LETTERS TO THE EDITOR

The Formation of Stacking Faults in Magnesium-Yttrium Alloy

The nature of stacking fault formation that occurred in a Mg-1%Y alloy was examined by diffraction contrast, using an electron microscope. In view of its wide application⁽¹⁾, the yttrium-magnesium system has been investigated.

A master alloy of eutectic composition (Mg-26wt%) was prepared from magnesium (99.97wt%) and yttrium (99.8wt%). It was melted in a high-purity alumina crucible (CC-SSA Type) under a dynamic atmosphere of argon. The alloy containing 1wt% yttrium was homogenized in argon atmosphere at 540°C for 20 hr. Strips, 0.3 mm thick, were prepared by extrusion and hot rolling. The specimens were all solution-treated for 3 hr at 540°C in argon atmosphere and quenched in water. They were aged in mixed dichromate salts. The foils for transmission electron microscopy (electron microscope JEM 200A operating at 200 kV) were prepared by electropolishing in a bath of 30% nitric acid in ethanol.

The stacking faults on basal planes in magnesium and beryllium and those on the basal and non-basal planes in titanium are often the $\{10\bar{1}2\}$ twins occurring due to deformation⁽²⁾⁽³⁾. The stacking faults in basal planes of cadmium and zinc are believed today to arise from precipitation of the vacancies produced by either cold work or surface oxidation of thin foil or bulk material^{(3)~(5)}.

The stacking fault energy for magnesium is estimated to be about 300 ergs/cm² for the basal plane⁽⁶⁾. Pure magnesium has a high stacking fault energy and the only fault observed is that associated with vacancy loops in the quenched metal⁽⁷⁾. The observation of stacking faults bounded by partial dislocations of the type $\frac{1}{3}\langle 10\bar{1}0 \rangle$ in magnesium alloys seems to have been restricted only in the case of trace addition of zinc to Mg-Th alloy; in this case stacking faults are formed on (0001) planes when the quenched alloy is aged at a tempera-

Photo. 1 Stacking-faults in a Mg-1%Y alloy.

ture between 300°~400°C⁽⁸⁾.

Photograph 1 illustrates the stacking faults in the Mg-1%Y alloy which were caused by quenching and aging at 300°C for 5 hr; the fault plane revealed by standard trace analysis⁽⁹⁾ is (0001). The nature of the stacking faults and values of $g \cdot b$ for partial dislocation has been determined by diffraction contrast techniques⁽⁸⁾. The stacking faults are intrinsic faults bounded by glissile partial dislocations of the type

$$\pm \frac{1}{3}\langle 10\bar{1}0 \rangle.$$

The extended dislocations observed in the Mg-1%Y alloy are due to dissociation of the perfect dislocations by partial shearing on (0001):

These results are in agreement with those by Noble et al. in thin-film electron transmission studies on magnesium-thorium alloys⁽⁸⁾. Photograph 2 shows dislocations near an inclusion; the alloy was furnace cooled after annealing at 540°C for 100 min (cooling rate: 100°/hr).

The inclusions associated with dislocations are quadrilateral in shape. Diffraction study

Photo. 2 Stacking-faults near an inclusion in a Mg-1% Y alloy.

indicates that they are Y_3Mg_{17} . According to Noble et al. in magnesium-thorium alloys containing traces of zinc, elastic force attracts thorium and zinc atoms to dislocations. The dissociation observed, therefore, is thought to be due to the reduction in free energy of the system caused by removal of the solutes from the supersaturated solid solution by adsorption at the stacking fault. The yttrium atom is 11.9% larger than the magnesium atom and the thorium and yttrium atoms have almost the same size. Dissociation of the dislocation may then take place in segregation of yttrium into the dislocations in the Mg-1%Y alloy.

The stacking fault energy can be obtained by measuring the equilibrium spacing of partial dislocations⁽¹⁰⁾. In the case of close-packed lattices, the stacking fault energy is given as

$$\gamma = \frac{Gb_1 \cdot b_2}{8\pi d_0} \cdot \frac{2-\nu}{1-\nu} \quad (1)$$

where b_1 and b_2 are the Burgers vectors of the partials ($b_1 + b_2 = b$), and d_0 is a factor related to the width of the partials. The relation between d_0 and the actual separation of the partials, d , (the width of the stacking fault) is expressed as

$$d_0 = d \frac{2-\nu}{2-\nu-2\nu \cos 2\phi} \quad (2)$$

where ϕ is the angle between direction of the faulted ribbon and the Burgers vector b . The values used for the constants were $G = 1.77 \times 10^5$ kg/cm², $b = 1.49$ Å and $\nu = 0.28$. In the

Table 1 Stacking-fault energy of Mg-1% Y alloy aged for 116 hr.

Aging temp. (°C)	Width		Angle (ϕ°)	Stacking fault energy (erg/cm ²)
	d (μ)	d_1 (μ)		
200	0.27 ± 0.08	0.37 ± 0.05	19 ± 2	12.8 ± 3.84
300	0.39 ± 0.09	0.54 ± 0.08	16.5 ± 4	8.9 ± 2.1
400	0.55 ± 0.16	0.76 ± 0.12	18 ± 3	6.3 ± 1.8

Mg-1%Y alloy, the apparent stacking fault energy γ obtained from eq. (1) is dependent on the heat-treatment applied; these results are given in Table 1. It is shown that the apparent stacking fault energy in the alloy aged at 200°C for 116 hr is larger than that in the alloy aged at 300°C for 116 hr. The effect becomes more pronounced in the case of aging at 400°C for 116 hr. From these results, it is concluded that the apparent stacking fault energy is reduced by high-temperature aging.

REFERENCES

- (1) E. D. Gibson and O. N. Carlson: *Trans. ASM*, **52** (1959), 1084.
- (2) J. P. Poitrier, J. Antolin and J. M. Dupouy: *Can. J. Phys.*, **45** (1967), 1221.
- (3) P. G. Partridge: *Met. Rev.*, **118** (1967), 169.
- (4) P. B. Price: *Electron Microscopy and Strength of Crystals*, Interscience Pub. New York and London, (1963), p. 41.
- (5) A. Bergherzan, A. Fourdeux and London S. Amelinckx: *Acta Met.*, **9** (1961), 464.
- (6) S. Friedel: *Electron Microscopy and Strength of Crystals*, Interscience Pub. New York and London, (1963), p. 605.
- (7) J. S. Lally and P. G. Partridge: *Phil Mag.*, **13** (1966), 9.
- (8) B. Noble, T. J. Pihe and A. Crok: *Phil Mag.*, **17** (1970), 543.
- (9) J. P. Hirth and J. Lothe: *Theory of Dislocations*, McGraw-Hill, (1968), p. 298.
- (10) L. E. Murr: *Electron Optical Applications in Materials Science*, McGraw-Hill, (1970), p. 434.

By Hideo Kayano*, Tokuji Hayase**
and Seishi Yajima*

* Oarai Branch, The Research Institute for Iron, Steel and Other Metals, Tohoku University, Oarai, Ibaraki 311-13, Japan.

** Research Laboratory, Nippon Carbon Co. Ltd., Shin-Urashima, Kanagawa-ku, Yokohama 221, Japan.

(Received May 29, 1975)