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The Effect of Extrusion Temperature on Recrystallized Grain Structures of Extruded Al-Mg-Si Alloys

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The effects of extrusion temperature on recrystallized grain size and texture of Al-Mg-Si alloy extrusions have been investigated. Materials were extruded at temperatures in the range of 753~793K at the speed of 3m/min. As the temperature of extrusion fell from 793K to 753K, average size of recrystallized grains increased from 170μm to 230μm and volume fraction of recrystallized cube oriented grains increased from 30% to 40%. In addition, to clear the formation process of recrystallized grains in the alloy, observation of hot-compression deformed and recrystallized grain structures were carried out. It was revealed that the number of recrystallized grains was smaller and the stored energy was larger after deformation at 753K compared with those after deformation at 793K. It is suggested that in these extruded alloys, increase of the stored strain energy and decrease of temperature promoted the preferential grain growth of recrystallized cube grains.

Keywords: *Aluminum Alloy, extrusion, recrystallization, texture*

1. Introduction

The control of grain size and texture is important for improving mechanical properties and corrosion resistance of extruded Al-Mg-Si alloys. The proof stress of the alloy gets higher as grain size was finer [1]. Toughness is higher with larger content of cube-oriented grains [2]. Intergranular corrosion is caused by high angle boundaries and precipitate free zones [3]. In addition, it has been reported that average grain size increased as the temperature of extrusion fell from 803K to 673K [1]. On the other hand, there are few studies about texture of extruded Al-Mg-Si alloys in comparison with rolled sheets [4]. By conventional studies about extruded materials, it is understood that the strain state in the surface layer and that in the center layer are different greatly. [5, 6]. That's why texture in the central layer is different from texture in the surface layer. In extruded plate, deformation texture components are mainly {112}<110> and {001}<110> in the surface layer and is β-fiber in the center layer. Recrystallization texture component is mainly {112}<110> in the surface layer and is cube texture in the center layer [7]. However, little is known about effects of extrusion conditions on texture, except effect of extrusion ratio [8]. Therefore the purpose of this study is to clarify the effect of extrusion temperature on recrystallization grain size and textures.

2. Experimental Procedure

The chemical composition of Al-Mg-Si alloy used in this study is presented in Table 1. It is classified as 6005C. The experiment process of extrusion is shown in Figure 1. Billets of 6005C alloy having 155mm in diameter were homogenized at 793K for 4 hours. After homogenization treatment, billets were preheated at 753K, 773K and 793K by an induction furnace prior to extrusion. The billets were extruded at the temperature of 753K, 773K and 793K and at the speed of 3m/min.

Table 1 Chemical composition of Al-Mg-Si alloys studied (wt.%)

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Specimen	0.40	0.20	0.15	-	0.80	-	-	0.02	bal.
AA 6005C	0.40-0.9	≦0.35	≦0.35	≦0.50	0.40-0.8	≦0.30	≦0.25	≦0.10	

Extrusion ratio was 44. Cross-section was the square-shape of 40×40mm with 2mm in thickness. Samples were quenched in water in 20s after extrusion. Extruded samples were aged by heating at the temperature of 463K for 3 hours. The aging condition of the specimens was T5. The proof stress of the extruded samples shown in Table 2 fell in the range of general value for the alloy 6005C. After that, extruded samples were machined into the specimens for observation by optical microscope (OM), for measurement by scanning electron microscope (SEM) – electron back scattering diffraction (EBSD) and also for observation by transmission electron microscope (TEM). For observation by OM, specimens were etched with 5% caustic soda solution. Specimens, observed by OM, were electropolished and subjected to EBSD analysis with the OIM device attached to JSM-7000F SEM. The measured step size was 5μm and the measured area was approximately 2mm x 2mm. Although the homogenization condition was common with all specimens, the size and space of dispersoids were measured by TEM. In addition, to clarify the behavior of the recrystallization in this alloy, high temperature compression tests were carried out with an apparatus *thermechmaster Z* made by Fuji Electronic Industrial Co.,Ltd. The schematic view of the process of the compression test was shown in Figure 2. The specimens were columnar, having 8mm in diameter and 12mm in height. In consideration of a difference of calorific value during extrusion and compression deformation, the heating temperature was controlled at 768~808K. Compression tests were carried out with an initial strain rate of $10s^{-1}$. After true strain was reached to 1.3, specimen was kept for 2s or 5s and quenched in water. The central parts of the deformed specimens were observed by OM.

