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Research of mine imitator interaction with nondeformable surface

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1. Introduction

Armed Forces of developed countries are widely using trainers for the training of artillery specialists. Presently, specialists from the Kaunas University of Technology (KTU) Institute of Defence Technologies are dealing with the problem of firing 60 mm and 120 mm mortar trainers, which is extremely urgent to the Armed Forces of Lithuania.

a b

Fig. 1 Composition of the mortar shooting trainer: a -60 mm mortar shooting trainer; b - 120 mm mortar shooting trainer; *1* - body ejecting device; *2* - mine imitator („warhead“); *3* - muzzle

The trainer consists of a body whose external surface, in principal, repeats the contour of a combatant mine, and its inside a barrel with an infixed charge is installed (Fig. 1). „Warheads“ are inserted into a muzzle with the main powder charge, while the rear part of the muzzle has several small holes intended for the distribution of the gas flow of the main powder charge. To imitate an explosion, „the warhead“ is filled with smoke powder, and while falling into the ground it should explode in this way imitating the explosion of a mine. The trainer has four charges, consisting of a „warhead“ and muzzle with respective amounts of powder, which ensure firing ranges to the scale of 1/10 [1,2].

Fig. 2. presents the operating scheme of the trainer. It shows separate phases of trainer‘s operation: the insertion of a mine‘s imitator into the barrel of the mortar (a); upon hitting of the main charge‘s capsule against the braking device at the bottom of the mortar barrel the explosion of the main charge occurs (b), whose energy of the gas flow via the main barrel of the muzzle and artillery holes distributes in such a way that it ejects the multiuse body of the mine in 5-25 m distance from the fire position of the mortar (c); and „the warhead“ – at the range necessary to hit the target (d). At the place where „the warhead“ falls into the surface of the ground, the detonator goes off and it initiates the explosion of the imitative smoke powder charge.

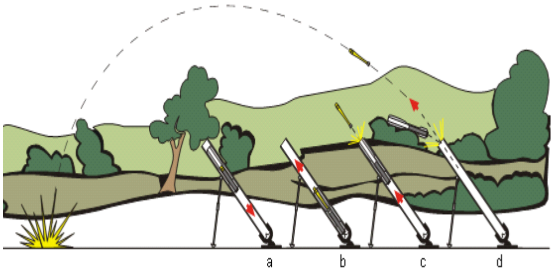


Fig. 2 Operating scheme of the trainer: a-mine inlet into the barrel of the mortar; b - explosion of the main charge; c - traffic of the body and „warhead“ in the mortar barrel and its environment; d - the falling phase of the “warhead”

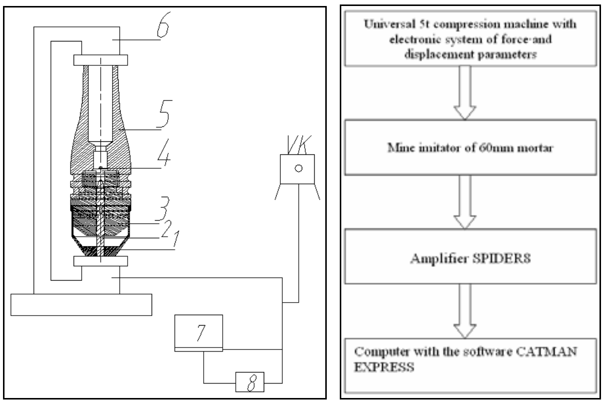
The trainer is used at different soil surface conditions and should ensure the reliable performance of the mine imitator. This is predefined by sufficient displacement of the detonator’s stud with respect to the capsule during interaction process of the detonator’s cap and the soil. The methods of experimental interaction research of detonator’s cap of the mine imitator and nondeformable surface, test rig structure and results of the performed experiments and computational modelling are presented in the paper.

2. Rig for experimental research

Special test rig the block and structural schemes of which are presented in Fig.3 for the determination of cap deformations and stud displacements is created.

The test rig consists of universal compression machine *6* into the grippers of which the tested mine imitator is fixed. The mine imitator consists of the detonator’s cap *1* and the stud *2* which is inserted into head *3*. Between the stud *2* and the capsule detonator *4* there is a small 1.5-2.5 mm gap. All parts of the mine imitator are inserted or joined with the body *5*. In universal compression machine *6* electronic system of force and displacement measurement is mounted. It is connected to the amplifier SPIDER *8* from which measurement data is transmitted to computer with the software CATMAN EXPRESS (Fig. 3).

