INFLUENCE OF SECONDARY ROLLING DIRECTION ON RECRYSTALLIZATION TEXTURES OF COMMERCIAL PURITY ALUMINUM

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ABSTRACT Hot rolled sheets of commercial purity aluminum were rolled to 90 % reduction and annealed at 250 ℃ for 30 min, to partially annealed state about 50 % softening ratio. Subsequently partially annealed sheets were rolled to about 20 % reduction at various directions, i.e. 0, 22.5, 45, 67.5 and 90 ° from the primary rolling direction, and annealed fully at 400 ℃ for 2 min. {111} pole figures were measured at the rolling surface and inner layer after chemical polishing. When the secondary rolling direction was parallel to the primary rolling direction, formation of cube texture with orientation spread around the primary rolling direction was observed, being consistent with the result of previous research. A sharp recrystallization texture with two components indexed as near (221) $[\overline{1}\overline{1}4]$ and (121) $[11\overline{3}]$ formed, when the secondary rolling direction was at 45 ° from the primary rolling direction. This was ascribed to retaining of rolling texture by strain induced boundary migration.

Keywords: *recrystallization , partial annealing, texture, rolling, strain induced boundary migration*

1. INTRODUCTION

Cube texture in rolled and annealed fcc metal such as aluminum and copper has been investigated frequently, because cube orientation is very symmetric and important for industrial products such as aluminum foil for condenser and the earing control of aluminum can for beverage. To obtain sharp cube texture in aluminum and aluminum alloy such as Al-Mn-Mg, it is effective to partially anneal and additionally deform before final annealing. This additional or secondary rolling is performed parallel to the primary rolling direction, resulting in orientational spreads around the primary rolling direction [1,2,3]. It is to be expected that the secondary rolling to other than the primary rolling direction may change the orientation of partial recrystallization, and texture after final annealing. In the present study, the possibility of

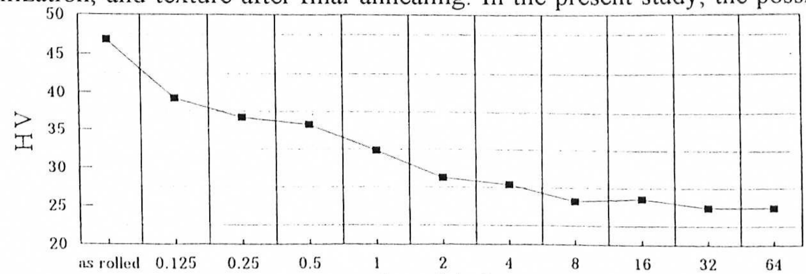


Fig. 1 Softening curve at 250 ° C after 90 % reduction.

controlling recrystallization texture by changing the secondary rolling direction and annealing condition was investigated.

2. EXPERIMENTAL PROCEDURES

The starting materials were hot rolled commercial purity aluminum sheets with 6mm thickness. The chemical composition was as follows; 0.12 wt% Si, 0.44 wt% Fe, 0.02 wt% Cu, balance Al. Hot rolled sheets were rolled to 0.62 mm thickness (90 % reduction), subsequently annealing characteristics at 250 ℃ were determined by micro Vickers hardness test at the rolling plane surface. Preliminary experiments were conducted to find the appropriate annealing condition and secondary rolling reduction for the formation of cube texture when the secondary rolling direction (S.R.D.) was parallel to the primary rolling direction (P.R.D.). After annealing at 250 ℃ for 30 min (53 % softening ratio), secondary rolling of 20 % reduction was performed to the direction at 0, 22.5, 45, 67.5 and 90° from the primary rolling direction, respectively, and final annealing temperature and time were 400 ℃ and 2 min. Annealing was carried out in a salt bath. {111} and {100} pole figures were measured by the Shulz method with nickel filtered copper radiation. Microscopic observation was conducted under polarized light after mechanical polishing and anodic oxidation treatment .

3. RESULTS AND DISCUSSION

Fig.1 shows annealing characteristics of 90 % rolled sheet. Micrographic observations at longitudinal section showed that softening occurred more slowly at the inner layer than at the surface layer. After annealing at 250 ℃ for 30 min, fine recrystallized grains with diameter about 10 μ m formed at the surface layer and at the center of thickness deformed structure was retained. The difference in softening characteristics through the thickness leads to the difference of recrystallization texture through the thickness after final annealing. In the present study, the texture evolution in the surface region of the sheet was mainly investigated.

