Texture analysis and R-value variation after severe shear deformed and heat treated Al alloy sheets

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Al alloy sheets were deformed by ECAP(equall channel angular pressing), asymmetry and frictional rolling without lubrication and subsequent heat treating, the textures and r-values of the samples measured by x-ray diffractometer and tensile tester, respectively. The r̅ and |∆r|-values variations after ECAP, asymmetry rolling and frictional rolling without lubricant process and subsequent heat treating of Al alloy sheets are compared and analyzed by using the changes of inverse pole figures and f(g) values of ODFs.

1. Introduction

It has been found that the r̅-values (average r-value) are increased and |∆r|-values are decreased with increasing <111> parallel to the ND of sheet plane in FCC metals [1]. To get the <111> parallel to the ND of sheet plane, many researchers have been studied in the various types of shear deformation processes. However, due to the high stored energy, the existence of structural heterogeneities and the critical annealing conditions in the deformed state, unwanted structures will be gotten during the heat treatment [2]. The r̅-values of ECAPed, asymmetry rolled and frictionally rolled (severe shear deformation processes) and subsequent heat treated Al alloy sheets showed about 1.2-1.8 times higher than those of the initial Al sheets [3-8]. The |∆r|-values of ECAPed and subsequent heat treated AA1050 Al alloy sheets showed lower than those of the initial Al sheets. The |∆r|-values of asymmetry rolled and frictionally rolled and subsequent heat treated AA1050, AA3003 and AA5052 Al alloy sheets showed higher than those of the initial Al sheets [3-8]. In this paper, the effect of texture changes on the variations of r̅-values and |∆r|-values after ECAPed, asymmetrically rolling and frictionally rolling without lubricant process is compared and analyzed by changes of inverse pole figures and f(g) values of orientation distribution functions (ODF) again.

2. Experimental procedure

AA1050 Al alloy sheets were used in present study for ECAP. For asymmetric and frictional rolling processes we used AA1050, AA3003 and AA5052 Al alloy sheets. The sheet samples, with dimensions of 35mm x 15mm x 2mm for ECAP and heat treated at 550°C during 2 hours (named initial Al sheet) and dimensions of 60mm x 40mm x 3.8mm for ECAP, asymmetric and frictional
rolling processes heat treated at 500°C during 2 hours (named initial Al sheet) were prepared. The ECAP was performed in a die with an oblique angle (Φ) of 90° and a curvature angle (Ψ) of 20° at room temperature and at a constant speed of 2mm/sec by using route A (without any rotation between each pass) and C (180° rotation along rolling direction between each pass) types. To investigate texture and r-value development, samples were heat treated at 300°C for 1 hour in an air condition.

The initial Al sheets were asymmetrically rolled to 90% reductions on a laboratory asymmetrical rolling mill with roll radius ratio of 1.5. Samples were rotated 180° around transverse axis of Al sheets, rolled with more than 50% reduction in thickness and heat treated for 5 minutes at 200°C per each pass and the total number of rolling passes was 3. To obtain high friction coefficient, lubricant did not use in the rolling process. After the asymmetric rolling, samples were subsequent heat treated at temperatures of 250-300°C in a salt bath. The initial Al sheets were frictionally rolled to 90% reductions on a laboratory symmetrical rolling mill with of 150 mm in diameter. Samples were rotated 180° around transverse axis of Al sheets, rolled with more than 40-50% reduction in thickness and heat treated for 5 minutes at 200°C per each pass and the total number of rolling passes was 4. To obtain high friction coefficient, lubricant did not use in the rolling process. After the frictional rolling, samples were subsequent heat treated at temperatures of 275-300°C in a salt bath.

To know the texture changes of the deformed and heat treated samples, the incomplete pole figures of (111), (200), and (220) for each sample were measured by using X-ray goniometer. Texture measurements were performed at one tenth thickness layer (S=0.9) and at one fourth thickness layer (S=0.75) from the surface, which means 10% and 25% of sheet thickness were removed from upper surface, respectively. Also, observations of a half thickness layer (S=0) were performed.

