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PLASTIC DEFORMATION IN BCC METALS*

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Similarity between the yield-stress versus temperature behaviour of solid solutions and that of pure body-centred cubic (*bcc*) metals suggests that the strength arising from the intrinsic lattice-friction in *bcc* metals may be viewed within the framework of the kink-pair model of solid-solution hardening in which the effect of alloying on the resistance to plastic deformation is considered rather akin to raising the Peierls barrier in metals. Recent experimental data on the yielding of high-purity single crystals of potassium and sodium between 1.5 and 300 K correlates well with the theoretical model.

The applicability of the kink-pair model of solid-solution hardening, initially developed for concentrated alloys ($c >$ lat.%) based on metals with low Peierls potential by Feltham[1], to concentrated as well as dilute face-centred cubic[2-6], hexagonal close-packed[7-10] and body-centred cubic[11,12] alloys has been extensively studied in recent years. The model is based on the considerations that the effect of alloying on the resistance to plastic deformation is rather akin to raising the Peierls barrier in metals so that a dislocation segment of length L experiences a solute-enhanced lattice-friction $L\,(Uc^{1/2}/b)$ in the slip plane. Here U is the mean binding energy ($< U_{max}$) of a solute atom with the dislocation, c the solute concentration (atomic) expressed as fraction, and b the magnitude of the Burgers vector.

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As the temperature dependence of the critical resolved shear stress (*CRSS*) of solid solutions is reminiscent of that of body-centred cubic (*bcc*) metals, one may expect that the strength arising from the intrinsic lattice-friction in *bcc* metals could also be encompassed by the *CRSS*-formalism of the kink-pair model[1,3] referred to, on replacing the solute-enhanced lattice-friction term $Uc^{1/2}$ by the binding energy U^* of a length b of glide dislocation in the slip plane[13]. The main object of the present work was to examine the validity of this hypothesis by taking into account the available data on the yielding of high-purity single crystals of potassium[14] and sodium[15] between 1.5 and 300 K.

The equation of relevance here appertain to the *CRSS*, $\tau(T)$. This for *bcc* metals is given by[13]

$$\tau = \tau_0 \Theta / [1 + (1 + \Theta)^{1/2}]^2, \tag{1}$$

where

$$\tau_0 = 4U^*/nb^3$$

and

$$\Theta = 4n^2\, Gb^3\, U^*/[kT \ln(\dot{\gamma}_0/\dot{\gamma})]^2.$$

As in the original solid-solution hardening treatment[1], τ_0 is the *CRSS* at 0 K, G the shear modulus, n the number of interatomic spacings in the slip plane through which a kink-pair-like dislocation segment would jump forward in the process of activation, $\dot{\gamma}$ is the shear rate of the crystal, $\dot{\gamma}_0$ a constant of the order of $10^7\ \mathrm{sec}^{-1}$ so that $\ln(\dot{\gamma}_0/\dot{\gamma}) \approx 25$ if plastic deformation is to occur at rates most often studied. However, Feltham[13] somewhat arbitrarily assumes $n = 1$ as an appropriate *working* estimate for *bcc* metals. Quantum effects[16–18] which may be of relevance below 0.1—0.2 T_{Debye} have not been taken into account in the derivation of Eq. (1).

Referring to Fig. 1 and 2, the points represent the measured values of the *CRSS* in (110) planes obtained by Basinski et al.[14] and by Herke et al.[15] with potassium and sodium single crystals, respectively. The error bars showing standard deviations of $\pm 10\%$ have been omitted for the sake of clarity. The curves drawn through the experimental points comply with Eq. (1) in which parameters given in Table 1 were used. It should be noted that the values of n and U^* selected in comparison of theory and experiment are unique, for fixing τ_0 determines U^*/n while the correct choice of Θ determines U^*n^2. A good representation of the experimental data appertaining to potassium and sodium by the *CRSS-T* formalism of Eq. (1) with reasonable values of the parameters (Table 1) is evident from Fig. 1 and 2. This suggests, in accordance with the hypothesis, that the kink-pair model of solid-solution hardening[1,3] can also provide a suitable basis for studying the low-temperature plastic deformation in *bcc* metals.

