INVESTIGATION OF SHEAR STRESSES IN METALS ON A SHOCK FRONT

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The behavior of materials in the range of relatively moderate shock loading pressures (to several hundred kilobars), which is of great practical interest for explosive treatment of metals, for example, depends greatly on the magnitude of the shear stress in both the shock compression and the subsequent expansion processes.

The papers [1, 2] are devoted to experimental investigations of the shear stresses in different materials under static test conditions upon application of hydrostatic pressure. Their results indicate that the critical shear stresses corresponding to the passage of the material into the plastic state grow monotonically as the hydrostatic pressure increases.

The following methods were used to study the shear stress under shockwave loading of materials: a) determination of the critical shear stresses by the amplitude of the elastic compression wave leading the plastic wave [3-5]; b) the method of the "overtaking unloading" to determine the shear stress during expansion from the shock-compressed state based on a study of damping of the shock excited in the material by the impact of a thin plate [6-9].

It is shown in [3-5] that the critical shear stresses for metal, determined by the amplitude of an elastic compression wave, will exceed corresponding quantities obtained in static simple tension or compression experiments.

The dependence of the critical shear stresses of metals on the pressure in the unloading phase (the papers [6-9]) has a maximum that is explained by the directly opposite influence of the pressure and temperature in the shock on the magnitude of the shear stress. The critical shear stresses grow as the hydrostatic pressure increases, and diminish as the temperature rises; they should vanish when the melting point is reached, as in a fluid. This is shown experimentally in [7], in the example of lead.

The possibility of direct measurement of the shear stress in materials subjected to impulsive loading appeared with the development of a method to measure impulsive pressures by using manganin and dielectric transducers [10, 11]. Transducers of quite small thickness are inserted in slits made perpendicularly and parallel to the front of a wave being propagated in a specimen in such experiments. Because of the moderate size of the transducer its influence on the wave process pattern in the material is negligible. The stresses p_n along the normal, and p_τ parallel to the shock front are measured in such tests. Since p_n and p_τ are the principal stresses for the state of stress realized under loading by plane shocks, the maximal shear stresses τ_c are realized on planes inclined at a 45° angle to the wave front, and equal

$$\tau_c = (p_n - p_\tau)/2.$$

Results of an experimental investigation of the shear stress on the front of a plastic shock following the elastic precursor in steels and aluminum are represented in this paper. The stresses p_n and p_τ were measured in the experiments by using manganin pressure transducers.

The diagram for the test setup is presented in Fig. 1 (1 is the explosive charge, 2 is the screen, 3 is the specimen to be investigated, 4, 5 are the manganin pressure transducers, and 6, 7 are the transducer leads). The explosive apparatus described in [12] were used to produce shock pressures of different intensity in the materials being investigated. Shock loading of the specimens was accomplished through screens of steel, aluminum, and copper.

The pressure transducer was in the form of a T loop from PEMM manganin wire of 0.05-mm diameter and 10 × 0.2-mm area. Copper leads 0.04 mm thick and 1 mm wide were soldered to the transducer. The transducer was insulated on both sides by a Fluoroplastic or Lavsan (Dacron) film 0.04-0.10 mm thick. The total thickness of the transducer was 0.20-0.25 mm, the resistance was 5 Ω, and the amplitude of the current passed through the transducer for the measurement was approximately 10 A. Recording was by a bridge circuit using an instrument PIID-4 and the oscilloscope OK-33 [13]. The response of the measuring channel was not less than 0.04 V/kbar, and the error in measuring the pressure was not more than 10%.

Gluing the transducers with the insulating films to the specimens under investigation and filling the vacancies in the specimen slits were accomplished by vacuum lubrication.

