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Author

Thomas, G.

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April 1963

Letter to the Editor

THE EFFECT OF SHORT-RANGE ORDER ON STACKING FAULT ENERGY AND DISLOCATION ARRANGEMENTS IN FCC SOLID SOLUTIONS

G. Thomas

Department of Mineral Technology and Inorganic Materials
Research Division, Lawrence Radiation Laboratory,
University of California, Berkeley, California

Recent experiments on α-brasses (Thomas, 1963a) have shown that under certain conditions the stacking fault energy increases with increasing amounts of zinc. Figure 1 shows the variation of the apparent stacking fault energy γ, determined from the radii of curvature of extended nodes (Howie and Swann, 1961) as a function of zinc content. An increase in γ was observed in Cu-(30-34 at. %) Zn for very slowly cooled alloys and for specimens aged one hour at 200°C after rapid quenching, whereas in quenched alloys γ falls continuously as observed previously by Howie and Swann (1961). The dislocations remain coplanar in the alloys which showed an increase in γ but were not extended. They are often arranged in groups of pairs of the same sign as shown in Fig. 2. Contrast experiments (Howie and Whelan, 1962) have shown that these pairs are not dipoles (as at B, Fig. 3) which are also frequently observed in alloys where dislocations remain coplanar (Swann and Louat, 1963, Thomas, 1963b).

About the same time that these observations were first made, Cohen and Fine (1962) showed theoretically that short-range order is expected to increase γ and cause dislocation pairing. The latter effect had been predicted previously by Cottrell (1953) and Seeger (1958). Furthermore, Cohen (private communication) has shown that clustering (negative short-range order) is not expected to produce pairing. Nevertheless, clustering may produce an increase in stacking fault energy since the surrounding matrix becomes more dilute as solute atoms are removed from solution and diffuse to clusters. Thus as with short-range order, alloys tending to cluster will also show differences in stacking fault energy with different heat treatments. However, clusters can be resolved by electron microscopy, as is now well known for aluminium alloys, and have not yet been observed in any of the alloys discussed here. In either case, quenched alloys, which should show only weak short-range order or clustering, would be expected to have a lower stacking fault energy than aged alloys as is shown by Fig. 1.

Since short-range order has been detected in α-brass by a number of workers (e.g., see Clarebrough et al, 1960, 1961), the results given here are presented as experimental verification of the theoretical predictions.

Swann and Nutting (1961) observed that during heating a Cu-7% Al alloy in the electron microscope an extended node collapsed and dislocations then paired together. This was explained in terms of long-range order. However, diffraction experiments have clearly shown that only local order, and no long-range order, exists in the α-phase Cu-Al solid solutions (Houska and Averbach, 1959). It is suggested, therefore, that the results of Swann and Nutting are better explained by short-range ordering.

Similar effects have also been found in certain austenitic stainless steels. When the nickel content of high purity Fe/Cr base alloys is increased, the stacking fault energy (again determined from node measurements) increases. For example γ for Fe/20Cr/10Ni is ~ 15 ergs/cm^2 and rises to ~ 25 ergs/cm^2 for Fe/20Cr/20Ni until at higher nickel contents no extended nodes are visible. If one extrapolates the change in γ with percent nickel, a value of 60 $ergs/cm^2$ is predicted for Fe/20Cr/40Ni. Thus in this alloy, after deformation, the dislocations would be expected to tangle. Actually they remain coplanar, often in pairs. This phenomenon is enhanced if nitrogen is also present (Fig. 3), yet nitrogen does not visibly affect the stacking fault energy.

Although there are no published data regarding ordering in austenitic alloys, Roberts (private communication) has shown by neutron diffraction that long-range order is present in a Fe/20Cr/55Ni alloy but not in Fe/20Cr/40Ni although strong local order is probable in the latter case. On this basis and by analogy with the results obtained on α-brasses, it is concluded that the increase in γ with increasing nickel in austenitic alloys is due to short-range order. Arguments have been given elsewhere to explain the effects of nitrogen in enhancing local order (Douglass et al, 1963). Neutron diffraction experiments are being continued to try to obtain further confirmation of these conclusions.

Whilst it is already known that transmission electron microscopy is a powerful method for investigations of long-range order (e.g., see Marcinkowski, 1962), from the foregoing it now appears that the technique may also provide indirect means for detecting short-range order. However, observations of dislocation pairing alone cannot be taken as proof of short-range order because pairs (superdislocations) are also present if long-range order exists. It is particularly difficult to distinguish between the two cases by electron microscopy if an alloy contains elements of similar atomic scattering factors. In this event even if long-range order is present the intensities of superlattice reflections are too weak for them to be observed.

Furthermore, antiphase domain boundaries cannot be detected because of the very large values of the extinction distances associated with weak superlattice reflections. Although long-range ordering can produce either an increase or a decrease in γ depending on the particular alloy (Marcinkowski, 1962), short range ordering is expected only to increase γ (Cohen and Fine, 1962).

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FIGURE CAPTIONS

Fig. 1 The apparent stacking fault energies of α-brasses determined from the radii of curvature of extended nodes. The results of Howie and Swann (1961) are also given for comparison. (Courtesy J. Austr. Inst. Metal).

