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CRITICAL LOADING PARAMETERS FOR THE DEVELOPMENT OF ADIABATIC SHEAR IN TITANIUM

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An increase in deformation normally leads to metal strengthening, which is connected with a reduction in the travel of mobile dislocations and an increase in defect density with a fixed amount of strain. However, with explosive and high-velocity impact experiments under different loading schemes (always with the presence of a free surface) there is a change in deformation mechanism from uniformly distributed shear to clearly nonuniform shear with formation of "adiabatic shear bands." The intensity of plastic flow in the bands is much greater than in the basic material, which leads to additional warm-up of the deformed region, its weakening, and as a consequence to its more active deformation in the band. The governing role of adiabatic shear in processes of high-velocity punching, formation of spalling, high-speed cutting, and stamping, was demonstrated in [1-4].

In order to study the nature of adiabatic shear and a credible solution of applied problems it is very important to consider the question of critical parameters for high-velocity loading leading to a change in deformation mechanism. In the known works on adiabatic shear there is no systematic study of this type, which is connected with the complexity of the experiments. For this purpose there are a number of procedures: radial disintegration of a tube under the action of explosive loading from the direction of the internal surface [2] and shock loading in shear [4]. In the present work a simple procedure is suggested making it possible to change the loading parameters over wide ranges.

Shown in Fig. 1 is the scheme for carrying out the experiment. The plate of test material is thrown by a smooth-bore gun or by means of an explosive charge (at velocities greater than 1100 m/sec) at a massive substrate. The angle of impact prescribes the amount of shear deformation to $\tan\gamma$. With prescribed deformation time the process may be controlled by changing the flight velocity of the thrown plate. To a first approximation the impact velocity v is proportional to the shear deformation rate. In view of the importance of this question, a series of special experiments was carried out for measuring by means of a pulsed x-ray emitter the dimensions of the transition zone with different impact velocities. In order to avoid welding by explosion, in some of the experiments a thin fluoroplastic or polyethylene film was placed on the impact surface, and no marked effect of the film on deformation within the volume of the thrown plate was noted. Impact velocity and angle were controlled by means of the standard procedure of charged needles.

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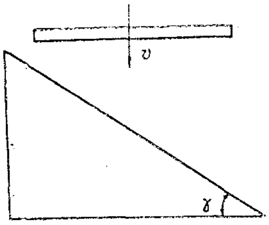

