3 - 19 Investigation of Nano-hardness of T91 Steel under Fe-ions Irradiation

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Ferritic/martensitic (F/M) steels are considered as candidate structural materials in advanced nuclear reactors. Since the self-ion irradiation causes only displacement damages without introducing foreign atoms, it can be then used as a useful method to screen candidate materials in their irradiation characters to simulate the displacement damages induced by neutron irradiation in the materials. In this paper, the nano-hardness of F/M steel T91 irradiated with Fe-ions was investigated by using nano-indentation technology.

The Fe-ions irradiation experiments were performed on the 320 kV multi-discipline research platform for Highly Charged Ions in Institute of Modern Physics, Lanzhou, China. The T91 steel samples with $15\times15\times1$ mm^3 in size were irradiated with 3.25 MeV Fe-ions to fluence of 2.7×10^{15} and 1.4×10^{16} ions/cm^2 at room temperature (RT) and 450℃, respectively, which correspond to the estimated displacement levels of 3 and 16 dpa at a damage peak according to the SRIM2008 code. The main parameters for the irradiation experiments are summarized in Table 1. After irradiation, the irradiated samples were analyzed by using nano-indentation technology with Nano Indentor G200 in a mode of continuous stiffness measurement (CSM).

Table 1 Irradiation parameters

No.	Ion	Energy(MeV)	T(℃)	Dose(ions/cm^2)	Peak damage level(dpa)
1#	Fe	3.25	RT	2.7×10^{15}	3
2#	Fe	3.25	RT	1.4×10^{16}	16
3#	Fe	3.25	450	2.7×10^{15}	3
4#	Fe	3.25	450	1.4×10^{16}	16

* 0# is the un-irradiated sample.

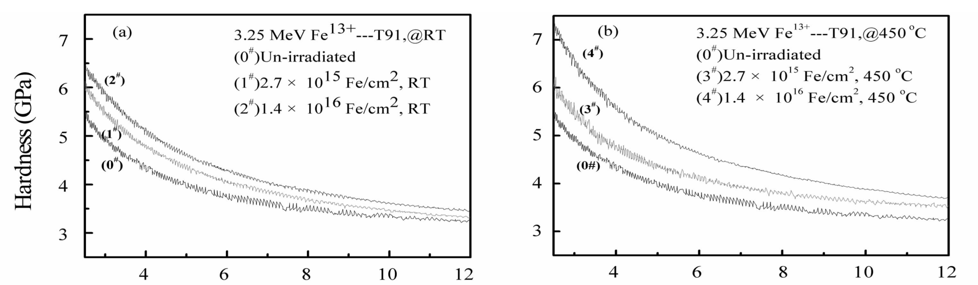

Fig. 1 Nano-hardness of T91 steel versus depth under different irradiation doses: a) RT, b) 450℃.

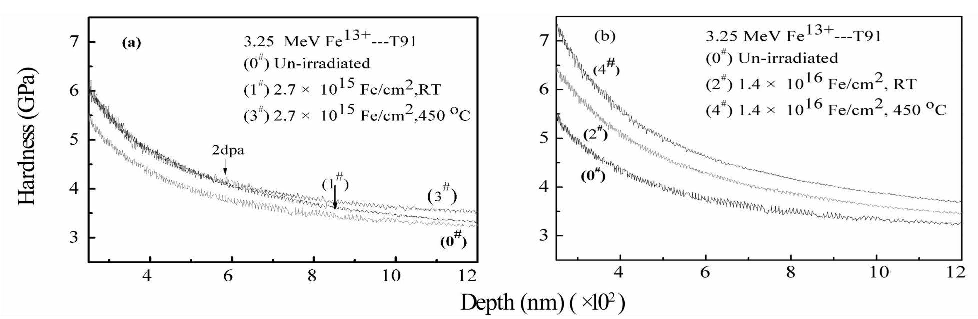

Fig. 2 Nano-hardness of F/M steel T91 versus depth under different irradiation temperature.

