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Effect of trace yttrium on cube texture of high-purity aluminum foils①

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[Abstract] The effect of trace yttrium on cube texture of high-purity aluminum foils has been investigated by means of orientation distribution functions (ODFs). The results show that a small addition of yttrium to high-purity aluminum brings about a considerable increment of the cube texture, and it reduces the content of R texture. The rare earth yttrium may combine with the other impurities to form the metallic compounds, such as $FeYAl_8$, Fe_6YAl_6, Fe_4YAl_8 and Si_2YAl_2. When the precipitation of these particles in the matrix is nearly completed and the Fe concentration in the matrix becomes low, the cube texture can develop well and the R texture can be suppressed.

[Key words] high-purity aluminium; rare earth; cube texture; deformation texture
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1 INTRODUCTION

The evolution of texture in aluminum and its alloys during deformation and annealing has been investigated using the electron backscattering pattern (EBSP) technique in a scanning electron microscope (SEM) and the orientation distribution functions (ODFs) used for a number of decades[1~4]. Vante et al[5] reported that the annealing texture of pure aluminum was mainly composed of cube orientation {100}〈001〉 and R orientation {124}〈211〉 which is similar to the previous S-deformation component {123}〈634〉. And the impurities, such as Fe and Si, have the critical effect on cube texture of high purity aluminum foils[6]. They may suppress the recrystallization and the development of the cube texture during the pre-annealing and the final annealing. Suzuki et al[7] concluded that the degree of the cube texture after recrystallization depended on Fe concentration in the matrix. When the Fe concentration in the matrix is much higher than the solubility limit, the development of the cube texture seems to be suppressed and the R-orientation grows. Hug et al[8] showed that a small addition of beryllium to high-purity aluminum brought about a considerable reduction in the recrystallization temperature. Therefore it can accelerate the growth of the recrystallization nuclei in sheets containing Be, which for the most part show {100}〈001〉 orientation. The mechanism of the preferential growth of the recrystallization nuclei in the {100}〈001〉 position may be that a small addition of beryllium is capable of precipitating iron in the matrix through the formation of Fe-Be or ternary Al-Fe-Be compounds. But a small addition of rare-earth to high purity aluminum has not reported yet.

2 EXPERIMENTAL

The materials used for this study were 99.99% high purity aluminum. Samples containing three different yttrium contents were prepared. Their compositions are shown in Table 1. Three alloys were molten from high purity aluminum and high purity yttrium, then cast in iron-mold with dimensions of 19 mm × 100 mm × 1 500 mm. After a homogenization treatment for 10 h at 610 ℃ the slabs were re-heated to 520 ℃ and held for 2 h. Then the materials were hot-rolled to thickness of 4.5 mm respectively. After hot-rolled, the plates were annealed at 190 ℃ for 1 h and 540 ℃ for 2 h, then cold-rolled to 0.11 mm in thickness. The cold-rolled foils were finally annealed at 240 ℃ for 1 h, 420 ℃ for 2 h and 540 ℃ for 2 h in a vacuum furnace.

The texture was determined by a fully automatic X-ray diffractometer using CuK_α radiation. The four incomplete pole figures {111}, {200}, {220} and {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 ($l_{max} = 22$)[9]. All ODFs were ghost corrected by using Gauss-type scattering functions[10].

