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Metallographic study of thermoelastic martensite transformation in a Cu-Zn-Al alloy①

Wang Mingpu(汪明朴), Xie Xianjiao(谢先娇), Yang Jie(杨 杰), Peng Chaoqun(彭超群)
Department of Materials Science and Engineering,
Central South University of Technology, Changsha 410083, P.R. China

Abstract: The structural characteristics of M18R martensite, self-accommodation configuration of single variant group and its formation process in a polycrystal Cu-Zn-Al alloy were studied by means of Polyver-MET. Mainly, one grain contains one variant group and one group contains 2～4 variants which consist of three kinds of twins, called as AC, AB and AD. The forming process of a group is related with the self-accommodation of stress and strain.

Key words: Cu-Zn-Al alloys; shape memory alloys; metallography **Document code**: A

1 INTRODUCTION

Cu-base shape memory alloy (SMA) is a low-price and high-quality alloy. Its shape memory effect (SME) comes from the thermoelastic martensite transformation. The structure of martensite and the procedure of martensite transformation have been studied by means of optical microscopy observation, X-ray diffraction and TEM for many years. The early studies which were concentrated on the monocrystalline Cu-Zn alloy and Cu-Zn-Ga alloy play a key role in the establishment of the mechanism of SME[1,2]. Delaey[3] and Cao[4] studied the martensite transformation in the monocrystalline and the polycrystalline Cu-Zn-Al alloy, respectively. Delaey put forward the concept of the self-accommodation of martensite transformation[5], but he didn't study the forming process of variant group. Recently, Tan[6] studied the process of martensite transformation in a monocrystalline Cu-Al-Ni alloy by means of optical microscopy observation and reported the forming process of some single variant and variant pair which may be 2H martensite structure. In this paper, the self-accommodation configuration of the M18R martensite and its formation process were observed and analyzed carefully. It is concluded that the forming process of variant group is related with the self-accommodation of the transformation stress and strain.

2 SPECIMEN PREPARATION AND EXPERIMENTAL METHODS

The alloy used for experiment, Cu-17.99 Zn-13.63Al(%, mole fraction), was melted in a medium-frequency induction furnace and the ingot obtained was hot-rolled into sheets of 1 mm in thickness. The specimens were solution-treated at 800 ℃ for 10 min, quenched into water, then aged in water at 100 ℃ for 30 min (β_1 parent phase state). By the electrical resistance method, the martensite transformation temperature was measured as follows: $M_s = 53$ ℃, $M_f = 23$ ℃, $A_s = 41$ ℃, $A_f = 62$ ℃. In order to obtain martensite relief, the metallographic specimen (15 mm × 15 mm) was mechanically polished in water at the temperature of 70 ℃, then electro-polished in phosphoric-acid solution at the same temperature. Optical microscopic observation was performed on Polyver-MET under polarized light. Under polarized light, different

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variant in one variant group shows different color, so they are easy to be distinguished from each other. Color films recorded the experiment results in a continuous photo manner. We processed the heating and cooling with a self-made accessory, which was heated by loading on electric current and cooled by liquid nitrogen. The heating and cooling speed can be adjusted within 0.1~2.0 ℃/min.

3 RESULTS AND DISCUSSION

3.1 Morphology characteristics of martensite in polycrystalline Cu-Zn-Al alloy

Fig. 1 shows the typical morphology characteristics of martensite in polycrystalline Cu-Zn-Al alloy at a low magnification. One grain contains one martensite variant group generally. Sometimes, 2 or 3 variant groups can be seen in a few grains. However, in a monocrystalline Cu-based alloy, one grain contains 6 martensite variant groups[2]. The difference may be related with the existence of the grain boundary. Every variant group is different with each other in morphology: some is spear ("*Z*" shape), some is parallel, some is prismatic configuration and some is random hunk. Even for the spear variant pairs, their included angle between variant A and C is different. Obviously, the difference in morphology is related with the difference of group configuration and the difference of grain orientation. The martensites, which have a fixed orientation relationship with parent phase, intersected with the polishing-face of specimen in which the grains orient randomly. Thus, the plentiful and colorful morphology characteristics are produced.

