Texture evolutions in aluminum and Al-3%Mg alloy subjected to shear deformation and subsequent annealing

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Abstract. Shear deformation is imposed on materials by several advanced techniques for microstructural and textural control. Shear texture evolved during deformation tends to remain after subsequent annealing. Texture evolutions with shear deformation and subsequent annealing in aluminum and Al-3mass%Mg alloy rolled sheets have been investigated by neutron diffraction technique. N-shaped specimen was prepared from the alloy sheet to impose shear strain in compression. The central objective part of the N-shaped specimen was sheared with slight rotation about the normal axis so as to develop preferred orientations of {111} parallel to the original shear plane and <110> parallel to the original shear direction before deformation. In-situ neutron diffraction analysis during step heating revealed that the preferred orientations formed by shear deformation remain and evolve as recrystallization texture during subsequent annealing in both materials. Evolutions of shear and recrystallization textures were compared after shear deformations with strains of 0.5 and 0.7 in two samples sheared parallel to rolling and transverse directions.

1. Introduction
Crystallographic textures often appeared in materials subjected to severe plastic deformation, because extremely large strain should be accompanied with necessary directional priority in slip deformation. The texture evolution during equal channel angular pressing (ECAP) by only the two shear systems {111}<110> and {001}<110> (shear plane<shear direction>) in an Al-Zn-Mg-Cu alloy having a strong initial texture was reported [1]. To an aluminum single crystal ECAP was applied with
consistence of theoretical shear plane and direction to crystal slip system [2], and moreover, a crystal plasticity finite element method model showed the textural change with the lattice rotation around the transverse axis of ECAP angle [3]. These imply correspondence of microscopic shear system with macroscopic shear deformation.

Sakai et al. [4] pointed out that the shear texture developed by the shear rolling had a broad one spreading around the typical shear components after annealing. Shi et al. [5, 6] reported that the shear texture formed in the commercial purity titanium sheet subjected to a friction roll surface processing (FRSP), which was proposed as an SPD process for the surface of the sheet materials in order to control microstructure and texture, remained preferential after annealing.

A part of present authors investigated preferred orientation formation with shear deformation and annealing in Al-3mass%Mg alloy rolled by SEM/EBSD technique [7]. It was reported that grain orientation with its slip plane parallel to shear one or its slip direction parallel to shear one tends to evolved through shear deformation and subsequent annealing, and moreover, orientation $E_{TD}$ \{111\}$<110>$ grew up remarkably in annealing after shear deformation.

The aim of the present study is to examine and compare texture evolutions with shear deformation and subsequent annealing in aluminum and Al-3mass%Mg alloy rolled sheets by neutron diffraction technique.

### 2. Experimental procedure

Commercial purity aluminum (1050) and Al-3mass%Mg alloy sheets of 6mm thick were manufactured through casting, homoginization, hot and cold rolling, and annealing. Chemical compositions of the materials are listed in Table 1. N-shaped specimen as shown in Fig. 1 was cut from the sheet with its longitudinal direction parallel to rolling or transverse direction (RD or TD) for the compressive shear test. A central neck part was sheared by compressing the specimen in vertical or longitudinal direction during the test after annealing at 653K for 3.6ks in Ar and scanning electron microscope/ back scatter diffraction (SEM/EBSD) analysis. The neutron diffraction measurement was conducted at iMATERIA, 20th beamline at J-PARCMLF [5]. The texture was analyzed by Materials Analysis Using Diffraction (MAUD) software. Shear strain was calculated from change in relative positions of Vickers hardness indents, which had been sited on the neck part as 15mm square lattice of four fiducial markers before the test.

| Material   | Si   | Fe   | Cu   | Mn     | Mg     | Cr    | Zn    | Ti    | Others | Al |
|------------|------|------|------|--------|--------|-------|-------|-------|--------|----|
| CP aluminum| 0.01 | 0.02 | <0.01| <0.01  | <0.01  | <0.01 | <0.01 | 0.01  | <0.01  | Bal |
| Al-3%Mg    | 0.01 | 0.02 | <0.01| <0.01  | 2.95   | <0.01 | <0.01 | 0.01  | <0.01  | Bal |

After indentation of the markers, the N-shaped specimen with the right side fixed by two bolts was compressed with left side in the vertical direction. By the compression, the central part of the N-shaped
specimen was sheared at an ambient temperature to a given shear strain of 0.5 or 0.7. Rectangular specimens for the neutron diffraction of $7 \times 20 \times 6$ mm$^3$ were cut out by electric discharge method from the central part.

The neutron diffraction measurement was made with the heat-treatment below after the shear. The specimen face with marker indentation was set to be perpendicular to an incident beam and its longitudinal direction was set to be parallel to vertical direction. The surface temperature of the specimen was measured by the thermocouple. Two specimens were step-heated from $260^\circ C$ to $360^\circ C$ by $20^\circ C$ Al-3%Mg alloy and from $220^\circ C$ to $320^\circ C$ by $20^\circ C$ for CP aluminium (1050Al). The holding time was 960s in each stage of temperature.

