EFFECT OF TEMPERATURE AND STRAIN RATE ON STRENGTH AND DUCTILITY OF TERBIUM, ERBIUM, AND HOLMIUM

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This work concerns the effect of temperature and rate of strain on the mechanical properties of terbium, erbium, and holmium (98.89%, 98.8%, and 97.8% pure) with hcp lattices.*

Samples for tensile tests 2 mm in diameter, gauge length 10 mm (total length of the sample 40 mm), were annealed in vacuum at T = 0.5 Tm K.

Samples for compression tests were 3 mm in diameter and 4.5 mm high.

To avoid oxidation of the surface at high temperatures, the mechanical tests (in tension and compression) were made in argon.

The tests were made in the temperature range from −110 to 940°C at strain rates of $10^{-3}$, $10^{-2}$, and $10^{-1}$ sec$^{-1}$, which in compression were determined by the formula

$$\varepsilon = \frac{\varepsilon}{t},$$

where $\varepsilon$ is the strain, $\varepsilon = \ln(h_0/h)$; $t$ is compression time; $h_0$ and $h$ are the initial and current heights of the sample.

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Fig. 1. True stress for terbium in relation to temperature with $\varepsilon = 0.2$ at different strain rates. 1) $\dot{\varepsilon} = 2 \cdot 10^{-3}$ sec$^{-1}$ ($B_1 = 0.00127, B_2 = 0.000778$ kg/mm$^2$/T); 2) $\dot{\varepsilon} = 1.5 \cdot 10^{-2}$ sec$^{-1}$ ($B_1 = 0.001135, B_2 = 0.000695$ kg/mm$^2$/T); 3) $\dot{\varepsilon} = 1.5 \cdot 10^{-1}$ sec$^{-1}$ ($B_1 = 0.00105, B_2 = 0.000644$ kg/mm$^2$/T).

Fig. 2. True stress for terbium in relation to strain rate at different temperatures. 1) 867°C ($n_1 = 0.165$); 2) 704°C ($n_1 = 0.137$); 3) 541°C; 4) 378°C; 5) 215°C; 6) 53°C; 7) −110°C.

Fig. 3. Temperature dependence of the reduction of terbium at a strain rate $\varepsilon = 2.3 \cdot 10^{-2}$ sec$^{-1}$.
The true stress was taken as the ratio

\[ \sigma = \frac{P}{F}, \]

where \( P \) and \( F \) are the current force of compression and the cross-sectional area of the sample.

The rate dependence \( n \) of the ultimate tensile strength was determined by the formula

\[ n = \left( \frac{\log \sigma_{b2}}{\log \dot{\varepsilon}_2} \right) \left( \frac{\log \dot{\varepsilon}_1}{\log \dot{\varepsilon}_2} \right) \]

(\( \sigma_{b1} \) and \( \sigma_{b2} \) correspond to the strain rates \( \dot{\varepsilon}_1 \) and \( \dot{\varepsilon}_2 \)); the effect of stress on ductility \( \pi \) [1] was calculated by the formula

\[ \pi = \frac{e_2 - e_1}{n_2 - n_1}, \]

where \( e_2 = \ln(h_0/h_f) \) is the true strain in compression at the time of fracture; \( e_1 = \ln(F_0/F_f) \) is the true strain in tension; \( n_1 \) is the stress factor in tension, \( n_1 = 1 \); \( n_2 \) is the stress factor in compression at the time of fracture, \( n_2 = P_{av}/\sigma_f \), where \( P_{av} \) and \( \sigma_f \) are the specific pressure and true resistance respectively; \( h_0, F_0, h_f, \) and \( F_f \) are the dimensions of the samples before and after deformation in compression (h) and tension (F).

The slopes \( B_1 \) (prerecrystallization section) and \( B_2 \) (postrecrystallization section) were determined by the formula

\[ B = \frac{d \ln \sigma}{dT}, \]

where \( T \) is the melting point of the metal, "K; \( \sigma \) is the true stress, kg/mm\(^2\).

Other aspects of this method are treated in [2].

Figure 1 shows the temperature dependence of the true stress of terbium in coordinates of \( \log \sigma \) vs \( T \). The variation is nonmonotonic, i.e., there is a peak of the strain-aging type. Also, it follows from the figure that with increasing strain rates the hump (strain-hardening anomaly) shifts to higher temperatures, and with increasing strain shifts to lower temperatures. The variation of the true stress with strain rate is manifest primarily as straight lines (Fig. 2).