MICROSTRUCTURE ANOMALIES IN THE DEFORMATION OF BARRIERS UNDER HIGH-SPEED PENETRATION BY PLANE JETS

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Numerical methods of solving problems of penetration with initial impact velocities of 1-4 km/sec are being developed intensively in the theory of high-speed deformation of metal barriers [1-3]. The agreement between the calculated and experimental values remains unsatisfactory, however, even though many fitting parameters are used and the computational algorithms and programs have become more complicated. It is assumed [4] that the most promising area of research on high-speed elastoplastic deformation of materials involves determining the viscous component of the strength, but the viscosity coefficient found by different methods may differ by one or two orders of magnitude [4, 5]. Among the causes of such discrepancy are the lack of reliable data on the properties of the materials of the obstacles and the physical processes that occur at such high speeds of penetration [6].

At the present time the physics of strength and plasticity is intensively developing new ideas about the plastic deformation of crystals, when translation in one structural level is accompanied by rotation in another level and vice versa [7]. A distinct collective mass transfer effect because of the motion of an ensemble of defects manifests itself in the vortex nature of plastic deformation and can be represented as a region of a highly excited state in the bulk of a crystal in an external field, analogous to the hydrodynamic flow of solids in strong inhomogeneous external fields [8]. Since rotations of the material as a rule make the dominant contribution to the total deformation [9], we have attempted to trace the microstructure of the metal of a barrier after the high-speed penetration of a plane jet with an impact velocity of 2.7-3.2 km/sec. For this purpose, using metallographic and x-ray methods we have analyzed the structure of the metal of the barrier at various distances from the site of penetration by the jet.

For our studies we took deformed barriers of steels and alloys with different strengths (see Table 1). From them we prepared thin sections, cut across the plane of penetration by the high-speed jet. The microhardness was measured with a PMT-3 instrument at a load of 0.5 N and three different levels of penetration: at the impact surface and half-way down and at the bottom of the crater at a distance of 0.1 mm from the edge of the crater. We carried out our x-ray structure analysis on a DRON-2 diffractometer, using Fe — k_α (1.93×10^{-10} m) and a plane graphite monochromator in the diffracted beam. X-ray photographs were taken at the same levels in the crater as in the metallographic analysis, where no less than three segments were studied: the first, along the edge of the crater and the other two were at distance of 2 mm away. The diameter of the irradiated spot was no more than 2 mm. On the x-ray photographs, which were taken at large diffraction angles, we measured the full width at half maximum (FWHM) of the diffraction lines. Under the conditions chosen for taking the x-ray photographs, the FWHM characterizes the distribution function of the residual elastic lattice strains, which arise during plastic deformation, and is directly proportional to the dislocation density [10].

Figure 1 shows photographs of the microstructure (with 50-fold magnification) of ductile St. 20 steel while Fig. 2 shows the photographs of the microstructure of high-strength 40Cr steel at various depths of penetration: a) near the impact surface, b) halfway down the crater, and c) at the bottom of the crater. For the conditions of our experiment a crater 4.5-5 mm thick formed in barriers 15-20 mm thick. Two zones with different structures could be distinguished in the microstructure of the thin section, irrespective of the strength of the metal considered. The first zone, extending from 0.1 to 0.3 of the depth of the crater and located near the impact surface, does not exhibit any size reductions or rotations of the subgrain structure and the second zone appears along the edges

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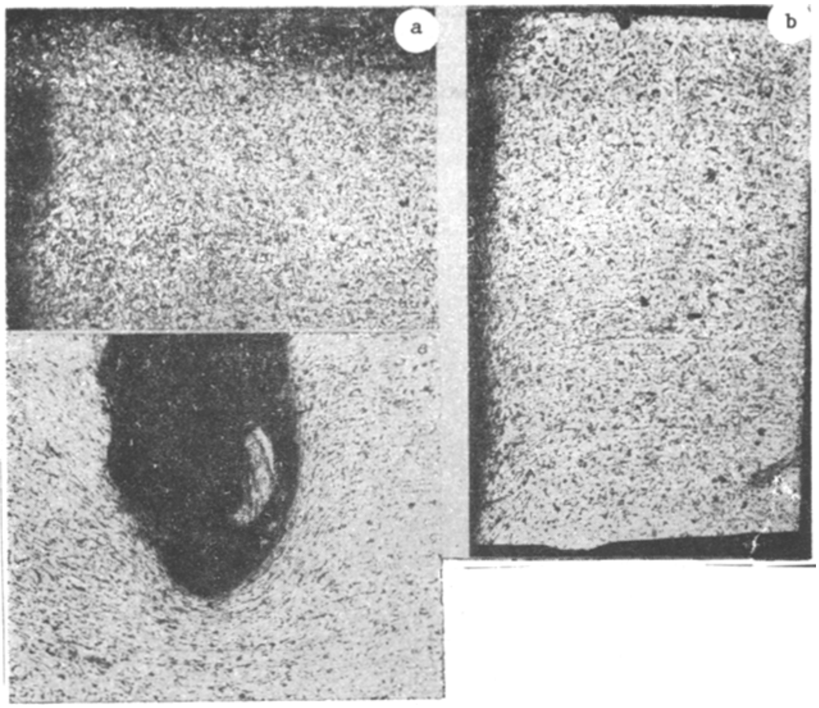

