Texture Evolutions of 5052 Aluminum Alloy Sheets Processed by Dissimilar Channel Angular Pressing

Jun Hyun Han¹,², Kyu Hwan Oh², Kwang Koo Jee¹, Young Hoon Chung¹ and Myung Chul Shin¹

¹ Div. of Materials Science and Technology, Korea Institute of Science and Technology, P.O Box 131, Cheongryang, Seoul 130-650, Korea
² School of Materials Science and Engineering, Seoul National University, Shinrim-dong 56-1, Kwanak-ku, Seoul 151-742, Korea

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Abstract. Studies on texture evolutions were conducted on the 5052 Al alloy sheets using the developed dissimilar channel angular pressing (DCAP) to investigate the feasibility of this process for producing metallic sheets with the high formability and the low planar anisotropy. This process is capable of introducing the shear deformation into the metallic sheets in a continuous mode. ODFs were calculated for evaluating texture evolutions due to DCAP. The Lankford parameter (r-value) was determined using the measured pole figures to judge the formability and the planar anisotropy of the samples. The deep drawing tests were conducted to verify the validity of the calculated r-value on evaluating the planar anisotropy. The production of the 5052 Al alloy sheets with a formability and a very low planar anisotropy could be possible by DCAP.

Introduction

Some BCC metals, such as steel, exhibit a high formability and a low planar anisotropy. On the other hand, FCC metals, such as Al alloys, tend to have a low formability and a high planar anisotropy. In order to enhance the formability and reduce the planar anisotropy of Al alloys, the presence of shear texture, such as \{111\}<110> and \{111\}<112>, is indispensable [1]. Such shear textures in Al alloys can be introduced by the shear deformation. However, most conventional metal forming processes including rolling or heat treatments failed to introduce the shear textures along the direction parallel to the surface of work piece. In recent years, extensive research works have been carried out on ECAP (Equal Channel Angular Pressing) to introduce the shear textures in Al alloys [2-6]. Although a significant amount of shear deformation can be obtained through ECAP, however, this method cannot be processed in a continuous mode and is restricted to bulk metals with rectangular or circular cross-section.

Recently, Lee et al. [7] introduced a so-called Continuous Confined Strip Shearing (C2S2) process based on ECAP. The developed process not only enables shear-deforming metallic sheets in a continuous mode but also has a potential for producing Al alloy sheets with enhanced formability and reduced planar anisotropy. The newly developed process was termed dissimilar channel angular pressing (DCAP) to distinguish this technique with the conventional ECAP and detailed explanations regarding the process are described elsewhere [7]. Saito et al. [8] also has proposed a shear deformation method called as the conshearing process having a concept similar to DCAP.

Although the deep drawing test is very useful for evaluating the planar anisotropy of metallic sheets, it has never been attempted on ECAPed materials till now, since metallic sheets with wide width could not be processed by the conventional ECAP. However, the DCAP process is capable of evaluating the planar anisotropy of metal sheets through the deep drawing test. In this study, the DCAP process was introduced as a means for enhancing the formability and reducing the planar anisotropy of the 5052 Al alloy sheets. Texture evolutions of sheets were investigated based on the pole figures and the calculated orientation distribution functions (ODFs). Effects of routes of the second pass for DCAP on texture evolution were also discussed.
Experimental Procedure

Figure 1 shows the schematic of the concept process for fabricating metallic sheets in a continuous mode. The DCAP die used in this study is equipped with two channels, whose thickness are dissimilar to each other such that the thickness of the outlet channel is slightly larger than that of inlet channel. When the 1.0mm thick sheet is fed into the rolls, it is reduced into 0.85mm thick sheet and continues to proceed toward the outlet channel. Once the sheet passes through the outlet channel, it regains its initial thickness (1.0mm). This concept is capable of deforming metallic sheets repeatedly.

A commercial 5 mm thick 5052 Al alloy (Al-2.7Mg-0.35Fe-0.25Cr-0.15Si, wt%) sheets were procured and annealed at 500°C for 1hr. Unidirectional cold rolling was carried out on the Al alloy sheets to produce a 1.0 mm thick sheet. The prismatic specimens with dimensions of 70 (w) x 1.0(t) x 300(l) mm³ were cut out from the rolled sheets with their long axis parallel to the rolling direction. The specimens were annealed at 350°C for 2hr. The annealed specimens were fed into the DCAP channel with an oblique angle (Φ) of 120° and a curvature angle (Ψ) of 0° as shown in Fig. 1, and processed at an approximate speed of 50 mm/s. The routes of the second process after 1 pass-DCAP were described in Table 1.

