X-ray diffraction analysis of reorientation regions formed in [111]-single crystal of aluminum under compression

I V Bespalova¹ and L A Teplyakova²
¹Kazakh National Technical University named after K.I. Satpaev, Almaty, 050013, Kazakhstan
²Tomsk State University of Architecture and Building, Tomsk, 634003, Russia

E-mail: besiv@mail.ru

Abstract. The paper presents results of the crystalogeometric analysis of the shear pattern formed on lateral faces of a single crystal of aluminum under compression along the direction [111]. Main features of shear strain in [111]-single crystals of aluminum have been revealed. Typical elements of strain relief have been identified and places of their location have been established. Occurrence of a bending in the crystal lattice at the macro level has been established using the Laue pattern method. The results of the X-ray analysis have been compared with the shear pattern.

1. Introduction

Currently, systematic studies on spatial organization of a shear strain at the macro level are carried out on symmetrically oriented single crystals of aluminum [1-5]. The fact of the course of macrofragmentation of the shear strain from the very beginning of the plastic flow has been experimentally established in these studies. It has been revealed that the initial macrofragmentation of the shear is caused by the heterogeneity of the slip on equally-loaded octahedral planes. At the macrolevel the heterogeneity of the slip is the reason for occurrence of bends in the crystal, as a rule, in joints of neighboring macrofragments with an asymmetric slip [2, 4]. As stated in [6, 7], the subsequent strain in regions of bending can lead to formation of discrete misorientation boundaries.

The paper presents the results of the X-ray analysis of the strained [111]-single crystal. [111]-single crystals of aluminum with orientation of lateral faces (110) and (112) have been investigated. With this orientation of the single crystal, three octahedral slip planes are equally-loaded (Figure 1, a). In addition, easy shear volumes (ESV) are allocated for each of them in the volume of the single crystal (Figure 1, b, c, d). The samples had the shape of a parallelepiped with linear dimensions of (3x3x6) mm³. Strain was carried out under compression up to small degrees of strain (ε<0,1) at room temperature with a velocity of 6x10⁻⁴ s⁻¹. An optical microscope MIM-10 and a scanning electron microscope Tesla BS – 301 were used in investigation of the strain relief pattern. The pattern of the strain relief on all of its free faces has been investigated in recreation of the spatial organization of the shear in the volume of the single crystal (macrolevel). The internal structure of single crystals after their strain under compression has been investigated using the X-ray method (shooting of Laue patterns).
2. Strain relief

Figure 2 shows the scheme of strain relief patterns formed under compression of the single crystal on all of its free faces after strain up to \( \varepsilon = 0.06 \) (Figure 2, I-IV). Analysis of the cumulative strain relief has showed that macrofragmentation and macrolocalization of strain takes place in \( \overline{1}11 \)-single crystals of aluminum from the beginning of the plastic strain. This is evidenced by formation of systems of strain macrobands of various types in the volume of the sample (Figure 2 a-e).

Figure 2. The scheme of macrorelief on lateral faces of the \( \overline{1}11 \)-single crystal: images of different types of macrobands – (a-d) and (e) – the region of the face with small strain folds.
At $\varepsilon=0.06$ the boundaries of strain bands, as a rule, are deviated from the outcrop of the nearest equally-loaded octahedral plane at angles of 5-6°. On sections of largest shear bands observed on faces of the single crystal there are shear traces and strain folds perpendicular to bands (Figure 2, a, b). Systems of perpendicular folds also occur outside of bands (Figure 2, II at the bottom part of the sample and Fig. 2, IV at the top part). Apparently, they are formed by the mechanism of kink bands.

The peculiarity of the strain relief pattern in $\{\overline{1}11\}$-single crystals is in the fact that the majority (70-80%) of face surfaces is occupied not by systems of traces of the octahedral shear, which is typical for aluminum single crystals of other orientations [1-5], but by systems of small deformation folds resembling hillocks (Figure 2, e). Furthermore, one bending region is allocated on each face ($\{\overline{1}1\}2$) (Figure 2, I and III) near the vertex of the sample. The internal structure of bending regions (on faces) represents a system of shear traces and strain folds, approximately parallel to the outcrop of the plane $\{11\overline{1}\}$.