Fig. 1

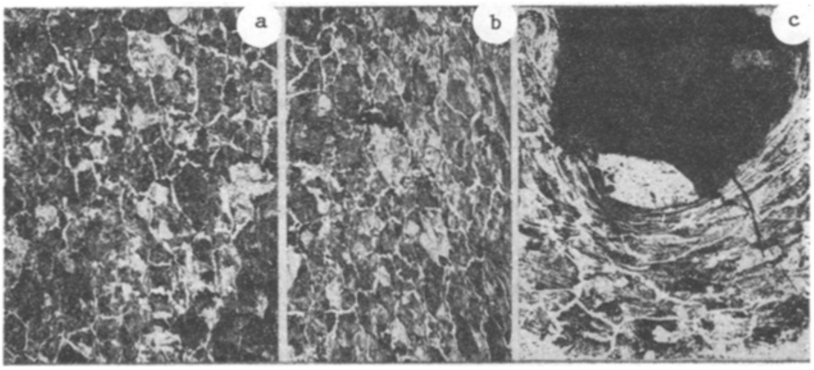

Fig. 2

TABLE 1

Material	σ_p, MPa	Arbitrary depth of penetration*	Microhardness, GPa								Half-width, 10^{-2} rad		
			Distance from edge of crater, mm										
			0,05	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0	2	4
Steel St. 20	515	1	2,58	2,1	2,1	1,93	1,88	1,88	1,83	1,68	3,1	3,1	3
		2	3,5	2,36	2,1	2,1	2,06	1,93	1,93	1,88	3,3	4,2	3
		3	2,22	2,17	2,1	1,99	1,88	1,84	1,84	1,78	2,9	3,6	3,2
Steel St. 40Cr	965	1	3,66	3,21	3,03	3	3	2,85	2,7	2,56	4	3,7	3,4
		2	4,25	3,41	3,29	3,2	3,1	3,1	3	2,78	5,4	5	3,6
		3	3,64	3,15	3,04	3,01	3	2,85	2,77	2,64	4,7	4,7	3,5
Alloy AMg-6	370	1	1,56	1,32	1,28	1,27	1,27	1,25	1,14	1,1	3,6	3,2	3,1
		2	1,85	1,64	1,45	1,4	1,39	1,39	1,25	1,18	3,8	3,3	3,3
		3	1,69	1,44	1,4	1,4	1,38	1,38	1,3	1,2	5,2	3	2,9
Alloy WTi6-Si	745	1	3,17	2,63	2,54	2,47	2,44	2,36	2,1	2,1	1,7	1,7	1,7
		2	3,54	2,86	2,86	2,77	2,77	2,44	2,36	2,17	1,6	1,8	1,7
		3	3,28	2,67	2,6	2,54	2,46	2,4	2,3	2,1	1,6	1,7	1,7

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*1) at impact surface, 2) halfway down the crater, 3) at the bottom of the crater.

and at the bottom of the crater. Collective rotations of grains with a simultaneous change in the grain size can be seen in the second zone. The results of microhardness measurements and data from x-ray structure analysis also indicate the existence of two zones, which were revealed metallographically.

From the body of experimental data we can conclude that when a high-speed jet penetrates into the first zone, metal of the barrier is cleaved and the very small particles of the metal are completely removed. Further penetration of the jet is accompanied by the development of processes in which individual structural elements (grains) may undergo plastic deformation concurrently with displacement of the grains and rotation as a whole. These are signs of rotational plastic deformation at different structural levels: from the mesoscopic level (the level of dislocation substructures), which is recorded by a change in the FWHM, to the structural level, which is characterized by rotations of groups of grains. The above also indicates that when solving problems of the resistance of barriers to high-speed penetration we must use the concepts of the theory of plasticity in two-level media [11, 12].

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