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Microscopic Observation of Plastic Deformation of Polycrystalline Aluminum by Laser Scanning Microscope

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Free surface of polycrystalline metal becomes roughened after plastic deformation. The surface roughening is closely related to the inhomogeneity of polycrystalline metals, that is, to the inhomogeneous plastic deformation of respective grains. In the present study, inhomogeneous deformation on the free surface of polycrystalline aluminum specimen during uniaxial tension is studied. The inhomogeneous deformation of grains in the central area of the free surface of specimen is observed by the laser scanning microscope, while the inhomogeneous deformation perpendicular to the surface is studied by the laser scanning microscope as well as the stylus measuring instrument.

It is shown that the surface roughness and the strain of respective grains increase with the applied strain. Discussions are made on the change in the surface roughness, the strain in each grain and the slip-line angles with the applied strain.

1. INTRODUCTION

Free surface of polycrystalline metal becomes roughened after plastic deformation. The surface roughening is important for the finishing of surface during plastic working. It is known that the surface roughening is closely related to the inhomogeneity of polycrystalline metals, that is, to the inhomogeneous plastic deformation of respective grains [1-8] . Then, the experimental study of the surface roughening is also important for the understanding of microscopic deformation behavior of polycrystalline metals. In the present study, inhomogeneous deformation on the free surface of polycrystalline aluminum specimen during uniaxial tension is studied. The inhomogeneous deformation of grains in the central area of the free surface of specimen is observed by a laser scanning microscope, while the inhomogeneous deformation perpendicular to the surface is studied by the laser scanning microscope as well as the stylus measuring instrument. The relation between the strain in respective grains, the shape of free surface roughness curve and the applied strain is investigated. Discussions are also made on the relation among the variations of strain in each grain, profile wavelength, slip-line angles and the surface roughness due to the applied strain.

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2. EXPERIMENTAL METHOD

2. 1 Specimen

The material used is polycrystalline pure aluminum for industrial use (99.5wt%). The shape of tensile specimen is shown in Fig. 1. The central surface of the specimen was finished with abrasive papers and diamond paste until its center-line average roughness becomes below Ra = 0.1 μm. Then, the specimen was annealed for 1hr at 400°C for Specimen A, while for 24hr at 600°C for Specimen B, and then cooled in the furnace. The surface of the specimen was electropolished and chemically etched in order to distinguish the grain boundary. The averaged grain sizes are 35~40 μm and 70~80 μm, respectively for Specimen A and B.

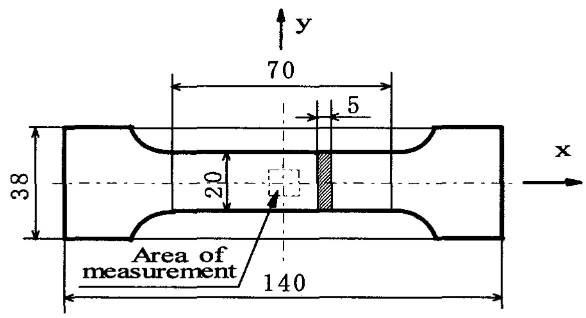


Fig. 1 Tensile specimen

2. 2 Surface Roughness Measurements and Observation of Microscopic Deformation

The specimen was taken out from the tensile testing machine after a certain fixed amount of strain. And microscopic deformation on the surface, that is, the surface roughening and the strain of grains were observed with the laser scanning microscope (Keyence, VF-7500). The operating principle of the laser scanning microscope is shown in Fig. 2.

The average surface roughness was also measured eight lines for the central area of 8×8mm^2 on the specimen surface, by the use of the stylus surface roughness measurement apparatus.

