MICROSTRUCTURES AND TEXTURES IN

COLD-ROLLED ALUMINIUM STRIP[①]

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ABSTRACT   The microstructures and textures in the cold rolled aluminium strip at different strains have been investigated. The rolling reductions of interest were from 25% ($\varepsilon = 0.28$) to 92.5% ($\varepsilon = 2.59$). The mechanical properties of the strip at different angles to rolling direction were measured by uniaxial tensile testing. The pole figures were determined with D-500 X-ray diffraction goniometer and ODF's were calculated by Bunge's method. The microstructures were studied by TEM. It was shown that the textures developed in the strip were different from those developed in the plate. The development of the microstructures, textures and mechanical anisotropy in the strip was analyzed. The influence of microstructures and textures on the plastic anisotropy was discussed.

Key words   aluminium alloy   rolling   microstructure   texture   deep drawing

1   INTRODUCTION

The rolling technology is very important to the properties of the aluminium sheets for deep drawing. There was a lot of investigation about this[1-5]. In the previous work, the study of the microstructures and textures was concentrated on the deep drawing aluminium sheet from slab. In this paper, the deformation substructures and textures of the strip from bar ingot in different cold rolling reduction have been investigated by means of transmission electron microscopy and orientation distribution function analysis, respectively. The effects of the deformation substructures and the textures on the mechanical anisotropy of the strip were discussed.

2   EXPERIMENTAL

The bar-ingots were cast in commercial pure aluminium ($> 99.75\%$) and was almost texture-free. First the bar of d 95 mm was hot rolled to 16 mm strip, which was cold rolled further. The cold rolling reduction of interest was 25% ($\varepsilon = 0.28$), 47% ($\varepsilon = 0.63$), 72% ($\varepsilon =$ 1.27), and 92.5% ($\varepsilon = 2.59$), respectively. The tensile specimens were cut from the cold-rolled strip in such a way that the tensile axis was at $0°$, $45°$ and $90°$ to the rolling direction. The tensile testing with a grip velocity of 2 mm/min was performed at room temperature on a WD-10A type universal test machine. Each result is the average value over three or more testing points.

The samples for TEM analysis were prepared parallelling to the rolling plane. The deformation substructures were examined with a HITACHI H-800 transmission electron microscope. The texture measurement was carried out on SIEMENS D-500 fully automatic diffractometer. The three-dimensional distribution function was calculated by the series expansion method of Bunge[6] and represented in the three-dimensional Euler angle space in the form of the constant φ_2.

3   RESULTS AND DISCUSSIONS

3.1   Mechanical properties

The mechanical properties (σ_b, $\sigma_{0.2}$, $\delta\%$)

of the strips at different angles to rolling direction with different deformation ratios are listed in Table 1.

The different mechanical properties of the specimens shown in Table 1 reveal that the plastic anisotropy increased with strain, but the strip with the strain of 72% showed less anisotropy. The strengths, σ_b and $\sigma_{0.2}$, increased significantly with strain but the elongation $\delta\%$ decreased. The tensile strengths vertical to rolling direction were higher than that of the other directions, but the elongation in transverse direction was the lowest in all directions.

Table 1　Mechanical properties of the cold-rolled strip in each direction with different strain

Mechanical properties	Direction / (°)	strain			
		25%	47%	72%	92.5%
σ_b/ MPa	0	110.3	114.7	137.4	184.0
	45	125.5	126.0	139.1	183.0
	90	131.1	132.8	139.2	199.9
	average	123.1	124.9	138.2	187.5
$\sigma_{0.2}$/ MPa	0	101.7	111.8	130.9	150.5
	45	113.3	121.4	133.4	153.0
	90	117.5	125.4	136.5	176.5
	average	111.5	121.3	133.6	158.3
δ/ %	0	18.6	13.8	9.6	3.9
	45	16.8	12.8	8.9	4.0
	90	16.4	11.6	8.7	3.3
	average	17.2	12.8	9.2	3.9

3. 2　Deformation microstructures

Fig. 1 shows the deformation substructures of the sample with 25% cold-rolling reduction. It is clearly showed that large cell structure was formed by dislocation tangles, with most of which was arranged into the cell walls, and that few dislocations existed within the cells. At about 50% strain the cell walls were sharply delineated, as shown in Fig. 2. The dislocation cell sizes were smaller than those in 25% cold rolled samples. At near 75% strain, the dislocation cells began to arrange in some directions, see Fig. 3. Some microbands were formed. After 90% reduction most of the dislocation cells were arranged in a certain direction, and the microstructure mainly consisted of microbands in all the plane, see Fig. 4.

