EXPERIMENTAL INVESTIGATIONS OF THE PROTECTIVE SHIELD – PROTECTED PLATE – TEST STAND SYSTEM UNDER BLAST SHOCK WAVE

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Abstract

The study presents preliminary experimental range tests of a system for testing protective shields for light armoured vehicles. The shields are designed against HE mines and IEDs up to 10 kg TNT. The system consists of the multiple-use portable range stand, a protected Armox 500T plate and a protective shield. The latter consists of the following main layers: PA11 aluminum, the SCACS hybrid laminate, ALPORAS aluminum foam, and the SCACS hybrid laminate. The layers are connected together with SOUDASEAL chemo-set glue. Overall dimensions of the test stand are ~ 800x800x180 mm, the protected plate has dimensions 650x650x5 mm, and a protective shield is of 450x450x76 mm dimensions. The system rests on a St3 steel plate stiffening the range subsoil. The range stand designed to be resistant up to 10 kg TNT blasts is composed of three appropriately shaped rigid frames connected with six high strength erection bolts. The explosive charge is suspended centrally at 400 mm distance from the top surface of the stand. Two range tests have been performed, i.e.: 1) the protected plate without a protective shield under 2 kg TNT blast shock wave, 2) the protected plate with the protective shield under 2 kg TNT blast shock wave. The effectiveness of the protective shield is assessed via comparing the maximum plastic deflection of the protected plate in both systems. The experimental results have been used to validate the FE model of the system.

Keywords: *light armoured vehicles, protective shields, multi-layer shields, range tests, validation*

1. Introduction

The study presents a new system for range testing [1] of protective shields for light armoured vehicles. A new protective shield has been designed by Authors as adequate against HE mines and IEDs up to 10 kg TNT [2]. The study is focussed on preliminary experimental range tests performed for the protected plate – range stand (PS) system and the protective shield – protected plate – range stand (SPS) system, both exposed against 2 kg TNT blast shock waves. The experimental results have been compared to the numerical simulation results presented in Ref. [3].

Recent research concerning protection against blast loading is mainly aimed on developing new concepts of protective shields for various structures and military vehicles [4-6]. The panels are usually designed and manufactured as removable and made from different types of energy-absorbing materials, such as polymer-matrix composites, ceramics, elastomers, and metal foams. Such materials are characterized by high relative energy-absorption capacity. The investigations also concern sandwich protective shields with a core composed of tubular or conical thin-walled elements [7-13].

A review of up-to-date protective shields against HE mines and IEDs presents Barnat in Ref. [14]. Various protective shields designed by Barnat differ from other solutions described in Ref. [2] and in patent applications [15, 16]. The writer presents both experimental tests and numerical simulations of dynamic response of various protective shield – protected plate systems to HE blast shock wave. Barnat performed FE modelling and simulation using MSC.Dytran code.

The structure of the range stand designed in this study differs from up-to-date very heavy or one-use range stands for blast testing [17-20]. The patent application [21] presents a range stand of very complicated structure.

2. A portable range stand [1]

The multiple-use portable range stand [1] for testing protective shields against blast loadings is composed of three closed steel frames, respectively graded and connected together with high strength M20 erection bolts. The total weight of the stand amounts to 326 kg, thus each frame may be carried by four persons with side holders. The stand has been designed to be resistant against HE blasts up to 10 kg TNT, i.e. the body can deform viscoelastically, the protected plate is freely put between the top and intermediate stand frames and is under elastoplastic deformations, and the protective shield absorbs majority of the blast energy and can fully fail.

The SPS system consists of the range stand, a protected Armox 500T plate and a protective shield. The main cross-sections of the SPS system are depicted in Fig. 1. On the internal perimeter of the top frame scants are shaped at 26º angle to the horizontal plane. These scants protect nearly full elimination of influence of the reflecting wave acting on the frame onto the protective shield vertical walls. The frames are profiled with meshes and gaps in the longitudinal direction. The protected plate is located in the 7 mm high circumferential clearance manufactured in the intermediate frame.

Overall dimensions of the test stand are approximately 800x800x180 mm, the protected plate has dimensions 650x650x5 mm, and the protective shield is of 450x450x76 mm dimensions. The system is supported by an additional steel plate with a square hole, stiffening the subsoil.

The range stand rests on the 20 mm thick horizontal plate stiffening the subsoil. The plate has a square hole coinciding the same square hole in the stand body.

