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ON THE EFFECT OF VACANCY SINKS AND SOURCES ON SERRATED YIELDING DUE TO SOLUTE LOCKING

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In a recent communication Murty et al. (1) have considered the effect of both vacancy creation and vacancy annihilation on the critical strain required for the onset of serrated yielding in substitutional alloys. In determining the total vacancy concentration present at a given strain, the rate of vacancy production and annihilation were incorrectly integrated as separate quantities (Eqs. (4) and (8) of ref. (1)) resulting in an incorrect expression for the vacancy concentration which preducts a net vacancy subsaturation at sufficiently low strain rates or high temperatures. In the present note this error is amended.

The total rate of vacancy change during deformation is given by

$$\dot{C}_v = \dot{C}_v^{\varepsilon} + \dot{C}_v^{-} \qquad (1)$$

where $\dot{C}_v^{\varepsilon}$ is the rate of vacancy production during straining and $\dot{C}_v^{-}$ is the rate of vacancy annihilation. For vacancies produced by the non-conservative motion of jogs on screw dislocations.

$$\dot{C}_v^{\varepsilon} = K_1 \dot{\varepsilon} \tag{2}$$

where the constant K_1 has been previously defined (1). Assuming first order annealing kinetics

$$\dot{C}_s^{-} = -K (C_v - C_v^{T}) \tag{3}$$

where C_s^{T} is the thermal equilibrium vacancy concentration and K is the effective rate constant for the annealing process. The rate constant will depend on the vacancy mean free path, the solute concentration, and will, in general, not exhibit a simple temperature dependence (2). If dislocations act as the primary sinks,

$$K = K^1\rho = K^1(\rho_o + R\varepsilon)$$

where ρ_o is the initial dislocation density and RK is a constant. On substituting Eqs. (2) and (3) into (1) the change in vacancy concentration with strain for constant strain rate tests is given by

$$\frac{d(C_v - C_v^{T})}{d\varepsilon} = K_1 - K^1 (\rho_o + R\varepsilon)(C_v - C_v^{T}) \tag{4}$$

where it is assumed that dislocations are the primary vacancy sinks.

Integrating Eq. (4) gives

$$C_v - C_v^T = K_1\left(\frac{2\dot{\varepsilon}}{K^1 k}\right)^{1/2} \frac{\pi^{1/2}}{2} Z e^{-Z^2} \gamma^*(1/2, -Z^2) \tag{5}$$

where

$$Z^2 = \frac{K^1}{Z\dot{\varepsilon}R} (\rho_o + R\varepsilon)^2$$

and

$$\gamma^* (1/2, -Z^2)$$

is an incomplete gamma function given by (3)

$$\gamma^*(1/2, -Z^2) = \frac{Z}{\pi^{1/2} Z} \int_o^Z e^{Z^2} dZ. \tag{6}$$

In the limit of low strain rates or high temperatures where vacancy annihilation is important $\gamma^*(1/2, -Z^2)$ may be expanded as

$$\gamma^*(1/2, -Z^2) \sim \frac{Z^{-2} e^{Z^2}}{\pi^{1/2}} \left[1 + \frac{1}{2Z^2} + \frac{3}{4Z^4} + \ldots\right] + (-Z^2)^{-1/2}. \tag{7}$$

Substituting (7) into (5) gives to first order

$$C_v - C_v^T \sim \frac{K_1 \dot{\varepsilon}}{K^1(\rho_o + R\varepsilon)} \tag{8}$$

A similar expression for the excess vacancy concentration is obtained for the case where K is constant. Integrating Eq. (4) with K substituted for $K^1 (\rho_o + R\varepsilon)$ gives

$$C_v = C_v^T = \frac{K_1 \dot{\varepsilon}}{K}\left(1 - e^{-\frac{K\varepsilon}{\dot{\varepsilon}}}\right) . \tag{9}$$

In the limit of low strain rates or high temperatures Eq. (9) reduces to

$$\left\{ C_v - C_v^T \sim \frac{K_1 \dot{\varepsilon}}{K} \right\} . \tag{10}$$

In the opposite limit of high strain rates or low temperatures Eqs. (5) and (9) both give

$$\begin{aligned} C_v - C_v^T &= K_1 \varepsilon \\ \dot{\varepsilon}_c &= k\varepsilon^2 \end{aligned} \tag{11}$$

as is usually assumed for the normal Portevin-Le Chatelier effect in substitutional alloys.

Although only the limiting cases have been considered, it is apparent that the behavior of C_s and hence the critical strain at the onset of serrated yielding may be significantly modified by vacancy annihilation during straining. It is also apparent that the general effect of vacancy annihilation at a given temperature and strain rate will be to increase ε_c by reducing C_v. A quantitative treatment of recent experimental measurements (4,5) of ε_c in terms of vacancy annihilation during straining is in progress (6).

REFERENCES

1. K. L. Murty, F. A. Mohamed, and J. E. Dorn, Scripta Met., 5, 1087 (1971).

2. A. C. Damask and G. J. Dienes, Point Defects in Metals Gordon and Breach, New York, (1963).

3. Handbook of Mathematical Functions, N.B.S. (1964).

4. P. G. McCormick, Scripta Met. submitted for publication.

5. S.J. R. MacEwen and B. Ramaswami, Phil. Mag. 22, 1025 (1970).

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