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BREAKTHROUGH OF A COMPOSITE OBSTACLE BY HIGH-VELOCITY PARTICLES AS A RESULT OF REALIZATION OF THE SUPERDEEP-PENETRATION EFFECT

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The results of investigations of the superdeep penetration of high-velocity microparticles into composite obstacles in the process of their collisions are presented. It is shown that the penetration process can be controlled, in principle.

In [1–3], the results of experiments on breakthrough of a steel obstacle of thickness 100–200 mm by high-velocity microparticles in the regime of superdeep penetration are presented. After the collision of a particle flux with an obstacle, traces of the material of the particles and of the obstacle were detected on the surface of thin aluminum, copper, or plastic foils packed in a stack of 30–40 foils positioned downstream of the obstacle [1]. It was established that, when an integrated circuit is placed downstream of an obstacle, its case (cover) is broken and the crystal is damaged [2, 3].

The superdeep-penetration effect is also realized when a flux of microparticles collides with fluoroplastic or aluminum obstacles [4]. The effectiveness of penetration, determined by the total number of penetrated particles per unit area of foils positioned downstream of an obstacle, is higher for fluoroplastic than for aluminum.

Open questions are the realization and efficiency of superdeep penetration in the case of collision of a particle flux with composite obstacles consisting of several layers of nonmetal materials having a different acoustic stiffness. The study of the breakthrough of such an obstacle, as well as a steel obstacle, by particles is of importance for providing the safety of space flights because a particle bunch can collide with the body of a spacecraft in the regime of superdeep penetration. The superdeep-penetration effect can be realized in outer space in the case of collision of a spacecraft with bunches of microparticles that can break through the body of the spacecraft. The microjets of the material of these particles penetrate into the body of the spacecraft and the material of the body itself will have a high residual penetrating power. The interaction of microjets with electronic elements (integrated circuits) located in the immediate vicinity of the body of the spacecraft can damage these elements, which can cause their failure or an inadmissible change in the operating parameters. In this case, the spacecraft will not be depressurized because particles that have broken through an obstacle in the regime of superdeep penetration do not form a through hole in it. This breakthrough is very dangerous since it is difficult to reveal and, therefore, the reason for a malfunction of electronic elements, as the most vulnerable, is difficult to explain in this case. Information on different particles and their bunches found in outer space appears frequently in publications [5, 6]. Particle bunches, including the so-called "cosmic refuse," have appeared as a result of the intensive and uncontrolled launching performed during the last 10–15 years. These bunches represent a serious hazard to spacecraft, which has generated the need for investigating the superdeep penetration of a particle flux into different obstacles for the purpose of developing additional means and methods of protecting the electronic elements of spacecraft.

There is a well-developed model of superdeep penetration, which is described in the literature by authors forming several independent groups (L. V. Al'tshuler, S. K. Andilevko, G. S. Roman, S. M. Usherenko [7, 8] and S. P. Kiselev and V. P. Kiselev [9]). This model is based on the assumption that the material of an obstacle loaded by

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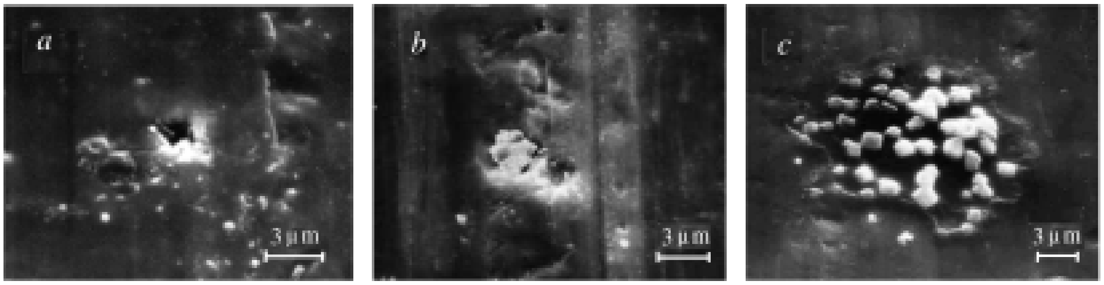

Fig. 1. Tracks of interaction of a striker with ten foils: a) complete break through a foil, ×5000; b) break through a foil with a striker remainder; ×3000; c) "plug" forced out from the ninth foil, ×3000.

a particle flux becomes superplastic. The validity of this model is supported by experimental data indicating that the superdeep-penetration effect does not arise in materials that are not transformed into the superplastic state under a load.

