STUDY OF OBSTACLE DESTRUCTION CHARACTER AT MULTIPLE IMPACT OF SOLID PROJECTILES.

E. E. Lin, A. L. Mikhaylov, V. V. Burtsev, P. S. Bushmelev, A. V. Gladtsinov, N. Yu. Ilyushkina, V. E. Kolomiitsev, Yu. M. Makarov, V. Yu. Mel'tsas, L. A. Morozova, G. F. Portnyagina, A. L. Stadnik, Z. V. Tanakov, V. N. Khvorostin, N. A. Yukina, Yu. V. Yanilkin

Russian Federal Nuclear Center – All-Russia Research Institute of Experimental Physics (RFNC-VNIIEF), 607190, 37 Mira ave., Sarov, Nizhni Novgorod region, Russia
Phone: (83130) 4-50-09, Fax: (83130) 4-59-58 e-mail: <root@gdd.vniief.ru>,

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Abstract.

The paper presents results of RFNC-VNIIEF works devoted to creation and study of synchronous and asynchronous multiple action of macroscopic projectiles upon obstacles (targets) at moderate impact velocities. With the purpose to study the nature of synchronous and asynchronous collective action of solids upon obstacles, different explosive systems are presently under development. These systems are capable to vary widely the impact parameters, such as weight, velocity, shape, number and mutual orientation of projectiles, asynchronous of impacts, combination of materials of projectile and obstacle, ratio of their sizes, etc.

Introduction

The study of the collective action of solids on targets is of interest for the development of means for protecting structural elements from explosion-produced fragments and from fluxes of technogenic wasters [1-3]. This interest is associated with the determination of the mechanism governing the response of the objects to the multiple impact of projectiles [4]. A collective character of the interaction between an target and a flux of solid macroscopic projectiles is most clearly manifested under conditions where the action of a single projectile is weak. This can take place at the moderate impact velocities for which compression and heating effects are relatively weak, and the deformation (strength) mechanisms play the main role. For an aluminum target and iron (steel) projectiles, such moderate impact velocities occupy the range U = 450 – 2000 m/s [3].

At present it has been revealed experimentally in [] the facts of heightened efficiency of collective penetration of steel spheres into duralumin plates at impact velocity on the order of 1 km/s than that occurs at single impact. Metallographic analysis [] of plates and spheres recovered after experiments, as well as numerical testing calculations [] testify to the fact that more weakening of resistance of obstacle medium occurs at multiple impact than at single impact. Probably, it is a result of interaction between stress waves caused in the obstacle by group of projectiles.

In this paper we present the results of development of explosive systems for investigating multiple impact of solid projectiles upon the obstacle at moderate impact velocities, namely, 1) explosive driven shock tube, in which steel spheres are accelerated by expanding explosive products; 2) ballistic gun, which provides an acceleration of "soft" plastic block carrying steel spheres with certain orientation from one to another; 3) ballistic gun, which provides an acceleration of the target towards the group of projectiles.

Primary experimental results

The scheme of steel spheres acceleration in an explosive driven shock tube has been presented in [1]. Two-dimensional numerical calculations show that under initiation of a plane explosive charge in a central point it is possible to accelerate a group of steel spheres within the shock tube up to velocities U = 1200 - 2400 m/s depending on sphere diameter d = 2 - 5 mm and explosive charge thickness Δ = 4 – 9 cm. In experiments we have recorded steel spheres within a shock tube with the help of impulsive X-ray device. The X-ray images of the spheres with d = 5 mm before the collision with duralumin obstacle are presented on figure 1. A comparison of X-ray data with calculated curves of spheres movement is given on figure 2. In the course of this study, we determined the mean value of the collision velocity $\langle U \rangle$ = 1200-1400 m/s for a compact group of steel spheres with duralumin obstacles of the relative thickness h/d = 3-20. The asynchronism of sphere impacts determined by the X-ray registration and with the help of electromechanical and manganin sensors, which are located within layered obstacles, lies within the range Δt = 3-200 μs. This range is comparable with propagation times of elastic ($\sim 10^{-6}$-10^{-5} s) and plastic ($\sim 10^{-5}$-10^{-4} s) waves between breaches and craters in the obstacle material. The facts found of the multiple piercing of the obstacle characterized by the ratio h/d = 3 and also the penetration of groups of spheres into thicker obstacles up to average (for 12 measurements) depth of $\langle z \rangle/d$ = 3.6 (with the standard deviation of ±0.1) exceeds the penetration depth (z/d = 2-2.2) by a factor of 1.6 for single-sphere impact. This fact testifies to the efficiency of the mutual effect of spheres in the course of the multiple penetretion.

