Texture evolution of 01570 aluminum alloy sheet

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Abstract: The texture configuration and evolution mechanism of 01570 aluminum alloy, under different stabilizing annealing systems, were studied by means of observations of optical microscopy and analysis of X-Ray. The results show that the major textures of 01570 alloy sheet, at cold-rolling condition, are of Brass texture{011}<211>, Copper texture {112}<111> and S texture{123}<634>, especially, the strength of Brass texture is strongest. Below the recrystallization temperature to make stabilizing annealing, the texture components change little compared with the cold-rolling sheet. When stabilizing annealing temperature reaches the recrystallization temperature, the deformation texture will disappear with the temperature rising gradually, and the recrystallization texture configuration will gradually increase; when the temperature reaches 590℃, the major textures are of the recrystallization texture of rotating cube texture and cube texture in the alloy.

1 Introduction

01570 alloy belongs to the series of containing scandium aluminum alloy, because it has high strength, good plasticity, excellent welding performance and strong corrosion resistance, so it has a broad application prospect in spaceflight, aviation and other fields[1]. 01570 aluminum alloy was first developed by the former Soviet union, and then there were quite a few countries to carry out research successively, our country began to research this alloy after entering the 21st century[2]. Now at home and abroad lots of works on microstructures and properties about this alloy have been done[3-5], but research on texture is rarely reported. The alloy to be used is mainly at the condition of stabilizing annealing after cold rolling, due to the deformation after hot and cold processing, so the texture will exist in the alloy. And the existence of the texture causes the performance difference on different directions, so the texture is used as an important reference index on engineering.

In the aluminum alloy after rolling it can form deformation texture, the deformation textures are mainly Brass texture {110}<112>, S texture {123}<634>, Copper texture {112}<111>, and they also may form Gauss texture {110} <001>and fiber texture of the surface{001} <110> [6-9]. After recrystallization annealing it mainly forms recrystallization cubic texture {001}<100> and R texture {124}<211> in aluminum alloy plate[10-11]. These textures under the different processing will exist in different configuration forms, and the evolution of each other will take place. With the development and the use of 01570 aluminum alloy, the studies on the existence form and the evolution rule under different process conditions will provide support for the design and production of the alloy. In this article the existence form and the evolution mechanism of the texture in 01570 aluminum alloy under different stabilizing annealing system will be studied.

2 Experimental

01570 experimental alloys were prepared by water chilling copper mould ingot metallurgy processing which was protected by active flux with pure Al, Mg and master alloys (Al−2.23%Sc, Al−4.48%Zr, Al−8.5%Mn), and Their nominal compositions(wt.%) are shown as follows: 5.8Mg, 0.4Mn, 0.25Sc, 0.1Zr， :Bal. Al. After homogenization at 460°C for 24h, the ingots are cut head and milled surface to 25mm thickness. Then a hot-rolling process is applied to 6mm after heat preservation for 3h at 470 °C, which is followed by intermediate annealing at 400 °C for 2h. Subsequently, the hot-rolled sheets are cold-rolled to a thickness of 2.0 mm. The total deformation rate is up to 92%. The cold-rolled sheets are annealed at 340 °C or 150°C for 1h. Homogenization; intermediate annealing and stabilizing annealing processing are made in SPC box-type resistance furnace, and the error is ±2℃.

2.1 Optical observation

The optical specimens were prepared firstly by mechanical polishing, then electrolytic polishing and anodizing, and at the end were examined using a POLYVER-Met optical microscope. The compositions of electro-polished solution were shown as follows: 10%$HClO_3$+90%C_2H_6O(vol.%). Electrolytic polishing voltage is 25V, about 30 second. The compositions of anodizing solution were shown as follows: 30mlHF+11gH_3BO_3+970mlH_2O, and anodizing voltage is 20V, about 3min.

