ELSEVIER

Journal of Nuclear Materials 283–287 (2000) 400–403

journal of nuclear materials

www.elsevier.nl/locate/jnucmat

Effects of helium implantation on creep rupture properties of low activation ferritic steel F82H IEA heat

Norikazu Yamamoto [a,*], Johsei Nagakawa [a], Kiyoyuki Shiba [b]

[a] National Research Institute for Metals, 1-2-1, Sengen, Tsukuba, Ibaraki 305-0047, Japan

[b] Tokai Establishment, Japan Atomic Energy Research Institute, Tokai 319-1195, Japan

Abstract

Thin plate specimens of a low activation ferritic steel, F82H IEA, were cyclotron-implanted with helium at 823 K to concentrations of 100 and 300 appm. Creep rupture properties were subsequently measured at the same temperature and were compared with those from unimplanted controls. No meaningful deterioration by helium was discerned in terms of both creep rupture time and elongation. In addition, the fracture surface remained transgranular and ductile after helium implantation, and no indication of grain boundary failure induced by helium was detected. These results would suggest good resistance of this material toward helium embrittlement.

1. Introduction

Among the candidates for first wall structural material of the prototype fusion reactor and beyond, the highest priority is placed on low activation ferritic steels in Japanese and European programs mainly because of their prominent maturity [1,2]. This family of steels, which includes not only low activation steels but also conventional Cr–Mo steels, has many advantages as fusion reactor structural materials, for example, large thermal conductivity, good compatibility with coolants, and low void swelling. It is also believed to be resistant to high temperature helium embrittlement, especially in comparison with austenitic steels [3]. However, almost all investigations that support this conclusion have been done through fast experiments such as tensile tests, and a very few studies [4–6] are available with respect to inspections with long duration, although deleterious helium effects arise more markedly in the latter [7–9]. In particular, if restricted to low activation species, there exists only one long-time-examination with rather low helium content [6]. It is hence necessary to accumulate further information concerning helium effects on long term mechanical properties to examine the helium-embrittlement-resistance of low activation ferritic materials.

For this purpose, we have conducted creep tests on a representative low activation ferritic steel, F82H, after hot helium implantation using an accelerator.

2. Experimental

The International Energy Agency (IEA) modified F82H (Fe–0.09%C–7.82%Cr–1.98%W–0.19%V–0.04%Ta–0.004%Ti–0.07%Si–0.1%Mn–0.003%P–0.001%S) [10] was obtained as 25 mm thick plates from NKK Corporation after normalizing (1313 K, 2.4 ks) and tempering (1023 K, 3.6 ks) treatments. Miniature creep specimens measured 10, 4, and 0.06–0.08 mm in gauge length, width and thickness, respectively, were fabricated from these plates through spark-cutting and mechanical polishing. The specimen thickness was limited by the penetration depth of incident α-particles described below.

The specimens were then subjected to helium injection at 823 K, the upper limit temperature of this steel for fusion applications, using an α-beam from a cyclotron. The incident energy of α-particles was varied between 0 and 20 MeV with an energy degrader, resulting in uniform helium loading over all the specimen depth.

* Corresponding author. Tel.: +81-298 59 2844; fax: +81-298 59 2801.

E-mail address: yamamoto@nrim.go.jp (N. Yamamoto).

0022-3115/00/$ - see front matter
PII: S 0 0 2 2 - 3 1 1 5 (0 0) 0 0 1 3 5 - 5

Lateral homogeneity was achieved by beam wobbling in the other two directions. The implanted helium concentrations were about 100 and 300 appm. An infra-red lamp heater was applied for target temperature control.

Post-implantation creep tests were performed in a vacuum at the same temperature on electro-mechanically controlled machines, in which the applied load is monitored with a load cell and a deviation from the nominal load is compensated by pull rod motion on the basis of feedback signals. Utilizing these computer installed rigs, deviations from the stated temperature and stress during creep tests were less than ±1 K and ±1 MPa, respectively. For comparison, unimplanted reference samples which received thermal histories identical to the implanted ones were similarly tested. After creep rupture, the fracture surfaces were studied under a scanning electron microscope (SEM) to determine the failure mode.

Details of the experimental procedures and instrumentation have been given elsewhere [11].

