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RESEARCH ON INFLUENCE OF IMPACT OF MICROPARTICLES AND SEWING NEEDLES ON DESTRUCTION OF SOLID BODIES

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Impact of powders and sewing needles accelerated by explosion on various obstacles has been studied. Formation of channels up to 100 particle diameters in length has been observed when corundum and tungsten powders impacts on steel and duralumin at speeds up to 2 km/s. A mechanism of such super deep penetration of powder jets into metals has been proposed. The possibility of destroying by needles such objects as plexiglass blocks, antimeteorite screens, containers with elastic and explosive materials with a released energy exceeding the energy of needles has been shown. At impact speeds up to 400 m/s the depth of needles penetration into metals is 3–5 times higher than the one calculated for pointed rods at plastic work. The obtained results can be useful for modeling of impact of meteorites, space scraps and technological wasteson space aircrafts and their components.

Key words: impact, microparticles, needles, obstacles, penetration, destruction, modeling, striker.

1. Introduction

Conducting of space research is complicated recently by growth of cosmic dust and debris. Modeling of their impact on space equipment is usually carried out at speeds close to the cosmic ones for spherical strikers under conditions of both melting and evaporation of the substances. The depth of penetration does not exceed several diameters for spherical strikers and weakly depends on the properties of colliding materials [1, 2].

Super deep penetration into targets by powders at speeds up to 3 km/s was considered in [3]. In accordance with the mechanism of super deep penetration proposed in [4], the plastic flow of metal does not arise at a high strain rate, and under brittle fractures particles penetrate into cracks for big depths with lower energy losses than at plastic flow.

Presented are the results of a study of impact of powders and sewing needles on obstacles at speeds ranging from 0.1 to 2 km/s when melting and evaporation have a low effect on penetration. Special attention is paid to the probability and mechanism of realization of super deep penetration of powders and needles into targets. The results can be useful for modeling of impact of meteorites, space scraps and technological wastes on space aircrafts and their components [5, 6].

2. Experimental arrangement

Targets made of steel, duralumin, aluminum, titanium, plexiglas, aluminum containers with plexiglas, pressed salt, gunpowder and various explosive substances were used in the experiments. Powders of both corundum (Al_2O_3) and tungsten with the particle diameters up to 50 microns, sewing needles with the Krupp hardness more than 600 kg/mm^2, weights of 0.2–1.3 g, diameters $d = 0.9$–2.2 mm, lengths $l = (30–50)d$, and wires made of copper and annealed steel were used as strikers. Strikers were accelerated up to the speeds of 0.5–2 km/s by explosive charges with 60 mm diameter and weights up to 200 g. Some needles were accelerated to the speeds of 0.15–0.6 km/s in an explosive shock tube with the mass of the explosives up to 5 g. The velocity U_0, impact energy e, depth of penetration in the obstacle L, volume of the holes V and kinematics of the needle motion were measured using the electric contact method and a high-speed movie camera with external illumination.

3. Measurements

After impact of powders on metals, erosion of the target surface and appearance of deep channels on their cross section were observed. The photographs show the emergence of powder jets accelerated by the explosion. Figure 1 shows a typical photo (microsection after etching, increased 200 times) of duralumin D16 after an impact of corundum powder with a particle diameter up to 50 mi-

Fig. 1. Photo of duralumin D16 after an impact of corundum powder at the speed of 1.5 km/s.

crons and the speed of 1.5 km/s. The channel length of about 50 powder particle diameters is more than an order of magnitude larger than typical channel lengths for high velocity strikes [1, 2]. The number of channels increases with the thickness of powder. Channels have not been observed at impact velocities $U_0 \geq 2$ km/s.

Some results of measurements and calculations of collisions of needles with metals are shown in Table 1 and following figures, where h is the thickness of impactor; m, d, $e = mU_0^2/2$ are the mass, maximum diameter, and kinetic energy of the needle; L, ΔL are the length of the hole and the height of the needle tip over the hole in the target; V is the volume of the hole ($P^* = e/V$ in the experiments when needles do not breach the target), H_1 is the dynamic hardness of the material (which does not depend on speed), H_2 is the Brinell hardness, and τ is the shear strength [1, 5].