To measure the r-value (ratio of true strain of width and true strain of thickness after tensile test), tensile test samples were prepared along the angles of 0°, 45°, 90° (180°), and 135° or 0°, 45°, 90° to ECAP or rolling direction, respectively. The r-value and |Δr|-value were obtained from the measured r-value data. The r-values were calculated by the use of $r = \frac{(r_0 + 2r_{45} + 2r_{90} + 2r_{135} + r_{180})}{8}$ or $r = \frac{(r_0 + 2r_{45} + r_{90})}{4}$, and $|\Delta r|$-values were calculated by the use of $|\Delta r| = \frac{(r_0 - r_{45}) + (r_{90} - r_{45}) + (r_{90} - r_{135}) + (r_{180} - r_{135})}{4}$ or $|\Delta r| = \frac{(r_0 - 2r_{45} + r_{90})}{2}$. Here, the $r_0, 45, 90, 135, and 180$ means the r-value of along the angles of 0°, 45°, 90°, 135°, and 180° to ECAP or rolling direction, respectively.

3. Results and discussion

Figure 1 The r-value and |Δr|-value variations after severe shear deformed and heat treated Al alloy sheets [3-8]
Figure 1 shows the $r$-values and $|\Delta r|$-values variations after severe shear deformed (ECAP, asymmetry and frictional rolling) and subsequent heat treated Al alloy sheets [3-8].

The $r$-values of ECAPed, asymmetrically rolled and frictionally rolled and subsequent heat treated Al alloy sheets showed about 1.2-1.5 times for AA1050 Al, 1.4-1.5 times for AA3003 Al and 1.4-1.8 times for AA5052 Al higher than those of the initial Al sheets in Figure 1.

Therefore, the increasing of $r$-values in AA3003 and AA5052 Al alloys is higher than that of AA1050 Al alloy and the increasing of $r$-values in AA5052 Al alloy is higher than that of AA3003 Al alloy after severe shear deformation and subsequent heat treatment in Figure 1.

The $|\Delta r|$-values of ECAPed, asymmetrically rolled and frictionally rolled and subsequent heat treated Al alloy sheets showed about 0.4-2.1 times for AA1050 Al, 2.2-3.3 times for AA3003 Al and 3.6-9.9 times for AA5052 Al higher than those of the initial Al sheets in Figure 1.

Therefore, the increasing of $|\Delta r|$-values in AA3003 and AA5052 Al alloys is higher than that of AA1050 Al alloy and the increasing of $|\Delta r|$-values in AA5052 Al alloy is higher than that of AA3003 Al alloy after severe shear deformation and subsequent heat treatment in Figure 1.

These changes of $r$-values and $|\Delta r|$-values will be related to the change of textures as the next results.

Figure 2 shows inverse pole figures of AA1050 Al alloy, where S=0.9 data are obtained from one tenth surface thickness layer and S=0.75 data are obtained from one-fourth thickness layer and S=0 data are obtained from center layer of the Al sheet.

AA1050 initial Al samples for ECAP exhibit <001>//ND texture through the whole thickness layer due to heat treatment at 550°C for 2 hours in the Figure 2(a, b) and AA1050 initial Al samples for asymmetrical and frictional rolling exhibit also <001>//ND texture through the whole thickness layer due to heat treatment at 500°C for 2 hours in the Figure 2(c, d). After ECAPed AA1050 Al by using route A and heat treated at 300°C for 1 hour, <111>//ND and near <115>//ND textures are observed in the one-tenth thickness layer and <110>//ND texture are observed in one-fourth thickness layer in Figure 2(e, f). The increasing of r and $r$-values is related to <111>//ND and <110>//ND textures in Figure 2 [1]. After ECAPed AA1050 Al by using route C and subsequent heat treated at 300°C for 1 hour, <110>//ND texture is observed in one-tenth thickness layer and <001>//ND and near <012>//ND textures are observed in on the one-fourth thickness layer in Figure 2(g, h). <110>//ND texture is related to increase r-value in Figure 2(g, h) [1]. Asymmetrically rolled and heat treated AA1050 Al at 300°C for 20 minutes shows random texture in one-tenth thickness and center layer in Figure 2(i, j). Frictional rolled and heat treated AA1050 Al at 275°C for 20 minutes shows <001>//ND texture in one-tenth thickness and center layer in Figure 2(k, l).

Figure 3 shows inverse pole figures of AA3003 Al alloy, where S=0.9 data are obtained from one tenth surface thickness layer and S=0.75 data are obtained from center layer of the Al sheet.