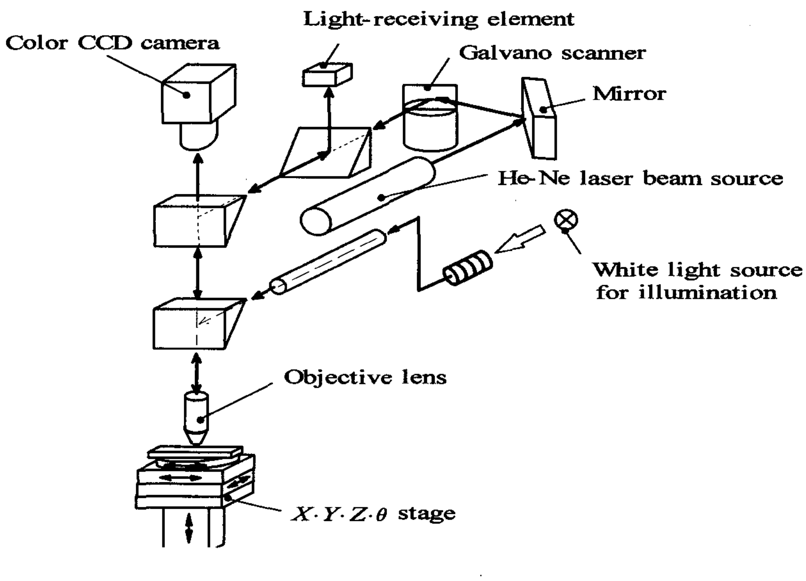


Fig. 2 Principle of Laser Scanning Microscope

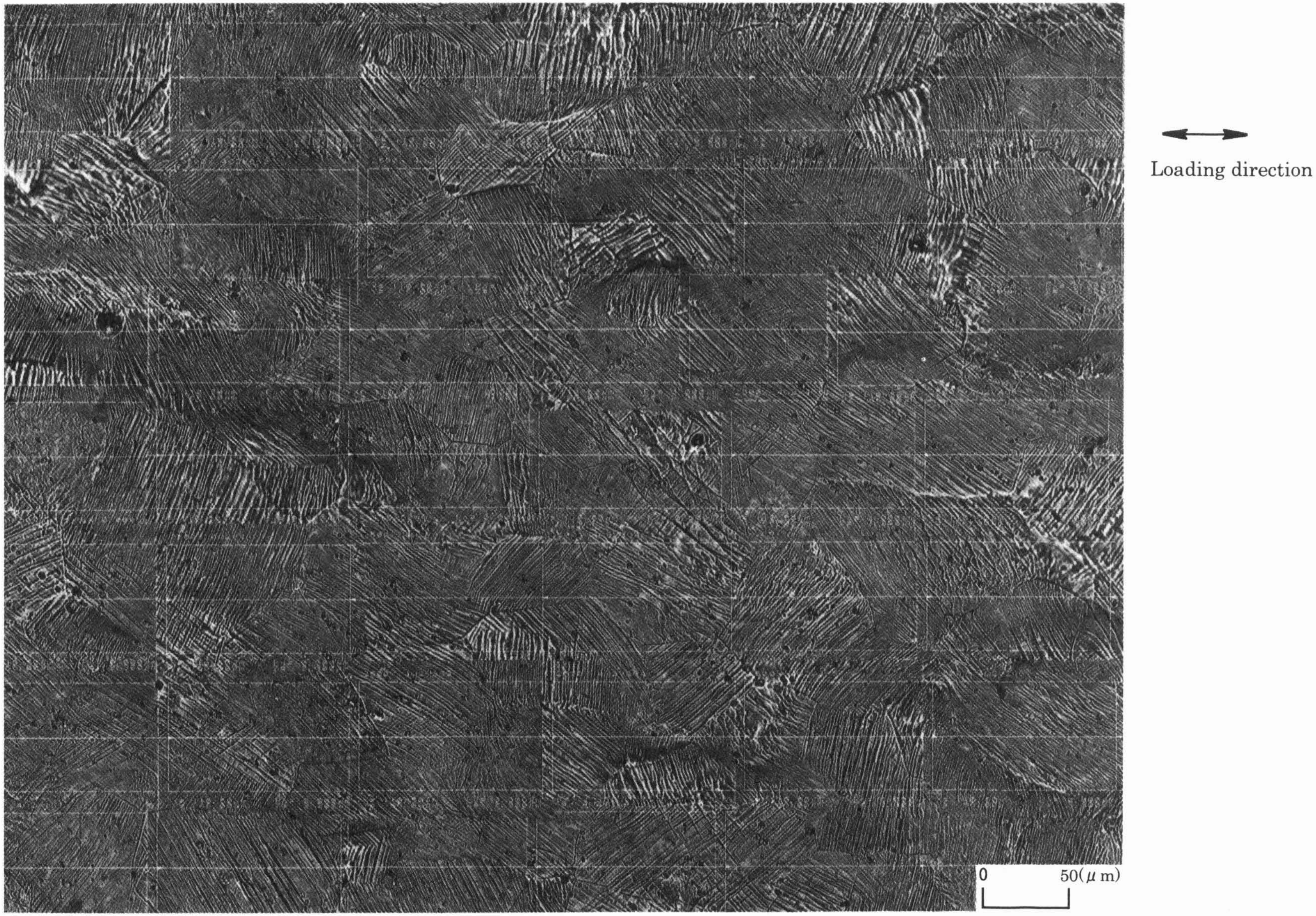


Fig. 3 Optical micrograph taken by laser scanning microscope and composed with personal computer ($\varepsilon_x = 0.17$)

2. 3 Measurement of Strain in Grains and Angle of Slip Lines

The strains of grains in the axial and in the perpendicular direction were measured for the area $0.7 \times 0.6 mm^2$ at the central area of Specimen B. The total number of grains used for the measurement was about 80.

