INFLUENCE OF PRECIPITATES ON THE ROLLING TEXTURE DEVELOPMENT IN (011)[100] ORIENTED Al-Cu AND Al-Mn SINGLE CRYSTALS

X. W. KONG, O. ENGLER, K. LÜCKE

Institut für Metallkunde und Metallphysik, RWTH Aachen,
D-5100 Aachen, W-Germany

ABSTRACT

In order to understand the influence of different types of precipitates on the deformation behaviour, the development of texture and microstructure during rolling of two (011)[100] (Goss) oriented single crystals of Al-1.8wt%Cu and Al-1.3wt%Mn was investigated by means of X-ray pole figure measurements and TEM. For both precipitate containing alloys significant orientation scatterings corresponding to rotations around the transverse direction were observed. They are discussed in connection with the presence of the various particles.

1. INTRODUCTION

The influence of precipitates on the microstructure and texture development during plastic deformation has been investigated in several studies^{1,5}. It was found that during cold working at the interface between matrix and large ($> 1\mu\text{m}$) non-deformable particles inhomogeneously deformed zones are formed. In these "deformation zones" the lattice is substantially rotated with respect to the matrix. For a single crystal under tensile strain the axis and magnitude of the rotation are observed to be given by the active slip systems and thus are basically understood. For cold working under rolling conditions, however, where mostly multiple slip is required, the information about the geometry of the lattice rotations in the deformation zones is still rather restricted. Moreover, also about the influence of size, shape and arrangement of the various particles is known only little.

In the present study the development of the texture and microstructure during rolling of two (011)[100] (Goss) oriented single crystals of Al-1.8wt%Cu and Al-1.3wt%Mn was investigated. The Goss-orientation was chosen since it exhibits a rather simple geometry for slip under rolling deformation. The main purpose of the investigation was to understand the influence of the different types of precipitates produced in

these alloys, in particular of their size and shape on the deformation behaviour and the resulting deformation zones. This will also yield useful informations about the nucleation during recrystallization in these materials⁶.

2. EXPERIMENTAL

The single crystals (25x10x50mm³) of the Goss-orientation were prepared from binary high purity (> 99.995%) Al-1.8wt%Cu and Al-1.3wt%Mn alloys by a modified Bridgman technique. To produce a reasonably uniform dispersion of precipitates, the Al-Cu single crystal was homogenized for 48h at 580°C and subsequently aged for 50h at 300°C, and the Al-Mn crystal homogenized for 48h at 630°C and aged for 50h at 550°C. In the Al-Cu alloy plate-like θ -(Al₂Cu) particles with a diameter of about 5-7 μ m and a thickness less than 1 μ m were precipitated parallel to the {001} planes (Fig.1a), according to their well known formation mechanism via coherent and semi-coherent metastable phases. In the Al-Mn alloy randomly distributed Al₆Mn particles with diameters of about 2 μ m and exhibiting a more or less globulitic shape were precipitated (Fig.1b). The single crystals were cold rolled homogeneously ($l_c/t > 1$) to a maximum reduction of 97%. The {111} pole figures of the rolling textures were determined by means of an automatic X-ray texture goniometer⁷. The foils for TEM observation were taken parallel to TD $\parallel$ [011] and ND $\parallel$ [100] with standard methods. The scattering of the local orientations were determined by SAD using a 120kV EM400T Philips microscope.

3. RESULTS

The texture developments of the initially Goss oriented crystals are shown in Fig.2a for a particle free (i. e. supersaturated) and in Fig.2b,c for the two particle containing alloys. One sees that in the supersaturated state the Goss-orientation remains stable except for only small rotations around TD at low and around ND at high reductions. In the aged state, however, significant scatterings occur. In the Al-Cu alloy a strong TD scattering was found after low and medium reductions (up to 82%). In one direction it reaches the Cu-orientation (112)[$\bar{1}\bar{1}\bar{1}$] which corresponds to a 55°<011> $\parallel$ TD rotation. By means of ODF analysis it is estimated that in this state about 10% of the volume is situated in the Cu-orientation. With further reduction no further TD rotation but a shift of the Goss-orientation towards the Bs-orientation (011)[21 $\bar{1}$] by a ND rotation takes place. The maximum ND rotation is about 25° after 97% rolling.

Fig.2b shows that the TD rotations are unidirectional, but, as to be seen in Fig.4, they are symmetrical with respect to the centre layer. This directionality corresponds to a systematic texture gradient over the sheet thickness⁶. The local misorientations in the vicinity of the particles are determined with TEM. An example is shown Fig.4 for the Al-Cu alloy rolled 78% and the foil taken perpendicular to TD. One sees that the orientations around the particle are spread by rotations of

about $15-38^\circ$ from the initial Goss-orientation around the $[011]\parallel\text{TD}$. The misorientations are also determined in equidistant steps of about $1\mu\text{m}$ from the particle. The maximum TD rotations are found to be directly at the particle interface amounting there to more than 50° for the 82% rolled specimen in the Al-Cu alloy. Fig.5 shows the degree of the misorientation as a function of the distance from the particle.

In the Al-Mn alloy also a strong TD scattering is observed at low and medium reductions, but it is somewhat smaller and symmetrical in all measured layers. At high reductions a rotation towards the Bs-orientation similar to that obtained in the Al-Cu alloy is observed.