2.2 Measurement of the plate texture

The samples of texture test were prepared firstly by mechanical polishing, and then electrolytic polishing to remove stress layer on the surface of the sample. Testing was done using a BRUKER D8 DISCOVER automatic X-ray diffractometer. And three incomplete pole figure of {220}，{200}，{111} were measured($0\leq\alpha\leq75°$，$0\leq\beta\leq360°$). The calculation of orientation distribution function need to the defocusing, basal correction and then Bunge series expansion, the results were showed with constant $\phi2$ ODF section diagram. When measuring the rake was Cu Kα, measuring step length was 5 °, tube current was 40mA, tube voltage was 40kV.

3 Results

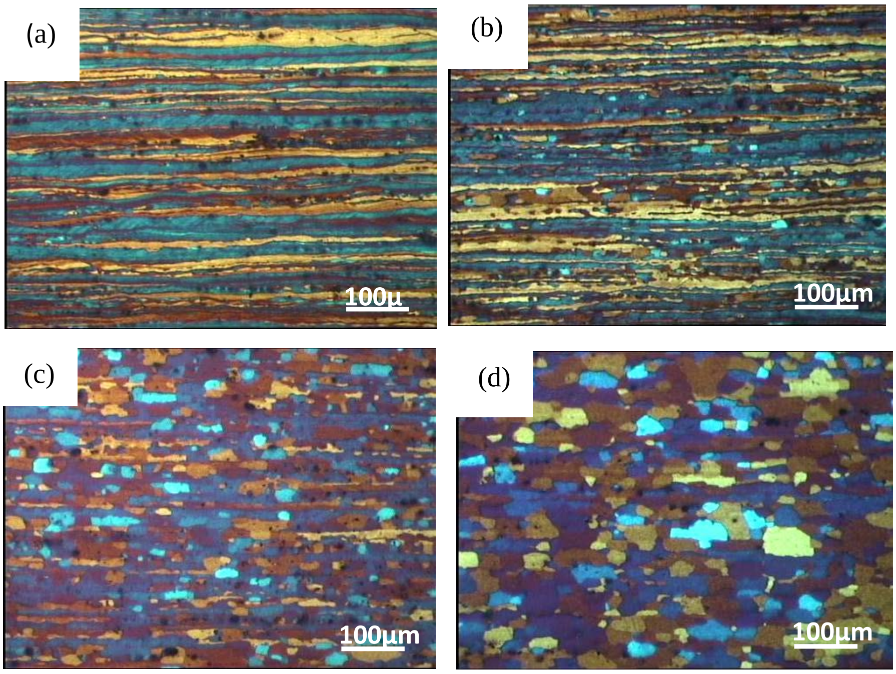

Fig.1 Optical microstructure of 01570 alloy in different annealing temperature

(a) 450℃/1h; (b) 550℃1h; (c) 570℃/1h; (d) 590℃/1h

3.1 Microstructure and texture of 01570 alloy

Fig.1 gives the optical microstructure of 01570 alloy in different annealing temperature. When annealing temperature is below 450℃, the microstructure keeps of the fibrous microstructure formed in the process of rolling deformation, no recrystallization phenomenon is found in the alloy(Fig.1a). When annealing temperature reaches 550℃, after annealing an hour, there are a small amount of recrystallization grains in the fibrous microstructure (Fig.b). Continuing to rise the annealing temperature to 570℃, the recrystallization phenomenon have become obvious in the alloy internal, and the fibrous microstructures become discontinuous(Fig.c). When the temperature is risen to 590℃ and the annealing time reaches an hour, the recrystallization process basically completes(Fig.d). The microstructure observations shows that when the annealing temperature is below 450℃, the deformation texture is maintained, and when the recrystallized grains appear in the alloy, the texture configurations come up with evolution, and when the temperature reaches 590℃, the deformation texture will be replaced by recrystallization texture.

