INVESTIGATION OF A PANEL WITH AN ELASTOMER LAYER PLUS CARBON FIBRES LOADED WITH A BLAST WAVE

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Abstract

Terrorist attacks are directed against the most important elements of the infrastructure and human life. Crews of the combat vehicles as well as transmission installation of oil, gas and electric energy are, first of all, exposed to such operations. Such a situation caused striving to increase the safety against the activity of short-time loads coming from explosions [1, 2].

The object of the presented investigations was a numerical-experimental analysis of an elastomer layer of the protective panel combined with an experimental verification. Developed elastomer structures constitute perspective materials and will be applied to solve the problems connected with the increase of combat vehicle safety as well as trouble constructions of pipelines and gas pipelines especially in the dangerous places such as passages over rivers. A plate with an elastomer layer (with carbon fibres) loaded with a 100 g TNT charge was subjected to the analysis. The numerical analysis was verified experimentally.

The results of the conducted analyses will be applied in further works on the selection of the kinds and parameters of the energy absorbing layers. They will be also used for further validating and optimizing investigations, which will aim at absorbing or dispersion of a maximum great value of energy influencing the energy absorbing panel. Such panels can be used for constructing armoured vehicles and protective elements of stationary strategic constructions.

The constructions which can be exposed to damages resulted from a different kind of dynamic forces such as impacts or influences of the pressure wave coming from detonation of an explosive material should have the structure enabling absorption of as great as possible part of energy which influences them. Energy absorbing elements are constructed in the form of sandwich structures coats with a specially selected core material. One of the interesting types of materials which can be used for this purpose is elastomer. These materials enable significant increasing of the protective degree due to their capacities of absorbing energy of a blast wave. Applying of these materials results in decreasing of vibrations frequency of a system loaded with a pressure impulse.

Keywords: *blast wave, experiment, FE analysis, elastomer layer*

1. Introduction

The article deals with one of the possible manners of increasing the resistance of the critic infrastructure construction. There are presented the possibilities of using the hyperelastic elastomer material plus carbon fibres as an energy absorbing layer. This type layers are widely applied in contemporary technology. First of all they are used for dispersion of energy generated as a result of an influence of the body (impact) or pressure (caused, for example, by explosion) on the structure [3-5].

In the considered case, an elastomer layer was placed on the steel base (protected) plate. The plate was subjected to loading with a pressure wave coming from explosive material detonation.

Additionally, various numerical analyses of the developed construction including an experimental verification of the executed calculations were presented in the paper. These analyses allow constructing more advanced panels and finite element models of these panels which are in better agreement with the experiment.

The finite element method implemented in MSC Dytran software was applied in the numerical investigation.

Results of numerical analyses were used during layer selection before constructing better absorbing impact energy panels.

2. Description of energy absorbing structures

Two research systems were subjected to numerical investigations:

- Model 1 - square (500 x 500 mm) steel plate made of alloy St3 0.002 m thick;
- Model 2 - square (500 x 500 mm) steel plate made of alloy St3 0.002 m thick with elastomer layer plus carbon fibres 0.009 m thick.

The examined systems were loaded with a blast wave coming from detonation of a 100 g TNT charge in the form of a cylinder. The obtained numerical results were compared to the own experimental data.