TABLE 1

Metal	τ_0 (MN/m²)	G (MN/m²)	Gb^3 (eV)	n	U^* (meV)
K	2.6	1200	0.68	1.7	0.63
Na	2.6	6000	1.92	1.8	0.37

Values of the parameters used in the *CRSS-T* formulation.

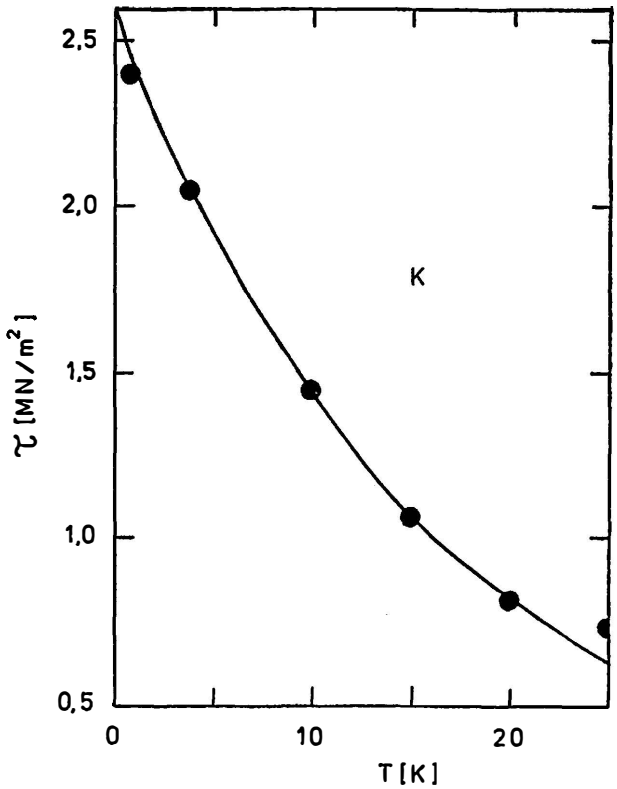

Fig. 1. The *CRSS* of potassium single crystals with orientation $\psi = 55°$, $\chi = 0°$, where ψ and χ are the angles made by the tension axis with the Burgers vector and the slip-plane normal, respectively. Points refer to Basinski et al's. measurements[14]; curve respresents Eq. (1) in which parameters given in Table 1 were used.

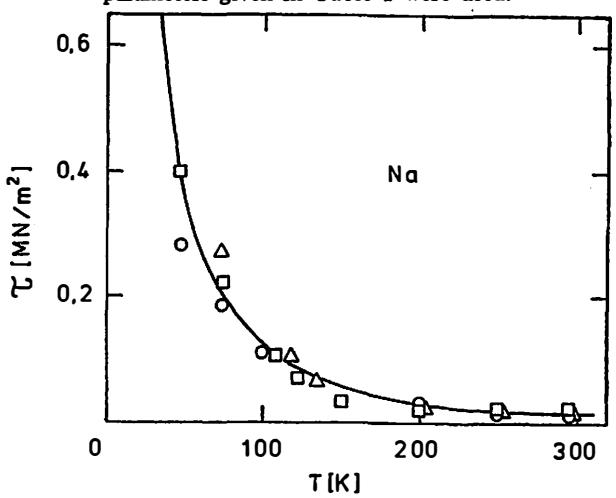

Fig. 2. The *CRSS* of sodium single crystals referred to (110) planes. Crystal orientations were $\psi = 45° \pm 5°$ and $\chi = 0°$ (0), $-20°$ (□) and $+20°$ (△). Curve drawn through experimental points of Herke et al.[15] was computed by means of Eq. (1) with the parameters given in Table 1.

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PLASTIČNA DEFORMACIJA U BCC METALIMA

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Sličnost čvrstih otopina i čistih volumno centriranih kubičnih (*bcc*) metala u ponašanju ovisnosti početka plastične deformacije o temperaturi sugerira da se čvrstoća nastala intrinsičnim trenjem rešetke u *bcc* metalima može tumačiti modelom očvršćavanja čvrstom topljivošću. U tom se modelu utjecaj legiranja na otpor plastičnoj deformaciji promatra na sličan način kao podizanje Peierlsove barijere u metalima. Taj teorijski model dobro se slaže s novim eksperimentalnim podacima o popuštanju vrlo čistih monokristala kalija i natrija u temperaturnom intervala od 1,5 do 300 K.