3.2 ODF analysis of texture

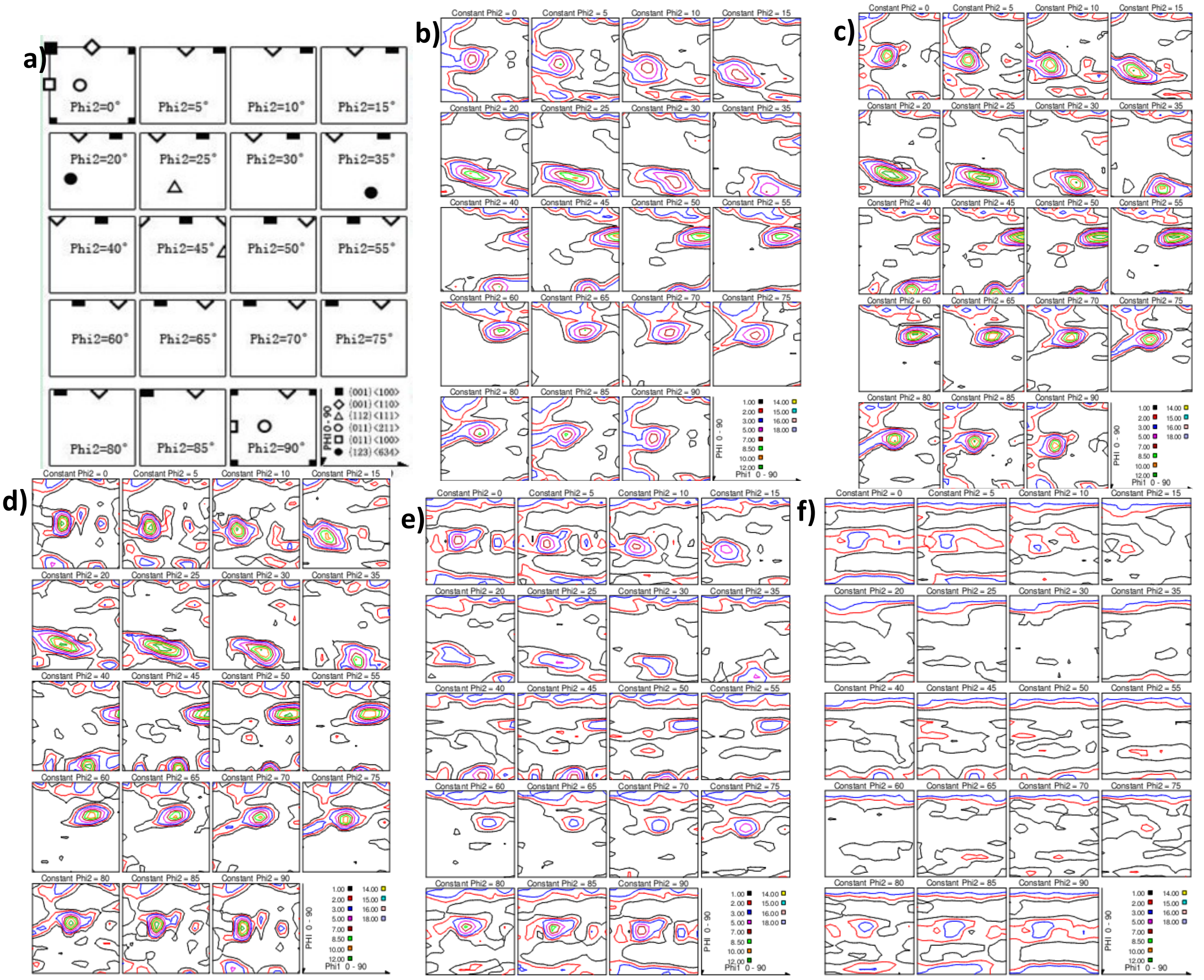

Fig.2 ODF of 01570 alloy sheet in different annealing temperature

a) the important orientation of cubic crystal; b) cold-rolling sheet

c) 450℃/1h; d)550℃/1h; e) 570℃1h; f) 590℃/1h

Figure 2 gives the orientation distribution of 01570 aluminum alloy under different annealing temperature(constant φ_2), and the distribution in Euler space of some common texture in cubic crystal is shown in Fig.2a. They are illustrate that the textures in 01570 aluminum alloy cold-rolling sheet are mainly composed of Brass texture{011}<211>, Copper texture {112}<111> and S texture{123}<634>, and the strength of Brass texture is significantly higher than the other two(Fig.2b). These sheets were annealed for an hour at 450℃ or 550℃, the texture components didn't change obviously, they were still mainly Brass texture, Copper texture and S texture, these results were shown in Fig2c,d. After 570℃/1h stabilizing annealing, because the partial recrystallization have taken place in the alloy, so the deformation texture strength decreases obviously, begins to slowly disappear, and a few cubic textures appear and are loose distribution in the plates, but their strength is low(Fig.2e). When annealing temperature rises to 590℃, after an hour annealing, the microstructure have changed into fully recrystallization microstructure, the deformation textures almost disappear, and the recrystallization texture of rotating cube texture and cubic texture become main texture, their strength increases than 570℃(Fig.2f).

3.3 Change of the texture strength with the annealing temperature

