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# Effect of hot finishing rolling on cube texture in high purity aluminum foils①

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[**Abstract**] The effect of hot finishing rolling temperature on cube texture in high purity aluminium foils was investigated by means of orientation distribution functions (ODFs). The results show that a relatively strong rotated cube orientation {100}⟨011⟩ exists when the end temperature of hot finishing rolling is 290 ℃, and the cube texture is the strongest after the final recrystallization. The cold rolling textures are comprised of S-, Cu- and Bs-components, and the orientation {100}⟨011⟩ is unstable, it may be split and evolved into two complementary copper components (112) [$\bar{1}\bar{1}$1] and ($\bar{1}\bar{1}$2) [111] during the cold rolling. And a sharp cube recrystallization texture would nucleate and grow in the deformation matrix with the Cu-orientation.

[**Key words**] high purity Al foil; hot finishing rolling; cube texture
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## 1 INTRODUCTION

The researches about textures formation in pure Al have been made for a long time. It has been demonstrated that textures in pure Al were mainly affected by chemical compositions[1], hot rolling temperature, final cold rolling reduction, intermediate annealing temperature and final annealing temperature[2, 3]. The recrystallization textures of high purity aluminum are composed of two components[4], the cube orientation {001}⟨100⟩ and the component similar to the former rolling texture, the so-called R orientation {124}⟨211⟩. And they are related to the end temperature of hot finishing rolling. Suzuki et al[5] demonstrated that the effect of hot rolling temperature on cube texture was related to the content of impurities Fe and Si. For the highest purity samples, higher end temperature of hot rolling was of great advantage to a stronger cube texture. On the contrary, for the less pure samples, higher end temperature of hot rolling resulted in a weaker cube texture. In this paper, the effect of end temperature of hot finishing rolling on cube texture in high purity Al foils is investigated in order to increase a fraction of cube texture and decrease R texture to the utmost extent.

## 2 EXPERIMENTAL

### 2.1 Samples and heat treatment

The composition of the samples are shown in Table 1. The slabs made by semi-continuous casting were subjected to heat treatment at 610 ℃ for 10 h, and then cooled down to room temperature. Hereafter, the slabs were reheated to 500 ℃ for 2 h and then hot-rolled at the different end temperatures of hot finishing rolling. After hot-rolled, the plates were annealed at 450 ℃ for 2 h, then cold-rolled to 0.11 mm in thickness. The cold-rolled foils were finally annealed in a vacuum furnace. The end temperatures of hot finishing rolling and the final annealing conditions are shown in Table 2.

**Table 1** Composition of samples after final annealing $w$ / %

| Fe | Si | Cu | Mg |
|---|---|---|---|
| 0.0011 | 0.0009 | 0.0035 | 0.0020 |
| Mn | Zn | Ti | Ni |
| < 0.002 | < 0.002 | < 0.002 | < 0.002 |

**Table 2** End temperature of hot finishing rolling and final annealing condition

| End temp. of hot finishing rolling | | | Final annealing condition |
|---|---|---|---|
| $t_1$ | $t_2$ | $t_3$ | |
| 270 ℃ | 290 ℃ | 310 ℃ | 230 ℃, 3 h+ 500 ℃, 3 h |

### 2.2 Measurements

The texture was determined by a fully automatic X-ray diffractometer using CuK$_\alpha$ radiation. The four

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incomplete pole figures {111}, {200}, {220}, {311} were measured by a reflection Schulz method ($0° \leqslant \alpha \leqslant 85°$, $0° \leqslant \beta \leqslant 360°$). The experimental orientation distribution functions (ODF) $f(g)$ were computed according to Bunge's series expansion method ($l_{max} = 22$). All ODFs were corrected by using Gauss-type scattering functions[6].