During tests the mine imitator is compressed by the compression machine. Compression force is measured and the received data via amplifier are transmitted to computer *8* and saved there. CDD camera records the deformation process of the mine imitator during experiment.



a b

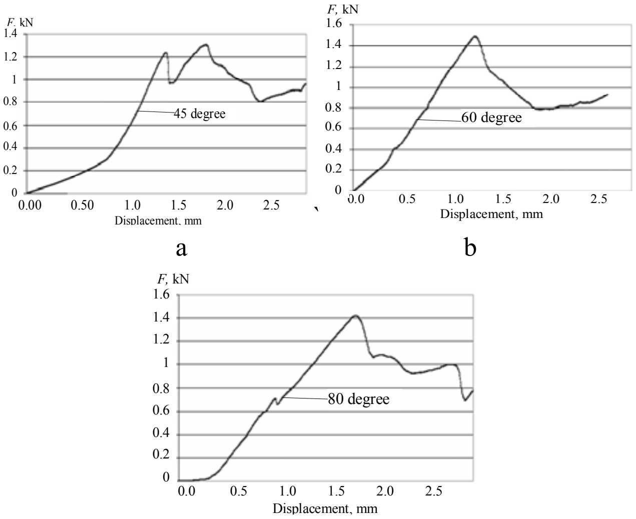
Fig. 3 Block (a) and structural (b) schemes of the test rig: *1*- detonator’s cap, *2* - stud, *3* - head, *4* - capsule of the detonator, *5* - body of the mine imitator, *6* - universal compression machine, *7* - computer, *8* - amplifier, *VK* - CDD camera

3. Investigation of mine imitator interaction with non-deformable surface

Interaction investigation of the imitator’s detonator and nondeformable surface was performed; i.e. the case when the trainer is used in specially prepared place with solid soil surface was analyzed. During tests 45°, 60°, 80° falling angles of the imitator were simulated. Research results are presented in Fig. 4 and 5.

a b c

Fig. 4 General views of detonator’s cap deformation at different angle interaction with non deformable surface: a - falling angle 45°, b - falling angle 60°, c - falling angle 80°



a b

c

Fig. 5 Dependency of deformation force acting on the detonator’s cap on displacement of the cap at different interaction with nondeformable surface angles: a - falling angle 45°, b - falling angle 60°, c - falling angle 80°

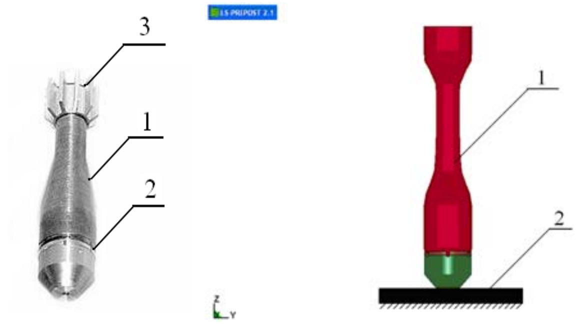
From the cap deformation views it is seen that the deformation character depends on falling angle: the greater is the falling angle the higher deformation asymmetry of the cap is obtained. Nevertheless it was determined that at all falling angles used in the investigation the stud displacement sufficient to initiate capsule detonator is obtained.

Character of the deformation force acting on the cap is very similar at different interaction angles.

At the beginning up to the cap cracking deformation force constantly grows (approximate displacement 1.00-1.32 mm), later up to the contact with capsule detonator decreases (approximate displacement 1.85-2.00 mm).

4. Modelling of the shell imitator and non deformable surface interaction

LS-DYNA software was selected for the modelling of shell imitator. This type program is usable the ballistics interactions a dealing problem.[3] Function “rigidwall” which acts as nondeformable surface and represents ground was used, but calculation time of the programme is shorter than the real one. (Fig. 6)



a b

Fig. 6 General view of the shell imitator: a – *1* - body , *2* - detonator, *3* - stabilization wings, b – impact model of the shell imitator to nondeformable surface: *1* - shell imitator, *2* - non deformable surface

For interaction modelling of the shell imitator and nondeformable surface the structure of the shell imitator is divided into separate elements. Their general views and FE mesh generated are presented in Fig. 7.

a b

Fig. 7 Construction and elements of the shell imitator: a – *1* - section view of the shell imitator, *2* - body of the shell imitator, *3* - stud, *4* - cap, *5* - bottom view of the cap, *6* - ring, b – FE mesh in the structure of the shell imitator

Body of the shell imitator is modelled as nondeformable element (rigid part) entering steel’s elasticity modulus and density which allow evaluating inertia properties of real imitator.

