TEXTURE IN INHOMOGENEOUSLY ROLLED ALUMINIUM SHEET①

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ABSTRACT

The changs of stress state in cold rolled aluminium sheet with large pass reduction, the combining activation process of slip systems as well as the formation mechanism of corresponding shear textures were investigated. It is shown that the rolling deformation with large pass reduction produces not only the general rolling stresses but also a strong shear stress in aluminium sheet. With increasing additional shear stress the general rolling textures, i. e. {112}<111>, {123}<634>, {110}<112> and {110}<001> decrease, and the shear texture, i. e. {001}<110> as well as {111} fibre texture become stronger. The internal relation of these two kinds of textures was also discussed.

Key words: inhomogeneous deformation, aluminium, texture

1 INTRODUCTION

It is well known that the structure state of cold rolled aluminium sheet would be changed if the deformation geometry is altered. Some investigations have shown that certain inhomogeneous deformation appears often[1, 2], during which the texture would be essentially changed with increasing distance to the sheet surface. The geometry parameters for homogeneous rolling of aluminium sheet have been found under certain deformation conditions. For instance the 1 / h relation has been used to describe the homogeneous deformation[1, 2]. But these parameters did not clearly explain the detail mechanism and physical reason of the inhomogeneous deformation.

The observations of grain orientation change and texture formation during rolling are the important ways to reveal the deformation inhomogeneities, and the orientation distribution function (ODF), i. e. orientation density distributtion is the most powerful method to analyze rolling texture, which is hardly used in the investigation of deformation inhomogeneity so far. The reported general textures in homogeneously rolled aluminium sheet are {110}<112>, {123}<634>, {112}<111> and {110}<001> etc.[3,4,5], and the textures in inhomogeneously cold rolled aluminium sheet are {001}<110> as well as {111} fibre texture[2], in which the {111} planes are parallel to rolling plane. The changes of texture components will drastically influence the properties of aluminium sheet and aluminium foil. The formations of different rolling

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texture in cold rolled aluminium sheet under large pass reduction and the corresponding correlation have been investigated in the present work.

2 EXPERIMENTS

Hot rolled ingot of aluminium in commercial purity (99. 9% Al) was taken as a rolling sample and forged 25% in three directions respectively for two times with subsequent annealing (10 min 500℃) and then forged with decreasing degree of deformation (25%, 15%, 10%, and 5%) from three directions in turn with subsequent final annealing (15 min, 500℃), in order to produce a fine grained structure without texture. After these treatments the average grain size was about 96 μm and there was no distinct initial texture in the rolling sample. The rolling sample, with an initial of 3.63 mm was cold rolled to 0.46 mm by three passes lubricated by engine oil. The pass reductions were 1.59 mm, 1.02 mm and 0.56 mm respective. If s represents the distance to the sample centre, then s = 1 expresses sample surface and s = 0 expresses sample centre. The rolling sample was etched in NaOH solution at 50℃ , meanwhile the {111} <200>, {220} as well as {113} pole figures were measured on different layers of the sample, after which the ODF was calculated using the series expansion method according to Bunge[6] followed by an error correction[7].

3 RESULTS

Fig. 1 gives the $\varphi_2 = 45°$ section of ODF showing textures in different layers of the cold rolled aluminium sheet. Fig. 1a shows also the positions of some important orientations. It could be seen from Fig. 1 that the general rolling texture components {112} <111>, {110} <112> and {110} <001> decrease with the increase of s, and the {001} <110> as well as {111} fibre texture represented by {111} <110> and {111} <112> are enhanced uninterruptedly. Therefore a distinct inhomogeneous deformation appears during the rolling of aluminium sheet. Fig. 2 shows an orientation fibre ($\varphi_1 = 90°$, $\varphi_2 = 45°$, $\varphi = 0° - 90°$, called τ fibre), on which the orientation densities could reflect the texture change from centre to surface of the aluminium sheet clearly. Φ value in Fig. 2 indicates a rotation of grain orientations on τ fibre around transverse direction(TD). The changes of other texture components e. g. {123} <634> in aluminium sheet are similar to that of texture component {112} <111>.