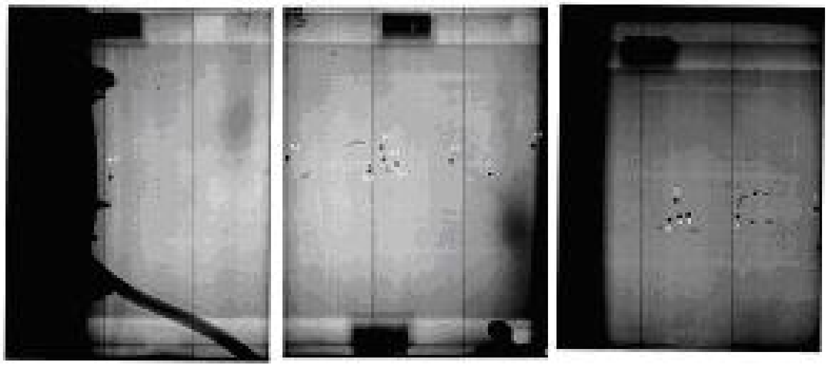


Figure 1. Pulse X-ray recording of steel spheres accelerated from the right to the left within evacuated explosive device for times of 2.5 ms (the right-hand shot) and 2.74 ms (two left-hand shots).

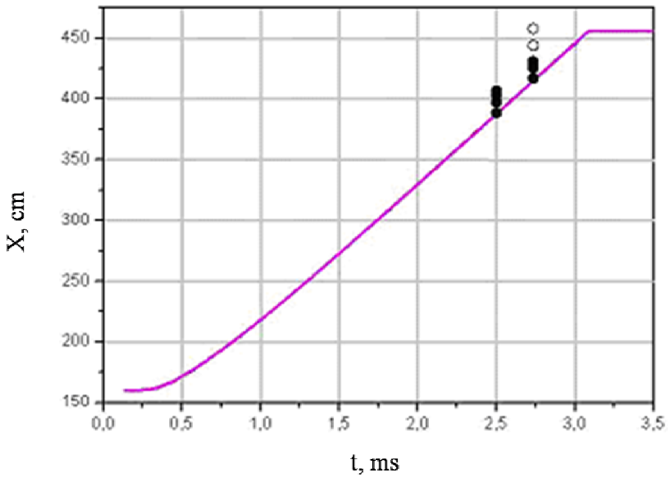


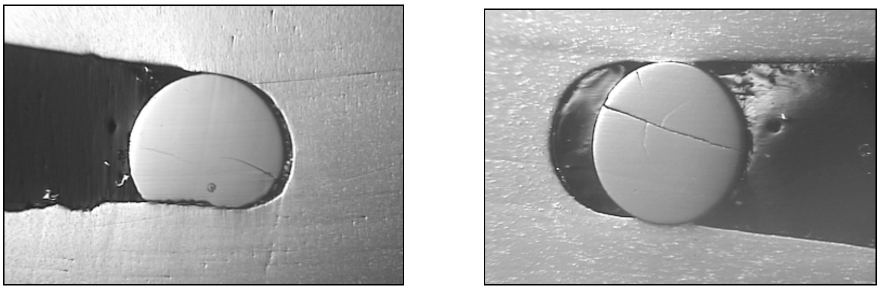
Figure 2. Comparison of experimental and calculated data of spheres location before impact: entire line – calculated curve of spheres movement, dots – data of X-ray recording, “white” dots correspond to two leading spheres at two left-hand shots in figure 1.

