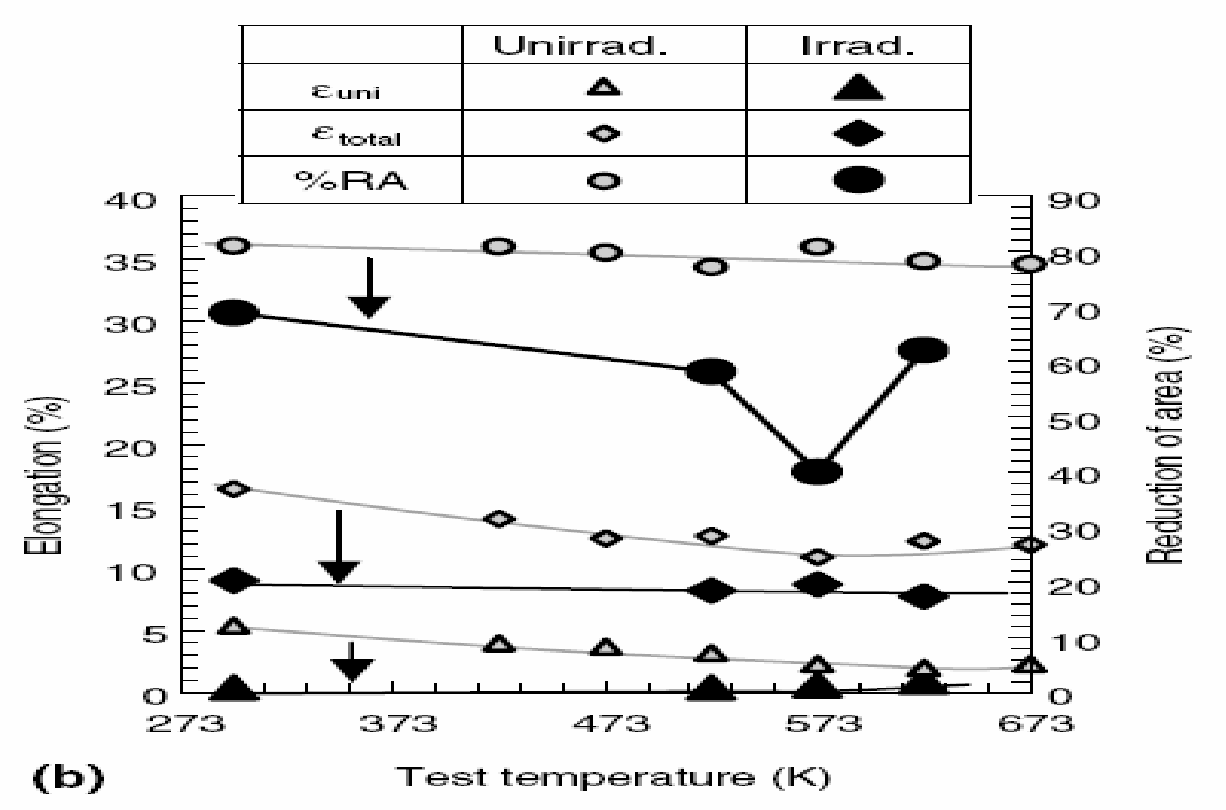
Material: Ferritic Steel: F82H
Property: Test temperature (K) versus Reduction of Area (%)
Condition: Irradiated and unirradiated
Data: Experimental