3. Results and discussion

Fig. 1 compares creep behavior of a helium bearing specimen and an unirradiated companion both applied with a nearly equal stress at each implantation level. The creep curve was hardly affected by helium at a level of 100 appm He, while implantation to 300 appm He seems to have resulted in a creep life extension. These features can be seen in Fig. 2 as well, in which standard creep strength vs rupture time relation is represented. The time to rupture values of a specimen containing 100 appm He and a corresponding helium free control which crept at almost the same stress normally fell within less than a factor of 2. This is the usual variation of creep rupture times in thin specimens [12], and they were accordingly taken to be identical. On the other hand, the 300 appm He implanted samples exhibited roughly five times larger rupture life relative to unimplanted references. Creep rupture data in Fig. 2 were analyzed by the method of linear regression based on a creep power law, $t_r \propto \sigma^{-n}$, and the results are summarized in Table 1. The stress exponents of implanted and unimplanted cases were very similar. This fact implies that the creep mechanism was not changed by helium introduction. The somewhat large errors shown in the table are probably attributed to the usage of miniature size specimens and the strong stress dependence of the rupture time.

To establish whether the above-mentioned increase of the creep lifetime by helium for 300 appm He implantation is statistically significant or not, the t-test was carried out under a null hypothesis that an experimentally obtained rupture time is equal to that estimated from the creep power law of counterpart data, since misjudgement might be induced when one draws a conclusion from a few data points, even if there seem to be a clear trend. The null hypothesis was rejected with a significance level less than 5% or 10% for every instance. This strengthening by helium was, thereby, statistically

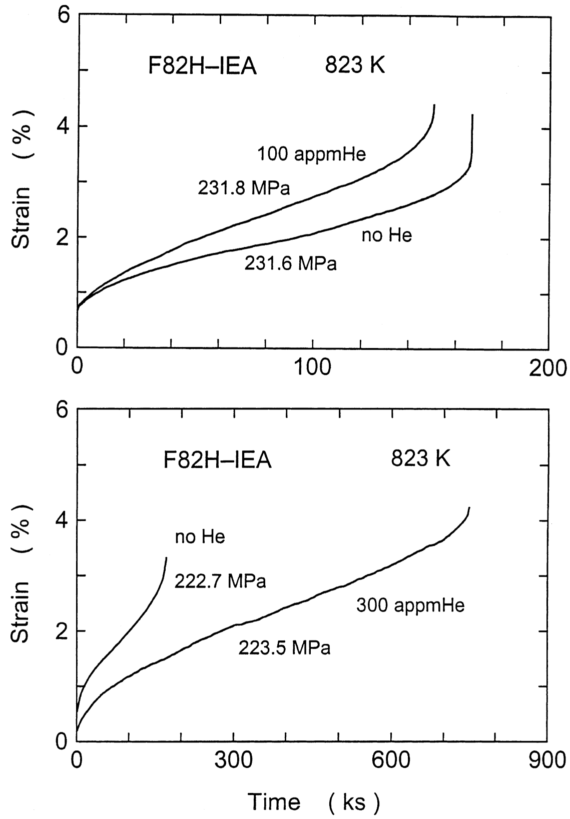

Fig. 1. Creep strain-time recordings of IEA modified F82H in helium implanted ($C_{He} = 100$ and 300 appm) and unimplanted conditions.

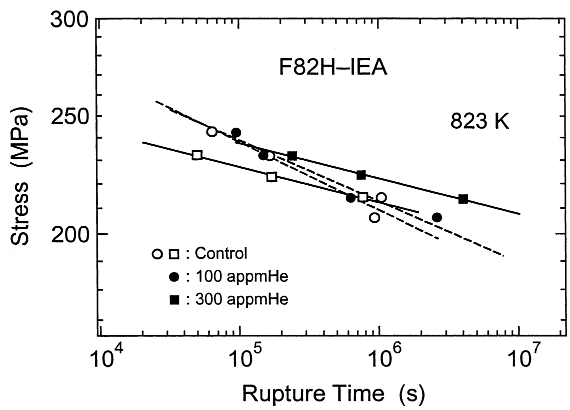

Fig. 2. A plot of creep stress vs time to rupture for helium implanted ($C_{He} = 100$ and 300 appm) and unimplanted F82H IEA heat material tested at 823 K.

Table 1
Stress exponent (n) and pre-exponential constant (C) of creep power law fitting, $t_r \propto \sigma^{-n}(\ln t_r\ [\mathrm{s}] = C - n\ln\sigma\ [\mathrm{MPa}])$, for helium implanted and unimplanted F82H-IEA tested at 823 K[a]

		n	C
100 appm He	Implanted	19.9 ± 5.9	121 ± 32
	Control	17.9 ± 6.1	110 ± 33
300 appm He	Implanted	34.6 ± 5.2	201 ± 28
	Control	34.4 ± 8.0	198 ± 43

[a] ±: 80% Confidence limit.