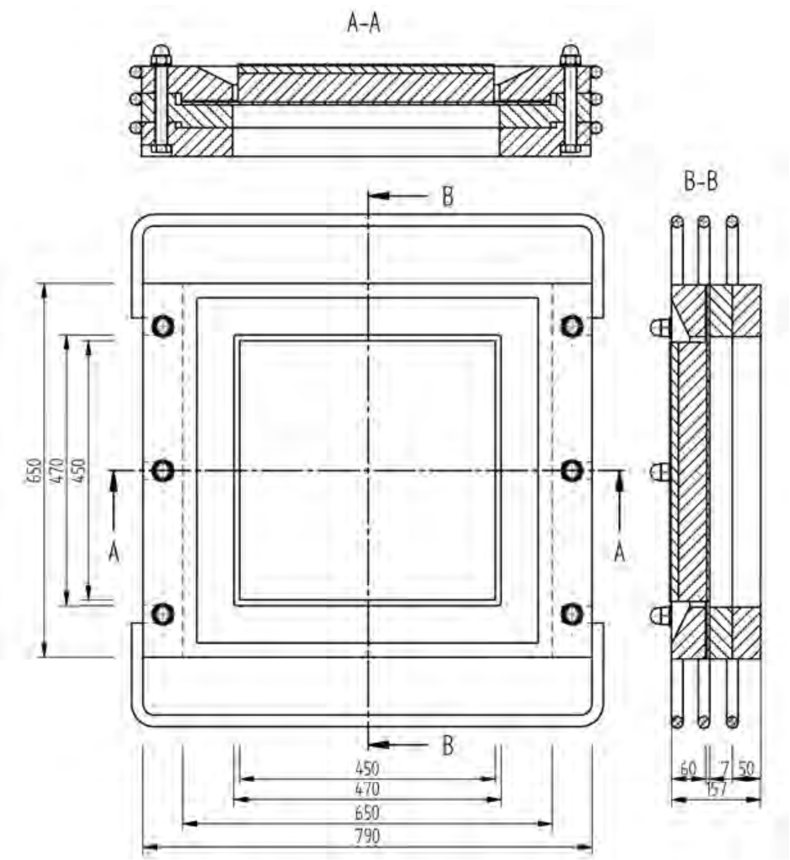

Fig. 1. The SPS system and the main cross-sections

3. The ALF protective shield [2]

The design requirements put on the protective shield are as follows:

1) the shield is to protect an armoured vehicle bottom against HE mines and IEDs up to the IV level according to STANAG 4569 standard [24],
2) a thickness of the shield cannot exceed 78 mm,
3) a surface mass density of the shield cannot exceed 55 kg/m^2.

Based on preliminary design calculations, ballistic tests and numerical simulations, Authors have designed the aluminium – hybrid laminate – foam shield, denoted with ALF code, of 76 mm thickness and 50 kg/m^2 surface mass density. The shield consists of the following main layers [2]: an EN AW-5754 (PA11) aluminum sheet, an SCACS hybrid laminate, 50 mm thick ALPORAS aluminum foam, and an SCACS hybrid laminate. The main layers are connected together using SOUDASEAL chemo-set glue in the form of additional layers.

Hybrid laminate plates, manufactured using the vacuum technology, are 28-ply composites with the sequence of selected composites based on the incombustible VE 11-M vinylester resin matrix, i.e. {GFRP$[(0/90)_{WF}]_{n1}$, CFRP$[(0/90)_{WF}]_{n2}$, KFRP$[(0/90)_{WF}]_{n3}$, CFRP$[(0/90)_{WF}]_{n2}$, GFRP$[(0/90)_{WF}]_{n1}$} [2]. The following fabrics have been applied: S SWR 800 glass fabric, Style 430 / Carbon 6K carbon fabric and Style 328 / Kevlar 49 T 968 / T 968 TG aramid fabric.

The 1st main layer in an ALF protective shield, i.e. PA11 aluminum plate, takes up the thermal shock induced by the HE blast. The 3rd main layer, i.e. aluminium foam, is a high energy-absorbing material. All main layers absorb the blast energy via different failure mechanisms and constitute resistance against IED fragments.

4. Description of the experimental range tests and analysis of the results

The tested object is a square plate of 650x650x5 mm dimensions, made of Armox 500 steel. The plate is located inside the test stand between the top and intermediate frames with vertical and horizontal clearances equal to 2 mm and 10 mm, respectively. Thus, the plate can slide with friction in the 100 mm wide edge zones. It results in possibility to select plastic deformations of the protective shield and the protected plate.

At the preliminary range tests stage, the shield is connected to the protected plate with the glue layer as well. The HE spherical charge is suspended centrally at 400 mm distance over the top surface of the stand. This distance reflects a typical distance of the vehicle plate bottom from the HE mine. The experiments have been carried out in July 2010 on the Navy Academy Range in Poland.

Figures 2 and 3 present photos of the PS system before and after 2 kg TNT explosion testing, respectively. One can observe high resistance of the range stand body due to the charge explosion. Fig. 4 shows a photo of the plastic deformations of the unprotected Armox 500T plate removed from the PS system after the explosion testing. On may observe valuable values of these deformations with the maximum value given in Tab. 1.

Figures 5 and 6 present photos of the SPS system before and after 2 kg TNT explosion testing, respectively. One can observe high resistance of both the range stand body and the ALF protective shield due to the charge explosion. Figure 7 presents the exemplary photo of failures in the ALF shield after the explosion testing (the side view). Only small horizontal cracks in the partly compressed aluminum foam and in the glue layers are observed. Small plastic deformations of the PA11 aluminum sheet exposed directly to the blast are also produced.