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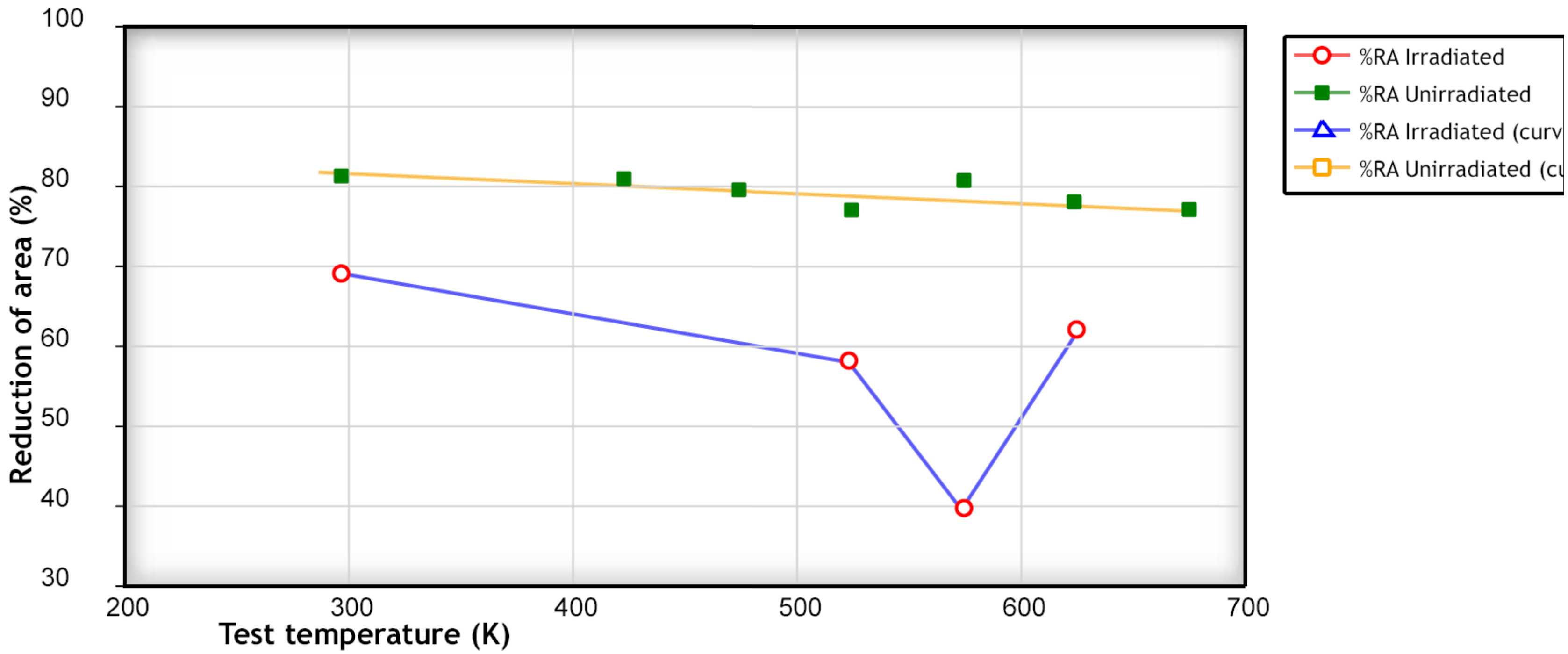
Journal of Nuclear Materials, 329-333, 2004, 1098-1102

Title of paper (or report) this figure appeared in:
Fatigue properties of F82H irradiated at 523K to 3.8 dpa

Author of paper or graph:
Yukio Miwa, Shiro Jitsukawa and Minoru Yonekawa

Caption:
Test temperature dependence of ductility of irradiated and unirradiated F82H.
Note: This is figure 2 of 2 providing the reduction of area data.



Test temperature dependence of ductility of irradiated and unirradiated F82H. Note: This is figure 2 of 2 providing the reduction of area data.

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Plot Format:

Y-Scale: ◉ linear ○ log ○ ln
X-Scale: ◉ linear ○ log ○ ln

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Fatigue properties of F82H irradiated at 523 K to 3.8 dpa

Yukio Miwa *, Shiro Jitsukawa, Minoru Yonekawa

Department of Materials Science and Engineering, Japan Atomic Energy Research Institute, Shirakata-Shirane 2-4, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan

Abstract

Fatigue properties were examined on a reduced activation ferritic/martensitic steel (F82H), and preliminary results are presented. F82H steel was irradiated at 523 K to 3.8 dpa, and then fatigue-tested at 298–573 K in vacuum with total strain range of 0.4–1.0%. The fatigue life of the irradiated specimen tested at 298 K with total strain range of 0.4% was revealed to be reduced to about 1/7 of that for the unirradiated specimen. The reduction of the fatigue life was attributed to the change of the fatigue mechanism to the channel fracture. The effect of test temperature is also discussed.