Fig.2 shows {111} pole figures at the rolling plane surface after annealing subsequent to partial annealing and secondary rolling to various directions. When the secondary rolling direction was parallel to the primary rolling direction, cube texture with orientation spread around the primary rolling direction was obtained, being consistent with the result of previous research. In case of the secondary rolling direction inclining at 22.5° to the primary rolling direction, cube texture with asymmetric orientational spread formed. When the angle between the secondary rolling direction and the primary rolling direction became 45°, a sharp recrystallization texture symmetric with the primary rolling direction was observed. In case of other angle, there was a tendency towards formation of texture with more orientation spread. Grain sizes after final annealing were not dependant on secondary rolling direction.

After about 15% of thickness was removed by chemical polishing from both surfaces, {111} pole figures were measured in the same way as in Fig.2. Recrystallization textures similar to Fig.2 were observed. In the present work, the most sharp recrystallization texture was observed when the secondary rolling direction angle was half of right angle. So texture change

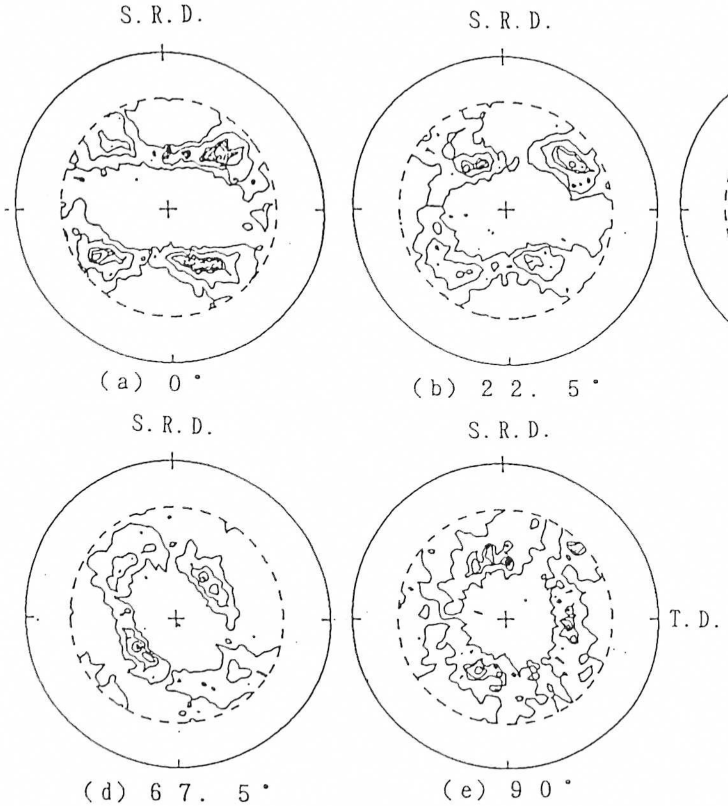
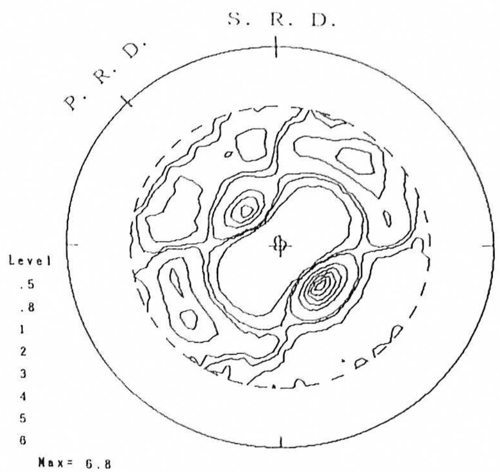


Fig.2 {111} pole figures at the rolling plane surface after annealing subsequent to partial annealing and secondary rolling to various directions of indicated angles from the primary rolling direction.

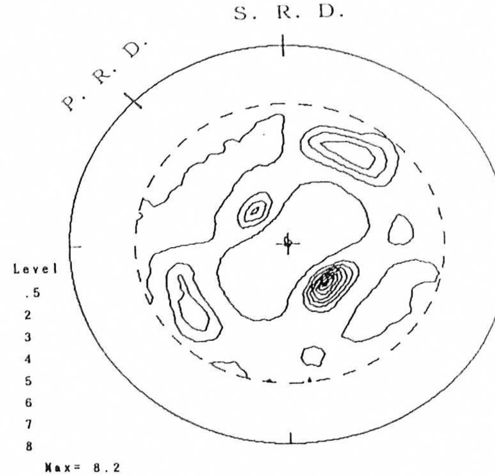
was investigated more detail in this case.

