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THE STRAIN ANALYSIS OF MICRSTRUCTURE BY DIRECT MEASUREMENT ON FLAT SURFACE OF METAL

Masashi Yoshida*and Masayoshi Akiyama†

*Ube National College of Technology
Tokiwadai 2-14-1, Ube, Yamaguchi, 755-8555, Japan
e-mail:yoshida@ube-k.ac.jp, web page: http://www.ube-k.ac.jp

†Sumitomo Metal Industries, Ltd.
Fuso-cho 1-8, Amagasaki, Hyogo, 660-0891, Japan
e-mail:akiyama-msy@sumitomometals.co.jp, web page: http://www.sumitomometals.co.jp

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Summary. *Using the correlation analysis of SEM images observed before and after the tensile test, it has been shown that strain distribution on the surface of deformed SUS316L plates can be determined with spatial resolution of as high as 1m. Three patterns of strain distribution have been observed:(A) a uniform distribution entire the grain, (B) large strain near the grain boundary and small one away from the boundary, and (C) large strain close to the corner of the grain boundary but no strain near the straight portion of the boundary.*

1 INTRODUCTION

It is important to understand the deformation mechanism of polycrystalline materials to develop high quality engineering materials. Ashby has proposed a model describing the deformation procedure in polycrystalline materials. In his model, each grain of a polycrystal deforms in a uniform manner. Overlap and voids appear at the grain boundaries, which causes accumulation of dislocations near grain boundaries.[1] Static dislocation structure formed by plastic deformation has been investigated intensively using transmission electron microscopy (TEM).[2] However, it is difficult by TEM observation to determine the strain distribution in grains which is directry connected to the movement of dislocations.

Recently, Akiyama et al have developed a sophisticated method to investigate strains in polycrystalline specimens in which lattices are drawn on surfaces by focused ion beam and deformation of lattices were measured by scanning electron microscopy.[3] They have found a thin layer of deformation near grain boundaries and a uniform deformation in the center of grains. However, information on the local distribution of strains is restricted because spatial resolution of their method is not satisfactory.

In the present study, in order to obtain distribution of strain in polycrystalline specimens, SEM images before and after the tensile test have been examined using image correlation analysis method. It has been proved that the distribution of strain can be determined with spatial resolution as high as 1μ using image correlation analysis.

2 EXPERIMENTAL METHOD

The parent material used for the experiment was SUS316L type stainless steel. Flat surfaces were machined from a round specimen of diameter 5^{ϕ} and mirror-polished. For stress relief, the specimen was placed in a vacuum furnace and heated at 873K for 7.2ks. The furnace was then switched off to allow furnace cooling to room temperature. Then a lattice was drawn on the flat surface using a field ion beam (FIB). The acceleration voltage of the FIB was 30keV, and the current was 350pA. The length between each lattice line was 10µ. Details of the Ga-lattice were described in ref.3. The tension test was conducted using a conventional testing machine. The crosshead speed was 5mm/min and the strain was measured by an extensometer. The amount of tensile plastic strain applied to the specimen was 3% or 6%. After the tensile test, SEM images ware analyzed using image correlation analysis method in order to obtain local strain distribution.

3 RESULTS AND DISCUSSION

Figures 1 (a) and (b) are the SEM images of the specimen before and after the tensile test of average elongation of 6%. In Fig. 1 (a) a square lattice of 10µ spacing drawn by Ga+ ion beam is seen in a random morphology formed by precipitates and surface roughness. The roughness may be caused by the recrystallization or poligonization of the strained thin surface layer during the heat treatment at 873K. A grain boundary is observed in the random morphology from upper left to lower right in Fig. 1 (a). After the tensile test, the lattice drawn by Ga+ is elongated in the vertical direction as shown in Fig. 1 (b). No slip band is observed in Fig. 1 (b).