1. Introduction

Irradiation effect on the fatigue properties of the structural materials is one of the concerns for the designing of the fusion devices, since the in-vessel components will be exposed to a high heat flux from the plasma. Reduced activation ferritic/martensitic steels (RAF/Ms) are recognized as the primary candidate alloys for the structures. F82H is one of the RAF/Ms being rather well characterized [1]. Effect of irradiation on the fatigue properties of RAF/Ms have been reported in several researchers, however the damage levels were limited (below 1 dpa) [2–10]. The first wall/blanket structure will be irradiated over 1 dpa. Therefore we have examined the fatigue properties of F82H irradiated to a higher dose level.

2. Experimental procedures

The material used was F82H-IEA heat [1] which was normalized at 1313 K for 38 min and tempered at 1023 K for 1 h. The size of prior austenitic grains was about 100–200 μm. The material was machined into the fatigue specimens with a gage section 4 mm in diameter and 6 mm in length (Fig. 1). Fins were formed at the both ends of the gage section of the fatigue specimen. They were used to measure the axial stains by the laser extensometer during the tests [11,12]. For tensile tests, sheet type specimens with 7.86 mm gage length, 1.54 mm width and 0.76 mm thickness were also prepared from the material. The fatigue specimens were irradiated at 523 K for 9308.7 h in Japan Research Reactor No. 3 (JRR-3) at Japan Atomic Energy Research Institute. Fluence of fast and thermal neutrons were 2.6×10^{25} n/m^2 ($E > 1$ MeV) and 7.0×10^{25} n/m^2 ($E < 0.68$ eV), respectively, which corresponded to about 3.8 dpa. The tensile specimens were irradiated at 493 K to 3.4 dpa at JRR-3.

Uniaxial strain-controlled constant strain range fatigue tests were performed in vacuum at temperatures of 298, 523 and 573 K. Specimens were subjected to a fully reversed triangular strain versus time program, beginning with tension, at a strain rate of 0.1%/s. Axial strain ranges were 0.4–1.0%. The stress–strain hysteresis loops were periodically recorded during testing. The fatigue life (N_f) was defined as the number of cycles at which the tensile stress decreased to 75% of the saturated tensile stress during testing. The plastic strain range and cyclic stress during testing were measured from the hysteresis loop at 1/2 N_f. Tensile tests were also conducted at 298,

* Corresponding author. Tel.: +81-29 282 6082; fax: +81-29 282 6122.

E-mail address: miway@popsvr.tokai.jaeri.go.jp (Y. Miwa).

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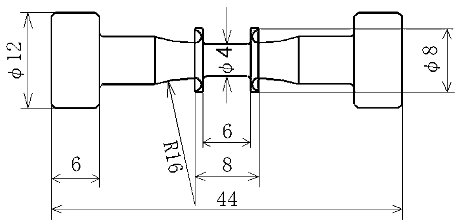

Fig. 1. Profile of fatigue specimen (unit: mm).

523, 573 and 623 K at a strain rate of 0.01%/s in vacuum. After the tests, fracture surface was observed using a scanning electron microscope (SEM).

3. Results

3.1. Tensile tests

Fig. 2 shows the test temperature dependence of (a) strength and (b) ductility of unirradiated and irradiated F82H. As seen in Fig. 2(a), the 0.2% offset stress ($\sigma_{0.2}$) and ultimate tensile strength (UTS) were increased by irradiation and were comparable to each other. The $\sigma_{0.2}$ and UTS monotonically decreased with increasing test temperature. Uniform and total elongations were decreased by the irradiation. The dependence on test temperature of the uniform and total elongation was small. Reduction of area (%RA) was also decreased by irradiation, and larger loss of the %RA was observed at test temperature of 573 K. Ductile fracture was observed in all specimens.

