NUMERICAL SIMULATION OF BLAST RESISTANT STEEL PLATE STRENGHTENED WITH COMPOSITE

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Abstract

The paper presents the process of enhancing blast resistance of a thin steel plate by reinforcing it by a composite. The composite consisted of five differently orientated layers of high resistant S2/Glass fabric. Such system was subjected to a pressure wave generated by detonation of small TNT charge placed at a certain distance from the plate. Reinforcing the plate with composite layer improved the ballistic and blast wave protection level of the shield. Due to the usage of the composite the overall mass of the entire plate raised only slightly. Proposed solution can be used to improve the characteristics of existing armours by adding extra panels or modifying armours of transport vehicles.

For the purpose of the numerical analysis, the Finite Element Method and explicit time integration were used. Calculations were done using LS-Dyna software. Numerical solutions of both steel plate and steel plate with composite are presented and evaluated.

Pressure wave of the blast impulse, the physical model of the blast test, Structure of the four composite layer, deformation shape of steel-composite plate (pressure wave in Z-direction, t=1 ms), failure of plies, Huber-Mises-Hencky stress as material effort on plate are presented in the paper.

Keywords: *blast, composite, FEM, ply, simulation*

1. Introduction

The shape of the pressure plot representing typical blast wave impulse is shown in Fig. 1. As can be seen, at the detonation front there is a rapid growth of pressure. Behind the front, pressure drops exponentially creating underpressure for a period of time. Pulse wave propagation speed is about 7-9 km/s (in the case of TNT or RDX).

From engineer point of view, one of the most important parts of the design process is to estimate the blast wave resistance of the structure. There are two kinds of methods allowing that estimation – empirical and numerical. One of the most important empirical method is ConWep (current version 2.1 [4]) created by Kinger and Bulmash in 1992. The empirical methods, however, perform well only when used to obtain pressure distribution in empty space. Analytic equations implemented in this method allow for determining the values of incident and reflected wave's pressure and force applied to an obstacle for spherical or semi-spherical charge with mass up to 400 kT. In case of complicated geometry where waves can reflect many times and interfere the method fails.

When such conditions occur, numerical methods (including FEM) give more reliable results. What is more, they are also more cost-effective. Numerical methods are based on mathematical equations describing the physics of blast phenomenon. They include mass, momentum and energy laws of conservation as well as constitutive equations of the material model. Computer programs designed for solving such problems are commonly using Finite Elements Method with explicit time integration scheme. In this work, the software used is LS-DYNA [3].

This paper presents one of the stages of the design process of a blast-resistant armour enhancement. The steel-composite shield is to be used on an off-road vehicle. The results of numerical simulation of blast load are presented.

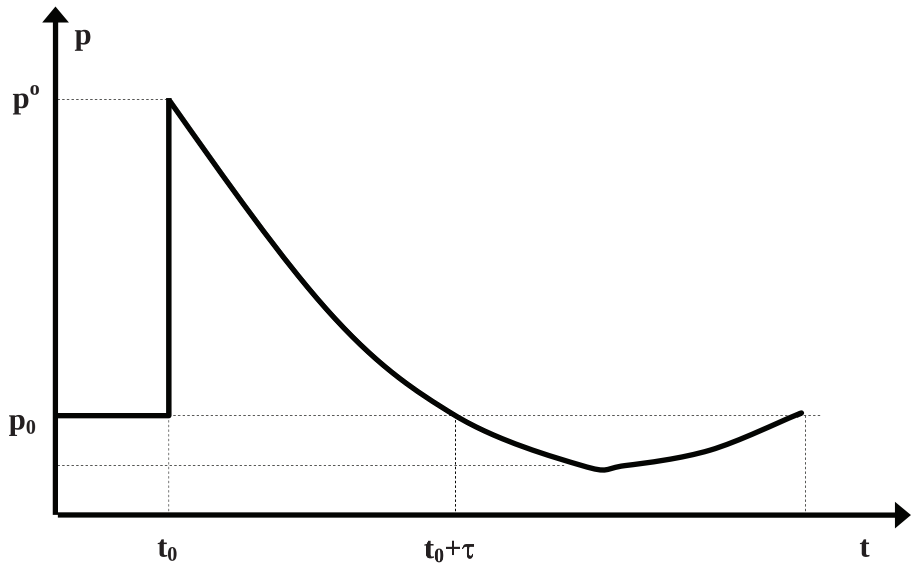

Fig.1. Pressure wave of the blast impulse

2. Configuration of the physical model

Steel plate with the dimensions shown in Fig. 2 was subjected to the blast wave from 100 g TNT charge placed 10 cm above the plate. The 4 mm thick plate was covered with 2.5 mm of composite.

