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Abstract

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REGULARITIES IN THE CHANGE OF THE YIELD STRENGTH OF METALS AT HIGH LOADING RATES AND LOW TEMPERATURES AND THEIR SIGNIFICANCE FOR ASSESSING THE DANGER OF BRITTLE FRACTURE

(Presented by Academician A. A. Blagonravov on 24 VII 1961)

Regularities in the change of yield strength

To determine the conditions of strength at sites of stress concentration under the simultaneous action of low temperature and high loading rates, it is necessary to know the regularities in the change of the yield strength of materials under such loading ([1]).

A method for oscillographic recording of the transition from elastic to small plastic strains under impact loading was developed in recent years ([2], [3]). This method, extended to the region of low temperatures ([4]), made it possible to investigate the resistance to initial plastic deformation of a number of structural materials over a wide range of loading rates and at several intermediate temperatures within the range from +20°C to −196°.

As shown in ([4]), for materials with a physical yield point, measurements from the oscillogram $P = f(\varepsilon)$ give conditional values $\sigma_{s\,0.2\%}$, very close to the upper yield strength. The results of measurements of $\sigma_{s\,0.2\%}$ for two aluminum alloys (AMg-6T and D-16), two steels (St-3 and St-45), and Armco iron are presented in the graph. From Fig. 1a, b, c it follows that, for St-45 and the aluminum alloys, the law of algebraic addition of the effects of rate and temperature is valid; through the dimensionless variables

$$\eta = \frac{\sigma_s(\dot{\sigma},\, t)}{\sigma_0}, \qquad \vartheta = \frac{\sigma_s(t)}{\sigma_0}, \qquad \xi = \frac{\sigma_s(\dot{\sigma})}{\sigma_0} \tag{1}$$

it can be expressed by the formula:

Fig. 1

Figure 1: Fig. 1

$$\eta = \vartheta + \xi - 1. \tag{2}$$

In (1) the notation is as follows: $\dot{\sigma} = \dfrac{\partial \sigma}{\partial t}$ is the loading rate ($\mathrm{kg/mm^2 \cdot s}$), t is temperature (°C), and σ_0 is the yield strength under static loading and $t = +20^\circ$.

However, the data from tests of St-3 and Armco iron under impact loading (Fig. 1g, d) deviated substantially from this law. To clarify the reasons for this deviation, it was of interest to investigate the change in yield strength at an intermediate loading rate: greater than in static tests, but less than in impact tests. The change in loading rate in these two cases amounted to more than a millionfold—approximately from 1 to 10^6 $\mathrm{kg/mm^2 \cdot s}$.

Measurements at an intermediate loading rate ($\sim 10^3$ $\mathrm{kg/mm^2 \cdot s}$) came to be called tests under "rate" loading. To carry them out, apparatus was developed and manufactured in the Laboratory of Strength of Materials of the Institute of Machine Science, consisting of a pneumatic, impactless loading device with an electron-oscillo-

with a graphic system for recording the loads and deformations of the specimen. The apparatus ensured loading of the specimen at a constant rate until the yield point was reached and made it possible to record the relationships: load—time and load—deformation. For recording loads, a dynamometer in the form of a steel rod was used, on which wire resistance strain gauges (sensors) were glued. The deformation was measured by the same type of sensors, glued to the reduced section of the specimen. The sensors used to measure load and deformation were connected into two measuring bridges supplied with alternating current of frequency 10 kc. When the load was applied to the specimen, the measuring bridges became unbalanced in accordance with the measured quantities, and the signals thus obtained were amplified by oscillograph amplifiers, detected, and fed in the form of direct current to the deflecting plates of the cathode-ray tubes of the oscillograph.

The results of tests under high-rate loading are plotted in Fig. 1, *g* and *d*, by dashed lines. It is easy to see that the dashed curves in the temperature interval from +20° to approximately −100° also confirm the validity of formula (2). As shown in (^{5}), the simple regularity found for the change in the yield-point value is not consistent with that proposed earlier by F. F. Wittman et al. (^{6}).

Fig. 1. *a* —AMG-6T, *b* —D-16, *v* —St-45, *g* —St-3, *d* —Armco iron.
1 —static loading, 2 —high-rate loading, 3 —impact loading (impact velocity $v_y = 3.6$ m/sec), 4 —impact loading ($v_y = 8.7$ m/sec).

As can be seen from the graph, the data from high-rate and impact tests of St-3 and Armco iron at temperatures −145 and −196° coincide. A thousandfold increase in rate in the transition from high-rate to impact loading did not lead to an increase in the yield point. Consequently, there exists a maximum value of the yield point, caused, apparently, by a sharp change in the mechanism of plastic deformation, arising under certain temperature and rate conditions of testing. From Fig. 1, *g* and *d*, it may be concluded that the relationships obtained in impact tests of St-3 and Armco iron are close to the limiting ones.

Significance of the revealed regularities for assessing the danger of brittle fracture. The data obtained make it possible to draw certain conclusions about the character of fracture as the loading rate increases. The condition of brittle fracture (^{1}), $\tau_{\max} < \tau_s$, $\sigma_1 = R_{\mathrm{b}}$ for uniaxial tension, can be represented in the form of the inequality $\sigma_s \geq R_{\mathrm{b}}$, where R_{b} is the resistance to fracture under static loading.

Values of R_{b} for St-3 and St-45 are given in (^{1}) for the temperature range investigated by us. If it is assumed that R_{b} changes insignificantly with loading rate, then comparison of the yield-point relationships obtained (Fig. 1) with the dependence $R_{\mathrm{b}}(t)$, given in (^{1}), makes it possible

to assess the danger of brittle fracture under the simultaneous action of very high loading rates and low temperatures.

The data for R_σ for temperatures from +20° to −196°, given in (^{1}), are plotted on a relative scale R_σ/σ_0 in Figs. 1 and by a dash-dot line. Comparison of the obtained yield-point characteristics with the dependence R_σ/σ_0 for St-3 and St-45 makes it possible to explain the known experimental data showing that, for these materials, completely brittle fracture is not observed under impact tension at a temperature of −196°.

This comparison also gives additional confirmation of the inadmissibility of the formula of F. F. Vitman et al. (^{6}), which, in the notation adopted in (1), has the form (^{5}):

$$\eta = \vartheta\xi. \tag{3}$$

If, using the experimental data obtained for the dependence $\vartheta(t)$ and the value of ξ at $t = +20°$, one constructs the dependence according to formula (3), then for St-45 and St-3 it would pass as shown in Figs. 1 and 2 by the dashed line with two dots. In this case, brittle fracture of St-45 under low-temperature impact tension should have begun at a temperature of −145°, and for St-3 at a temperature of −125°, which is not confirmed by experiment.

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Note: Figure translations are in progress. See original paper for figures.

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