To study the effects of routes of the second process for DCAP on microstructures of the specimens, the side surfaces of the specimens were polished mechanically followed by electrochemical etching using the Barker’s reagent. Microstructures of the specimens were observed using an optical microscope under the polarized light. The specimens before and after DCAP were prepared to evaluate textures by X-ray diffractometry. To avoid possible changes in textures during mechanical polishing, the specimens for evaluating the texture development were chemically thinned to half the thickness of the specimens in a NaOH solution at 60°C.

The textures of the samples were determined by measuring pole figures by means of an automated X-ray goniometer of the X-ray diffractometer (Philips X’Pert) with Cu-Kα radiation. Three sets of {111}, {200}, and {220} pole figures corresponding to each sample were measured using the Schültz reflection method [9]. The orientation distribution functions (ODFs) were calculated from three incomplete pole figures according to the WIMV method.

Table 1. The variation of routes of the second DCAP process after 1 pass-DCAP.

<table>
<thead>
<tr>
<th>A Process</th>
<th>Two passes in same direction</th>
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<tr>
<td>B Process</td>
<td>Second pass : 180° rotation to ND direction</td>
</tr>
<tr>
<td>C Process</td>
<td>Second pass : 180° rotation to TD direction</td>
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Fig. 2. Optical micrographs recorded from the side surfaces of (a) the annealed and (b) the 1 pass-DCAPed specimens, and the specimens 2 pass-DCAPed through process (c) A, (d) B, and (e) C.

The $r$-value (Lankford parameter), which, in general, can be used as a parameter for assessing the formability of the metallic sheets, was determined based on the measured pole figures. The formability and the planar anisotropy of the specimens were evaluated using the average $r$-value ($\overline{r}$) and $\Delta r$-value, respectively. The $r$-values along $0^\circ$-$90^\circ$ at $15^\circ$ interval with respect to the direction of rolling (or DCAP) were calculated using the rate sensitivity model [10]. The average $r$-value ($\overline{r}$) and $\Delta r$-value were calculated by Eq. 1 and 2, respectively.

$$\overline{r} = \frac{r_0 + 2r_{45} + r_{90}}{4}$$ (1)

$$\Delta r = \frac{r_0 - 2r_{45} + r_{90}}{2}$$ (2)

The deep drawing tests were conducted to verify the feasibility of calculated $\Delta r$-value as a criterion for evaluating the planar anisotropy. The earing ratios (ERs) were calculated by Eq. 3.

$$ER = \frac{A - B}{M}$$ (3)

A: mean cup height of $0^\circ$ family ($0^\circ, 90^\circ, 180^\circ, 270^\circ$)
B: mean cup height of $45^\circ$ family ($45^\circ, 135^\circ, 225^\circ, 315^\circ$)
M: total mean value of cup height

Results and Discussion

Microstructure and Texture Evolution. Figure 2 is the optical micrographs observed from the side surfaces of the annealed and DCAPed 5052 Al alloy sheets. The annealed specimen exhibits a relatively uniform and coarse-grain structure with an average grain size of ~40 µm. After 1 pass-DCAP, grains are elongated to a certain angle along a direction parallel to the shearing direction. After 2 pass-DCAP through the process A and C, grains are elongated far longer, from which shear deformations are observed to be more accumulated by the second pass. However, there is no evidence of shear deformation after the process C and grains were only slightly elongated along the direction parallel to the long axis of specimen.
Fig. 3. [111] Pole figures and $\varphi_2 = 45^\circ$ sections of orientation distribution functions (ODFs) obtained from (a) the as-rolled, (b) the annealed and (c) the 1 pass-DCAPed specimens, and the specimens 2 pass-DCAPed through process (d) A, (e) B, and (f) C.

To study the effect of DCAP on the texture evolution in the 5052 Al alloy sheets, [111], {200}, and {220} pole figures are recorded from DCAPed specimens. Shown in Fig. 3 are the {111} pole figures and the ODFs calculated from the pole figures obtained from the rolled, annealed, and 1 pass and 2 pass-DCAPed specimens in the $\varphi_2 = 45^\circ$ section, showing a sequence of the texture development by annealing and DCAP of 1 pass and 2 passes.

As seen in this figure, texture of rolled sheet with Bs orientation of [110]<112> and Cu orientation of [112]<111> is changed to the cube texture of {001}<100> by annealing. After DCAP, significant changes in texture was observed such that <111>/ND textures, i.e., [111]<110> and [111]<112>, and the rotated cube texture of {001}<110> are developed, while the intensity of the {001}<100> cube texture decreases. This result indicates that DCAP results in the development of the <111>/ND textures and the {001}<110> rotated cube texture by introducing shear deformation into the metallic sheets.