The angle of slip lines was also measured on the display of the laser scanning microscope

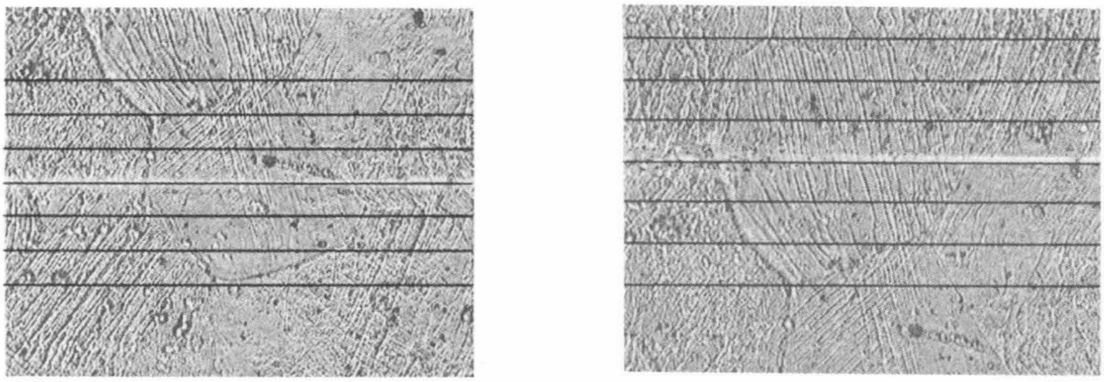
3. EXPERIMENTAL RESULTS AND DISCUSSION

3. 1 Deformation and Surface Roughness of Respective Grains

At first, deformation and surface roughness for respective grains are observed with laser scanning microscope. Figures 3 and 4 show examples of surface observation. Figure 3 is the micrograph taken by the CCD camera and composed with the personal computer, which shows the grain deformation and the slip lines in respective grains.