Fig.3 shows {111} pole figures at various stage from 90% rolled state to finally annealed state. Pole figures in Fig.3 were obtained after about 30% of thickness was removed by chemical polishing from both surfaces. Two main components of rolling texture are nearly indexed as (221) [$\bar{1}\bar{1}4$] and (121) [$11\bar{3}$]. In the ideal orientation, the direction are parallel to the primary rolling direction. It seems mixture of surface shear texture and typical rolling texture of aluminum with slight asymmetry as to the primary rolling direction. After partial annealing to about 53 % softening, orientational spread are almost same as rolled state. Secondary rolling of 15 % reduction did not alter texture. So there is no appreciable change in {111} pole figure other than slight decrease in pole density. On final annealing at 400 ℃ for 30s, rolling texture was almost retained. In other words, it looks like on the pole figure there is no orientational change after recrystallization. This results were confirmed by measuring of {100} pole figures.

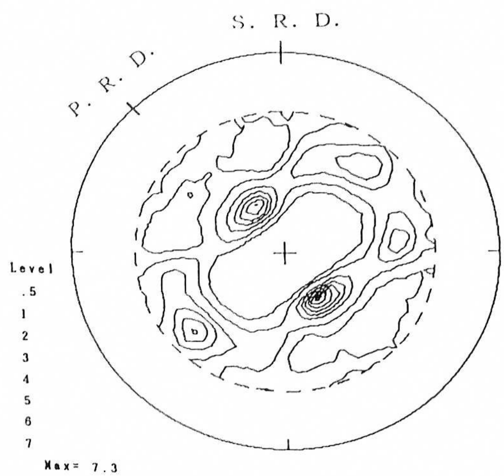
Fig.4 shows optical micrographs at longitudinal section at various stages from 90% rolled state to fully annealed state. Vickers hardness numbers measured at each section are indicated to



