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NUMERICAL ANALYSIS OF CERAMIC-STEEL-COMPOSITE SHIELD SUBJECTED TO BALLISTIC IMPACT OF THE FRAGMENT

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Abstract

The issue of missile impact resistance is discussed in detail in many articles and standard papers dealing with body armour. The experience from many armed conflicts, however, may be proof that the real risks are related to a greater degree to fragments than those of bullets. It can be shown that the more often the object is destroyed as a result high-velocity impact of fragments.

The paper describes the results of numerical simulations of 22 calibre bullet shrapnel piercing multilayer ballistic shield. The shield was made of ceramics, steel and composite materials. The shape of the fragment is based on the American the defence standard MIL-DTL-46593B. The fragment tested is made through the process of cold rolling steel 4337H or 4340H characterized by hardness of about 30 units on the Rockwell scale. The mass of the fragment is 17 grains (1.14 g). The ballistic shield, that was hit by fragmentation, was a rectangular plate made of a Kevlar composite and, in another variant, an epoxy composite. The test was conducted in accordance with the terms of ballistic fragmentation resistance test V50 contained in standard MIL-STD-662F.

In undertaking the simulation was used the Finite Element Method (FEM) which is implemented in LS-Dyna programme. The numerical calculations were performed in the explicit option on a multiprocessor computational cluster. The necessary information to build a model like materials' properties is taken from extensive literature.

The numerical simulation resulted in, inter alia, maps and diagrams of stress, strain and energy, which were treated to further detailed analysis. On this basis of an evaluation was carried out and correction made to the FEA model.

The resulting model has enabled an observation of the penetration of the ballistic shield and the ballistic behaviour of the fragment when it contacts with obstacle. These observations are essential in the design of modern protective structures and undertaking research without incurring excessive financial costs generated by laboratory experiments.

Keywords: *ballistics, ceramics, composite, fragment, multilayer, simulation*

1. Introduction

Modern ballistic shields are kind of compromise between sufficient protection level and high mobility while being relatively cheap. To satisfy those opposite requirements, s lightweight, inexpensive and effective structure must be developed. Material response to impact load like bullet or blast wave plays a key role in the design process. Since experimental studies are very expensive, FEM simulations could be useful tool in minimize the costs as well as to understand phenomenon.

In American standardization „V50 Ballistic Test for Armor" [1], ballistic resistance of a shield is determined by the kinetic energy of a bullet or a a fragment. Energy is computed using the formula (1):

$$E_K = \frac{1}{2} m V^2 , \tag{1}$$

where:
m - mass, V - velocity.

Due to the fact that energy is the key parameter to calculate the penetration depth and the mass in formula (1) is constant, velocity is most fundamental parameter of a ballistic test. In many experiments a maximum velocity for which the penetration do not occur is computed. As well as that, the experimental procedure is also standardized [2, 3].

In ballistic tests the fragments used are normalized. Such models are described in Polish Standards [4] and in United States Military Standards [5]. The scheme of the fragment made by authors of this article is shown in Fig. 1.

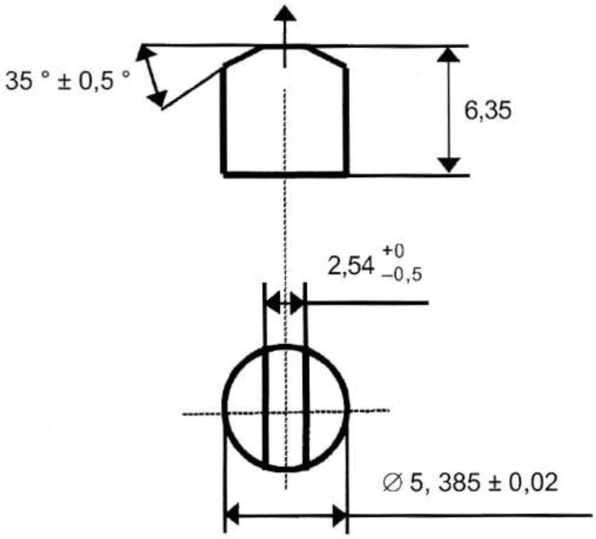

Fig. 1. The fragment-simulating calibre .22 (PN-V-87000-870001)

During the research a numerical simulation of ballistic test for standard 0.22 calibre fragment and multilayer plate was conducted. The model was built using Finite Element Method. The calculation was conducted in LS-Dyna software [6,7]. Physical model of simulated phenomenon is shown in Fig. 2.

