Surface Undulation of Pure Titanium Grains under Elastic and Plastic Tensile Conditions

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Abstract. A tensile test was carried out using a plate specimen of pure titanium, and the microscopic deformation was observed under elastic and plastic loading conditions. In the test, surface undulation in each grain was measured on the order of nano-meter by means of the digital holographic microscope, and their change by macroscopic tensile load under elastic and plastic conditions were compared.

Introduction

Commercial pure titanium has been widely used in aerospace, chemical, and biomedical industries for its lightweight, high corrosion resistance, high strength, high heat resistance and good biocompatible properties. Since most of the parts and components are made of polycrystalline titanium, their deformation shows microscopic inhomogeneity, which often brings about small cracking and failures. In this paper, a tensile test was carried out using a plate specimen of polycrystalline pure titanium on the stage of the digital holographic microscope and the small undulation on the surface of specimen was measured. The microscopic deformation based on the change in height distribution in each grain of titanium under elastic and plastic conditions was discussed.

Experimental Procedures

Specimen and tensile test. A plate of commercial pure titanium (CP-Ti) with the purity of 99.5 wt.% was used. The shape and size of specimen is shown in Fig.1. Tensile test was carried out using a compact type tension-compression material testing machine with a load capacity of 2 [kN]. The machine was setup on the stage of the digital holographic microscope and the height distribution on the surface of specimen was acquired under elastic and plastic tensile conditions. The tensile load was given manually by turning a handle, and increased step by step (P=0 (before test), 53, 106, 212, 317, 423, 476, 529, 582, 635, 688, 0 [N] (after test)). Tensile load and load point displacement were measured by load cell and dial gauge, respectively.

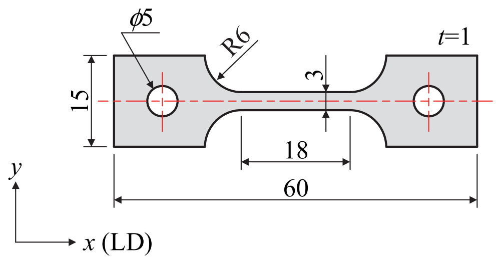


Fig. 1 Shape and size of plate specimen.

Digital holographic microscope and digital height correlation method (DHCM). Height distribution on the surface of specimen was acquired during tensile test by a reflection configured digital holographic microscope R1100 manufactured by Lyncee Tec, Switzerland. Locations of evaluation areas at different loading steps were identified by digital height correlation method (DHCM) [1, 2] with reference to natural undulations of the order of nano-meter which remained after the surface treatment of electropolish and chemical etching.

Observation area and average height of grain. A square observation area of 500×500 [μm^2] was set on the parallel part of plate specimen as shown in Fig.2. Vickers indentations were introduced at each corner of the area for easy recognition. Height distribution was acquired in this area at each load step.

Average height change was evaluated for each numbered grain using

$$h_{\mathrm{m}} = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} h(x_i, y_j) \quad (1)$$

where h_{m} is the average height in a region of 21×21 pixels (for small grains 11×11 pixels) around the center of grain.

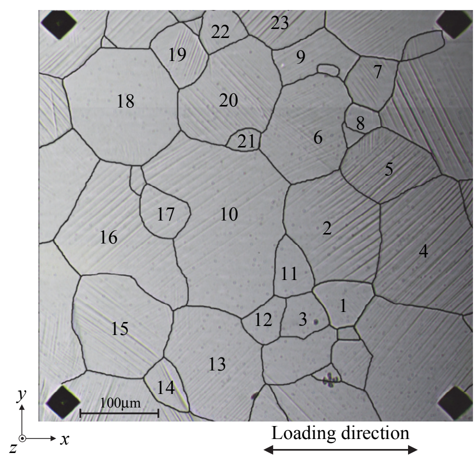


Fig. 2 Measurement area on the specimen surface after tensile test.

Results and Discussions

Height distribution and maximum gradient direction. Height distribution in grain 2 is shown in Fig.3. While very small undulation exists at P=0 [N], the undulation with sink (blue) and bulge (yellow) areas appeared on the grain surface at P=635 [N]. Stripe pattern corresponding to slip lines due to plastic deformation is also found on the right-hand side of the grain.

Maximum gradient direction of grain 2 is shown in Fig.4. Reversal change in the direction is found around the slip line area. In the other area, broad band area is found which shows small reversal of direction change.

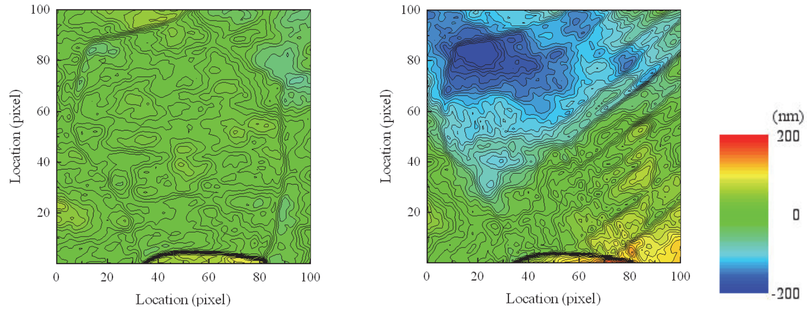


Fig. 3 Height distribution in grain 2 at P=0 (initial) and 635 [N].