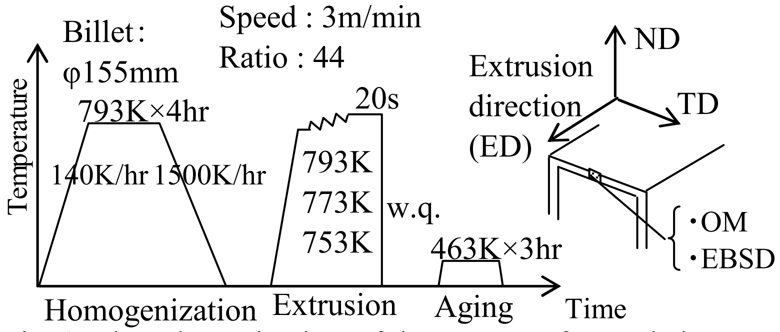


Fig. 1 The schematic view of the process of extruded 6005C-T5 alloys.

Table 2 The proof stress of extruded 6005C-T5 specimens.

Extrusion temperature [K]	$\sigma_{0.2}$ [MPa]
793	255
773	252
753	241

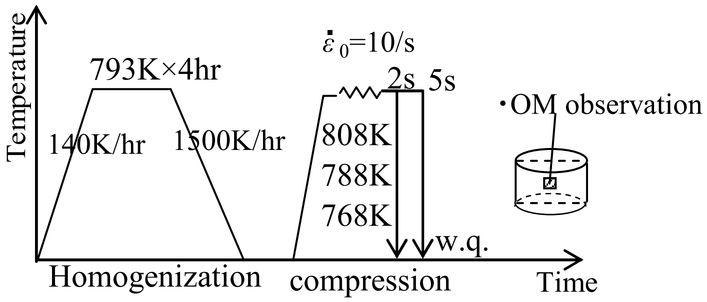


Fig. 2 The schematic view of the process of hot compression

3. Results and Discussion

3.1 Microstructure in specimens

Optical microstructures in ND-TD cross-section of the extruded specimens were shown in Figure 3. As the temperature of extrusion fell, the size of recrystallized grains increased. Relationships between extrusion temperature and the recrystallized grain size in each layer were shown in Figure 4. In the range of 753~793K, the average grain size in the central layer got larger as extrusion temperature lowered. The surface layer was not affected by extrusion temperature. The maps of crystallographic orientation distribution in extruded specimens measured by using SEM-EBSD technique were shown in Figure 5. The upper section of Figure 3 shows crystallographic orientation