Figure 8 shows an exemplary photo of the protective shield – protected plate subsystem removed from the SPS system after the explosion testing. Damages in the ALF energy-absorbing shield are observed mainly in the central part of the shield. Plastic deformations of the protected Armox 500T plate are negligibly small (see Tab. 1).

The same tests have been simulated numerically in Ref. [3] for 20 ms real time and 2 kg TNT blast loading. Values of the maximum plastic deflection at the midpoint of the examined plate for

Fig. 2. The PS system before 2 kg TNT explosion testing

Fig. 3. The PS system after 2 kg TNT explosion testing

Fig. 4. Plastic deformations of Armox 500T plate removed from the PS system after 2 kg TNT explosion testing

Fig. 5. The SPS system before 2 kg TNT explosion testing

Fig. 6. The SPS system after 2 kg TNT explosion testing

Fig. 7. The exemplary photo of failures in the ALF protective shield removed from the SPS system after 2 kg TNT explosion testing

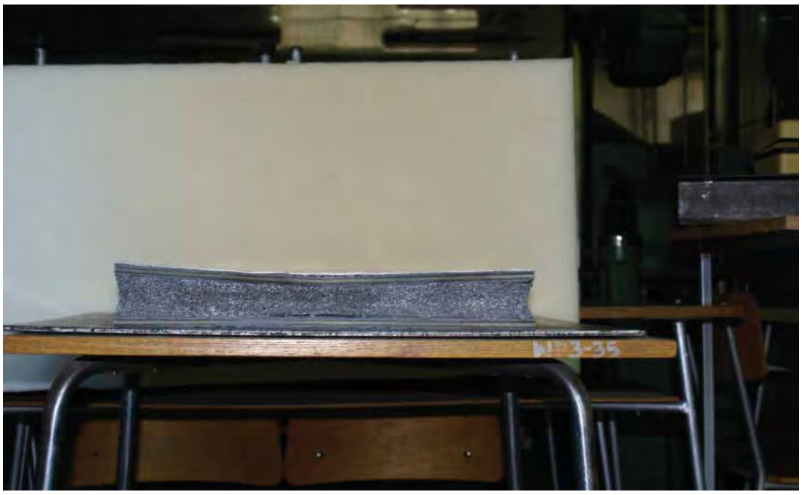

Fig. 8. The protective shield – protected plate subsystem removed from the SPS system after 2 kg TNT explosion testing

both experiments are given in Tab. 1. The relative error related to the simulated deflection is calculated from the formula

$$\delta_d = \frac{|\, d_{num} - d_{exp} \,|}{L} \cdot 100\% \,, \tag{1}$$

where:
d_{num} - the maximum plastic deflection obtained in the numerical simulation,
d_{exp} - the maximum plastic deflection obtained in the experiments,
L = 740 mm - the reference length (width of the square hole in the stand body).

Tab. 1. Values of the maximum plastic deflection at the midpoint of the examined plate for the PS and SPS systems under 2 kg TNT blast loading

Test	d_{exp} [mm]	d_{num} [mm]	δ_d [%]
PS system under 2 kg TNT blast loading	12.8	13.5	0.15
SPS system under 2 kg TNT blast loading	0.2	-1.0	0.26

Experimental validation of the FE modelling and simulation of the PS and SPS systems for 2 kg TNT blast shock wave, presented in Ref. [3], is positive.

5. Conclusions

The main goal of this study is to develop the SPS system, i.e. the protective shield – protected plate – range stand system, which could be useful in engineering practice. An original multi-use portable range stand for testing resistance and energy-absorption capability of various protective shields is presented. Protected plates correspond to vehicle bottoms of 5.0, 5.5, 6.0, and 6.5 mm thickness. The structural solution of the SPS system fulfils the following basic assumptions: the stand is working in the viscoelastic range, the protective shield can failure without any limitations, and the examined plate is effectively protected by the shield. If the shield is not used, the tested plate is due to large plastic deformations. The real range test time does not exceed 30 minutes.

A new type of passive protective shields to protect bottoms of light armoured vehicles to HE mines and IED explosions up to 10 kg TNT is developed. The ALF shields have competitive features, i.e. a shield thickness amounts to 76 mm, a surface mass density equals 50 kg/m^2.

The study presents the results of the range tests carried out for 2 kg TNT blasts. The obtained results have pointed out that the ALF protective shields of advanced multi-layer structure have increased blast resistance and high energy-absorption capability.

The FE models have been validated positively by the range tests. There were compared maximum plastic deflections of the examined Armox 500T steel plates.

Further research will concern the following items:

1) development of manufacturing the ALF shields and mounting them to vehicle bottoms,
2) realization and numerical simulation of range tests for 6 kg TNT and 10 kg TNT blasts.

The additional preliminary test performed in July 2010 for 4.38 kg TNT blast shock wave, not described in this study, has pointed out that for larger explosives bolts connecting the shield to the protected plate are necessary.

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