INTERACTION OF HIGH-SPEED MICROPARTICLES WITH A SYSTEM OF POLYMER OBSTRUCTIONS

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The velocity and size distribution of high-speed glass microparticles in a flow under identical conditions of acceleration is estimated with the use of the known statistical approach. The results are applied for the study of the interaction of microparticles with a system of polymer obstructions made of polyethylene and polyethelene terephthalate. The critical impact velocities corresponding to complete transition of the particle to the viscous-fluid state are determined.

1. The interaction of calibrated glass spheres with density $\rho_0 = 2.7$ g/cm^3 and diameter $d_0 = 80 \pm 5$, 95 ± 5, 175-225 μm with aluminum foils and semiinfinite obstructions of aluminum and copper was investigated earlier [1]. The velocity v_0 of the fastest particles in the stream accelerated by a high-speed plasmoid was estimated from the signal from a photomultiplier by the oscillographic method; the error in the measurement did not exceed 10%. The plan of the experiment involved simultaneous use of a thin aluminum foil with thickness $l = 10$ μm and a semiinfinite metallic obstruction with known properties located in the same plane with three photomultipliers.

Under identical conditions of the experiment (constant initial size d_0 and density ρ_0 of the particles, given regime of operation of the electrodynamic accelerator) the statistical distribution $Q(a)$ of the craters in the semiinfinite target and the distribution $P(d_*)$ of the holes in the foil could be obtained separately (a and d_* are, respectively, the depth of the crater in the target and the diameter of the hole in the foil).

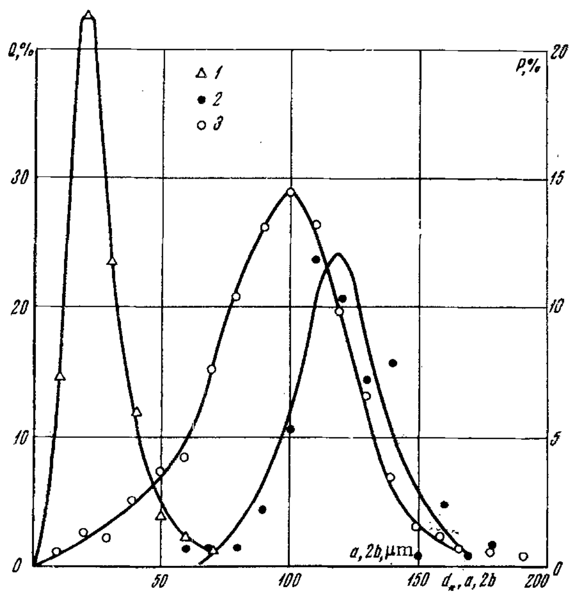

Fig. 1

The corresponding values of d_0 and v_0 were determined from the known dependences of a/d_0 and d_*/d_0 on v_0 for a given impactor–obstruction pair [1].

In the present work the interaction of glass microparticles with a system of polymer obstructions collected in a packet has been studied in identical experimental conditions. The number of layers in the packet depended on the initial size of the particles, the thickness of each layer and the assumed maximum velocity.

The packets are coated on the front side by condenser paper with thickness $l = 8$ μm in order to protect the polymer material from the action of the plasma. The interaction of high-speed particles with polymer obstructions had been investigated earlier in [2, 3]. It was found that the sailing in has an effect on the size of the holes especially at small impact velocities v_0. Due to this an aluminum foil with $l = 10$ μm was placed on the rear side of the packet a

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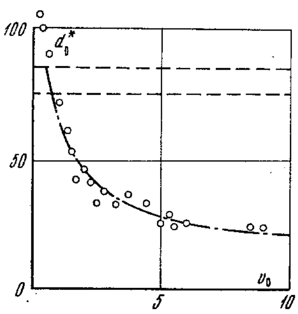

Fig. 2

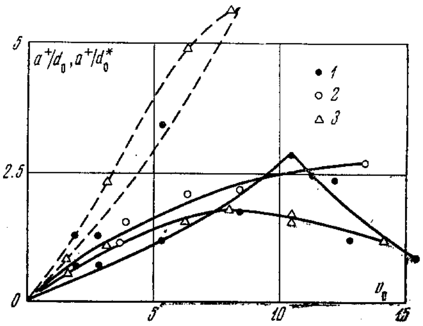

Fig. 3

certain distance away from it and served as an indicator of rupture [2]. In some cases the packet was put on a photomultiplier in order to improve the number of ruptured layers, covering half of its screen by a lightproof foil. For the analysis of the microgeometry of the surfaces,microscopes based on action of luminous cross section were used. In the case of diffuse reflection of light from the polymer materials molds of their surfaces made out of a special sheet were used. Packets made of polyethylene sheet with $l = 60\ \mu$m and polyethelene terephthalate with $l = 25\ \mu$m were used. After pumping out the air from the vacuum chamber the packet represented several obstructions placed at some distance from each other.

