FRACTURE SURFACE OF A REDUCED-ACTIVATION MARTENSITIC STEEL IRRADIATED IN HFIR - N. Hashimoto (Oak Ridge National Laboratory), H. Tanigawa (Japan Atomic Energy Research Institute), K. Shiba (JAERI), and R.L. Klueh (ORNL)

OBJECTIVE

The objective of this effort is to provide information of postirradiation deformation mechanisms controlling in ferritic/martensitic steels

SUMMARY

A reduced activation ferritic/martensitic steel, F82H (IEA heat), developed for fusion energy applications was irradiated at 300 and 500°C to 5 dpa in the High Flux Isotope Reactor (HFIR). In order to investigate test temperature and strain-rate effects on deformation mode, fracture surfaces were examined by scanning electron microscopy (SEM). Changes in yield strength, deformation mode, and strain-hardening capacity were seen, with the magnitude of the changes dependent on irradiation temperature. Irradiation at 300°C led to a significant loss of strain-hardening capacity with a large change in yield strength. Irradiation at 500°C had little effect on strength. The fracture surface of the specimens irradiated at 500°C and 300°C in tests at –100°C with a strain rate of $1x10^{-4}$ s^{-1} showed a martensitic mixed quasi-cleavage and ductile-dimple fracture in the center. On the other hand, in the specimen irradiated at 300°C, tensile test at –100 °C with a strain rate of $1x10^{-1}$ s^{-1} resulted in brittle (cleavage) fracture.

PROGRESS AND STATUS

Introduction

For structural applications in fusion energy systems, the ferritic/martensitic steels have several advantages based upon their resistance to void swelling, good thermal stress resistance, and well-established commercial production and fabrication technologies. Ferritic/martensitic steels, however, undergo radiation-induced hardening during neutron irradiation at temperatures up to 400°C, with a transition to fluence-dependent radiation softening at temperatures above 400-450°C. Radiation hardening is often accompanied by a reduction in strain-hardening capacity and uniform elongation, an increase in the temperature delineating the transition from quasi-cleavage to ductile fracture, and increased propensity for brittle failure under certain combinations of temperature and loading conditions. In order to investigate test temperature and strain rate effects on deformation mode, scanning electron microscopy (SEM) was performed on tested (fractured) tensile specimens of irradiated reduced activation F82H (IEA heat).

Experimental Procedures

The material studied was F82H (IEA heat), austenitized at 1040°C for 38 minutes, air cooled, and tempered at 750°C for 60 minutes. The chemical composition of the F82H (IEA heat) is shown in Table 1. SS-3 sheet tensile specimens with gage section of 7.62 mm x 0.76 mm x 1.5 mm were irradiated in the HFIR RB-11J and -12J capsules with europium thermal neutron shields for neutron spectrum tailoring. Irradiation conditions for these capsules are summarized in Table 2, and further information on the experiment can be found elsewhere [2-5]. Using an Instron universal testing machine for the tensile testing, the specimens irradiated at 300 and 500°C were tested at –100 °C with strain rates of $1x10^{-1}$ s^{-1} and $1x10^{-4}$ s^{-1}. The 0.2% offset yield strength (YS), ultimate tensile strength (UTS), uniform elongation (E_U), and total elongation (E_t) were

calculated from the engineering load-elongation curves. Following deformation, the specimens were examined using SEM to investigate the fracture surfaces.

Table 1. Chemical composition of F82H-IEA (wt.%) (Balance Fe).

	Cr	W	V	Ta	Mn	Al	C	B	Si	P	S	N
82H (IEA heat)	7.71	1.95	0.16	0.02	0.16	0.003	0.090	0.0002	0.11	0.002	0.002	0.006

Table 2. Summary of irradiation conditions.

Capsule		Nominal Irradiation Temperature (°C)	Neutron fluence (n/cm^2) Thermal (E<0.5eV)	Neutron fluence (n/cm^2) Fast (E>0.1MeV)	Dose (dpa)	He (appm)
11J	Shielded	307±19	1x10^{21}	1x10^{22}	4.5~4.8	3
12J	Shielded	497±22	1x10^{21}	1x10^{22}	4.7~4.8	3

Results and discussion

Tensile Behavior

Stress-strain curves of F82H (IEA heat) irradiated at 300 and 500°C in tests at –100°C at two strain rates are shown in figure 1. The tensile test data are summarized in Table 3. The irradiation at 300°C led to significant hardening and loss of strain-hardening capacity. The specimen irradiated 300°C in test with a strain rate of 1x10^{-1} s^{-1} showed brittle failure, while, the test with a strain rate of 1x10^{-4} s^{-1} resulted in ductile fracture. In contrast, the specimens irradiated at 500°C did not show irradiation hardening or degradation in ductility.

