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## 論文要約

THESIS OUTLINE

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### **Cyclic deformation behavior and dislocation structures of multiple-slip-oriented copper single crystals**

Metal fatigue occurs in various key engineering components and is known to be regarded as the main factors responsible for the fracture in engineering structures during the cyclic deformation. Therefore, the basic understanding of fatigue behavior of metals is the most important aspect to study the fatigue of metals. Because the cyclic deformation behavior is highly related to the activated slip systems during the deformation, which indicates that it is easily formed in the multiple slip orientations. Therefore, this work was dedicated to investigating the cyclic deformation behavior and dislocation structures of multiple-slip-oriented copper single crystals. However, for the three kinds of multiple-slip-oriented copper single crystals, it has been well accepted that the cyclic deformation behavior of the  $[011]$ -oriented copper single crystal is quite different from those of  $[001]$  and  $[\bar{1}11]$  orientations. This is because the activation of secondary slip in this orientation was strongly suppressed and will result in the formation of dislocation wall structure, which has already been fully understood. Therefore, in this thesis, the cyclic deformation behavior and dislocation structures of  $[001]$  and  $[\bar{1}11]$  multiple-slip-oriented copper single crystals are mainly studied to obtain a thoroughly understanding of the relationship between the combination of the relationship between the combination of activated slip systems and the corresponding dislocation structures. In addition, the study on the cyclic deformation behavior, such

as the formation of deformation bands (DBs), can also provide the understanding of the preferred sites for the initiation and propagation of cracks during the cyclic deformation, which can give an inspiration to avoid the initiation and propagation of cracks of the metals used in the engineering and industry.

### **Chapter 1: General introduction.**

In Chapter 1, the basic knowledge of the fatigue behavior of face-centered cubic (fcc) single crystals was introduced, including the cyclic stress-strain (CSS) curve, surface slip morphologies and microscopic dislocation structures. The intrinsic relationship between dislocation structures and crystal orientations in a cyclically deformed fcc single crystal was also introduced in this chapter.

### **Chapter 2: Crystallographic features of deformation-kink bands in coplanar double-slip-oriented copper single crystals.**

In Chapter 2, DBs formed in a coplanar-double-slip oriented copper single crystals during the monotonic deformation was investigated as a preliminary study for the following study on the cyclic deformation behavior. The characteristics of DBs with kink bands features are studied via multiple-plane observation by scanning electron microscopy (SEM), and electron back-scattered diffraction (EBSD). Experimental results show that the inhomogeneous deformation during the compression test causes DBs to form at comparatively low plastic strain, i.e., less than 1%. When the coplanar-double slip system is activated as the secondary slip system together with the primary slip system, the formation plane of DB is perpendicular to both the coplanar-slip plane and the sum of the Burgers vectors for the activated primary and coplanar slip systems (i.e., the  $\{211\}$  plane) under the coordinates in the DB. From the EBSD results, it can be recognized that the DB regions are rotated approximately 10 degrees with respect to the matrix after the inhomogeneous deformation. The rotation axis of the DB should lie

in the (111) slip plane and be normal to the sum of the Burgers vectors of the activated dislocations in the double-slip system, namely, the  $[0\bar{1}1]$  direction. By observing the dislocation structures using SEM, a cell-like dislocation structure is observed in the DB. The relationship between the deformation behavior and the activated slip systems is well explained by studying the crystallographic features of the DB, which improves our basic understanding of cyclic deformation in copper single crystals.

### **Chapter 3: Analysis of deformation bands and cell structure in cyclically deformed near- $[\bar{1}11]$ multiple-slip-oriented copper single crystals.**

In Chapter 3, the DBs and dislocation structures formed in the near- $[\bar{1}11]$ -multiple-slip-oriented copper single crystals during cyclic deformation are investigated. The DBs, including DBI and DBII, and corresponding dislocation structures was carefully investigated using SEM and EBSD. Experimental results show that at lower plastic strain amplitudes ( $\gamma_{pl} = 5 \times 10^{-4}$  and  $\gamma_{pl} = 1 \times 10^{-3}$ ), the dislocation structures are mainly characterized by vein-like and wall structures while the cell structure can be regarded as the main dislocation structure at higher  $\gamma_{pl}$  ( $\gamma_{pl} = 1 \times 10^{-2}$ ). Based on the experimental results and crystallographic geometry, three different types each of DBIs  $[(111)$ ,  $(\bar{1}\bar{1}1)$ , and  $(\bar{1}1\bar{1})]$  and DBIIs  $[(\bar{2}11)$ ,  $(\bar{1}21)$ , and  $(\bar{1}12)]$  can be summarized as the primarily activated slip plane and the combination of activated primary and coplanar slip systems, respectively. In addition, the formation planes of cell bands (CBs)  $[(121)$ ,  $(\bar{1}\bar{1}2)$ , and  $(\bar{2}1\bar{1})]$  formed in the DBs can be regarded as the plane which is perpendicular to the cross-slip plane and parallel to the primary slip direction. Furthermore, due to the highly symmetrical characteristics of  $[\bar{1}11]$  multiple-slip-oriented single crystals, the inconsistent correspondences between DBs and CBs can also be detected based on the numerous observations of the cyclically deformed copper single crystals. In addition, from the EBSD results, it can also be found that there is a

weak rotation between the two neighboring CB formed in the DB, which induced the formation of the (111) twist boundary. The cell band with opposite contrast rotates  $0.7^\circ$  around the rotation axis [111] with the plus and minus direction, respectively.

#### **Chapter 4: Formation of dislocation structures during cyclic deformation in near-[001] multiple-slip-oriented copper single crystals.**

In Chapter 4, the evolution of dislocation structure during the cyclic deformation in the near-[001]-oriented copper single crystals is investigated across a wide range of plastic strain amplitude  $\gamma_{pl} = 1.7 \times 10^{-4} - 1.7 \times 10^{-2}$  using SEM. When  $1.7 \times 10^{-4} < \gamma_{pl} < 1.0 \times 10^{-3}$ , the dislocation structures were mainly characterized as vein-like structure. When  $3.5 \times 10^{-3} < \gamma_{pl} < 1.0 \times 10^{-2}$ , the dislocation structure comprised a labyrinth with a set of parallel (100) and (001) walls, which is highly correlated to the activation of primary and critical slip systems. However, when  $\gamma_{pl}$  increased to  $1.5 \times 10^{-2}$ , the labyrinth structure is decomposed with the formation of cell structures to accommodate the higher plastic strain. The formation of cell structures formed on the (111) [or  $(\bar{1}\bar{1}1)$ ] plane, owing to the local activation of the primary and primary coplanar [or critical and critical coplanar] slip systems. The formation plane of the cell boundary depends on which slip system is activated as the primary slip system. In addition, a slight misorientation in the dislocation cell structures formed at higher  $\gamma_{pl}$  can also be detected by EBSD with approximately  $3^\circ$  misorientation angle. The rotation axis can be regarded as [010], which is simultaneously perpendicular to the primary and critical slip direction due to the formation mechanism of dislocation cell structures.

#### **Chapter 5: General conclusions.**

Finally, in Chapter 5, the conclusion of this work is summarized.

Overall, this study proposes the relationship between the activated slip systems

and the formation of DBs and related dislocation structures during the cyclic deformation, which deepens our understanding of the fatigue of metals.