Figs. 1, 2, 3 and 4 show that the higher the strain was, the smaller the dislocation cells and the sharper the cell walls were. At 50% strain the dislocation density in the walls was higher than that at 25% strain, the low angle twist and asymmetrical boundaries within the cells increased, the arrangement of the dislocation cell changed gradually, and the obvious characteristics of microbands did not emerge. With increase of cold rolling reduction, deformation microbands developed gradually in the cell structures, and at more than 90% strain the microstructure consisted of a lot of microbands.
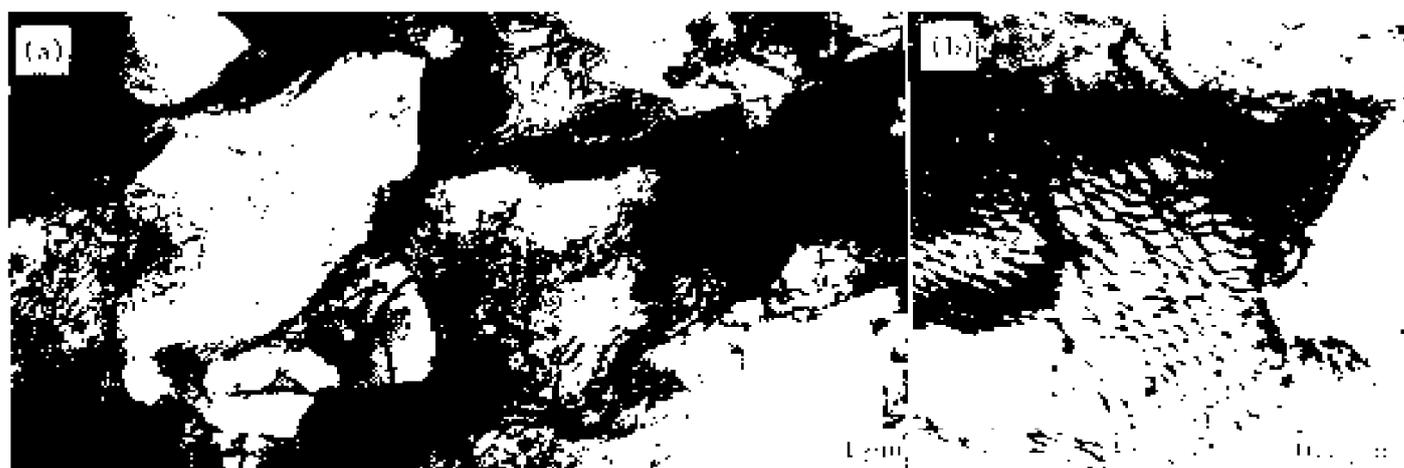

Fig. 1　TEM micrographs showing deformation substructures of the specimens with 25% strain
(a) —dislocation tangles exhibiting the emergence of cell structure (× 10 000);
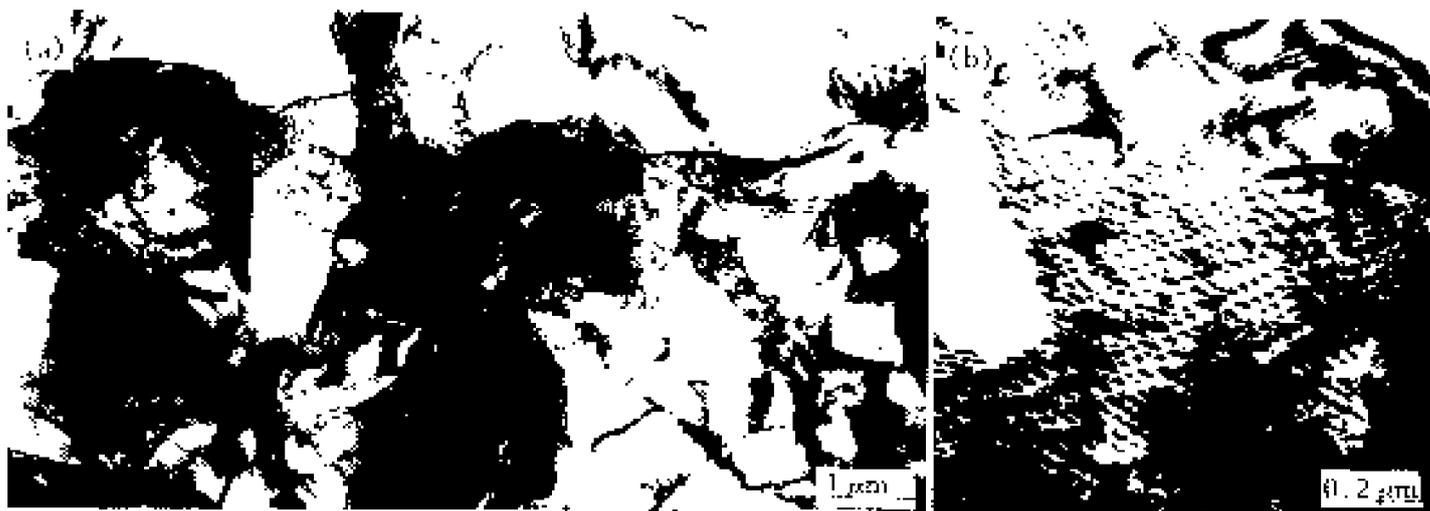(b) —dislocation network within cells (× 50 000)