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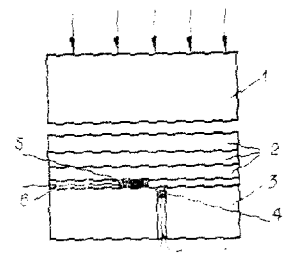

Fig. 1

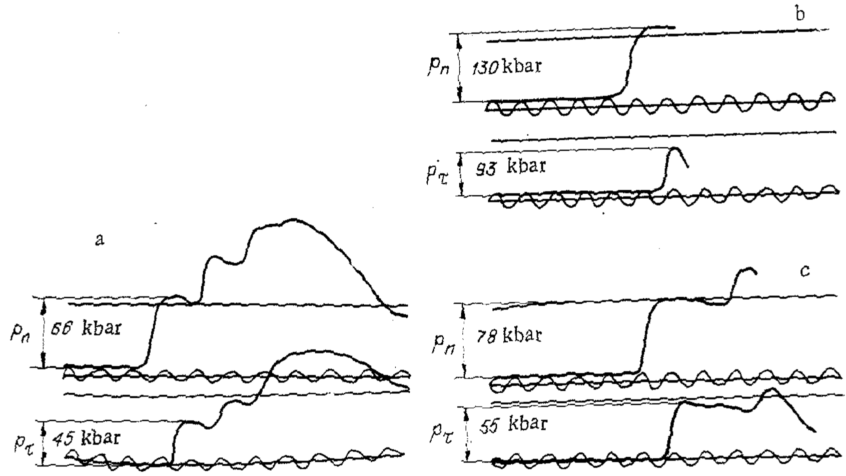

Fig. 2

TABLE 1

Material being studied	Stress		Magnitude of the shear stress $2\tau_c$, kbar	Source
	normal p_n, kbar	tangential p_τ, kbar		
St. 3	12,0	5.0	7,0	This paper
»	46,5	31,0	15,5	
»	52,0	35,0	17,0	
»	62,0	41,0	21,0	
»	66,0	45,0	21,0	
»	66,0	44,0	22,0	
»	83,0	57,0	26,0	
»	102,0	72,0	30,0	
»	130,0	93,0	37,0	
St. 45	70,0	44,0	26,0	
»	71,0	44,0	27,0	
»	130,0	93,0	37,0	
St. 20	10,16	4,0	6,02	[14]
»	26,9	21,2	5,7	[14]
»	10,0	5,0	5,0	[15]
»	34,0	27,4	6,6	[15]
»	90,0	83,4	6.6	[15]
Aluminum AD-1	78,0	55,0	23,0	This paper
»	119,0	91,0	28,0	
»	37,0	32,0	5,0	
Aluminum D-16	18,25	15,0	3,02	[16]
»	170,0		1,0±0,5	[16]
Aluminum V95	34,0	30,0	4,0	[15]
»	70,0	66,0	4,0	[15]
»	10,0	6,0	4,0	[15]

The shear stresses in steel St. 3 and St. 45 were studied in the range of shock compression pressures from the Hugoniot elastic limit to the phase transition 130 kbar, and in aluminum to the pressure ∿120 kbar.

Typical oscillograms obtained in the experiments are presented in Fig. 2 (*a* is the shear stress determination in St. 3 at a ∿70-kbar shock compression pressure, b is the determination of τ_c in St. 45 at the phase transition point, *c* is the determination of the shear stress in aluminum at a 80-kbar shock compression pressure). The results of the investigations are presented in Table 1. Also represented are results of analogous measurement performed by other authors [14-16].

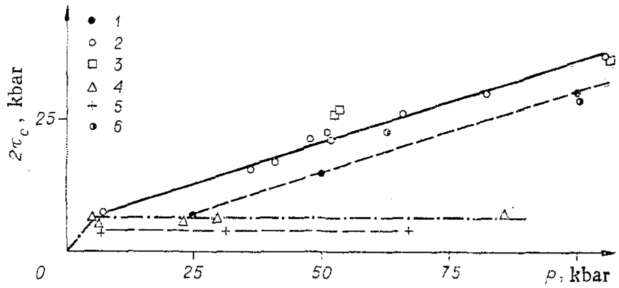

Fig. 3

Dependences of the shear stress in steel and Aluminum AD-1 on the hydrostatic pressure

$$p = (p_n + 2p_\tau)/3$$

are superposed in Fig. 3 in the coordinates $2\tau_c - p$. Comparisons between the results in [1], obtained under hydrostatic compression conditions (St. 45 points 1, data from the paper [15] points 5 for aluminum V95, the authors' data for aluminum AD-1, points 6).

