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Variations of Mechanical Properties Before and After a Irradiation of Type 304 and 316LN Stainless Steels

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1. Introduction

Type 304 and 316 austenitic stainless steels are used in the structural and core components of a PWR and a SFR (sodium-cooled fast reactor). These components are exposed to a neutron irradiation from the nuclear environment as well as high temperatures and pressures. Core structures of PWRs accumulate neutron fluences of 10^{20-22} n/cm^2 (E>0.1MeV), and the fuel elements of a SFR accumulate neutron fluences of up to 10^{23} n/cm^2 (E>0.1MeV) during a design life of over 20~30 years [1, 2]. It is known that the hardness and strength due to an irradiation are increased by irradiation defects, such as dislocations, voids, Frank loops, and precipitates, and that the ductility is decreased. Low ductility caused by an irradiation hardening considerably shortens the life of nuclear components. However, until now, the material behaviors due to a neutron irradiation are not well known, and the irradiation data is insufficient because of the relatively little work that has been performed [3].

In this study, mechanical properties before and after an irradiation are investigated for type 316NG (LN) and 304UC steels. The irradiated tensile properties are compared with the un-irradiated ones with temperature variations, and some changes of their values are presented.

2. Experimental

Chemical compositions of type 304UC and 316NG stainless steels in this study are listed in Table 1. Here, "NG" steel is developed at KAERI as a nuclear grade, containing a low carbon content (0.03C wt. %) and an appropriate amount of nitrogen (0.1N wt. %) [4], and "UC" steel is archive materials which were used for Ul-Chin (UC) 3/4 ho-gi of the KNPPs. Tensile specimens were fabricated with a pin-loaded plate type of a one-inch gage length, referring to the ASTM E8/E21 standard [5] and by considering the size effects. Tension tests were performed by remote control equipment in the IMEF hot cell of KAERI, while employing a strain rate of $2x10^{-3}$ /sec. Test temperatures were chosen as room temperature (R.T.), 200°C, 300°C, 400°C, 500°C, 600°C, and 700°C.

An irradiation test was performed with a 30MW output power at the CT hole of HNARO for 46 days, using the "04M-17U" capsule, designed and fabricated at KAERI. Type 304UC and 316NG specimens are embedded at 4 stages in the capsule. The specimens accumulated neutron fluences of about $4.4\sim5.6x10^{20}$ n/cm^2 (E>1.0 MeV) at 350°C.

Table 1 Chemical compositions of type 304UC and 316NG

	C	Si	Mn	P	S	Cr	Ni	N	Mo	Fe
316NG	0.021	0.70	0.97	0.021	0.006	17.3	12.34	0.10	2.36	Bal.
304UC	0.050	0.56	1.28	0.026	0.003	18.25	8.56	-	-	Bal.

3. Results and Discussion

Figs. 1 and 2 show typical results of the tensile stress and elongation for the type 316NG steel, respectively. The irradiated samples are higher in their stress and lower in their ductility than the un-irradiated ones, and especially the yield stress has increased considerably. However, above 500°C, the stress and elongation of the irradiated ones were almost the same as those of the un-irradiated ones. The reason for this is that the irradiation defects are recovered to a virginal state due to a thermal activation at the higher temperatures.

Fig. 3 shows the variations of the yield ratio (S_y/S_u) with temperatures for the un-irradiated and irradiated steels of type 316NG steel. Where, S_y is the yield stress and S_u the ultimate tensile stress. The irradiated ones are higher in their stress than the un-irradiated ones. It is clear that the strength was increased by an irradiation hardening. However, at 600°C, it is very apparent that the stress of the irradiated ones is almost overlapped to the un-irradiated ones.

Figs. 4 shows the comparative results of the strain hardening exponent, n with temperatures before and after irradiation for type 304UC steel. The n value was obtained by using the Hollomon type Eq. [6],

$$\sigma = K\varepsilon^n \quad (1)$$

The irradiated materials are lower in n values than the un-irradiated ones. The irradiated steel gradually approached to the un-irradiated one as the temperature increases. When reaching 600°C, the two values are almost similar. In addition, type 316NG showed higher n values in a comparison with type 304UC. In general, the n values are sensitive to a thermo-mechanical treatment; they are larger for materials in the annealed condition and smaller for those in the cold-worked state. The reason, for the n values of the irradiated ones being lower than the un-irradiated ones, is that the irradiated ones have a higher strength than the un-irradiated ones.