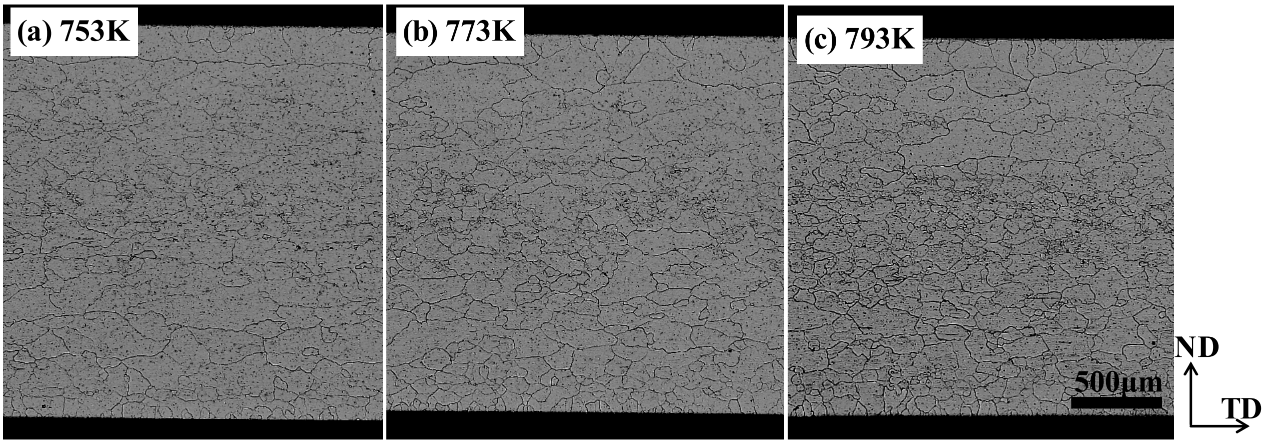


Fig. 3 Optical microstructure of LT-ST cross section in 6005C alloys after extrusion at (a)753K, (b)773K, (c)793K.

distribution in ND-TD cross section. The middle section and the lower section of this figure show distribution of texture components in ND-TD cross section and ED-ND cross section, respectively. The orientation components are recognized with misorientaiton within 15 degrees. As extrusion temperature fell from 793K to 753K, the volume fraction of recrystallized cube grains increased.

Relationships between extrusion temperature and fractions of textual components for Cube, Goss, Brass, S, Cu, {112}<110>, {001}<110> and total of other orientations in exruded specimens were shown in Figure 6. The results measured in ND-TD cross section and ED-ND cross section were shown together in this figure. In the temperature range of this study, the fraction of Cube increased as extrusion temperature lowered. In a specimen extruded at 753K, the fraction of Cube amounted to 40% and was about 10% higher in the quantity than a specimen extruded at 793K. The fractions of Goss, Brass, S, Cu, {112}<110> and {001}<110> had little changes by extrusion temperature. As extrusion temperature increased, the total fraction of other orientations increased, while the fraction of Cube decreased. It was suggested that recrystallized grains with various orientations were easier to be formed as extusion temperature increased.

Dispersoids in specimens extruded at 753~793K were shown in Figure 7. It is

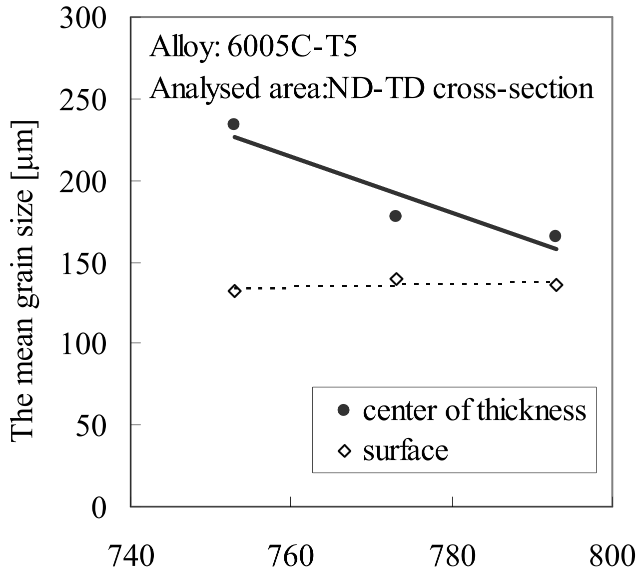


Fig. 4 The relationship of extrusion temperature and recrystallized grain size.

Table 3 Microstructual factors for 6005C alloys.