## 3 RESULTS AND DISCUSSION

### 3.1 Experimental results

Fig. 1 gives the ODFs of three hot-rolled plates annealed at 450 ℃ for 2 h, which were rolled at different temperature of hot finishing rolling. Fig. 2 reveals the effect of some orientation differences on the α and CND-skeleton lines. The results show that the cube texture can be hardly observed and the preferred orientation {001} ⟨110⟩ is dominant. Under the condition of the end temperature of hot finishing rolling at 270 ℃, it was weaker, and when end temperature increased to 290 ℃, it became stronger; to 310 ℃, however, decreased. There no Bs component existed when the end temperatures were both at 290 ℃ and 310 ℃, although weaker Bs texture was observed at 270 ℃.

Fig. 3(a), (b) and (c) gives the ODFs of the Al foils rolled to 98% reduction. The texture evolution is summarized in Figs. 4(a), (b) and (c) by plotting the maximum intensity along the α-, β- and τ-fiber versus the corresponding Euler angles $\phi_1$, $\phi_2$ and $\phi$. The results show that the initial texture of the material has a significant influence on texture evolution dur-

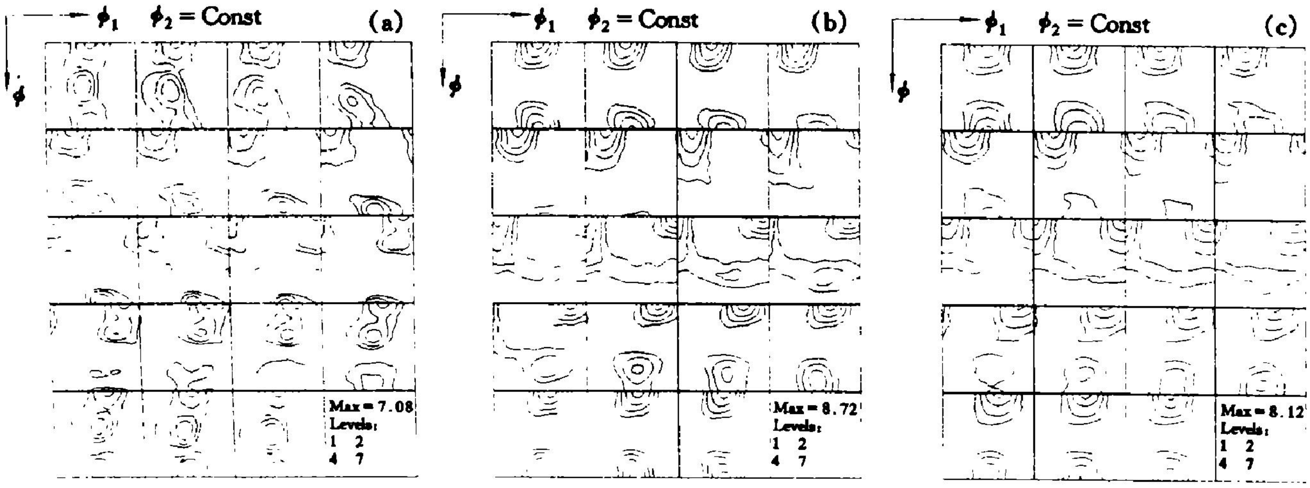


**Fig. 1** True ODFs of hot-rolled material at different end temperatures after intermediate annealing at 450 ℃ for 2 h
(a) —$t_1$ = 270 ℃; (b) —$t_2$ = 290 ℃; (c) —$t_3$ = 310 ℃