3.2. Fatigue tests

Testing of the planned matrix is not complete at this time, especially for the irradiated specimens at 573 K. The relationship between fatigue life (N_f) and total strain range ($\Delta\varepsilon_t$) for unirradiated and irradiated specimens are shown in Fig. 3. The fatigue life curve of unirradiated F82H was also indicated in the figure [13]. Except for the data on the irradiated specimen which was fatigue-tested at 298 K with $\Delta\varepsilon_t$ of 0.4%, the plotted data of N_f was in the range of 0.5–2 N_f of the curve. Large reduction of N_f was observed for the irradiated specimen. The N_f of the irradiated specimen was reduced to about 1/7 that of unirradiated specimen [13].

Fig. 4 shows the relationship between N_f and plastic strain range ($\Delta\varepsilon_p$). Tensile data were also plotted according to the Manson–Coffin formula (1):

$$N_f^k \Delta\varepsilon_p = \frac{1}{2} \ln\left(\frac{1}{1-\%\text{RA}}\right), \qquad (1)$$

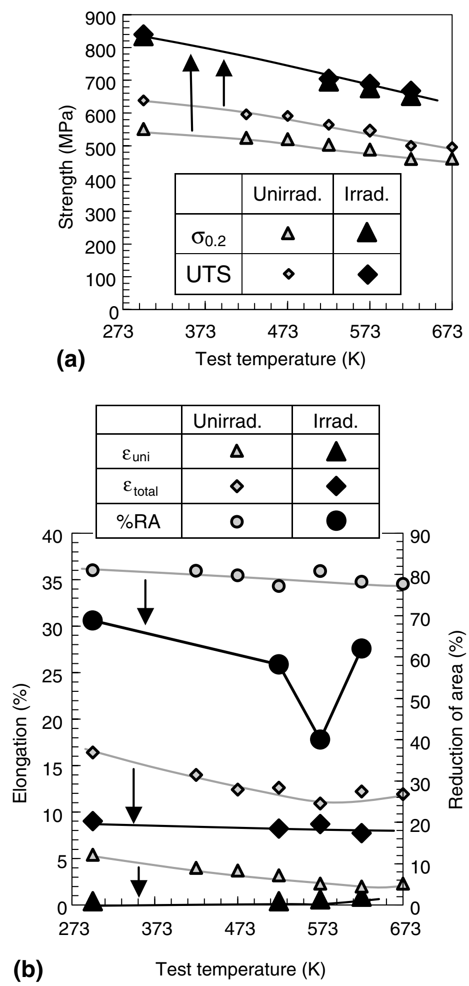

Fig. 2. Test temperature dependence of tensile properties.

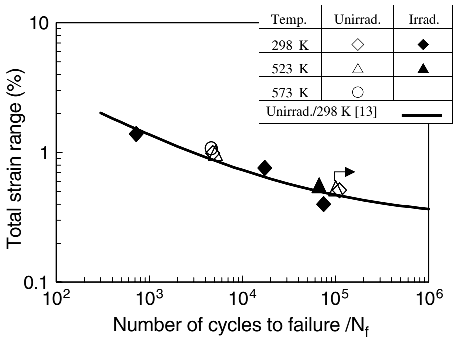

Fig. 3. Total strain range ($\Delta\varepsilon_t$) as a function of number of cycles to failure (N_f) for unirradiated and irradiated F82H specimens.

where k is a constant. A linear relationship was observed between tensile data and fatigue data, and the N_f was in

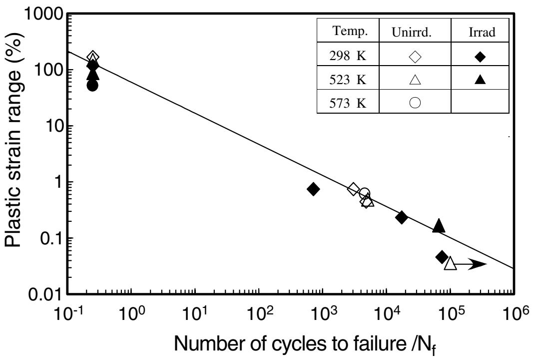

Fig. 4. Relation between the plastic strain range ($\Delta\varepsilon_p$) and the number of cycles to failure (N_f). Results of tensile tests were also plotted according to Manson–Coffin formula.

the range of 0.5–2 N_f calculated by the formula. However the data of irradiated specimen fatigue-tested at low strain range and of irradiated specimen tensile-tested at 573 K was smaller than the calculated N_f.