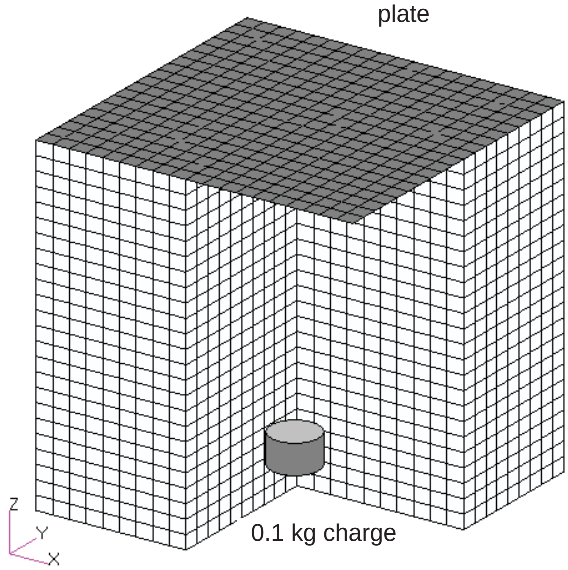

Fig. 1. A general view of the numerical model

PNMU elastomer with a linear construction of macromolecules with admixture of carbon fibres were used for the examinations. Macromolecules of such elastomer are built of flexible and stiff segments composed of flexible (G) and stiff (S) parts. Flexible parts were obtained as a result of addition of OAE – commercial name Alfaster T-620 – with MDI. Stiff parts originated as a result of reaction of -NH2 groups DCDA with –NCO groups included in MDI [6, 7]. Application of DCDA as an extending mean causes originating in each stiff part strongly polar carbamide groups separated by only one carbon atom as well as originating of a substituent. These features of macromolecules structure of applied elastomers cause that they are hard and characterised by small water absorption and great hydrolytic resistance. Due to this fact, the elements made of such elastomers can long-lastingly work in the water environment of ph ranged from 3 to 11. They are characterized also by great resistance to abrasion, especially hydro-abrasion. This type elastomers have been used so far in industry for production of a wide range of parts, especially parts operating in conditions of mineral materials processing [8].

Changing the participation of different kind of substrates, the content of flexible and stiff segments in macromolecules can be changed and thus it can influence on the structure and elastomer properties. Depending on the participation of certain parts in relation to other parts, hardness according to the Shore method [9] can be changed from 65 to 95°ShA, and resiliency determined by Schob method [10] can be changed from 50 to 35%.

Elastomer obtained at the molar relation of substrates MDI/(OAE+DCDA) amounting to 1.5 what is equivalent to relation of stiff to flexible parts 0.5 mol/mol was selected for investigation. Such elastomer is characterised by density at the level of 1.23 kg/dm^3, coefficient of linear thermal expansivity $2.4 \cdot 10^{-4}$ 1/°C, hardness 70°ShA, resiliency equal to 47% and abrasive wear at the level of approximately 30 mm^3 (determined by Schopper – Shlobach method [11]). The PNMU elastomer usage temperature of stiff to flexible relation equal to 0.5 mol/mol doesn't exceed 160°C.

In regular conditions this material remains in the highly elastic state what means that energy of thermal vibrations exceeds the energetic barrier of rotation vibrations.

In the result, elastomer behaves, first of all, as an elastic body easy and quick returning to the initial state after removing the loading.

During deformation of elastomer, its internal energy doesn't change, however material entropy decreases.

3. Results of numerical analysis

The previous papers [2, 4, 12, 14] presented the results of investigations concerning, among others: the influence of Euler elements mesh, the influence of explosive material detonation energy values on an interaction phenomenon and selection of coupling between the Euler and Lagrange domain on the results of analyses in the considered structures. On the base of the obtained experiences, the models used in the present considerations were constructed.

The analysed objects were influenced by a pressure wave coming from detonation of a 0.1 kg cylinder-shaped TNT explosive charge. Propagation of a blast wave coming from detonation of this charge in the Euler domain is presented in Fig. 2.