The changes of texture strength along the line of orientation in different annealing temperature are showed in figure 3. It can be seen that Brass texture{011}<211> distributes in the alpha orientation of face-centered cubic metal, and with the increase of annealing temperature. At the initial stage the strength of Brass texture changes not obviously, but in some stage drops significantly. Namely when annealing temperature is below 570℃, with the increase of annealing temperature, Brass texture orientation density decreases slightly. But when annealing temperature is higher than 570℃, such as annealing for an hour at 570℃ or 590℃, Brass texture orientation density decreases sharply. Fig.3b is illustrate that there are deformation textures of Brass texture{011}<211>, Copper texture {112}<111> and S texture{123}<634> distributing in the beta orientation of face-centered cubic metal, their orientations begin from Brass texture, via S texture and then transfer to Copper texture. In 01570 alloy cold-rolling sheet the orientation density of Brass texture{011}<211> is highest, and the orientation density of S texture{123}<634> and Copper texture {112}<111> are also higher. With the increasing of annealing temperature, the orientation densities of these three kinds of textures have a tendency to decrease. When annealing below 570℃, orientation density slightly reduced, but annealing above 570℃, the orientation densities of these three kinds of texture decrease sharply, and annealing at 570℃ the textures have

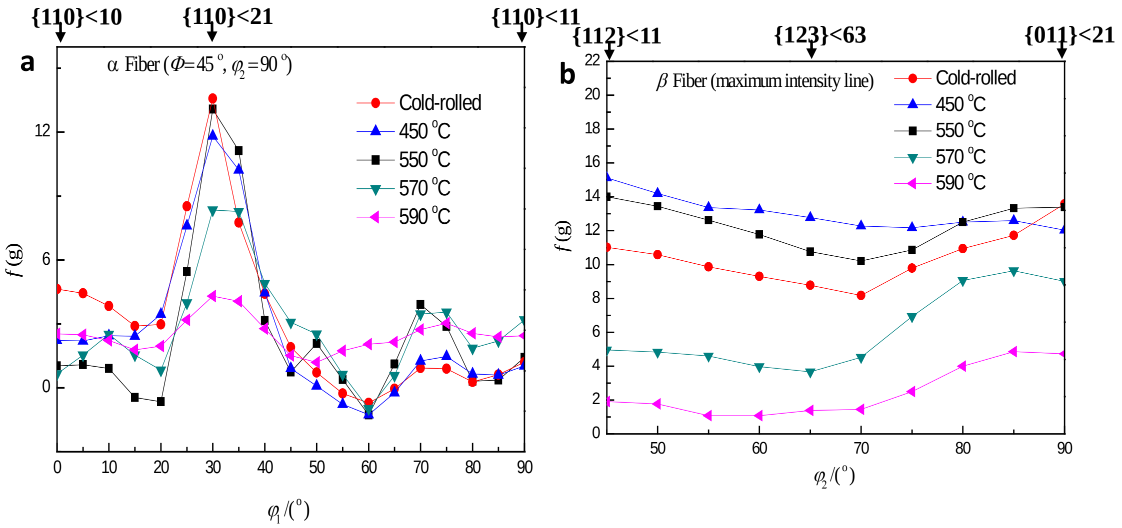

Fig.3 the orientation distribution of 01570 alloy sheet in annealing process

a) α orientation line; b) β orientation line

been almost disappear.