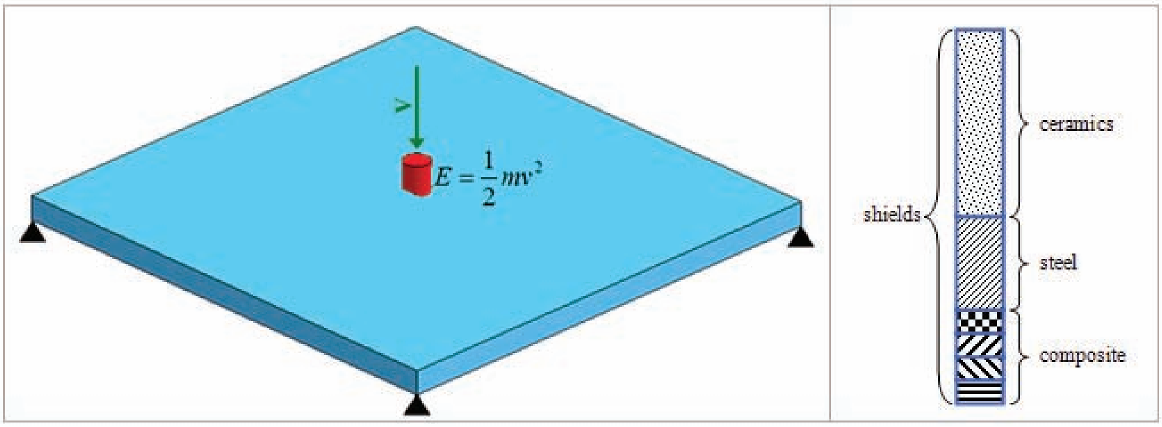

Fig. 2. The physical model of ballistic test

2. FEM model

2.1. Ballistic shield

The ballistic shield was cubic shaped with dimensions 100x100x8mm. It consisted of 500 000 geometrically uniform finite solid elements. The mesh consisted of 11 layers (5 layers ceramic, 2 layers steel, and 4 layers composite - Fig. 3.). The ballistic shield was constrained in 4 corners by taking translational degrees of freedom in the direction of fragment movement.

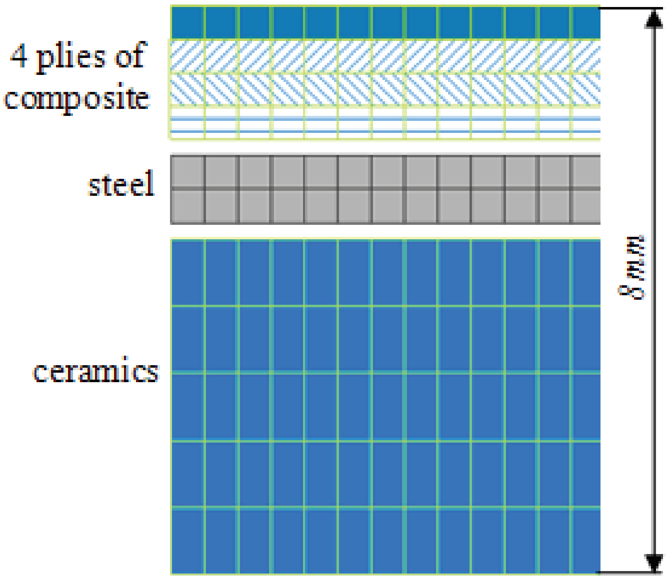

Fig. 3. Mesh structure of the 3-layers shield

Contact occurring between the fragment and the plate was modelled using ERODING_ NODES_TO_SURFACE algorithm that allows subsequent failure of elements in each layer. Maximum strain failure criterion was used. Contact between shields layers was modelled using AUTOMATIC_SINGLE_SURFACE algorithm.

Material properties of the composite were defined using MAT162_MAT_COMPOSITE_DMG_MSC which is one of the standard models implemented in LS-Dyna. It allows to observe the beginning of the delamination process as well as progressive failure of orthotropic materials. Furthermore, it allows to observe the delamination process. A few failure criteria for the fibres and the matrix (Hashin criterion) can be defined in MAT162. Fibre failure is due to effective strain which is a function of quadric components stains. Moreover, this material model allows modelling high stain rates which is especially important in ballistic simulations.

The composite used in the simulation contained highly resistant glass fibres S-2 Glass in epoxy matrix SC-15 [8]. The structure of examined composite with the structure [0,45,-45,90] is shown in Fig. 4.

