Analysis of the kinetic energy transfer to the target during impact of the antitank projectiles

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Abstract

The paper presents research results of a feasibility study to develop a new concept of the modern Armor Mounting System (AMS) for the Light-Weight Army Vehicle (LAV). Relationship between potential mounting system properties and the target perforation process were examined. The kinetic energy transferred to the targets was studied for several cases of antitank projectiles and armor configurations. Results of this study helped to identify the amount of projectile energy which would be dissipated by the AMS. This assessment was made through a series of simulations of armor perforations by antitank kinetic energy penetrators. Three types of the high kinetic energy (KE) projectiles were considered: shape charges, explosively formed projectiles (EFP), and sub-caliber projectiles. Modern armor concepts including multilayer armor (with ceramic), active armor (where some parts can move against the attacking projectile) were considered. Several finite element (FE) models for the modern light armor and high KE anti-tank projectiles (up to 10 MJ) were developed. These models consist of over 150,000 elements for the projectiles and over 500,000 elements for the targets respectively. The finite element analysis was conducted using an explicit, 3-D, dynamic, nonlinear finite element method supported by the LS-DYNA computer code. 3-D eroding finite elements were used for all FE models throughout the study. Depending on the type of projectile and armor, the energy transfer was examined and the efficiency of each system was examined.
Keywords: armour perforation; protective design; numerical simulations; finite element analysis, antitank projectiles.

1 Introduction

Considerations for the armor mounting systems (AMS) should be leaded in two areas. The first of them is related to the influence of the potential mounting system on the target perforation. Second one should study the role of AMS in momentum transfer to Light-weight Army Vehicle (LAV) structure during antitank projectile impact. This work focuses on the analysis of possible relations between AMS and perforation process. The kinetic energy transferred to the targets is studied in different cases antitank projectiles and armor configurations. These results will let to assess what part of projectile's energy would be dissipated by the AMS. Armor mounting system can absorb only this part of projectile's kinetic energy (PKE) which was transferred to the target as its movement – final target kinetic energy (TKE). This assessment was realized through a series of simulations of armor perforations by antitank kinetic energy penetrators. A several armor configurations were studied which cover the modern armor concepts including multilayer armor (with ceramic), active armor (where some parts can move against the attacking projectile). Dimensions and mass of the basic element of the armor structure were defined as a compromise between enough large for low cost, simplicity mounting and enough small to minimize the inertia effect. Small mass of the basic armor element is especially important in cases with active armor concepts, where some parts of the armor move against attacking projectile. They should be enough light so that it is possible to accelerate them in very short time period (less then perforation time). It may be reached only by controlled detonation of special high explosive. As a result of these considerations a 170x170mm square element was selected as a basic armor element in next studies. Its thickness was assumed to 50mm what leads to the hull mass about 12.2 tons in case of homogeneous RHA steel armor for the Piranha type LAV. Of course the combine composite or ceramic armor types will have smaller masses adequately [4]. For example the total mass of the basic armor element in the case TC1 (reference case - homogeneous RHA steel armor) equals about 11.3 kg. The studies of the maximum kinetic energy transfer to the target were leaded with assuming the free boundary conditions applied to target (lack of any constrains). The most dangerous case was studied i.e. the case of perpendicular impacts. Tables 1 and 2 include detailed description of the specific armor configuration and studied impact cases. In case of TC5 target configuration it was assumed the initial lateral layer's velocity 100 m/s. This assumption is based on the preliminary study of the available high explosives efficiency. During lateral velocity assessment considered steel layer as a rigid body loaded pressure constant in time. The pressure value was found basis of the immediate detonation model. Therefore obtained velocity 100 m/s should be treated as upper limit available in conventional chemical explosion used for the rapid steel plate's acceleration. The specific abbreviations meaning used in the tables below are:
B4C - ceramics: Borone Carbide, LM – layer moving lateral to the projectile, SBP – sub-caliber projectile, EFP – explosively formed projectile, SCJ – shaped charge jet.

