Impurities and the Thermal Components of Flow Stress in BCC Metals: A Discussion on the Letter "A Method for Determining The Thermal and Athermal Components of Flow Stress from Stress-Relaxation" by P. Rodriguez (J. Materials Sci. **3** *(1968) 98)*

Conrad [2, 3] splits the flow stress into its thermal and athermal components in the manner shown in fig. 1

$$\tau = \tau^* (T, \dot{\gamma}) + \tau_\mu$$

In accordance with this view, the thermal component vanishes when

$$\frac{d\tau}{dT} = \frac{\tau}{\mu} \frac{d\mu}{dT}$$

i.e., when the temperature dependence of τ is determined only by the temperature dependence of the shear modulus μ.

In our investigations on polycrystalline tantalum [4] we found, within a medium temperature range, an increase in tensile strength and strain hardening rate which is due to the interaction, typical for the body-centered cubic metals, between interstitial solutes and migrating dislocation lines. The temperature dependence of the lower yield strength in the same temperature range also shows such an increase (fig. 2); here again, it is a case of dislocation blocking by impurity atoms during microstrain. The cause for the two successive maxima is the effect of different types of atoms; calculation has shown that oxygen (content ~ 30 ppm) is responsible for the first increase and carbon (~ 60 ppm) and nitrogen (~ 40 ppm) for the second. The position of the maxima as a function of strain rate is in agreement with the calculation results, too [4].

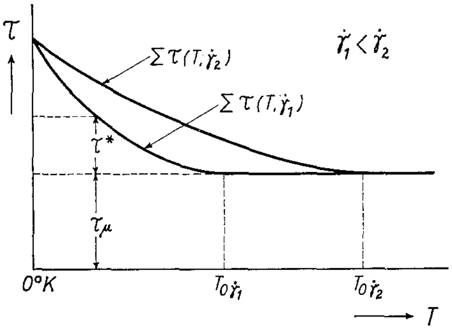


Figure 1 Variation of thermal and athermal components of flow stress with temperature and strain rate, according to Conrad [3].

Fig. 3a shows schematically how in tensile tests of normal strain rates the flow stress is increased by an additional component

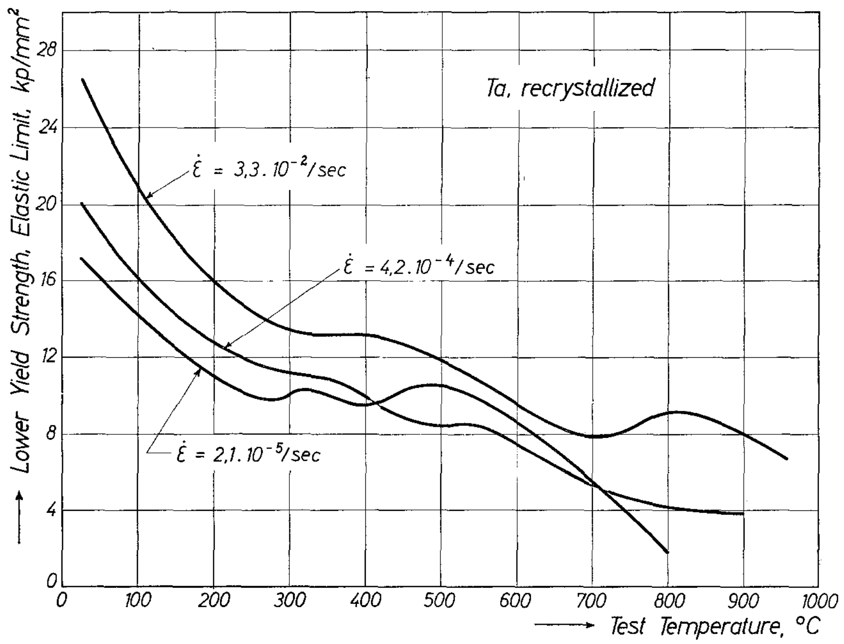
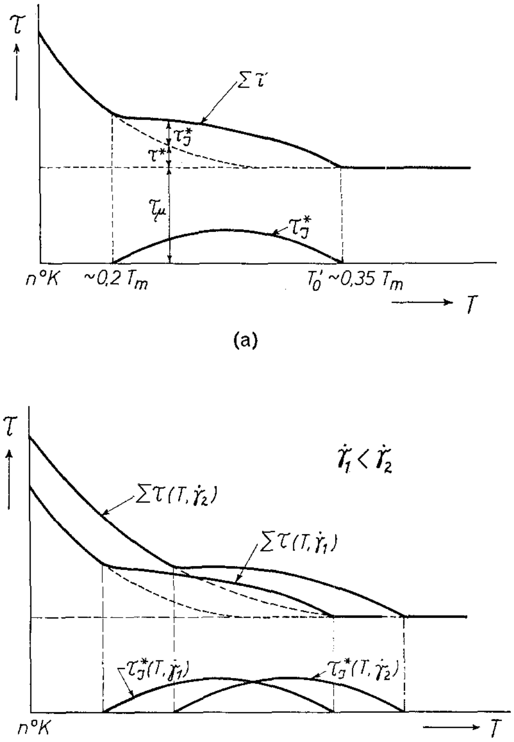


Figure 2 Lower yield strength versus temperature for recrystallised tantalum, tested at various strain rates.

$$\tau = \tau^* (T, \dot{\gamma}) + \tau_j^* (T, \dot{\gamma}) + \tau\mu.$$

τ_j^*, caused by impurities, must be considered as a thermally activated quantity since the temperature and strain rate dependence (figs. 2 and 3b) applies to it as it does for τ^* (fig. 1).



(a)

(b)

Figure 3 Additional component of flow stress due to impurity atoms (a), and its strain rate dependence (b).

In the work [2] the agreement between the T_0 values for various metals amounting to about 0.20 to 0.25 T_M is stressed: as the flattening of the stress-temperature curve is explained by the disappearance of the thermal component τ^*, the value for T_0 is the same as that for the onset of impurity effects (table I). The values of τ^* and τ_μ thus obtained should consequently be too low and too high, respectively, because the effect of the impurity atoms has not been taken into account.

TABLE I T_0 according to Conrad [2] and onset of impurity effects.

Metal	T_0 ($\tau^* \rightarrow 0$) (° C)	T_m	Temperature range of starting impurity effect ° C	Reference
Fe	77	0.190	0-100	5
Nb	207	0.1750	50-240	5
Ta	287	0.180	300	4
Mo	400	0.230	400	4

Rodriguez [1] used a relaxation method for the determination of the thermally activated proportion. The values for σ^* thus found are indeed always larger than those measured by the conventional method; in particular, T_0 appears to be shifted towards higher temperatures (the further trend has not been indicated). In our relaxation tests on tantalum we found above 200° C, where the other mechanical properties are also increased, a maximum of σ^* (table II), situated approximately at the temperature T_0 as given in [2]. Above 400° C, owing to ageing effects, the real relaxation is no longer detectable. Relaxation results from high temperature tests [6], by the way, show the difficulty involved in obtaining an unequivocal correlation between τ^* and the results from the stress-relaxation method.

TABLE II σ^* (true stresses) for tantalum as determined by stress relaxation (strained 10%, relaxation time 30 min).

Test temperature (° C)	$^*\sigma$ kg/mm^2
100	9.1
200	3.3
300	7.1
350	6
400	(2.3) ageing

Acknowledgement

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