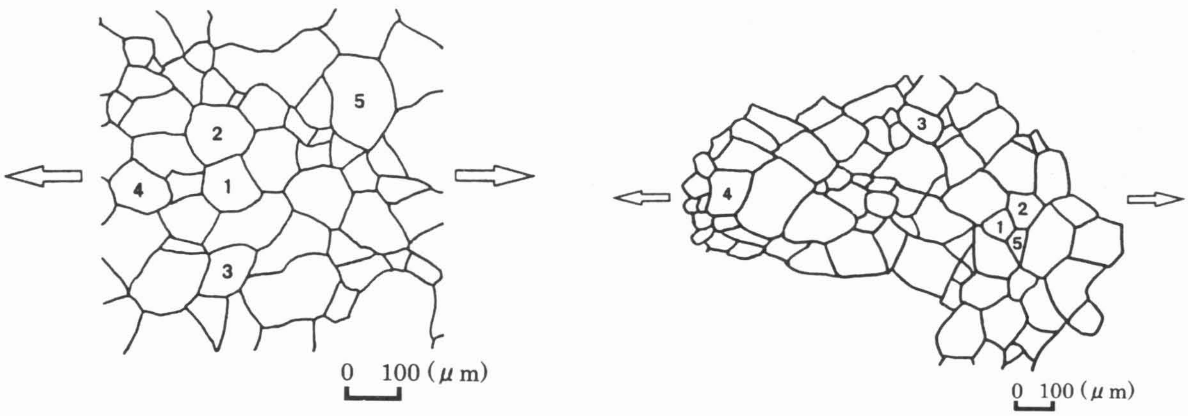
Five different grains (Grain 1~5) were chosen respectively for Specimen B-1 and Specimen B-2 as shown in Figs. 5 (a) and (b), respectively. Figs. 4 (a) and (b) show of the photographs at the applied strain $\varepsilon_x = 0.10$ for Grain 1 and for Grain 2, respectively. Figs. 6 (a) and (b) show the corresponding surface roughness profiles for Grain 1 and Grain 2, respectively.

Fig. 7 shows the change in the average surface roughness measured for the five grains shown in Fig. 5 with the applied strain. Fig. 8 shows the change in the strain of grain for the five grains shown in Fig. 5 with the applied strains. It is seen from Fig. 7 and 8 that there are large variety of the deformation mode in respective grains



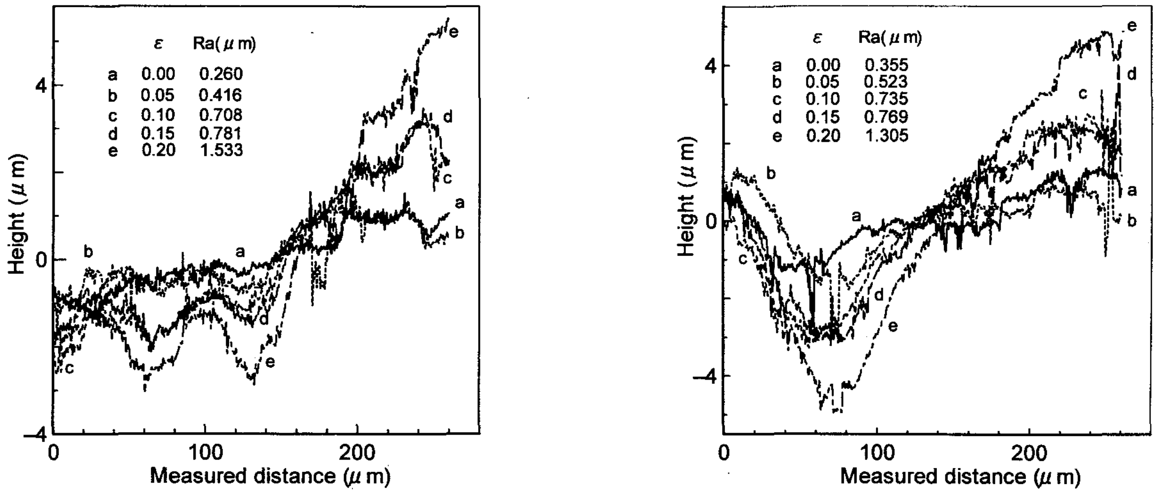
(a) Grain 1 of Specimen B-1 (b) Grain 2 of Specimen B-1

