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POSSIBILITY OF EVALUATION OF STRENGTH OF METALS AND ALLOYS BY A NONINTRUSIVE ULTRASONIC METHOD

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The dependence of the propagation velocity of ultrasonic waves on the acting stress in plastically deformable polycrystalline metals and alloys is examined. The relationship between the acting stress and the velocity of ultrasound is found to be linear; this dependence is typical of all materials studied. A method is proposed for determining the time resistance to breakdown of materials (ultimate strength) for the case of deformation in the region of small plastic strains without failure of the specimens.

It was shown [1–4] that the propagation velocity of ultrasound measured directly in tension of metal specimens depends in a complex manner on the material structure, overall strain, and acting stress. Similar data within the range of lower strains were obtained previously in [5, 6]. It is of interest to study the dependence of the propagation velocity of ultrasound $V_{\rm s}$ on the acting stress σ; a typical form of this curve for LS59-1 brass is plotted in Fig. 1. Three clearly expressed linear sections of this dependence are described by the equation [3]

$$V_{\rm s} = V_0 + \xi\sigma, \tag{1}$$

where the empirical constants V_0 and ξ are different for different stages of the process. It follows from Fig. 1 that $\xi < 0$, though sometimes $\xi > 0$ is possible (see, for example, [1, 3]); but within one stage we always have $V_{\rm s} \sim \sigma$ with a correlation coefficient $|\rho| \geqslant 0.9$.

The objective of the present work is to determine the area of applicability of Eq. (1) and to evaluate the possibility of using it for determining mechanical characteristics by a nonintrusive method. The dependences $V_{\rm s}(\sigma)$ were obtained for a number of materials. In addition to brass, we used alloys of various engineering applications: 15KhSND, 09G2S, and 12Kh18N10T steels, transformer steel (Fe–3% Si), É110 alloy (Zr–1% Nb), 1420 alloy (Al–2.2% Li–5.6% Mg), and 1450 alloy (Al–2% Li–3% Cu), and also pure cobalt (Co). All these materials have no clear yield point, and the curves of their plastic flow σ–ε have the form of a parabola. The velocity of ultrasound was measured directly in tension of planar specimens by the method of autocirculation of acoustic pulses [5]. The test technique is described in detail in [7], and here we only note that pulses of the Rayleigh surface waves with a filling frequency of 2 MHz were used for measurements.

It was found in the experiments that the character of the dependences $V_{\rm s}(\sigma)$ for different materials is rather universal. Therefore, using the dimensionless coordinates $V_{\rm s}/V_{\rm s}^*$ and $\sigma/\sigma_{\rm t}$ ($V_{\rm s}^*$ is the velocity of sound in a nondeformed material and $\sigma_{\rm t}$ is the time resistance of this material to breakdown), we can obtain a common dependence for all alloys examined (Fig. 2). With this normalization, the experimental data for different alloys are rather close, and the first two sectors of the dependence $V_{\rm s}(\sigma)$ are described by the relation similar to (1):

$$V_{\rm s}/V_{\rm s}^* = æ_i + \alpha_i\sigma/\sigma_{\rm t}. \tag{2}$$

Here $i = 1, 2$ is the stage number; the constants $æ_i$ and α_i are independent of the material and can be determined from experimental data plotted in Fig. 2. For the first sector ($\sigma/\sigma_{\rm t} < 0.6$) of dependence (2), we have $æ_1 = 1 \pm 2.7\cdot 10^{-4}$ and $\alpha_1 = -6.5\cdot 10^{-3} \pm 4.7\cdot 10^{-4}$ and for the second sector ($0.6 < \sigma/\sigma_{\rm t} < 1$), we have $æ_2 = 1.03 \pm 3\cdot 10^{-3}$ and $\alpha_2 = -3.65\cdot 10^{-2} \pm 3.2\cdot 10^{-3}$.

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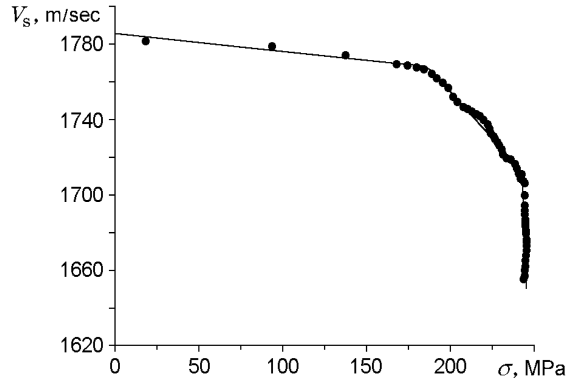