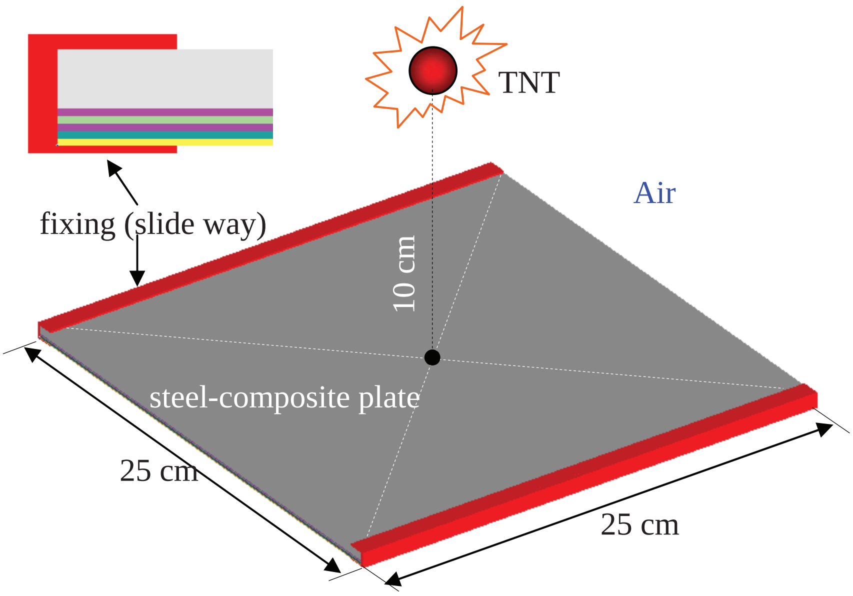

Fig.2. The physical model of the blast test

The structure of the composite protective shield consisted of 5 layers of high-resistant glass fibres S-2 Glass in the epoxy matrix SC-15. The composite was placed in a sequence [0, -45, 90, 45]. The composite scheme is shown in Fig. 3.

Material properties for chosen material model (MAT162) of S-2 Glass/SC15 were obtained from the literature [2]. The values of individual parameters are listed in Tab. 1.

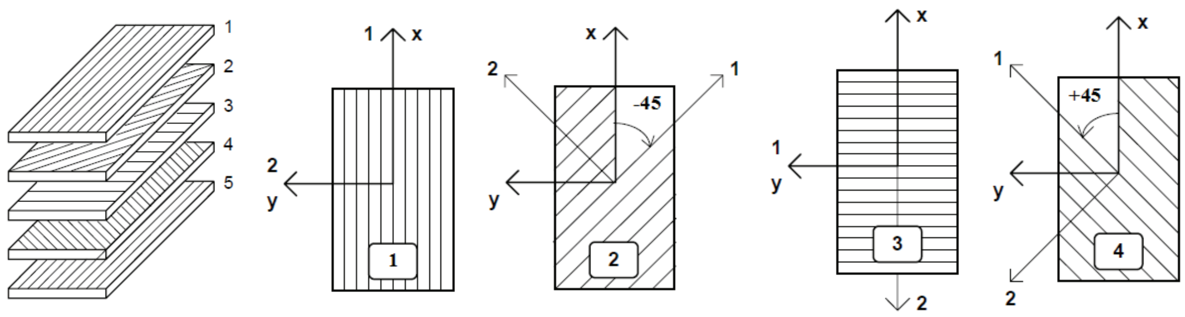

Fig. 3. Structure of the composite layer [0,-45, 90, 45]

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	CERATE2	CERATE3	CERATE4	—	—
4	4	4	0	0	0	—	—

Steel layer of the shield was made of low resistant steel with modulus E=2.1e11 Pa, Poisson's ratio nu=0.3 and strength R_e=300MPa.

3. FEM model description

The numerical model was built using Finite Elements Method. Physical model was meshed using 160 000 cube-shaped elements type SOLID of 0.5 mm side. Steel plate was modelled with isotropic PLASTIC-KINEMATIC material model. Mounting brackets were described using perfectly stiff material RIGID. The composite layer was modelled using COMPOSITE_DMG_MSC material model.