Fig. 4 Examples of surface photograph taken by laser scanning microscope (×1250)



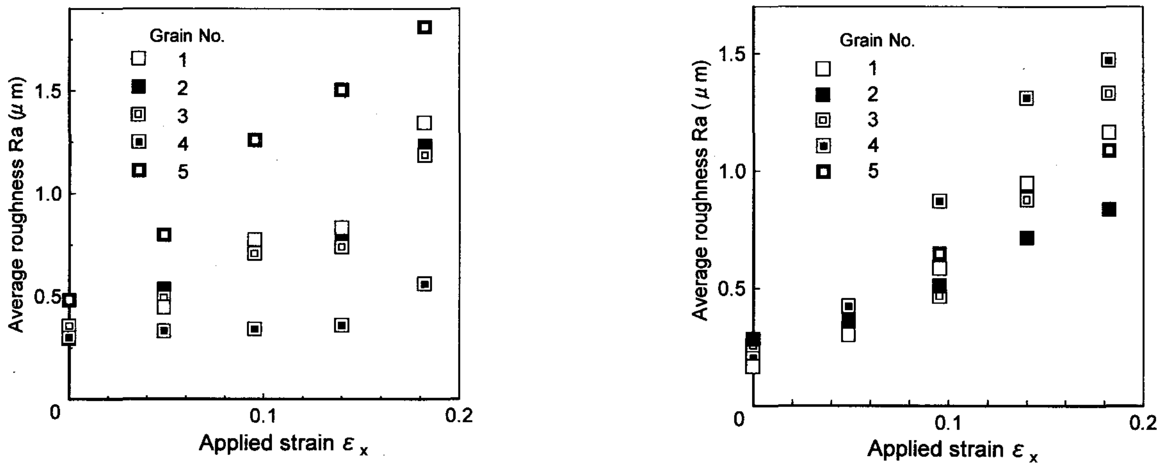
(a) Specimen B-1 (b) Specimen B-2

Fig. 5 Distribution of grains for Specimen B-1 and Specimens B-2



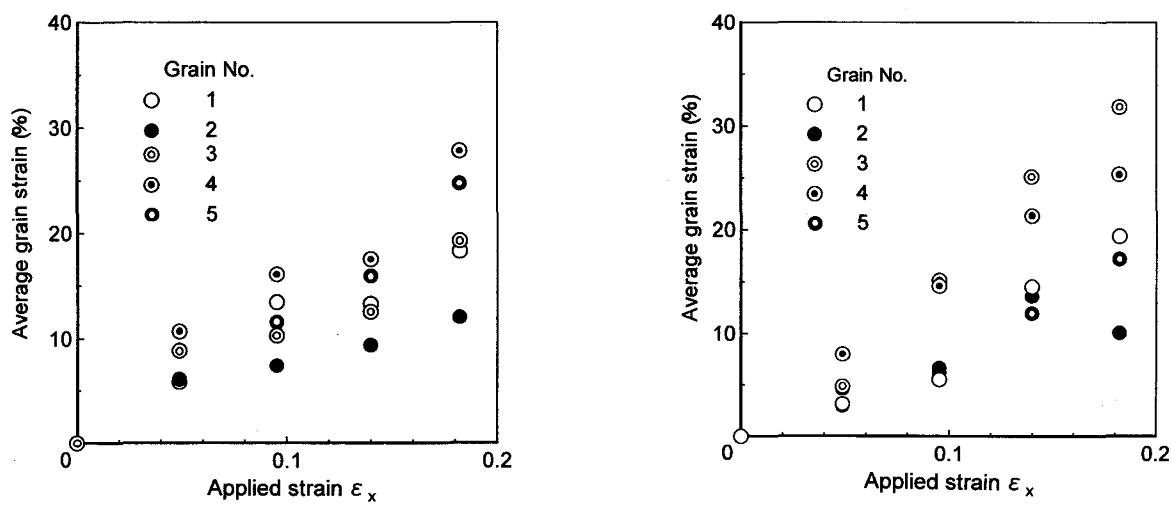
(a) Grain 1 (b) Grain 2

Fig. 6 Observation with laser scanning microscope along center line of grains (Specimen B-1)



(a) Specimen B-1 (b) Specimen B-2

Fig. 7 Change in average surface roughness measured for the grains shown in Fig. 4 with applied strain.



