# THE EFFECT OF HARDENING HEAT TREATMENT ON THE TENSILE STRENGTH AND EARINGS OF AA 3104 ALUMINUM ALLOY SHEET

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ABSTRACT Aluminum alloys of can-body sheet requires high tensile strength and small ears. Tensile strength of AA3104-H19 is basically determined by the amount of final cold rolling. However, higher tensile strength and small ears can be obtained by applying precipitation hardening treatment to AA3104 sheet. The effects of precipitation hardening treatment on crystallographic textures and tensile strength are analyzed, and a new thermo-mechanical processing of AA3104 alloy sheet for can-body is proposed.

***Keywords:*** *AA3014, can-body, texture, earing, tensile strength*

## 1. INTRODUCTION

AA3104-H19 alloy sheet for can body has been studied widely and deeply for improving forming characteristics and mechanical properties[1-13]. Tensile strength of AA3104-H19 alloy sheet is basically determined by the amount of final cold rolling. Earings developed by deep drawing are directly related to rolling textures[2,10,14,15]. For offsetting the earings developed by rolling textures, some recrystallization textures, such as (100)[001] Cube texture, should be coexisted.

To produce can-body sheet with balanced amount of rolling and recrystallization textures, multiple-stand hot-rolling mills and rapid heating and cooling facilities are required in conventional process. Improvement of strength and earing properties without rapid heating system is difficult in the conventional process. However, a higher tensile strength and small ears could be obtained in AA3104 alloy by adding precipitation hardening effects. The effects of precipitation hardening heat-treatment on crystallographic textures and tensile strength of AA 3104 alloy sheet are studied.

## 2. EXPERIMENTAL PROCEDURES

Two kinds of hot rolled AA3104 alloy sheet are supplied by Aluminum Korea Ltd. Co. One is a DC casting alloy and the other is an ingot mold-casting one(IMC). Chemical compositions of the experimental alloys are shown in Table 1.

Table 1. Chemical compositions of the experimental alloys (wt.%)

| Elements / alloys | Mn | Mg | Fe | Cu | Si | Al |
|---|---|---|---|---|---|---|
| IMC alloy | 0.87 | 1.24 | 0.49 | 0.24 | 0.22 | bal. |
| DC alloy | 1.05 | 1.25 | 0.40 | 0.21 | 0.20 | bal. |
| AA3104 spec. | 0.4-1.4 | 0.8-1.3 | max. 0.7 | max. 0.25 | 0.12-0.3 | bal. |

Various cold rolling and heat-treating processes, as shown in Fig. 1, are applied to hot-rolled sheet for obtaining the solution treatment effects. In process A, the hot rolled sheet is recrystallized at high temperatures of 520℃ and 560℃ for 1 hour after the primary cold rolling in 85% reduction ratio. These recrystallized specimens are cold rolled again in 55%, 65% and 75% reduction ratio and aged at 140℃ for 6 hours. In process B, homogenization at 607℃ and aging at 475℃ for 6 hours is applied before primary cold rolling for controlling dispersoids. The next steps of thermo-mechanical treatment in process B are the same as those of process A. Each pass of cold rolling before recrystallization treatment is controlled below 10% reduction for developing deep surface-textured region. The final thickness of the cold rolled sheet is 0.5mm.

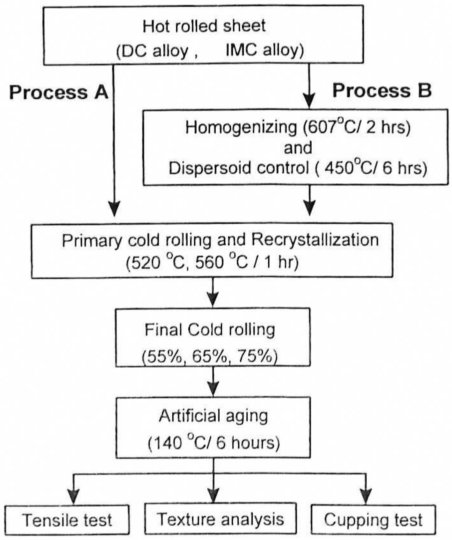


Fig. 1 Flow chart of thermo-mechanical treatment

Macroscopic textures are measured on the surface, 1/4 and center position of the sheet thickness by a pole figure X-ray diffractometer (XRD). Ghost corrected ODFs and Lankford parameters are characterized from three incomplete pole figures of (200), (220) and (111) by using PopLa-Lapp program[16].