Physical properties of the explosive used corresponded to typical TNT. It was modelled using HIGH_EXPLOSIVE_BURN model and EOS_JWL (Jones-Wilkins-Lee) equation of state [1, 3].

The vicinity of the shield and the charge was filled up with air modelled using SOLID elements with NULL material model. Due to the fact, that air was modelled as an Euler domain whereas structure was described in Lagrange domain, the ALE (Arbitrary Lagrangian- Eulerian) coupling was used [1, 3]. The algorithm is used to model the explosive burning process and blast wave propagation.

Boundary conditions for the plate were added by constraining certain nodes of the mounting brackets.

4. Simulation results

As a result of the numerical simulations stress maps and deformation of steel-composite plate were obtained (Fig. 4-7). Plots of internal and kinetic energies as functions of time are presented in Fig. 8. Fig. 4 shows general outlook of the shield after the experiment with visible deformation and failure of the composite.

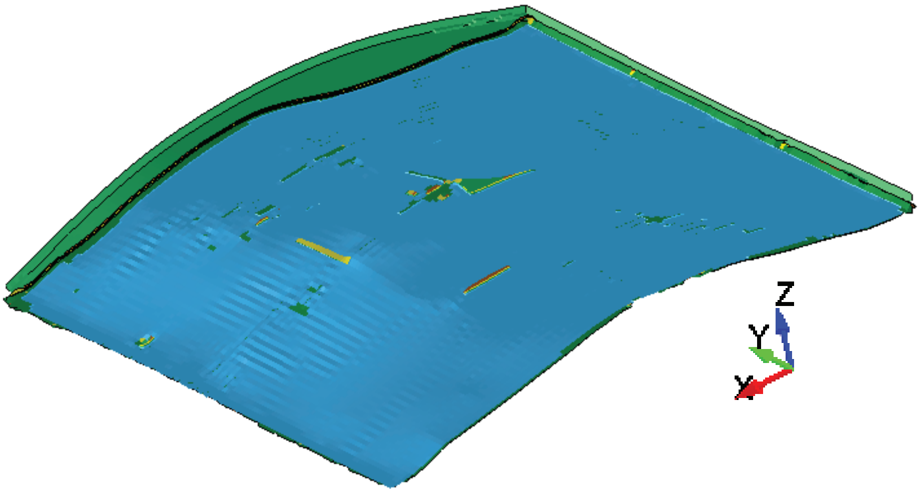

Fig. 4.Deformation shape of steel-composite plate (pressure wave in Z-direction, t=1 ms)

Initially, the destruction of the first layer of the composite was observed. Subsequent stages of the process are shown in Fig. 5.

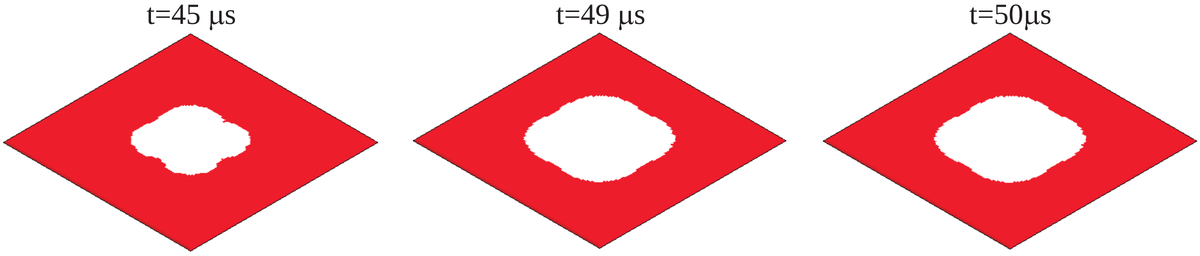

Fig.5. Failure of ply=1

Afterwards, other layers of the shield are destroyed. However, the process does not include the entire surface. Fig. 5 presents the visual condition of each layer after time t = 1 ms. Several ruptures are observed.

At the same time (for t > 1 ms) the steel plate reinforced with composite layer undergoes deformation as shown in Fig. 7. The plate alone is, however, subjected to very high stress. The equivalent stress value computed using Huber-Mises-Hencky formula reached 300 MPa. This value is very close to the strength limit of the material.

The process of absorbing the blast energy by the composite-steel shield is shown in Fig. 8. Reinforcing layers takes considerable part of the blast energy. Layer 5 absorbs nearly as much as the plate. The diagram shows that the composite layer can enhance the capabilities of the entire system.

