GRAIN GROWTH BEHAVIOR OF AL-MG ALLOYS

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ABSTRACT The effect of the clustering conditions of cube orientation on the grain growth process for Al-5mass%Mg alloy was studied focusing on the amount of cube cluster and the spatial distribution of cube-oriented grains. Primary recrystallized specimens which had different initial textures except for cube component were isothermally annealed at 773K and their microstructures were observed with an optical microscope and a SEM. Grain orientations and grain boundary structures were characterized using the SEM-ECP technique. The development of cube component with small volume fraction during grain growth was closely related to the frequency of cube clusters. The spatial distribution of cube component, especially the spacing of isolated cube-oriented grains, played an important role in the development of cube orientation.

Keywords: *Al-Mg alloy, grain growth, electron channeling pattern, orientation distribution function, grain boundary character distribution*

1. INTRODUCTION

Grain growth process for polycrystalline materials are important process to control the microstructure such as grain size, grain orientation, and grain boundary character (GBC) [1]. The effects of these structural factors on mechanical, physical and chemical properties have been investigated and various attempts to control these factors have been made [2-7]. Furthermore, clarification of the mechanisms of changes in these structural factors during grain growth is needed.

In the previous papers, it has been proposed that changes of grain orientation and grain boundary character distribution (GBCD) during grain growth are strongly dependent on the initial microstructure such as spatial distribution of grain orientation, GBCD, and grain size for Al-Mg alloys [8-10]. In brief, well-developed cluster of cube component ({001}<100>) plays an important role in development of cube-oriented grain and Σ 1 boundary during grain growth. The developing process of cube cluster is dominated by the locally distributed condition of GBC (LGBCD) and grain size. However, the developing process for cube component with less-developed cluster is not clear.

In this paper, the effect of clustering conditions of cube orientation on the grain growth process for Al-5mass%Mg alloy was studied focusing on the amount of cube cluster and the spatial distribution of cube-oriented grains.

2. EXPERIMENTAL PROCEDURE

Al-4.7%Mg ingot was melted from pure Al(99.99%) and Mg(99.98%) and homogenized at 753K for 172.8ks. After hot rolling to 80% reduction at 723K, cold rolling to 60% reduction was carried out. Subsequent intermediate annealing at 673K for 3.6ks was performed and cold rolling to 50% reduction was carried out. Finally, cold rolled sheet with a thickness of 1mm was obtained. The annealing for primary recrystallization was performed under the following conditions, in order to induce the different spatial distribution of cube-oriented grains.

Specimen 1: heated rapidly (about 100K/s) up to 773K in a salt bath, held at the temperature for 20s and quenched into water.

Specimen 2: heated slowly (about 0.1K/s) up to 673K, held at the temperature for 1.8ks and quenched into water.

In addition to the annealing mentioned above, annealing for grain growth was performed at 773K for an adequate time from 1.0ks to 0.1Ms.

Microstructure was investigated in the mid-section of annealed specimen using an optical microscope and a scanning electron microscope (SEM). The crystallographic orientations of 180-250 grains were investigated using SEM-ECP (Electron Channeling Pattern) technique for each sample. The grain size was determined by measuring the area of individual grains whose orientations were analyzed by SEM-ECP technique. Orientation distribution function (ODF) of these specimens were evaluated from individual orientation measurements by SEM-ECP technique[11]. The grain boundary was characterized by Σ value from the relative orientation relationship between neighboring grains across the boundary. Brandon's condition [12] was used as the criterion of the coincidence orientation relationship.

3. RESULTS AND DISCUSSION

3.1 Changes of grain orientation distribution during grain growth

Fig.1 and 2 shows the changes of orientation distribution of grains and volume fraction of the

