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VISCOELASTICITY OF ALUMINUM IN RAREFACTION WAVES

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It has been shown previously [1-3] that in shock-compressed metals both loading compression waves and rarefaction waves have elastic precursors. Analysis of the change of state in compression and rarefaction waves following a shock wave has shown that increments in deviator stresses in these waves can significantly exceed the stress anisotropy behind the shock wave front. Such a situation does not agree with simple models of an elastoplastic body, according to which increments in deformation in the plastic region are related to insignificant or even zero increments in deviator stresses, while the corresponding rate of propagation of weak loading waves is close to the "volume" speed of sound $c_b = (\partial p/\partial \rho)_s{}^{1/2}$. Such features of stress-deformed states and their changes behind a shock wave in metals have been explained by stress relaxation processes [1, 4, 5] or the specifics of high-speed metal deformation in the shock wave [3], involving heating of slip planes which leads to significant short-term loss of shear strength in the metal. In the latter cases resistance to deformation is reestablished as temperatures equalize behind the shock wave front and is practically independent of deformation rate.

In a Maxwell-type elastoviscous medium after the specimen is maintained at a fixed deformation, independent of their sign weak perturbations should propagate like purely elastic waves with a velocity $c_l = \sqrt{(K + (4/3)\,G)/\rho}$. In particular, for a steplike rarefaction the speed of the loading wave front should be equal to c_l. If the processes of

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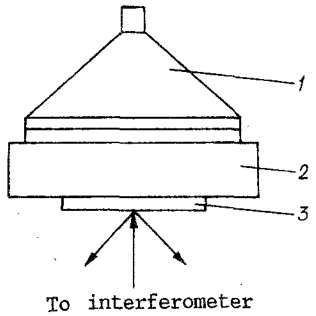

Fig. 1

stress relaxation are insignificant, then maintenance should not affect the course of plastic deformation.

The present study recorded extension waves in an aluminum specimen unloading after shock compression. A diagram of the experimental arrangement is shown in Fig. 1. A plane shock wave with approximately rectangular pressure profile, excited by explosive generator 1, was introduced into the type AD1 aluminum specimen 3, 2 mm in thickness, through a massive copper screen 2. Continuous recording of the rate of motion of the free back surface of the specimen was accomplished by laser Doppler interferometry [6]. The shock compression pressure in the aluminum was 5.3 GPa.

Steplike rarefaction in the shock-compressed aluminum was produced by reflections of waves from the free back surface of the specimen and then from the specimen-screen contact surface. In the unloading wave formed upon reflection of the shock wave from the free surface the pressure falls to zero. Because of a difference in the dynamic impedances of the aluminum specimen and the copper screen the unloading wave is rereflected from the contact surface. Wave reflection from the boundary with the more rigid medium occurs with conservation of the sign of the loading, so that an extension wave is formed in the unloaded specimen, propagating from the screen to the back surface. Thus, after shock compression the specimen undergoes stepped rarefaction – initially in the unloading wave, then, after a pause, in the extension wave. There is no resistance to extension on the contact surface, so at this surface the process of unloading wave reflection is completed by return of the pressure to zero. As a result a short extension pulse is formed, which then undergoes multiple reflections between the specimen surfaces. If the shock compression intensity is sufficiently high failure of the specimen near the contact surface is possible.

The measured velocity profile of the rear specimen surface w(t) is shown in Fig. 2a. The unique features of its wave process are evident: one can see the exit to the surface of the elastoplastic compression wave, then, after a pause, the exit of the extension pulse. The arrows denote calculated exit times of the extension pulse onto the surface, assuming that its propagation rate is equal to the longitudinal (1) or volume (2) speed of sound. In both cases the speed of the unloading wave front was assumed equal to the longitudinal speed of sound in the shock-compressed material, the value of which was calculated assuming constancy of the Poisson coefficient. For zero pressures the volume speed of sound in aluminum was taken equal to 5.25 km/sec, with longitudinal speed being 6.4 km/sec. Their dependence on p was calculated in the form [7]

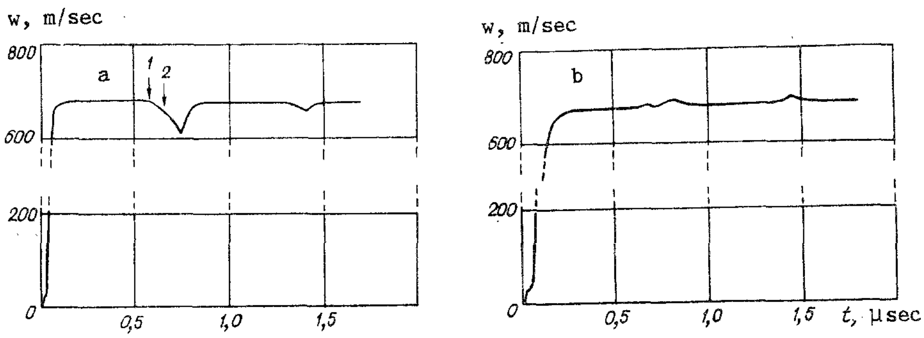

Fig. 2

$$c_b(p) = V/V_0 \sqrt{c_0^2 + 4bp/\rho_0},\ c_l(p) = (c_l/c_0)\, c_b(p),$$

where c_0 = 5.25 km/sec, b = 1.39 is the coefficient of the linear expression for the shock adiabat ($D = c_0 + bu$), V is the specific volume, and ρ_0 is the initial density. Measurement results show that the front of the extension pulse propagates at a rate close to c_l. In other words, for stepped rarefaction of shock-compressed aluminum after maintenance of the material at a fixed deformation weak perturbations have a purely elastic character.

In the given case the tensile stress values near the contact surface reached 0.75 GPa, which is sufficient to initiate failure by splitting [8]. A similar loading scheme was used for low-speed explosive launching of strikers in [8]. It is then important that destruction of the striker not be permitted. Figure 2b shows the profile of velocity of the aluminum plate surface obtained in a slightly changed configuration, with a polyethylene film 0.2 mm thick inserted between it and the copper screen. In this case the unloading wave reflection regime changes. Upon reflection from the less rigid interlayer a brief compression pulse is formed. The speed of its front is also equal to the longitudinal speed of sound. We note that in the given case the first plastic compression wave has a significantly greater width upon exit to the surface than in the experiment without the interlayer (~120 and 15 nsec, respectively).

Thus, the experiments with stepped rarefaction in shock-compressed aluminum confirm the relaxation character of the deformation. It has been shown that a thin interlayer of material with low dynamic rigidity changes the wave reflection regime on the contact surface and eliminates the danger of damaging the striker when driving it with the shock wave.

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