The aim of the present work is to experimentally verify the supposition that the superdeep-penetration effect can arise in the case where a particle flux collides with a composite obstacle consisting of layers of materials having different acoustic stiffnesses, including a material that is not transformed into the superplastic state in the process of loading by this flux.

The superdeep penetration of particles into composite obstacles was detected and its effectiveness was estimated using the simple "method of foils" [10]. The choice of this method is explained by the simplicity of its use and by the fact that traces of penetration — tracks left by particles in nonmetal materials (in particular, in the fluoroplastic and board used in our experiments) — cannot be revealed by simple analysis of the changes in their structure. The channel left by a penetrating particle collapses and has a diameter of less than 1 μm or is completely absent, i.e., the penetrating particle can leave only a track representing a deformation zone with inclusions of the material of this particle. It is necessary to increase (by etching) this zone to a size that will make it possible to examine the indicated track with the use of a scanning electron (or even optical) microscope. However, a fluoroplastic possesses a high chemical stability, while a board, in contrast, is easily etched, which prevents the visualization of tracks left in them by penetrating particles. Particles can be detected only after their penetration through an obstacle by the tracks of interaction with detectors (foils) positioned downstream of the obstacle.

The "method of foils" was realized with the use of a container, the frontal part of which, struck by a particle flux, represents an obstacle of a material studied. In the container, positioned downstream of the obstacle, aluminum foils (serving as detectors) were placed. The foils were interlayed with a tracing paper and were packed. The thicknesses of the foil and of the tracing paper were ~10 and ~40 μm respectively. The number of the foil was written at its edge. The design of the container prevented the penetration of foreign particles, in particular of the ground in which the container was located, into it in the process of collision with a particle flux.

Obstacles of three types were used in the experiments. The obstacle in the first container was made of steel 45 and had a thickness of 50 mm. The second obstacle was a two-component steel–fluoroplastic obstacle. The thickness of the steel layer, upon which a particle flux impacted, was 20 mm and the thickness of the next fluoroplastic (polytetrafluoroethylene (CF_2–CF_2–$(...)_n$) layer was 25 mm. The third obstacle was a three-component obstacle; in it, layers were arranged in the following order: a steel layer of thickness 20 mm, four sheets of a dense board of total thickness 6 mm, and a fluoroplastic layer of thickness 25 mm. A particle flux was formed, as in [1–3], by compression of an aluminum cumulative lens, filled with nickel particles of size 20–40 μm, by the detonation products of an explosive. The obstacles were treated by the scheme presented in [11]. This scheme allows one to realize a stable superdeep penetration. The effectiveness of penetration of particles to the obstacles studied to a definite depth (equal to the obstacle thickness) was estimated by calculating the number of tracks of interaction of particles with the foils after their penetration through these obstacles. The tracks (inclusions), the form of which differed from the defects existing initially in the foils before their use as detectors, were also calculated [1, 10]. The foils were examined on a METAM RV-21 optical microscope. For calculations, the surface of a foil of area not less than 20 mm^2, accounting for about 5–7% of the whole surface of the foil, was used. The second, fourth, and tenth foils, counted from the back side of an obstacle, were additionally examined on a Com–Scan scanning electron microscope (England) with an x-ray microanalyzer.

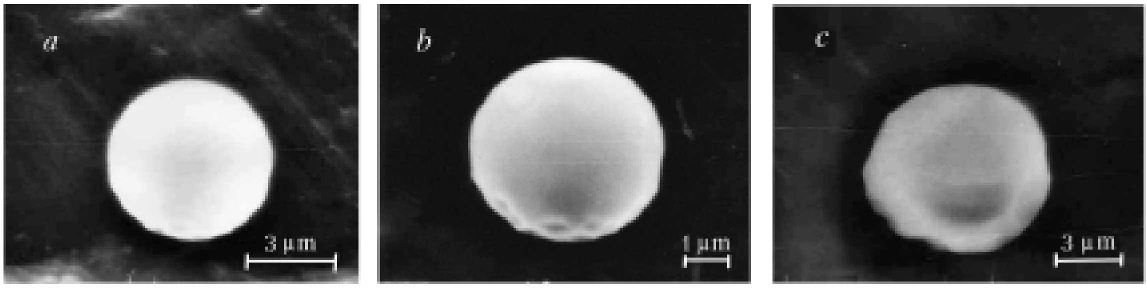

Fig. 2. Inclusion on a foil from the stack positioned downstream of the three-layer steel–board–fluoroplastic obstacle: a) at the instant of its detection; ×7000; b) after 10 sec, ×10,000; c) after 20 sec, ×5000.