4 DISCUSSION

In a general rolling process alumimium sheet between two rolls undergoes mainly compressive stresses in three directions, if the hydrostatic pressure is removed which has no influence on the plastic deformation. But the actual stresses which the aluminium sheet undergoes could be described as

$$\begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix}$$

where $\sigma_1 > 0$ means drawing stress in rolling direction (RD) and $\sigma_3 < 0$ compressive stress in normal direction(ND) [5], which is called principal stress state. Under this principal stress state, the texture components {112} <111>, {123} <634>, {110} <112> and {110} <001> would form in polycrystalline aluminium sheet. However a strong shear stress will be created on the surface if the sheet is brought into roll gap with large pass reduction which

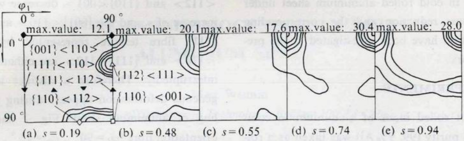


Fig. 1 The textures of the cold rolled aluminum sheet

could appear easily in aluminium because of its low defromatiom resistance. Therefore, the strong shear stress would obviously change the deformation behaviour of grains, at least on the sheet surface. The texture in Fig. 1e is also called shear texture because the same texture could be produced in torsion test under shear stress[2].

Aluminium is a fcc metal with high stacking fault energy. Its principal mechanism of plastic defromation is dislocation movement. Fig. 3 gives orientation factors of eight slip systems which could be most easily activated under the general rolling stress state in the grains, of which the orientations lie along the τ fibre in Fig. 2. Because of the symmetry of τ fibre in orientation space, each couple of the eight slip systems has the same orientation factor. The curves A, B, C and D in Fig. 3 represent the change of orientation factor of two slip systems respectively, therefore the slip system would be often activated in couples during rolling. Furthermore the direction of grain changes made by corresponding slip systems is also shown in Fig.3, in which the stability of grain orientation around $\Phi = 35°$ i. e. {112} <111> could be seen because of the alternate activation of four slip systms among B and C. In fact the stable orientation of polycrystalline aluminium in τ fibre is not located at $\Phi = 35°$ but near $\Phi = 30°$ (Fig.2)[3, 4]. Detailed calculations showed that B slip system would produce relative small orientation change and certain shear strain[8], which would be obstructed by neighbour grains oriented differently. If the orientation change and corresponding shear strain are defined as positive, and therefore the relative large orientation change and corresponding shear strain made by C slip systems may be defined as negative. If grain orientation goes to $\Phi = 30°$ (Fig. 3)the slip amount of B systems, becaues of their higher orientation factor, would be more than that of C systems with a lower orientation factor. Hence the sum of the shear strain would be obviously reduced by the alternate activation of B and C slip systems. Simultaneously the positive and negative orientation change would reach a balance on the whole, and therefore the grain orientations would be stabilized around $\Phi = 30°$, which has been proved by theoretical simulations[3]. For this reason the real stable grain orientation($\Phi \approx 30°$) in τ fibre shown in Fig. 2 has almost the same distance from {001} <110> and {111}<112> i. e. about $\pm$ 30° rotated around TD.

The aluminium sheet under rolling deformation with large pass reduction undergoes not only the stresses σ_1 and σ_3, but also an additional shear stress on its surface along RD.

The shear stress would produce a rotation of the general principal stress state around TD. In this case the sample has to be rotated more or less around TD, if the texture under principal stress state is measured and observed again. However this would be rather difficult. Depending on the relationship of the grain orientations(Fig.3) to RD the additional shear stress would induce two orientation changes in the grain defromation process. On one hand the C slip systems will become more active and make the grain orientations move to a position with lower Φ so the A slip systems would be activated abruptly and the grain orientations would reach {001}<110> (Fig. 2). On the other hand the B slip systems will become more active and make the grain orientations move to a position with higher Φ so the D slip systems would be activated abruptly and the grain orientation would reach {111}<112> (Fig. 2). In this way the observed shear texture is formed, in which the {001}<110> component appears stronger than that of {111}<112> (Fig. 1e) probably bacause the A

