THE DETERMINATION OF STACKING FAULT ENERGY BY THE TETRAHEDRON METHOD*

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At present there are three methods for obtaining values of the stacking fault energy γ of face-centred cubic (f.c.c.) materials by direct observation of dislocation–stacking fault configurations in the electron microscope. These are based on measurements of extended three-fold dislocation nodes (e.g. Whelan 1958; Brown and Thölen 1964), faulted dipole configurations (e.g. Häussermann and Wilkens 1966; Steeds 1967), and triangular Frank dislocation loops and stacking fault tetrahedra (e.g. Silcox and Hirsch 1959; Loretto, Clarebrough, and Segall 1965). The main advantages of the third method over the other two are that it is applicable to materials of a very wide range of stacking fault energy and involves only simple length measurements of defects that are easily recognized. However, it has suffered from the disadvantage that the values of γ deduced from these measurements relied on an incomplete theory. The present authors have reconsidered this problem and, subject to the limitations of isotropic linear elasticity, have taken into account the major variables that may affect the values of γ. It is the purpose of this note to present the results of this theory in a form in which values of γ may easily be obtained from measurements of Frank dislocation loops and stacking fault tetrahedra without the resources of a large digital computer.

Loretto, Clarebrough, and Segall (1965) have shown that triangular Frank dislocation loops and stacking fault tetrahedra are formed in f.c.c. metals and alloys when these are plastically deformed. Their experiments indicated that a dislocation mechanism was responsible for the formation of the triangular Frank loops and that all the stacking fault tetrahedra were formed by the dissociation of these in the manner originally suggested by Silcox and Hirsch (1959). Thus, by observing the size of the largest tetrahedron and the smallest Frank loop in a given plastically deformed material, it is possible to determine the critical edge length l_c above which the transformation of loops to tetrahedra is energetically unfavourable.

Several authors (Czjzek, Seeger, and Mader 1962; Jøssang and Hirth 1966; Humble, Segall, and Head 1967) have computed the energy balance between triangular Frank loops and stacking fault tetrahedra as a function of defect size, but they have considered only the terms in the dislocation interaction energy and stacking fault energy. We have recently reformulated the problem considering the total energy of the defect (Humble and Forwood 1968). This formulation includes terms such as the kinetic energy of the moving Shockley dislocations T, the energy dissipated to the crystal lattice μ, and the work done by the stress W, as well as terms in the interaction energy E_{td} and fault energy $E_{t\gamma}$. The potential energy of a crystal containing the defect $E_{td}+E_{t\gamma}-W$ was plotted as a function of dissociation,

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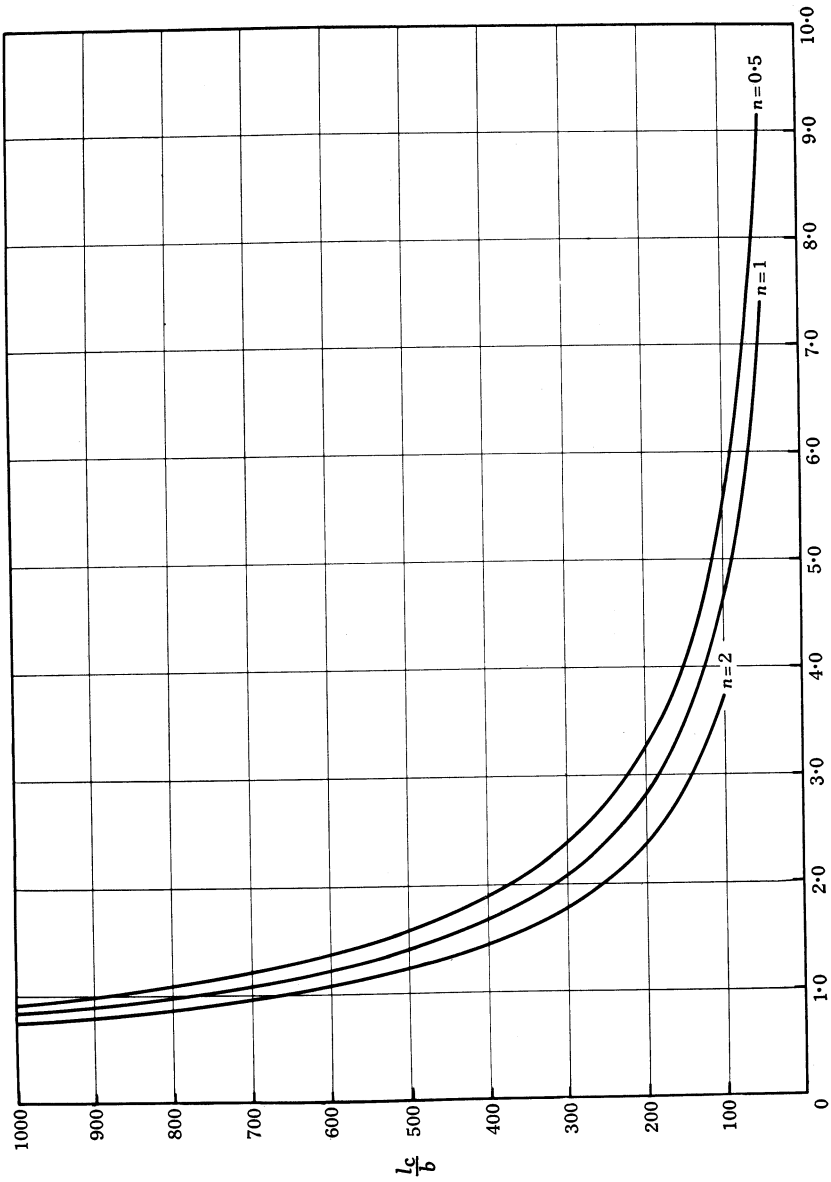