Change in average height of grain under elastic and plastic tensile conditions. Change in average height by a unit load, $\Delta h_m/\Delta P$, is shown in Fig.5. Fig.5(a) shows the relationship between $\Delta h_m/\Delta P$ under small elastic loading and that under relatively large elastic loading. Fig.5(b) shows the relationship between those under elastic and plastic loading conditions. The results indicate that height change of each grain occurred in proportion to the macroscopic load under elastic condition and that the height change under plastic condition is strongly correlated with that under elastic condition. In other words, the inhomogeneous deformation of grains under plastic condition can be predicted from that under elastic condition.

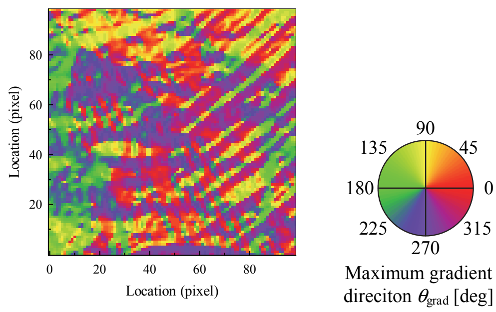


Fig. 4 Maximum gradient direction in grain 2 at P=635 [N].

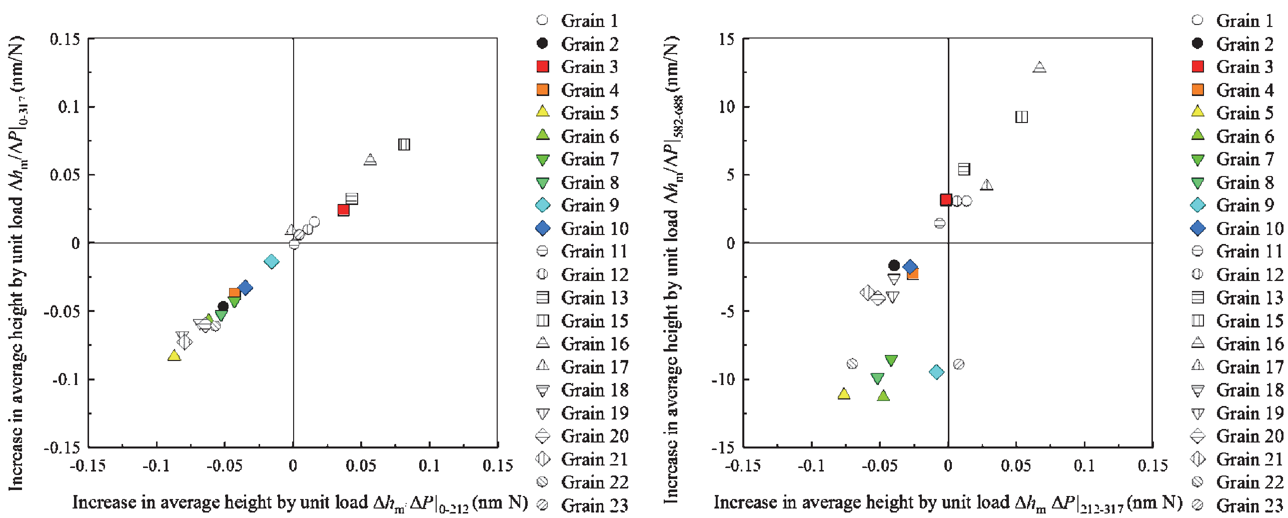
Conclusions

The undulation on specimen surface under tensile load was measured and compared. The relationship between undulations in elastic and plastic loading conditions was clarified. The slip lines showing the initiation of local plastic deformation was also found by the microscopic height change. The inhomogeneous deformation of grains under plastic loading condition is predictable from that under elastic loading conditions.

References

[1] N. Tada, N. Yagi, I. Shimizu and M. Uchida: *Regional Identification by Digital Height Correlation of Nanolevel Surface Profile*, Final Program and Abstracts, SEM 2009 Fall Symposium and Workshop, The Society for Experimental Mechanics, Bethel, USA, (2009) p.15.

[2] N. Tada, M. Uchida and Y. Uenoyama: *Non-Destructive Crack Detection by Nanometric Change in Surface Profile Using Digital Holographic Microscope*, Proc. PVP2012, (2012) Paper No. PVP2012-57299.



(a) Elastic (abscissa) – elastic (ordinate) relation

(b) Elastic (abscissa) – plastic (ordinate) relation

Fig. 5 Relationship between average height chage by a unit load under elastic and plastic loading conditions.