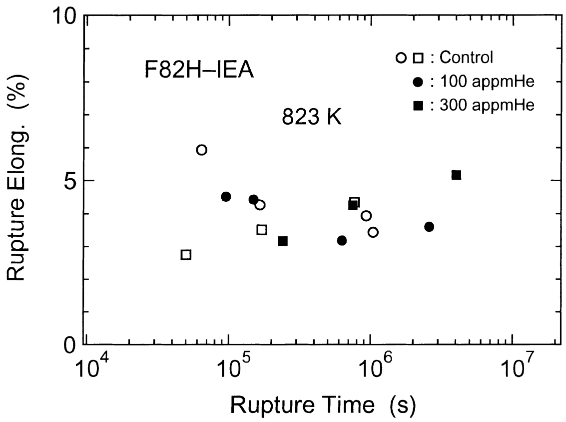

Fig. 3. A plot of creep rupture elongation vs time to rupture for helium implanted ($C_{\mathrm{He}} = 100$ and 300 appm) and unimplanted F82H IEA heat material tested at 823 K.

significant. Small helium clusters and/or bubbles in the matrix which impede dislocation motion by pinning [13] may be responsible for the increased lifetime.

The elongations at rupture are plotted in Fig. 3 against creep rupture time. On average there was no distinguishable difference among all test series and the overall scatter lay within a commonly acceptable error band. Helium thus caused no effective reduction in rupture elongation, when injected up to 300 appm He. The observed rupture strains were distributed from 3% to 6% and were considerably lower compared to those of bulk specimens [10]. This disagreement could be correlated with specimen size effects [14], chiefly reflecting pre-mature fracture in the accelerated creep region as shown in Fig. 1.

Fig. 4 indicates typical results of fractographic inspections on ruptured specimens. The fracture surfaces of implanted and unimplanted materials did not differ in character, revealing the same transcrystalline and ductile fracture mode. No evidence of grain boundary separation induced by helium was found. As regards helium effects on fracture morphology, it has been reported [5,15,16] that helium decreased the tendency toward necking at transcrystalline ductile fracture surfaces in mechanical tests of ferritic steels. In order to check whether the same held in this experiment, ruptured surfaces were grouped in two portions, viz., regions of glide plane decohesion (significantly necked parts: Fig. 4(a) and (c)) and those decorated with dimples