Fig. 1.—Curves of the critical defect edge length l_c/b versus the stacking fault energy γ/Gb along which triangular Frank dislocation loops just transform to stacking fault tetrahedra. See text for full details.

and any decrease in the potential energy from its value at zero dissociation (the Frank loop) corresponds to an equivalent increase in $T+\mu$. By considering the maximum kinetic energy available to the Shockley dislocations for the cases of copper, silver, and gold, it was possible to estimate their maximum velocity and thus show that very little energy is lost to the crystal lattice. It is possible, therefore, to consider the transformation to be conservative.

For a given critical size of defect l_c, the stacking fault energy was determined by finding that value of γ at which the total drop in potential energy from the value for the undissociated Frank loop, A, to the minimum in the curve, B, was equal to the increase from B to a maximum at C, which took place during the later stages of dissociation. This procedure for determining stacking fault energy by equating the potential energy at A to that at C was shown to be reliable, since, within the limitations of the model, these two points are independent of the exact detail involved in the dynamics of the transformation.

On the basis of these considerations, curves of stacking fault energy γ/Gb (where G is the shear modulus and b the interatomic distance) have been calculated as a function of the critical edge length l_c/b. Three such curves are shown in Figure 1. They were calculated on the basis of a three-parameter model for the way in which triangular Frank loops dissociate (Humble, Segall, and Head) and on the assumption that all the kinetic energy of the moving dislocation is conserved.

In calculating the curves in Figure 1, the inner cutoff radius ϵ for a particular dislocation has been taken to be directly proportional to the Burgers vector **B** of that dislocation, that is, $\epsilon = n\,|\,\mathbf{B}\,|$. The three curves in Figure 1 correspond to values of $n = 0{\cdot}5$, 1, and 2.

The value of the shear stress used in the calculations was $1{\cdot}57\times10^{-5}G$. This corresponds to a tensile stress σ of $0{\cdot}5\times10^{-3}G$ in the metal acting normal to the plane of the Frank loop. This is of the order of the flow stress for most metals. To indicate the variation in the value of γ with variation in stress, the values of γ/Gb for three values of l_c/b at tensile stresses of 0, $0{\cdot}5$, and $1{\cdot}0\times10^{-3}G$ for $n = 1$ are given in Table 1.

TABLE 1

VARIATION OF γ WITH VARIATION IN STRESS FOR $n = 1$

	$(\gamma/Gb)\times10^3$ at:		
l_c/b	$\sigma = 0$	$\sigma = 0{\cdot}5\times10^{-3}G$	$\sigma = 1{\cdot}0\times10^{-3}G$
100	4·54	4·63	4·72
400	1·58	1·67	1·76
1000	0·75	0·84	0·93

The value of Poisson's ratio ν used throughout the calculations was $0{\cdot}4$. To within 1%, the l_c versus γ curves for other values of ν may be obtained from the curves in Figure 1 by multiplying the values of γ/Gb for a particular l_c by the factor $(1-0{\cdot}4)/(1-\nu)$.

It may be seen from Table 1 that the values of γ/Gb show a different dependence on l_c from that deduced using previous theories. For example, the values deduced on the theory of Humble, Segall and Head (1967) using the same model

as that used here with the energy criterion of Czjzek, Seeger, and Mader (1962) for values of l_c equal to $100b$, $400b$, and $1000b$ are $4 \cdot 37 \times 10^{-3}$, $1 \cdot 33 \times 10^{-3}$, and $0 \cdot 60 \times 10^{-3}$ respectively.

The curves given in Figure 1, together with the variations indicated above, provide a means of estimating the stacking fault energy of a wide range of f.c.c. metals under varying conditions whenever the determination of a critical edge length for the transformation of triangular Frank loops to stacking fault tetrahedra is possible.

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Corrigendum

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Throughout the paper *replace* 2·077 MeV *by* 2·081 MeV for the energy of the second level.