3.4 Texture changes of the volume fraction

Figure 4 gives the changes of texture configuration volume fraction with the change of annealing temperature. The figure shows that when the annealing temperature is below 400℃, the texture changes in volume fraction is very small, the texture configuration is composed of Brass texture{011}<211>, Copper texture {112}<111> and S texture{123}<634>, rotating cube texture almost does not exist, cubic texture is very few. When annealing temperature is over 450℃, the speed of change in volume fraction will increase. And when the annealing temperature is over 550℃, the speed will mutate, at this time the rotating cubic texture and cubic texture are in the leadership place. At 590℃, Brass texture, Copper texture and S texture almost disappear. These are mainly because when the temperature is above 450℃, the partial recrystallization phenomenon occurs in the alloy, and with the temperature rising the degree of recrystallization increases. As the temperature reaches to 590℃, the microstructure has been fully recrystallization microstructure, thus the deformation texture transfers into recrystallization texture.

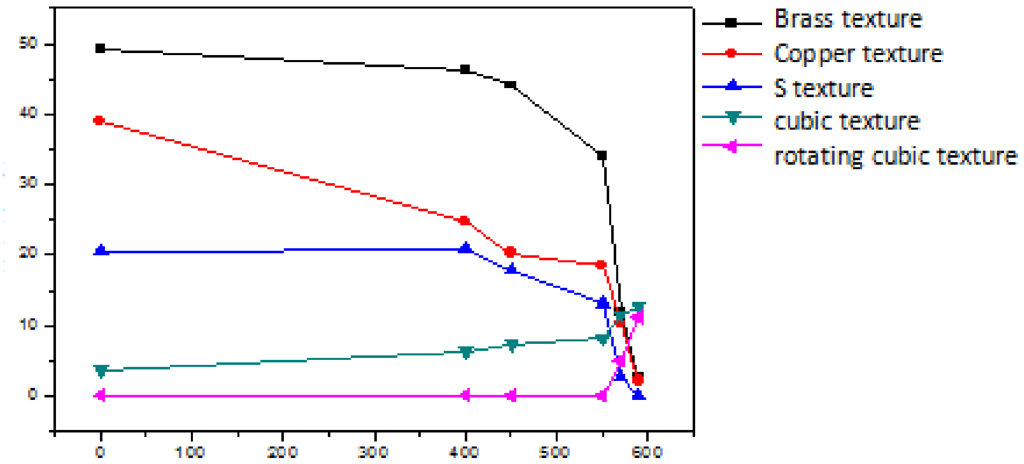

Fig.4 Texture changes of the volume fraction of 01570 alloy sheet in annealing process

3.5 Grain orientation difference distribution

The grain orientation difference distributions of 01570 aluminum in different annealing temperatures are showed in figure 5. As can be seen from the Fig.5a, the orientation difference in cold-rolling condition mainly concentrated in the vicinity of 2°, thus the most part in the grain boundary is less than 15° and belongs to small angle grain boundary, and the large angle grain boundary that the orientation difference is over 15° is account for only a little part of it. The reasons are that after cold rolling deformation, the grains bear the extrusion and appear serious breakage, the dislocations form cellular substructure by tangles. These substructures and the dislocation slip line producing by slip pile up together in the grain interior, thus make the alloy internal appear a large number of small angle grain boundaries. Fig.5b gives the orientation difference distribution of the alloy after 350℃/ 1 h annealing. It shows that the distribution density of small angle grain boundary is in reducing, but the large angle grain boundary is on the rise. This is mainly because there is reply phenomenon appearing in the alloy when annealing at 350℃, under the effect of thermal the dislocation will move, and the substructures also can migrate and merge, so can form more large angle grain boundaries. When the annealing temperature rises to 550℃, the partial recrystallization appears in the alloy, and some isometrics are found in the fibrous microstructure. At this time the small angle grain boundary content is further reduced, and the large angle grain boundary content increases significantly(Fig.5c). Continuing to increase annealing temperature to 570℃, the content of small angle grain boundary is already very low, and the large angle boundary takes leadership in the alloy. The boundary orientation differences are mainly concentrated in 25°~60° and take normal distribution, and the value of large angle boundary which the orientation difference is about 45° is most. These are mainly because with the increase of annealing temperature the degree of recrystallization increases, the isometric number is on the rise correspondingly, and large angle grain boundary density also increases. By above observation the results already show that when the annealing temperature reaches to 590℃ the alloy will be fully recrystallization microstructure and almost large angle grain boundaries,

