Material: Ferritic Steel: F82H
Property: Yield Stress & Radiation Hardening
Condition: Irradiated
Data: Experimental

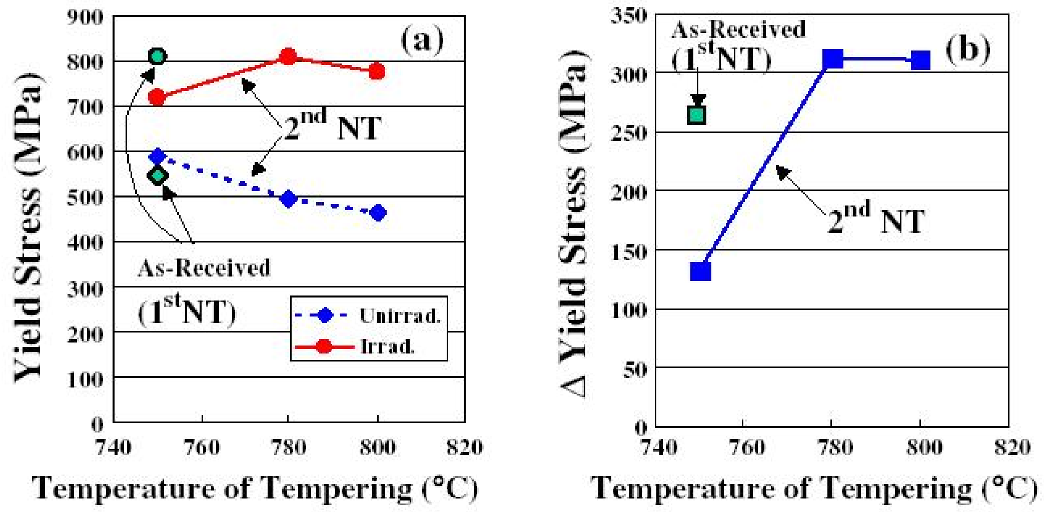

Fig. 1. Yield stress (a) and radiation hardening (b) of F82H tempered at 750, 780 and 800 °C for 0.5 h and irradiated at about 250 °C to 1.9 dpa in the JMTR.

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Effect of Tempering Temperature and Time on Tensile Properties of F82H Irradiated by Neutrc

Author of paper or graph:
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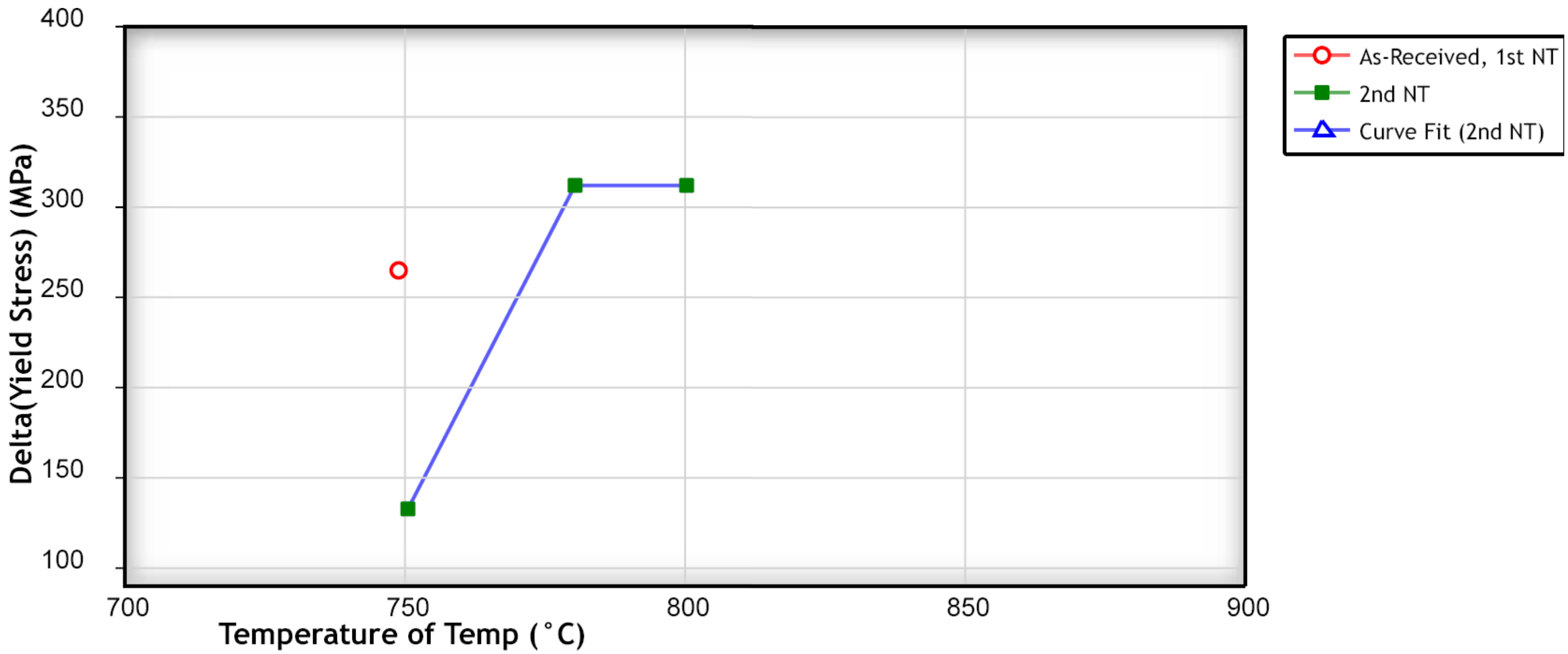

