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Study on stacking faults of bainites in a Cu–Zn–Al alloy

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Bainitic transformation is a common type of solid phase transformation in which plate-like precipitates are formed in ferrous, non-ferrous alloys and ceramics. However, considerable disagreements still remain between diffusion and shear schools, as this transformation is of a rather complicated nature.

Wayman [1], Christian [2] and Lieberman [3] proposed that if a transformation product is formed by a shear mechanism, it should display some special inhomogeneity of microstructure, such as twins, stacking faults or interfacial dislocations, which can produce lattice invariant deformation (LID). It is known that the internal substructure of bainite plates (α_1) in Cu–Zn–Al alloys is stacking faults [4, 5]. However, whether stacking faults appear inside initial α_1 plate is a point in dispute. According to the shear mechanism [6–8], α_1 plates are the products of a shear process which involves an invariant plane strain (IPS), and the stacking faults serve as the heterogeneity producing the IPS. However, many experimental results indicate that no any stacking faults exist in initial α_1 plates [9, 10].

Furthermore, the present authors [11] discovered that evolution of α_1 plates in Cu–Zn–Al alloys passes through three stages: initial, intermediate and degenerate. In the initial stage, stacking faults are absent in α_1 plates, while there exist ledges on the broad faces and at the tip of them [12]. In the intermediate stage stacking faults appear in α_1 plates. Upon further ageing, α_1 plates enter the third stage. The stacking faults disappear gradually and finally α_1 plates transform to equilibrium α phase. Up to now, both the shear and diffusion schools share the same viewpoints on the characteristics of intermediate and degenerate α_1 plates. The controversy is whether stacking faults exist in initial α_1 plates, which is one of the key pieces of evidence needed to clarify the mechanism of bainite reaction in Cu–Zn–Al alloys.

In the light of our experimental results, i.e. stacking faults appear in the second growth stage not the initial one, it is reasonable to infer that there is a formation process of stacking faults during the initial and intermediate growth stages. Unfortunately, this is only a deduction and so far no papers about the formation process of stacking faults have been published. This paper deals with this topic and describes the fault formation for the first time.

Specimens of Cu-25.9Zn-4.0Al (wt %) alloy were soluted at 1073 K for 5 min and then quenched in ambient water. They were subsequently aged in a nitrate–nitrite bath at a mediate temperature for different times to form bainites at different stages. Their microstructures were observed using a H-800 transmission electron microscope (TEM), operated at 200 kV.

Fig. 1 is a bright field micrograph of initial α_1 plates. No stacking faults were observed within these two plates no matter how the specimen was tilted and rotated in the microscope. Moreover, thickness fringes indicate the existence of three-dimensional ledges on the broad face of initial α_1 plates. As mentioned above, this is the characteristic of initial bainites which implies that bainite plates are formed by a diffusion mechanism not shear. In Fig. 1, there are four ledges with a height of 20 nm or so on the broad face of the bainite plate A. As plate A takes on a gradual tapering morphology from the original part to the tip, it is reasonable to consider that these ledges will move along the longitudinal direction of this plate, as illustrated by the thick arrow. After all the ledges move to the tip, plate A will take on a thicker morphology similar to plate B.

Fig. 2 shows the microstructure of two degenerate bainite plates. Plate A is at the early stage of degeneracy and stacking faults exist. In plate B, stacking faults have vanished and there exist only irregular dislocations inside. Some of the dislocations tangle together, or even form a network, as indicated by arrows C and D.

Fig. 3 shows the formation process of stacking faults. Here the bainite plate is around 0.6 μm wide and more than 3 μm long. Obviously, this is an α_1

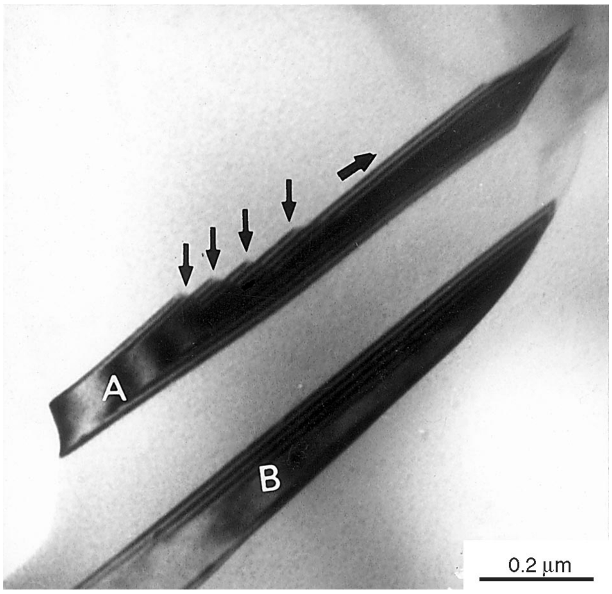

Figure 1 Initial α_1 plates (523 K, 360 s).

