TIME DEPENDENCE OF FRACTURE STRESSES DURING SPALL IN COPPER, NICKEL, AND TITANIUM

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The characteristic loading time τ was $\sim 10^{-6}$ sec in the majority of experimental investigations of the fracturing stresses during spall (spall strength) σ_{sp}. It is noted in a number of papers [1, 2] that the magnitude of the spall strength is practically independent of τ under the effect of pulses of such duration. A conclusion is made in [3, 4] that the longevity $\tau \cong 10^{-6}$ is the limit value of the load action time below which spalling fracture does not occur.

It is known that the strength of materials σ in the longevity range 10^{-4}-10^{-6} sec considerably exceeds the corresponding quantities calculated from the Zhurkov equation

$$\tau = \tau_0 \exp[(u_0 - \gamma\sigma)/kT], \quad (1)$$

that contains the Boltzmann constant k and the constant parameters of the material τ_0, u_0, γ. The slope of the dynamic branch of the time dependence of the strength in semilogarithmic coordinates $\log \tau - \sigma$ is considerably less than the slope of the quasistatic branch. The value of the longevity, $\tau \approx 10^{-4}$ sec, starting with which dependence (1) is not satisfied, is obtained provisionally at the intersection of lines extrapolating the quasistatic and dynamic branches in the coordinates mentioned. We know of no experimental points on the dynamic line in the range 10^{-4}-10^{-5} sec. For $\tau < 10^{-4}$ sec the deviation from (1) is associated with the fact, say, that in the region of short times the time of athermal crack growth, whose rate is limited by the speed of sound [2], becomes substantial.

To describe the time strength for short tension pulses, and in particular, for a more objective construction of the dynamic branch of material longevity, investigations of the spalling fracture in submicrosecond loading regions ($\tau < 10^{-6}$ sec) are of interest.

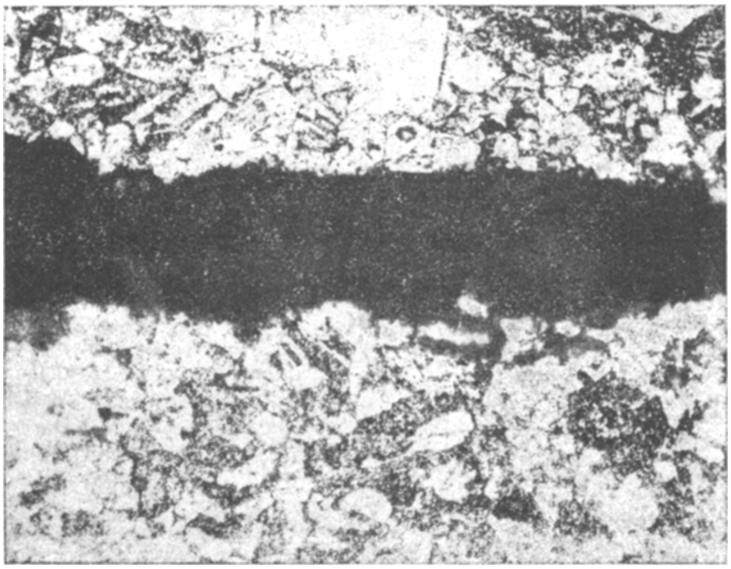

Fig. 1

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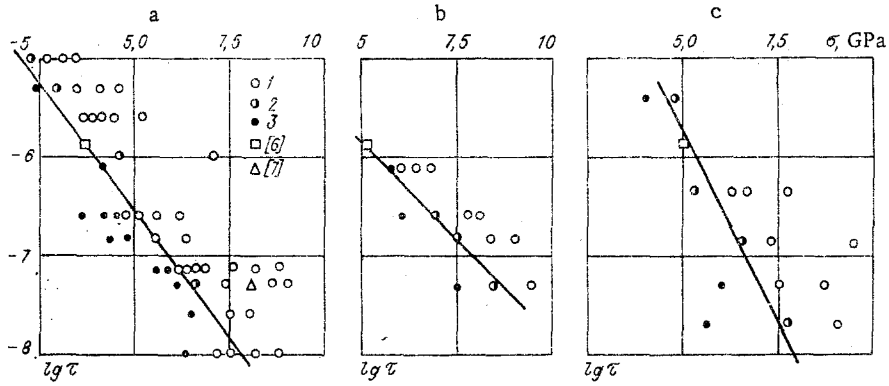

Fig. 2

TABLE 1

Metal	A	B
Cu	0,141	7,88
Ti	0,168	5,05
Ni	0,091	9,1

Results of experiments with copper specimens destroyed by the impact of thin copper foils are represented in [5]. The loading time in the experiments varied in the $5 \cdot 10^{-8}$–10^{-6} sec range. It is shown that in this interval, the σ_{sp} for copper is very much weaker than according to (1) but increases with noticeable linearity as log τ diminishes.