Table 1: Detailed description of the specific armor configuration

Target code	Description
TC1	homogeneous RHA steel
TC2	3-layer RHA steel: steel/void/steel/void/steel
TC3	5-layer RHA steel/ceramics: steel/B4C/steel/B4C/steel
TC5	3-layer RHA steel active armor: steel-LM/void/steel-LM/void/steel

Table 2: Detailed description of the studied impacts configuration

Case code	Description: impactor/target
IC1A	SBP/TC1
IC1B	EFP/TC1
IC1C	SCJ/TC1
IC2A	SBP/TC2
IC2B	EFP/TC2
IC2C	SCJ/TC2
IC3A	SBP/TC3
IC3B	EFP/TC3
IC3C	SCJ/TC3
IC5A	SBP/TC5
IC5B	EFP/TC5
IC5C	SCJ/TC5

2 Finite element models

Based on literature review [1,2], the typical sub-caliber projectile was identified. It is a cylindrical object with sharpened nose moving with the velocity 1.8 km/s. The characteristic dimensions are: length about 700 mm, diameter about 23 mm. The finite element model of the typical sub-caliber projectile was developed, Figure 1. It includes over 150,000 wedge elements with the typical edge length 1-4 mm in the cylindrical region and 0.1-0.4 mm near the tip. It is built from tungsten heavy alloy (WHA). Johnson-Cook constitutive material model is used for WHA with linear-polynomial equation of state eqn (1). Then the flow stress is expressed as:

$$Y = \left(A + B\varepsilon_p^n\right)\left(1 + C\ln\dot{\varepsilon}_p^*\right)\left(1 - T^{*m}\right) \tag{1}$$

where ε_p - effective plastic strain, $\dot{\varepsilon}_p^*$ - normalized effective plastic strain rate,

$$T^* \equiv \frac{T - T_{room}}{T_{melt} - T_{room}} \tag{2}$$

T – temperature, T_{room} - room temperature, T_{melt} - melting temperature,
A, B, C, n, m - material constants.

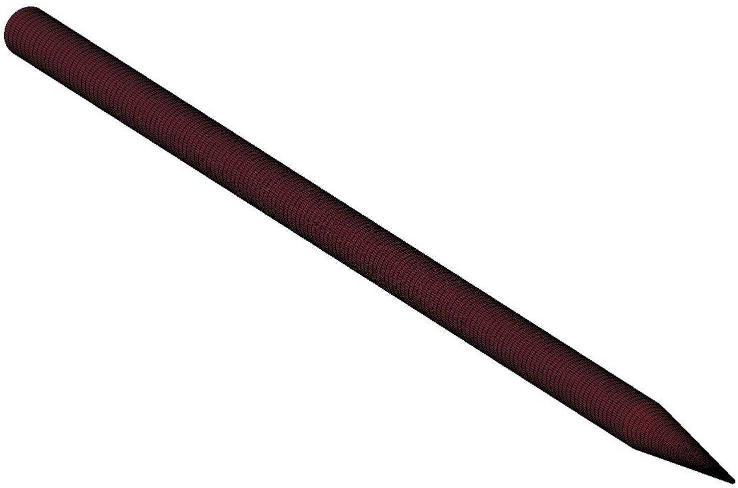

Figure 1: FE model of the typical sub-caliber projectile.

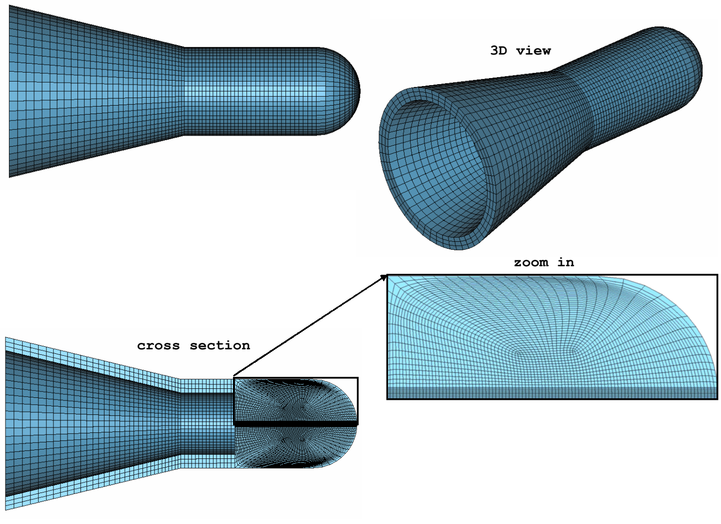

Figure 2: FE model of the Explosively Formed Projectile (EFP).