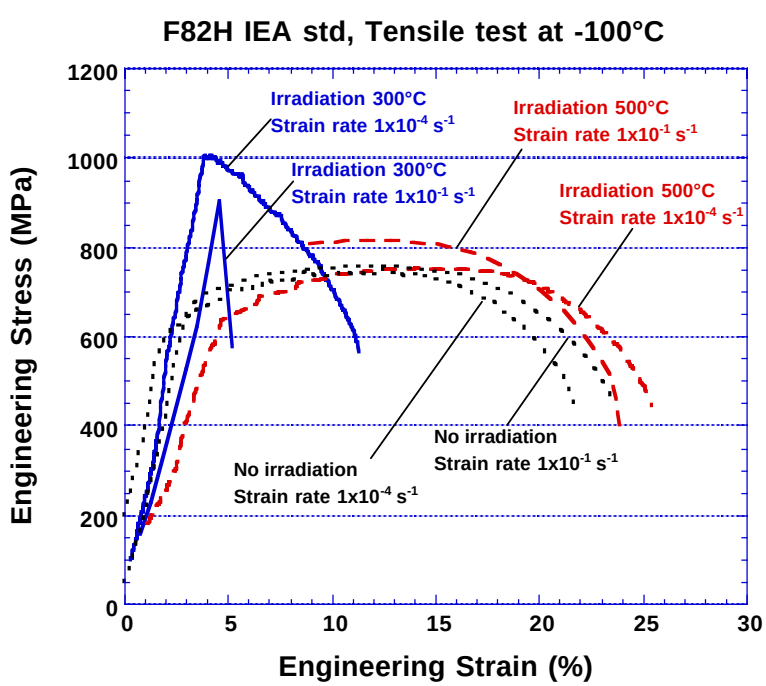

Fig. 1. Stress-strain curves of F82H-IEA irradiated at 300 and 500°C and tested at –100°C.

Table 3 Summary of tensile test at –100°C

ID	Dose (dpa)	Irr. Temp. (°C)	Test Temp. (°C)	Strain Rate (s^{-1})	YS (MPa)	UTS (MPa)	E_u (%)	E_t (%)	Remark
A048	-	-	-100	$1x10^{-4}$	571	742	10	20.1	
A050	-	-	-100	$1x10^{-1}$	664	758	7.0	20.5	
A008	4.5	307±19	-100	$1x10^{-4}$	1002	1002	0.2	7.2	
A012	4.8	307±19	-100	$1x10^{-1}$	903	903	0	0	Brittle
A029	4.7	497±22	-100	$1x10^{-4}$	651	752	8.9	20	
A031	4.8	497±22	-100	$1x10^{-1}$	-	814	-	-	Ductile