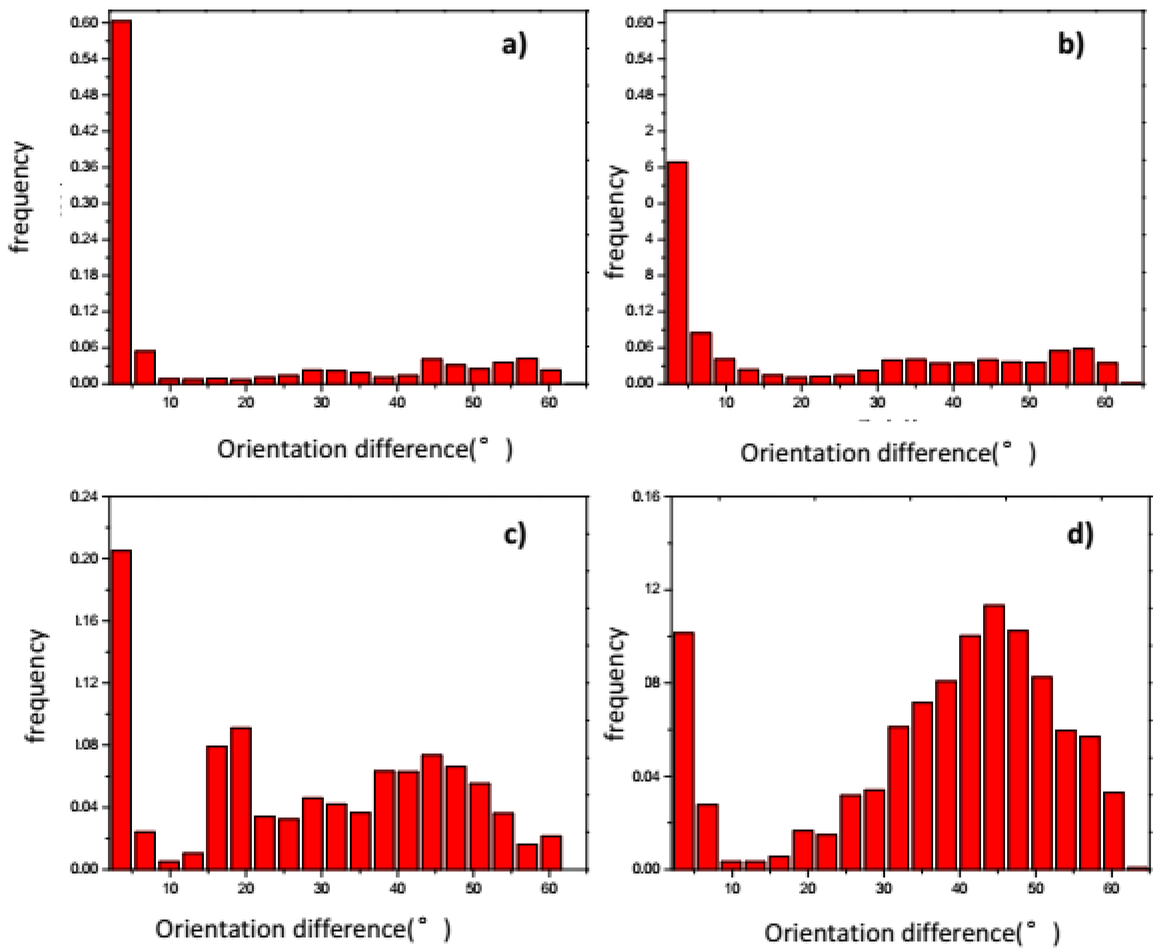

Fig.5 Interface orientation difference distribution of 01570 alloy sheet in different annealing temperature

a) cold-rolling condition; b) 350℃/ 1 h; c) 550℃/ 1 h; d) 570℃/ 1 h

4 Discuss

4.1 Texture forming mechanism of 01570 cold-rolling sheet

Brass texture{011}<211>, Copper texture {112}<111>, and so on, which belong to deformation textures, have appeared in 01570 cold-rolling sheets. These textures often appear in the metal of face-centered cubic crystal structure. Figure 6 is the orientation triangle of polar stereographic projection in face-centered cubic metal. When the face-centered cubic metals are rolled, their primary slip system is, and the secondary slip system is. Under the action of tensile stress, the crystals take rotation, and the action line rotates to the direction of . When it passes through the attachment line of [001]-[111], the primary slip system is replaced by the second slip system, and the tensile stress axis direction will turn to the new slip direction of [011], when it crosses the attachment line of [001]-[111], the primary slip system is reactivated. This phenomenon repeats for many times, at the end the action line direction falls on the attachment line of [001]-[111], and on the [112] direction which is symmetric with [101] and [011]. Point C in figure 6 is the pressure axis direction, at the beginning it is in the orthogonal state with Under the action of compression force along the normal direction on the rolling surface, point C will also rotate to direction. When point T crosses the attachment line of [001]-[111] the original slip system is replaced by the new slip system. And point C will turn to again, after turning back and forth, point C falls on direction. So in 01570 alloy can form Brass texture{011}<211> which has high strength. In addition to the above sliding systems, there will be other sliding systems involved in sliding during the process of rolling. So in 01570 alloy can also form Copper texture{112}<111>, Gauss texture, S texture and the other.