Table 1.

tests			needles				measurements				calculations	
No.	U_0 [m/s]	h [mm]	No.	m [g]	d [mm]	e [J]	L [mm]	ΔL [mm]	V [mm^3]	P^* [GPa]	V_c [mm^3]	L_c [mm]
Steel-3, $H_k = 1.88$ GPa, $P_1^* = 2.9$ GPa, $\tau = 0.25$ GPa												
28	190	11.5	10	0.36	1.16	6.5	11	0	7.47	0.88	2.2	3.6
29	190	5.75	10	0.36	1.16	6.5	5.75	8				
38	190	5.75	10	0.36	1.16	6.5	5.75	8				
38a	190	5.75	12	1.3	1.6	23.4	5.75	60				
41	233	5.75	10	0.36	1.16	9.8	5.75	10				
41a	233	5.75	13	1.3	2.24	35.2	5.75	60				
Titan, $H_k = 2.14$ GPa, $P_1^* = 2.9$ GPa, $\tau = 0.32$ GPa												
64	280	14.5	13	1.3	2.24	50.96	12	0	20.3	2.5	16.1	10.2
65	320	14.5	13	1.3	2.24	66.6	14.5	0	28.4	2.35	21.0	12.1
67	350	14.5	13	1.3	2.24	79.6	14.5	3	28.4	2.8	25.3	13.3
69	420	14.5	13	1.3	2.24	115	14.5	10.5				
70	430	14.5	13	1.3	2.24	120	14.5	18				

Photos on Fig. 2 show the results of impacts of needles on targets of duralumin, steel, and plexiglas. When hardened needles breach metals channels with the diameter equal to the diameter of the needles are formed. Needles with the energy of 2 J breach 8 mm of duralumin or 16 mm of aluminum, whereas needles with the impact energy of about 6 J breach more than 11 mm of steel, 12 mm of duralumin or 20 mm of aluminum, respectively. The minimal specific energies e/V for channel formation are 0.2, 0.5, 1, and 2 kJ/cm^3 for aluminum,

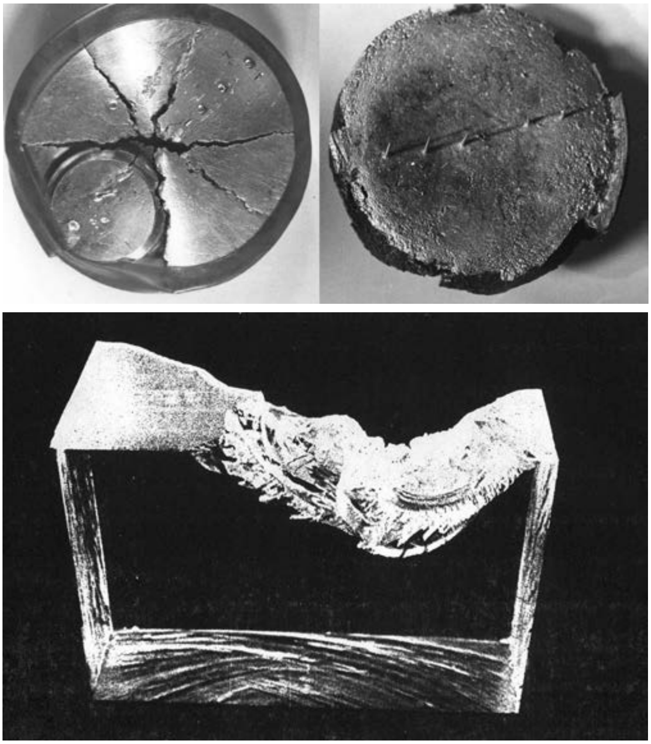

FIG. 2. Results of the impact of needles on the targets of duralumin, steel, and plexiglas.

D16T, steel, and titanium, respectively. Simultaneous impact of needles along the diameter of the circle of a target causes its disintegration along these lines.