Explosively Formed Projectile (EFP) was identified as a hollow cylindrical with rounded nose and flared near the rear end for stable movement [5,6]. The degree of solidity is about 50%. Length/Diameter ratio is about 4. Dimensions: length about 116 mm, diameter from 29 mm near the front end to 57 mm at the tail. It is built from tantalum and can reach the velocity to 3 km/s. A finite element model of the typical Explosively Formed Projectile was developed,

Figure 2. It includes over 170,000 elements with the typical edge length 0.1 mm close to symmetry axis and 3 mm near tail part. Johnson-Cook constitutive material model is used for tantalum with Mie-Gruneisen equation of state.

Based on literature review [6], Shaped Charge Jet (SCJ) characteristics were defined. They can correspond to the shaped charge warhead with caliber about 150 mm (similar to the Copperhead 155 warhead, widely used in Desert Storm). The jet is a cylindrical shape with sharpened nose. Dimensions: initial length 150 mm and diameter about 15 mm, final length (just before impact) about 900 mm. Initial location represents a distance about 6 calibers from target surface where the most efficient depth of penetration is observed. It is built from copper and has initial linear velocity distribution along symmetry axis from 3.5 km/s (jet tail) to 10 km/s (jet tip). Finite element model of the typical Shaped Charge Jet was developed, Figure 3. It includes total over 130,000 wedge elements with the typical edge length 0.1 mm near tip and 3 mm at the maximum elongation. Johnson-Cook constitutive material model is used for copper with linear polynomial equation of state.

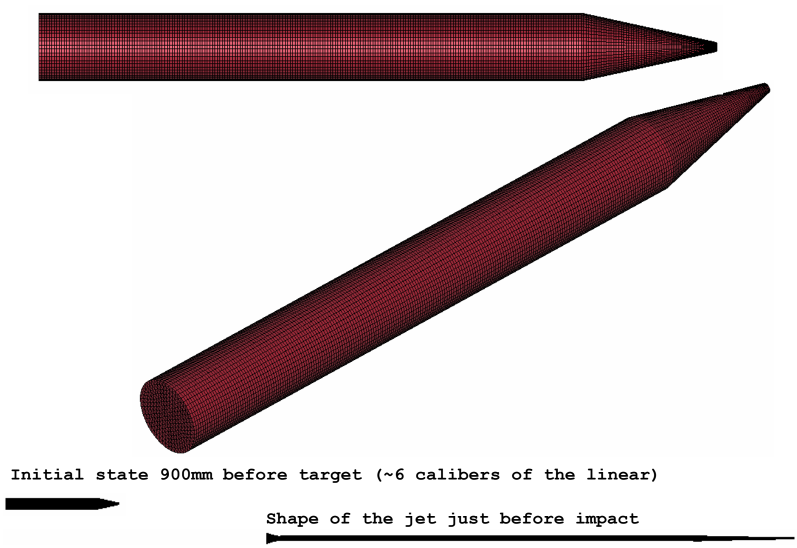

Figure 3: FE model of the Shaped Charge Jet (SCJ).

A 170x170mm square element was selected as a basic armor element. Its thickness was assumed to 50mm. The finite element model of the target was intentionally prepared to work well with the sharpen projectiles (Figure 4, below). It includes a very dense mesh region (wedge element length 0.1 mm) close to impact point with sharpen tip of projectile, medium dense hex element region next to this finest mesh, and an intermediate zone with variable number of elements per plate's thickness. Presently FEM of the one 50mm thick plate consists over 500,000 elements. Also, a finite element model was developed for a multilayer target. The topology of this FEM is the same as the homogeneous model. One layer of such a multilayer target is 170x170x10 mm square plate. For the steel material, such a plate will weigh about 2.4 kg (half the weight of a typical sub-caliber projectile).