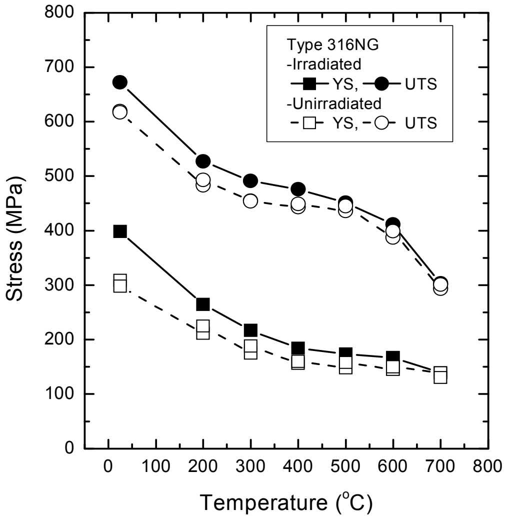

Figure 1. YS and UTS results with temperatures before and after irradiation of type 316NG stainless steel

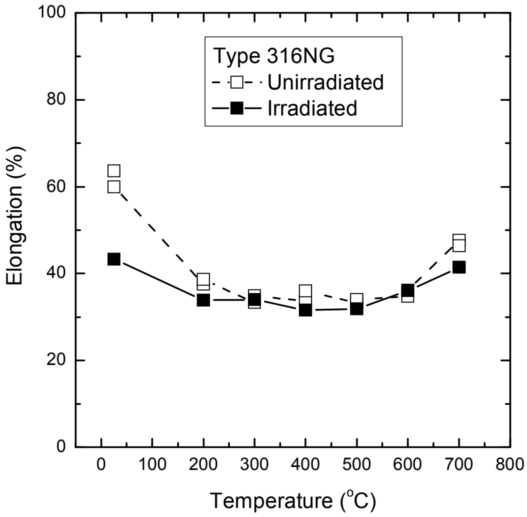

Figure 2. Comparison of tensile elongation with temperatures before and after irradiation of type 316NG stainless steel

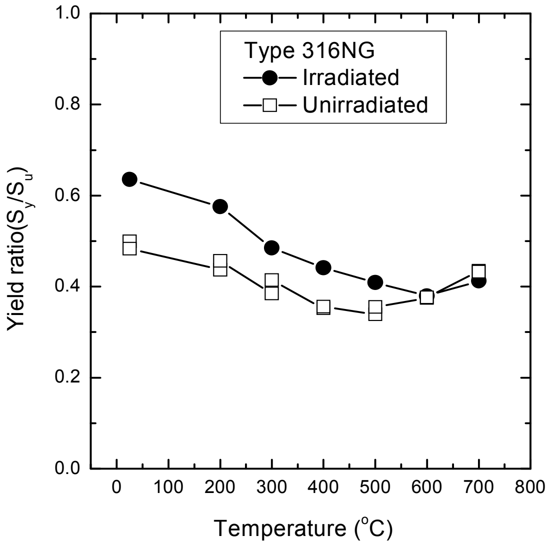

Figure 3. Comparison of yield ratio with temperatures before and after irradiation of type 316NG stainless steel

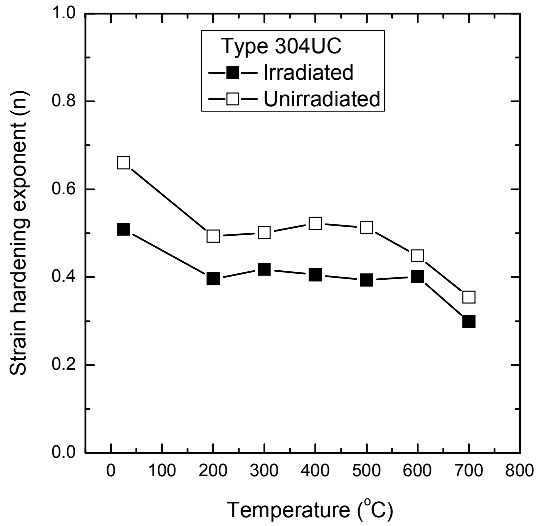

Figure 4. Comparison of strain hardening exponent with temperatures before and after irradiation of type 304UC stainless steel

3. Conclusion

Mechanical properties of irradiated type 304 and 316 stainless steels showed a typical irradiation hardening and low elongation, especially their yield strength was increased considerably. However, when reaching above 600°C, the strength of the irradiated materials was almost recovered to that of the un-irradiated ones. Also, the strain hardening exponent of the irradiated ones was lower than that of the un-irradiated ones, but as the temperature increases, the irradiated ones approached the un-irradiated ones. The reason for this is the recovery of the irradiation defects due to a thermal activation at a higher temperature.

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