3.2 Metallographic analysis of a typical martensite variant group in polycrystalline Cu-Zn-Al alloy

Fig. 2 shows a typical morphology of variant group in polycrystalline Cu-Zn-Al alloy. It can be seen that one group is composed of four different variants, called as A, B, C and D. They showed different color under the polarized light. In single variant, there are no twin substructure characteristics which can be seen in 2H-type

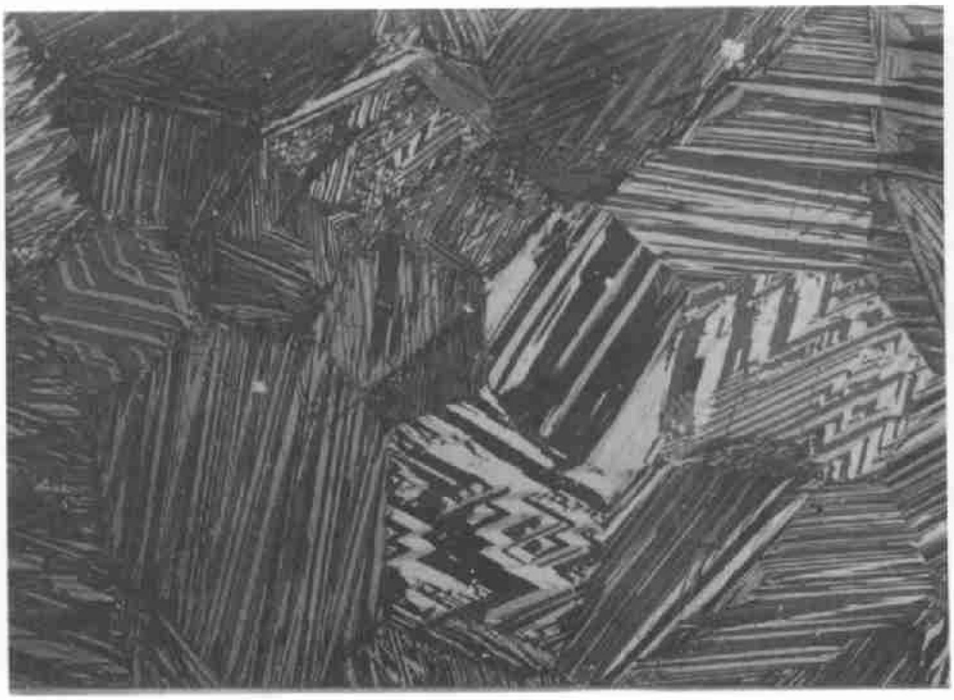

Fig. 1 Typical morphology of martensite in polycrystalline Cu-Zn-Al alloy

martensite[7]. So it is concluded that the martensite is 9R or 18R structure. In fact, the X-ray diffraction and electron diffraction analyses of the martensite indicate that its structure is faulted M18R[8]. Unlike the monocrystalline alloy, it is difficult to determine the crystalline orientation in the polycrystalline alloy, but the martensite configuration in single variant group can be analyzed by means of the transformation crystallography knowledge[2]. In one group (Fig.2), there are three kinds of manner in the combination of variants:

(1) Spear variant pair AC (or BD);

(2) Fork variant pair AD (or BC);

(3) Parallel variant pair AB (or CD).

The interface of the AC variant pair is flat and variants A and C are twin-related with respect to the interface. The twin-plane is $\{110\}_{\beta_1}$ (or $\{128\}_M$)[2]. The interface of the AB pair is flat too. Variants A and B are twin-related with respect to the $\{155\}_{\beta_1}$. In fact, the $\{155\}_{\beta_1}$ plane is the habit plane of martensite. The interface of the AD pair is more complicated than that of the AB pair and that of the AC pair. Firstly, it is not as flat as those of the AB pair or the AC pair. Secondly, many small twins crossed variant A near the interface(see" ↑ "). The interior of the small twin has the same color as that of variant D. So it is concluded that the small twins is the fragment of variant D. The interface of the AD pair is the joint face only. Variant A and D are twin-related with respect to the $\{1020\}_M$. In Fig.2, small twin structure often can be seen in the big martensite variant (see" ↑↑ "). These small twins still belong to the group. They intersected or joined each other in the big variant and their relationship was marked in Fig.2.

3.3 Optical microscopy observation of martensite variant group forming process in polycrystalline Cu-Zn-Al alloy

Fig.3 shows a variant group forming process of M18R martensite. Fig.3(a) shows the metallographs of the alloy above M_s temperature. It is single β_1 parent phase. Some etch pits, which were produced during electro-polishing, can be seen as the sign of the visual field. When temperature decreased to M_s, the variant C grew up at first and the variant B grew up on both ends. The variant B was joined to variant C, which formed the BC-type fork variant structures. There are no accommodation twin in the joint between B and C. These phenomenon may be related with the existence of β_1 parent phase which made the adjusting of transformation

