planning and Building Construction (IRB)
Project period: 12/2014 – 11/2018

Background and aims

'WiTraBau – Knowledge Transfer in the Construction Industry' is the name of a joint research project being conducted by seven partners from the fields of research, industry and standardisation to accompany the practical use of new innovative building materials within the framework of the BMBF funding schemes 'NanoTecture – Nanotechnology in the Construction Industry' and 'HighTechMatBau – New materials for urban infrastructures'. The project supported by the BMBF forms part of the ministry's material research programme. The overriding aim of the programme is to actively promote innovative developments on future-oriented markets such as the construction industry in Germany.

An important aspect of the project is to analyse and process the research results in a manner appropriate to the various target groups in the building trade value chain (e.g. construction material producers, consulting engineers, architects and building companies). In addition, the project results obtained are to be distributed and opened up to discussion in the trade. For VDZ, the main focal points of the project include the study and processing of the results for the concrete sector in particular, discussion of the research results in the trade and VDZ committees, and the development and management of a central information and communication platform.

Approach

Firstly, the results available from the projects forming part of the 'NanoTecture' funding scheme were recorded on a newly developed information and communication platform by the WiTraBau partners. In order to rule out one-sided opinions as far as possible, each project was initially assessed separately by two WiTraBau review bodies, who then agreed upon a coordinated proposal regarding channels for further utilisation. Based on the information content and degree of maturity (e.g. fundamental research or application-related research) of the results, the review bodies proposed one or more of the following utilisation options:

- Follow-up research projects
- Trade publications, talks and trade journals etc., entry in research databases
- Lectures at universities, colleges etc.
- Manuals and instruction materials for the trade and industry (e.g. for training and development programmes for works personnel)
- State-of-the-art reports and information documents as precursor to standardisation
- Codes of practice for specific branches (cement industry, building industry, ready-mixed concrete industry)
- Regulations of 'standard' nature, regulations of project partners (e.g. directives); inclusion in existing or new regulations

Fig. 3.5.3-1 Kick-off event on 28.09.2015

- National technical approvals (abZ), submission to DIN standards committees (Committee for Building Standardisation, NABau)
- Application-related development
- Utilisation proposals of grant recipients

The results and the proposed utilisation channels arising from the reviews were discussed in the extensive networks of the seven project partners:

- Discussion of the research results in committees
- Presentations of the research results
- Production of information and teaching material

Following completion of the analysis and processing of the research results from 'NanoTecture', the partners turned their attention to the active utilisation of the research results obtained within the framework of the BMBF funding scheme 'HighTechMatBau – New materials for urban infrastructures'. As the 'HighTechMatBau' research projects are running concurrently with the transfer project, 'WiTraBau' acts primarily in an advisory capacity for these projects. This will make it possible to provide the companies, research institutes and universities with support right from the start of their work in the form of the joint preparation of appropriate distribution and the planning of practical implementation of the research results.

Current status of the work

The project results from the 'NanoTecture' funding scheme have been fully entered into the project database, evaluated and assigned to the above-mentioned utilisation options. For VDZ this gave rise to a total of 67 assignment pairs to be further processed in the course of the project. A coordinated opinion was formed for each result in the VDZ committees and confirmed by way of surveys. These results and utilisation activities were again stored in the database to record the currently applicable utilisation status in each case. With a figure of almost 40 %, utilisation within the framework of new research projects accounted for the majority of the options.

Following on from the launch event on 28.09.2015 at VDZ, work started on the accompaniment of the ongoing projects from the 'HighTechMatBau' funding scheme with regard to utilisation (**Fig. 3.5.3-1**). VDZ and the other WiTraBau partners will be helping the research bodies to identify and systematically study results and utilisation strategies in their projects. All the activities taking place and the results obtained will again be entered in the central database. This should ultimately permit an assessment of the ways in which project results were able to be utilised.

More than 400 representatives from science, the construction industry and politics attended the 'HighTechMatBau - Conference on New Materials in the Construction Industry' in Berlin in January 2018 (**Fig. 3.5.3-2**). The many talks held presented the results of the supported projects to a diverse trade audience. Selected projects were highlighted in a short film initiated by VDZ together with the WiTraBau partners and produced by a service provider.

All the supported projects from the 'NanoTecture' and 'HighTechMatBau' funding schemes, as well as selected projects from the SME Innovation programme, are available on the website of the WiTraBau project www.hightechmatbau.de for further study.

Fig. 3.5.3-2 'HighTechMatBau - The Conference for New Materials in construction', took place in Berlin in January 2018

Annex

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Safety codes of practice
Nr. 129 Gefahr des Einziehens bei Förderbändern
Nr. 130 Absturz mit Todesfolge beim Tausch eines Ofenschusses
Nr. 131 Absturz bei Arbeiten mit einem Presslufthammer
Nr. 132 Sichere Begehung von Kugelmühlen
Nr. 133 Absturz einer Plattform bei Trennarbeiten
Nr. 134 Mehldurchschuss
Nr. 135 Staubaustritt durch fehlendes Freischalten
Nr. 100-2 Ladungssicherung bei Zementsackware und Big-Bags (aktual. Version d. Merkblatts Nr. 100)
Nr. 136 Umgang mit chromathaltigen Bauteilen und Ansätzen im Ofenbereich
Nr. 137 Einsatz und Prüfung von Lichtgitterrosten

Safety checklists
Nr. 109 Gefahr des Einziehens bei Förderbändern
Nr. 110 Gefahr des Absturzes bei Arbeiten in der Höhe
Nr. 111 Arbeiten mit schweren Handarbeitsgeräten
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Nr. 113 Trenn- und Schweißarbeiten an Anlagenteilen
Nr. 114 Sofortmaßnahmen Gefahr eines Mehldurchschusses
Nr. 115 Freiwerdende Energien

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