Figs. 1 and 2 give the curves of the nano-hardness values versus depth for the irradiated and un-irradiated samples. The results show that nano-hardness values of the irradiated samples are all higher than that of the un-irradiated sample. Moreover, the nano-hardness value of T91 steel increases with increasing irradiation dose both at RT and 450 ℃, as shown in Fig. 1(a) and (b). Fig. 2(a) shows that the nano-hardness values of irradiated steel to 2.7×10^{15} ions/cm^2 at different temperatures are almost the same within penetrated depth of ~600 nm. When the depth deeper than 600 nm, the nano-hardness value of the sample irradiated at 450 ℃ is higher than that at RT. Fig. 2(b) presents that the nano-hardness values of the samples irradiated to 1.4×10^{16} ions/cm^2 increase with increasing irradiation temperature.

When the irradiation fluence to 2.7×10^{15} ions/cm^2, the displacement damage induced by Fe irradiation is below 2 dpa according to estimated displacement levels by SRIM2008 at the depth of ~ 600 nm, meanwhile, the displacement damage level is higher at deeper region in sample. Therefore, it is suggested that irradiation temperature has little effect on the nano-hardness of the steel when the displacement damage level is below 2 dpa. With increasing irradiation temperature, the nano-hardness value of steel increases at the condition of higher displacement damage level. The nano-hardness is mainly related to the microstructure of the materials induced by irradiation, that is, the formation of point defects and defect clusters at different temperatures and dose.

In summary, irradiation hardening of T91 steel may be caused by the increment of irradiation fluence and temperature. Further investigations on the microstructural changes of T91 steel are undertaken.

3 - 20 Nano-hardness of T91 and SIMP Steels under Helium Ion Implantation at Different Temperatures

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The appearance of embrittlement is often accompanied with hardening. Irradiation induced defects (vacancies, interstitials, interstitial/dislocation loops, bubbles and so on) act as obstacles to pin the dislocations from moving, which results in the increase of hardening[1]. In the nuclear reactor, production rate of helium is high by (n, α) reaction and the transmutation production helium is detrimental to mechanical properties of structural materials at different ambient temperatures[2]. The low solubility of helium atoms in structural materials makes it easy to aggregate in sinks, resulting in bubbles, which contribute to the material hardness.

To investigate the temperature effects on irradiation hardening, we performed a series of experiments at 320 keV multi-discipline research platform for highly charged ions. The samples used in the experiments were T91 and SIMP steels that were implanted with 500 keV helium ions to 1.0×10^{17} He/cm^2 at room temperature (RT), 300, 450 and 550 (C, respectively. Then these samples were characterized by nano-indentation measurements. Typical results are shown in Figs. 1 and 2.

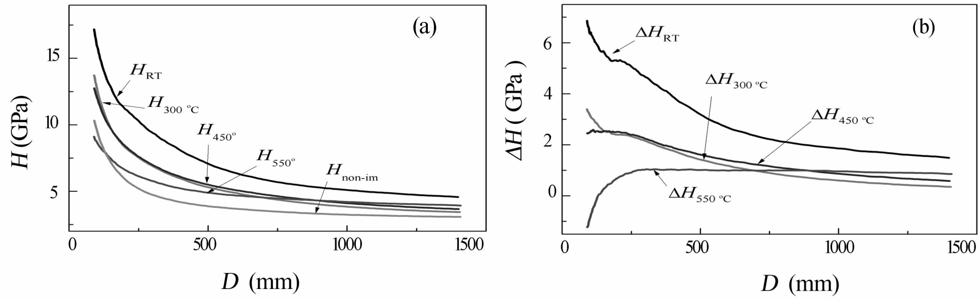

Fig. 1 Hardness H(a) and hardness increment ΔH(b) versus ion penetration depth D of T91 steel bombarded with 500 keV helium ions to 1.0×10^{17} He/cm^2 at room temperature (RT), 300, 450 and 550 ℃.