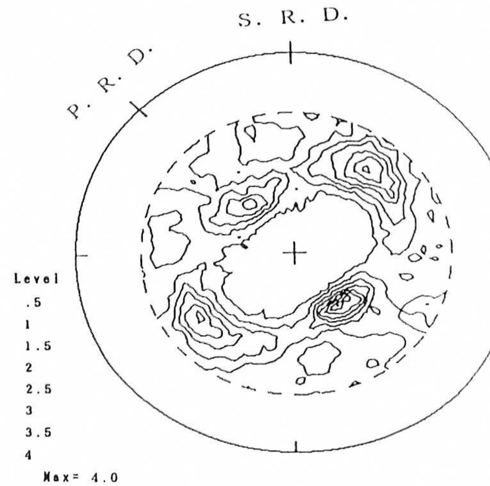
(a) rolled 90 % reduction



(b) partially annealed



(c) secondarily rolled 15 % reduction

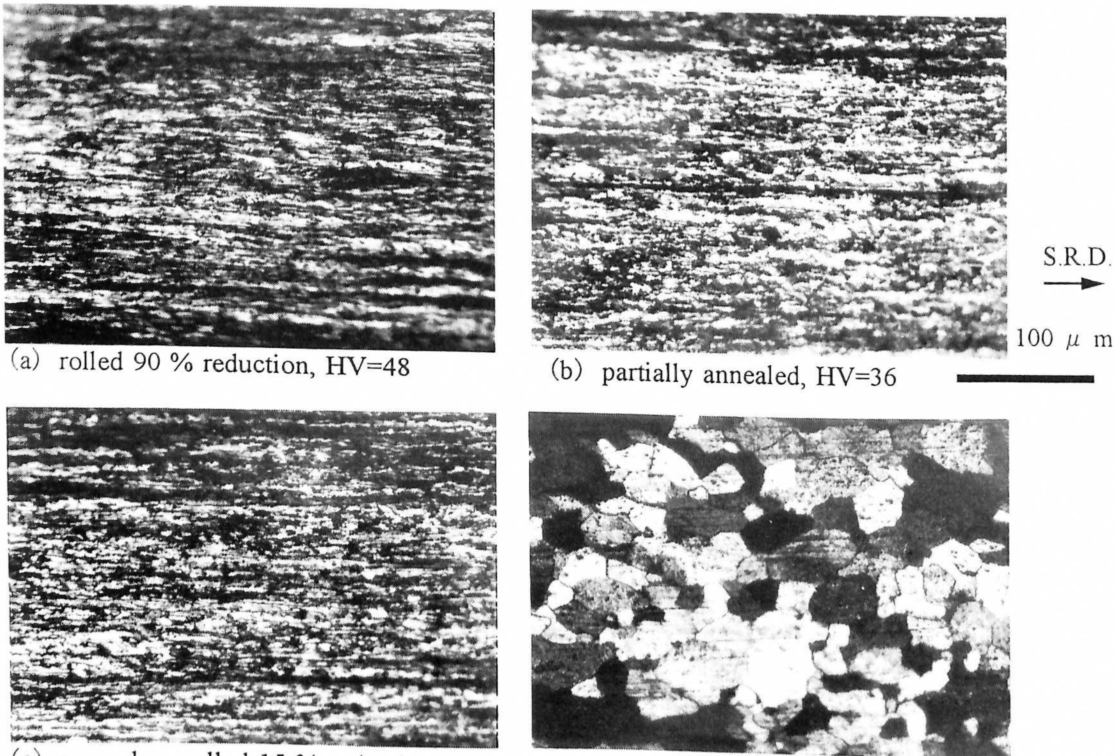


(d) fully annealed at 400 ℃ for 30s

Fig.3 {111} pole figures at various stages from 90% rolled state to finally annealed state.

show deformation and softening state. After 90% reduction, grains are flattened to pancake-like morphology and laminar fiber structure was developed. Shear banding was not observed. Partial annealing at 250 ℃ for 30 min led to formation of fine recrystallized grain between laminar fiber structure and decrease in Vickers hardness number from 48 to 36. Secondary rolling of 15 % reduction caused little change in microstructure and slight increase in hardness number to 38, indicating very small strain hardening by 15 % secondary rolling. Final annealing at 400 ℃ for 30s was sufficient to cause full recrystallization.

To observe an early stage of recrystallization, specimen was prepared after immersion in a salt bath for 3s. Fig.5 shows an example of intermediate stage of recrystallization during final annealing at 400 ℃. Bulging of grain boundary towards the rolling plane surface suggests that



(a) rolled 90 % reduction, HV=48 (b) partially annealed, HV=36

(c) secondary rolled 15 % reduction, HV=38 (d) fully annealed at 400 ℃ for 30 s, HV=27

Fig.4 Optical micrographs at longitudinal section at various stages from 90% rolled state to finally annealed state. Vickers hardness numbers measured at each section (HV) are indicated.

Fig.5 Optical micrograph showing an early stage of recrystallization during final annealing at 400 ℃.

recrystallization occurs by mechanism analogous to strain induced boundary migration.

Fig.6 shows stereographic projection showing {111} poles of two main components of textures shown in Fig.3. The components are designated as orientation I and II, respectively.

Orientations I and II are indexed as nearly (221) [$\bar{1}\bar{1}4$] and (121) [$11\bar{3}$] as reference of the primary rolling direction, respectively. By calculation of 24 sets orientational relationship between I and II[4], it was found that the rotation of about 47° around a rotational axis on the primary cross rolling direction indicated in Fig.5 as R.A., can coincide orientation I with II. Deviation angle of the rotation axis from [111] are 7.6°. This orientational relationship is not just exactly the favorable orientation relationship for growth in aluminum; the 40° rotation around the common [111] direction, but comparatively preferential relationship for the growth of grain with I orientation formed at partial annealing to the deformation matrix with orientation II by the mechanism of strain induced boundary migration, vice versa. It was proposed that mutual invasions by two way strain induced boundary migration led to preserving rolling texture on the pole figure. It is known that in some instance, there is no essential change in texture after recrystallization, although reorientation by high angle boundary migration has occurred. Examples are those containing symmetrically oriented deformation bands which are related in orientation by rotation around [111] direction shared by both bands [5,6].

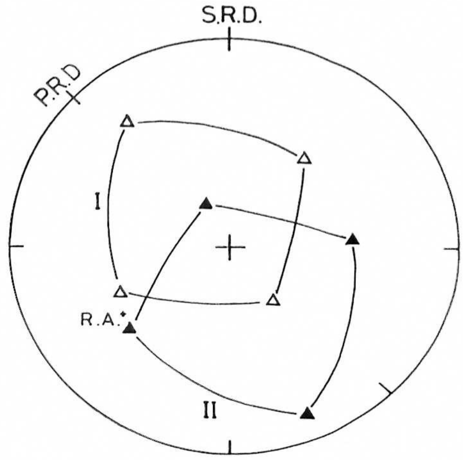


Fig.6 Stereographic projection showing {111} poles of two main components of textures shown in Fig.3.

4. SUMMARY

Possibility of controlling of recrystallization textures in aluminum by partial annealing and secondary rolling at different angles from the primary rolling direction was investigated. Partial annealing of about 53 % softening and secondary rolling at 45° from the primary rolling direction led to the formation of sharp recrystallization texture with components nearly indexed as (221) [$\bar{1}\bar{1}4$] and (121) [$11\bar{3}$]. The formation of the texture was attributed to retaining of rolling texture by strain induced boundary migration of boundary formed at partial annealing.

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