3 RESULTS AND DISCUSSION

3.1 Rolling textures

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The (111) pole figures of cold-rolled samples with thickness of 0.11 mm (see Fig. 1) look rather similar to each other independent of yttrium contents. Fig. 2 presents the ODFs for samples with 0.0030%, 0.0050%, and 0.0070% yttrium, respectively. The results show that the final rolling texture components are mostly situated on the well-known stable texture fibre (β fibre) and the differences in the various trace yttrium result in different density distributions along this fibre (see Fig. 3). That is to say, in the specimen with 0.0070% yttrium, Bs component {011}⟨211⟩ is formed stronger than in those with lower Y content, but they all remain at lower intensities. The *S* orientation {123}⟨634⟩, which is one of the most stable rolling textures, strongly develops. The density of this orientation shows almost no difference among samples with various trace elements cold-rolled to 98% reduction in thickness. But the *S*-position containing 0.0070% Y is shifted toward the Bs-composition to about $\phi_2 = 75°$. Fig. 3(b) reveals the effect of such differences in orientation on the shape of the skeleton lines. The high intensity of the Cu-orientation is due to the fact that it has a multiplicity of 48 instead of 96 (i.e. always two symmetrically equivalent Cu-positions fall on top of each other, thus giving an impression of a higher volume fraction)[11]. Actually, the copper component {112}⟨111⟩ only developed to a small degree. The physical origin of the effect of trace yttrium on the rolling textures is not clear. Most probably it is the influence of the compounds for trace yttrium combining with Fe on the dislocation motions during

Table 1 Chemical compositions of sample (mass fraction, %)

No.	Fe	Si	Cu	Mg	Mn	Zn	Ti	Ni	RE	Al
1	0.0035	0.0007	0.0027	0.0016	< 0.001	< 0.001	< 0.001	< 0.001	0.0030	Bal.
2	0.0037	0.0011	0.0029	0.0022	< 0.001	< 0.001	< 0.001	< 0.001	0.0050	Bal.
3	0.0039	0.0013	0.0046	0.0029	< 0.001	< 0.001	< 0.001	< 0.001	0.0070	Bal.

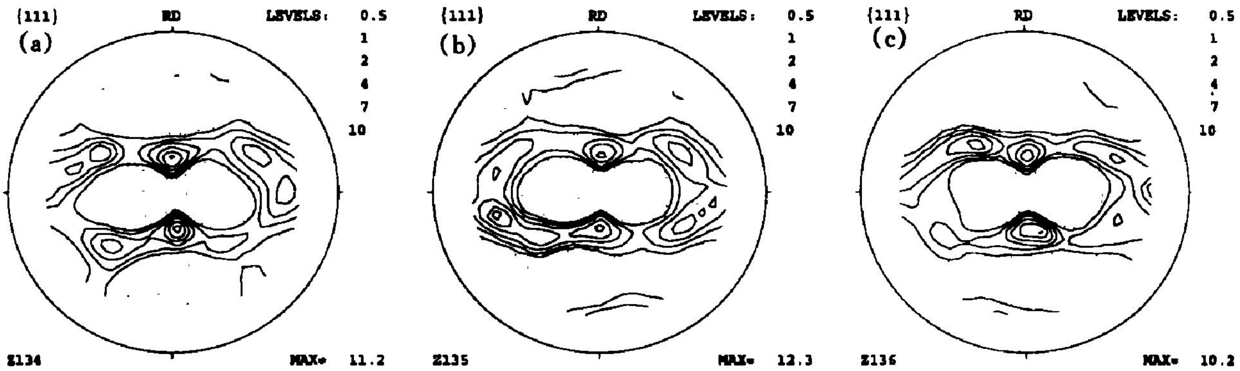

Fig. 1 (111) pole figures for samples with thickness of 0.11 mm
(a) —0.0030% Y; (b) —0.0050% Y; (c) —0.0070% Y

