

Analysis of the kinetic energy transfer to the target during impact of 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). Relationships 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. 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 as well as 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 led in two areas. The first of them is related to the influence of the potential mounting system on target perforation. The second one should be the study of the role of AMS in momentum transfer to a 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 of antitank projectiles and armor configurations. These results will allow the assessment of what part of projectile's energy would be dissipated by the AMS. An 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. 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). The dimensions and mass of the basic element of the armor structure were defined as a compromise between sufficiently large for low cost, simplicity of mounting and sufficiently small to minimize the inertia effect.

The 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 sufficiently light so that it is possible to accelerate them in very short time period (less than the perforation time). This may be reached only by controlled detonation of a special high explosive. As a result of these considerations, a 170×170 mm² square element was selected as a basic armor element in the subsequent studies. Its thickness was assumed to be 50 mm which leads to a hull mass of about 12.2 tons in case of homogeneous RHA steel armor for the Piranha type LAV. Of course, the combined composite or ceramic armor types will have adequately smaller masses [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 carried out with the assumption of free boundary conditions applied to the target (lack of any constrains). The most dangerous case was studied, that is, the case of perpendicular impact. Tables 1 and 2 include detailed description of the specific armor configuration and studied impact cases. In the case of TC5 target configuration, it was assumed that the initial lateral layer's velocity is 100 m/s. This assumption is based on the preliminary study of the available high explosives efficiency. During lateral velocity assessment, the steel layer was considered as a rigid body loaded by pressure constant in time. The pressure value was found on the basis of the immediate detonation model. Therefore, the obtained velocity of 100 m/s should be treated as an upper limit available in a conventional chemical explosion used for the rapid steel plate's acceleration.

The meaning of specific abbreviations 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 impact configurations.

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

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

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

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

T the temperature, T_{room} the room temperature, T_{melt} the melting temperature and A, B, C, n, m are material constants.

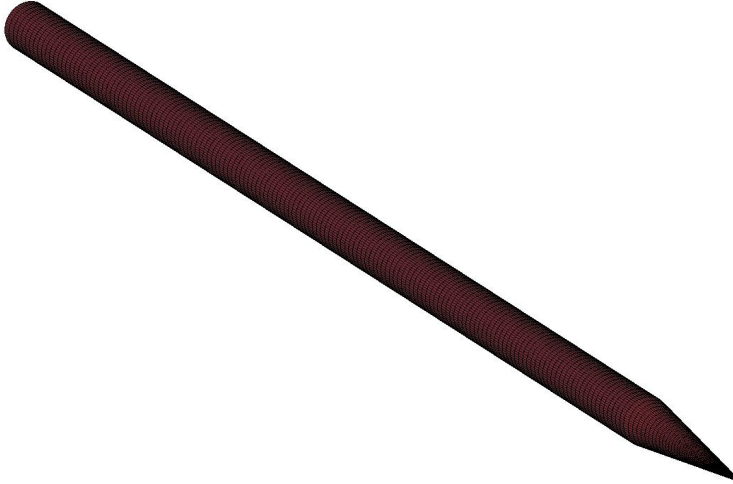


Figure 1: FE model of a typical sub-caliber projectile.

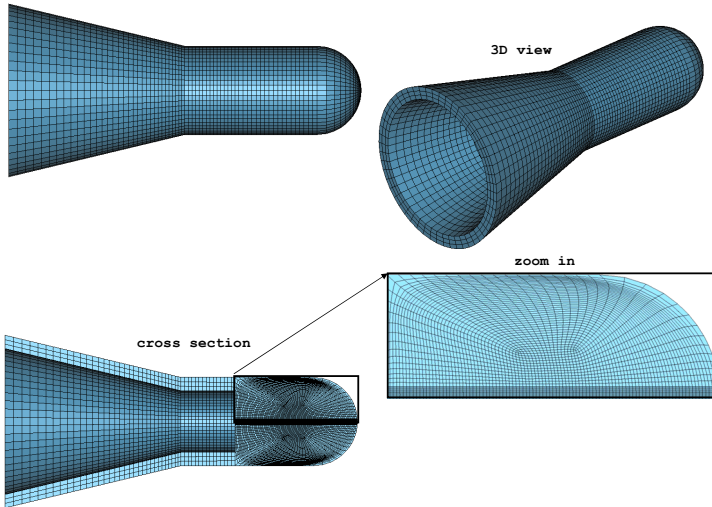


Figure 2: FE model of the explosively formed projectile (EFP).