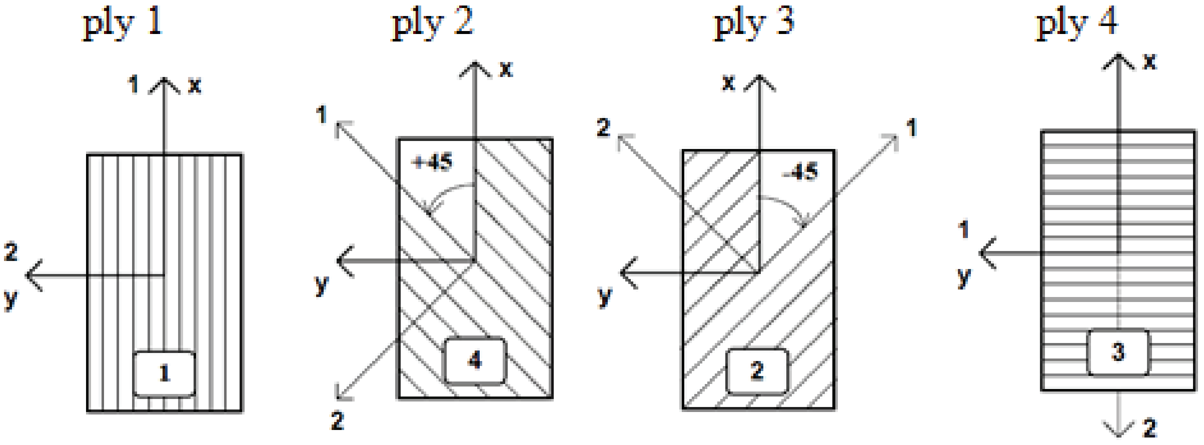

Fig. 4. Structure of the composite-layer [0, 45,-45,90]

The necessary material properties of MAT162 for S-2 Glass/SC15 were obtained from the literature [8]. They are presented in Tab. 1.

Tab. 1. S-2 Glass/SC15material data sheet

MID	**RO [kg/m^3]**	**EA [GPa]**	**EB [GPa]**	**EC [GPa]**	**PRBA**	**PRCA**	**PRCB**
1	1.85E+ 03	27.5	27.5	11.8	0.11	0.18	0.18
GAB [GPa]	**GBC [GPa]**	**GCA [GPa]**	**AOPT**	**—**	**—**	**—**	**—**
2.9	2.14	2.14	2	—	—	—	—
XP	**YP**	**ZP**	**Al**	**A2**	**A3**	**—**	**—**
0	0	0	1	0	0	—	—
VI	**V2**	**V3**	**D1**	**D2**	**D3**	**beta**	**—**
0	0	0	0	1	0	0	—
SXT [MPa]	**S XC [MPa]**	**SYT [MPa]**	**SYC [MPa]**	**SZT [MPa]**	**SFC [MPa]**	**SFS [MPa]**	**SXY [MPa]**
604	291	604	291	472	800	500	58
SYZ [MPa]	**SZX [MPa]**	**SFFC**	**AMODEL**	**PHIC**	**E LIMT**	**S DELM**	**-**
58	58	0.3	2	20	1.3	1.5	-
OMGMAX	**ECRSH**	**EEXPN**	**CERATE 1**	**AMI**	**—**	**—**	**—**
0.999	0.1	2	0	4	—	—	—
AM2	**AM 3**	**AM4**	**CERATE 2**	**CERATE 3**	**CERATE 4**	**—**	**—**
4	4	4	0	0	0	—	—

The steel layer was modelled using elastic-plastic material model (PLASTIC_KINEMATIC) with reinforcement for construction steel (R_e=400MPa, E=210GPa, ν=0,3).

Ceramic layer was made of silicon carbide (SiC). Material model used in that case was MAT_JOHNSON_HOLMQUIST_CERAMICS with material properities taken from the literature [11].

2.2. Fragment-simulating

The fragment was built using 3-dimensional, 10-note isoparametic elements type TETRAHEDRON [6, 7] with 5 integration points and quadric shape function. (Fig. 5.).

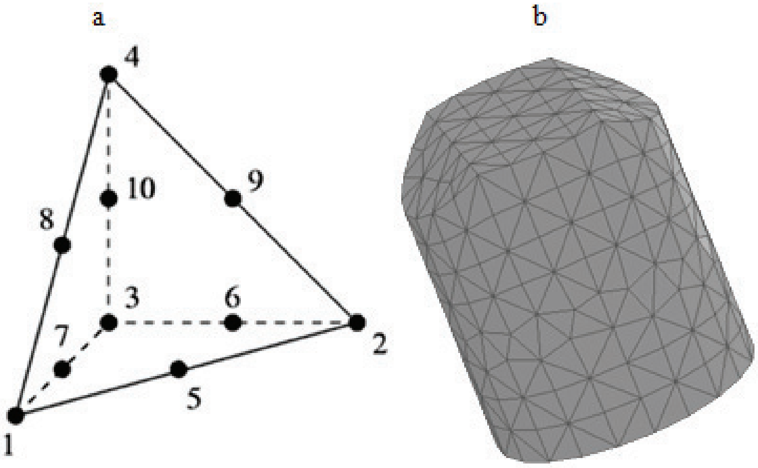

Fig. 5. FEM model of fragment-simulating: a- TETRAHEDRON element used to building, b- mesh

The initial velocity of the fragment was directed perpendicular to the plate. Kinetic energy E_k of the fragment was 142J. To simplify the calculation, the fragment was made of perfectly stiff (RIGID) material. Therefore, the internal energy of the fragment was equal to zero.

