Proceedings IRF2018: 6th International Conference Integrity-Reliability-Failure
Lisbon/Portugal 22-26 July 2018. Editors J.F. Silva Gomes and S.A. Meguid
Publ. INEGI/FEUP (2018); ISBN: 978-989-20-8313-1

PAPER REF: 7234

ANALYSIS OF THE PENETRATION OF BARRIERS BY IMPACTORS WITH AN EXPLOSIVE SUBSTANCE

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ABSTRACT

The process of interaction of titanium impactors, filled with explosives, with steel targets and targets from alloy of tungsten, nickel and iron has been numerically investigated. The behavior of the medium is described from the general positions of the mechanics of continuous media. The material is considered isotropic, elastoplastic, compressible, porous. The problem is solved in a two-dimensional formulation for the case of axial symmetry. The calculations were carried out using a technique that takes into account the fragmentation of the material in shear and shear failure. The current configurations of the impactor-target are obtained during penetration and under the action of detonation products, as well as the parameters of the shock waves.

Keywords: projectile, barrier, penetration, detonation, deformation, destruction.

INTRODUCTION

The urgency of research on high-speed deformation and destruction of solids is due, first of all, to the need to obtain the basic laws of processes for the purpose of using them in the development of shockproof protection for various purposes. Mathematical modeling at the same time (Glazyrin, 2009; Gerasimov, 2013; Johnson, 1981) is an effective method for obtaining detailed information about the ongoing processes, substantially supplementing the experimental results. In addition, in carrying out complex rational design, it is possible to calculate predictably the behavior of promising impact-resistant protections in order to facilitate the search for the optimal design.

In the work (Glazyrin, 2009) the problem of the introduction of a steel large-sized impactor with an ogive shape of the head part filled with an explosive substance in an ice plate lying in one variant on an aqueous one, in another variant on a granite substrate was numerically solved. In the works (Glazyrin, 2007; Orlov, 2017), shock-wave loading of functional gradient materials was simulated. In work (Zelepugin, 2017) the shock wave propagation under explosive loading is numerically analyzed.

In the present work, computational experiments on simulation of the penetration process of obstacles by a titanium axisymmetric cylindrical impactor filled with explosives are carried out and analyzed. As the target materials, strong steel and an alloy of tungsten, nickel and iron (TNI) are considered. For detailed analysis of the shock wave pattern, the current state parameters in steel, TNI, titanium and explosives on the symmetry axis were recorded.

FORMULATION OF THE PROBLEM

The statement of the problem and the initial data are as follows. A titanium cylindrical container, radius R = 17 sm, is filled with explosives (Figure 1). The thickness of the front wall of the container is 0.188R, the rear and side 0.082R, the height is 5.159R, the initial velocity projectiles is 450 m/s. As a barrier we used plates 0.206R thick made of strong steel or TNI (alloy: tungsten-nickel-iron). An explosive with an initial density of 1.6 g/sm^3 and a detonation velocity of 6.9 km/s. The characteristics of the materials are taken from the work (Orlenko, 2004).

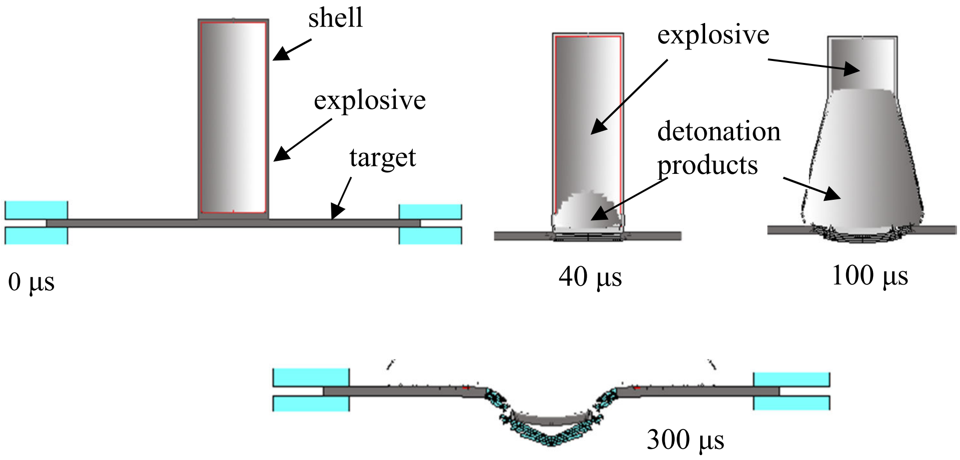


Fig. 1 - Interaction of the impactor with the filler with a plate (3.5 sm) from TNI with the initial velocity of the projectile 450 m/s

The mathematical description of the behavior of materials is based on the phenomenological macroscopic theory of a continuous medium, that is, a model based on fundamental conservation laws with determining equations is used, the adequacy of which has been repeatedly confirmed by numerous calculations and experimental data.