4. DISCUSSION

The obtained results show that the stability of the Goss-orientation up to high reductions is strongly influenced by the presence of the various particles. Fig.6 presents the stereographic projection of the Goss-orientation with the slip systems with the largest resolved shear stress for rolling. By the activation of all four slip systems the Goss-orientation remains stable. A preferred activation of one of the slip system pairs, e. g. due to a small deviation from Tucker's stress state¹ or to a local inhomogeneity, results in a TD rotation of the Goss-orientation. This, however, leads to a stronger activation of the other slip system pair and therefore to a rotation back into Goss. Such slight TD scatterings are observed e. g. in the supersaturated Al-Cu crystal (Fig.2a). Against slight ND rotations, in contrast, the Goss-orientation is not stable, i. e. no back rotating slip systems become activated so that at high reductions ($> 90\%$) the Goss-orientation rotates towards the stable Bs-orientation. This is in good agreement with earlier results observed on pure metals⁹.

In the particle containing alloys the situation is changed in so far as significant TD scatterings were observed in Al-Mn and especially in Al-Cu alloys at low and medium rolling reductions. The magnitude of the particle-induced lattice rotations depends on the presence of various particles, the orientation of the single crystal^{6,10} and the shear stress (i. e. tensile or rolling) during cold working. The TEM observed misorientations near a particle being largest at its interface rapidly decrease with the distance from it within a range of the size of the particle which should be also the size of the deformation zones (Fig.4,5). These misorientations are obviously the reason for the scattering in the textures. In single crystals deformed by single slip Ashby¹ and Humphreys² predicted rotations of the matrix near the particles around a $\langle 112 \rangle$ axis, which is perpendicular both to the slip plane normal and the slip direction of the active slip system. In the Goss-orientation under rolling conditions two symmetrical pairs of slip systems are activated causing rotations, which by superposition lead to the observed $\langle 011 \rangle \parallel \text{TD}$ -scatterings.

The very large TD-scattering in the Al-Cu alloy must be due to the plate-like shape of the θ precipitates (see Fig.1a), and especially due to those situated perpendicular to RD.

Moreover, the rotation of these particles caused by the interaction with the piled up dislocations leads to a TD rotation of the adjacent matrix. Near the centre layers with a plane strain compression state both directions of rotation are equally possible, depending on which pair of slip systems accidentally experience the necessary activation first. Once this direction is fixed, the activation of the other slip system pair becomes more difficult. In contrast to the behaviour of homogeneous metals, this is due to a rotation of the particle and the adjacent matrix. Near the surfaces of the sheet, however, this direction is determined by the superimposed shear stress⁶ which leads to the observed gradient of rotation shown in Fig.3.

It is obvious that in Al-Mn alloy, due to the globulitic particles, the degree of the misorientation in the deformation zones and thus the scattering of the texture and also the formation of a texture gradient is less pronounced.

5. CONCLUSIONS

In the supersaturated state the Goss-orientation is stable in the Al-1.8wt%Cu and the Al-1.3wt%Mn alloys during rolling which is in good agreement with the earlier results observed on pure metals. In the particle containing alloys, however, significant TD scatterings occur which, corresponding to the rotation of the particles, could be attributed to the misorientations in the deformation zones adjacent to the particles. The magnitude of these rotations strongly depends on the nature of the various particles which act as different obstacles for the operating dislocation glide.

REFERENCES

1. M. F. Ashby, *Phil. Mag.* 21 (1970), 399
2. F. J. Humphreys, *Acta Met.* 27 (1979), 1801
3. P. N. Kalu, F. J. Humphreys, *Proc. ICOTOM 8, Santa Fe* (1988), 511 and *Acta Met.* 38 (1990), 917
4. O. Engler, J. Hirsch, K. Lücke, *Acta Met.* 37 (1989), 2743
5. K. Lücke, O. Engler, *Mat. Sci. Tech.* in press (1990)
6. X. W. Kong, O. Engler, K. Lücke, to be published
7. J. Hirsch, G. Burmeister, L. Hoenen, K. Lücke, in *"Experimental Techniques of Texture Analysis"*, ed. by H. J. Bunge, DGM-Verlag (1986), 63
8. E. Tucker, *J. Inst. Met.* 82 (1954), 655; and *Acta Met.* 12 (1964), 1093
9. G. D. Köhlhoff, *Dissertation RWTH Aachen*, (1988)
10. O. Engler, J. Hirsch, K. Lücke, *Proc. ICOTOM 8, Santa Fe* (1988), 637

Fig.1 Micrographs of (011)[100] oriented crystals. a), For Al-1.8wtCu with Al_2Cu precipitates; b), for Al-1.3%Mn with Al_6Mn precipitates.

Fig.2 Texture development of the various (011)[100] oriented crystals. The orientations (011)[100], $(11\bar{2})[111]$ and (011)[211] are indicated in a), b) and c), respectively.

Fig.3 Scattering of the Goss-orientation corresponding to the microstructure in different layers of the aged Al-Cu single crystal (after 45% reduction).

Fig.4 a), TEM micrograph and b), {111} pole figure of the maxima of the TD scattering around particle in the Al-Cu single crystal (after 78% reduction).

Fig.5 Misorientation θ as a function of the distance d from the particle (after 82% reduction).

Fig.6 Stereographic projection of the (011)[100] with the main slip systems.