The Explosively Formed Projectile (EFP) was identified as 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 of 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 a velocity of up to 3 km/s. A finite element model of a typical Explosively Formed Projectile was developed, fig. 2. It includes over 170,000 elements with a typical edge length of 0.1 mm close to the symmetry axis and 3 mm near the tail part. The Johnson-Cook constitutive material model is used for tantalum with the 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 a caliber of 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 of 150 mm and diameter of about 15 mm, final length (just before impact) of about 900 mm. The initial location represents a distance of about 6 calibers from the target surface where the most efficient depth of penetration is observed. It is built from copper and has initial linear velocity distribution along the symmetry axis from 3.5 km/s (jet tail) to 10 km/s (jet tip). A finite element model of a typical Shaped Charge Jet was developed, fig. 3. It includes a total of over 130,000 wedge elements with a typical edge length of 0.1 mm near the tip and 3 mm at the maximum elongation. The Johnson-Cook constitutive material model is used for copper with a linear polynomial equation of state.

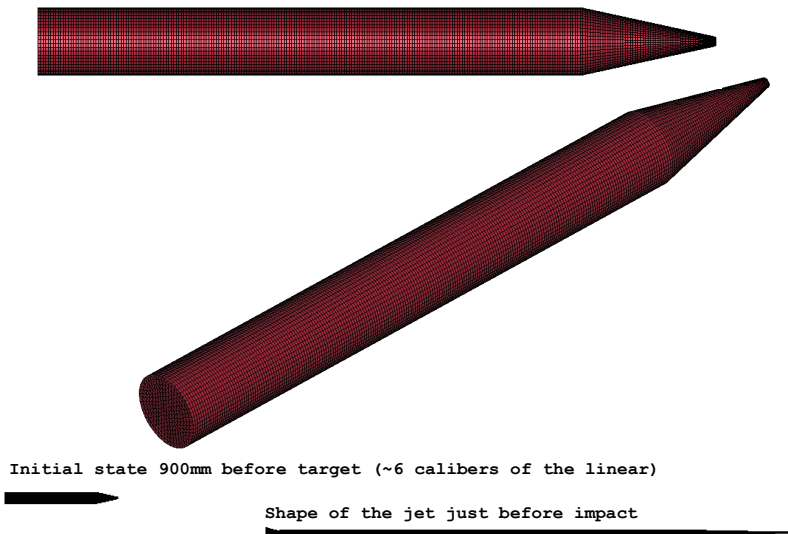


Figure 3: FE model of the Shaped Charge Jet (SCJ).

A $170 \times 170 \text{ mm}^2$ square element was selected as a basic armor element. Its thickness was assumed to be 50 mm. The finite element model of the target was

intentionally prepared to work well with the sharpened projectiles (fig. 4, below). It includes a very dense mesh region (wedge element length of 0.1 mm) close to impact point with the sharpened tip of the projectile, medium dense hex element region next to this finest mesh, and an intermediate zone with variable number of elements through plate thickness. Consequently, the FE model of one 50 mm thick plate consists of over 500,000 elements. Also, a finite element model was developed for a multilayer target. The topology of this FEM is the same as that of the homogeneous model. One layer of such a multilayer target is a $170 \times 170 \times 10 \text{ mm}^3$ square plate. For the steel material, such a plate will weigh about 2.4 kg (half the weight of a typical sub-caliber projectile).

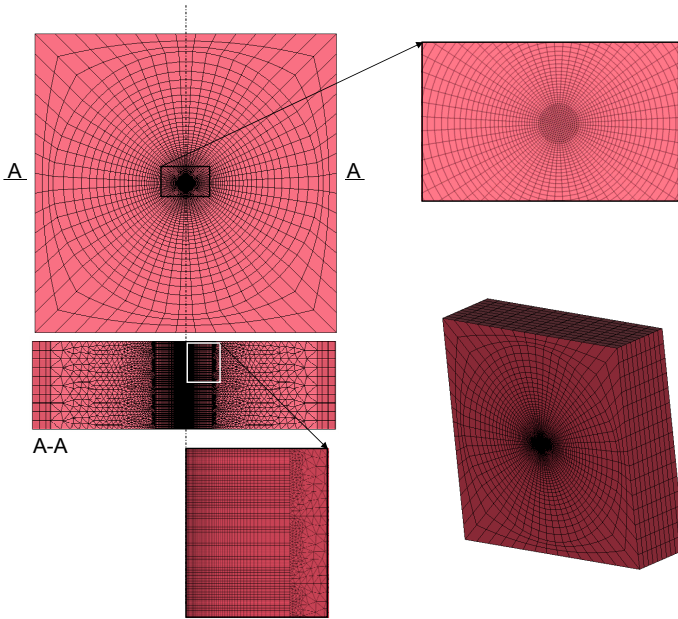


Figure 4: FE model of the target plate.