Extrusion temperature[K]		753	773	793
Grain size [µm] (ND-TD cross section	surface	132	139	136
	center	234	178	165
The area fraction of texture [%] (ND-TD cross-section)	Cube	38	30	29
	Goss	8	8	9
	(112)[110]	3	2	2
	(001)[110]	3	1	1
	Brass	4	3	5
	S	3	2	6
	Cu	3	1	2
	others	37	52	46
Dispersoids	Diameter[nm]	140	136	140
	Spacing[µm]	2.2	2.5	2.2

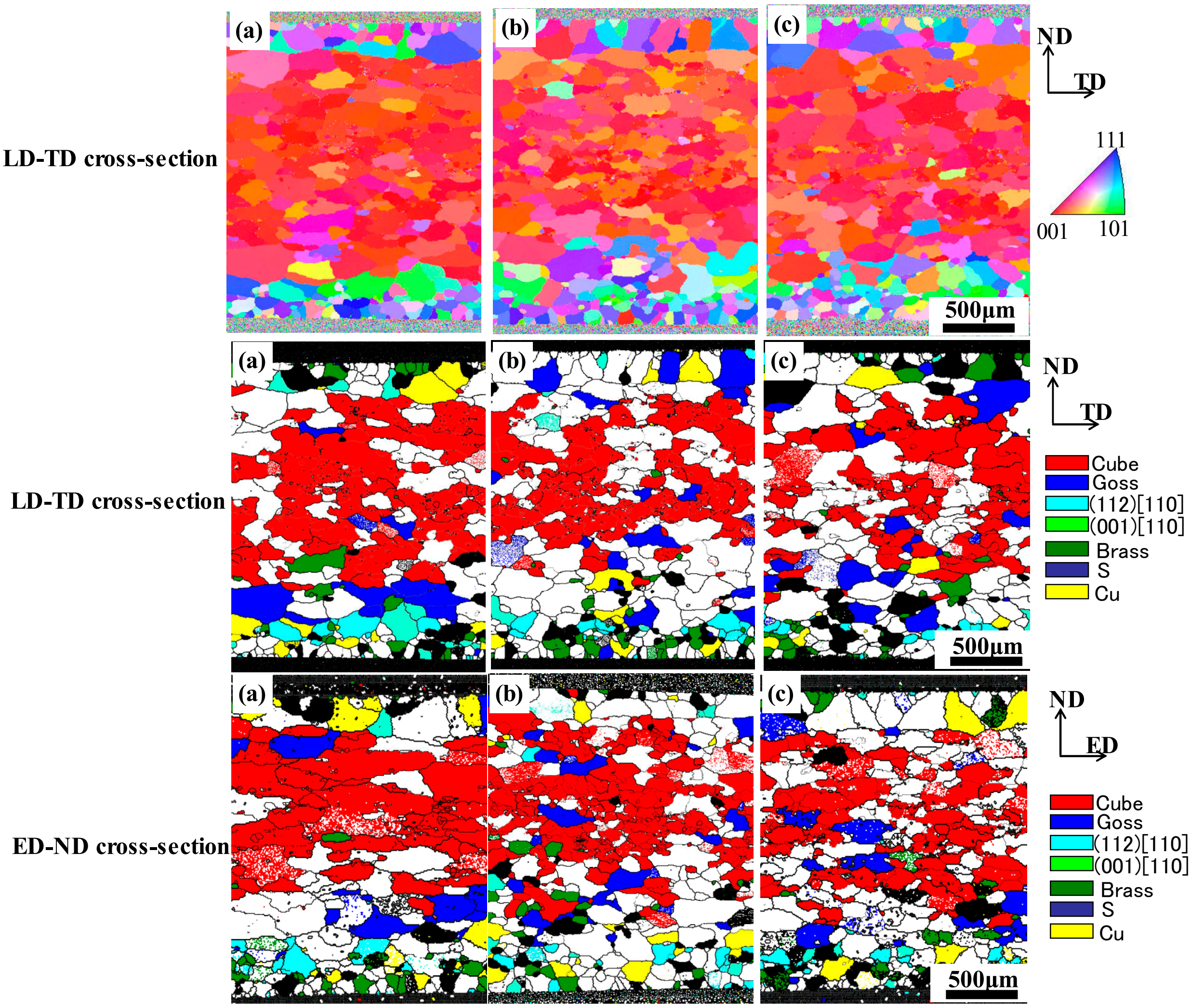


Fig. 5 SEM-EBSD maps of 6005C alloys extruded at (a)768K, (b)788K, (c)808K.