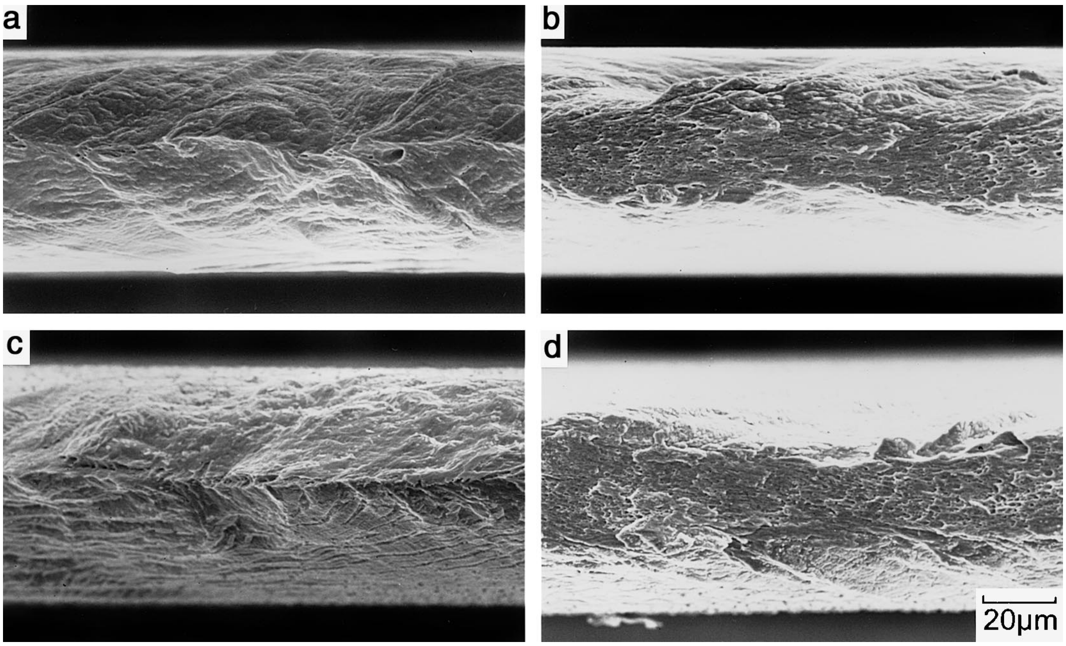

Fig. 4. SEM micrographs showing representative fracture appearance of IEA modified F82H crept at 823 K, 232 MPa: (a), (b) unimplanted control ($t_r = 50.1$ ks); (c), (d) helium implanted specimen ($C_{\mathrm{He}} = 300$ appm, $t_r = 240$ ks).

(less necked parts: Fig. 4(b) and (d)), and proportions of each were evaluated on the basis of line analysis. The estimated percentages of the latter were spread from 11% to 55%, and there observed no substantial effect of helium on the amount of dimple fracture. Thus, the above-mentioned helium effect of supressing necking did not appear in our case.

4. Conclusions

The mechanical response of a low activation ferritic steel, F82H, to implanted helium was investigated through post-implantation ($T_{impl.} = 823$ K, $C_{He} = 100$, 300 appm) creep testing at 823 K. The material demonstrated that it is quite insensitive to high temperature helium embrittlement in the present range of test conditions. The salient results which led to this conclusion are:

1. Both creep rupture time and elongation were not degraded by helium implantation up to 300 appm. Furthermore, helium prolonged the creep lifetime in the case of 300 appm He implantation.
2. Creep rupture was completely intragranular and ductile, irrespective of the presence or the absence of helium, and regardless of helium concentration. Helium, therefore, did not bring about any kind of intergranular decohesion.

References

[1] A. Kohyama, A. Hishinuma, D.S. Gelles, R.L. Klueh, W. Dietz, K. Ehrlich, J. Nucl. Mater. 233–237 (1996) 138.

[2] A. Kohyama, A. Hishinuma, Y. Kohno, K. Shiba, A. Sagara, Fus. Eng. Des. 41 (1998) 1.

[3] R.L. Klueh, K. Ehrlich, F. Abe, J. Nucl. Mater. 191–194 (1992) 116.

[4] C. Wassilew, K. Herschbach, E. Materna-Morris, K. Ehrlich, in: J.W. Davis, D.J. Michel (Eds.), Proceedings of Topical Conference on Ferritic Alloys for Use in Nuclear Energy Technologies, AIME, New York, 1984, p. 607.

[5] U. Stamm, H. Schroeder, J. Nucl. Mater. 155–157 (1988) 1059.

[6] A. Kimura, H. Kayano, S. Ohta, J. Nucl. Mater. 179–181 (1991) 741.

[7] B. van der Schaaf, M.I. de Vries, J.D. Elen, in: M.L. Bleiberg, J.W. Bennett (Eds.), Proceedings of International Conference on Radiation Effects in Breeder Reactor Structural Materials, AIME, New York, 1977, p. 307.

[8] C. Wassilew, K. Ehrlich, H.-J. Bergmann, in: F.A. Garner, C.H. Henager, N. Igata (Eds.), Proceedings of 13th International Symposium (Part II) on Influence of Radiation on Material Properties, Part II, ASTM STP 956, ASTM, Philadelphia, 1987, p. 30.

[9] N. Yamamoto, J. Nagakawa, H. Shiraishi, H. Kamitsubo, I. Kohno, T. Shikata, J. Nucl. Sci. Technol. 28 (1991) 1001.

[10] K. Shiba, A. Hishinuma, A. Tohyama, K. Masamura, JAERI-Tech 97–038, 1997.

[11] N. Yamamoto, J. Nagakawa, K. Shiba, Key Eng. Mater. 171–174 (2000) 115.

[12] H. Schroeder, J. Nucl. Mater. 141–143 (1986) 476.

[13] A.A. Sagüés, H. Schroeder, W. Kesternich, H. Ullmaier, J. Nucl. Mater. 78 (1978) 289.

[14] N. Yamamoto, J. Nagakawa, K. Shiba, unpublished data.

[15] A. Hasegawa, H. Shiraishi, J. Nucl. Mater. 191–194 (1992) 910.

[16] A. Hasegawa, N. Yamamoto, H. Shiraishi, J. Nucl. Mater. 202 (1993) 266.