A008
Irr. 300°C

Tested
-100°C
1×10^{-4} s^{-1}

A012

Irr. 300°C

Tested
-100°C
1×10^{-1} s^{-1}

A029

Irr. 500°C

Tested
-100°C
1×10^{-4} s^{-1}

A031

Irr. 500°C

Tested
-100°C
1×10^{-1} s^{-1}

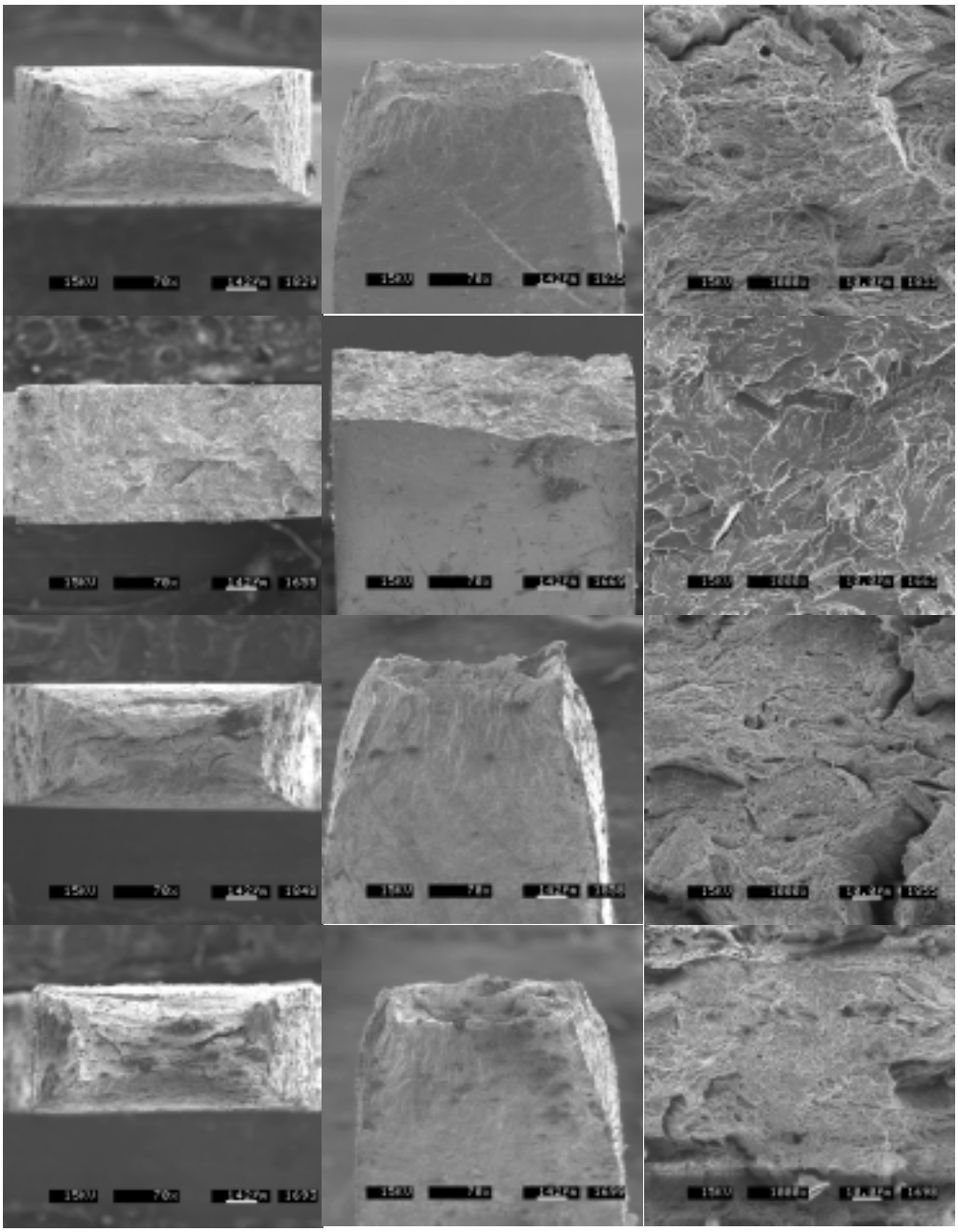

Figure 3. Fracture surfaces of irradiated specimens tensile-tested at -100°C with strain rates of $1x10^{-4}$ and $1x10^{-1}$ s^{-1}.

Fracture Surface Features

Fracture surfaces of the specimens irradiated at 300 and 500°C in tests at -100°C with strain rates of $1x10^{-4}$ and $1x10^{-1}$ s^{-1} are shown in figure 3. At lower magnification, it can be shown that strain of A008, A029 and A031 is very localized following irradiation. The grain size is on the order of 100 μm, and each grain contains slip steps appearing as wavy lines. At higher magnification, fracture surfaces of A008, A029 and A031 showed a typical martensitic mixed quasi-cleavage and ductile-dimple fracture in the center. The sizes of large and small dimples were about 4-5μm and 0.5μm, respectively. As shown in figure 1, the specimen irradiated at 300°C showed a loss of strain-hardening capacity with a large change in yield strength compared with 500°C. However, the fracture surface of the specimens irradiated at 300°C showed similar fracture features as specimens irradiated at 500°C. Hashimoto *et al.* reported similar tensile behavior and fracture surfaces in the irradiated F82H-IEA tested at 25°C [5], TEM observation for the specimens suggested that irradiation-induced dislocation loops are responsible for the irradiation hardening, and dislocation channeling appears to be the dominant deformation mechanism. For a specimen irradiated at 500°C, there was little effect of irradiation on the tensile behavior and little change in microstructure, indicating a change in the deformation process with temperature.

Shiba *et al.* reported that the strain-rate effect on tensile behavior in F82H-IEA [6] tested at 25°C at $1x10^{-4}$ and $1x10^{-2}$ s^{-1} showed an increase in yield stress and a decrease in elongation with increasing strain rate. The specimens irradiated at 500°C did not exhibit any change in strength, although the slowest strain rate produced less total elongation. In the present experiment, the change of strain rate did not affect yield stress and elongation, but fracture mode was effected. As seen in figure 3, the fracture surface of the A012, irradiated at 300°C in tests at –100°C with a strain rate of $1x10^{-1}$ s^{-1}, showed transgranular cleavage fracture with some splitting (figure 2), meaning faster strain rate led to brittle fracture.

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