Fig. 1

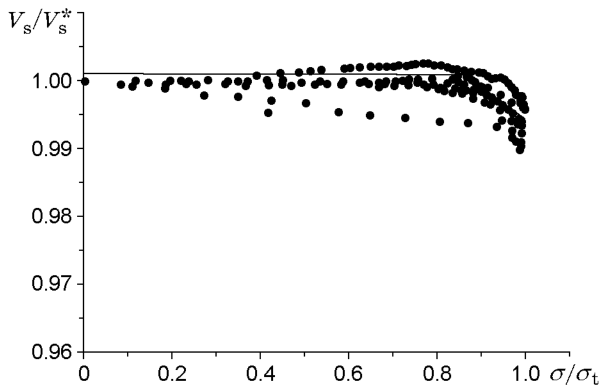

Fig. 2

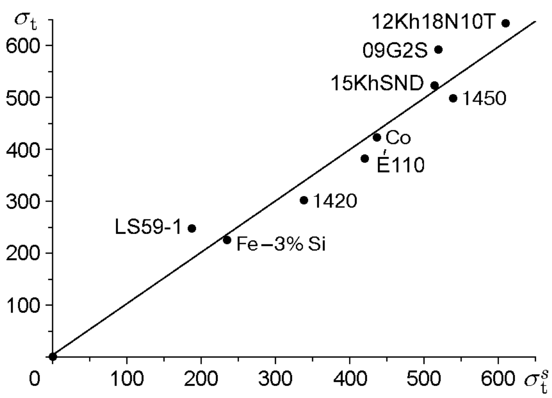

Fig. 3

Equation (2) yields

$$\sigma_t = \alpha_i \sigma (V_s/V_s^* - æ_i)^{-1}. \tag{3}$$

Obviously, relation (3) can be used to evaluate the time resistance as early as at the stage of small plastic strains without specimen failure. For this, it is sufficient to measure the velocity of ultrasound V_s for a stress σ that causes a small plastic strain and belongs to the interval $\sigma_{0.2} < \sigma < 0.6\sigma_t$ ($\sigma_{0.2}$ is a conventional yield point).

Figure 3 shows the relationship between the time resistance to breakdown (σ_t) determined by the diagram of uniaxial tension and the time resistance to breakdown (σ_t^s) calculated by Eq. (3). The velocity of sound in the loaded specimen V_s was determined for a strain $\varepsilon \approx 1\%$, which corresponds to a stress $\sigma \approx 0.1\sigma_t$. It turned out that the quantities σ_t and σ_t^s are related linearly: $\sigma_t = 0.96\sigma_t^s$, and the coefficient of their correlation is $\rho \approx 0.94$ (Fig. 3). Thus, the values of the time resistance to breakdown obtained by two methods are almost coincident. An attempt to use the results for $\sigma/\sigma_t > 0.6$ in calculations failed because of a large scatter of data. The results presented may be considered as justification of the ultrasonic method for determining the time resistance to breakdown without specimen failure on the basis of test results in the region of low plastic strains. This method seems to be promising for development of some methods of nonintrusive control of mechanical properties.

Hardening of material is known to be determined by the magnitude of fields of internal stresses (in terms of amplitudes) should be overcome by dislocations in slipping [8]. At the same time, the more stressed the material state, the smaller the propagation velocity of ultrasound [9]. Thus, the quantities σ_t and σ_t^s depend on the degree of material stress, which, apparently, is responsible for their correlation.

REFERENCES

1. L. B. Zuev, B. S. Semukhin, and K. I. Bushmeleva, "Variation of the velocity of ultrasound in plastic deformation of Al," *Zh. Tekh. Fiz.*, **70**, No. 1, 52–56 (2000).
2. B. S. Semukhin, L. B. Zuev, and K. I. Bushmeleva, "The velocity of ultrasound in low-carbon steel deformed at the low yield limit," *Prikl. Mekh. Tekh. Fiz.*, **41**, No. 3, 197–201 (2000).
3. L. B. Zuev, B. S. Semukhin, K. I. Bushmelyova, and N. V. Zarikovskaya, "On the acoustic properties and plastic flow stages of deforming Al polycrystals," *Mater. Lett.*, **42**, Nos. 1/2, 97–101 (2000).
4. L. B. Zuev, B. S. Semukhin, K. I. Bushmeleva, and N. V. Zarikovskaya, "Velocity of propagation of ultrasound in Al polycrystals with different grain size," *Fiz. Metal. Metalloved.*, **89**, No. 4, 111–112 (2000).
5. R. Truell, Ch. Elbaum, and B. Chick, *Ultrasonic Methods in Solid State Physics*, Academic Press, New York (1969).
6. A. B. Lebedev, S. V. Kustov, and B. K. Kardashov, "Internal friction and defect of Young's modulus in the crystal-deformation process," *Fiz. Tverd. Tela*, **34**, No. 9, 2915–2921 (1992).
7. V. V. Murav'ev, L. B. Zuev, and K. L. Komarov, *Velocity of Sound and Structure of Steels and Alloys* [in Russian], Nauka, Novosibirsk (1996).
8. T. Suzuki, H. Yoshinaga, and S. Takeuchi, *Dislocation Dynamics and Plasticity*, Syokabo, Tokyo (1986).
9. T. Tokuoka and Yu. Iwashimizu, "Acoustical birefringence of ultrasonic waves in deformed isotropic elastic materials," *Int. J. Solids Struct.*, **4**, No. 3, 383–389 (1968).