3. Experimental results and discussion

The Al-3%Mg alloy was confirmed to show a typical rolling recrystallization texture before shear deformation, that is, as received specimen. The major components were S orientation $\{123\}<634>$ and Cube orientation $\{001\}<100>$. The neutron diffraction measurement was conducted as starting materials with the initial texture of rolling recrystallization.

3.1. Analysis of the Al-3%Mg alloy pole figure which sheared TD

(111), (200) and (220) pole figures before heating, $280^\circ C$, $320^\circ C$ and $360^\circ C$ in TD sheared specimen, are displayed in Fig. 2. The vertical direction of the figure is TD, and a horizontal direction is RD. Texture at an ambient temperature before the heat-treatment is a deformation texture formed by shear. In the texture before the heating, S orientation $\{123\}<634>$ and Cube orientation $\{001\}<100>$ seem to rotate about the ND axis. In addition, the texture component in which normal direction of (111) is parallel to RD direction gradually increases as temperature rises up. Because a plane (111) was slip one for fcc structure, the component in which shear plane and direction consistent with slip plane and direction, respectively developed by recrystallization. Further, the (110) pole figure revealed that a texture component of $<110>$ parallel to a slip direction, $<110>/TD$ somewhat grew up also.

3.2. Analysis of the Al-3%Mg alloy pole figure which sheared RD

Figure 3 illustrates (111), (200) and (220) pole figures before heating, $280^\circ C$, $320^\circ C$ and $360^\circ C$ in RD sheared specimen. Before heating, ND-rotated S $\{123\}<634>$ and Cube $\{001\}<100>$ orientations are observed. However, as shown in (111) pole figure, the highest concentration is found in the other direction than TD or RD, which is different from a result of the TD sheared specimen. In the RD shear specimen, S and Cube orientations exist in an initial state, an orientation with priority on slip deformation is formed, that is, easily deformed. In other words, preferred orientation formation naturally depends on the initial texture component before the shear deformation. In (110) pole figure the highest concentration of preferred orientation is seen near the original TD. However, the concentration is weakened as temperature rises.

3.3. Comparison with EBSD analysis of Al-3%Mg

The preferred orientation formation in Al-3%Mg was examined by SEM/EBSD [7]. Preferred orientation evolution was investigated from the EBSD data. The shear textures $<111>/TD_0$ and $<110>/TD_0$, which mean that slip plane and direction are consistent with shear plane and direction, respectively, evolved considerably to fractions of 19.3% and 23.0% after shear deformation in the specimen subjected to TD-compressive shear test. The fractions of the shear texture increase markedly during step heating and reach 27.4% and 44.2% at 607K. On the other hand, in RD-compressive shear specimen the shear textures on RD, $<111>/RD_0$ and $<110>/RD_0$, do not evolve remarkably. The fractions after shear deformation are only 10.2% and 15.7%, and moreover, less than 10% after the heating at 607K.

The difference in the preferred orientation formation between TD-shear and RD-shear tests by SEM/EBSD is similar to that by the neutron diffraction in the present study. This reveals that the
preferred orientation generated by shear deformation evolves more through subsequent annealing not only in the surface layer but also in whole bulk specimen.

3.4. Comparison analysis with the result of CP aluminum 1050Al

The preferred orientation development in CP aluminium refers to rotation about ND of S and Cube orientations in CP aluminum specimen as well as in Al-3%Mg one. CP aluminum indicated clearer formation of the preferred orientation (Fig. 4) compared with in Al-3%Mg because of higher stacking fault energy leading to easy cross slip. On the other hand, as for the Al-3%Mg alloy, the preferred orientation developed markedly compared with in CP aluminium. This is attributed to larger strain stored and subsequent annealing.

Fig. 2 Pole figures in TD specimen of Al-3%Mg alloy subjected to shear and subsequent step heating: (a) before heating, (b) heating at 280°C, (c) 320°C and (d) 360°C.
4. Conclusions
In the present study, preferred orientation formation with shear deformation and annealing in CP aluminum and Al-3mass%Mg alloy rolled sheet has been investigated by neutron diffraction. The obtained results are summarized as follows:
1. In the Al-3%Mg alloy and 1050 aluminum alloy, preferred orientations $\langle 111 \rangle \perp$ TDO and $\langle 110 \rangle //TDO$ were formed by shear in two specimens of TD shear and the RD shear, and developed by recrystallization.
2. It is revealed that TD shear led to the remarkable formation of the preferred orientations by the comparison of TD shear and the RD shear to depend on the initial rolling texture.

Fig. 3 Pole figures in RD specimen of Al-3%Mg alloy subjected to shear and subsequent step heating: (a) before heating, (b) heating at 240°C, (c) 280°C and (d) 320°C.
3. The difference in the preferred orientation formation between TD-shear and RD-shear tests by SEM/EBSD is similar to that by the neutron diffraction.
4. CP aluminum indicated clearer formation of the preferred orientation (Fig. 4) compared with in Al-3%Mg.

![Fig. 4 Pole figures in TD specimen of CP aluminum subjected to shear and subsequent step heating: (a) before heating and (b) heating at 320°C.](image)

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