thought that these were Al-Fe-Si particles precipitated during homogenization treatment. Particle diameter and space between these dispersoids hardly had difference because all these were homogenised in the same condition. On this account it is said that the above changes of grain size and texture were not influenced by these dispersoids. Table 3 summarizes results of the above microstructure analysis. In the next section, the effect of deformation temperature and amount of strain stored during deformation on recrystallization behavior will be considered.

3.2 The effect of deformation temperature and strain on recrystallization behavior

Compression tests were carried out to observe the early stage of recrystallization

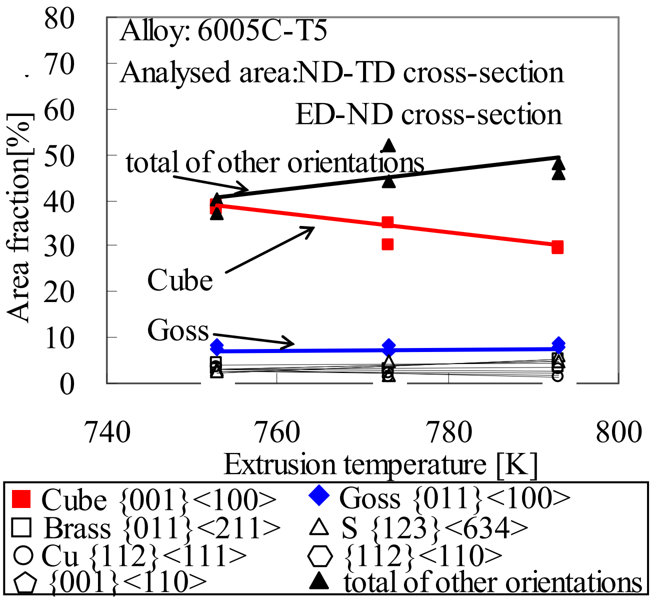


Fig. 6 The relationship between area fraction of textual components and extrusion temperature.

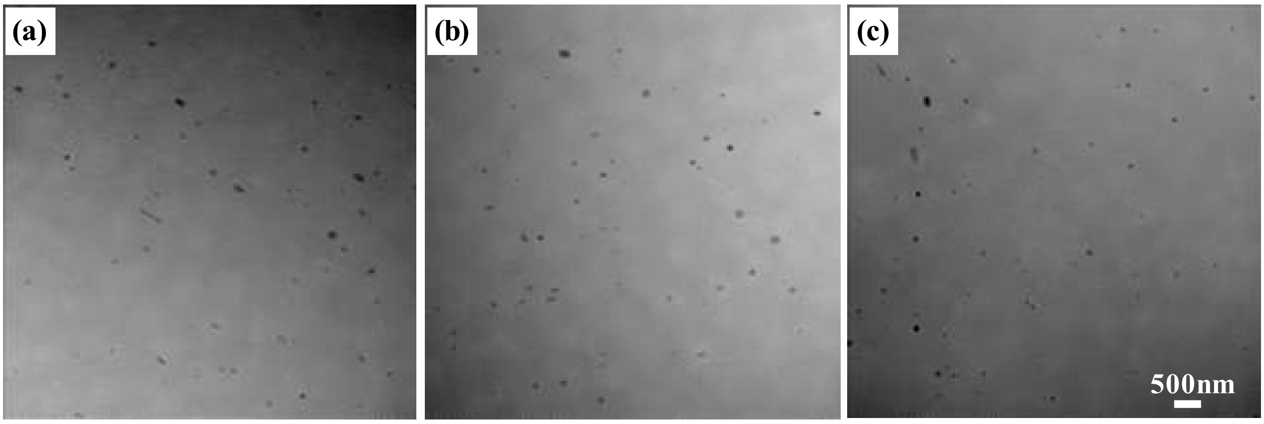


Fig. 7 Dispersoids in 6005C alloys extruded at (a)753K, (b)773K, (c)793K.