During the impact of needles No. 13 with the energy 96 J each on a plexiglas block sized $10 \times 7 \times 5$ cm^3 a piece of the 50 cm^3 size was thrown out because the stored elastic energy was released when cracks came out to the surface. A model of an antimeteorite screen consisting of three 1 mm thick duralumin plates with 3 mm gaps in between and an additional 12 or 14.5 mm thick duralumin plate positioned behind it were breached through by needles No. 13 at the speeds of 350 and 430 m/s respectively. Containers with plexiglas and salt impacted by needles were destroyed or plastically deformed due to allocation of the stored elastic energy of the samples $e = \sigma^2 V/2E$ from their brittle fracture. The elastic compression σ was previously created on the ends of the container by bolt clamped plates. Allocation of energy occurs along the axis of an impact, apparently because the stored elastic energy cumulates there. Containers with gunpowder, pressed PETN, and RDX were destroyed because of burning of the samples upon an impact with needles which penetrated through the walls of the container. Containers with plastic explosives were breached by needles without significant external effects.

4. Discussion of the results

In the tests with powders at the impact velocities of $U_0 \leq 2$ km/s, smaller than the speed of cracks in metals, conditions of a super deep penetration, when the length of the channels exceeded a hundred as much the particle diameters, sometimes were encountered. It was assumed that this was accompanied by brittle fracture under the action of powder jets when the particles penetrated into a crack, one after another. Although for microparticles the probability of a super deep penetration is small, this effect should be taken into account for their long-term interference with space objects.

Penetration of pointed rods into a hard material was studied in [1, 2, 7]. In a simplest formulation the following equation of motion is solved when a rod makes plastic work against the force SP^*:

$$mUdU/dx = -SP^*, \tag{4.1}$$

where $S(x)$ is the section of the rod. Resistance to penetration $P^* = P_1^* = H_1 + H_2 = \text{const}$ at $U_0 \leq 2$–3 km/s, where the dynamic hardness H_1 of the material does not depend on velocity and H_2 is the Brinell hardness, was studied in [5]. Calculation of P_1^* at these values gives a penetration depth L 3–5 times smaller than in the tests with needles at the impact velocities of 150–300 m/s. Therefore, it was suggested that at these impact velocities work of brittle fracture and friction is defining, plastic flow has no time to develop, and the plastic work is lower than the calculated one.

Figure 3 shows the dependence of the penetration resistance $P^* = e/V$ on the impact velocity U_0 of needles with different sizes. Figure 4 shows the

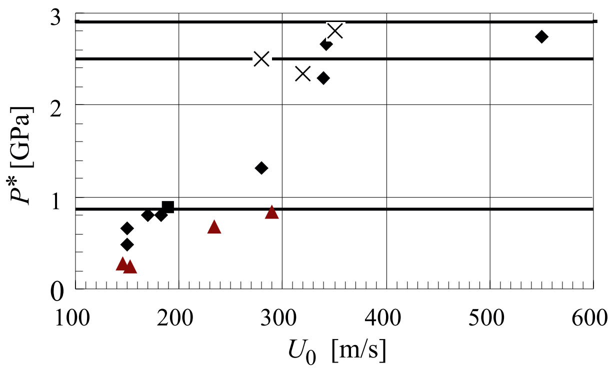

Fig. 3. Dependence of the resistance P^* to penetration of needles on the impact velocity U_0. Squares, triangles, rhombi, and crosses are used for steel, aluminum, duralumin, and titanium, respectively. For comparison, the parallel lines are the values $P_1^* = H_k + H_b$ for plastic work [2, 7], which equal to 2.9, 2.5, and 0.86 GPa for pointed rods of steel, duralumin, and aluminum, respectively.

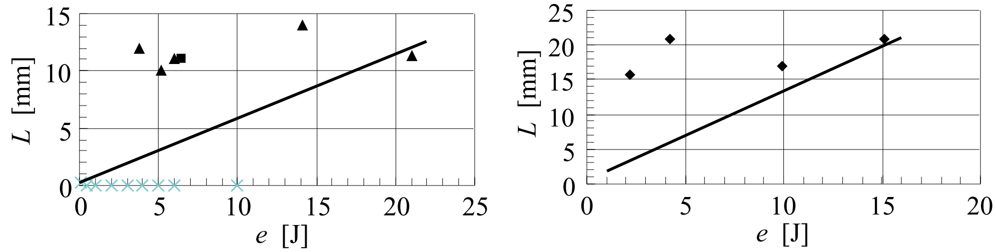

Fig. 4. Dependence of the penetration depth L on the impact energy e of needles No. 10 for steel and duralumin as targets (on the left) and of needles No. 7 and 10 for aluminum as a target (on the right). The meaning of symbols is as in Fig. 3. Solid lines denote calculations for plastic work at $P_1^* = 2.5$ and 0.86 GPa for duralumin and aluminum respectively.

dependence of the penetration depth L on the impact energy ε. When $U_0 \approx 150$–300 m/s, values of P^* are several times smaller (and the depths of penetration are respectively higher) than for rods [3]. With the increase of the impact velocity values up to 400–500 m/s, the value of P^* stops increasing and approaches the values of P_1^* in [3], which characterize the plastic work.