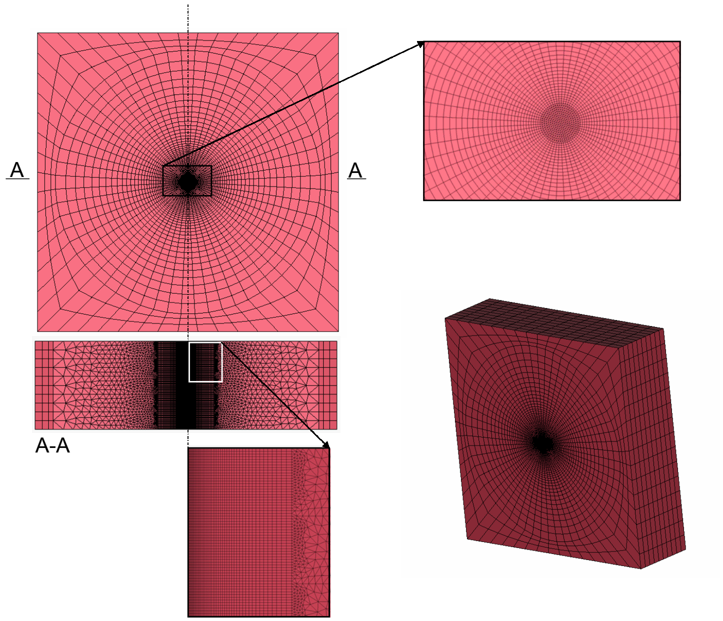

Figure 4: FE model of the target plate.

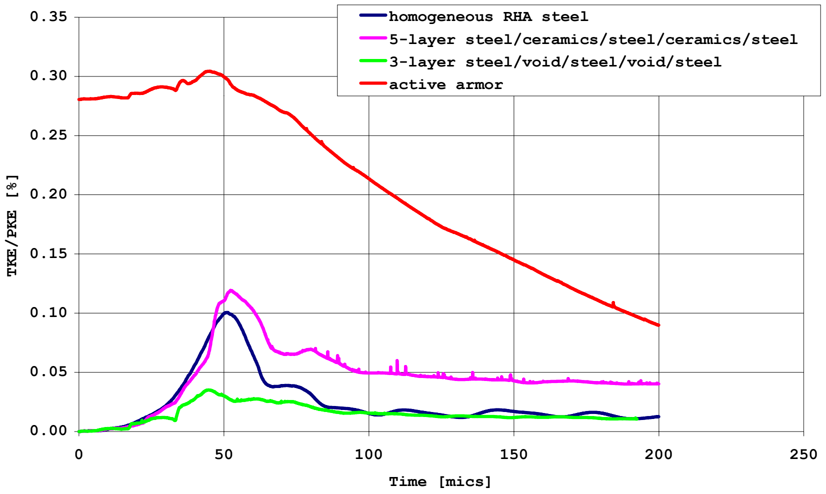

Figure 5: Kinetic energy transfer to the target for different types of the armor. Cases with sub-caliber projectile. PKE - initial Projectile Kinetic Energy, TKE - Target Kinetic Energy.