3 Results

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

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

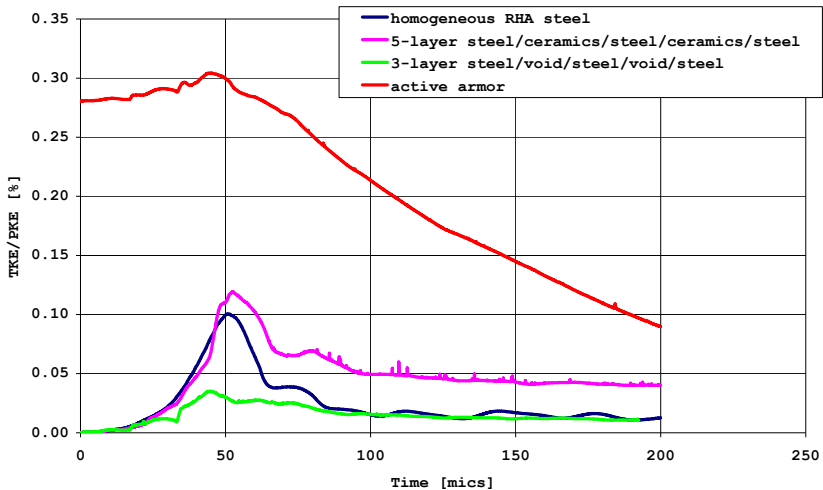


Figure 5: Kinetic energy transfer to the target for different types of armor. Cases with sub-caliber projectile. PKE – initial Projectile Kinetic Energy, TKE – Target Kinetic Energy.

Figs. 6 and 8 depict the armor perforation process by a typical sub-caliber projectile. They show different points of view at several instants of time. Figures marked a) and d) present the side views of the initial state and the pierced target state. The plane and isometric views of the cross-section are shown in the figures marked b) and c), respectively, for some intermediate states. In the isometric view case, the projectile was not sectioned for a better observation of the perforation process.

The last group of results consisting of simulations of armor perforation by a shaped charge jet is shown in fig 9. The highest final value of the TKE/PKE parameter is about 0.035% and it is reached for the homogeneous steel armor concept (TC1). A little lower value was obtained for the steel/ceramic armor (TC3). Armor concepts based on the separate plates (TC2 and TC4) reached very low levels of kinetic energy transfer. In the case of the combined

