PIERCING PLASTIC-MATERIAL BARRIERS WITH A RIGID PUNCH

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In contrast to barriers made of structural alloys, the penetration of which is usually accompanied by the spreading of cylindrical cracks in the barrier and the knocking-out of a plug [1], barriers made of the materials considered here are pierced as a result of heavy plastic deformation of the material under the punch. This is clearly seen in Fig. 1, which shows photographs of polished sections of plates with the thickness h = 4.85 mm made of commercially pure aluminum after impact by a steel ball with a diameter of 6.37 mm, where the initial punch velocities in normal and oblique (70 deg with respect to the normal) impacts are marked on the photographs.

The exact solution of the piercing problem, even in our relatively simple case (a rigid punch and a plastic barrier), requires detailed analysis of the stress fields and the related deformations and displacements of the barrier material. This, in turn, requires knowledge of the determining relationship for the barrier material under conditions of high pressures and deformation rates.

In these circumstances, it is of interest to consider simple piercing models (see, for instance, [2]); a variant of the scheme of piercing description is suggested below.

We assume that the punch shape does not vary during the piercing process and that each elementary area dS of the surface of contact between the punch and the barrier is acted upon by a resistance force directed along the normal to the elementary surface:

$$d\mathbf{p} = -F(v_n)d\mathbf{S},$$

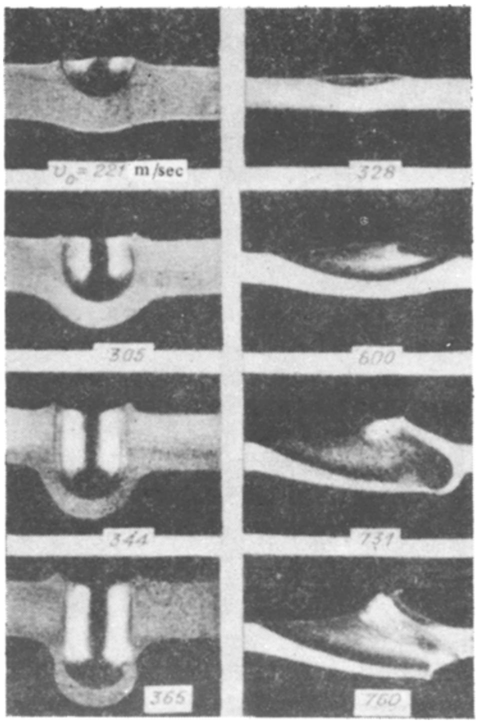

Fig. 1

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TABLE 1

Material	Pb	Cu	Al	Nb	In	Fe
ρ, g/cm^3	11,35	8,96	2,70	8,40	7,28	7,80
c, m/sec	1200	3790	5080	4310	1190	5170
h, mm	5,00	2,40	4,85	4,00	12,50	2,00
v_*, m/sec	190	355	366	600	235	435
σ_0, kgf/mm^2	7,8	67	37	103	4,4	123
HM, kgf/mm^2	5,8	57	36	119	—	119

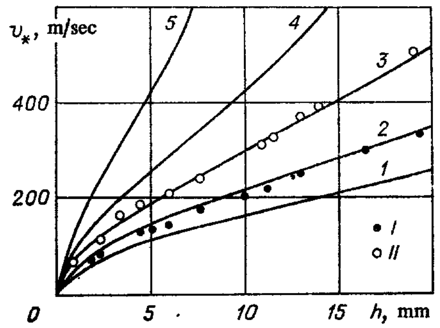

Fig. 2

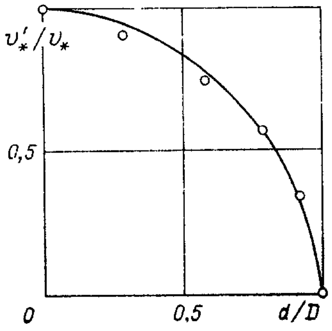

Fig. 3

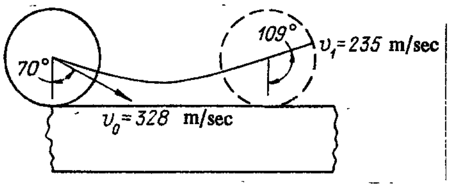

Fig. 4

where v_n is the normal component of the velocity of the surface.

We approximate the function F in the following manner:

$$F(v_n) = \begin{cases} E\left(\frac{\sigma_0}{E}\right)^{1-v_n/c} & \text{for} \quad v_n > 0, \\ 0 & \text{for} \quad v_n \leqslant 0, \end{cases} \tag{1}$$

where E is the Young modulus of the barrier material, σ_0 is the parameter characterizing the barrier material, and c is the velocity of sound in a thin rod made of the barrier material.

We assume that the equation of motion of the punch in the barrier is given by

$$m\frac{d\mathbf{v}}{dt} = \int\limits_S d\mathbf{p}, \tag{2}$$

where **v** is the velocity of the elementary surface dS relative to the barrier, m is the punch mass, and S is the surface of contact between the punch and the barrier.

Numerical integration of Eq. (2) is performed from the instant of time t = 0, when $\mathbf{v}_v = \mathbf{v}_0$, to the instant of time when $\int\limits_S d\mathbf{p}=0$, , which occurs for either **v** = 0 or **v** = $\mathbf{v}_1$ = const (the condition of the punch's emergence from the barrier).

The approximation given by (1) comprises σ_0, the single constant to be determined experimentally. One of the possible procedures for determining this constant is to compare the critical piercing velocity v_* for a normal impact relative to the barrier surface, obtained by numerical integration of Eq. (2) for different σ_0 values, with the velocity v_* obtained directly from experiments (the experimental method and technique are described in [3]). The σ_0 value to be used is that for which the calculated and the experimental values of v_* agree with an accuracy to 1% (experimental accuracy). The results of this procedure for certain materials are given in Table 1. It is interesting that the obtained values of σ_0 are close to the values of the Mayer hardness H [4, 5] for these materials with the accuracy necessary for determining v_* (the hardness values in Table 1 were obtained experimentally by means of a TSh-2M instrument).

The proposed scheme was used for calculating the values of $v_*(h)$ for steel balls with different diameters and certain plastic barriers (the results for lead are given in Fig. 2; theoretical calculations: D = 16; 10, 3; 6.37; 4.0; 2.0 mm — curves 1-5, respectively; experimental results: D = 10.3; 6.37 mm — points I and II, respectively), the critical piercing velocity v_*^1 of a plate 4.85 mm thick, made of commercially pure aluminum, involving the impact of a steel ball with the diameter D = 6.37 mm at the center of a cylindrical through opening for different diameters d (Fig. 3; solid curve, calculation; circles, experiment), and the trajectory of the center of the same punch resulting from impact at an angle of 70 deg with respect to the normal on a barrier made of commercially pure aluminum (Fig. 4).

The satisfactory agreement between the theoretical and experimental relationships demonstrated on concrete examples suggests that, in spite of the obvious limitations of the described model, it may also prove useful in solving more complex piercing problems, since it can be used for calculating the relationships for a punch of arbitrary shape, which have practical importance, while, in the case of a ball, the similarity of the piercing process with respect to h/D follows from Eq. (2), which was noted earlier in experiments [6].

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