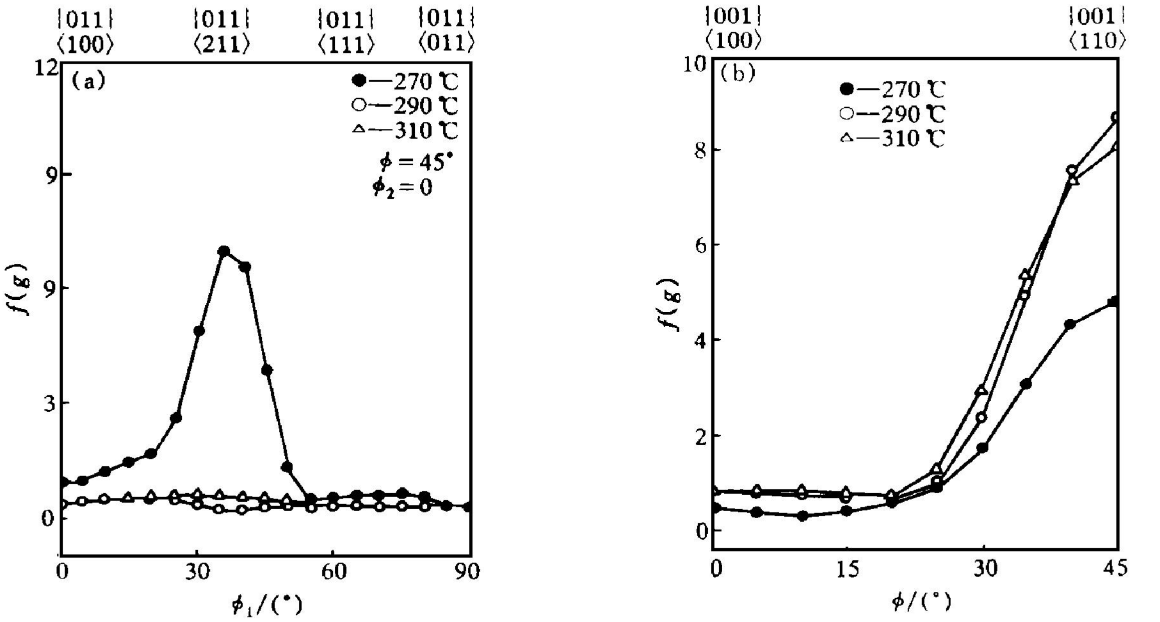


**Fig. 2** Orientation density along α and CND-skeleton lines
(a) —α-fiber; (b) —CND

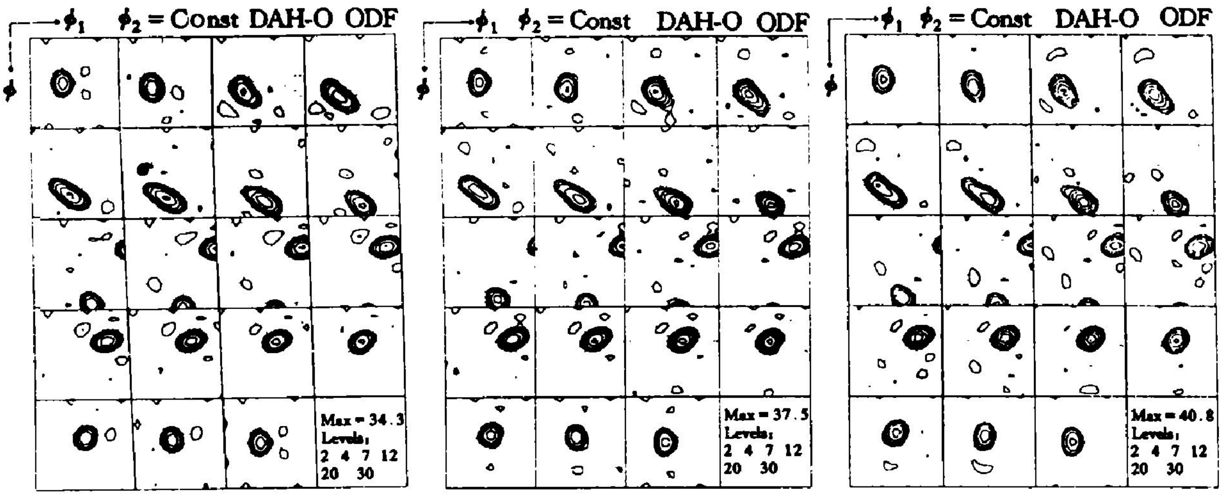

**Fig. 3** True ODFs of cold-rolled foils with thickness of 0.11 mm
(a) —$t_1$= 270 ℃; (b) —$t_2$= 290 ℃; (c) —$t_3$= 310 ℃