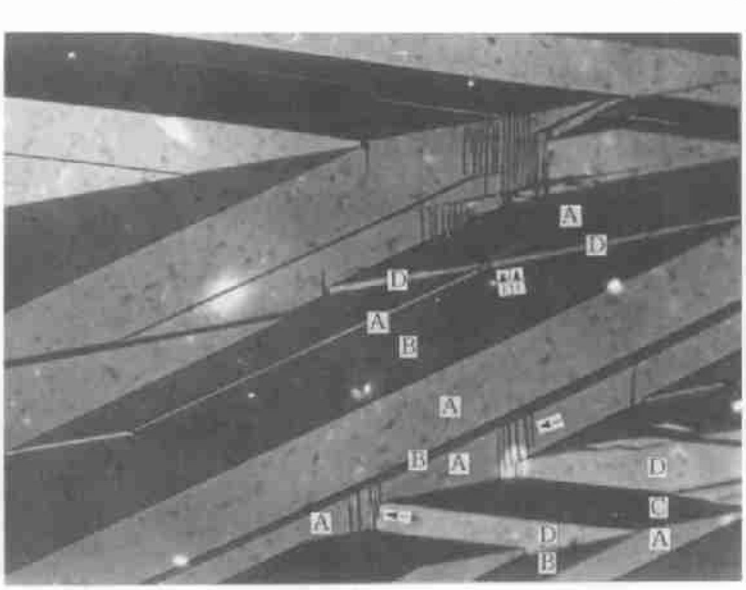

Fig.2 Configuration of variant group M18R martensite

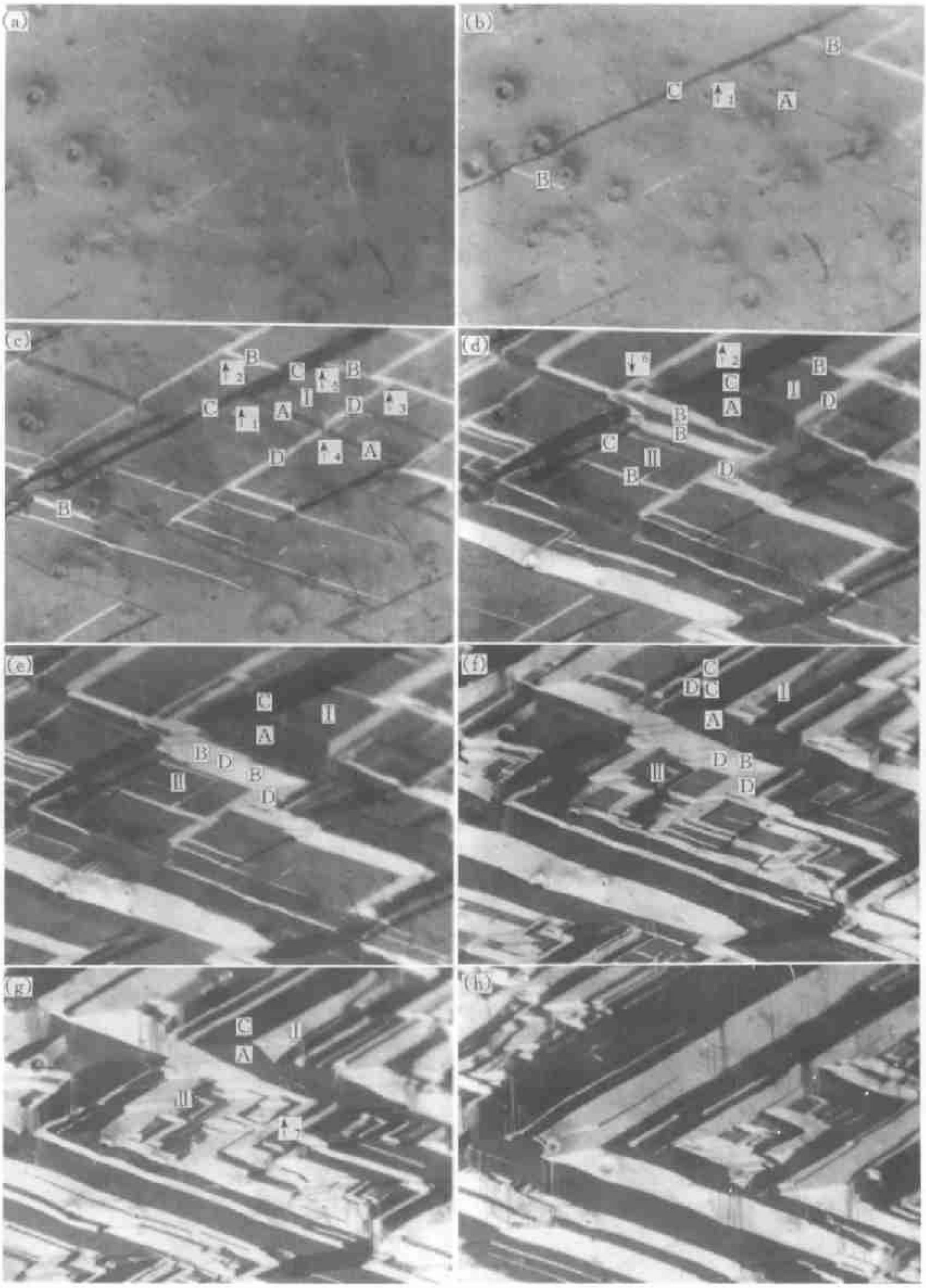

Fig.3 Variant group forming of M18R martensite

easy. Another variant A grew out and was joined to variant C, which formed the spear variant structure AC(Fig.3(b), "↑1").