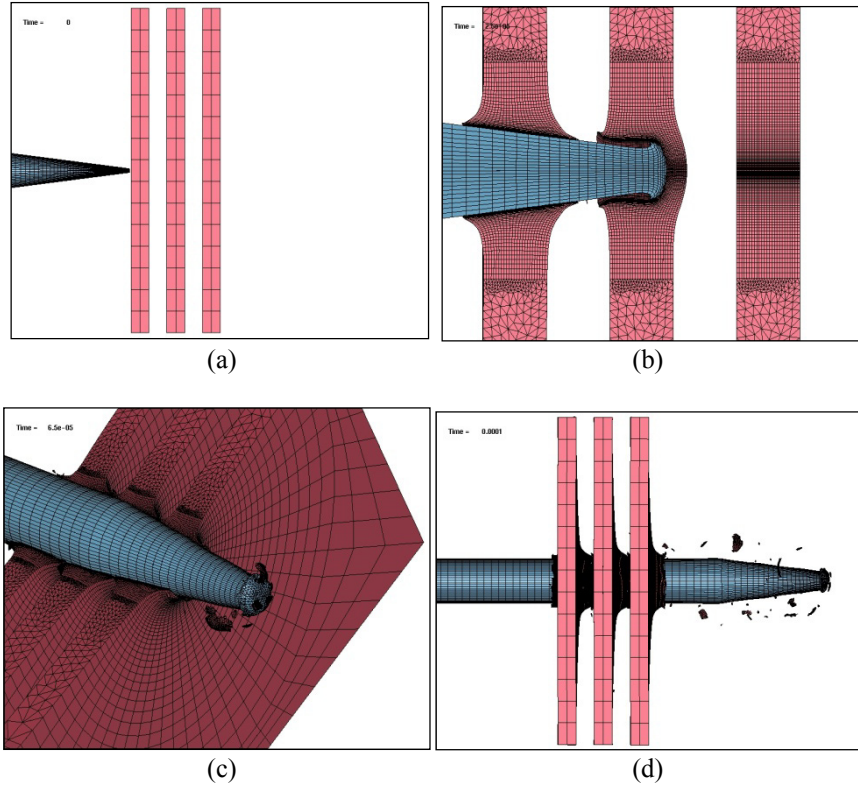


Figure 6: Perforation of a 3-layer RHA steel armor by a typical sub-caliber WHA projectile. Each plate's thickness: 10 mm and total target's thickness: 50 mm. Initial projectile's velocity: 1.8 km/s. (a) initial state – side view, (b) 25 μ s after impact – cross-section view, (c) 65 μ s after impact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

steel/ceramics armor concept (TC3, pink curve in fig. 9), the observed group of pikes with the exponential decay may be interpreted as a brittle cracking in ceramics plates. The elastic energy accumulated in the ceramic material is released by crack propagation and then temporarily produces jumps in the kinetic energy of the target.

4 Conclusions

The objective of implementing mounting systems on a light-weight army vehicle is to dissipate as much as possible the kinetic energy transferred by the armor to

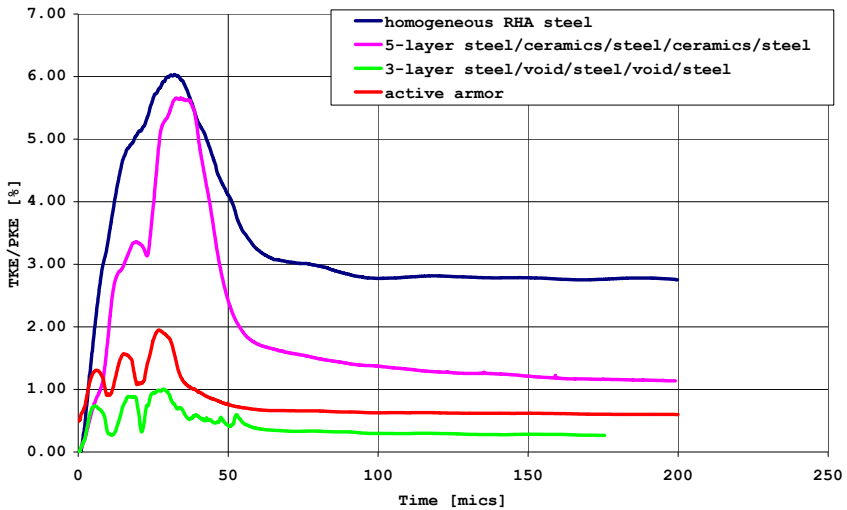


Figure 7: Kinetic energy transfer to the target for different types of the armor. Cases with Explosively Formed Projectile (EFP). PKE – initial Projectile Kinetic Energy, TKE – Target Kinetic Energy.

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 revealed that only a small part of the total projectile kinetic energy (PKE) was transferred to the armor. An 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 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).