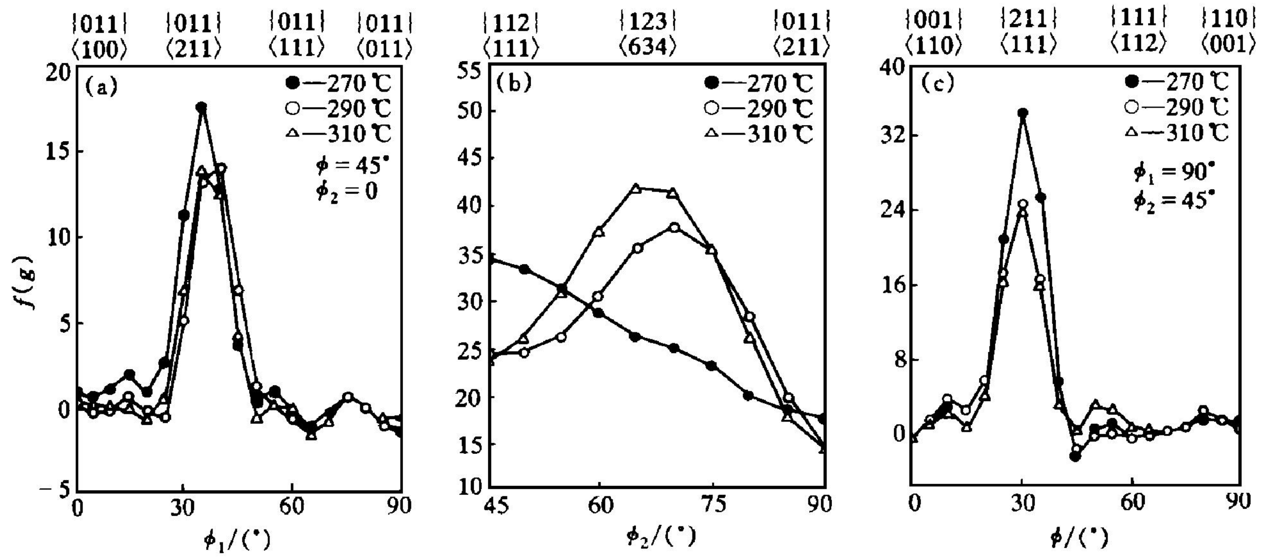

**Fig. 4** Orientation density along α-, β- and τ-skeleton lines
(a) —α-fiber; (b) —β-fiber; (c) —τ-fiber

ing deformation. The cold rolling textures in high purity Al foils with two different starting textures with rotated cube and Bs component are very different. The rolling textures are also composed of Bs, S and C components. But the S intensity in the sample with initial texture Bs is very weak. The C and Bs intensities are relatively weak compared to S component in the sample with no starting texture Bs.

Figs. 5(a), (b) and (c) give the (111)-pole figures of the foils after the final annealing at 230 ℃/3 h + 500 ℃/3 h. Fig. 6(a) shows orientation density along β-fibre. To illustrate the evolution of the cube orientation, Fig. 6(b) shows the orientation density along CND fibre from {001}〈100〉 to {001}〈110〉. The results show that the cube component after the final annealing is obviously dominent. And there exists very weak R texture, although it becomes stronger when the end temperatures of hot finishing rolling are 270 ℃ and 310 ℃. At 290 ℃, cube texture is the strongest.

### 3.2 Discussion

It has been demonstrated that end temperature of hot rolling is one of the important processing parameters which influence on the cube texture of Al and its alloys[2,3,7]. In the present work, it has been found that the cube texture is the strongest when the Fe content equals 0.0010% ~ 0.0011% and the end temperature of hot finishing rolling is 290 ℃.