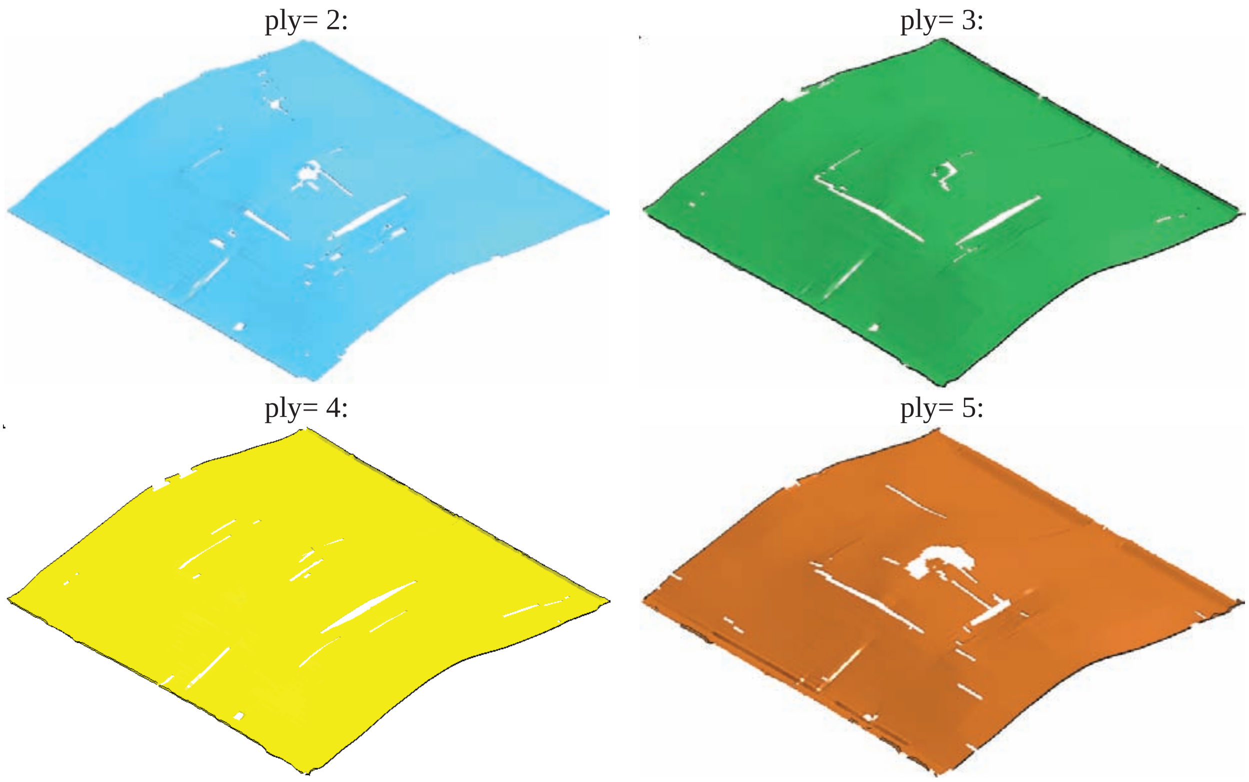

Fig.6. Failure of plies 2.-5.