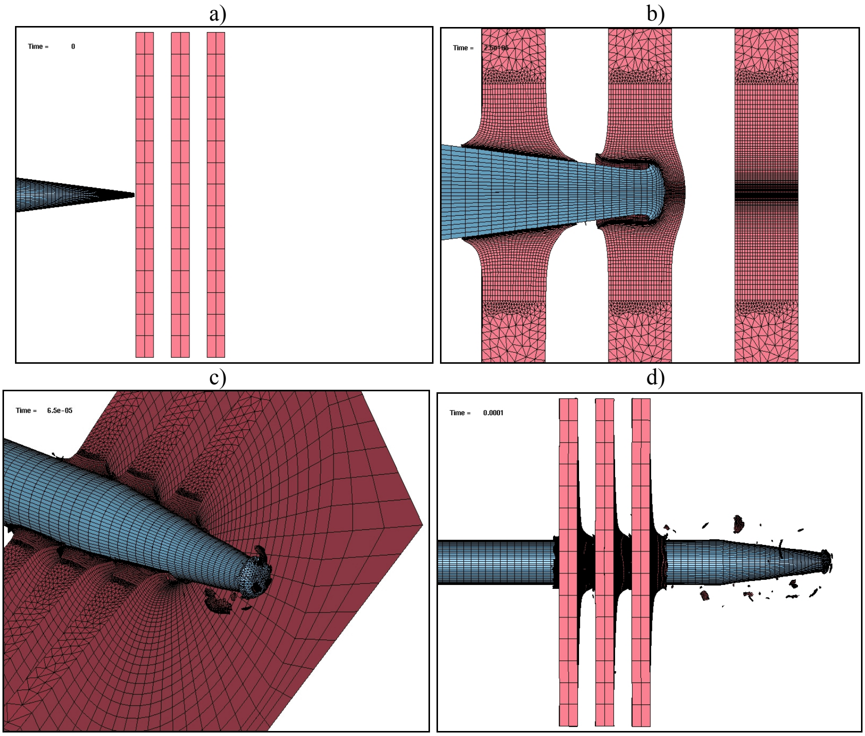

Figure 6: Perforation of the 3-layer RHA steel armor by a typical sub-caliber WHA projectile. Each plate's thickness: 10mm and total target's thickness: 50mm. Initial projectile's velocity: 1.8 km/s. (a) initial state – side view, (b) 25 mics after impact – cross-section view, (c) 65 mics after impact – cross-section in 3D view, (d) 100 mics pierced state – side view.

3 Results

The problem was studied using LS-DYNA, an explicit, 3-D, dynamic, nonlinear finite element program [3]. Several curves are presented in the pictures 5, 7 9, grouped adequately for the sake of the projectile kind and type of the armor. They represent ratio TKE/PKE variable in time. From the armor mounting system point of view the final value of this parameter is crucial. Than that one should be taken into consideration to assessment the AMS energy dissipating abilities. The initial growing of the kinetic energy transferred to the target, observed for all cases, is temporary. It includes the kinetic energy related with waves propagation inside the target and relative movement of some its parts (deformation). Finally the waves vanish and the deformation stops. Then the

AMS can absorb the residual part of the target kinetic energy. Figure 5 shows the set of results obtained for the different armor types perforated by typical sub-caliber projectile. These results prove that in case of sub-caliber projectile the highest final value of the TKE/PKE is less then 0.1% and still goes down. It was observed for the active armor type (TC5), but it should be noticed that into this value was counted some part of the initial armor kinetic energy (energy of the moving layers). Therefore the real energy transferred to the target is smaller. In case of other armor types TKE/PKE keeps constant value from about 0.05% (TC3) to 0.01% (targets TC1 and TC3) after 150 mics.

Figures 6 to 9 depict the armor perforation process by a typical sub-caliber projectile. They show several time moments in different points of view. Pictures marked a) to d) present the initial state and the pierced target state in the side view. The cross-section and cross-section in 3D view was shown in the pictures marked b) and **c)** for some intermediate states. In the 3D view case the projectile was not crossed for the better perforation process observation.