Both unirradiated and irradiated F82H exhibited cyclic-softening behavior in all test conditions. Steady-state hysteresis loops were established before about 10% of N_f for both unirradiated and irradiated specimens. The irradiated specimens were observed to have slightly higher cyclic strength than the unirradiated specimen, as seen in Fig. 5. Large hardening was observed on monotonic stress–strain behavior on irradiated specimens (Fig. 2) while the effect of irradiation on cyclic stress–strain behavior was not significant (Fig. 5).

Fracture surfaces of specimens that were fatigue-tested at 298 K with $\Delta\varepsilon_t$ of 0.4–0.5% are shown in Fig. 6. On the fracture surface of the unirradiated specimen, a flat plane with river pattern was observed (Fig. 6(a)). However many small planes were observed on fracture surface of the irradiated specimen (Fig. 6(b)). The size of the small planes was larger than the prior austenitic grain size of F82H IEA heats.

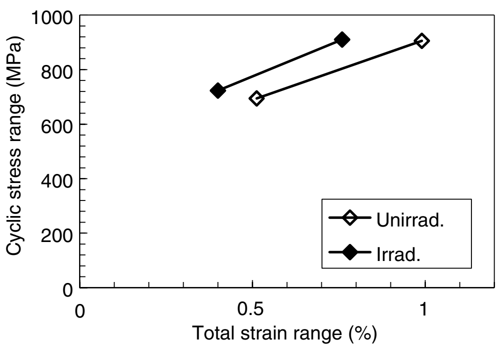

Fig. 5. Cyclic stress–strain behavior of unirradiated and irradiated F82H specimens. Fatigue tests were conducted at 298 K.

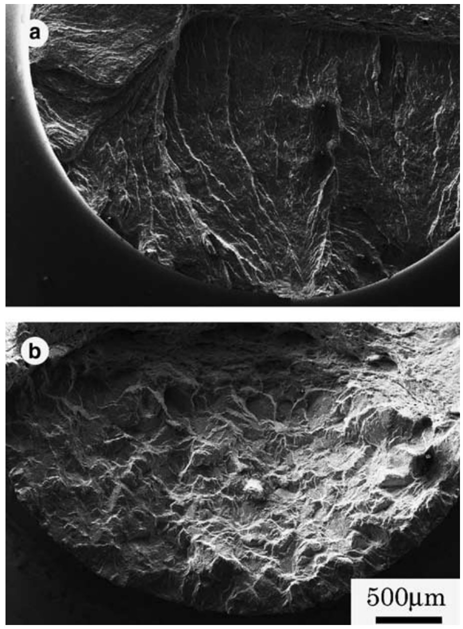

Fig. 6. Fracture surfaces of (a) unirradiated and (b) irradiated F82H specimens. The fatigue tests were performed at 298 K with total strain range of 0.4–0.5%.

4. Discussion

A large reduction of N_f was observed on a specimen which was neutron-irradiated at 523 K and fatigue-tested at 298 K with $\Delta\varepsilon_t$ of 0.5% (Fig. 3). It was seen in previous fatigue test results of ion-irradiated RAF/Ms specimens [4,6] that larger reduction of N_f occurred in specimens tested at 553–693 K with $\Delta\varepsilon_t$ of about 0.6%. These specimens were irradiated at temperature of 523–693 K. The martensitic steel Fe–9Cr–1MoVNb irradiated at 328 K to 3 dpa did not exhibit the reduction of N_f at $\Delta\varepsilon_t$ of 0.3–0.5% [14]. It is considered that the reduction of N_f at $\Delta\varepsilon_t$ of about 0.5% is related to the irradiation temperature.