MATHEMATICAL MODEL

The medium under consideration is assumed to be compressible, isotropic with no mass forces, internal heat sources and thermal conductivity. An elastoplastic model with the Prandtl-Reis flow equations associated with the Mises yield condition is used. The equation of state is chosen in the Walsh form. The effect of porosity on the stress-strain state of bodies and their deformation hardening is taken into account by the correction of the yield strength and shear modulus.

The pressure in the detonation products (PD) is calculated from the Landau-Staniukovich polytropic P = Aρ^3, which after transformations takes the form $P=\rho_0 D^2(\rho/\rho_0)^3/8$. The initiation criterion explosives is chosen in the form P^2t = const. This criterion well describes the experimental data in the region of small times, at relatively high pressures.

The problem is solved numerically in a two-dimensional formulation for the case of axial symmetry, using the Johnson method based on the Lagrangian approach, which was modified to the case of large deformations and fragmentary fracture by introducing into the model mechanisms for splitting the nodes and eliminating computational elements with large distortion on the contact surfaces (Glazyrin, 2007; Orlov, 2017). This approach allows us to simulate different types of impact interaction, which is inherent in Lagrangian methods, high efficiency and accuracy in tracking contact and free surfaces: deep penetration, splitting, through penetration with the possibility of obtaining current process parameters.

NUMERICAL RESULTS (TARGET FROM THE ALLOY TNI)

The calculated current configurations of the impactor-target during the penetration of the plate from the TNI and under the action of the detonation products are shown in Figure 1. The initial loading scheme is shown at the initial time. Immediately after the interaction, a disintegration of the discontinuity occurs on the contact surface of the titanium- TNI and shock waves propagate in both directions from it. Detonation of explosives occurred at 20 μs of the collision process. At this time, the maximum pressure in the residence permit was 6.18 GPa, in titanium - 20.0 GPa, in the explosive - 3.46 GPa. At a time of 40 μs, detonation of explosives, deformation and destruction of the materials of the striker and obstruction are also observed. At a time point of 100 μs, these processes are further developed. Finally, at a time of 300 μs, the side walls of the impactor are completely destroyed by small fragments, and the bottom of the striker, while retaining its shape, breaks through the barrier like a plate. Similar calculations were carried out for the process of interaction between a impactor filled with explosives and a steel plate.

NUMERICAL RESULTS (STEEL TARGET)

The calculated current configurations of the impactor-target during the penetration of the steel plate are shown in Figure 2. Here, also after interaction on the contact surface of titanium-TNI, disintegration of the discontinuity occurs and shock waves propagate in both directions from it. In this variant, the detonation criterion was not fulfilled. This is explained by the fact that the intensity of the shock wave forming in the barrier depends on the shock impedance of the barrier material, which is higher for a TNI than for steel. At the time of 20 microseconds, the maximum pressure in the TNI was 2.95 GPa, in titanium 1.9 GPa, in explosives 3.15 GPa.