The image in Fig. 1 (a) is divided into 1µ x1µ square regions. Using the random morphology formed on the surface, local displacement of each square is determined by image correlation analysis. Figure 2 (a) and (b) show displacement and strain, respectively, of each square after the tensile test. In Fig. 2 (a) bars represent displacement of each square relative to the top left square. Continuous displacement is obtained in Fig. 2 (a). In Fig. 2 (b), elongation along the loading direction is shown in the vertical direction while the compression perpendicular to the loading direction is shown horizontally. As large as 10% local strain has been detected in the direction of loading though average strain is 6%. The ratio of elongation in the parallel and compression in the perpendicular directions must be 1/2 to conserve the density. This value is realized in regions where uniform deformation occurs. On the other hand, in regions where non-uniform deformation occurs, rotation occurs and the ratio deviates from 1/2.

A solid line in Fig. 2 (b) indicates the position of the grain boundary observed in Fig. 1. We call the grain on the right (left) side as grain I (grain II), hereafter. The distribution of strain in grain I and II differs to each other. The amount of strain of almost all regions in grain I is around 10% even though a few regions of small strain below 3% are observed. The density of dislocation is directly related to the gradient of strain with distance. The fact that strain distributes uniformly in the grain implies that dislocations have moved through the grain I.

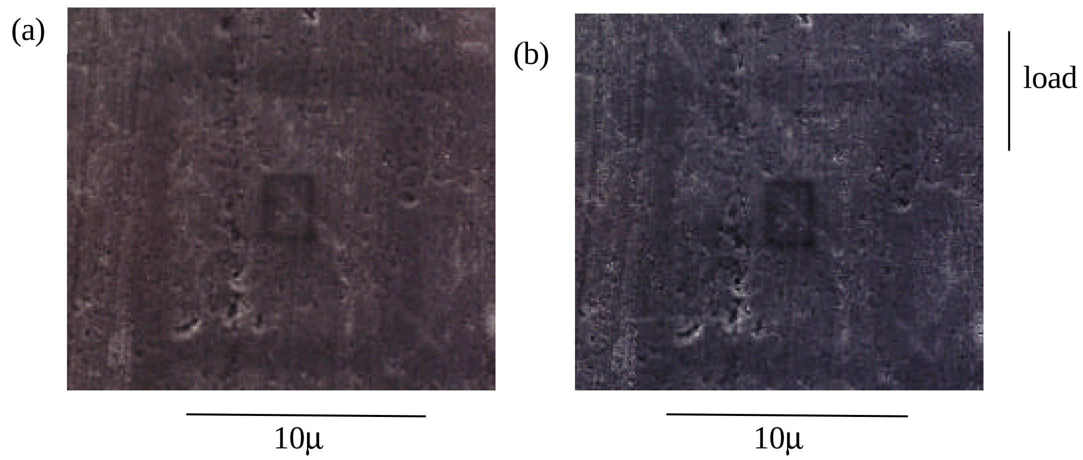

Fig.1 SEM image of the specimen before (a) and after (b) the tensile test. The average elongation of the specimen is 6%.

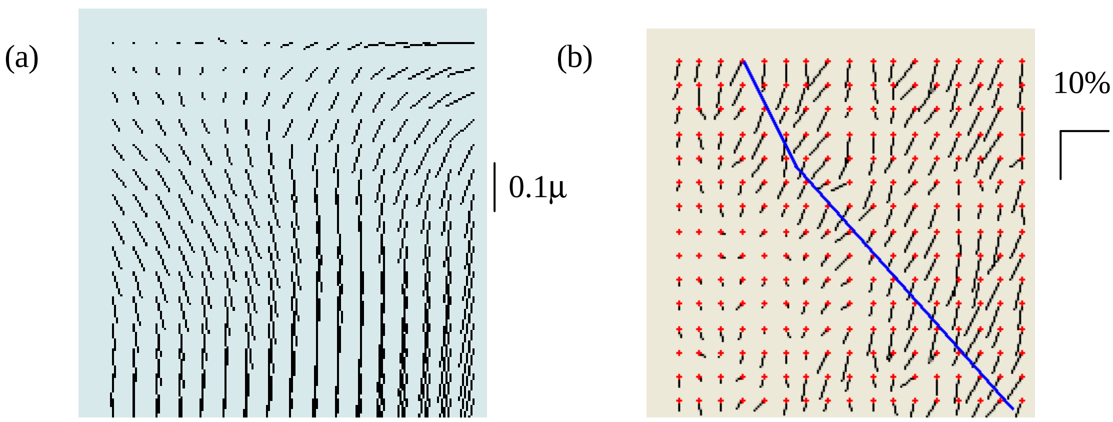

Fig. 2 Distribution of displacement (a) and strain(b) of the specimen shown in Fig. 1.A solid line in Fig. 2 (b) indicates the position of the grain boundary observed in Fig. 1.