3. X-ray diffraction analysis of the strained $\{\overline{1}11\}$-single crystal of aluminum

Shooting of Laue patterns of regions of the $\{\overline{1}11\}$-single crystal strained up to $\varepsilon=0.06$ has been carried out in the work. Shooting was carried out in three mutually perpendicular directions (single crystal was X-rayed through). Figure 3 shows the obtained Laue diffraction patterns and regions of the sample on which the X-ray beam was aimed. Asterism of spots in Laue patterns is clearly visible, indicating the occurrence of continuous misorientations in the strained single crystal. The results of interpretation and analysis of Laue patterns obtained in three mutually perpendicular directions of the beam to the surface of the single crystal faces should be examined.

Figure 3. Laue patterns obtained during irradiation of the $\{\overline{1}11\}$-single crystal ($\varepsilon=0.06$) perpendicular to: end (a); face ($\{\overline{1}1\}2$) (b-d), and face (110) (e-g).

1. As a result of interpretation of the Laue diffraction pattern taken during irradiation along the compression axis of the single crystal it has been established that two families of planes, namely ($\{\overline{1}1\}1$) and (9.9.10), make a contribution to the cumulative picture. The angle between the normals to these planes is 3 degrees. Measurement of the radial misorientation by blurring of spots on the investigated Laue pattern (Figure 3, a) yields the result from 2 up to 6°.
2. Laue diffraction patterns obtained during shooting in three regions of the sample along the direction \(\{\bar{1}1\bar{2}\}\) (Figure 3, b - d) were similar. Their interpretation showed that only the family of planes \(\{\bar{1}1\bar{2}\}\) is perpendicular to the X-ray beam. Most spots of the discussed Laue patterns (Figure 3, b) are indicative of radial misorientations by 2-3 degrees.

3. Finally, Laue diffraction patterns obtained from different regions of the face \((110)\) during successive shooting along the direction \([110]\) are shown in Figure 3, e - g. It is seen that Laue diffraction patterns taken from the upper and the middle part of the sample are similar, and in interpretation give planes \((110)\) (Figure 3, e, f). Interpretation of the Laue diffraction pattern taken near the end (Figure 3, g) showed that the main contribution to the pattern of spots on the Laue pattern is made by planes \((10.7.1)\). The angle between the normal to this plane and to the plane of the face \((110)\) equals to \(11^0\).

4. Conclusion
The obtained results confirm the conclusion, which was made above based on the study of the strain relief, on formation of the bending region of the crystal-lattice in the \([\bar{1}1\bar{1}]\)-single crystal under strain. Formation of bending regions from the beginning of the plastic strain may be associated both with the heterogeneity of the stress state caused by a rectangular shape of the single-crystal sample [8] and by the presence of volumes of the constrained shear in \([\bar{1}1\bar{1}]\)-single crystals for families of equally-loaded octahedral planes.

References
[1]  Teplyakova L A, Lychagin D V and Kozlov E V 2002 Localization of shear under strain of aluminum single crystals with orientation of the compression axis Phys Mesomech 5 49-55
[2]  Teplyakova L A, Lychagin D V and Bespalova I V 2004 Regularities of strain macrolocalization in aluminum single crystals with orientation of the compression axis Phys Mesomech 7 63-78
[3]  Teplyakova L A, Lychagin D V and Bespalova I V 2006 Peculiarities of spatial organization of the shear at the macrolevel in \([111]\)-aluminum single crystals Phys Mesomech 9 63-71
[4]  Teplyakova L A, Bespalova I V and Lychagin D V 2006 Regularities of organization of the shear strain in \([001]\)-aluminum single crystals with lateral faces \{100\} under compression Phys Mesomech 9 77-84
[5]  Teplyakova L A and Kozlov E V 2005 Formation of scale-structural levels of plastic strain localization in metallic single crystals. I. Macrolevel Phys Mesomech 8 № 6 57-66
[6]  Беспалова И В, Теплякова Л А и Кущицына Т С 2009 Рентгеноструктурное исследование областей переориентации деформированных \([1\bar{1}2]\)-монокристаллов алюминия Вестник. Серия физическая 1 128-131
[7]  Gubkin S I 1961 Plastic strain of metals (Moscow: Metallurgy) 1 376