STUDY OF HIGH-VELOCITY BODY IMPACT IN A LIGHT POROUS MATERIAL

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Impact at high velocity (5-10 km/sec) in the case in which the density of the medium ("target") is much less than that of the impacting body has not been examined in the literature [1]. In the following we present results of an experimental investigation of the characteristics of this process.

In the experiments we used steel spheres of dimensions of the order of a few millimeters, accelerated to a speed \( v_0 = 5-10 \text{ km/sec} \) by explosive charges [2]. The targets were blocks of styrofoam, polyurethane foam (poroplast), porous rubber, and fibrous materials. The density of these materials lies in the range from 0.06 to 0.35 g/cm\(^3\). As a rule, the pore dimension and distance between pores is much less than the sphere diameter \( d_0 \).

For all the impact velocities in the experiments the initial embedding stage is a hypersonic process, since the sound wave propagation velocity in porous media is low [3].

The experiments disclosed several basic regimes of the body embedding process.

1. The stresses which arise in the body are less than the body material strength. This is obviously possible for sufficiently small values of \( \rho t v_0^2 \) (here \( \rho t \) is the density of the target material). The following experiment can serve as an example: for \( \rho t = 0.11 \text{ g/cm}^3 \) (styrofoam), \( v_0 = 5.1 \text{ km/sec} \), the sphere \( d_0 = 3.35 \text{ mm} \) does not fracture, covering the distance \( p = 780 \text{ mm} \approx 230 d_0 \) before stopping. The final body mass amounts to 0.85 times the initial mass, which permits considering the dimensions at the beginning of penetration unchanged. We compare the embedding process with supersonic gas flow over a sphere. In this case the force acting on the sphere is

\[
F = -k (\rho p_v r_0^2 v^2) \tag{1}
\]

where \( \rho p \) and \( v \) are the flow density and velocity, and \( r_0 \) is the sphere radius. We note that \( k(v) = \text{const} = 1.44 \) for values of the Mach number \( M \geq 4 \) [4]. From (1) for \( v = v_0 \) and \( s = 0 \) (\( s \) is the body travel distance) we obtain the deceleration law

\[
v = v_0 \exp \left( \frac{-k v_0^2 r_0^2}{m} \right), \quad \text{or} \quad v = v_0 e^{-k s} \left( \frac{s}{d_0} \right)^{3/2}, \quad \text{where} \quad x = \frac{3}{2} \frac{\rho t}{\rho b} s \tag{2}
\]

Here \( m \) is the sphere mass, and \( \rho b \) is the body material density.

Recording of the body motion in the target material was performed with the SFR photorecorder. Gaps of 1-1.5 mm were left between the 20-30 mm thick material layers. Scanning of the embedding process makes it possible to establish body passage through the gap and determine the average velocity of the body in a given segment. The measurements were made up to \( s = 50-60 d_0 \), results are shown in Fig. 1. Comparison with the curve \( f(x) = e^{-2x} \) shows that \( k \approx 2 \) for the materials studied. In order of magnitude this is close to the data of [4] for a gas (the difference of up to a factor of 1.5 is obviously related with the change of the nature of the flow).

In the study we did not investigate the deceleration near the stopping point. There are indications [5] of an abrupt change of the deceleration law and drag coefficient for small motion velocities in the case of impact in sand (\( v_0 = 0.7 \text{ km/sec} \)).
Fig. 1. Deceleration of steel sphere in material: $d_0 = 3.35$ mm, $v_0 = (5.1 \pm 0.15)$ km/sec. 1) Styrofoam with $\rho_1 = 0.06$ g/cm$^3$; 2) styrofoam with $\rho_1 = 0.11$ g/cm$^3$; 3) porous rubber with $\rho_1 = 0.15$ g/cm$^3$.

Fig. 2. Breakup of steel sphere: 1) region of retention of integrity; 2) region of body breakup; 3) region of body material flow.

Fig. 3. Impact in poroplast (polyurethane foam): $d_0 = 1.7$ mm; $v_0 = 7.35$ km/sec, $\rho_1 = 0.28$ g/cm$^3$.

In the considered embedding mechanism the maximal penetration depth corresponds to the maximal velocity for which breakup is still absent. The actual process is complicated by change of the body dimension as a result of mass erosion from the surface.

The breakup condition for a sphere traveling at hypersonic velocity $v$ in a gas of density $\rho_1$ has the form [6]

$$\rho_1 v^2 \gg a \sigma \quad (a \sim 3.5)$$

Here $\sigma$ is the body material strength in tension or shear (depending on the material properties). Comparison of the deceleration processes makes it possible to suggest an analogous form of the breakup condition for motion in a light porous medium. Then for the same strength characteristics of the bodies used in the experiments the breakup (retention of integrity) boundary is represented in the plane of the variables $v_0^2$, $1/\rho_1$ by the ray $c_1 = \rho_1 v_0^2$.

2. The stresses which arise in the body are greater than the strength of the body material. Figure 2 shows results of experiments made in our study in the plane of the variables $v_0^2$, km$^2$/sec$^2$ and $1/\rho_1$ (g/cm$^3$)$^{-1}$. Region 1 corresponds to retention of body integrity (points 1), region 2 corresponds to breakup (points 2). We recall that here the bodies are steel spheres. The breakup boundary is obviously close to OA. The diagram (Fig. 2) is very approximate, but it does make possible a preliminary estimate of the nature of the interaction with a given body for a known body material. In cases of practical interest the choice of the body material is limited: meteorites are stony and iron-nickel; the bodies accelerated in laboratory conditions are made from steel, duraluminum, sometimes polymer materials.

The nature of the breakup depends strongly on the quantity $\rho_1 v_0^2$ and the body material. Spalling of the material at the surface and formation of short splinter tracks can be observed (glass at low impact velocity); breakup with plastic deformation of the body is possible (here deformation without breakup may