2. The results obtained in [1] were used in the comparison of sizes and velocities of particles in a single experiment. We note that these can be checked using the well-known statistical approach for finding the law of distribution of a random function or its numerical characteristics [4]. Actually, in the present case d_0 and v_0 are functions of random unknown parameters d_* and a.

In the case of a semiinfinite obstruction the interaction of glass–aluminum was estimated from the known dependence $a/d_0(v_0)$ for aluminum-aluminum pair [5].

The dependence $d_*/d_0(v_0)$ for a thin aluminum foil with $l/d_0 = 0.125$ (for $d_0 = 80 \pm 5\ \mu$m) has been determined in [1]:

$$a = 0.7\ d_0 v_0^{2/3},\quad d_* = d_0\,(1 + 0.125\ v_0) \tag{2.1}$$

The experimental dependence for a and d_* are comparable up to velocities $v_0 \sim 10$ km/sec; the values of a, d_0, d_* are calculated in μm, that of v_0 in km/sec. The solution of (2.1) reduces to a system of two third-degree equations for $v_0^{1/3}$ and $d_0^{1/2}$:

$$\begin{gathered} v_0 - v_0^{2/3}\, 5.6 d_* / a + 8 = 0,\quad d_0^{3/2} - d_0^{1/2} d_* + 0.2 a^{3/2} = 0 \\ d_0 = \left\{\left[-0.1a^{3/2} + (0.01a^3 - {}^1/_{27} d_*^3)^{1/2}\right]^{1/3} + \left[-0.1a^{3/2} - (0.01a^3 - {}^1/_{27} d_*^3)^{1/2}\right]^{1/3}\right\}^2 \\ u_0 = 1.71 a^{3/2} \left\{\left[-0.1a^{3/2} + (0.01a^3 - {}^1/_{27} d_*^3)^{1/2}\right]^{1/3} + \left[-0.1a^{3/2} - (0.01a^3 - {}^1/_{27} d_*^3)^{1/2}\right]^{1/3}\right\}^{-3} \end{gathered} \tag{2.2}$$

Thus there are two random functions d_0 and v_0, whose forms are known. If the arguments d_* and a take a number of discrete values

$$d_{*1}, d_{*2}, \ldots, d_{*q}\ (1 \leqslant i \leqslant q),\quad a_1, a_2, \ldots, a_p\ (1 \leqslant j \leqslant p)$$

the probability distribution of each of the functions d_0 and v_0 is given by the sum

$$\sum_{k=1}^{N} P(d_{*i})_k\, Q(a_j)_k \quad (ij = k,\ pq = N)$$

If several probabilities PQ correspond to a single value of d_0 (or v_0), then such a pair of d_0 and v_0 is chosen whose joint appearance corresponds to the largest value of PQ.

The experimental probability distribution curve $P(d_*)$ is shown in Fig. 1 (curve 3) for thin aluminum foils with $l = 10\ \mu$m and for the range of variation of velocities recorded on the photomultiplier, i.e., 1-10 km/sec. As shown in [1], this curve almost exactly coincides with normal distribution. The maximum velocity recorded in experiments with aluminum plate was 8.6 km/sec. The total number of craters was 234.

Figure 1 also shows curve 1 for the distribution $Q(a)$ over the depth a and curve 2 for the distribution Q(2b) over the diameter 2b. It is evident from the figure that the depth of most of the craters is in the range 10-20 μm, while the diameters are in the range 110-120 μm.