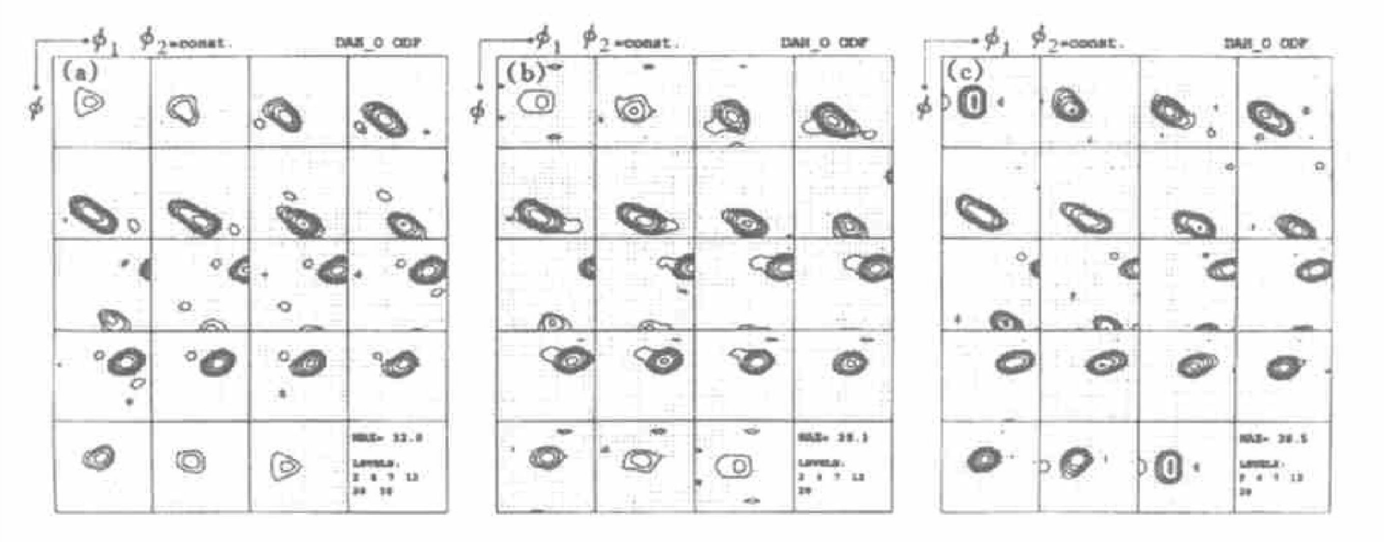

Fig. 2 ODF figures for samples with thickness of 0.11 mm
(a) —0.0030% Y; (b) —0.0050% Y; (c) —0.0070% Y

cold deformation.

3.2 Recrystallization textures

The (111) pole figures of samples with different Y content after final annealing are shown in Fig. 4. The recrystallization texture is shown by the ODFs in Fig. 5. The results show that the textures only consist of the well separated cube and R components. For