As in statics, the dynamic dependences $2\tau_c - p$ exhibit a smooth increase in the shear stress due to pressure. However, the results of the dynamic experiments are arranged considerably higher than the corresponding static measurements. This distinction can be explained by the inhomogeneity of the stress state over the specimen diameter in the static measurements, for which τ_c is the shear stress averaged in a certain manner over the specimen area. A detailed analysis of the static experiment for a more accurate comparison with our results does not seem to be possible. It is impossible to relate this discrepancy to the temperature difference in the two kinds of experiments since the temperature increment in the shocks is not large in the pressure range being investigated, and even more, it should not result in diminution in the magnitude of the shear stress.

Let us note also the noticeable difference in the behavior of the dependences $2\tau_c = f(p)$ obtained for St. 3 and St. 45 obtained in this paper (points 2 and 3) from the analogous dependence for St. 20 obtained in [14, 15] (points 4), from which data τ_c is independent of the shock compression pressure in the range to 90 kbar.

Attention is turned to the fact that the shear stresses coincide at the phase transition point for two stages investigated, while they differ significantly in the intermediate domain (from the Hugoniot elastic limit to the phase transition pressure).

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INVESTIGATION OF STRESS WAVES IN GLASS TEXTOLITE AND FLUOROPLASTIC ARISING WITH RAPID HEATING BY RADIATION

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1. As a result of rapid heating of a condensed medium up to a level corresponding to a concentration of absorbed radiation energy much less than the heat of vaporization, stress waves are excited in the medium [1-3]. Recording these waves gives information concerning the physical properties of the irradiated substance.

Let the concentration distribution of absorbed energy as a function of the coordinate follow an exponential law $\varepsilon(x) = \varepsilon_0 e^{-\mu x}$, where μ is the linear absorption coefficient and ϵ is the concentration of absorbed energy. The propagation of stress waves in the acoustical approximation for one-dimensional deformation of semiinfinite liquid media or for one-dimensional deformation of a linear elastic half-space with instantaneous heating is described, in dimensionless variables, by the wave equation

$$\partial^2 S/\partial \xi^2 = \partial^2 S/\partial \tau^2.$$

The solution of this equation with the initial and boundary conditions

$$S(\xi, 0) = e^{-\xi},\ S(0, \tau) = 0$$

is given by the expression

$$S = h(\tau) e^{-\xi} ch\tau - h(\tau - \xi) ch(\tau - \xi), \tag{1.1}$$

where $h(\tau)$ and $h(\tau - \xi)$ are unit Heaviside functions; $\tau = \mu c_0 t$ is the dimensionless time; c_0 is the speed of sound; $\xi = \mu x$ is a dimensionless coordinate; $S = \sigma_x/\mu\gamma_\Gamma E_0(1-\alpha)$ is the dimensionless stress; γ_Γ is the Grüneisen coefficient; α is the coefficient of reflection of radiation; E_0 is the energy density of the incident radiation; σ_x is the stress in the direction of propagation of the wave $(\varepsilon_0 = \mu E_0(1-\alpha))$. The first term on the right side of Eq. (1.1) describes the compression wave. It follows from (1.1) that along the characteristic $\tau = \xi$, the stress σ_x changes sign in a discontinuous manner from positive (compression) to negative (tension). Both positive as well as negative stresses with maximum amplitude are realized along this same characteristic. According to (1.1), the maximum compression stress with instantaneous heating varies with distance as

$$S^+_{0\max} = e^{-\xi} ch\tau \big|_{\tau=\xi} = \frac{1 + e^{-2\xi}}{2},$$

i.e., it rapidly decreases with ξ, approaching its limiting value $\lim S^+_{0\max} = 1/2$ for $\xi \to \infty$.

The finite value of the heating time leads to a decrease in the maximum amplitude of both phases of the stress wave. The transition from compression to expansion in this case occurs smoothly in a zone with finite dimensions.

The maximum compression stresses can be represented in the form

$$S^+_{\max} = S^+_{0\max} f(\tau_0) = \frac{1 + e^{-2\xi}}{2} f(\tau_0), \tag{1.2}$$

where the function $f(\tau_0) \leqslant 1$ takes into account the finiteness of the heating time; $\tau_0 = \mu c_0 t_0$ is the dimensionless heating time; t_0 is the characteristic heating time taken as equal to the characteristic duration of the radiation pulse.

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