Fig. 2　TEM micrograph showing deformation substructures of the specimens with 47% strain

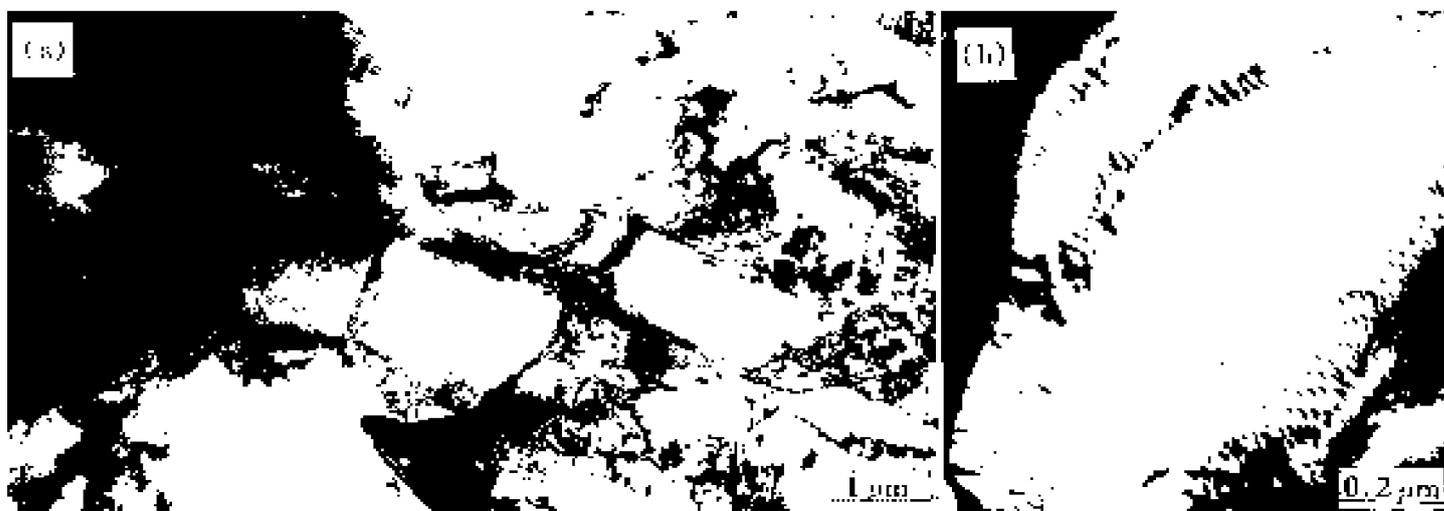(a) —well developed cell structure (× 10 000) ; (b) —dislocation network within cells (× 50 000)

Fig. 3　TEM micrographs showing deformation substructures of the specimens with 72% strain