As shown in Fig. 6, the fracture mode of the irradiated specimen fatigue-tested with $\Delta\varepsilon_t$ of 0.5% was found to be a channel fracture. Channel fracture [15–17] and similar cleavage fracture [18,19] were reported after fatigue tests at $\Delta\varepsilon_t$ of about 0.5% in irradiated austenitic stainless steels. In martensitic steels tested by cyclic stress, however, channel fracture has not been reported previously. The fatigue crack fracture surface of the irradiated F82H was less flat than that of unirradiated specimen and consisted of small inclined planes. Therefore the fracture mode of the irradiated F82H was thought to be channel fracture.

It was reported that in austenitic stainless steel, the channel fracture easily occurred at 573 and 673 K rather than at 298 K [17]. In our study, the channel fracture was observed at 298 K in a martensitic steel F82H. It is believed that the martensitic steel seems to be sensitive to channel fracture at lower temperature than the austenitic stainless steels. Fatigue tests will be conducted at 523–623 K in our study. The effect of test temperature on fracture mechanism is speculated on below.

The channel fracture is thought to be associated with dislocation channeling. The dislocation channeling is a consequence of the sweeping out of irradiation-induced defects such as dislocation loops by mobile dislocations. In face-centered cubic (FCC) metals, the dislocation loops are eliminated by an unfaulting process due to the intersection with the mobile dislocation [20]. In body-centered cubic (BCC) metals, on the other hand, the dislocation loops may be easily removed without the unfaulting process [21]. It is speculated, therefore, that the dislocation channeling is easily formed at lower test temperature in F82H than in austenitic stainless steels, and then the channel fracture also occurs at lower test temperature in F82H than in austenitic stainless steels.

It was reported that the Fe–9Cr–1MoVNb steel irradiated at 323 K did not show a reduction of N_f even at $\Delta\varepsilon_t$ of 0.3% [14]. In this steel, it is expected that the channel fracture dose not occur and therefore the effect of dislocation channeling on plastic deformation behavior is not significant. It was suggested that the dislocation channeling was influenced by the size and density of dislocation loops [22,23], and the critical size of dislocation loops existed above which the loops were cleaned up by mobile dislocations [23]. The size of dislocation loops in the Fe–9Cr–1MoVNb steel irradiated at 323 K is expected to be smaller than that in F82H irradiated at 523 K, since in martensitic steels larger size dislocation loops develop at higher irradiation temperatures [24]. It is speculated, therefore, that the irradiation at 523 K to 3.8 dpa developed the radiation defects that allow the dislocation channeling.

The results of tensile tests on irradiated F82H indicated a larger loss of %RA at 573 K, as seen in Fig. 2. Low cycle fatigue lives of unirradiated and irradiated specimens showed a good correlation with %RA using the Manson–Coffin formula (Fig. 4). Low cycle fatigue tests of irradiated specimens were performed at 298 and 523 K, but unfortunately have not yet been conducted at and above 573 K. If the Manson–Coffin relation is applied at 573 K, larger reduction of N_f is expected for irradiated F82H which was fatigue-tested around 573 K. The reduction of N_f is calculated to be about 1/10. The effect of test temperature on fatigue behavior must be studied for irradiated F82H steel.

5. Summary

Post-irradiation fatigue properties were measured for F82H which was irradiated at 523 K to 3.8 dpa. The preliminary results were presented in this study. The effect of irradiation on fatigue life was observed in tests at 298 K with total strain range of 0.4%. The fatigue life of irradiated specimens was reduced to about 1/7 that of unirradiated specimens. The reduction of the fatigue life was attributed to the occurrence of channel fracture. It is speculated from tensile test results that the fatigue life of the irradiated F82H may also be reduced if fatigue-tested around 573 K. Further studies are needed for the effect of irradiation on fatigue properties of F82H.

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