(a) Specimen B-1 (b) Specimen B-2

Fig. 8 Change in strain of five grains with applied strain

3. 2 Change in Surface Roughness of Specimen

Figure 9 shows an example of the surface roughness curve with laser scanning microscope along the same selected line on the specimen surface, for different applied strain. Fig. 9 shows the change in the surface profiles for the fixed different applied strain with respect to the initial length. The figure is processed and combined from several roughness measurements in a personal computer.

The wavelength of the free surface profile increases with the applied tensile strain. The mountains and valleys produced at the early stage remain their shape, though their heights increase. In some area of grains, the deformation in the normal z-direction is large, while it is small in the other parts of grains.

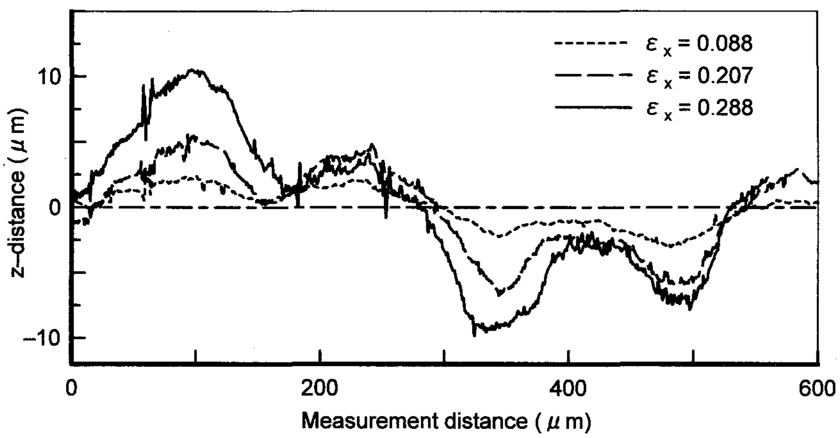
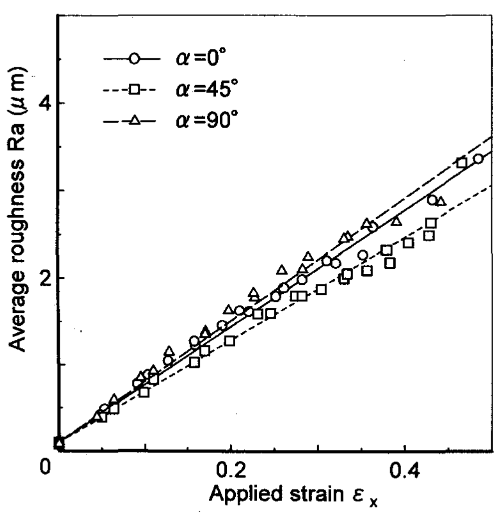
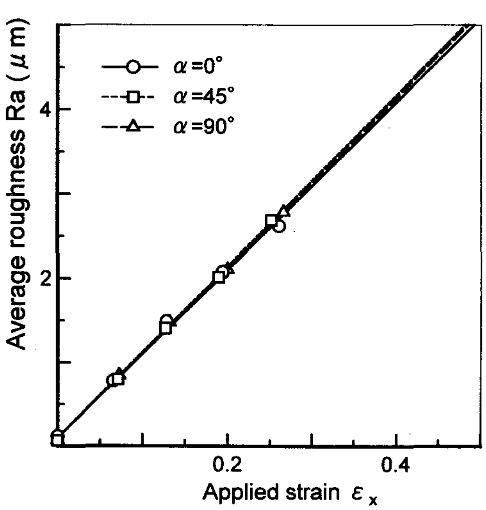