Earring properties are evaluated by cupping test. Cupping test specimens are 0.5mm in thickness, 55㎜ in diameter. Drawing ratio of the cupping test is 1.67. Mechanical properties are tested by tensile tests in the rolling direction, 45° to the rolling direction and transverse direction. The tensile test specimens are sub-size ones of 25mm in gage length. TEM, SEM and optical microscope are used for characterizing dispersoids and grain structures.

## 3. RESULTS AND DISCUSSION

### 3.1. Microstructures

The grains of DC alloy in process A are finer than that in process B when the alloys are recrystallized at 560℃ for 1 hour. Fig. 2 shows size distribution of the dispersoids measured before primary cold rolling. Total number density of the dispersoids in the specimen of process B (specimen B) is 678×200/㎟ which is 50% higher than that of process A(specimen A). However, the only dispersoids, larger than 1㎛ in diameter, are known to be effective for particle stimulated nucleation (PSN) of recrystallization in aluminum alloys [17.18]. The number density of these large dispersoids is 156×200 /㎟ in specimen A and 65×200 /㎟ in specimen B. High density of these large dispersoids in specimen A results in fine grain structures.

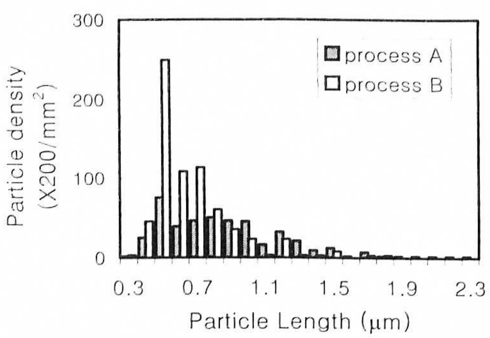


Fig. 2. Size distribution of dispersoids in DC alloy

### 3.2. Strength

Variation in tensile properties with reduction ratios of final cold rolling are shown in Fig. 3. Strength anisotropy is increased with increasing reduction ratio of final cold rolling. Fig. 4 and 5 show the effects of recrystallization temperatures on tensile properties. The higher the recrystallization temperature is, the higher the tensile strength is obtained. If the major component of textures is a recrystallization texture, the lowest tensile strength should be found in the rolling direction. On the other hand, if the major component of textures is rolling texture or shear texture, the lowest tensile strength should be found in 45° to the rolling direction. The lowest tensile strength is found in 45° to the rolling direction. It results from shear textures developed during cold rolling. The effects of textures on strength anisotropy are to be discussed in detail in the next section.

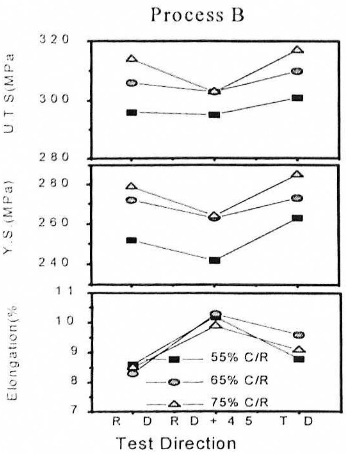


Fig. 3. Tensile properties of IMC alloy with various reduction ratios of final cold rolling in process B

Recrystallized micro-structures of DC alloy in process B are shown in Fig. 6. Many particles in the specimen recrystallized at 520℃ dissolves when the alloy is recrystallized at 560℃. Dissolution of these large particles at 560℃ could improve tensile strength by two effects. The one is reduction of particle originated cracks under tensile load. The other is enlarged age-hardenability with increased amount of solutes in solid solution. Therefore, recrystallizing at higher temperature is favorable for a higher strength.

