Hardness Anisotropy in Molybdenum Single Crystals Bombarded with 50 MeV He Ions

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In order to assess surface deterioration such as blistering in the wall materials bombarded with high-energy He ions, mechanical property change near the surface must be estimated.1) Micro Knoop hardness technique was very useful to study the ion-irradiation hardening in the local region near surface.2) There are, however, two problems to be solved in comparing Knoop hardness data with the bulk irradiation hardening data. One is that micro hardness depends on load especially when small load is used to indent micro region.3) The other is that micro Knoop hardness has anisotropy with orientation of indentation.4)

In the previous work2) where hardness-depth profile was obtained in molybdenum polycrystals bombarded with 10 MeV He ions, it was difficult to get direct answer to above questions because the width of hardened layer was less than 2 μm. In the present work, we bombarded molybdenum single crystals with 50 MeV He ions in order to study the load dependence and the anisotropy in the He-ion bombarded specimens. The projected range of the ion is about 340 μm in molybdenum. The hardened layer is relatively so wide (∿10 μm) that large indentation i.e., large load can be used.

Experimental Procedures

A molybdenum single crystal was produced by electron-beam zone-melting in a vacuum of 1×10^{-4} Pa. Its impurity concentration was C=30, O=2 and N<5 wt.ppm. The crystal was sliced into pieces of size 0.5 mm × 5 mm × 20 mm, with side surfaces parallel to (100) and (110) planes. The beam direction was parallel to [010] and [110] of the samples with side surfaces of (100) and (110), respectively. The specimens were irradiated by 50 MeV He ions in a vacuum of 6×10^{-3} Pa using the materials irradiation chamber in the [32] course of the AVF cyclotron at Tohoku University. The irradiation temperature was controlled by combination of beam heating and water cooling of sample holder, and was measured by thermocouples and an infrared pyrometer. The irradiation conditions were 373 and 1273 K, and 0.46 – 11×10^{21} ion/m^2.

After irradiation, these specimens mounted in resin were electropolished at the test surfaces using a solution of sulphuric acid to remove surface contamination and the residual damage layer. Then, the Knoop hardness test was done at room temperature using loads of 0.1 to 200 gf with a loading time of 20 s and a loading speed of 0.01 mm/s on the side surface.

Results and Discussion

The load dependence of the hardness increment is shown in fig. 1. The hardness increment also increases with decreasing load. The hardness measured by a large load i.e., a 200 gf can be used as bulk hardness, although the hardness values at small loads may be influenced by surface effect.6) Using the relation7), $\Delta Hv = 3\Delta\sigma$ (kgf/mm^2), the increment of the uniaxial flow stress ($\Delta\sigma$) can be estimated from the increment of Vickers hardness (ΔHv). When the testing load is greater than 200 gf weight, the Knoop hardness number is nearly equal to the Vickers hardness number.5) For example, at the peak ΔH(2 gf) = 400 and ΔH(200 gf) = 240, the increment of flow stress was estimated to be about 80 kgf/mm^2 (784 Pa).

Influence of load and test plane on the hardness anisotropy was obtained. Figure 2 shows the anisotropy on (100) plane for the plateau and unirradiated region, where the long-axis orientation θ is measured from the [001] direction. In the unirradiated conditions, the maximum hardness was obtained in the [001] and [010] directions and the minimum hardness was in the [011] direction on (100) place for both 2 and 200 gf loads. When the testing plane was (110), the maximum was in the [001] and the minimum was in the [011] direction. These tendency in unirradiated regions is similar to the anisotropy in other bcc metals.4)

In the case of irradiated region, although scatter of the hardness number became large, the increment of hardness from unirradiated one was nearly independent of θ except the case for 2 gf and (110) plane. The hardness anisotropy for 2 gf weight was relatively smaller than for 200 gf weight. The increment of hardness on the (110) by irradiation was smaller than that on the (100) plane, thus, the irradiation hardening depended not only on the testing loads but also on the crystal orientation of the specimens.

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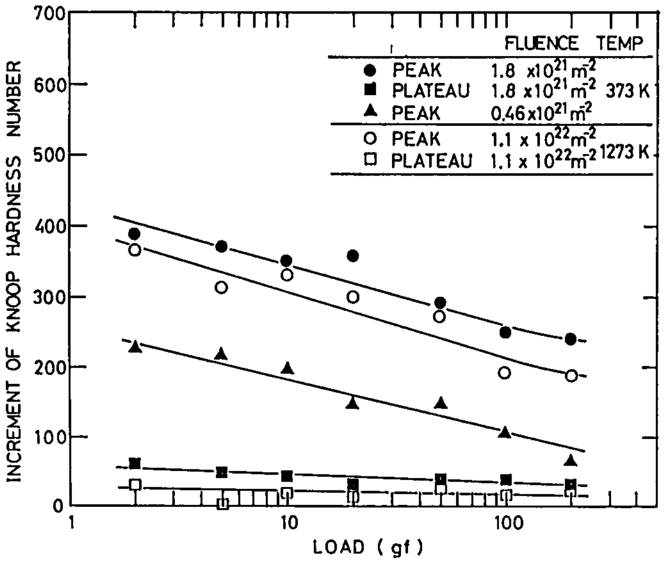

Fig. 1. The load dependence of the increment of hardness number after He ion bombardment. The tested crystal plane was a (100) orientation.

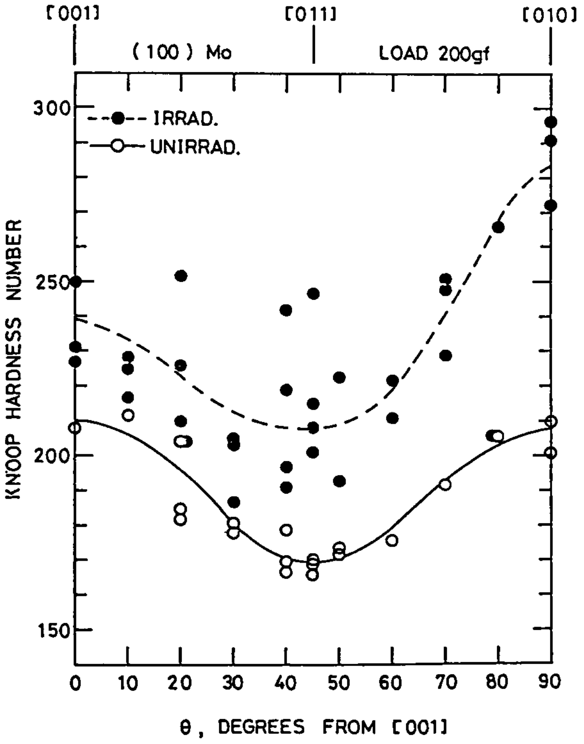

Fig. 2. The hardness anisotropy in plateau region of molybdenum single crystal on (100) plane with 200 gf weight. The irradiation condition is 1.8×10^{21} ion/m^2 and at 373 K.