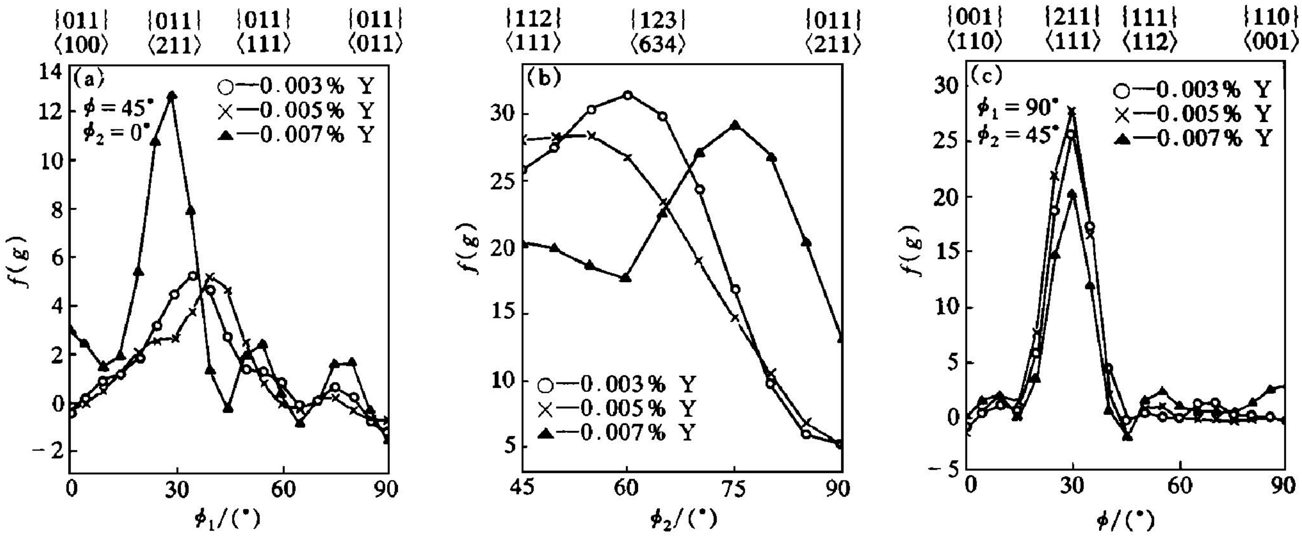

Fig. 3 Skeleton lines analysis of rolling textures
(a) —α-fibre; (b) —β-fibre; (c) —τ-fibre

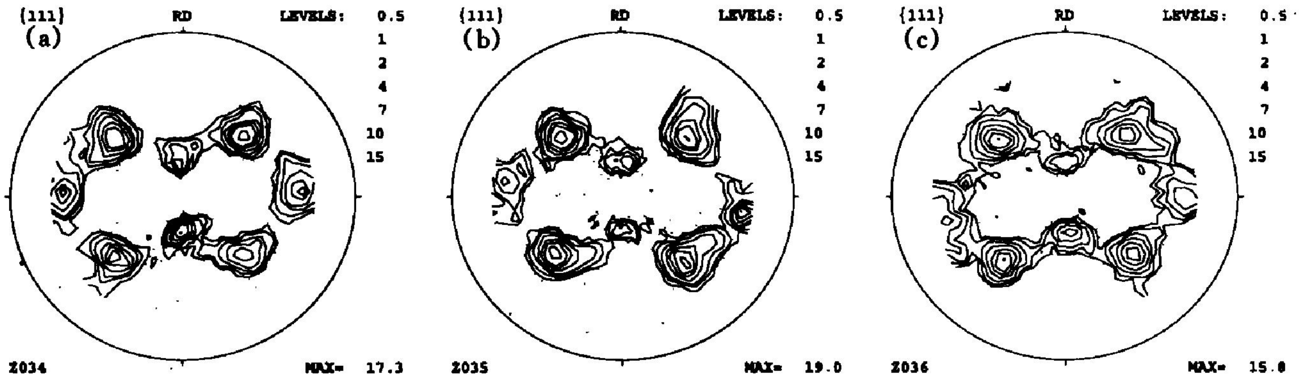

Fig. 4 (111) pole figures for samples with thickness of 0.11 mm after final annealing
(a) —0.0030% Y; (b) —0.0050% Y; (c) —0.0070% Y

