MORPHOLOGY AND STRUCTURE OF TRANSFORMATION PRODUCTS FORMED AT INTERMEDIATE TEMPERATURE IN A Cu–Zn–Al ALLOY①

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ABSTRACT

A TTT diagram for the precipitation formed at some intermediate temperatures through cooling from high temperature parent phase in a Cu–27.27Zn–3.73Al alloy is established by means of dilatometric measurement. The morphology and structure of transformation products formed at some intermediate temperatures isothermally through cooling from high temperature parent phase and up-quenching from DO_3 parent phase are studied by metallographic, X-ray and electron microscopy analyses. Three regions in the two separate C curves are obtained according to different morphology of precipitate: rod-like α, plate-like bainite and α rods, and bainite plates. Prolonged aging makes bainite plate change gradually into α whose lattice parameters are no different from that of α formed equilibriumly from parent phase. The structure is almost orthorhombic long period structure for bainites formed from B_2 and DO_3 parent phase, but monoclinic for martensite from DO_3. They correspond to the overlapping and separating of (1 2 10) and (2 0 10) diffraction peaks respectively, showing the lower degree of ordering in bainite.

Key words: Cu–Zn–Al alloy transformation at intermediate temperature morphology and structure

1 INTRODUCTION

Garwood[1] found that the isothermal transformation products formed from high temperature parent phase in a Cu–41.3 wt.–% Zn alloy are plate-like bainite below 315 ℃, rod-like α above 430 ℃ and their mixture in between. Flewitt and Towner[2] gave out, in Cu–40.5～44.1 wt.–% Zn in alloys, TTT diagrams for the precipitation formed through up-quenching from martensitic state shows that there exists three regions for the transformation products which was conformed by many researchers[3] in Cu–Zn–Al alloys, the structure of the bainite formed through up-quenching from martensitic state was found to be $9R$ by Takezawa and Sato[4, 5] and $N9R$ by Yang, *et al*[6]; however, Wu, *et al*[7] concluded the $N9R$ after 350 ℃ for short time aging and $M18R$ after 150 ℃ for 96 h. The stacking faults in bainite plates are gradually annealed out and the plates eventually transformed to α during aging[7–9]. Up to now, no detailed study about the transformation products and their structures in Cu–Zn–Al alloy has been reported. In present investigations

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the isothermal transformation products formed through cooling from high temperature parent phase are studied and compared with the bainite formed through up-quenching from DO_3 parent phase. The structures are analyzed for bainite formed from $B2$ and DO_3 parent phase and for martensite from DO_3.

2 EXPERIMENT AND RESULTS

2.1 *Isothermal Transformation Diagram*

The Cu−27.27 Zn−3.37Al (wt.−%) alloy is prepared for 12 mm × 2 mm × 1 mm specimens cooled from high temperature parent phase. After annealed at 550 ℃ for 1 h, cooled to 200 ℃ in furnace and then air cooled, these specimens are set in LK−02 dilatometer, heated to 800 ℃ for 10 min, at a rate of 10 ℃ / s, and then quenched to different temperatures at a rate of 100−120 ℃ / s. The measured TTT diagram is shown in Fig.1, which is composed of two separate C curves and the B_s = 370 ℃[10].

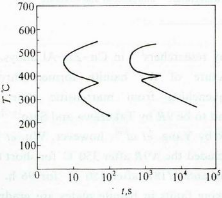

Fig.1 TTT diagram for the precipitation formed through cooling from high temperature parent phase in a Cu−27.27 Zn−3.37Al (wt.−%) alloy

2.2 *Morphology of Transformation Products*

Three regions in the TTT diagram can be obtained according to the metallographic observation:

(1) The high temperature region (370 ℃). The transformation product is rod-like α, as shown in Fig.2.

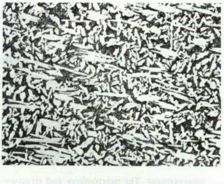

Fig.2 α rods formed by an isothermal holding at 450℃ for 30 min. × 320

(2) The intermediate temperature region (370∼300 ℃). The mixed products of α rods and plate-like bainite are shown in Fig.3 (a). At temperature below 350 ℃, the bainite plates nucleate initially and the α rods form subsequently, but at above 350 ℃ the α rods nucleate first. In the range of 300∼325 ℃, there mainly produces bainite plates, as shown in Fig.3 (b).

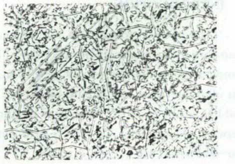

Fig.3(a) Mixed products of α rods and bainite plates formed by an isothermal holding at 370 ℃ for 2 min. × 320

(3) The low temperature region (below 300 ℃). Only bainite plates are observed. They generally occur as V-pairs separated by an ob-

tuse angle, see Fig.4 (a). The typical electron microscopy photograph of the internal faulted bainite plate formed at the initial stage is shown in Fig.4 (b). It can be seen that the morphologies of transformation products in Cu-Zn-Al alloy, at least in alloys with few contents of Al, are similar to that previously reported in Cu-Zn alloy. The straight boundaries of bainite plates gradually become uneven and wavy during a long time aging, as shown in Fig.5.