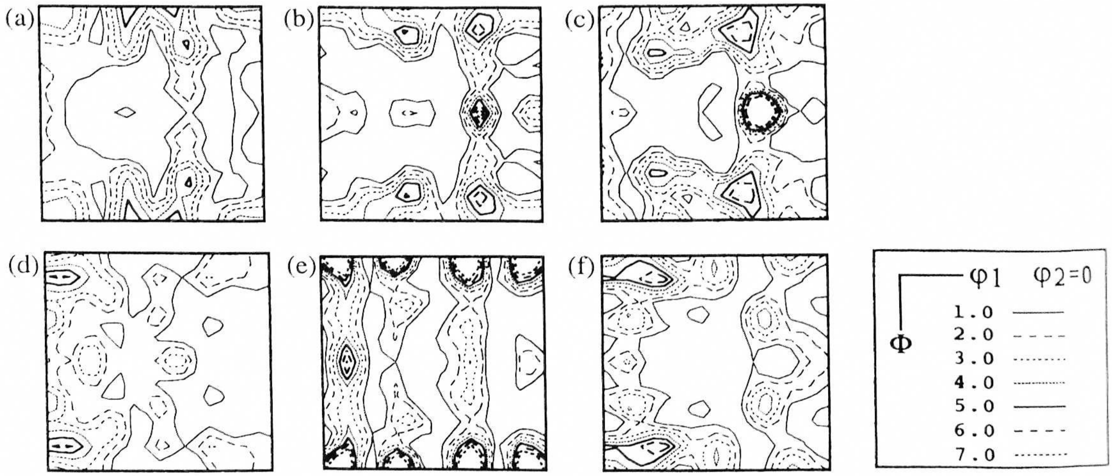

Fig.1 ODF for specimen 1 and 2 evaluated from SEM-ECP data with several annealing conditions and various average grain sizes.
(a) specimen 1, 773K-20s, 70 μ m; (b) specimen 1, 773K-1.0ks following 773K-20s, 206 μ m; (c) specimen 1, 773K-0.1Ms following 773K-20s, 480 μ m;
(d)specimen 2, 673K-1.8ks, 73 μ m; (e) specimen 2, 773K-1.0ks following 673K-1.8ks, 220 μ m; (f) specimen 2, 773K-0.1Ms following 673K-1.8ks, 406 μ m.

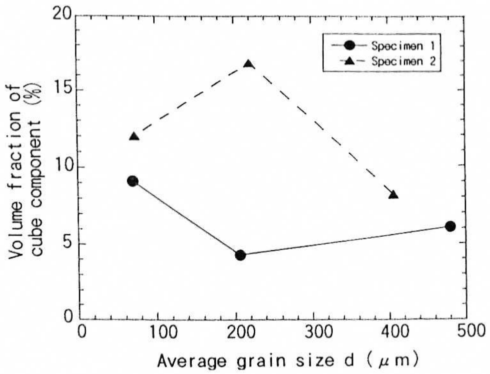

Fig.2 Variation of volume fraction of cube components with the average grain size.

cube component during grain growth. In the present paper, the volume fraction of the cube component was calculated for grains with a deviation of less than 15° from an exact cube orientation. The main orientation components for the initial specimens were different between specimen 1 and 2; cube component and ND-rotated cube components (from CR component {001}<310> to RW component {001}<110>) for specimen 1, cube component, R component ({123}<634>) and Copper component ({112}<111>) for specimen 2. Annealing textures during grain growth were also different, corresponding to the difference in the initial textures. ND-rotated cube and PP component ({011}<122>) developed during grain growth as for specimen 1, while cube and Goss component ({011}<100>) developed as for specimen 2. As to cube component, there was no significant difference in the initial volume fraction between both specimens (about 10%) and the average grain size (about 70 μm). However, cube component did not developed for specimen 1 as grain growth proceeded.

3.2 Effect of spatial distribution of cube-oriented grains on development of cube component

To investigate the difference in the grain growth behavior of cube component for these two specimens in detail, the variation of the volume fraction of cube component was separated into two parameters; frequency and size of cube component. Fig.3 shows variations in the frequency of cube

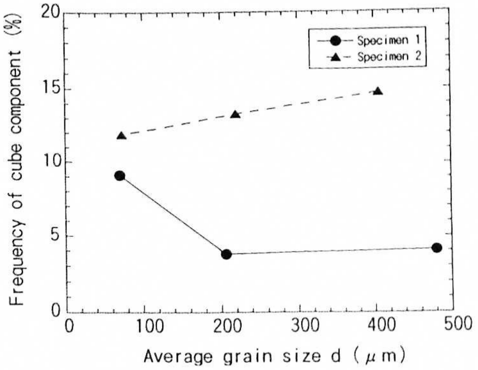

Fig.3 Variation of frequency of cube components with the average grain size.

component during grain growth. From this figure, the frequency of cube component decreased during grain growth for specimen 1. As to specimen 2, on the other hand, the frequency of cube component increased during grain growth in spite of almost the same initial frequency of cube component as specimen 1.

However, in the present study, SEM-ECP analysis has determined that there were a few cube clusters at recrystallized structure and most of cube-oriented grains were isolated in the matrix. Furthermore, grain sizes of cube component were almost the same for these primary recrystallized specimens. Thus, the new factor describing the microstructural difference between these two specimens should be introduced in order to explain these difference in the development of cube component.

During grain growth, the isolated cube-oriented grains in close vicinity would come into contact with each other and form cube clusters, being stabilized and growing preferentially. Thus, the tendency to form cube cluster during grain growth should be evaluated by the spacing among the isolated cube-oriented grains. In the present paper, the structural parameter l/d was introduced, where d is the cube-oriented grain size, l is the length between centers of gravity in two cube-oriented grains with first neighbor potion, as shown in Fig.4. The lower l/d value means the higher probability to form cube cluster during grain growth. In the present paper, in order to evaluate l/d value briefly, it is assumed that all the cube-oriented grains do not shrink and annihilate during grain growth process.