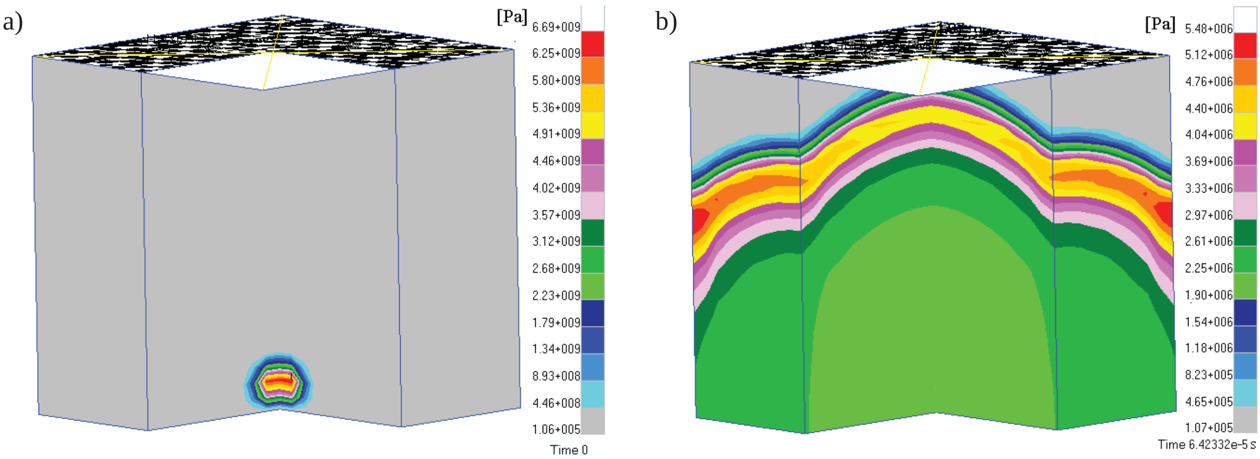

Fig. 2. A view of the pressure wave for two moments of time a) 0 s, b) 6.4233E-5s

Additionally, Fig. 3 presents the graph of wave pressure reflected from 2 mm metal plate (model 1).

Displacement of the plate central node which is in the planes of symmetry and reactions coming from the ground was used to evaluate the results. The displacements character of the central node in the function of time is presented in Fig. 4. Additionally, Fig. 5 presents the final forms of deformations of the metal plates obtained by numerical calculations with the use of explicit implementation of a finite elements method implemented in MSC Dytran software.

In both considered cases, from moment t = 0 s to approximately 3.954E–5 s corresponds to the approach of the wave to the object and is characterised by the lack of displacements of the plate central node. Time duration of the pressure impulse is relatively short in comparison to the increasing time of displacement which is significantly longer and amounts to approximately 0.75 ms. In the case of model 1, the stabilisation and damping of the vibration of the plate central

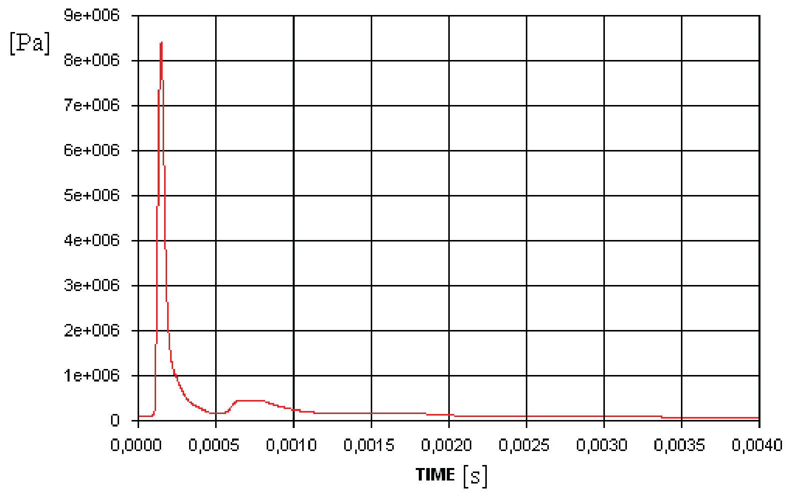

Fig. 3. A blast wave reflected from a 2 mm thick steel sheet metal

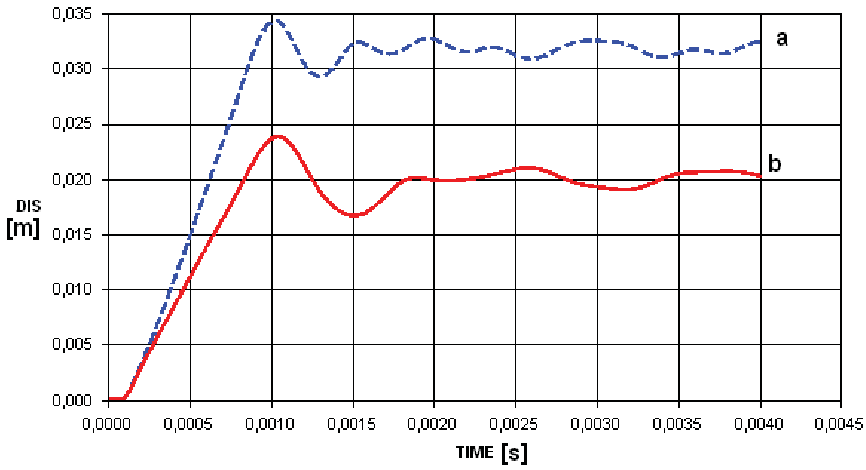

Fig. 4. Displacements of the central node of the metal plate in the function of time, a – model 1, b – model 2