AA3003 initial Al samples for asymmetric and frictional rolling show <001>//ND texture in the one-tenth thickness layer and random texture is observed in center layer due to heat treatment at 500°C for 2 hours in the Figure 3(a, b). After asymmetrically rolled AA3003 Al and heat treated at 300°C for 20 minutes, <111>//ND and <100>//ND textures are observed in the one-tenth thickness layer and <100>//ND texture is observed in center layer in Figure 3(c, d). <100>//ND texture was occurred after heat treatment in Figure 3(c, d). After frictionally rolled AA3003 Al and heat treated at 300°C for 20 minutes, <113>//ND texture is observed in the one-tenth thickness layer and near <113>//ND, <100>//ND and <110>//ND textures are observed in center layer in Figure 3(e, f). <100>//ND texture is also occurred after heat treatment in Figure 3(e, f).

Figure 4 shows inverse pole figures of AA5052 Al alloy, where S=0.9 data are obtained from one tenth surface thickness layer and S=0 data are obtained from center layer of the Al sheet. AA5052 initial Al samples for asymmetric and frictional rolling show <001>//ND texture in the one-tenth thickness and center layer due to heat treatment at 500°C for 2 hours in the Figure 4(a, b). After asymmetrically rolled AA5052 Al and heat treated at 250°C for 30 minutes, <111>//ND and
<100>//ND textures are observed in the one-tenth thickness and center layer in Figure 4(c, d). After frictionally rolled AA5052 Al and heat treated at 300°C for 20 minutes, strong <111>//ND and <100>//ND are observed in the one-tenth thickness layer and near <013>//ND texture is observed in center layer in Figure 4(e, f). The increasing of r and r-values is related to <111>//ND texture in Figure 3 and 4 [1].

Figure 2 Inverse pole figures of one tenth thickness from the surface layer (S=0.9) and one-fourth and a half thickness layer (S=0.75 and S=0) of AA1050 Al alloy sheet: (a, b) initial Al sheet for ECAP, (c, d) initial Al sheet for asymmetric and frictional rolling, (e, f) 4 passes ECAPed and heat treated at 300°C for 1 hour (Route A), (g, h) 4 passes ECAPed and heat treated at 300°C for 1 hour (Route C), (i, j) 90% asymmetrically rolled and heat treated at 300°C for 20 min., (k, l) 90% frictionally rolled and heat treated at 275°C for 20 min.

Figure 3 Inverse pole figures of one tenth thickness from the surface layer (S=0.9) and center layer (S=0) of AA3003 Al alloy sheet: (a, b) initial Al sheet, (c, d) 90% asymmetrically rolled and heat treated at 300°C for 20 min., (e, f) 90% frictionally rolled and heat treated at 300°C for 20 min.

Figure 5 shows f(g) changes of AA3003 Al alloy, where S=0.9 data (a, b) and S=0 data (c, d) of the initial and asymmetric and frictional rolled and subsequent heat treated Al sheet, respectively. Due to the full recrystallisation at 500°C for 2 hours, textures of initial AA3003 Al sheet show high {001}<001> and {013}<231> textures in both one-tenth thickness (S=0.9) and center layers (S=0). Textures of asymmetrically rolled and heat treated AA3003 Al sheet at 300°C for 20 minutes show high {001}<110> and {123}<634> textures in one-tenth thickness layer (S=0.9) and {001}<110>, {123}<634>, [012]<021>, [111]<112> and [111]<110> textures in center layer (S=0). Textures of frictionally rolled and heat treated AA3003 Al sheet at 300°C for 20 minutes show high {112}<111>, {111}<112>, {110}<112> and {110}<001> textures in one-tenth thickness layer (S=0.9) and {013}<231>, [112]<111>, [001]<100>, [110]<001> and [110]<111> textures in center layer (S=0).

The higher r-values in Figure 1 are also related to increase the {111}<112>, {111}<110>, {123}<634>, [110]<001>, [112]<111> and [110]<111> texture components [1] after deformed and heat treated at 300°C for 20 minutes in Figure 5. Because, P. H. Lequeu et al [1] shown that the calculated r-value of {111}<112>, {111}<110>, {110}<001> and {110}<112> ideal textures are higher than that of <100>//ND ideal texture. The |Δr|-value of the ECAPed and the subsequent heat treated Al sheet is lower than that of the initial Al sheet. This lower |Δr|-value is related to the
decreasing of <100> // ND texture component, the increasing of other types of texture components at 300°C for 20 minutes heat treated Al sheet in Figure 5.