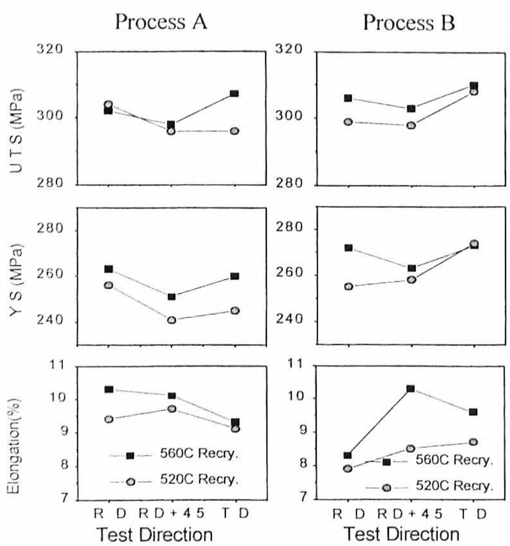


Fig. 4. Tensile properties of IMC alloy with recrystallization temperature variation (65% cold rolling)

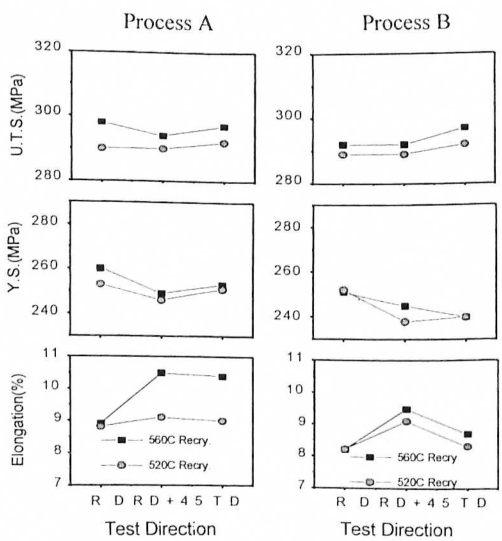


Fig. 5. Tensile properties of DC alloy with recrystallization temperature variation (65% cold rolling)

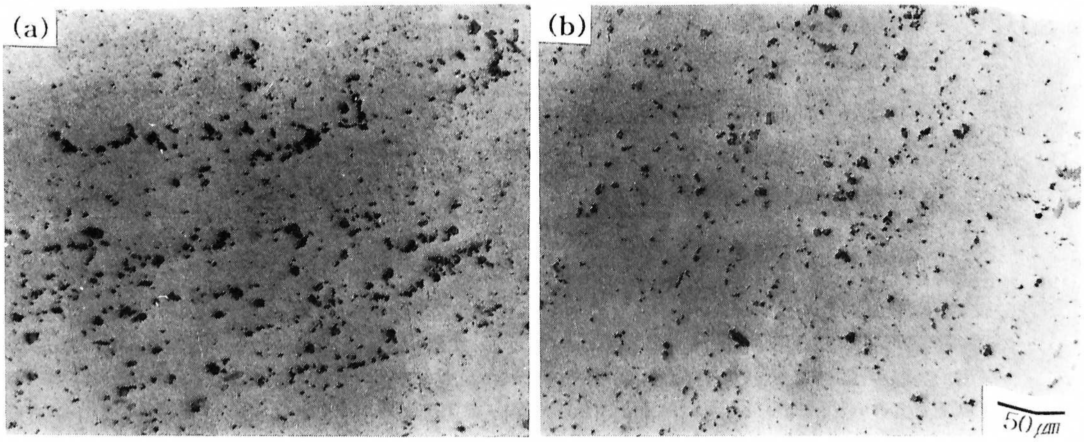


Fig. 6. Particle distribution of DC alloy (process A) recrystallized
(a) 520°C for 1 hr. (b) 560°C for 1hr.

### 3.3. Texture analysis

All 65% cold-rolling specimens show strong rotated-cube component of shear texture halfway between the surface and the center of sheet thickness(s=0.4). Weak cube and rotated-Goss textures are also found in these specimens. However, in the center of sheet thickness(s=1), strong Cu, S and Bs components of rolling texture are found. Orientation distribution function (ODF) of the experimental alloys at $\Phi_2=0°$ in s=0.4 position are compared one another in Fig. 7. Cube textures in the specimens of process A are higher than those in the specimens of process B. The latter shows higher content of shear texture. Between DC alloys and IMC alloys, DC alloys show higher density of recrystallization texture and lower density of shear texture.