The Bs texture which was produced during the hot rolling and survived in the hot-rolled plates after the intermediate annealing when the end temperature of hot finishing rolling is 270 ℃. And it developed strongly during the cold rolling. Lee[8] reported that the copper {112}〈111〉 texture appeared to be responsible for the recrystallization cube texture, and

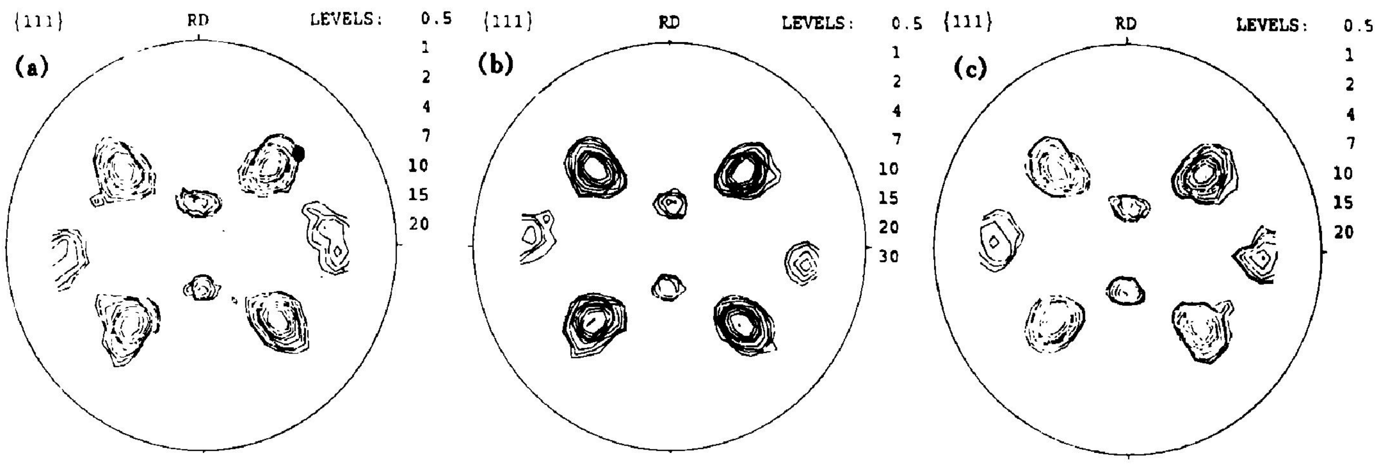


**Fig. 5** (111) pole figures after final annealing
(a) — $t_1$ = 270 ℃; (b) — $t_2$ = 290 ℃; (c) — $t_3$ = 310 ℃

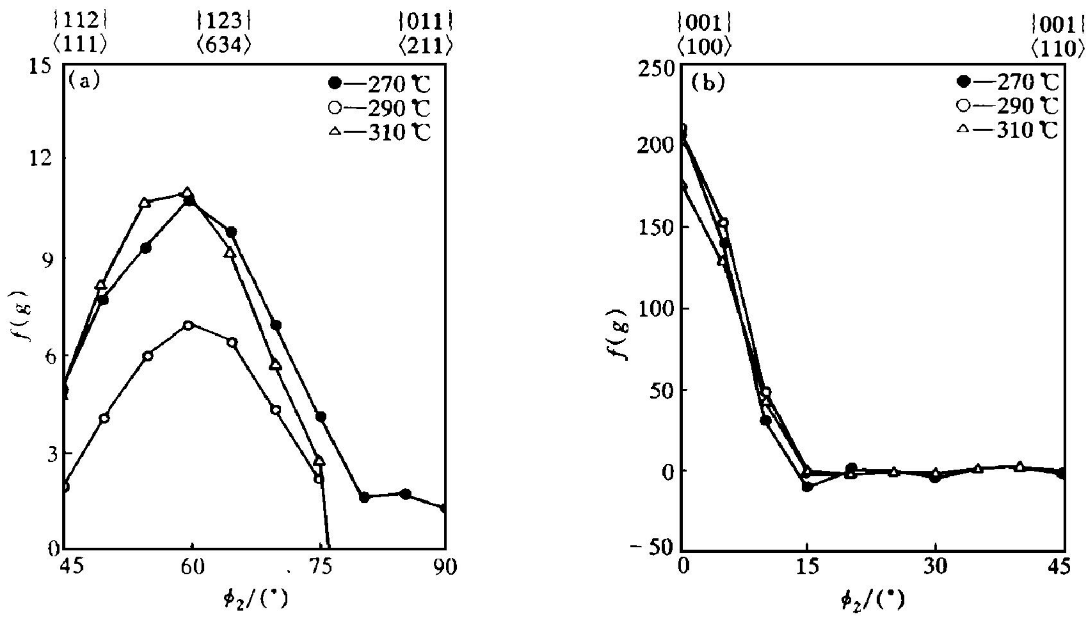


**Fig. 6** Orientation density along β and CND skeleton lines
(a) —Beta line; (b) —CND

brass {011} ⟨211⟩ texture results in the extended recovery, i. e. in-situ recrystallization, which is unfavorable to cube texture. Therefore, the relatively stronger Bs texture exists in the sample hot-rolled at lower temperature, and the final annealing resulted in a strong R texture. When the end temperature of hot finishing rolling is 310 ℃, the cold rolling S texture is the strongest. According to the R texture formation mechanism suggested by Engler[9], the R-oriented grains may form either through in-situ recrystallization or through discontinuous recrystallization by nucleation within S-oriented grains at the grain boundaries between the deformed bands, and subsequent growth under consumption of the as-deformed microstructure. Usually, higher dislocation densities and stronger orientation gradients are present in the vicinity of the S orientation grain boundaries as a result of the activation of additional slip systems to reduce strain incompatibilities at the grain boundaries during deformation. Therefore, the best conditions for recovery and nucleation process are prevalent in regions close to the grain boundary. Furthermore, a favourable growth condition of the nuclei is provided by the already existing large-angle grain boundary between the two neighbouring grains. The recovered subgrain structure and nucleation at grain boundaries may result from the growth of a given subgrain on one side of the boundary into the deformed structure on the other side of the boundary. This mechanism of so-called strain-induced