Radiation hardening of F82H tempered at 750, 780, and 800°C for 0.5 h and irradiated at about 250°C to 1.9 dpa in the JMTR.

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X-Scale: ◉ linear ○ log ○ ln

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Effect of tempering temperature and time on tensile properties of F82H irradiated by neutrons

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Abstract

The dependence of tensile properties on tempering time and temperature was examined for a martensitic steel F82H irradiated at 250 °C to a neutron dose of 1.9 dpa in the Japan Materials Testing Reactor. The specimens were first normalized at 1040 °C for 0.5 h and tempered at 750 °C for 1 h. A second heat treatment was performed at temperatures from 750 to 800 °C for 0.5 h after the normalizing at 1040 °C for 0.5 h. The second tempering time at 750 °C was varied from 0.5 to 10 h. The tensile specimens of F82H + 2Ni, pure iron and Fe + 0.1C were also irradiated. Tensile tests were carried out at room temperature. The radiation hardening of F82H was significantly relieved by the second heat treatment, and it was smaller than that of the first heat treated other steels. The radiation hardening depended on the tempering conditions and tended to increase with increasing the temperature and time of tempering.

1. Introduction

Reduced-activation ferritic/martensitic steels are candidate materials for the blanket structure of fusion reactors. Radiation hardening of 9%Cr martensitic steels irradiated by neutrons occurs mainly at irradiation temperatures lower than about 400 °C, and it increases with decreasing irradiation temperature down to 250 °C [1,2]. The shift of DBTT also increases with decreasing irradiation temperature, and the shift increases largely for irradiation at 250 °C [3,4]. Several researchers [1–7] reported that the increase of yield strength and the shift of DBTT were different in several martensitic steels, such as F82H, JLF-1, JLF-1B, ORNL 9Cr-2WVTa, OPTIFER Ia, II, MANET II and Mod.9Cr-1Mo, which had different concentrations in some elements and were tempered at different temperatures. The effects of the normalizing and tempering of heat treatment on tensile and impact behavior in martensitic steels before irradiation were reported by Schafer [8] and Gondi [9]. However, the mechanisms of the changes of yield strength and DBTT due to irradiation in these martensitic steels are not clear, and it is necessary to reveal the effects of heat treatment and impurities on them. The optimum heat treatment will be required to improve resistances to radiation hardening and embrittlement. In this study, the dependence of tensile behavior on tempering time and temperature has been examined for martensitic steel F82H (Fe–8Cr–2W–0.2V–0.04Ta–0.1C) irradiated at 250 °C to a neutron dose of 1.9 dpa.

2. Experimental

The chemical compositions of F82H, F82H + 2Ni, Fe + 0.1C and pure iron used in this study are shown in Table 1. The specimens were first normalized at 1040 °C for 0.5 h and tempered at 750 °C for 1 h. A second heat treatment was performed on the F82H steel, which was secondly normalized at 1040 °C for 0.5 h and tempered at temperatures of 750, 780 and 800 °C for 0.5 h. The tempering time at 750 °C was varied between 0.5 and 10 h. SS-3 tensile specimens were prepared from the

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Table 1
Chemical compositions of the specimens used in this study (wt%)

Alloy	C	Sol. Al	Si	Mn	P	S	V	Ti	Cr	Ni
F82H	0.09	0.001	0.07	0.1	0.003	0.001	0.19	0.004	7.82	0.02
F82H + 2Ni	0.097	<0.001	0.10	0.11	0.003	0.0025	0.19	0.005	7.92	1.97
Fe	0.0019	–	<0.001	<0.0001	0.0003	0.0003	–	–	–	0.0020
Fe–0.1C	0.10	–	<0.001	<0.0001	0.0004	0.0002	–	–	–	<0.0001