Fig. 9 Example of surface profile processed and combined in personal computer

Changes in the average surface roughness measured in the axial and the perpendicular directions of Specimen A with the stylus measurement apparatus are shown in Fig. 10(a). Similar results for Specimen B are shown in Fig. 10(b). In the figures, α is the angle between the specimen axis and the rolling direction of the original aluminum plate. It is seen that little effect of α is observed on the changes of the surface roughness.



(a) Specimen A

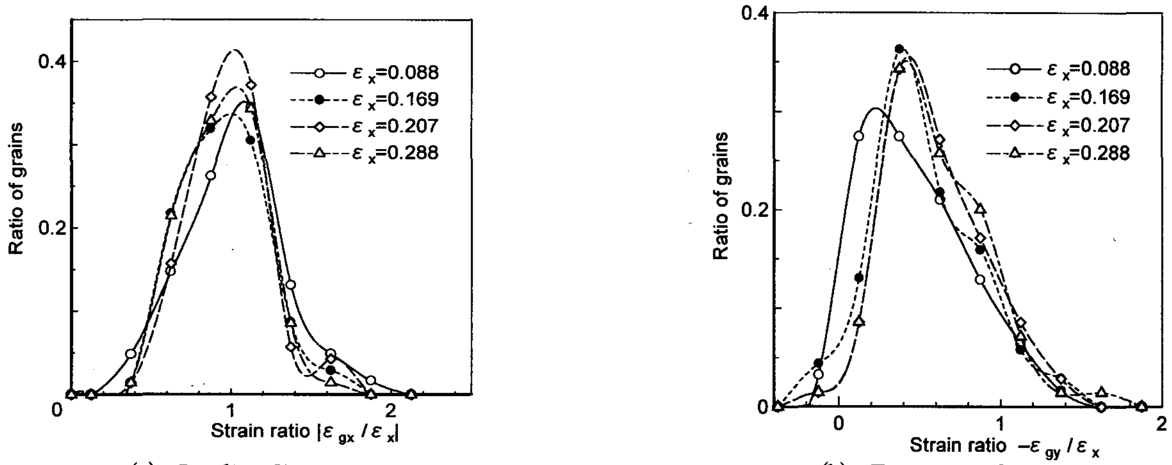


(b) Specimen B

Fig. 10 Change in average roughness measured in loading and transverse direction with applied strain for Specimen A and B

3. 3 Strain Distribution of Grains

Figure 11 (a) and (b) show the strain of respective grains in the axial (x-) direction and in the perpendicular (y-) direction, respectively, where the distribution of strain is shown with ratio of the strain ε_{gx} or ε_{gy} and the applied strain ε_x . The data are obtained from the measurements for about 70 grains of Specimen B. It is seen that the shapes of the distribution are almost the same, irrespective of the applied strain ε_x, which implies that the deviation of the strain of respective grains also increases with the applied strain.