Function of the stud is to initiate blast at its contact with the detonator's capsule. As the main measured parameters displacement and velocity of the contact surface of the stud and the capsule were chosen because in order to initiate the stud should be displaced at certain distance and with certain velocity with reference to the capsule. Stud displacement is obtained at plastic deformation of the cap.

Geometrical model of the cap is divided into 3 parts and "shell" elements are used for its modelling.

Stiffness of the cap should be selected with sufficient accuracy. If it would be too low the detonator would be initiated during firing process as the cap would deform under the action of inertia forces. If stiffness would be too high the detonator would not start in case the imitator would hit surface. That's why the aim of numerical modelling is to find out deformation features of the cap with the verified in advance the numerical model by experimental results.

For the modelling process the following structural and geometrical parameters of the shell imitator and nondeformable surface are evaluated:

- construction of the shell imitator,
- structural materials,
- detonator's cap height,
- detonator's cap width,
- diameter of the detonator's cap contacting with nondeformable surface,
- number of elements of detonator's cap contacting with nondeformable surface,
- surfaces contacting during deformation process.

The body and stud of the detonator are made of steel and the cap aluminium alloy.

Modelling interaction of the shell imitator and nondeformable surface with LS-DYNA software the following parameters were selected: calculation time and step, boundary conditions at translation and rotation (about x, y, z axis) of the body and nondeformable surface (BOUNDARY SPC SET), contact of the body and the cap nondeformable surface at the interaction (RIGIDWALL PLANAR), gravity force of the imitator (LOAD BODY Z), initial velocity of motion (INITIAL. VELOCITY GENERATION) [3].

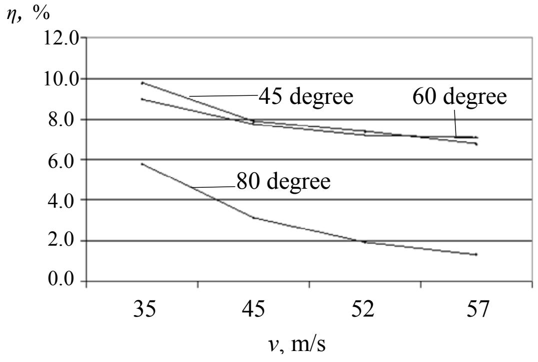


Fig. 8 Dependency's of percentage of absorbed by the detonator cap energy at various values of velocity and hitting angles

During interaction between the cap and nondeformable surface the cap absorbs small energy percentage of impact energy. The percentage of impact energy computable

$$\eta = \frac{E_{cap}}{E_{imp}} 100\%$$

there E_{cap} is absorbed energy, J; E_{imp} is impact energy, J.

Difference of the impact angles and velocity's is shown in Fig. 8.

5. Modeling results

The absorbed energy characteristics of the detonator deformation in case of 2.5 mm displacement (initial distance from the stud end to the detonator) were determined at minimal firing angle 45°, 80° and hitting speeds of the imitator – 35, 45, 52, 57 m/s. The comparison of deformation views obtained at experimental research and modelling was performed as well (Figs. 9 and 10).

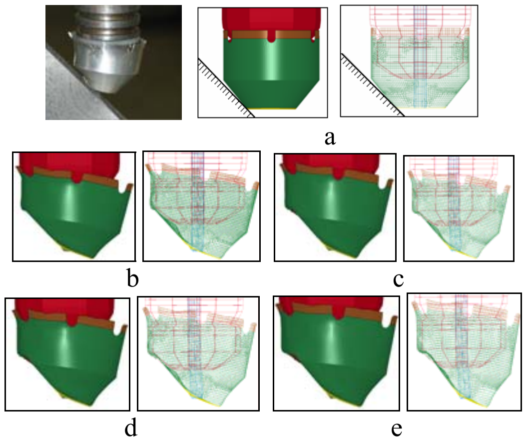


Fig. 9 Deformation of the detonator cap – views of the interaction with non deformable surface at hitting angle 45° (on the left – experimental view, on the right – modelling results): a - initial position $t = 0$, b - $v = 35$ m/s; c - $v = 45$ m/s; d - $v = 52$ m/s; e - $v = 57$ m/s

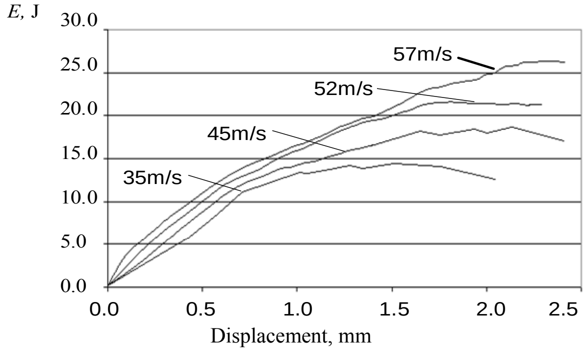


Fig. 10 Dependency of absorbed by the detonator cap energy on displacement at 45° hitting angle: for velocity values 35, 45, 52 and 57 m/s

As it can be seen in the presented views the displacement is sufficient to initiate the detonator not taking into account the stud deflection (Figs. 11 and 12).