Figure 5 shows the dependence of $V(e)$ on the investigated materials. The reduction of the kinetic energy of a needle (which determines its penetration) when the plastic losses are small was estimated. The resistance to penetration P^* of hard rods into elastic-plastic materials was shown in [7]:

$$P^* = \tau + 2\gamma l/S, \qquad \gamma = \gamma_0 + \gamma_1 = K^2/2E, \tag{4.2}$$

where τ ($\approx$0.2 GPa for steel) is the shear strength of the target material; γ is the surface energy of cracks appearance per unit of length l; S is the area of contact of a rod with the surface of a crack; γ_0 is the energy breaking of cracks; γ_1 is the energy of plastic deformation of a crack; K is the parameter of a crack which according to the static experiments is equal to 200 kg/mm$^{3/2}$ for steel and 1.7 kg/mm$^{3/2}$ for glass; and E is the Young's modulus. When $\gamma_0 \ll \gamma_1$ (for steel

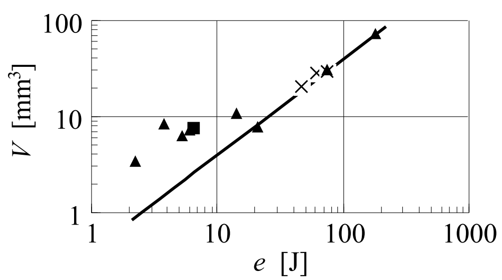

Fig. 5. Dependence of the channel volume V on the needle energy e for different materials. The meaning of symbols is as in Fig. 3. The curve denotes the calculations for plastic work at $P_1^* = 2.5$ GPa for duralumin.

$\gamma_0 \approx 1$ N/m and $\gamma_1 \approx 10^4$ N/m) the surface energy of cracks $\gamma = \gamma_0 + \gamma_1 \approx \gamma_1$ is determined by the plastic work.

At the characteristic for the experiments strain rates $d\varepsilon/dt = U/d \approx 10^6$–$10^7$ s^{-1}, apparently, the condition $\gamma_1 \ll \gamma_0$ is realized, i.e. plastic deformation has no time to develop. In this case $\gamma \approx \gamma_0$, which strongly reduces the resistance to deformation upon a little friction, for example, due to melting of the material. With a reduction of the needle diameter d, the velocity of deformation increases and the conditions of brittle fracture can be satisfied at lower speeds of impact. This calculation explains qualitatively the test results, where the possibility of destruction of large constructions with the minimal impact energy was shown. At the impact velocities above 300–400 m/s resistance to penetration of the needle $P^* \approx P_1^*$ causes their transverse vibrations and the loss of their stability. Needle penetration depths are consistent with those obtained for pointed rods [2, 7].

5. Conclusion

Impact of corundum and tungsten powders and sewing needles on various barriers was studied at the velocities of 0.1–2.5 km/s when melting and evaporation has little effect on penetration. It was observed that powders at the speeds of up to 2 km/s and sewing needles at the speed of 0.6 km/s penetrate into metals on depths over 100 and 50 impactors' diameters respectively. Formation of powder jets was noted when powder was accelerated by blasts. A mechanism of such a super deep penetration of powder jets into metals wass proposed, i.e. brittle fractures occur with minimal losses of energy, therefore, plastic flows have no time to develop. An accurate estimation of the probability of a super deep penetration of powder is not possible. The possibility of destruction of various designs, e.g. blocks of plexiglas, antimeteorite screens, containers with elastic and explosive materials, was shown. This happens due to the release of the stored energy, which is much greater than the energy of the needles. The results can be useful in industry and nanotechnology for modeling of impact of meteorites, space scraps and technological wastes on space aircrafts and their components [5, 6].

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