Fig. 2 Paired dislocations in Cu-$33\frac{1}{3}$ at % Zn deformed 10% in tension after furnace cooling from 800°C.

Fig. 3 Coplanar dislocations in Fe/20Cr/40Ni/0.04N deformed 10% in tension. There are groups of the same sign at A; the contrast at B is due to dipoles. The stacking fault energy in this alloy is too large to be determined.

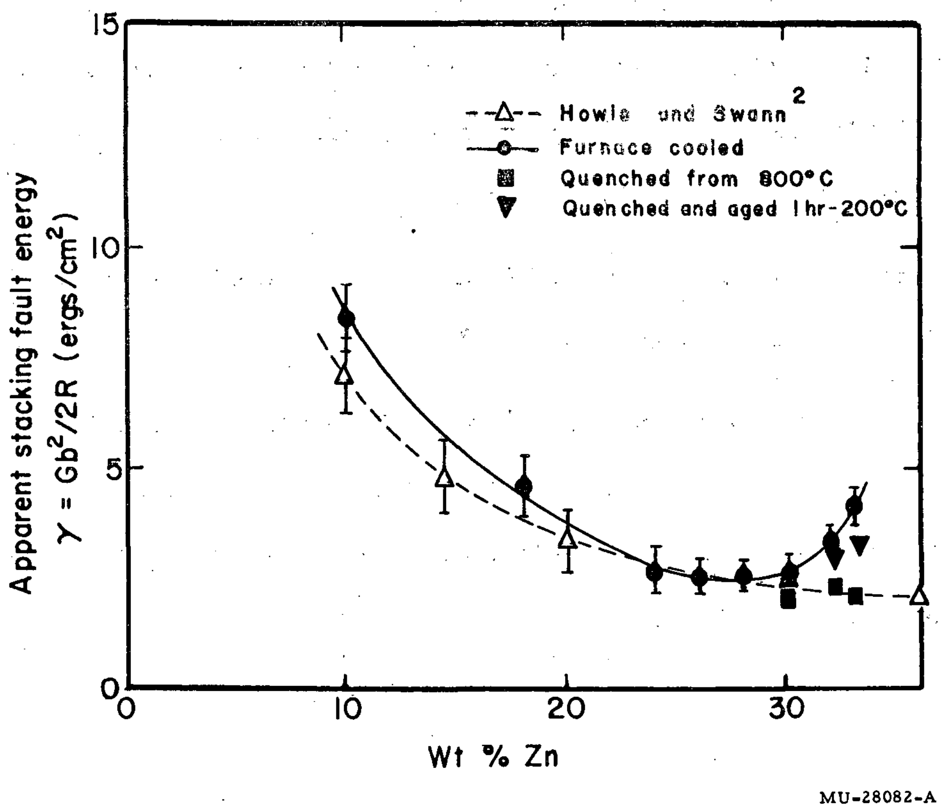
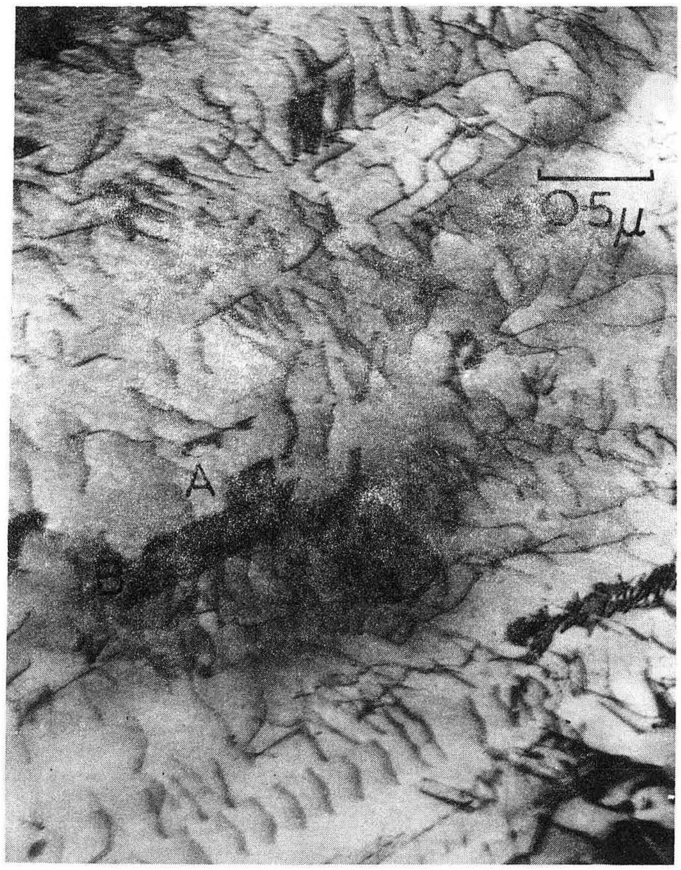

15
10
5
0
0
10
20
30
Wt % Zn
Apparent stacking fault energy
γ = Gb²/2R (ergs/cm²)
Howie and Swann 2
Furnace cooled
Quenched from 800°C
Quenched and aged 1 hr-200°C
MU-28082-A

Fig. 1

ZN-3663-A

Fig. 2



ZN-3665-A

Fig. 3