Alloy	Cu	Nb	Ta	W	B	O	N
F82H	0.01	0.0002	0.04	1.98	0.0002	–	0.007
F82H + 2Ni	–	–	0.06	1.99	–	–	0.0036
Fe	0.0007	–	–	–	0.00002	0.0059	0.0002
Fe–0.1C	0.0023	–	–	–	0.00003	0.0015	0.0002

normalized and tempered F82H, F82H + 2Ni, Fe + 0.1C and pure iron. The SS-3 sheet tensile specimens were 0.76 mm thick with a gage length of 7.6 mm. Irradiation was carried out in the Japan Materials Test Reactor (JMTR) to neutron fluences of 1.2×10^{21} n/cm^2 ($E > 1$ MeV) and 2.2×10^{21} n/cm^2 ($E < 0.5$ MeV), resulting in a displacement damage value of 1.9 dpa. Capsule 00M-61A, nominally at 250 °C, was a shrouded type with reactor coolant flowing over an aluminum cladding tube containing the specimens; gamma-heating was used to raise the specimen temperature. After irradiation, tensile testing was carried out in air at room temperature at a strain rate of 4.4×10^{-4}/s.

3. Results

The changes of tensile properties with tempering temperature and time in F82H steel irradiated at 250 °C to 1.9 dpa are also shown in Figs. 1 and 2. The summary of tensile data of the irradiated and non-irradiated specimens is given in Table 2. The yield stress and the increment of yield stress caused by irradiation, radiation hardening, in F82H tempered at 750, 780 and 800 °C for 0.5 h are shown in Figs. 1(a) and (b), respectively. The yield stress of F82H steel tempered at 780 and 800 °C was lower than that tempered at 750 °C before irradiation, but the former was slightly higher than the latter after irradiation. As a result, the radiation hardening of F82H steel tempered at 780 and 800 °C was about twice as large as that of F82H steel tempered at 750 °C. Radiation hardening of F82H steel heated by the first normalizing and tempering (N&T) treatment was considerably larger than that by the second N&T treatment. The loss of ductility due to irradiation was recovered by the second N&T treatment from 5.4% to 3.6%. In Fig. 2, the dependence of yield stress on time of tempering in F82H steel tempered at 750 °C was given, and the increment of yield stress largely changed between 1 and 2 h for the time of tempering. The change of yield stress of the irradiated pure iron, Fe + 0.1C, F82H and F82H + 2Ni is given in Fig. 3. The radiation hardening of F82H steel was comparable to that of pure iron and Fe–0.1C alloy, but the radiation hardening of F82H + 2Ni increased. The loss of ductility of pure iron and Fe + 0.1C largely occurred. The ability to strain harden was completely lost for pure iron (UE ~ 0.1%) and was very low for F82H (UE: from 0.1 ~ 0.5%) and relatively high for Fe + 0.1C (UE ~ 1.2%) and F82H + 2Ni (UE ~ 8.3%).

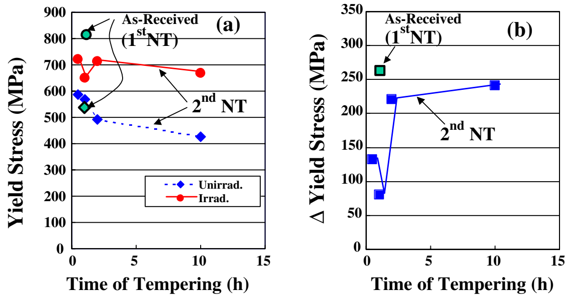

Fig. 2. Changes of yield stress (a) and radiation hardening (b) of F82H, tempered at 750 °C for 0.5, 1, 2 and 10 h and irradiated at about 250 °C to 1.9 dpa in the JMTR.

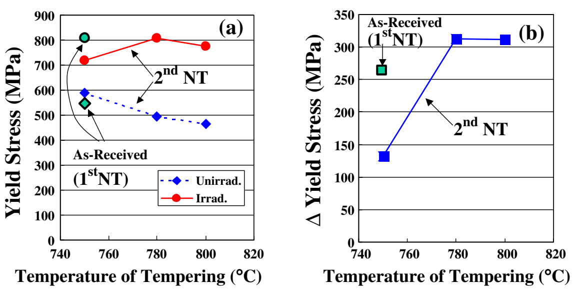

Fig. 1. Yield stress (a) and radiation hardening (b) of F82H tempered at 750, 780 and 800 °C for 0.5 h and irradiated at about 250 °C to 1.9 dpa in the JMTR.

