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核融合材料の微小押し込み変形挙動
Nanoindentation on fusion reactor materials

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1. Introduction

The ion-irradiation techniques using MeV self-ion (ex. Fe ion for steels) beam are of great use in experimentally simulating neutron irradiation effects on fusion reactor materials because of their advantages: the high damage rate, no induced-radioactivity, precisely-controllable irradiation conditions, and co-implantation with helium and/or hydrogen. In order To investigate the mechanical properties of ion-irradiated materials, nanoindentation has been used to measure the hardness of materials in the surface up to a few micron meters. However it has been believed that the nanoindentation hardness of ion-irradiated materials has difficulty to compare with the bulk mechanical properties including Vickers hardness of the neutron-irradiated materials because of the indentation size effect (ISE).

One of the authors (RK) suggested a useful model to evaluate bulk-equivalent hardness for the ion-irradiated materials, which is mechanistically related to Vickers hardness [1]. The present study examines a modified model to evaluate depth-dependent bulk-equivalent hardness of the ion-irradiated F82H reduced-activation ferritic steels with a consideration of damage gradient effect (DGE).

2. Experimental Procedure

The materials used in the present study were F82H (nominal compositions: Fe-8Cr-2W-0.2V-0.05Ta-0.1C) and 1 wt.% Ni added F82H (F82H–1Ni). It is known that Ni addition has a great impact on irradiation hardening behavior. Ion-irradiation experiments were performed with a single-ion beam of 10.5 MeV Fe^{3+} in the TIARA facility at JAEA. The irradiation temperature was controlled at 270 °C. The nominal dose rate and nominal dose were 1.3×10^{-3} dpa/s and 5 dpa, respectively. The nominal values stand for the ones at approximately 1 μm below the irradiated surface.

The nanoindentation hardness was measured by using a NanoIndenter G200 (Agilent Technologies) with a Berkovich-type indentation tip. The continuous stiffness measurement (CSM) was used to continuously obtain the hardness (*H*) - depth (*h*) profile.

3. Results and Discussion

Fig. 1 shows indentation-depth profile of the averaged nanoindentation hardness of F82H-1Ni steel before and after the ion-irradiation in TIARA. The unirradiated F82H-1Ni showed increase in hardness with decreasing indent size or depth, i.e., ISE. Our new method can evaluate a bulk-equivalent hardness at each indentation depth, $H_0(h)$ from the gradient of Nix-Gao plot at each $(1/h)$ as

$$H_0(h) = \sqrt{H(h)^2 - \frac{1}{h}\frac{dH(h)^2}{d(1/h)}} \quad (1).$$

The calculated $H_0(h)$ are plotted against h in Fig. 2. The increase of $H_0(h)$ in the shallow depth region up to approximately 0.2 μm in the ion-irradiated materials suggests an existence of DGE.

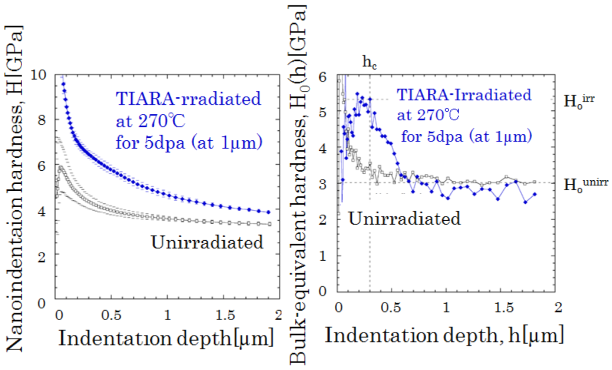

Fig. 1 (left) Depth dependence of nanoindentation hardness of F82H-1Ni before and after ion-irradiation.
Fig. 2 (right) The bulk-equivalent hardness of F82H-1Ni shown in Fig. 1.

4. Conclusion

Thus, we have successfully developed a new model to evaluate the depth-dependent bulk-equivalent hardness of ion-irradiated materials. Further advance on utilizing nanoindentation method will be shown in the conference.

Reference

[1] R. Kasada, Y. Takayama, K. Yabuuchi, A. Kimura, Fusion Eng. and Des., 86 (2011) 2658–2661.