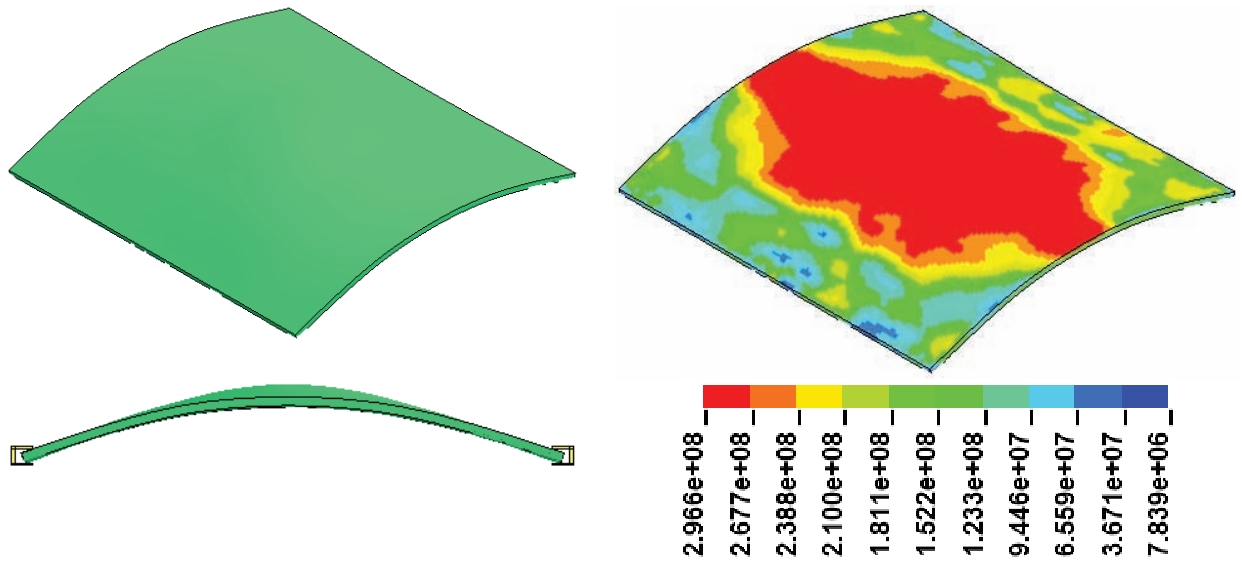

Fig.7. Huber-Mises-Hencky stress as material effort on plate (Pa)

5. Conclusions

The paper presents an analysis of the concept of enhancing blast resistance of steel shields. The idea is to add composite layer to the existing shield. Preliminary research was carried out using Lagrange-Euler coupling implemented in LS-Dyna. The ALE algorithm allows the simulation of high energetic dynamic load generated in Euler domain (air) and its propagation and interaction with physical objects (shield) modelled in Lagrange domain.

Presented simulation model allows for effective design process of new concepts. As well as that, it can be applied to complex physical problems that cannot be solved using other methods including analytical techniques. The simulation, however, requires the verification of the results using experimental methods.

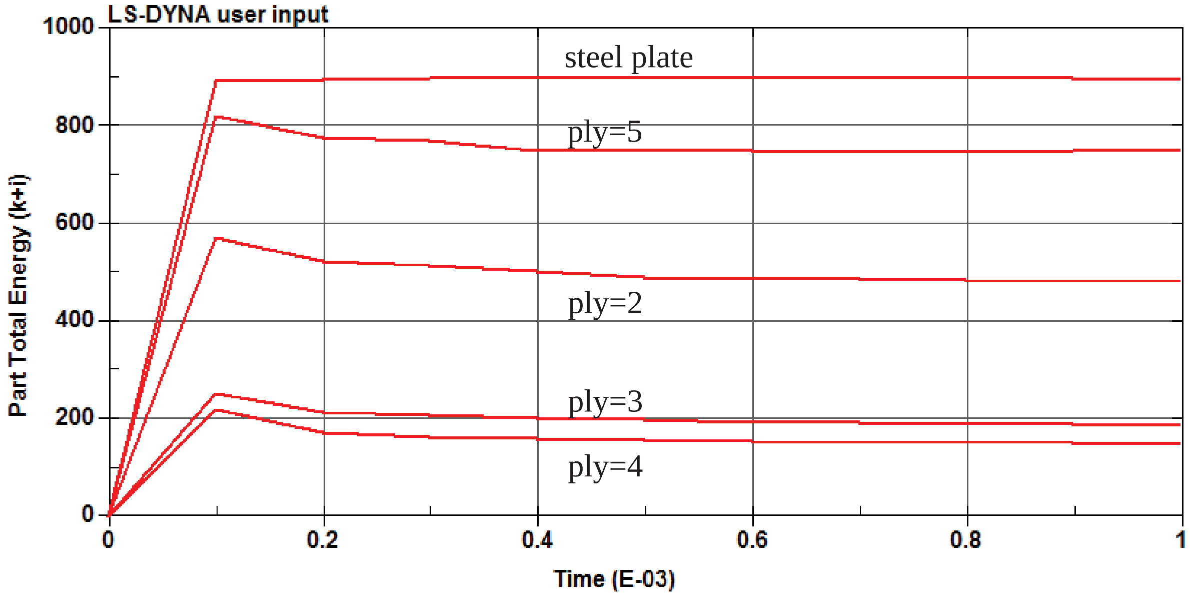

Fig. 8. The blast energy absorption of the steel-composite plate

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