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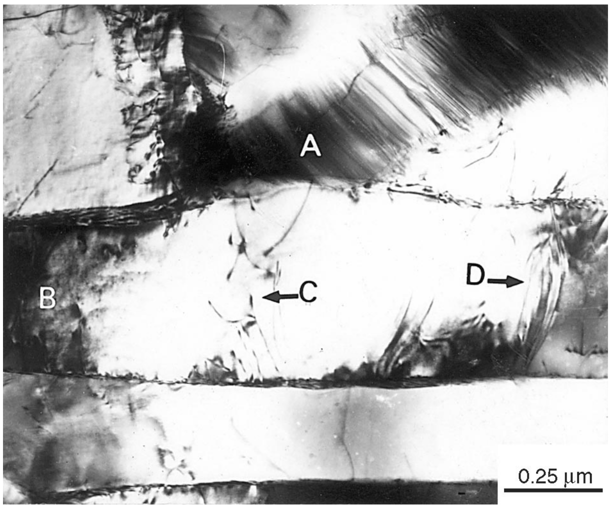

Figure 2 Degenerate α_1 plate (623 K, 1200 s).

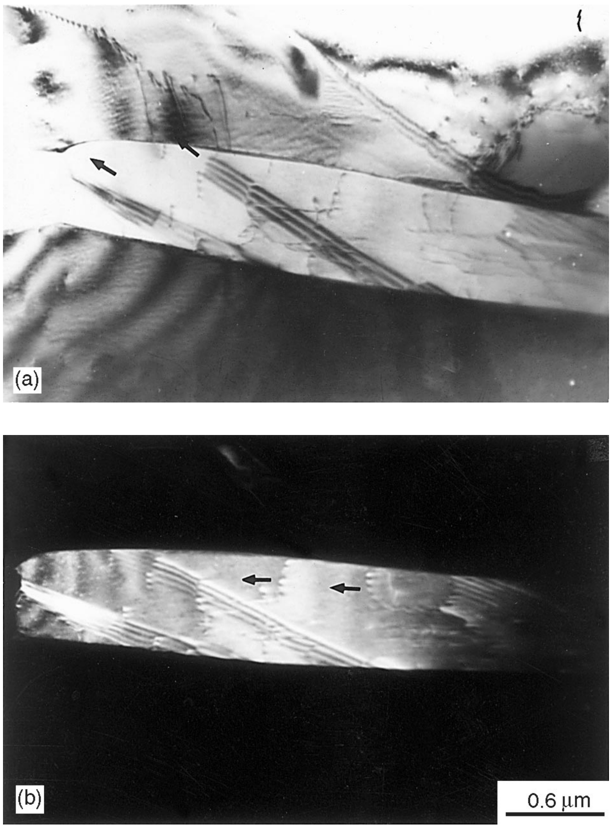

Figure 3 Formation of stacking faults (573 K, 400 s): (a) bright field image; (b) dark field image.

plate which has grown to a certain extent but not a nucleus of bainite or an initial one. It reveals clearly that two sheaves of stacking faults extend from one broad face to the opposite side of the plate, as shown by the arrows. There are dislocations in other parts of this plate which are arranged regularly.

What is to be emphasized is that an intermediate bainite plate is different from a degenerate one. This can be easily distinguished in Fig. 2 and Fig. 3. The interfacial structure of a degenerate α_1 plate is not even, and displays an arched shape which results from the long-range diffusion of solute atoms upon long-term ageing. Moreover, in degenerate bainite plates the dislocations show a dense and irregular dispersion. In contrast, the interfacial structure of the intermediate bainite plate in Fig. 3 is even and the density of dislocations is very low. The dislocations distribute regularly and move forward along the growth direction of the plate.

From the experimental results we can see that stacking faults do not appear simultaneously with the formation of α_1 plates in the Cu–Zn–Al alloy. This indicates that bainite is not formed by a shear mechanism. Furthermore, there exist ledges on the broad faces and (or) at the tip of bainite plates. Many experimental results demonstrate that the growth of bainite is governed by a ledgewise mechanism [10, 12]. Stacking faults appear at the intermediate stage and have nothing to do with shear. As there is volume contraction between the matrix and the α_1 phase (according to a rough calculation, the volume contraction amounts to around 3.5%), high internal strains take place in the α_1 plates during the transformation. Also, the stacking fault energy of brass is very low (only 0.07 J/m^2 [13]). The formation of stacking faults is thus considered to relax the internal strains of bainite [11].

Acknowledgements

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