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PENETRATION OF A RIGID SHELL INTO A STEEL OBSTACLE AT MODERATE IMPACT VELOCITIES

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The effect of the impact velocity and shape of the head of a rigid shell of caliber 20 mm *on the depth of its penetration into a thick obstacle made of mild low-carbon steel for impact velocities of up to* 600 m/sec *is studied experimentally. Experimental relations between the penetration depth and the impact velocity are obtained for shells with conical and semispherical heads. It is found that for a penetration depth equal to* 1 *or* 2 *calibers, the penetration resistance does not depend on the head shape and is characterized by an average stress equal to* 2.98 GPa.

The impact and penetration of shells into various obstacles are extensively studied by experimental and numerical methods [1]. However, in view of the great diversity of situations, some particular questions require further investigation or refinement. The goal of this paper is to study the effect of the impact velocity and head shape of a rigid shell of caliber 20 mm on the penetration into a thick steel obstacle for relatively low velocities (up to 600 m/sec).

The obstacles examined were massive disks of diameter 160 mm and thickness 70 mm made from low-carbon steel St. 3 in the supply state. A square grid with a 5-mm step was scribed on the front surface of the obstacles by rolling. The control determination of the standard mechanical properties gave the following average values: yield point $\sigma_{0,2} = 203$ MPa, ultimate strength $\sigma_{\text{temp}} = 458$ MPa, and elongation at rupture $\delta_5 = 24.5\,\%$. The average value of the Brinell hardness H_{B} was found to be 1.26 GPa.

The obstacles were loaded by the impact of shells with conical (90° opening of the cone) and semispherical head shapes. The shells of length 80 mm and diameter 20 mm ($r = 10$ mm) were made of ShKh15 steel and had Rockwell hardness $H_{\text{Rc}} = 60$–64 kg/mm^2. The shells were accelerated by a powder gun of the corresponding caliber. Variable-induction pickups (chronographs) were used to determine the velocities of the shells.

No distortion of the shells was observed in the tests. Figure 1 shows photographs of the shells with semispherical and conical heads after impacts at velocities of 425 m/sec (Fig. 1, at the left) and 410 m/sec (Fig. 1, at the right). The surface fragments of two obstacles with the formed craters are shown in Fig. 2. Figure 2a refers to the impact from a shell with a conical head ($v = 410$ m/sec) and Fig. 2b to that with a semispherical head ($v = 425$ m/sec). The experiments show that, for almost equal impact velocities, a greater part of the material is involved in the formation of the bead in the case of the conically headed shell. Its edge diameter and height are greater than those for the semispherically headed shell. Radial cracks appear around the crater. Cracking is more significant the higher the impact velocity, and this process is more pronounced for the semispherical head. Deformation of the obstacle front surface, which is determined by the distortion of the measuring grid, is noticeable at a distance of one caliber from the bead edge. One can observe traces of the measuring grid at the bottom of the semispherical crater formed at the minimum impact velocity. This can be attributed to adhesion of the head of an impactor to the obstacle material during penetration. The

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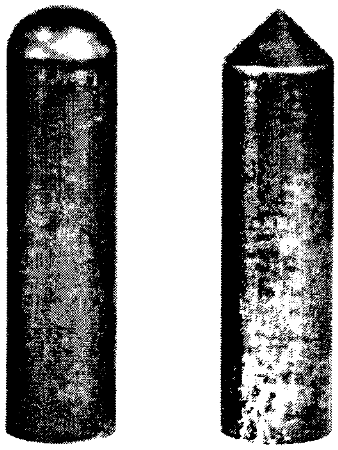