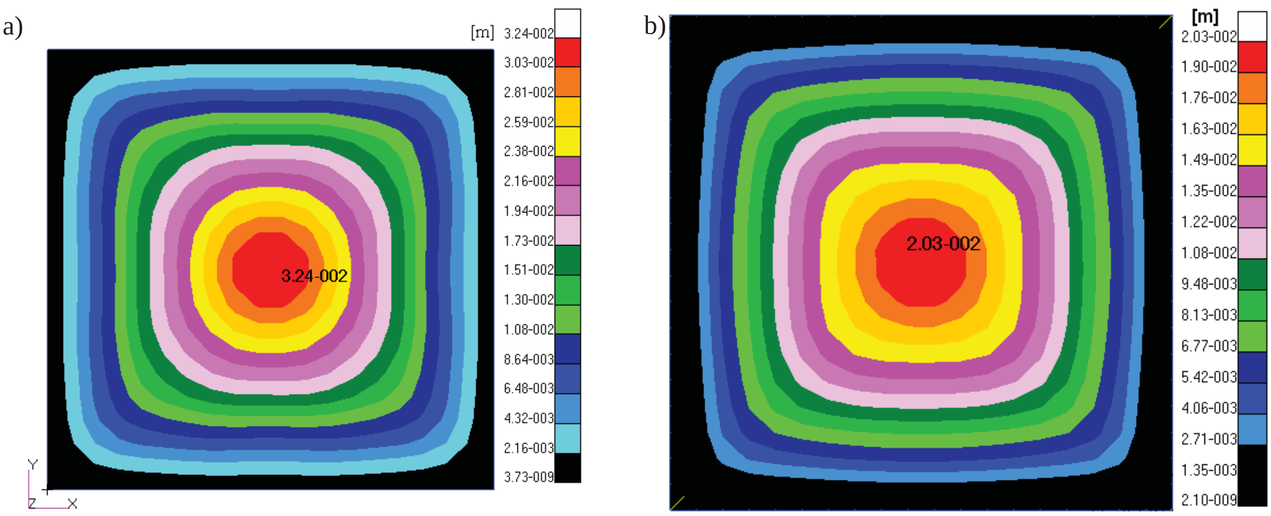

Fig. 5. The final form of deformation, a – model, b – model 2

node around the fixed level 0.0031 m occurs after approximately 0.0015 s. The similar course of displacements of the point was recorded for model 2, however in that case a vibration amplitude was smaller– what was caused by an additional elastomer layer. The final deformation of the central node amounted to 0.02 m.

It should be noted that the manner of deformation of the steel metal plate in both considered models is different. The plate deformation is smaller in the case of structures with elastomer in comparison with structures without elastomer. Such character of deformation is caused by an elastomer protective layer increasing the stiffness of the structures, thus causing the spreading of loading on the greater surface of the considered object.

The maps of equivalent stress for the considered systems are presented in Fig. 6.