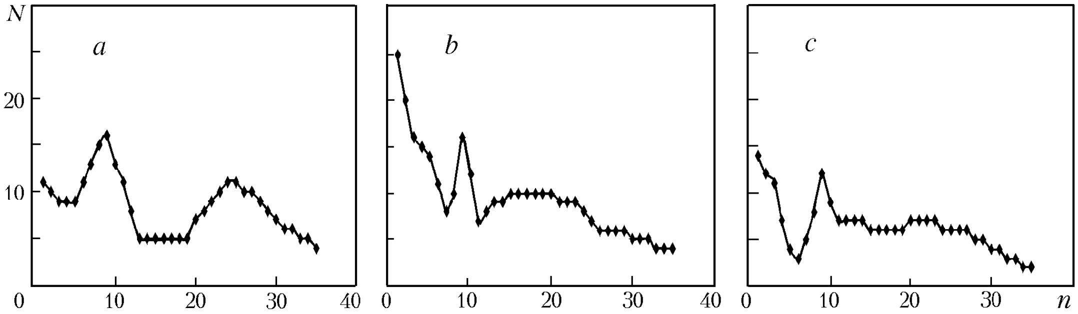

Fig. 3. Dependence of the density of penetration tracks N on the ordinal number of a foil n positioned downstream of an obstacle: a) steel obstacle; b) steel–fluoroplastic obstacle; c) steel–board–fluoroplastic obstacle. N, particles/mm^2.

The typical tracks of interaction of strikers with a steel obstacle can be conditionally divided into three types. Figure 1a shows a characteristic track of particles broken through a steel foil. Figure 1b shows the track shaped as a crater with a part of the striker material. Figure 1c shows parts of the so-called "plug" — the material of the previous foil, forced out as a result of the collision of a striker with this foil, which is supported by the data of point analysis of the inclusions with the use of the x-ray microanalyzer, which point to the presence of aluminum — the foil material — in them.

On the foils positioned downstream of the two- and three-component obstacles, we detected, besides the above-described tracks, nontypical formations shaped as practically ideal spheres, which were not observed earlier on the foils positioned downstream of the steel obstacle. The surface of these formations was deformed as though it "floated" under the action of an electron beam of the scanning electron microscope. This process is shown in dynamics in the photographs presented in Fig. 2, in which the inclusions were detected at different instants of time elapsed from the beginning of their appearance. Analysis has shown that these inclusions consist of light elements that cannot be identified by our analyzer. It is natural to suggest that this is a fluoroplastic (elements of the fluorocarbon polymer chain (CF_2)) of the last layer of the two- and three-component obstacles, which was forced out of the obstacle, solidified, and took the form with a minimum surface. Since a fluoroplastic softens at a temperature of higher than 260°C (it melts at 327°C), the supposition made reasonably explains the appearance of such spherical inclusions.

Figure 3 shows the dependences of the density of the tracks of interaction of penetrating strikers with foils positioned downstream of the obstacles studied (density of penetration tracks).

The total densities of the penetration tracks of particles on all the foils of the stack positioned downstream of the obstacles studied, reflecting the total number of particles broken through an obstacle, are as follows:

	particles/mm^2
Steel	299
Steel–fluoroplastic	330
Steel–board–fluoroplastic	223

CONCLUSIONS

1. The effectiveness of penetration of particles from a flux striking an obstacle in the regime of superdeep penetration is smallest (of the obstacles compared) for the three-component obstacle including a steel layer, a fluoroplastic layer, and four board sheets: approximately 223 particles are broken through 1 mm^2 of this obstacle. The two-component steel–fluoroplastic obstacle retains the smallest number of particles (330 particles per mm^2 were detected on the foils). The steel obstacle occupies the intermediate place.

2. Introduction of additional board layers makes it possible to retain all particles (of all energies) of a flux (the curves in Fig. 3b and c are identical in shape; however the latter is positioned lower).

3. A fluoroplastic is more "transparent" than a steel for low-energy particles (the density of tracks on the 1st–20th foils in Fig. 3b is higher than that in Fig. 3a and the number of foils broken through by a striker depends directly on its energy). In contrast, high-energy particles are retained more effectively by the fluoroplastic (the density of tracks detected on the 24th–30th foils in Fig. 3a is higher).

4. Composite obstacles allow one to control the superdeep penetration of particles.

5. Since particles that had broken through the board were detected on the foils, it may be suggested that the superdeep-penetration effect arises in materials that are not transformed into the superelastic state under a load.

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