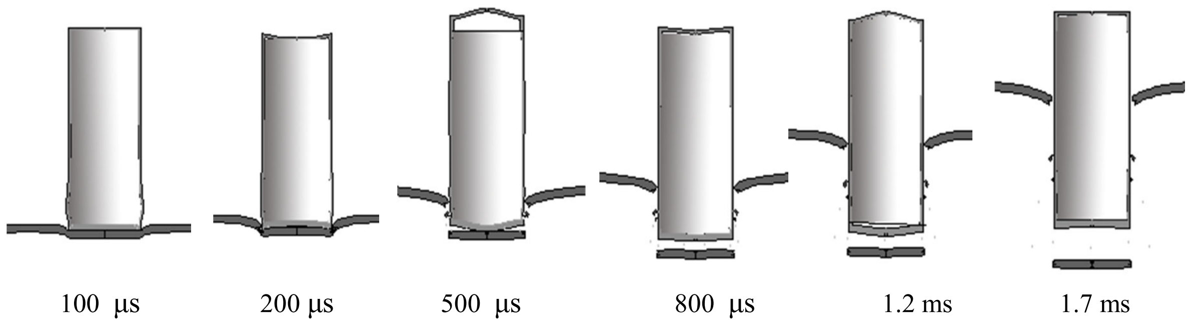
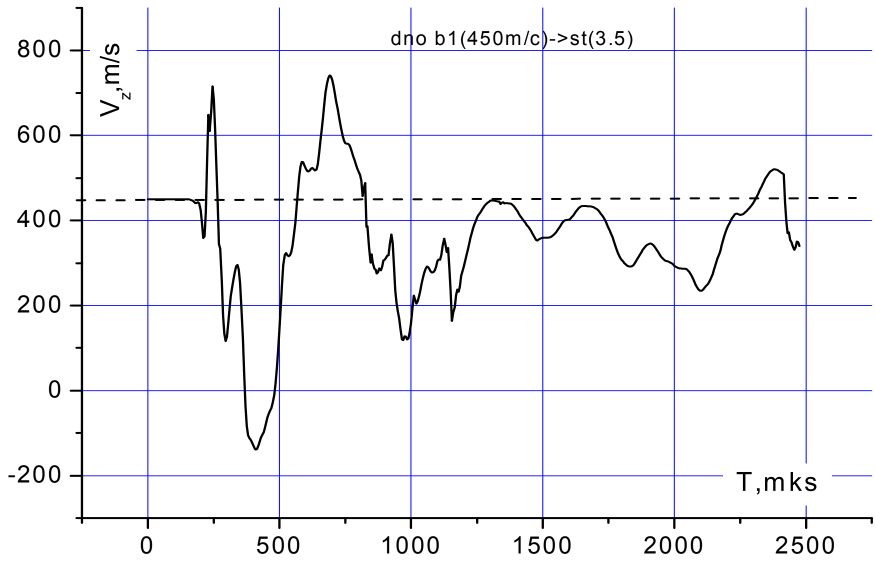
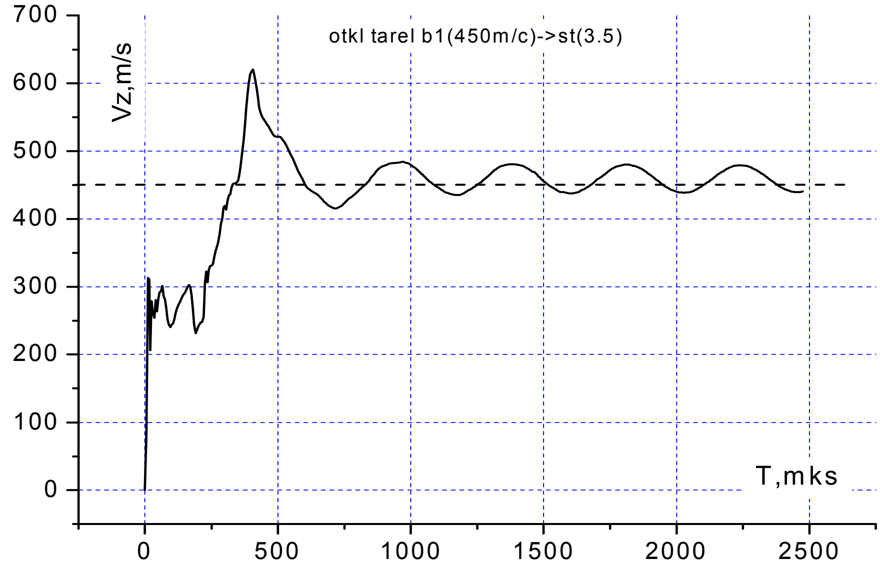


Fig. 2 - Impact of a container filled with explosives from a 3.5 sm diameter steel plate with the initial velocity of the projectile 450 m/s

At a time of 100 μs, the deformation of the materials of the impactor, filler, and obstruction in the interaction region is observed. At a time point of 200 μs, these processes are further developed. At the time point of 500 μs, a through penetration of the target is observed, and a cavity appears in the rear part of the container due to the fact that the filler leaves forward, slipping along its side walls. The bottom of the container, like a membrane, changes the concave shape to a convex shape. It can be seen from the figure that at 800 μs the embossed part of the target goes forward, as the speed of the container is reduced due to the braking of its edges with holes. By the time of 1.7 ms, the container acquires almost the original shape.



(a)



(b)

Fig. 3 - Change in the speed of the axial part of the bottom of the container (a) and the rear part of the target (b) on the interaction axis when striking a steel target

The dynamics of penetration, the character of the movement of the bottom of the container and the cork knocked out from the target are shown in Figure 3. The graphs show that, after penetration, there are oscillations in the speed of both the container and the obstructions, which are apparently due to the shock-wave character of the deformation. From these illustrations it can be concluded that the movement of the bottom of the container and the filler does not always correspond to each other, so it is impossible to unambiguously associate the deformation of the shell and the filler, and therefore, the stresses arising in them.

CONCLUSION

Thus, using the developed mathematical modeling tools, numerical studies of collision processes of titanium shockers filled with explosives, with obstructions from steel and TNI have been carried out. The character of the axial and radial deformation of the striker is revealed when they are beaten by obstacles. The current and final process parameters are obtained. It is shown that the initiation of detonation of the explosive charge, under otherwise equal conditions, depends on the material of the target.

ACKNOWLEDGMENTS

This work was financially supported by RFBR, proposal no. 16-08-00037.

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