In the specimen deformed once more through the process A, a significant change in texture is not noticed except the increase in intensity of the {001}<110> rotated cube texture. In the specimen deformed through the process C, more increases in intensities of the {001}<110> rotated cube texture and the <111>/ND textures are observed. This feature indicates that the <111>/ND textures and the {001}<110> rotated cube texture introduced by shear deformation are stable orientations in DCAP, and further rotation to the stable orientation of extra orientation, which is not rotated to the stable orientation after the first pass, occurs through the second pass. After DCAP through process B, the texture development of the specimen is similar to that of the annealed specimen (b); the {001}<100> cube texture is mainly developed. This result is attributed to the fact that grains shear-deformed by DCAP of the first pass are deformed in the opposite direction to the first pass in DCAP of the second pass.

A careful observation of the results shows that the <111>/ND textures and the {001}<110> rotated cube texture are developed due to DCAP. Both the 2-pass DCAPs (process A and C) promotes the development of the <111>/ND and the {001}<110> textures.
Formability and Planar Anisotropy. It is well known that the $<111>/ND$ textures increase the $\bar{r}$-value and decrease the $\Delta\gamma$-value, leading to enhancement of the formability and suppression of the planar anisotropy. On the other hand, the $\{001\}<110>$ rotated cube texture, leading to $45^\circ$ earing, decreases $r$-value and increases $\Delta\gamma$-value [11].

Figure 4 shows the variations in $\bar{r}$-value and $\Delta\gamma$-value calculated from the specimens processed by rolling, annealing, 1 pass-DCAP, and 2 pass-DCAP. The rolled specimen has a high $\bar{r}$-value (1.35) and a very high $\Delta\gamma$-value (1.72) due to development of Bs and Cu orientation, resulting in $45^\circ$ earing to rolling direction. The annealed specimen exhibits a bad formability and a high planar anisotropy due to low $\bar{r}$-value (0.56) and high $\Delta\gamma$-value (0.6). It is attributed to the fact that the $\{001\}<100>$ cube texture causes $0^\circ$ and $90^\circ$ earings. On the other hand, the 1 pass-DCAPed specimen is expected to exhibit a very low planar anisotropy due to the very low $\Delta\gamma$-value close to zero. The very low $\Delta\gamma$-value can be understood based on the earing direction caused by textures; the $<111>/ND$ direction causes no earing at any direction, and effect of the $\{001\}<110>$ rotated cube texture on the earing can be compensated by the $\{001\}<100>$ cube texture. The increase of the $\bar{r}$-value in 1 pass-DCAPed specimen is due to the development of the $<111>/ND$ textures.

Fig. 5. Variations in cup height measured as a function DCAP direction and calculated earing ratios from the as-rolled, the annealed and the DCAPed specimens.
After the 2 pass-DCAPs through the process A and C, high $\bar{r}$-values (~0.9) and low $\Delta r$-values (<0.26) are obtained. Such a fact indicates that Al alloy with a high formability and low planar anisotropy can be produced by DCAP of 2 passes. The specimen deformed through process B, however, has a moderate value of $\bar{r}$ (0.74) with a low $\Delta r$-value (0.2) due to the weak $<111>/\text{ND}$ textures.

Deep drawing test is a very useful method for evaluating the planar anisotropy of metallic sheets. Figure 5 is the variations of cup height measured around the cup along 0~315° at 45° interval with respect to the direction of rolling or DCAP. It is indicated that the rolled and the annealed specimen have high values of ER, and show the 45° earing and 0° and 90° earings, respectively. The earing direction can be understood from the results of Fig. 3 and 4. On the other hand, all the DCAPed specimens including 1 pass and 2 pass-DCAP of process A, B, and C have very low ERs (<0.0052). The results obtained from deep drawing tests were well fitted to that of planar anisotropy evaluation with the calculated $\Delta r$-value in Fig. 4. Such a result indicates that the evaluation of planar anisotropy of metallic sheets is considered to be possible through the discussion with the $\Delta r$-value calculated from the texture analysis.

Conclusions

1. Introduction of the shear deformation into the wide width of metallic sheets is possible through DCAP process.
2. DCAP on annealed 5052 Al alloy sheet promotes the formation of $<111>/\text{ND}$ textures such as $\{111\}<110>$ and $\{111\}<112>$ and the $\{001\}<110>$ rotated cube texture.
3. In DCAPed specimens, the $<111>/\text{ND}$ textures are developed, leading to improvement of the formability and suppression of the planar anisotropy.
4. The validity of the $\Delta r$-value calculated from the texture analysis on evaluation of the planar anisotropy of metallic sheets is verified through the deep drawing test.
5. DCAP process is very effective for developing the shear textures, and production of the 5052 Al alloy sheet with a high formability and a low planar anisotropy is considered to be possible by 2 pass-DCAP through the process A and C.

References