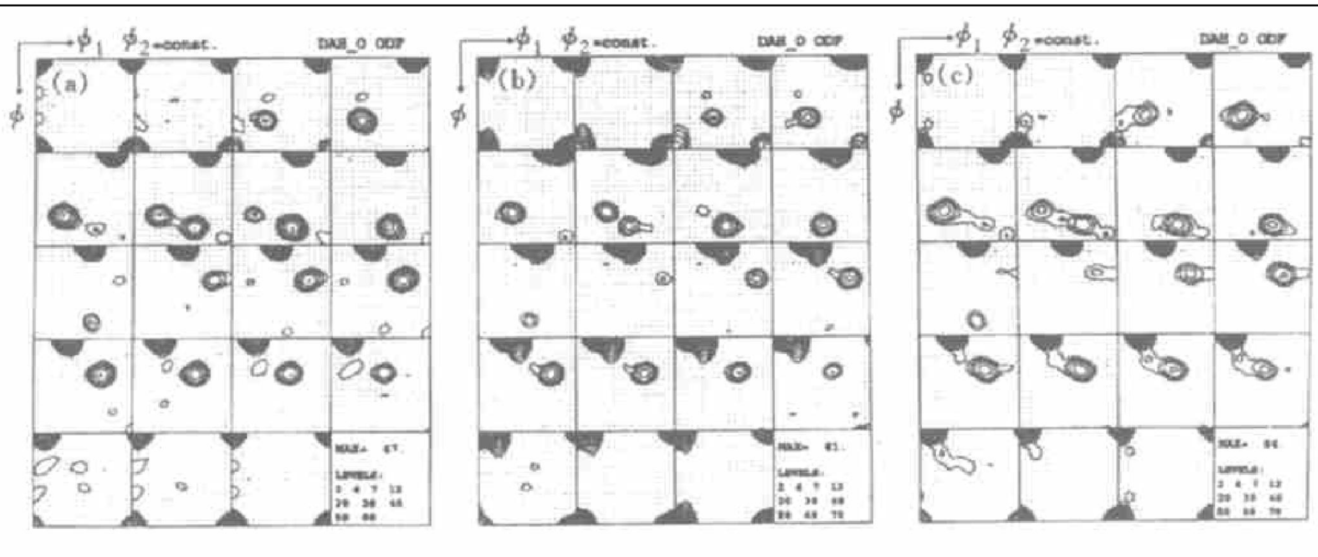

Fig. 5 ODF figures for samples with thickness of 0.11 mm after final annealing
(a) —0.0070% Y; (b) —0.0050% Y; (c) —0.0030% Y

the interpretation of recrystallization textures, there are two major theories: the oriented nucleation and the oriented growth[4]. The former says that the recrystallization texture is determined by the orientations of the available nuclei. They are mainly found in transition bands, i. e. close to strong orientation gradients where they are able to build up fast high-angle grain boundaries of high mobility. Dillamore and Katoh mechanism[12] explained that these transition bands were formed in divergent orientation zones, i. e. in regions where one orientation splits into two orientations by slip on different, but symmetrically equivalent (slip) systems. The latter is assumed that the recrystallization texture is determined by those orientations which have the best growth conditions with respect to the surrounding deformed matrix, i. e. grains with a 40° 〈111〉 orientation relationship to neighbouring grains were found to possess an especially high growth rate in aluminum[13]. Concerning the present recrystallization textures, the cube orientation can be interpreted by means of oriented growth. The cube nuclei can grow because of their 40° 〈111〉 orientation relationship to the *S* orientation, which is the strongest rolling texture in the sample with 0.0030% yttrium. The cube intensity is decreased with increasing yttrium content, which can be attributed to the retardation of the migration of the cube grain boundaries by solute atom drag. The *R* component {124} 〈211〉, which also has a 40° 〈111〉 relationship to the *S* orientation, can develops as well[14]. Fig. 5 shows such a cube + *R* texture in high purity aluminum.

In the present study the recrystallization behaviour of high purity aluminum can be greatly affected by trace yttrium which can be present in solid solution or as precipitated particles. According to Al-Y phase diagram, the solubility of yttrium in aluminum is very small. Its maximum is about 0.17% at the eutectic temperature (910 K). While at 900 K and 800 K it is 0.15% and 0.08% respectively, and at the room temperature it is about zero. This means that above 800 K for the alloy in equilibrium all yttrium is in solution, while at room temperature precipitates are always present. These precipitates probably consist of $FeYAl_8$, Fe_6YAl_6, Fe_4YAl_8, Si_2YAl_2 and $SiYAl_2$. They may reduce the migration rate of grain boundaries, or hinder the dislocation motion to decrease the cube texture during the recrystallization annealing.

It is generally observed that the presence of particles in a metallic matrix may have an effect upon the texture changes both during deformation and during recrystallization. Ito et al[11, 15] reported that a small volume fraction of particles had little effect on the deformation texture, and the present results confirm these findings. However, the effect of particles on recrystallization process is much stronger. Because of the precipitation of Fe impurity, Fe concentration in the matrix becomes low, the cube texture can develops well and the *R* orientation seems to be suppressed during the final annealing[7].

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