Analogous experiments are performed in this paper for nickel and titanium specimens in the range 10^{-6}–10^{-8} sec. The dependence for copper is supplemented by experimental points for $\tau = 10^{-5}$, i.e., in a region not investigated earlier.

Specimens of M1 copper, NP2 nickel, and VT14 titanium in the delivered state, in the shape of 40-150 mm diameter discs from 0.05-60 mm thick, were used in the experiments. The impactor plates were fabricated from the same material as the specimens, and were ∿1/3 the thickness of the specimens (from 0.017-20 mm) in order for the overtaking unloading wave not to influence the fracture process. Tests with impactors more than 5 mm thick were performed at atmospheric pressure; and in a vacuum chamber with a residual pressure not more than $5 \cdot 10^{2}$ Pa for impactors less than 5 mm thick. Acceleration of the impactors to the requisite velocities was accomplished by the sliding detonation of a thin high explosive layer of the appropriate thickness. The presence or absence of spalling fracture was determined visually by the scaling of the material being spalled or by the presence of microcracks after the specimen had been cut.

A microphotograph of a copper specimen in the mainline crack zone, which shows a very smooth fracture surface under the interaction of rarefaction waves in the spall zone for the impact of a 0.1-mm-thick foil on a 0.28-mm-thick specimen (× 500 magnification), is represented in Fig. 1. The pressure at the shock front resulting in the appearance of spall was taken as the magnitude of the spall strength. The pressure was found from the impactor velocity measured in the test and from the known shock adiabat for the materials under investigation. The characteristic time of pulse action is $\tau = 2\delta/c$, where δ is the impactor thickness, and c is the speed of sound.

Therefore, the time of load action varied by three orders of magnitude in the tests conducted.

The experimental results obtained are represented in Figs. 2a-c in the semilogarithmic coordinates $\sigma - \log \tau$ (for copper, nickel, and titanium, respectively), where 1 is the spalling fracture of the specimen, 2 is spall generation, and 3 is the absence of macrocracks. Experimental points from [6] corresponding to $\tau = 1.3 \cdot 10^{-6}$ sec as well as a point for copper from [7] are presented in all the graphs.

The experimental dependences drawn from the points characterizing the spall generation are described well by straight lines. They separate the plane σ—log τ into a domain on which spall formation occurs (to the right of the line), and a domain in which there is no fracture. Extrapolation of all three lines to $\tau \approx 5 \cdot 10^{-13}$ sec yields values of $\bar{\sigma}$ close to the theoretical strength $\sigma_T = (1/6-1/10)E$, where E is Young's modulus.

In this connection, we note that upon extrapolation of (1) to $\tau \approx 5 \cdot 10^{-13}$ sec, the value obtainable for σ is considerably less than the magnitude of the theoretical strength. As was noted in [8], for the intersection of the isotherm $\sigma = \sigma(\log \tau)$ with $\tau \approx 5 \cdot 10^{-13}$ sec to attain the value σ_T, it is necessary that parameter γ in (I), proportional to the local concentration of stress at the source of fracture generation, appear as a decreasing function of τ. Its estimate from the results of this paper for copper yields the value $\gamma \approx 0.1$ kcal · mm²/mole · kg, say, for $\tau = 10^{-8}$ sec, and $\gamma = 2.3$ kcal · mm²/mole · kg for the quasistatic longevity branch. Therefore, the results obtained in this paper are in agreement with the scheme represented in [8].

So significant a diminution in γ indicates a reduction in the volume of sources of fracture generation during spalling fracture in the submicrosecond range with diminution in the time of load action.

This is explained by the fact that because of the boundedness of the crack velocity ($v < c$), the spacing between the sources should be diminished for the cracks to join as the time of load action diminishes. In the limit, the spacing between the sources becomes interatomic for τ $5 \cdot 10^{-13}$ sec, and the magnitude of the fracturing stress becomes equal to the theoretical strength. The results presented are described by the dependence

$$\tau = Ke^{-(A\sigma+B)},$$

where K = 1 sec, and the coefficients A and B are presented in Table 1 for the metals investigated. The fact that the dependences of the spall strength on the time of load action are described well by lines drawn through values of the theoretical strength $\tau = 10^{-12}$-10^{-13} sec in semilogarithmic coordinates in the range investigated, permits the assumption that such a regularity is conserved even for other metals. This affords the possibility of predicting their behavior in a submicrosecond loading time range.

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