3. Test results and conclusions

The calculations were done using explicit algorithm in LS-Dyna software on multiprocessor claster. As a result of the simulations, graphs and spatial maps of selected physical parameters were obtained. The process of shield penetration (section through symmetry plane) is depicted in Fig. 6.

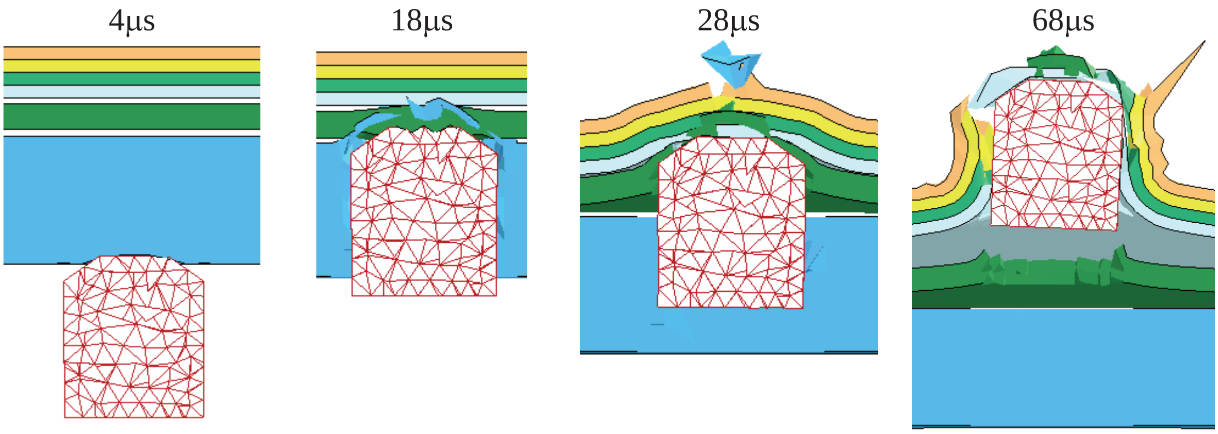

Fig. 6. Successive phases of fragment piercing (cutting plane)

The kinetic energy of the fragment was absorbed by the plate through different failure criteria. Therefore, the internal energy of the entire system increased. (Fig. 7.).

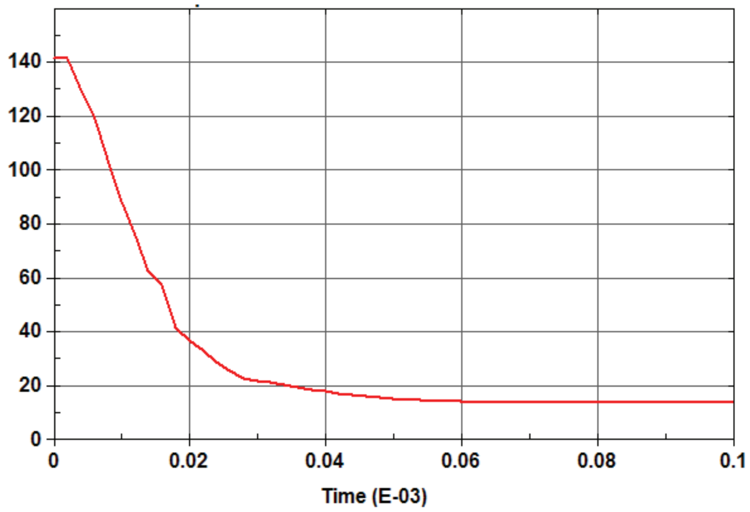

Fig. 7. The course of the energy absorption - diagram of fragment's kinetic energy [J-s]

The results of the numerical analyses allow the better understanding of the failure mechanisms of the protective structures of light armoured vehicles and bulletproof vests. Using a standard fragment makes it easier to investigate the phenomena of shield penetration.

The research showed, that protective shield design process should, among other factors, concern fragment resistance. The kinetic energy of such fragment is sufficient to perforate thin shield but the damage is considerably larger than in case of a bullet impact.

Wide variety of fragments shapes causes that numerical analysis requires standardized fragment shape (MIL-DTL-46593B (MR)) and procedure of the experiment (MIL-STD-662F).

Presented results will be used to further examination of complex protective structures against improvised explosive devices.

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