To study the synchronous multiple impact we use an explosive ballistic gun with a calibre of 30 mm which provides acceleration of “soft” plastic block with steel spheres having pre-given orientation from one to another. The projectile is accelerated towards duralumin target in a smooth manner by explosion products of a plastic explosive charge. Since both the density and acoustic hardness of polyethylene are smaller than that of duralumin, therefore, the action of significantly hard steel spheres on an obstacle can be marked out evidently in the background of the action of a soft plastic block. The velocity of the projectile at the gun cut was U = 1500 m/s. The depth of a shell-hole created in duralumin obstacle by polyethylene projectile was near 5 mm. The depths of spheres penetration into obstacle from the bottom of a shell-hole were z = 16 mm, 17 mm, and 18 mm. Under impact of a single sphere in the same polyethylene projectile having the same velocity the penetration depth from the bottom of a shell-hole was 13 mm. Therefore, the higher effectiveness of projectiles penetration under simultaneous multiple impact is observed.

An acceleration of the target with the thickness of 30 mm towards the group of spheres with the diameter of 5 mm is carried out with the help of explosive ballistic gun with a calibre of 100 mm. It has been stated that under multiple impact with the velocity U = 900 m/s an average (for 34 measurements) penetration depth is $\langle z \rangle$ = 14 mm (with deviations of ± 1 mm), and that under single impact the penetration depth is z = 11 mm. Thus, the higher effectiveness of projectiles penetration under simultaneous multiple impact is observed in the regime of the “reverse” acceleration of the target.

Metallographic studies and numerical simulations

The detailed metallographic studies of recovered samples [2-4] have revealed the following features of the observed phenomenon. While implanting a single sphere, and a group of spheres into obstacles, the melting of the medium occurs in adjacent lateral layers of the thickness x = 5-20 μm. For both the single and multiple actions, localized-fragmentation traces 10-20 μm in the size are observed for the projectiles and obstacles in zones of their immediate contact. Breaks of the material in the form of irregular-shape cracks demonstrate the distinctive difference in multiple and single impacts. In thin obstacles (h/d = 3) after multiple impact, the cracks near breachers are about 1 mm long. In the case of the multiple impact on the thick target, the gap between the crater bottom and the spheres is noticeably greater than in the case of single-sphere impact (figure 3). This fact testifies to the considerable reduction of the resistance of target material under multiple action of solids.



a) single impact b) multiple impact

Figure 3. Macrostructure of steel spheres and duralumin obstacles.

Three-dimensional numerical simulations [2, 4] have revealed the influence of the loss of material resistance on the character of sphere penetration into target. In particular, the calculations show that the reduction in the yield strength of the medium in front of the sphere in the channel region of the transverse size *d* results in a noticeable increase in the penetration depth for the thick obstacle (figure 4).

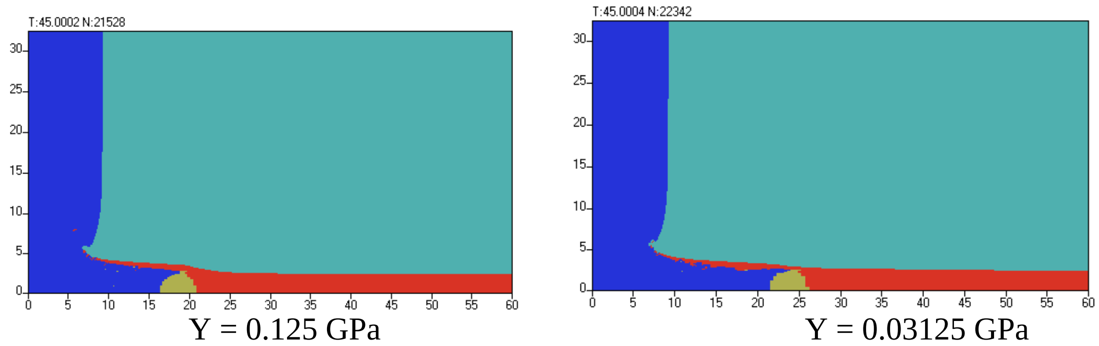


Figure 3. Calculated picture of steel sphere penetration into duralumin plate observed at 45 μs after impact with the initial velocity of 1300 m/s. The narrow channel at the axis of impact is characterized by a reduced yield stress Y. The sizes along coordinate axes are given at millimetres.

Conclusion

The experiments with developing explosive systems testify to higher effectiveness of steel spheres penetration into aluminum targets both at synchronous and asynchronous multiple impact with the velocities of 900-1500 m/s. It is reasonably to conclude that the collective action of macroscopic solids having a moderate velocity on solid targets results in the weakening of the medium resistance due to the interference of stress waves produced by the projectiles.

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