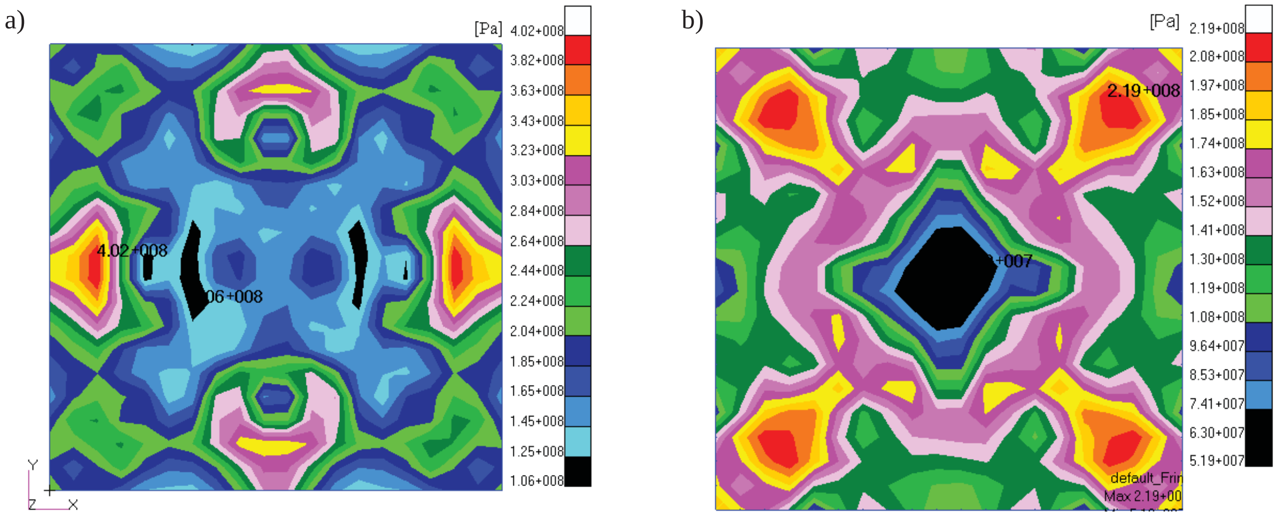

Fig. 6. Comparison of equivalent stress maps for model 1 and 2, a – model 1, b – model 2

In the case of the first model the maximal stress values are twice as much higher than in the case of model 2 and amount to $4.02 \cdot 10^8$ Pa (model 1) and $2.19 \cdot 10^8$ Pa (model 2), respectively.

4. Devices and equipment used in investigations

Experimental investigations of energy absorption of different kind of layers were executed in the Department of Explosive Materials, Military University of Technology, on the authorial stand for measurement the force influencing the examined panel. The stand was designed and constructed in the Department of Mechanics and Applied Computer Science. The stand enables the measurement of the forces induced by dynamic forces, even the processes such as influencing of the pressure wave coming from detonation of an explosive material. Fig. 7 presents a test stand with a system for measurement of forces used in the investigations.

In the system of signals processing, an amplifier Ms 1001 produced by INFEL company from Świdnik is used to strengthen the signals coming from extensometer. Recording of the courses was performed with the use of a measurement card model NI-USB 6251, produced by National Instruments company, including a fast analogue – digital converter (sampling 1.25 MHz on each of the channels), a notebook TOSHIBA Satellite as well as a software.

5. Results of experimental investigations

After conducting the investigations on the stand, the obtained courses were subjected to calibration in order to prepare the graphs of force changes in the function of time. Fig. 8 and 9 present the recorded force courses for the examined models. Due to difficulties in measurement during the experimental investigations, one limited to the reading of the force influencing on the frame and the final deformation of the system centre.

Figure 10 presents the photo of the base plate before and after the experiment (deformed plate). Fig. 11 presents analogously the photo of the experimental system corresponding to model 2, therefore the metal plate with an additional elastomer layer plus nonotubes.

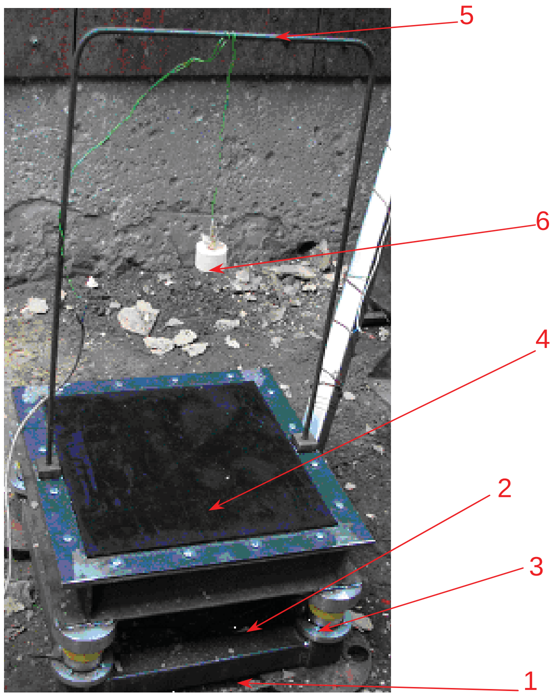

Fig. 7. The system for forces measurement used in the investigations: 1 – a base, 2 – a frame for fixing the panel, 3 – a extensometer force convector (4 items), 4 – an energy absorbing panel, 5 – a frame of fixing the explosive material, 6 – an explosive material