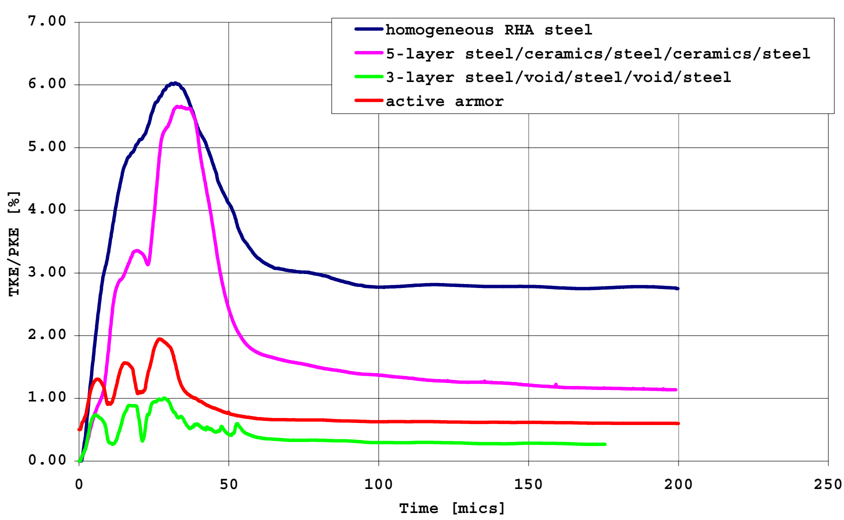

Figure 7: Kinetic energy transfer to the target for different types of the armor. Cases with Explosively Formed Projectile (EFP). PKE - initial Projectile Kinetic Energy, TKE - Target Kinetic Energy.

Dynamic response of the targets during impact a typical EFP projectile depicts Figure 7. The Results show that in case of EFP the highest final value of the TKE/PKE is less then 3% and it takes place for the homogeneous RHA steel plate. The 3-layer steel armor and active armor belong to the group with the smallest kinetic energy transfer ratio. Figures below depict the armor perforation process by a typical Explosively Formed Projectile. EFP is almost fully destroyed after target's perforation in all analyzed cases.

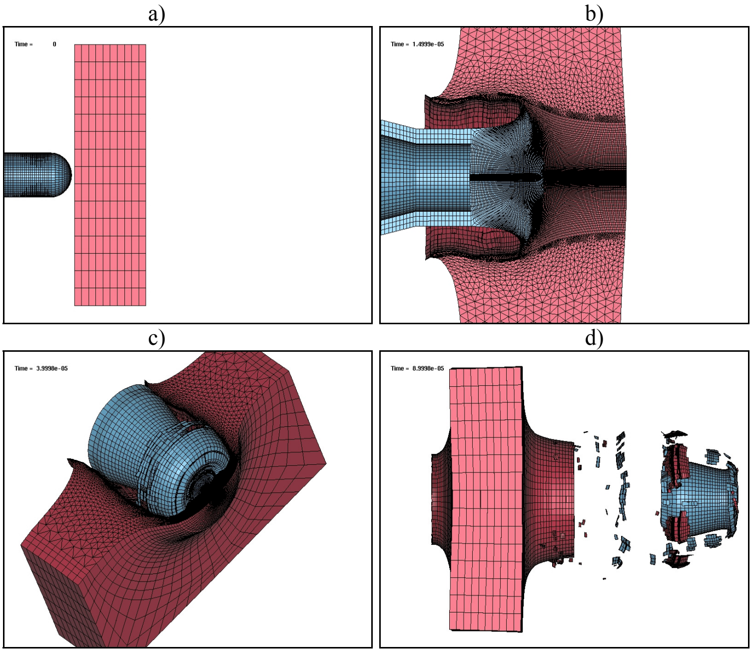

Figure 8: Perforation of the 50mm thick RHA steel plate by a typical EFP. Initial projectile's velocity: 3 km/s. (a) initial state – side view, (b) 15 mics after impact – cross-section view,(c) 40 mics after impact – cross-section in 3D view, (d) 90 mics pierced state – side view.