Table 2
Summary of tensile properties of F82H, F82H + 2Ni, pure iron and Fe–0.1C tested at room temperature

Alloys	Tempering temperature (°C)	Tempering time (h)	Irradiation (°C, 1.9 dpa)	Test temperature (°C)	YS (MPa)	UTS (MPa)	UE (%)	TE (%)
F82H	750	0.5	250	25	760	786	0.5	12.9
F82H	750	1	250	25	708	708	0.4	13.0
F82H	750	2	250	25	786	786	0.3	12.3
F82H	750	10	250	25	725	725	0.1	11.2
F82H	780	0.5	250	25	872	872	0.4	9.7
F82H	800	0.5	250	25	846	846	0.1	9.7
F82H	750*	1*	250	25	812	812	0.3	10.5
F82H + 2Ni	750*	1*	250	25	1390	1468	1.2	6.7
Fe	750*	1*	250	25	250	250	0.1	11.5
Fe + 0.1C	750*	1*	250	25	310	363	8.3	19.0
F82H	750	0.5	–	25	588	685	5.0	15.8
F82H	750	1	–	25	569	663	5.5	16.6
F82H	750	2	–	25	492	608	7.0	18.5
F82H	750	10	–	25	428	562	11.0	25.1
F82H	780	0.5	–	25	494	614	7.4	19.6
F82H	800	0.5	–	25	464	592	8.7	21.0
F82H	750*	1*	–	25	548	652	5.5	15.9
F82H + 2Ni	750*	1*	–	25	671	802	4.9	14.3
Fe	750*	1*	–	25	83.2	170.2	30.6	48.3
Fe + 0.1C	750*	1*	–	25	121	279	31.2	48.0

The symbol * indicates the first normalizing and tempering (N&T) heat treatment (the first N&T: 1040 °C for 0.5 h and 750 °C for 1 h). No symbol * shows that the second N&T heat treatment was performed after the first N&T (the second normalizing: 1040 °C for 0.5 h).

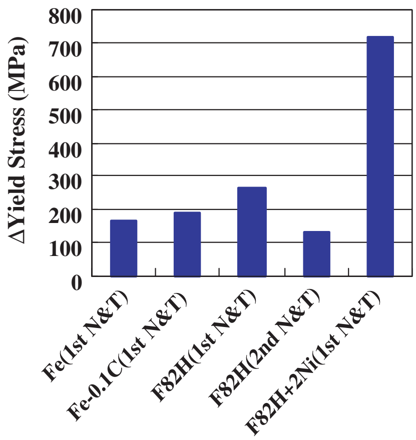

Fig. 3. Radiation hardening of pure Fe, Fe–0.1C and F82H + 2Ni tempered at 750 °C for 1 h and irradiated at about 250 °C to 1.9 dpa in the JMTR.

4. Discussion

Microstructures of martensitic steels, such as dislocations, carbides and lath width, depend strongly on the temperature and time of tempering. The density of dislocations of F82H decreased with increasing temperature and increasing time of tempering [10]. The concentration of carbon in solution in the matrix will increase with tempering temperature and time. In the specimen tempered at higher temperatures, the sink density for point defects due to dislocations becomes lower and the formation of dislocation loops may increase and the growth rate of dislocation loops will increase. The mobility of interstitial atoms in martensitic steels will be reduced with increasing an concentration of carbon in solution, and the formation of dislocation loops will also increase. Radiation hardening can be evaluated by Orowan's theory for athermal bowing of dislocations around obstacles on a slip plane [11–13] and depends on the number density and size of defect clusters. The changes of sink density and the concentration of carbon in solution can affect the formation and growth of dislocation loops, and, therefore, radiation hardening should depend on the temperature and time of tempering.

As shown in Figs. 1 and 2, the radiation hardening of F82H was reduced by the second N&T treatment, however, the reason for the difference in radiation hardening between the first N&T and second N&T can not be exactly explained by that alone, and it needs further investigation.

The effects of tempering in martensitic steel on radiation hardening were also investigated by a micro-indentation technique using specimens irradiated with high-energy ions up to high dose levels [14]. The initial microstructures related to tempering conditions also affected the swelling behavior [10,15,16], and therefore the control of tempering conditions is a very important to provide the steels high resistances to radiation hardening, radiation embrittlement and swelling.

5. Conclusion

The dependence of tensile properties on tempering time and temperature and microstructures resulting from different heat treatments were examined for a martensitic steel F82H (Fe–8Cr–2W–0.2V–0.04Ta–0.1C) irradiated at 250 °C to 1.9 dpa in JMTR. The results showed that radiation hardening depended on the tempering conditions. The tempering conditions in this experiment are in the regime of standard heat treatment for martensitic steels, and it is thought to be an effective method to provide the steels high resistances to radiation hardening and embrittlement.

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