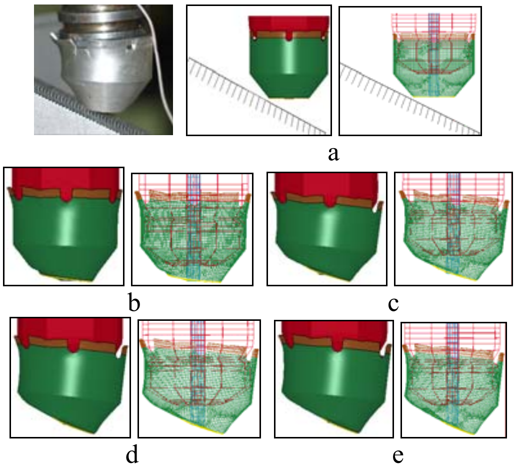


Fig. 11 Deformation of the detonator cap – views of the interaction with non deformable surface at hitting angle $\alpha = 60°$ (on the left – experimental view, on the right – modelling results): a – initial position $t = 0$, b – $v = 35$ m/s, c – $v = 45$ m/s, d – $v = 52$ m/s, e – $v = 57$ m/s

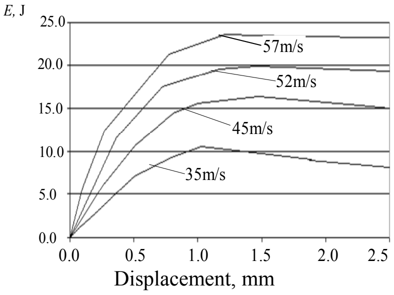


Fig. 12 Dependency of absorbed by the detonator cap energy on displacement at 60° hitting angle

Deformation views at the detonator's cap of the shell imitator interaction with non deformable surface when hitting angle of the imitator to the ground is maximal 80°(Figs. 13 and 14).

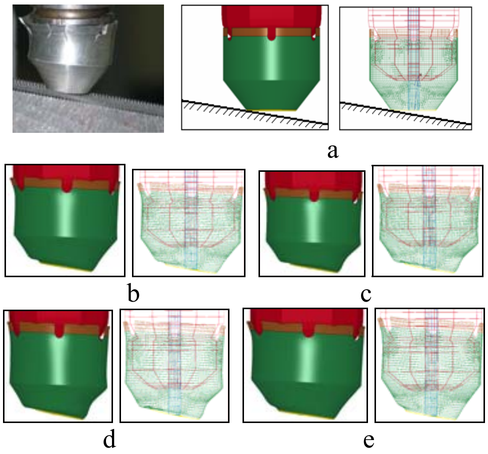


Fig. 13 Deformation of the detonator cap – views of the interaction with nondeformable surface at hitting angle $\alpha = 80^{\circ}$ (on the left – experimental view, on the right – modelling results): a – initial position $t = 0$, b – $v = 35$ m/s, c – $v = 45$ m/s, d – $v = 52$ m/s, e – $v = 57$ m/s

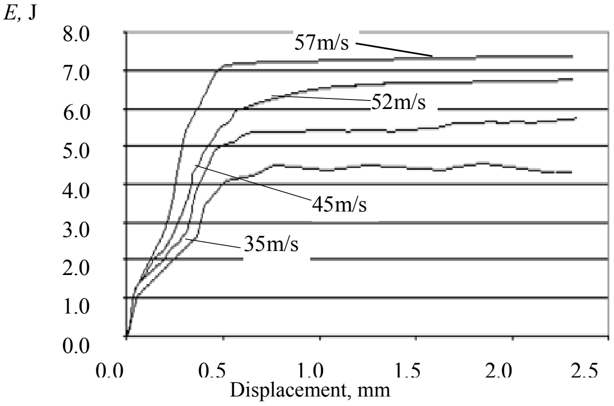


Fig. 14 Dependency of absorbed by the detonator cap energy on displacement at 80° hitting angle

From the dependences in Fig. 9 and 11 it can be seen that the energy absorbed by the detonator cap increases with the increase of hitting speed. From the views in Fig. 9 and 11 it can be seen as well that the cap deformations are greater at lower hitting angles what is also reflected by the energy amount necessary for the cap deformation Fig. 10 and 14.