In grain II, the amount of strain is around 6% in the region close to the grain boundary but is below 1% away from the boundary. The fact that strain close to the boundary is larger than that of the center means that dislocation has generated at the grain boundary but has been trapped and have not been able to move to inside the grain and accumulation of dislocations has occured near the grain boundary.

Figures 3 (a) is the SEM image of the specimen after the tensile test of average elongation of 3%. A grain boundary with two corners of the angle of around 3/4π radian is observed. We call the grain on the right (left) side in Fig. 3 (a) as grain III (grain IV), hereafter. Local displacement of every 1μ x1μ square in Fig. 3 (a) is determined by image correlation analysis.

Fig. 3 (b) shows strain of each 1μ x1μ square after the tensile test. The solid line in Fig. 3(b) represents the position of the grain boundary observed in Figs. 3 (a). In grain III, the amount of strain is around 3 to 5%. Strain distributes rather uniformly throughout the grain III

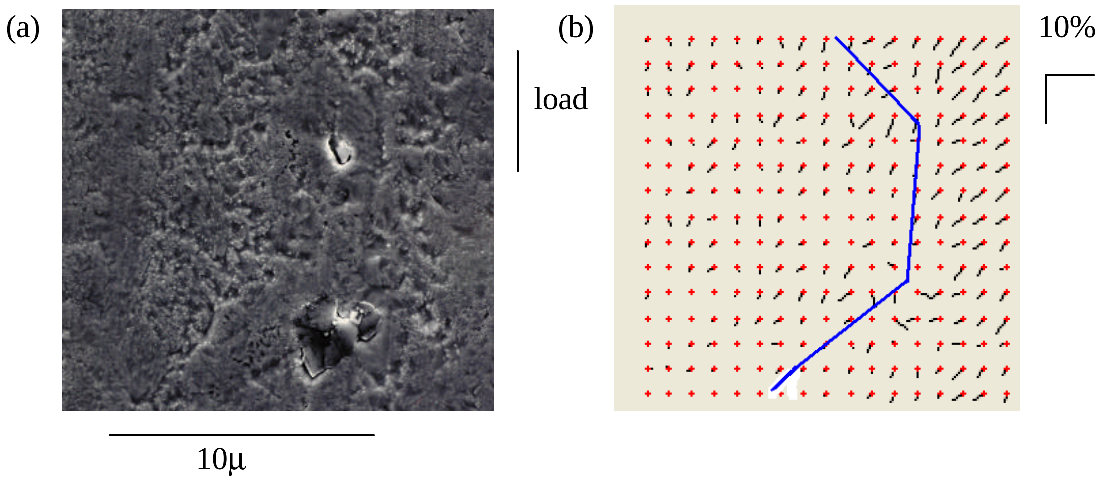

Fig.3 SEM image of the specimen after tensile test of average elongation of 3% (a)and distribution of the strain determined by correlation analysis method (b). A solid line in Fig. 3 (b) indicates the position of the grain boundary observed in Fig. 3 (a).

implying that slip has occurred entire the grain and dislocations have moved through the grain. In grain IV, on the other hand, the amount of strain is nearly zero in the central region of the grain. It should be noticed that the strain close to the straight portion of the grain boundary is also very small (below 1%). This fact suggests that dislocations in grain IV have not been able to cross this grain boundary. On the other hand, strain of around 5% has been detected near the two corners of the grain boundary in grain IV. This indicates that dislocations are generated at the corner of the grain boundary in grain IV and moved inside the grain.

4 CONCLUSIONS

Using the correlation analysis of SEM images observed before and after the tensile test, it has been shown that strain distribution can be determined with spatial resolution of as high as 1µ. Three patterns of strain distribution have been observed in deformed SUS316L specimen: (A) a uniform distribution entire the grain, (B) large strain near the grain boundary and small one away from the boundary and (C) large strain close to the corner of the grain boundary but no strain near the straight portion of the boundary.

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