Crystal textures of DC alloys are analyzed after recrystallizing at 560℃. On the surface of specimens, the maximum densities of rotated cube component are 5.35 and 2.49 in the specimen A and B, respectively. In the center of specimens, the maximum density of rotated cube in specimen A is a little higher than that of specimen B. It is caused by the difference of particle densities between specimens of the process A and B. The specimen A has higher density of particles larger than 1μm in diameter as shown in fig. 2. These particles could accumulate large deformation during hot and cold rolling, and become nucleation sites of recrystallization through particle stimulated nucleation(PSN) mechanism[17,18].

### 3.4. Earings

Ears are measured by cupping test as shown in Fig. 8. All specimens show earings developed in 45° to the rolling direction, as predicted by texture analysis. It is found that the earing properties are insensitive to the variation of recrystallization time and temperatures. It implies that long time heating at these temperatures could be applied to this alloy without deterioration of earing properties. This long period of recrystallization treatment makes it possible to obtain a high strength and small earings without rapid heating facilities. Earings of DC alloys are smaller than that of IMC alloys. At the same time, earings of specimen A's are also smaller than those of specimen B's. 305MPa of tensile strength and 1.95% of earings are obtained in a AA3104 alloy sheet by applying the new thermo-mechanical processing. For improving earring properties, it is important to increase the number density of particles larger than 1μm in diameter, and increase the amount of recrystallization texture.

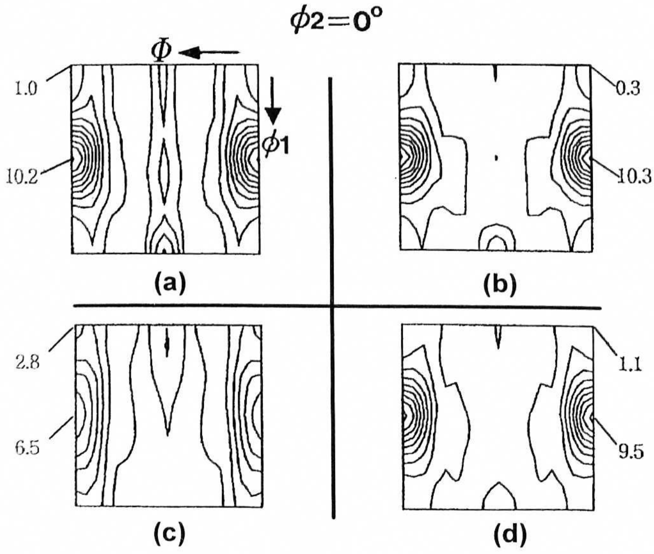


Fig. 7. ODFs of shear and cube textures
IMC alloy: (a) Process A (b) Process B
DC alloy: (c) Process A (d) Process B

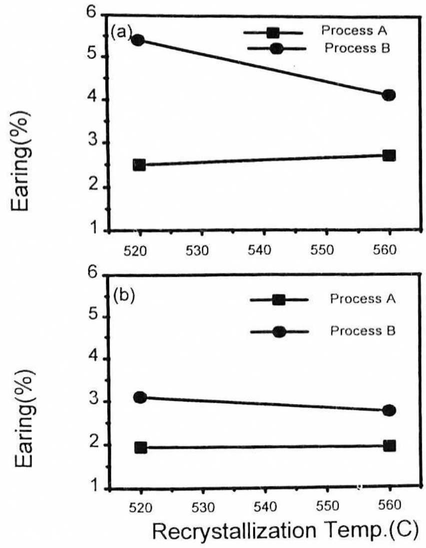


Fig. 8. Earings of IMC and DC alloys
(a) IMC alloy (b) DC alloy

## 4. CONCLUSIONS

1. A new thermo-mechanical processing of AA3104 alloy sheet for can body is proposed. High temperature recrystallization over 520℃ after primary cold-rolling and 140℃ aging after final cold-rolling are applied to AA3104 alloy sheet. In this new process, the long period of recrystallization treatment makes it possible to obtain high strength and small earings without rapid heating facilities.

2. Higher tensile strength and yield strength without changing earring properties are obtained by increasing recrystallization temperature. It results from the enlarged effect of solution treatment and precipitation hardening.

3. For improving earring properties, it is important to increase the amount of particles larger than 1$\mu$m in diameter, and cube texture. Large particles could serve as nucleation sites of recrystallization through particle stimulated nucleation(PSN) mechanism.

4. 305MPa of tensile strength and 1.95% of earings are obtained in a AA3104 alloy sheet by applying the new thermo-mechanical processing.

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