in specimens at 768~808K. Stress-strain curves were shown in Figure 8. It has been known that flow stress is in proportion to a square root of dislocation density at high temperature [9]. According to Figure 8, it was estimated that stored energy at 768K was 1.7 times larger than that at 808K because flow stress at 768K was 1.3 times larger than that at 808K.

Optical microstructures at the center of specimens obtained 2s and 5s after true strain reached to 1.3 were shown in Figure 9. Recrystallization occurred partially after 2s (Figure 9 A-1, B-1) and grain growth occurred in the whole observed area after 5s (Figure 9 A-2, B-2). In deformed microstructures in Figure 9 A-1 and B-1, small grains (10~20μm in diameter) were observed. These are considered as recrystallized grains because these grains are equiaxed in shape. At 2s after deformation was interrupted, the number of recrystallized grains having 10~20μm in diameter in the specimen deformed at 808K were larger than that in the specimens deformed at 768K. It is thought that the above phenomenon was caused by the decreased nucleation rate with decreased deformation temperature. With the lapse of holding time (5s), recrystallized grains were coarsened, and the average diameter became more than 100μm in 768K deformation specimen. It is surmised that these coarsened grains were originally small grains which were equiaxed in shape at 2s after deformation was stopped and grew up preferentially.

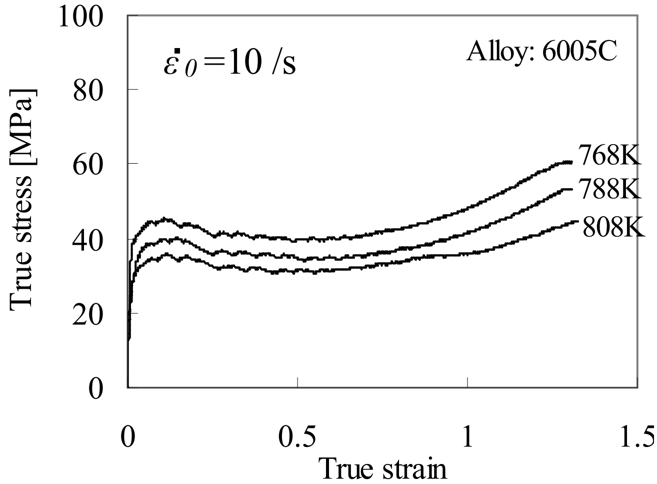


Fig. 8 Stress-strain curves for 6005C alloys: (a) at 768K, (b) at 788K, (c)808K

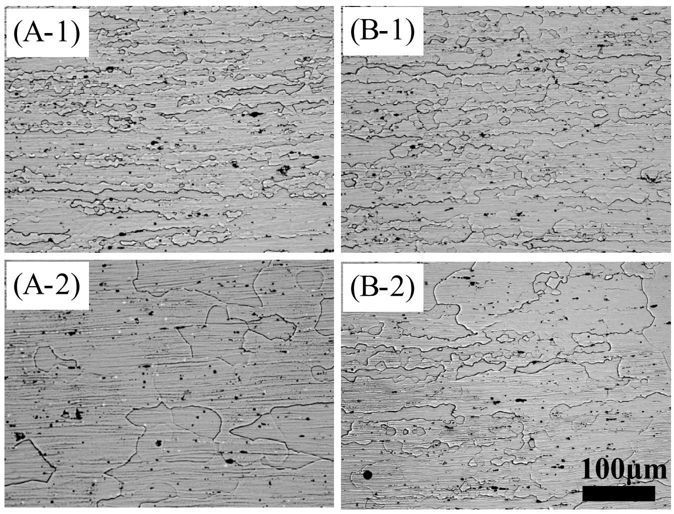
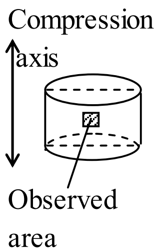


