Effect of Irradiation Fluence on Tensile Properties in Ferritic/Martensitic Steel

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1. Introduction

Ferritic/martensitic steels are widely used as high temperature materials in the power plants and chemical industries due to their high strength and thermal conductivity, low thermal expansion, and good resistance to a corrosion.[1] Owing to the better irradiation characteristics (e.g. excellent irradiation swelling resistance) of these steels than austenitic alloys they have been receiving attention for an application to the fuel cladding or reactor pressure vessel of various advanced nuclear reactors.

The microstructure of ferritic/martensitic steels is changed by neutron irradiation. These irradiation-induced microstructural changes lead to lattice hardening, which causes an increase in the yield strength and ultimate tensile strength and a decrease in the elongation. The magnitude of the hardening changed with irradiation temperature and fluence. In the present work, we quantitatively evaluated the effect of neutron fluence on the irradiation hardening of FM steel.

2. Experimental Procedure

Chemical composition of 10Cr-Mo steel was 10wt%Cr-1.2wt%Mo-0.2V-0.02N. These steels were laboratory melted in a vacuum by an induction furnace. Heat treatment was carried out in vacuum furnace. The heat treatment consisted of austenitizing at 1050^{o}C for one hour followed by air cooling and tempering at 750^{o}C for two hours also followed by air cooling.

Table 1 Irradiation conditions

	Temperature (^{o}C)	Fluence (n/cm^2) (E>0.1MeV)
1st irradiation	320	1.1×10^{20}
2nd irradiation	300	6.4×10^{20}

1st irradiation test was carried out at IR2 test hole for 11 days and 2nd irradiation test was performed at CT test hole for 29 days in HANARO. Irradiation conditions of 1st and 2nd irradiation were shown in Table 1. 1st and 2nd irradiation temperature was about 320^{o}C and 300^{o}C, respectively. And 1st and 2nd irradiation fluence was 1.1×10^{20} n/cm^2 and 6.4×10^{20} n/cm^2, respectively. High temperature tensile tests after irradiation were performed at hot cell in IMEF. Tensile test temperature range was from room temperature to 600^{o}C. The strain rate was 2×10^{-3}/sec. After tensile test we observed the fracture surface of specimens with SEM.

3. Results and Discussion

3.1 Change of strength with irradiation fluence

Figure 1 shows the change of yield strength with irradiation fluence. Yield strength increased by neutron irradiation. As the tensile test temperature increased, the increase of strength by irradiation was gradually diminished. Eventually irradiation hardening effect completely disappeared at high temperature tensile test. As the irradiation fluence increased, the increment of yield strength also increased. The yield strength of irradiated 10Cr-Mo steel was nearly recovered at 500^{o}C in low irradiation fluence. But in high irradiation fluence, the yield strength was completely recovered at 600^{o}C. The increase of yield strength with irradiation was about up to 20% and 30% in low and high irradiation fluence, respectively.

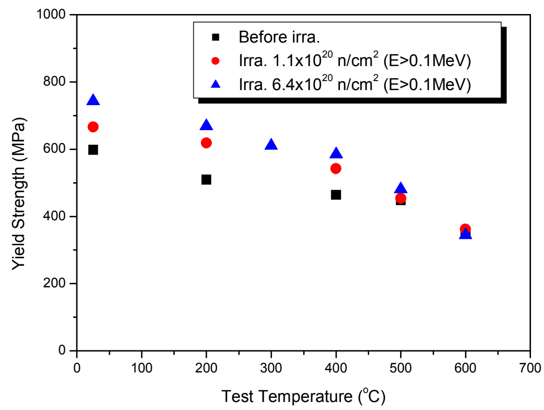

Fig. 1. Change of yield strength with neutron fluence

Figure 2 shows the change of tensile strength with irradiation fluence. The change of tensile strength was similar to the change of yield strength. But the increase of tensile strength with irradiation was about up to 7% and 12% in low and high irradiation fluence, respectively. So the increase of tensile strength with irradiation was lower than that of yield strength. The complete recovery of tensile strength was also occurred at 500^{o}C in low fluence. But the tensile strength was not completely recovered at 600^{o}C in high fluence.