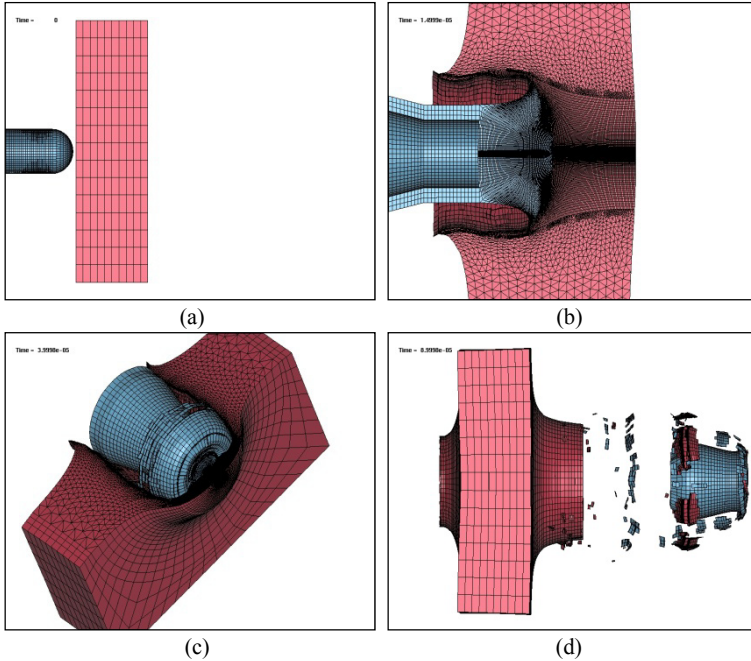


Figure 8: Perforation of the 50mm thick RHA steel plate by a typical EFP. Initial projectile’s velocity: 3 km/s. (a) initial state – side view, (b) 15 mics after impact – cross-section view, (c) 40 mics after impact – cross-section in 3D view, (d) 90 mics pierced state – side view.

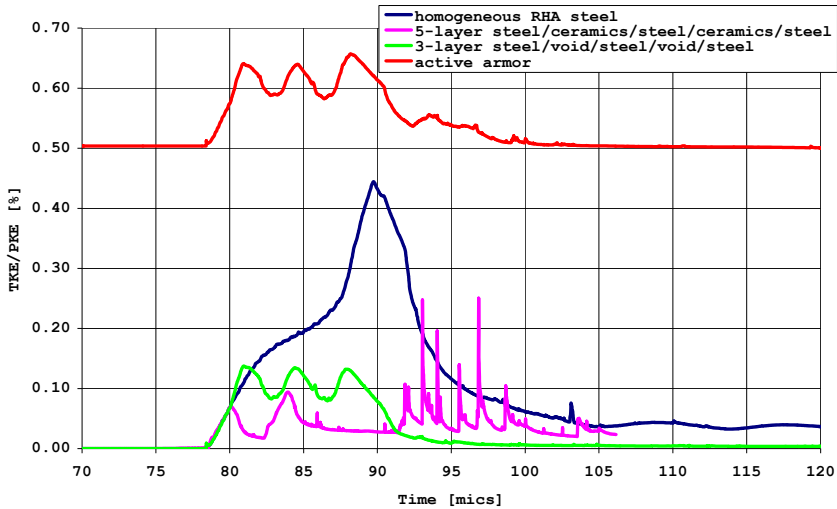


Figure 9: Kinetic energy transfer to the target for different types of the armor. Cases with shaped charge jet (SCJ). PKE – initial Projectile Kinetic Energy, TKE – Target Kinetic Energy.

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Author index

Abdel-Wahab M. M.	203	Laissy M. Y.	203
Abraitieni A.	149	Langseth M.	31
Anderson, Jr., C. E.	43	Máca P.	97
Attia W. A.	203	Mattone M.	139
Ayllon E.	119	Miyoshi H.	87
Barauskas R.	149	Morka A.	219
Bonora N.	139	Nettuno P. G.	171
Børvik T.	31	Nishimoto Y.	109
Chocron I. S.	43	Ohba H.	87
Daliang Z.	183	Ohno T.	109
Degiovanni M.	139	Olovsson L.	11
Dekel E.	55	Ray S. E.	1
Dey S.	31	Rosenberg Z.	55
Di Sciuva M.	139	Ruggiero A.	139
Fang Q.	19	Sanchez Paradela L.	191
Frola C.	139	Sánchez-Gálvez V.	191
Gherlone M.	139	Shanbiao Z.	183
Gómez L.	119	Siriphala P.	63
Gooch W. A.	73	Sovják R.	97
Hankins M. D.	161	Stoltz B. C.	161
Helte A.	11	Stryk R. A.	1
Hiroe T.	87	Tanaka N.	109
Holmquist T. J.	73	Tanapornraweekit G.	63
Hopperstad O. S.	31	Torres K. L.	161
Inoue T.	87	Vavříník T.	97
Ishikawa N.	109	Veeraklaew T.	63
Janszen G.	171	Vilkauskas A.	149
Johnson A. A.	1	Wang M. Y.	183
Johnson G. R.	1, 73	Wekezer J. W.	219
Jones S. E.	161	Wells J. M.	129
Kitamura H.	87	Wu H.	19
Kong X.	19	Yan H.	19
Kulsirikasem W.	63		







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SUSI XIII contains the proceedings of the 13th International Conference in the successful series of Structures Under Shock and Impact. Since the first meeting in Cambridge, Massachusetts (1989) the conference has brought together the research works of scientists and engineers from a wide range of academic disciplines and industrial backgrounds that have an interest in the structural impact response of structures and materials.

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