Fig. 1

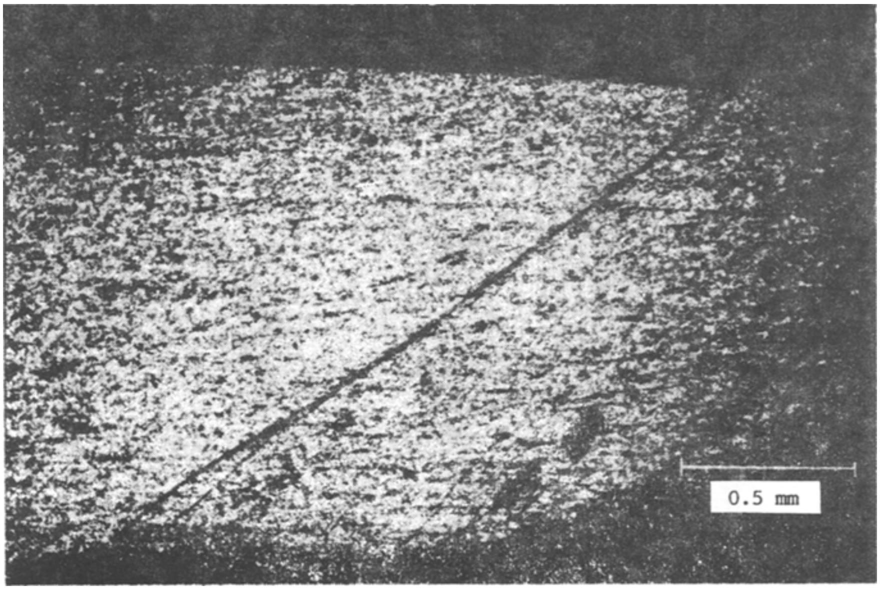

Fig. 2

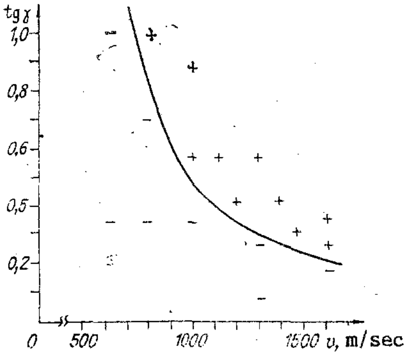

Fig. 3

A series of tests was carried out by this scheme on titanium VT-1-0 in the as-supplied condition (initial hardness HV = 180 kg/mm^2, grain size 0.02 mm) with a plate 2 mm thick. Deformed specimens were cut in the longitudinal direction in an electric-arc machine. The presence or absence of an adiabatic shear band was checked metallographically in polished and etched microsections. Shown in Fig. 2 is the structure of titanium with an adiabatic shear band after loading with parameters $\gamma = 30°$, $v = 1000$ m/sec. Broad, comparatively rare bands run right through the plate, and the amount of shear of the band reaches 0.3 mm. The angle at which the band runs normally corresponds to the calculated impact angle, and with large impact angles the picture is distorted by material flow along the impact surface. The distance between bands, and hardness in the matrix depends on the amount and rate of deformation. Currently a systematic study of these dependences is being carried out.

Presented in Fig. 3 are the first of the results obtained, i.e., critical impact parameters for development of adiabatic shear in titanium VT-1-0; the curve separates regions with presence and absence of an adiabatic shear band (experimental data are marked by plus and minus signs respectively). Thus, a changeover from uniform deformation with high velocity shear strain to adiabatic shear is governed by two loading parameters: the amount of deformation and impact velocity (deformation rate).

The existence of this dependence points to the following sequence of deformation development. In the first stage there is comparatively uniform development of plastic deformation throughout the volume. With an increase in strength there is an increase in defect density, and the distance of travel for mobile dislocations decreases. The changeover to the adiabatic shear stage occurs at a level of strengthening when intense development of shear along some band at considerable distances with surmounting of existing barriers requires less increase in flow stress than follows from extrapolation of the deformation of shear. Changes in microhardness indicate that with a prescribed amount of deformation, strengthening increases with an increase in impact velocity, then it emerges into saturation with the start of development of adiabatic shear.

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CONSIDERATION OF VISCOSITY DURING SUBSONIC PENETRATION OF A SOLID BODY INTO ISOTROPIC BARRIERS

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In solving the problem of the reaction of solids with isotropic barriers during their impact, one of the main questions is determination of the penetration resistance of the solid into the barrier. Currently in calculating this resistance as a basic phenomenological approach use is made of the hydrodynamic anomaly in accordance with which the penetration resistance in the plastic region is assumed to be equivalent to the resistance of an ideal liquid.

In domestic practice during determination of the force of resistance in the case of subsonic impact there has been widespread use of the so-called two-term equation of the Leningrad Physicotechnical Institute (LETI) suggested in [1] based on this analogy. According to this relationship force of resistance to penetration is written in the form

$$R = -F\left[H_d + k\frac{1}{2}\rho v^2\right], \tag{1}$$

where H_d is dynamic hardness determined by experiment with impact velocities $v \sim 10$ m/sec; v is local penetration velocity; ρ is barrier material density; k is shape coefficient for the body, assumed to equal 1.0 for a body with spherical head; F is body cross-sectional area. Similar relationships were derived in [2]. For supersonic impact velocities in working out penetration use is made of modifications of the Lavrent'ev–Neuman hydrodynamic theory [2-4].

At the same time, as has been established by experiment [5], the majority of ductile materials behave beyond the yield point as a ductile liquid. It was shown in [6] on the basis of numerical modelling of the penetration process for a deformed body into a barrier

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