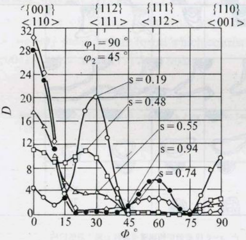


Fig. 2 The orientation densities along τ fibre

system possesses higher orientation factor than D system (Fig.3). A further analysis has demonstrated that other general texture components could also be decomposed in similar way by inhomogeneous rolling with large pass reduction.

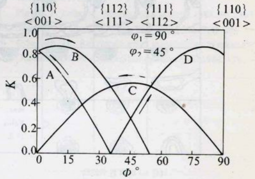
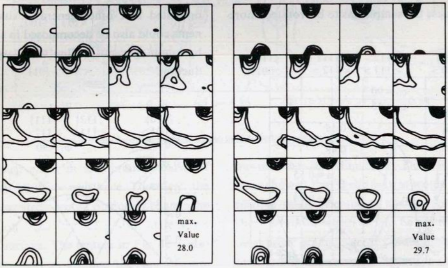


Fig. 3 The orientation factors along τ fibre

Based on the assumption above, 75% of the general texture components of {112}<111>, {123}<634>, {110}<112>, {110}<001> etc, which are near the centre of the aluminium sheet (s=0.19), was rotated −30° around TD, e. g. the {112}<111> approaches {001}<110>, and 25% of them was rotated +30° around TD, e. g. the {112}<111> approaches {111}<112>. Afterwards a theoretical ODF was calculated by means of the Gauss model [7, 9] according to the rotated texture components, and compared with the rolling texture near the surface of the aluminium sheet s=0.94. Fig. 4 demonstrates the Φ_2 sections of the (s=0.94) ODF of the rolling sheet (Fig. 4a[10]) and of the ODF, which were calculated after the texture components at s=0. 19 have been rotated ± 30° around TD (Fig. 4b). The comparison in Fig. 4 shows that the analysis above is essentially reasonable.

The changes of orientation density (Fig.2)



(a) $s=0.94$ 处的织构 (b) $s=0.19$ 处的织构绕横向旋转 ±30° 后的织构

Fig. 4 The relationship between shearing texture and rolling texture

indicate that the shear stress near the surface of rolling sheet is the strongest. With decreasing s the additional shear stress drops and then disappears near the centre. The changes of orientation factors and grain orientations induced by the activation of slip systems along τ fibre (Fig.3) demonstrate that, besides {112}<111>, the factors of slip systmes A and B at {001}<110> are the same but they produce opposite orientation changes and therefore induce certain stability of grain orientations near {001}<110>. For the same reason the systems C and D could produce similar stability around {111} <112>. These agree with the orientation density changes. If the shear stress become higher, i. e. s rises, the orientation density near {112}<111> does not move towards both sides along τ fibre, but disappears in situ while the densities around {001}<110> and {111}<112> increase(Fig.2), which illustrates that all other orientations between {001}<110> and {111}<112> have no distinct stability rolling with large pass reduction.

5 SUMMARY

The stress state and texture configurations in aluminium sheet during rolling with large pass reduction were investigated. The induced additional shear stress decreases along ND towards sheet centre. The shear stress would rotate the principal stress state in rolling sheet around TD, and the activated slip systems producing plastic deformation would change correspondingly, so that the stable grain orientations {112}<111>, {123}<634>, {110}<112> and {110}<001> etc. rotate around TD to {001}<110>, or so rotate around TD that their {111} planes turn towards the rolling plane. This is the formation process of shear texture. This process is discontinuous, i. e. the general rolling texture are gradually reduced in situ while {001}<110> and {111} fibre texture increase. This indicates that the two kinds of textures mentioned above are produced by rather different activations of slip systems. On the surface of rolling sheet with large shear stress only shear texture forms which consist of {001}<110> and {111} fibre texture.

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