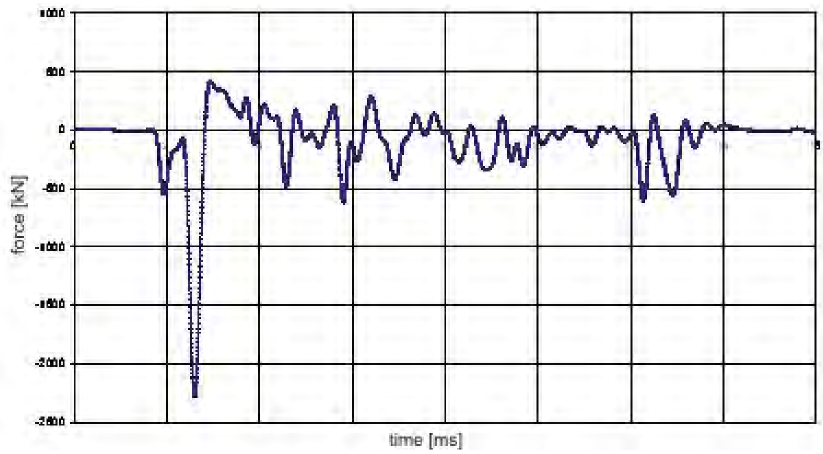

Fig. 8. The course of changes of loading a panel made of steel metal plate

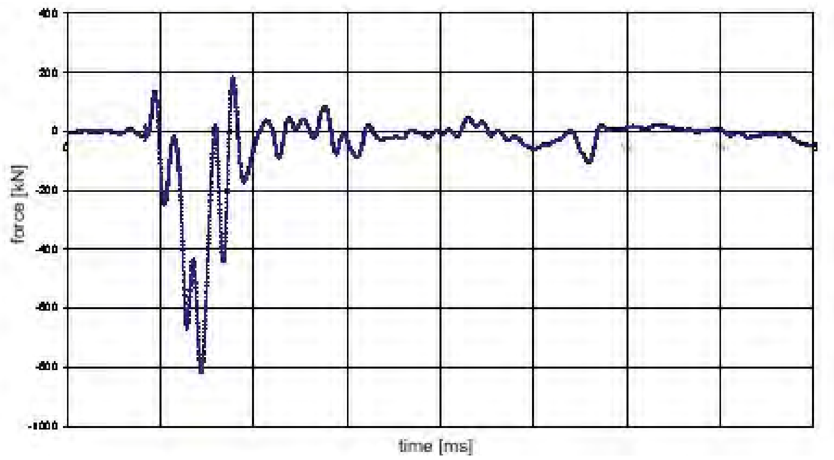

Fig. 9. The course of changing of loading a panel made of steel metal plate with an elastomer layer filled with nanotubes