Fig. 1

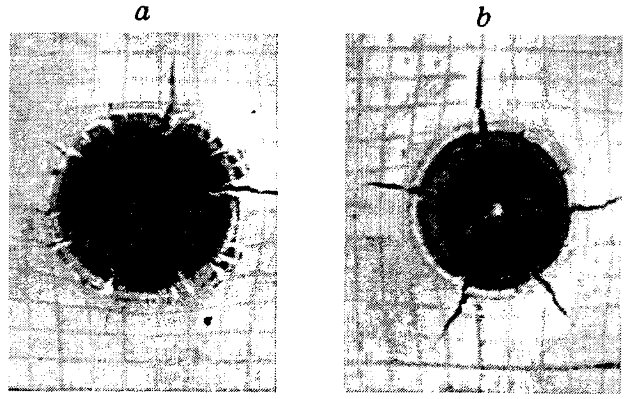

Fig. 2

TABLE 1

Shape of the shell head	m, g	v, m/sec	h, mm	h_b, mm	d_b, mm
Cone	179.3	390	22	28	30.5
	179.1	410	24	30	31.0
	179.5	530	34	40	35.0
	179.3	540	36	42	35.5
Hemisphere	187.1	364	19.5	23.5	26.8
	186.7	425	23.0	28.0	29.0
	188.3	435	24.0	30.0	29.4
	187.3	524	33.5	38.5	32.0

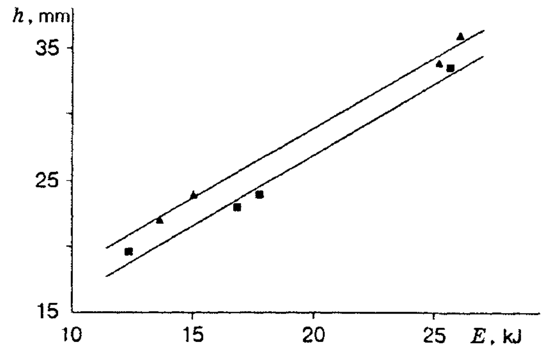

Fig. 3

presence of iridiscence colors indicates a deformation heating of about 300°C.

The experimental results are listed in Table 1 [m is the shell mass, v is the shell velocity, h is the bead height relative to the front surface, h_b is the crater depth relative to the upper part (edge) of the formed bead, and d_b is the bead-edge diameter]. Figure 3 shows the resulting experimental relations $h(E)$ ($E = mv^2/2$ is the kinetic energy of a shell) for shells with conical (triangles) and semispherical (squares) heads. The solid lines refer to the linear regression relations of the form $h = a + bE$ determined by the least-squares technique. The values of the coefficients a and b, their standard deviations s_a and s_b, the standard deviations of the points from the regression s_h, and the correlation coefficients R are listed in Table 2.

A regression analysis shows that the relations between h and E are linear in the impact-velocity range of 300–600 m/sec and for penetration depths of 1 or 2 calibers. Thus, a constant resistance force $F = dE/dh$ acts on a shell when it moves at depths of 1 or 2 calibers. In practice, its magnitude does not depend on the head shape and is equal to 935 kN (932 and 938 kN for the conical and semispherical heads, respectively). The corresponding average resistance stress over the cross-sectional area $\sigma_r = F/(\pi r^2)$ is equal to 2.98 GPa.

The following empirical formula [2] is widely used to estimate the stress of resistance to penetration of a rigid shell into metal obstacles at impact velocities of up to 1000 m/sec:

$$\sigma_r = H_d + k\rho v^2,$$

where H_d is the dynamic hardness of the material, which is determined experimentally for impact velocities of about 10 m/sec, ρ is the density of the material, and k is the coefficient that corrects the head shape of the

TABLE 2

Shape of the shell head	a, mm	s_a, mm	b, mm/kJ	s_b, mm/kJ	s_h, mm	R
Cone	7.682	1.027	1.065	0.049	0.563	0.998
Hemisphere	5.468	1.632	1.073	0.087	0.832	0.994

shell. In Vitman and Stepanov's opinion [2], the formula is applicable to metal obstacles of different strength if the velocities are greater than a certain critical velocity determined from the formula $v_k = \sqrt{H_{\rm B}/(k\rho)}$. In the present paper, we have $k = 0.5$ for both types of head shape considered and, hence, $v_k = 567$ m/sec. Thus, in accordance with the data of [2], a significant effect of the impact velocity on the resistance of penetration of a rigid shell into an obstacle from St. 3. steel should not be expected in the studied range of moderate velocities. Therefore, a few tests are required to determine the penetration resistance.

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