When temperature continuously decreased (Fig.3(c)), variant B grew out ("↑2") and formed the fork variant structure with variant C. The variant D grew out and formed spear variant pair BD with variant B("↑3"). During forming the spear variant pair (AC or BD), the variant that grew up early (C or B) broadened obviously when it was joined to the variants that grew up later. At the site of "↑4", variants A and D grew along the right-down and left-down direction, respectively. They intersected at the "↑4", crossed each other, and formed the step-liked crossed structure. If variant A is taken as the main variants, it can easily be seen that the structure is composed of two variant pairs AD. By now, variant A, B, C and D constituted the prismatic self-accommodation configuration, which composed of two spear variant pairs(AC or BD) and two fork variant pairs(AD or BC). For pair AB(or CD), two variants did not join up with each other yet, and there exists an angle difference between them. In fact, the angle difference between them reflects that between their habit planes.

When temperature further decreased (Fig.3 (d)), the spear variant pair AC broadened rapidly, but pair BD broadened slowly. It is interesting that the variant B disappeared on cooling(Fig.3(c)"↑2"). This may be related to the transformation stress that comes from the broadening of the variant C. The direction of the broadening of the variant C is mainly towards right-up. Its transformation stress may hinder the growth of the variant B. Similar to the process of the martensite re-orientation under the external stress, under the transformation stress, the variant with the disadvantageous orientation will be replaced by the advantageous one. Similarly, the growth of two B variants broke the variant C(Fig.3(c)"↑1") and formed the pair AC as shown in Fig.3(d). In the area Ⅱ, the fresh variant B and the old variant D and C formed another prismatic configuration which composed of two BD pairs and two BC pairs. In addition, another prismatic structure, which composed of variants BDBD appeared at the "↓6". The prismatic structure which composed of variants ABCD, as shown in area Ⅰ, is regarded as the typical self-accommodation configuration. But the prismatic structure at the area Ⅱ and "↓6" are completely different from that at the area Ⅰ. The difference shows the multiplicity and complexity of the self-accommodation configuration.

On the subsequent cooling, while the remainder parent phase changed into martensite continuously, the formed martensite continuously adjusted its pattern and structure under the stresses that come from fresh martensite forming and the release process of its transformation stress. As shown in Fig.3(e), the variant B (area Ⅱ) adjusted into BDBD-type step-like structure gradually while the parent phase transformed into martensite. And the small D variant step moved continuously, changed its location (Fig.3(f)), then formed the pattern which composed of double spear pairs BD and AC at last(Fig.3(g) "↑7"). On the left of area Ⅱ, the fresh variants are mainly variant pair BD (Fig.3(f)) and the small variant (A, B, C, D) filled up in the center at last. For the two variant pairs BD (up-left of the pair AC in area Ⅰ), through self-accommodation, variant B disappeared and variant C grew up, which formed the CDCD-type parallel variant pair at last (Fig.3 (f), (g)).

It is must pointed out that the variant group forming process mentioned above was taken at the second thermal cycling. Its final morphology is showed in Fig.3(g). The first cooling process completed after the electro-polishing. At the same area, the martensite morphology of the first cooling was showed in Fig.3(h). It is very different from those of the second thermal cycling. It is suggested that not all the growing process of thermoelastic martensite was reversible, but they grow up along the same direction, and still belong to the same variant group.

4 CONCLUSIONS

(1) The morphology characteristics of martensite in polycrystalline Cu-Zn-Al alloy are

very plentiful. It is the result of the intersection between different variant groups with metallographic polished face in different orientations. In most case, one grain mainly contains one variant group.

(2) A typical martensite variant group composes of four variants (A, B, C and D). There are three morphologies in one group: spear variant pair (AC or BD), fork variant pair (AD or BC), and parallel variant pair (AB or CD). The variant pair is twin-related with each other.

(3) The growing process of a variant group is very complicated. The variants grow early is not always stable. With the action of growth stress of other variants and the release of its growth stress, it adjusts its morphology continuously, even changes its type of variant in order that whole variant group exists in state with minimum growth stress and strain.

(4) On the view of morphology, not all the growing process of thermoelastic martensite is reversible, but the same area stills belong to the same variant group.

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