Fig.5 and 6 shows l/d value of cube-oriented grains and variations in the frequency of cube cluster during grain growth, respectively. From these figures, l/d value of specimen 2 is smaller than

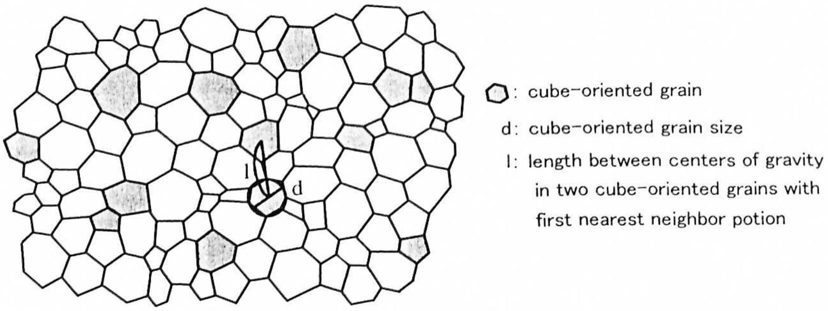

Fig.4 Definition of l/d value.

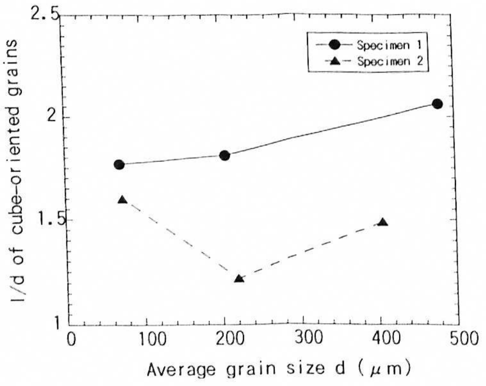

Fig.5 Variation of l/d of cube-oriented grains with the average grain size.

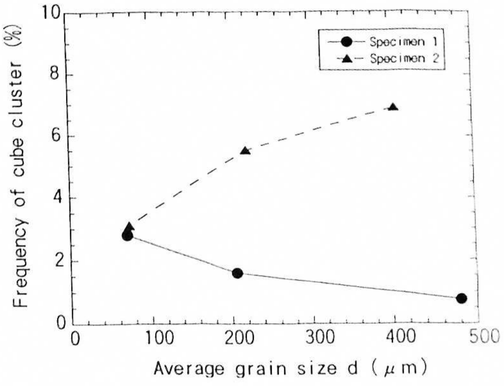

Fig.6 Variation of frequency of cube cluster with the average grain size.

that of specimen 1. Furthermore, these l/d values correspond to the frequency of cube cluster; the frequency of cube cluster for specimen 2 increases although that for specimen 1 decreases during grain growth. Consequently, the initial spatial distribution of cube-oriented grains and/or clusters induces changes in microstructure and dominates the development of cube component during grain growth even if cube-oriented grains are located isolatedly.

3.3 Effect of local GBCD on the growth rate of cube component

As to the grain size of cube component, the difference in the environment around cube-oriented grains brought about the difference in the growth rate of cube component, which corresponded to the difference of the local GBCD around cube-oriented grains. Grain growth was described using the following equation [13];

$$D^n - D_0^n = kt \qquad (1)$$

where D is the average radius of grains, D_0 is the initial value of D, t is the annealing time, k is constant parameter and n is also constant parameter called grain growth exponent. Table 1 shows apparent grain growth exponent of total and cube components. This table shows that the grain growth behavior of these specimens is different from each other; the apparent grain growth rate of cube component is slightly faster than that of total as for specimen 1, while the apparent grain growth rate of cube component for specimen 2 is much slower than that of total. These differences corresponded to the variation of frequency of cube cluster as shown in Fig.6; increase in the frequency of cube cluster induced decrease in the growth rate of cube-oriented grains.

Matsumoto et al. reported that the development of cube component during grain growth was due to formation of well-developed cube cluster [10]; the local GBCD around cube-oriented grains becomes more advantageous for cube component to be stabilized and grow preferentially, by forming cube cluster. Fig.7 shows the variations in the frequency of Σ 1 boundary around cube-

Table 1 Grain growth exponent for each component of specimen 1 and 2

Texture component	Grain growth exponent n	
	Specimen 1	Specimen 2
Total	5.4	7.6
Cube	4.6	25.3

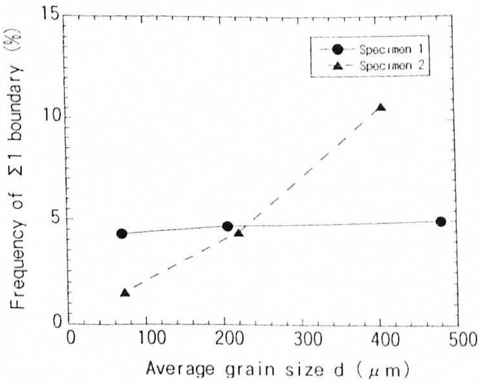

Fig.7 Variation of frequency of Σ1 boundary around cube-oriented grains with the average grain size.