§16. Effect of Ion-irradiation on Nanoindentation Hardness of V-4Cr-4Ti Alloys

Miyazawa, T., Nagasaka, T., Hishinuma, Y., Muroga, T., Kasada, R. (Kyoto Univ.), Watanabe, H. (Kyushu Univ.), Yamamoto, T. (UCSB), Nogami, S. (Tohoku Univ.), Hatakeyama, M. (Univ. Toyama)

To simulate fusion neutron irradiation damage in structural materials, heavy ion-irradiation experiments have been carried out because of rapid damage production and the absence of induced radioactivity. However, heavy ion-irradiations also have some problems, such as inhomogeneous and shallow damage profiles. Nanoindentation test is effective to evaluate the irradiation hardening in the shallow depth area. The purpose of the present paper is to clarify the effect of ion-irradiation on nanoindentation hardness of V-4Cr-4Ti alloys.

Figure 1 plots depth profiles of nanoindentation hardness before and after 2.4 MeV Cu^{2+} ion-irradiation at 200 °C. For the unirradiated materials, the decrease in hardness with increasing indentation depth was observed at the indentation depth of $h > 50$ nm. Such depth-dependent hardness behavior has been as an indentation size effect (ISE).[1] After the ion-irradiations, the nanoindentation hardness increased at the measured indentation depth. Therefore, irradiation hardening was identified.

Nix and Gao developed a model based on a concept of geometrically necessary dislocation (GND) in order to explain ISE.[1] Using the Nix-Gao model, the hardness depth profile is given as follows:

$$H = H_0\left(1+\frac{h^*}{h}\right)^{1/2} , \qquad (1)$$

where H is the hardness at a given indentation depth, h, H_0 is the hardness in the limit of infinite depth and h^* is a characteristic length which depends on the material and the shape of indenter. In Fig. 2, the hardness data were plotted as H^2 versus $1/h$ to compare with the Nix-Gao model. The hardness for the unirradiated materials show good linearity in the range of $h > 100$ nm. The hardness for the ion-irradiated materials, however, appear to have a bilinearity in the range of $h > 100$ nm with a shoulder at critical indentation depth (200-400 nm). Over the critical indentation depth, a contribution of softer unirradiated region beyond the harder ion-irradiated region to the measured hardness cannot be neglected with increasing the indentation depth. The unirradiated region will begin to plastic deformation before the indenter tip reaches the region. Kasada et al. have developed a model to extrapolate the experimentally obtained nanoindentation hardness to the bulk-equivalent hardness of ion-irradiated Fe-based binary alloys.[2] Using the experimental analysis model, the bulk-equivalent hardness for V-4Cr-4Ti alloys before and after ion-irradiation was extrapolated from the least squares fitting of hardness data of Eq. (1) in the range of 300-1000 nm for unirradiated materials and of 100-200 nm for ion-irradiated materials. Figure 3 shows dose dependence of bulk-equivalent hardness. The irradiation hardening increased with displacement damage and appeared to be saturated at 2.5 dpa. It is due to the saturation of irradiation defects. Irradiation hardening behavior has been clarified from nanoindentation test.

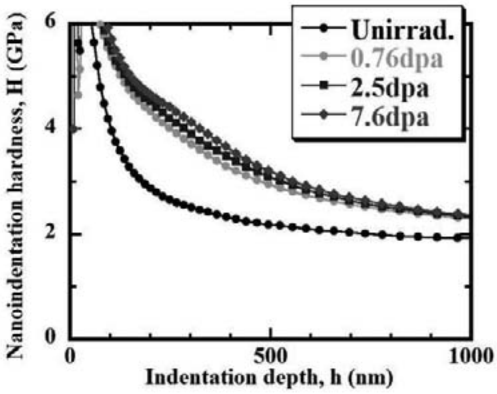

Fig. 1. Depth profiles of nanoindentation hardness before and after ion-irradiation at 200 °C.

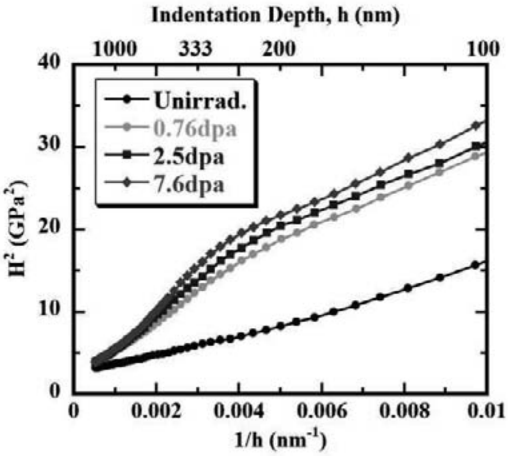

Fig. 2. Plots of H^2 versus $1/h$ before and after ion-irradiation at 200 °C.

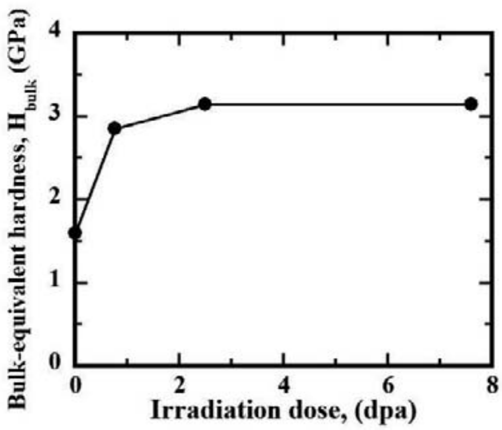

Fig. 3. Dose dependence of bulk-equivalent hardness.

1) Nix, W.D. and Gao, H.: J. Mech. Phys. Solids **46** (1998) 411.
2) Kasada, R. et al.: Fus. Eng. Des. **86** (2011) 2658.