boundary migration (SIBM) would result in R texture, which is similar to the former S-orientation {123} ⟨634⟩. Thus, the R orientation in the sample after the final annealing is also strong when the end temperature of hot finishing rolling is 310 ℃, which has the same orientation density as the R texture when the end temperature of hot finishing rolling is 270 ℃. When the end temperature was of 290 ℃, it formed a stronger rotated cube texture, which can be evolved into cube texture.

It is well known that there are two principal theories for the interpretation of recrystallization cube textures, the oriented nucleation and the oriented growth. The later is related to the cube transition band within the deformation structure[8]. Hjeln et al[10] and Becker et al[11] demonstrated that the rotated-cube orientation {100} ⟨011⟩ is unstable during the plane strain compression, and lattice rotations are around the TD-direction. As the true strain increases from 0.511 ( ε= 40%) to 2.3 ( ε= 90%), the crystals have firstly split into two nearly symmetric orientation groups near ($\bar{1}\bar{1}4$) [221] and (114) [$\bar{2}\bar{2}1$], and finally evolves into the stable complementary copper components ($\bar{1}\bar{1}2$)[111] and (112)[$\bar{1}\bar{1}1$]. This is agreement with the rotated mode advanced by Dillamore and Katoh[12]. During the final annealing, the cube-oriented {100} ⟨001⟩ grains nucleate and grow preferably in a Cu-type deformation matrix, although the cube and Cu orientations do not satisfy any 40° ⟨111⟩ relationship.

## 4 CONCLUSIONS

1) The cold rolling textures of high purity Al foils are composed of three components, S {123} ⟨634⟩, Cu {112} ⟨111⟩ and Bs orientations {011} ⟨211⟩.

2) A strong rotated-cube orientation can be observed in the hot-rolled samples after the middle annealing at the end temperature of 290 ℃. Subsequently, the strong cube texture in Al foils can be produced after the final annealing.

3) The cube texture decreases and the R texture becomes stronger in the foils after the final annealing, if the end temperature of hot finishing rolling become higher or lower than 290 ℃.

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