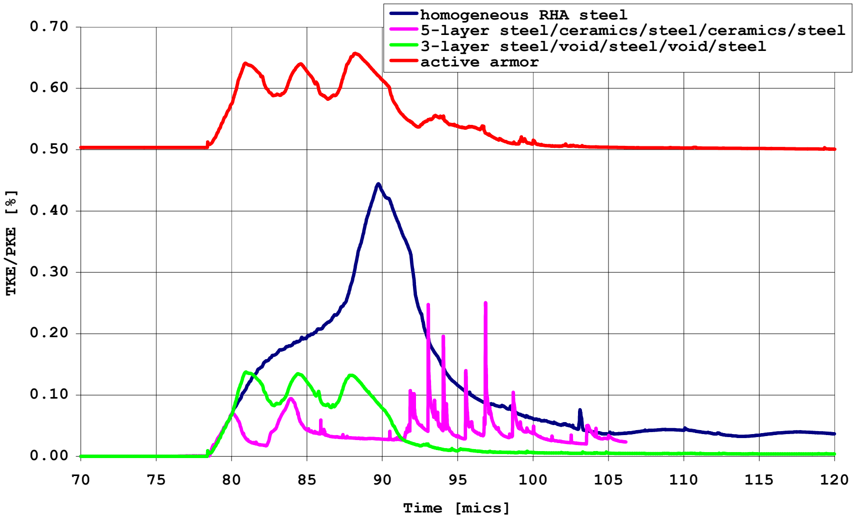

Figure 9: Kinetic energy transfer to the target for different types of the armor. Cases with shaped charge jet (SCJ). PKE - initial Projectile Kinetic Energy, TKE - Target Kinetic Energy.

The last group of results consisting simulations of armor perforation by a shaped charge jet was shown in picture 9. The highest final value of the TKE/PKE parameter is about 0.035% and it is observed for the homogeneous steel armor concept (TC1). A little less value was obtained for the steel/ceramic armor (TC3). Armor concepts based on the separate plates (TC2 and TC4) reached very low level of the kinetic energy transfer. Observed in case of combined steel/ceramics armor concept (TC3, pink curve in Figure 9) the group of pikes with the exponential vanishing may be interpreted as a brittle cracking in ceramics plates. The elastic energy accumulated in the ceramic material releases by cracks propagation and then temporary jumps in kinetic energy of the target.

4 Conclusions

The objective of implementing mounting systems on the light-weight army vehicle is to dissipate as much as the kinetic energy transferred by the armor to the vehicle body. The mounting system plays a major role in absorbing the armor or target kinetic energy (TKE) thereby reducing the chances of high accelerations in the LAV body. Absorbing the kinetic energy and lowering the accelerations in the LAV body is crucial for the survival of the crew and the electronic system inside the vehicle. The study of the kinetic energy transfer to the armor for all types of armors and projectiles reveled that only a small part of the total projectile kinetic energy (PKE) was transferred to the armor. Armor mounting system can dissipate only this part of the projectile's kinetic energy which was transferred to the armor as a target kinetic energy. The study of the kinetic energy transfer for all the concepts of armors and projectiles was based on a real anti-tank projectiles. The results of the analysis are given as the ratio of the target kinetic energy to the projectile kinetic energy (TKE/PKE).

References

[1] Lanz W., Odermatt W., Weihrauch G., *Kinetic energy projectiles: development history, state of the art, trends*, 19th Int. Symp. of Ballistics, Interlaken, Switzerland, 2001.

[2] Sharoni H., Bacon D., *The Future Combat System: Technology Evolution Review and Feasibility Assessment. Part II: Armament*, Armor,09/10 1997.

[3] *LS-DYNA Keyword user's manual volume 970*, Livermore Software Technology Corporation, April 2003.

[4] Johnson G,R,, Holmquist J., *Response of boron carbide subjected to large strains, high strain rates, and high pressure*, J. Appl. Phys. 85(12), 1999.

[5] Rondot F., *Terminal Ballistics of EFPs–A Numerical Comparative Study Between Hollow And Solid Simulants*, 19th International Symposium of Ballistics, Interlaken, Switzerland, 2001.

[6] Jach K., Morka A., Mroczkowski M., Panowicz R., Sarzynski A., Stepniewski W., Swierczynski R., Tyl J., *Komputerowe Modelowanie Dynamicznych Oddzialywan Cial Metoda Punktow Swobodnych*, PWN Warsaw, Poland, 2001.