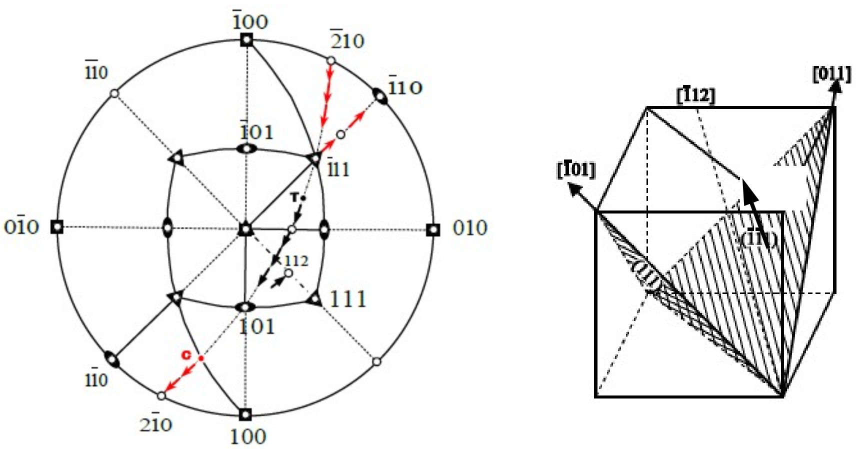

Fig.6 Face-centered cubic crystal orientation change in the rolling process

4.2 Texture evolution of 01570 aluminum during the process of stabilizing annealing

The texture configurations of 01570 aluminum alloy will vary with the change of stabilizing annealing. When the annealing temperature is below 550℃, the areas of Brass texture, Copper texture and S texture decrease as the temperature increases and discontinuously distribute along the rolling direction. The type of copper texture and R texture make their occupying areas widen by expanding them into the areas occupying by Brass texture and Copper texture. So it can be judged that the formation of R texture transforms from S texture and Copper texture. When annealing temperature reaches to 570℃, the recrystallization has taken place in the alloys, Copper texture and the type of copper texture gradually reduce, the cubic texture obviously increases, but there is a small amount of Brass texture preserved. In addition, there exist R texture and the grains which orientation close to {110}<111>. Work [12] had shown that the orientation formation of {110}<111> deflected from Brass texture and Copper texture, it is the transition texture from deformation texture transforming into cubic texture, and is particularly unstable texture type. Under high temperature annealing, it can transform into the stable cubic texture via rotating around <110> and <111> axes. When annealing temperature reaches to 590℃, the alloy has been fully recrystallization microstructure, this time the deformation texture will be replaced by recrystallization texture.

Figure 7 is the space schematic diagram which shows Brass texture how to transform into annealing texture in the annealing process in 01570 alloy sheet. With the annealing temperature rising, the grains with the orientation of (011)[$2\bar{1}1$] will do 30° rotation around <111> axis[11], and make {011}<$2\bar{1}1$> orientation gather in {112}<$1\bar{1}0$> orientation area. The non-ideal orientation grains which clustering near the brass texture orientation do 30°~40° rotation and transform into {011}<111> unstable texture. {112}<$1\bar{1}0$> and {011}<111> belong to unstable orientation, under the high temperature annealing, the grains with the two orientations will rotate around <100> axis and transform into stable cubic texture orientation[13], thus make the transformation process from deformation texture into recrystallization texture complete.