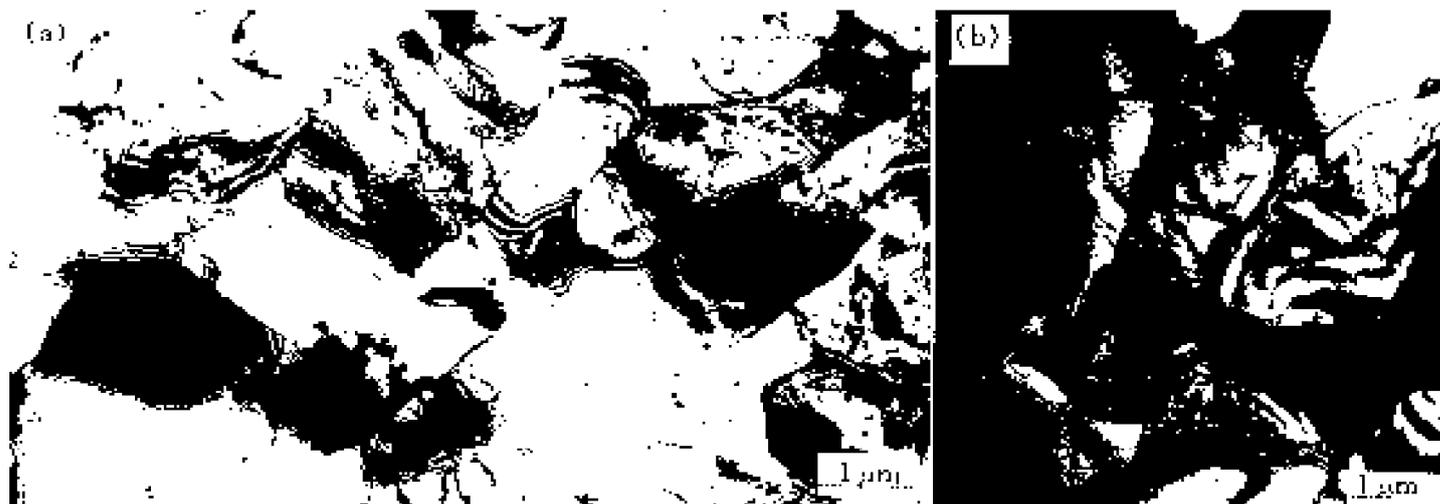(a) —emergence of microbands (× 10 000) ; (b) —dislocation network within cells (× 50 000)

Fig. 4　TEM micrographs showing deformation substructures of the specimens with 92. 5% strain

(a) —microband structure (× 10 000) ; (b) —microband arrangement (× 10 000)

With further cold working, more dislocations within the cells will be produced. The partial dislocations 1/6[211] and 1/6[121] in aluminium are easy to be contracted for its high stacking fault energy. The dislocations tend to be stable and to be attracted to the cell walls, which leads to the increase of the dislocation density in the cell walls and to the development of twist and asymmetrical boundaries. With higher cold reduction it is possible to identify the dislocation network consisted by 1/2[110] dislocation within the cell[7]. It is indicated that the increasing resistance of plastic deformation with further cold working demonstrated the effects of dislocation tangles and the increase of asymmetrical low angle boundaries. When the dislocation cells develop into strip structure and emerge in a direction, the anisotropy of the specimens increase. The boundaries in rolling direction can also contribute to the strength σ_b or $\sigma_{0.2}$.

Figs. 1 – 4 also show that the microstructure in the specimen with 25% strain is obviously uneven, and with increasing strain, the deformation substructure is getting homogeneous. At 50% strain the homogeneous structure is developed, but with further deformation the substructure is getting inhomogeneous again.

3.3 Textures

Fig. 5 shows the ODF's of the cold-rolled aluminium strip with different strains. In Fig. 5(a) it can be seen that there were the texture {015}< 951> and the N-rotated cube textures, the typical surface textures, in the 25% cold rolled specimen. All the orientation densities were lower with some left nature of hot-rolling textures. Fig. 5(b) shows that the textures in the specimen with 47% strain were stronger than those in Fig. 5(a). The texture {001}< 110> , {035}< 11 106> , S- {123}< 634> and the transition textures between S- and approximate Br- position developed strongly, and the rotated cube texture {001}< 510> as well as Cu-component {112}< 111> emerged. When the strain got to 72%, the texture {035}< 1053 > was very strong, see Fig. 5(c), the {001}< 510> component disappeared and the shear tex-

ture {100}< 011 > remained and developed. Furthermore, when the strain was up to 92.5%, as shown in Fig. 5(d), the textures {112}< 111> + {123}< 634> + {011}< 211> were very strong and the other textures in Fig. 5 (a– c) had almost disappeared. It is pointed out that there was very strong S- position in the studied cold-rolled strip at 92.5% strain which was some different from very strong brass position in the conventional hot-rolled plate and subsequently cold rolled sheet to high strain[8]. From the alteration of the orientation distribution functions of the cold-rolling strip with different strains, it can be seen that although as the reduction increases, the crystal orientations prefer to concentrate on the β-fibre consecutively, the brass position is unstable. At lower strain, the crystal orientations began to turn to the shear texture and with increasing strain it was getting stronger. Then the crystal orientations rotated to the Cu- ,S- and Br- orientation which became stronger and stronger, and seemed to be stable in the stress state of rolling strip.