Fig.3(b) Bainite plates and little amount of α rods formed by an isothermal holding at 325 ℃ for 2.5 min. × 320

Fig.4(a) Bainite plates formed by an isothermal holding at 280 ℃ for 10 min. × 320

The up-quenching treatment in the present paper is different from general up-quenching from martensite formed through quenching from high temperature parent phase. The specimens are first heated to 800 ℃ for 7～10 min, then quenched to 150 ℃ for 15～20 min for DO_3 ordering of the parent phase[11] and finally up-quenched to a certain temperature. Experiment shows that the morphology of bainite formed through cooling from high temperature parent phase is no different from that of bainite formed through the up-quenching from DO_3 parent phase.

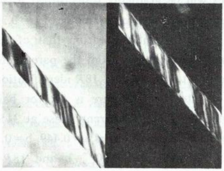

Fig.4(b) Typical electron micrographs (BF and DF) of bainite plate formed at initial stage in an isothermal holding at 300 ℃ for 5 min. × 35,000

Fig.5 The overannealed bainite plates formed by an isothermal holding at 315 ℃ for 6 h. × 500

2.3 *Structures of Transformation Products*

Plate and powder specimens are prepared respectively for the analyses of lattice parameter and ordering with a D / MAX–ⅢA automatic X–ray diffraction apparatus. Powder specimens are heat-treated in a sealed copper tube. The transition temperature of $B2-DO_3$ in the alloy used is about 290 ℃[12] Experiments show that the lattice parameters of the fcc α phase and the retained parent phase are a= 0.367,7 or 0.586,4 nm respectively. When the specimens are quenched from high temperature parent phase to 315 ℃ and held for 6 min, 1, 3, and 6 h respectively, the bainite plates will be gradually transformed to the α phase with the lattice parameter of a = 0.368,3 nm, being no different from that of the α formed equilibriumly from the parent phase. Referring to the 9*R* and 18*R* identification of the bainite, the structure is 9*R* for bainite formed from the *B2* parent phase at 315 ℃ with the lattice parameters a = 0.449, b = 0.259, c= 1.902 nm, β= 89.80(°), and 18*R* for bainite formed from the DO_3 parent phase through an up-quenching to 260 ℃ with the lattice parameters of a= 0.450, b= 0.520, c= 3.827 nm, β= 89.81(°). The structure is *M*18*R* for martensite formed from DO_3 parent phase through quenching to 0 ℃ from 150 ℃ with the lattice parameters a = 0.452, b = 0.522, c= 3.838nm, β = 88.56(°).

3 DISCUSSION

The dilatation and metallography analyses show that the kinetics characteristics and morphologies of isothermal transformation products in Cu–Zn–Al alloy with lower Al contents are similar to those in Cu–Zn–Al alloys[1,2]. In crystal structure, the DO_3 parent phase and the 18*R* long period bainite are likely to appear in Cu–Zn–Al alloy. However, the weak (111) and (019) superlattice X–ray diffraction peaks are difficult to distinguish because of the lower Al contents in the alloy used. The spacing difference of diffraction peaks (1 2 10) and (2 0 10) is reported to be directly proportional to the degree of ordering[13]. X–ray diffraction experiment shown that the (1 2 10) and (2 0 10) diffraction peaks are overlapping in bainite formed from DO_3 parent with d < 0.002,0 nm, and separating in martensite with Δd = 0.007,0 nm. These reflect the lower degree of ordering in bainite structure and the higher degree of ordering in martensite structure so that bainite is close to an orthorhomic long period structure and martensite is monoclinic, conforming to the computation results of lattice parameters according to the diffraction crystal face indexes and spacings.

Metallographic observation reveals that bainite plates grow slowly along the perpendicular direction of the broad face, maintain straight boundaries due to its fixed lattice orientation relationship with the matrix, and grow faster along the paralleled direction of the broad face. As the parallel faults are gradually annealed out during the prolonged aging, many α nuclei are formed at different spots inside the bainite plates. These α nuclei can grow quickly along the perpendicular direction of the broad face of the bainite plates becauce of its incoherent lattice orientation relationship with the matrix. Thus, as the bainite plates are partially or wholly transformed to α the morphology characteristics of bainite plates will change from straight boundaries into uneven and wavy ones, and the plates become coarser and irregular. X–ray analyses show that the transformation from bainite to α will be completed at 315 ℃ holding for 6 h.

4 CONCLUSION

The TTT diagram for the transformation products formed through cooling from high temperature parent phase is composed of two separate C curves. The first C curve corresponds to the precipitation of α rods and the second one reflects that the mixed products of α rods and the bainite plates change to single bainite plates with the lowering of the isothermal temperature. The kinetics characteristics and morphologies of transformation products in a Cu–Zn–Al alloy with lower Al contents are similar to those in Cu–Zn alloys. The morphology of bainite formed through cooling from high temperature parent phase is the same as that of bainite formed through the up-quenching from DO_3 parent phase. During aging, the straight-boundery bainite plates are gradually transformed to coarse uneven and the wavy-boundary α plates whose lattice parameter is no different from that of α formed equilibriumly from parent phase. The structure of bainite is close to orthorhombic with lower degree of ordering rather than that of martensite with monoclinic long period structure.

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