Figure 4 Inverse pole figures of one tenth thickness from the surface layer (S=0.9) and center layer (S=0) of AA5052 Al alloy sheet: (a, b) initial Al sheet, (c, d) 90% asymmetrically rolled and heat treated at 250°C for 30 min., (c) 90% frictionally rolled and heat treated at 300°C for 20 min.

Figure 5 The f(g) value variations of various types of texture components obtained from the ODFs of the (a, b) one tenth surface layer (S=0.9) and (c, d) center layer (S=0) depth thickness of initial AA3003 Al sheet, and 90% asymmetrically rolled and heat treated at 250°C for 30 min. and 90% frictionally rolled and heat treated AA3003 Al sheets of at 300°C for 20 min.

Figure 6 shows f(g) value changes of AA5052 Al alloy, where S=0.9 data (a, b) and S=0 data (c, d) of the initial and asymmetric and frictional rolled and subsequent heat treated Al sheets, respectively.

Due to the full recrystallisation at 500°C for 2 hours, textures of initial AA5052 Al sheet show high {001}<001>, {110}<001> and {013}<231> textures in one-tenth thickness (S=0.9) and high {001}<001>, {110}<112>, {012}<021>, {001}<110> and {013}<231> textures center layers (S=0). Textures of asymmetrically rolled and heat treated AA5052 Al sheet at 250°C for 30 minutes show the increasing of {001}<110> and decreasing of {001}<100> and {013}<231> textures in one-tenth thickness layer (S=0.9) and increasing of {001}<110>, {123}<001>, {111}<110>, {111}<112> and {012}<021> and decreasing of {001}<100>, {013}<231>, {110}<112> and {110}<001> textures in center layer (S=0). Textures of frictionally rolled and heat treated AA3003 Al sheet at 300°C for 20 minutes show the increasing of {111}<112>, {111}<110>, {001}<110>, {012}<021> and {110}<110> textures and decreasing of {001}<100> and {013}<231> textures in one-tenth thickness layer (S=0.9) and increasing of {011}<110>, {112}<111> and {110}<112> textures and decreasing of {001}<100>, {013}<231> and {012}<021> textures in center layer (S=0). The higher r-values in Fig. 1 are also related to increase the component of {111}<112>, {111}<110>, {123}<634>, {110}<001>, {112}<111> and {110}<111> textures [1] after deformed and heat treated at 250-300°C for 20-30 minutes in Figure 6. Because, P. H. Lequeu et al [1] have shown that the calculated r-value of
{111}<112>, {111}<110>, {110}<001> and {110}<112> ideal texture components are higher than that of <100> // ND ideal texture. The $|\Delta r|$-values of the asymmetrically and frictionally rolled and the subsequent heat treated Al sheet are higher than those of the initial Al sheets. The higher $|\Delta r|$-value is related to the mixed effect of changes of texture components of the heat treated Al sheets at 250-300°C for 20-30 minutes in Figure 6.

![Figure 6](image)

**Figure 6** The f(g) value variations of various types of texture components obtained from the ODFs of the (a, b) one tenth surface layer ($S=0.9$) and (c, d) center layer ($S=0$) depth thickness of initial AA5052 Al sheet, and 90% asymmetrically rolled and heat treated at 250°C for 30 min. and 90% frictionally rolled and heat treated AA5052 Al sheets of at 300°C for 20 min.

4. **Conclusions**

1. The r-values of ECAPed, asymmetry rolled and frictionally rolled and subsequent heat treated Al alloy sheets showed about 1.2-1.5 times for AA1050 Al, 1.4-1.5 times for AA3003 Al and 1.4-1.8 times for AA5052 Al higher than those of the initial Al sheets.

2. The $|\Delta r|$-values of ECAPed, asymmetry rolled and frictionally rolled and subsequent heat treated Al alloy sheets showed about 1.2-1.5 times for AA1050 Al, 1.4-1.5 times for AA3003 Al and 1.4-1.8 times for AA5052 Al higher than those of the initial Al sheets.

3. The changes of r-values and $|\Delta r|$-values are related to the decreasing of {001}<100> and increasing of {111}<112>, {111}<110>, {123}<634>, {110}<001>, {110}<112>, {112}<111> and {110}<111> texture components after severe shear deformation and heat treatment of Al alloys.

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