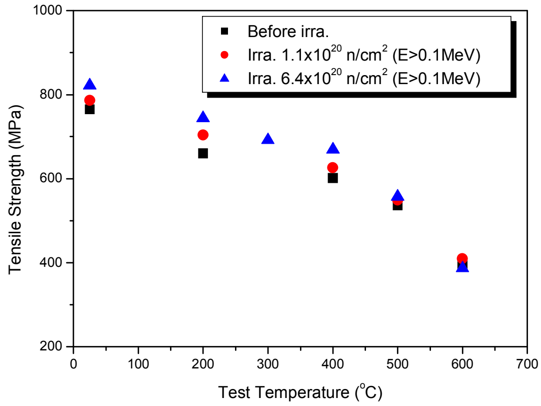

Fig. 2. Change of tensile strength with neutron fluence

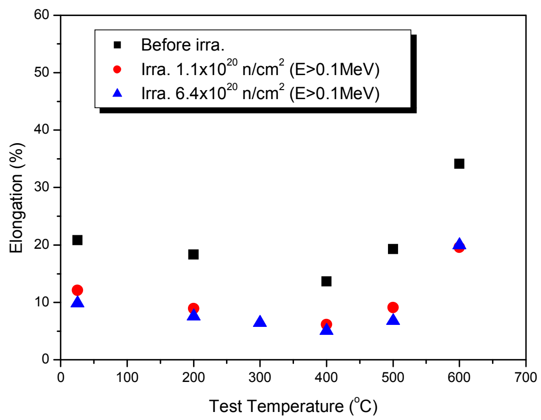

Fig. 3. Change of elongation with neutron fluence

3.2 *Change of elongation width irradiation fluence*

Figure 3 shows the change of elongation with irradiation fluence. Elongation was not recovered even though tensile test was carried out at 600°C. As the irradiation fluence increased, the reduction of elongation also increased. But the reduction of elongation with irradiation fluence was not larger than increase of strength with fluence. The decrease of elongation with irradiation was about up to 55% and 63% in low and high irradiation fluence, respectively.

Hardening is caused by irradiation-induced dislocation loops and precipitation. Irradiation-produced dislocation loops have their greatest effect for low-temperature irradiation, and irradiation-induced precipitation has its largest effect at high irradiation temperature. If the specimens are irradiation at high temperature, the vacancy and interstitial which generated by neutron irradiation can be mobile, and a part is eliminated by a one-to-one recombination and have a little effect on mechanical properties. So the irradiation hardening is reduced when the irradiation temperature is high.[2] Eventually hardening apparently disappeared at higher irradiation temperature regardless of neutron fluence. The hardening is also changed with irradiation fluence. The rapid hardening occurred at low fluence, after which it saturated with fluence at low temperature irradiation.[3] So significant irradiation hardening was observed at lower temperature and low damage level. These results suggest that the irradiation degradation in an early stage of irradiation is important. Irradiation fluence was 6.4×10^{20}n/cm^2 in our irradiation test until now. It is still very low. So we have an irradiation test plan to investigate the irradiation hardening behavior of 10Cr-Mo steel in early stage of irradiation by increasing the irradiation fluence and temperature.

4. Conclusion

The changes of tensile properties with irradiation fluence have been studied. The following conclusions were obtained:

As the irradiation fluence increase, the maximum increase of yield was changed from 20% to 30%, and the maximum increase of tensile strength was changed from 7% to 12%. The decrease of elongation was about up to 55% and 63% in low and high irradiation fluence, respectively. To add to the increase of irradiation fluence, the irradiation temperature of 2nd irradiation test is lower than that of 1st irradiation test. So an increase of strength and a decrease of elongation might be larger.

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