The values of a were divided in segments of 10 μm up to 70 μm; the values of d_* for thin foils were divided in similar segments in the range up to 160 μm. Thus, the values of q and p were 7 and 16 respectively. The total number of products $P(d_{*i})\, Q(a)$ was N = 112. For each of these the solution of system (2.2) for d_0^* and v_0 was found on Minsk-14 computer (d_0^* is the true size of the particle at the time of impact and is different from d_0). The results of computation for the correponding d_0^*, v_0 pairs, whose appearance corresponds to the same maximum probability, are plotted in Fig. 2 (dashes denote the limit of the initial size d_0). The graph in Fig. 2 is bounded on the right by the maximum obtained velocity of 8.6 km/sec. The distribution of the points corresponds to decrease of the probability of their appearance with the increase of v_0.

The results confirm the conclusion of [1], that the rate of acceleration corresponding to the start of burning of the glass particles in the conditions of the experiments is ~0.6-1.0 km/sec and that most of the particles must "stick together" and have velocities $v_0 < 0.5$ km/sec (computed values of d_0^* are found to be larger than the initial value d_0).

We now turn to the discussion of the experimental results.

3. The results of the injection of glass spheres into the polymer packets, referred to their initial size d_0, are given in Fig. 3 (continuous lines); a^+ is the total thickness of the ruptured sheets of the packet corresponding to the particle with velocity recorded by the photomultiplier. The points 1 pertain to the impact of glass ($d_0 = 95 \pm 5$ μm) with polyethylene, points 2 to the collision of glass (d_0 = 175-225 μm) with polyethylene packet, and points 3 to glass ($d_0 = 95 \pm 5$ μm) with a packet of polyethylene terephthalate sheets. The dashed denote the dependence of a^+/d_0^* on v_0 for $d_0 = 95 \pm 5$ μm using the computed results (Fig. 2) up to $v_0 \sim 9$ km/sec (a possible extrapolation of the results (Fig. 2) shows that the nature of the dependence a^+/d_0^* is qualitatively similar to that of a^+/d_0).

The crater formed by the fastest particle, i.e., the leading particle, was determined by a comparison of the sizes of the escaped particle with the computed size (Fig. 2), and also indirectly, i.e., from the maximum entrance diameter of the hole in the first sheet of the packet. Since the thickness of the sheets in the packet $l \sim d_0$, the diameter d_* of the holes in them must depend on v_0 all the more noticeably even with the sailing taken into consideration. Moreover, at sufficiently large v_0, characteristic darkening of the material (polyethylene) or carbonization (polyethylene terephthalate) could be observed along the edges of the hole.

Experimental results on the impact of glass spheres $d_0 = 95$ μm on polyethylene ($l = 60$ μm) showed that up to v_0 = 10-11 km/sec a^+ increases, but later decreases although the entrance hole in the first layer increases. At $v_0 \sim 20$ km/sec only the first layer is ruptured, while on second sheet there is a deposit of homogeneous material with the diameter of the damage on the polyethylene layer equal to ~ 600 μm.

It can be assumed that the decrease of a^+ for the fastest particles corresponds to the velocity v', at which the glass particle of a given size (perhaps having already undergone fractionation and burning) passes completely to viscous-fluid state due to pressure and temperatures appearing at the point of impact with the polymer material and, therefore, has increasingly smaller rupture capability.

At $v_0 = 21$ km/sec a glass sphere with $d_0 = 95 \pm 5$ μm is apparently completely melted just after the rupture of the first sheet with $l = 60$ μm. The critical velocity for spheres of this size is 10-11 km/sec. For larger sizes d_0 = 175-225 μm it is larger, although the melting processes in the material of the particle begin always at a constant threshold velocity for a given impactor-obstruction pair, which could be determined if the equations of state of glass and polyethylene are known. In the collision of a sphere with $d_0 = 95 \pm 5$ μm with polyethylene terephthalate ($l = 25$ μm) the critical velocity is ~8 km/sec.

Below the critical velocity of impact v' the distance between the sheets of the packet has usually no effect on a^+, which is typical for piercing of several obstructions by a nonfractionized particle. For $v_0 > v'$, a^+ will decrease, although in the experiment maximum values of a^+ might be observed for particles with $v_0 = v'$. In some cases a decrease of the hole size d_* was observed with the increase in the number of layers up to their complete disappearance in the rupture of polyethylene packets, although the particles were still detected across 3-4 layers. This confirms the effect detected earlier about the increase of sailing with the decrease of the impact velocity v_0 [2, 3].

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