Both by modeling and experimental research it was determined that as the result of the detonator cap interaction with nondeformable surface the sufficient displacement to ensure the detonator start is induced to the stud.

6. Experimental field tests

Experimental field tests of the developed training facilities were performed. For this purpose a batch of 100 test imitators was manufactured. Imitators of the batch were tested simulating all firing charges and all firing angles - 45°, 60°, 80°.

There were at all no non performance cases during the tests. That's why it is possible to state that the found out technical solutions of the problem and research results are correct.

For test simulation cap views of the mine imitator after initiation when firing with initial speed 45 m/s at 45°, 60°, 80° firing angles are shown (Fig. 15).

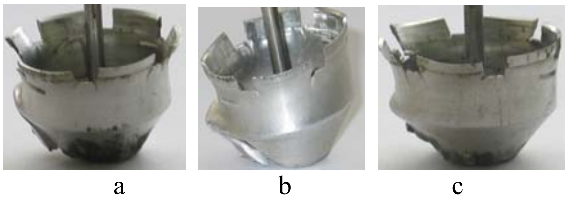


Fig. 15 Detonator's cap views of the mine imitator when firing with initial speed 45 m/s at different firing angles: a - firing at the angle 45°, b - firing at the angle 60°, c - firing at the angle 80°

7. Conclusions

1. Structural parameters of the cap ensuring initiation of the detonator at any mechanical characteristics of the soil were determined.

2. Using FEM software LS-DYNA the modelling methods of the interaction of shell imitator and nondeformable ground was worked out.

3. Modelling of the interaction of detonator cap of the shell imitator and nondeformable surface was performed and dependences of the cap deformation and the energy absorbed for deformation on hitting speed and interaction angle were determined.

4. It was clarified that with the increase of hitting angle the energy amount consumed for the detonator's cap deformation increases.

5. It was determined the deformation of the detonator cap and energy consumed for this deformation increase with the decrease of interaction angle.

6. It was found out that as the result of detonator's cap interaction with nondeformable surface the sufficient displacement is induced for the stud what ensures initiation of the detonator.

7. Comparative analysis of experimental research and modelling results showed agreement of the results.

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MINOS IMITATORIAUS SĄVEIKOS SU NESIDEFORMUOJANČIU PAVIRŠIUMI MODELIAVIMAS

Reziumė

Straipsnyje pateikti minosvaidžių treniruoklių minos imitatoriaus sprogdiklio gaubtelio sąveikos su nesideformuojančio ir grunto paviršiumi tyrimai. Tam tikslui sudaryta eksperimentinių tyrimų metodika, sukurtas stendas ir atlikti eksperimentiniai tyrimai. Eksperimento metu nustatytos gaubtelio deformacijos ir gautos sąveikos jėgos priklausomybės nuo gaubtelio deformacijų ir smeigės poslinkio esant įvairiems sąveikos kampams. Naudojant LS-DYNA programą, atliktas gaubtelio sąveikos su nesideformuojančiu paviršiumi kompiuterinis modeliavimas ir pateikti tyrimo rezultatai. Taip pat parodyti minos imitatoriaus sprogdiklio gaubtelio deformacijų, esant įvairiems šaudymo kampams, poligoninių bandymų rezultatai.

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RESEARCH OF MINE IMITATOR INTERACTION WITH NONDEFORMABLE SURFACE

Summary

This paper presents experimental interaction research of the detonator's cap of the mortar trainer's mine imitator and nondeformable soil surfaces. For this purpose experimental research methods were developed, test rig created, and performed. The experimental testing during which the cap deformation was determined and interaction force dependences on cap deformations and stud deflections at different interaction angles were obtained. Field test results of the deformations of detonator's cap of the mine imitator at different firing angles are presented.

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МОДЕЛИРОВАНИЕ ВЗАИМОДЕЙСТВИЯ ИМИТАТОРА МИНЫ С НЕДЕФОРМИРУЮЩЕЙСЯ ПОВЕРХНОСТЬЮ

Резюме

В настоящей статье представлены исследования взаимодействия колпачка взрывателя имитатора мины с недеформирующейся поверхностью. Создана методика и стенд для экспериментальных исследований, в ходе которых выявлены деформации колпачка и получены зависимости сил взаимодействия, а также хода от величины деформаций колпачка при разных углах взаимодействия. Используя программу ЛС - ДИНА выполнено компьютерное моделирование взаимодействия колпачка с недеформирующейся поверхностью и представлены результаты исследования. Представлены результаты полигонных испытаний деформаций колпачка взрывателя имитатора мины при разных углах выстрелов.

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