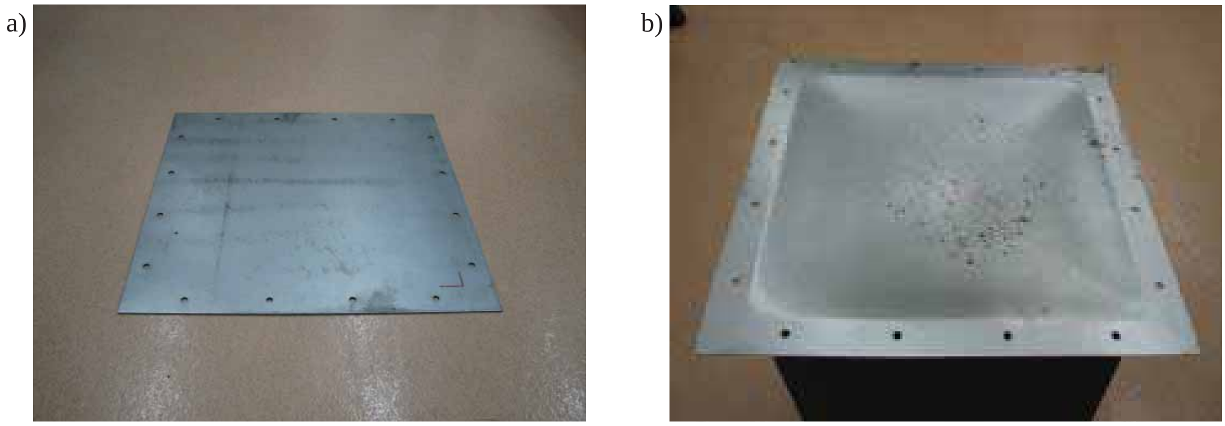

Fig. 10. Object 1: a) a 2 mm thick plate; b) deformation obtained from the experiment

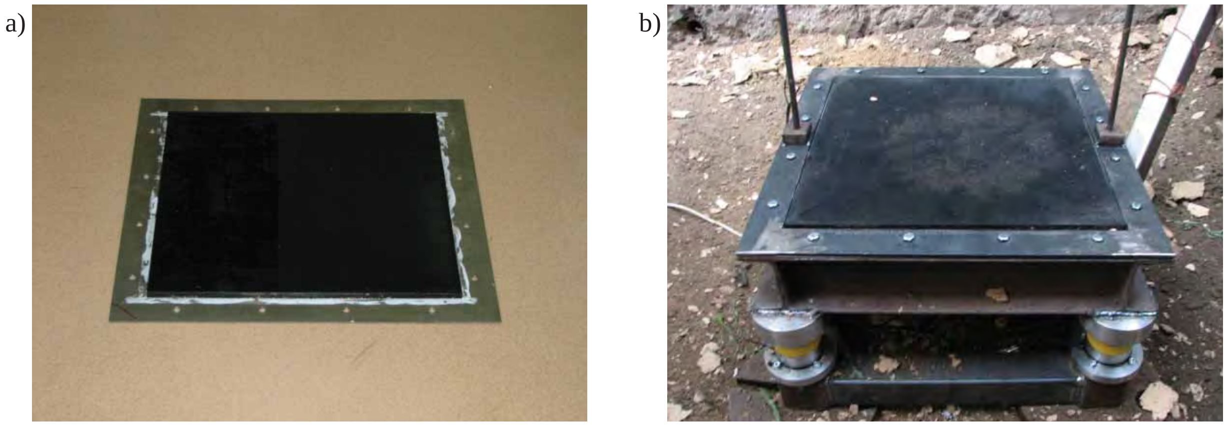

Fig. 11. Object 2: a) a 2 mm thick plate with an elastomer layer; b) deformation obtained from the experiment

The measured permanent displacement of the central node of the steel plate amounted to 32 mm. Application of the protective layer decreased the value of this displacement by 36.5% (displacement amounted 20.3 mm). Additionally, on the base of the recorded results, the maximum values of the forces (Fig. 7 element no. 3) influencing on the measurement system for the particular object were determined. The comparison of the results is presented in Tab. 1.

Tab. 1. Comparison of the results obtained experimentally and numerically for the examined objects

sample	displacement obtained numerically [m]	displacement obtained experimentally [m]	sample mass [kg]	the value of the recorded force
a 2 mm steel metal plate	0.032	0.032	4.4	2278.1
a 2 mm steel metal plate with an elastomer layer with admixture of nanotubes	0.027	0.0203	6.5	660.0

6. Conclusions

Structures which can be destroyed as a result of influencing of different kind of dynamic forces, such as impacts, or influencing of the pressure wave coming from detonation of an explosive material should have the structure enabling the absorption of as great as possible part of forcing energy which influences them. One of the interesting types of materials which can be used for this purpose is elastomer. These materials are capable to absorb energy of a blast wave coming from explosion and allow the significant increasing of a protection level. Applying these materials causes decreasing of the vibration frequency of the system loaded with a pressure impulse.

The smallest displacement of the central node was recorded for model 2 in which the elastomer layer with the admixture of nanotubes was used. The experimental investigations also confirmed that elastomer layers absorb and disperse well impact energy protecting the object against the effects of influencing of the pressure wave coming from detonation of explosive materials.

The authors presented the extract of the investigations executed in the Department of Mechanics and Applied Computer Science, Military University of Technology.

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