The specimen with 25% strain was rolled by two passes, which led to the weak shear texture and N-rotated cube textures in the surface of the strip, see Fig. 5(a). With further reduction to 47%, the shear texture was getting stronger, and the N-rotated cube textures were split up, Fig. 5(b), which developed abnormally. Although the substructures with lower strain (25%, 47%) showed only cell structures and no microbands (Figs. 1, 2), there were large discrepancies of the mechanical properties between the rolling and the transverse direction (RD and TD) of the specimens(Table 1). It is obvious that the mechanical anisotropy can be attributed to the textures in the specimens. At mediate strain (72%) the crystal orientations tended to be preferred, but the textures became much weaker, see Fig. 5(c). Microbands could be observed(Fig. 3), and mechanical anisotropy was very small (Table 1). At higher stain(92.5%) the crystal orientations further tended to concentrate in Cu- ,S- and Br- position (Fig. 5 (d)), a lot of microbands developed(Fig. 4) and the mechanical anisotropy increased again. Hereby, the mechanical anisotropy depends on not
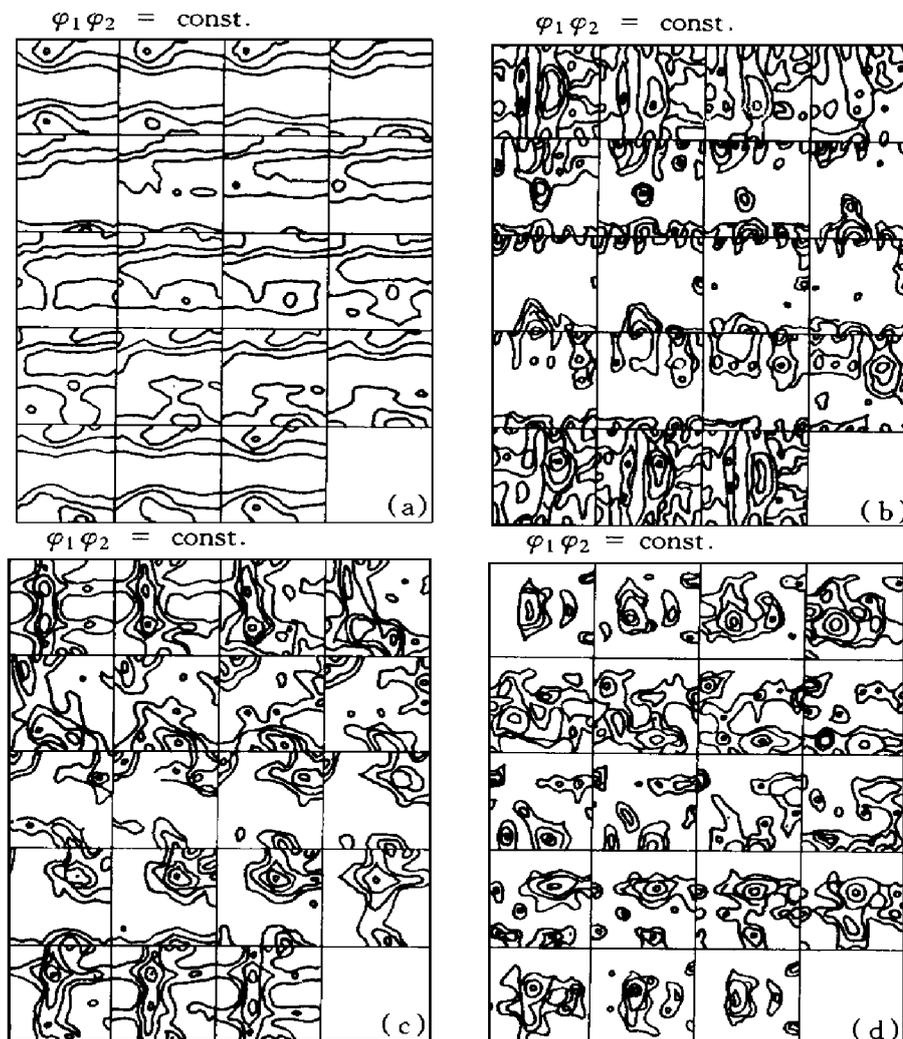
Fig. 5 ODF' s of the aluminium strip with different strains
(a) —25% ; (b) —47% ; (c) —72% ; (d) —92. 5%

only textures but also microstructures.

4 CONCLUSIONS

(1) The texture evolution in the strip from aluminium bar shows some different characteristics as in aluminium plate or sheet, and at 92. 5% high strain S-position is stronger than Br-position in the cold-rolled strip.

(2) With increasing strain cell structure at low strain develops into microbands at high strain, and the development of the microstructures is just the same to that in the rolled plate or sheet.

(3) At low strain the mechanical anisotropy depends on the textures, and at high strain on the textures and the microstructures.

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