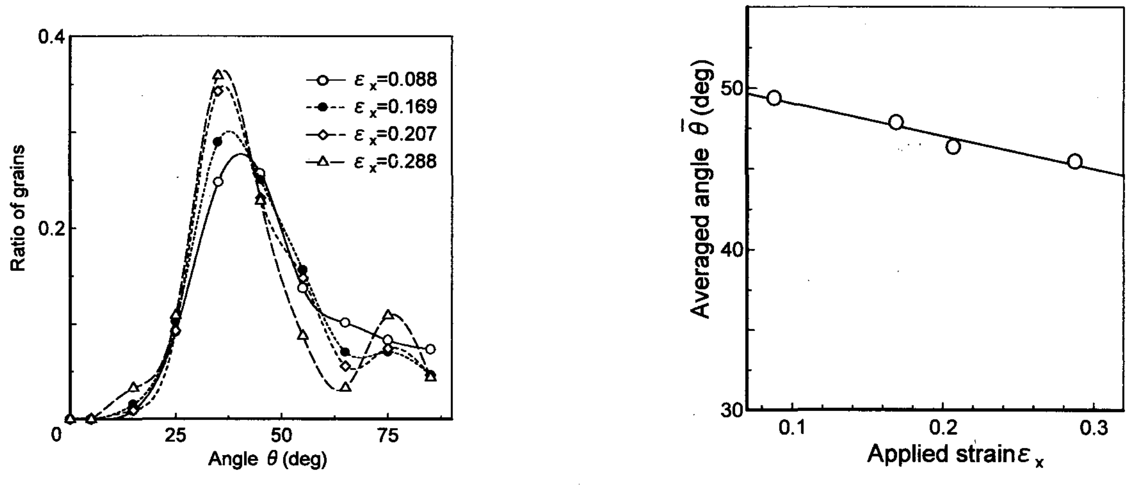
(a) Loading direction (b) Transverse direction

Fig. 11 Distribution of grain strain measured in loading and transverse directions

3.4 Direction of Slip-lines in Grains

Figure 12(a) shows the measured angle θ between the slip-lines on the surface and x-direction for respective grains in Specimen B. Figure 12(b) shows the change in the averaged slip-line angle $\bar{\theta}$ with respect to the applied strain. It is seen that the angle $\bar{\theta}$ decreases with the increase of the applied strain.

Figure 13 shows the angle ϕ between two kinds of slip-lines appeared in a grain, where the angle is measured so as to the x-direction lies in between the two slip-lines. It is seen the angle ϕ between the two slip-lines also decreases with the applied strain.



(a) Distribution of angle θ (b) Change in averaged angle $\bar{\theta}$ with applied strain

Fig. 12 Distribution of angles between slip-line in grains and loading direction

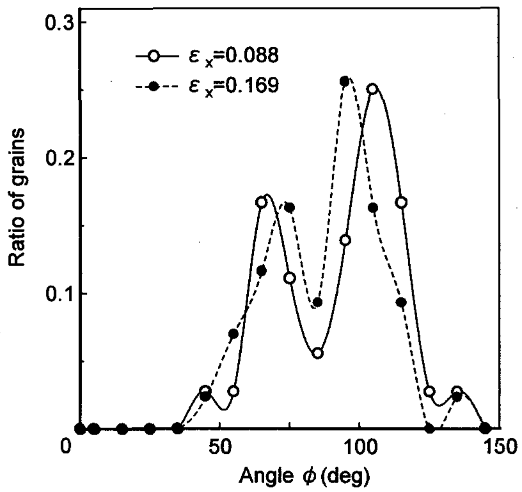


Fig. 13 Distribution of angle ϕ between two slip-line systems in grains

4. CONCLUSIONS

Microscopic deformation behavior of polycrystalline aluminum was observed with the laser scanning microscope. The surface roughening is also measured with the laser scanning microscope as well as the stylus surface roughness measuring apparatus. The main conclusions are as follows.

(1) The microscopic deformation behavior of respective grains in polycrystalline metal is observed successfully with laser scanning microscope. It is applicable to clarify the deformation behavior in the plane of the specimen surface as well as that out of the plane of the surface.

(2) It is also possible to process and combine the measured digital data of surface profile and surface photographs by the use of personal computer. In some are in respective grains, the surface roughness increases with the applied strain, while in the other area the surface profile scarcely changes with the applied strain.

(3) The distribution of grain strain is similar for different applied strain, if the strain of grains is expressed with the ratio to the applied strain.

(4) The angle between the slip lines and the tensile direction slightly decreases with the applied strain. When two pairs of the slip lines are observed in the same grain, the angle between them also decreases with the applied strain.

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