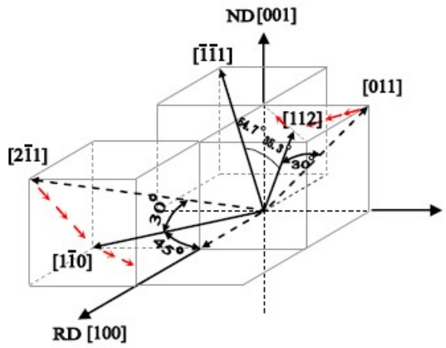

Fig.7 Texture evolution during the process of annealing

Through the rotation of grains and the migration of grain boundaries, Copper texture and S texture will gradually form the transition orientation zone which are composed of R texture orientation and the type of copper texture orientation[14]. R texture orientation during the subsequent annealing process will gradually turn to cubic texture orientation. $A1_3$(Sc,Zr) particles which have the role that can strongly hinder the grain boundary migration impede the process that makes R texture orientation transform into recrystallization texture orientation, so that R texture orientations preserves a lot of in 01570 alloy. When continuing to improve the annealing temperature, it makes the role of $A1_3$(Sc,Zr) particles to hinder the grain boundary migration reduce, thus R texture orientation is able to transform into the stable cubic texture orientation. So when the annealing temperature reaches to 550℃ the density of deformation texture in 01570 alloy still keeps in high level. But when the annealing temperature reaches to 570℃, the recrystallization has taken place obviously in the alloy, thus lead to the density of deformation texture sharply reduce and the strength of recrystallization texture begin to increase significantly.

5 Conclusions

(1) The textures in cold-rolling sheet of 01570 aluminum alloy are mainly composed of Brass texture{011}<211> , Copper texture{112}<111> and S texture{123}<634>, and the strength of Brass texture is highest.

(2) 01570 aluminum alloy is annealed for an hour below 550℃, the texture components have no obvious changes, still are mainly Brass texture, Copper texture and S texture.

(3) When annealing temperature reaches to 570℃, partial recrystallization microstructure appears in the alloy sheet, and deformation texture intensity drops, some of deformation textures transform into recrystallization texture. When annealing temperature reaches to 590℃, there are full recrystallization microstructure existing in the alloy, the deformation texture almost disappearance, and the recrystallization textures, such as rotating cube texture and cubic texture, become main textures.

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