Fig. 9 Optical microstructure in the center of 6005C alloys compressed.
A-1: deformed at 768K and quenched in 2s,
A-2 : deformed at 768K and quenched in 5s,
B-1 : deformed at 808K and quenched in 2s,
B-2 : deformed at 808K and quenched in 5s.



Coarsened grains in a specimen deformed at 768K were larger than those in a specimen deformed at 808K. It is thought that there were two reasons for above phenomena. At first, stored energy was larger in a specimen deformed at 768K than at 808K. Secondly, there was less numbers of recrystallized grains in a specimen at 768K than at 808K. The same may be said in the case of extruded 6005C alloys. It is guessed that there was less number of recrystallized grains just after extrusion and stored energy was large in an extruded specimen at 753K. In this situation, it is thought that Cube grains of which growth rate was larger than other oriented grains preferentially grew up and coarsened Cube grains developed in recrystallized microstructure after extrusion at 768K. On the other hand, when extrusion temperature was high at 793K, it is thought that there was much larger number of recrystallized grains just after extrusion and stored energy was smaller. On the basis of the facts that 6005C alloy extruded at 793K had smaller recrystallized grain than that at 753K and a fraction of non-Cube in 6005C alloy extruded at 793K was higher than that at 753K, it is proposed that a lot of non-Cube grains were already included in recrystallized grain structure in 6005C alloy extruded at 793K. The schematic view of recrystallization in 6005C alloy is shown in Figure 10.

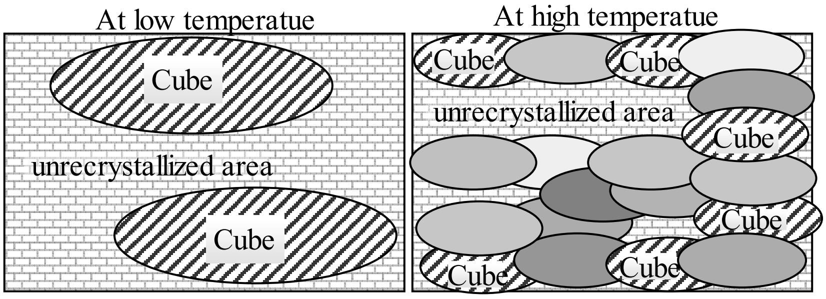


Fig. 10 The schematic view of recrystallization in 6005C alloy.

4. Conclusions

From the present investigation on the effect of extrusion temperature on recrystallized grain size and texture of 6005C alloys, the following knowledge were provided. As the temperature of extrusion fell from 793K to 753K, average size of recrystallized grains increased from 170μm to 230μm and volume fraction of recrystallized cube grains increased from 30% to 40%. It is suggested that there was few recrystallized grains just after the deformation and was large stored energy in 6005C alloy extruded at 753K. In this situation, it is thought that Cube grains of which growth rate were faster than other oriented grains grew up preferentially and coarse Cube grains developed in recrystallized microstructure after extrusion at 753K. On the other hand, when extrusion temperature was high at 793K, it is thought that there was larger number of recrystallized grains just after extrusion and stored energy was smaller. Based on the experimental results that recrystallized grain size was smaller and a fraction of non-Cube was higher in 6005C alloy extruded at 793K than at 753K, it is suggested that a lot of non-Cube grains were already included in recrystallized grain structure in 6005C alloy extruded at 793K.

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