Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Nuclear Materials 329–333 (2004) 324–327

journal of nuclear materials

www.elsevier.com/locate/jnucmat

Effects of heat treatment process for blanket fabrication on mechanical properties of F82H

T. Hirose [*], K. Shiba, T. Sawai, S. Jitsukawa, M. Akiba

Blanket Engineering Laboratory, Department of Fusion Engineering Research, Japan Atomic Energy Research Institute, 801-1 Mukouyama, Naka-machi, Naka-gun, Ibaraki-ken 311-0193, Japan

Abstract

The objectives of this work are to evaluate the effects of thermal history corresponding to a blanket fabrication process on Reduced Activation Ferritic/Martensitic steel (RAF/Ms) microstructure, and to establish appropriate Hot Isostatic Pressing (HIP) conditions without degradation in the microstructures. One of RAF/Ms F82H and its modified versions were investigated by metallurgical methods after isochronal heat treatments up to 1473 K simulating HIP thermal history. Although conventional F82H showed significant grain growth after conventional solid HIP conditions, F82H with 0.1 wt% tantalum maintained a fine grain structure after the same heat treatment. It is considered that the grain coarsening was caused by dissolution of tantalum-carbide which immobilizes grain boundaries. On the other hands, conventional RAF/Ms with coarse grains were recovered by post HIP normalizing at temperatures below the TaC solvus temperature. This process can refine the grain size of F82H to more than ASTM grain size number 7.

1. Introduction

Reduced activation ferritic/martensitic (RAF/M) steels are the leading candidates for the first wall structural materials of breeding blankets [1]. A mechanical properties database, including before and after neutron irradiation, has been established [2]. Moreover, the application techniques, such as joining and compatibility between coolant and the steel, have also been developed [3,4]. The RAF/Ms are the tempered martensitic steels, their mechanical properties before and after the irradiation depend strongly upon the thermal history experienced during fabrication. Recently it was reported that a certain tempering heat treatment suppresses the irradiation hardening of RAF/Ms.

The breeding blanket structure consists of walls which contain cooling channels to remove the high heat flux from the plasma [5]. Hot Isostatic Pressing (HIP) bonding has been investigated as a practical fabrication process to develop a near-net-shape structure. Because of HIP is a solid state bonding process, the process requires heating above temperatures that results in phase transformation. However, the HIP process can cause coarsening of Prior-Austenite-Grains (PAG) of in F82H [6,7]. It is known that the ductile to brittle transition temperature (DBTT) and the shift of DBTT can depend upon the PAG size. The HIP process requires heating above the normalizing temperature and the final microstructural features depend upon the HIP processing conditions. Therefore it is necessary to investigate the effect of the thermal history corresponding to the HIP process on the material properties of F82H. This work presents the microstructural evolution caused by thermal history, and identifies heat treatment conditions to avoid microstructural change and recovery of the thermally altered microstructure.

2. Experimental procedure

Materials used were Japanese RAF/Ms F82H steel. The chemical compositions of the steels are presented in

---

[*] Corresponding author. Tel.: +81-29 270 7516/70; fax: +81-29 270 7489.

E-mail address: hiroset@fusion.naka.jaeri.go.jp (T. Hirose).

0022-3115/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnucmat.2004.04.047

Table 1
Chemical composition of F82H steels (wt%)

	C	Si	Mn	S	Cr	W	V	Ta	Ti	N
F82H-IEA	0.090	0.07	0.10	0.0010	7.82	1.98	0.19	0.040	0.004	0.0070
F82H-TMCP	0.100	0.10	0.13	0.0007	8.01	1.96	0.19	0.052	0.004	0.0065
F82H + 0.1%Ta	0.100	0.10	0.13	0.0010	8.16	1.94	0.20	0.092	<0.001	0.0017

Table 1. F82H-IEA and F82H-TMCP heat have almost the same compositions. However, the ASTM grain size number of the IEA heat was 3 and that of TMCP was 8 [8]. TMCP heat was produced by a Thermo-Mechanically-Controlled-Process, with the final roll temperature was below 1223 K. This temperature was just above A_{C3}, where the temperature at which transformation of ferrite into austenite is completed upon heating. Tantalum carbide (TaC) is known to immobilize the PAG boundary. The Ta-rich steel F82H + 0.1%Ta, which has a grain size number 9, was also used. The details of this steel are reported elsewhere [9]. All steels are normalized at 1313 K × 30 min and tempered at 1023 K × 60 min. These steels were cut into 10 × 10 × 10 mm^3 pieces and heat treated in the a vacuum furnace to temperature in the range 1213–1373 K for 2 h. The heating and cooling rate was determined to be 400 K/s to simulate HIP furnace conditions. After the heat treatment microstructure were investigated by optical microscopy. PAG sizes have been measured by the method described in [8].

3. Results and discussions

3.1. Grain coarsening

The metallurgical features and ASTM grain size number after heat treatment are shown in Figs. 1 and 2. As shown in these figures, all steels kept their original grain size after heat treatment at the temperatures below 1273 K. Moreover the 0.1%Ta steel maintained a fine grain size after heat treatment at 1313 K. However, the others showed grain coarsening above 1273 K. All of steels showed grain coarsening after heat treatment at 1373 K.

Although the IEA-heat and TMCP-heat has the same chemical compositions and experienced the same thermal history, the steels showed different grain size numbers after the same heat treatment at temperatures below 1373 K. These results imply that 1313 K, the conventional normalizing temperature of F82H, cannot normalize the grain size change caused by thermal and/or mechanical processing.

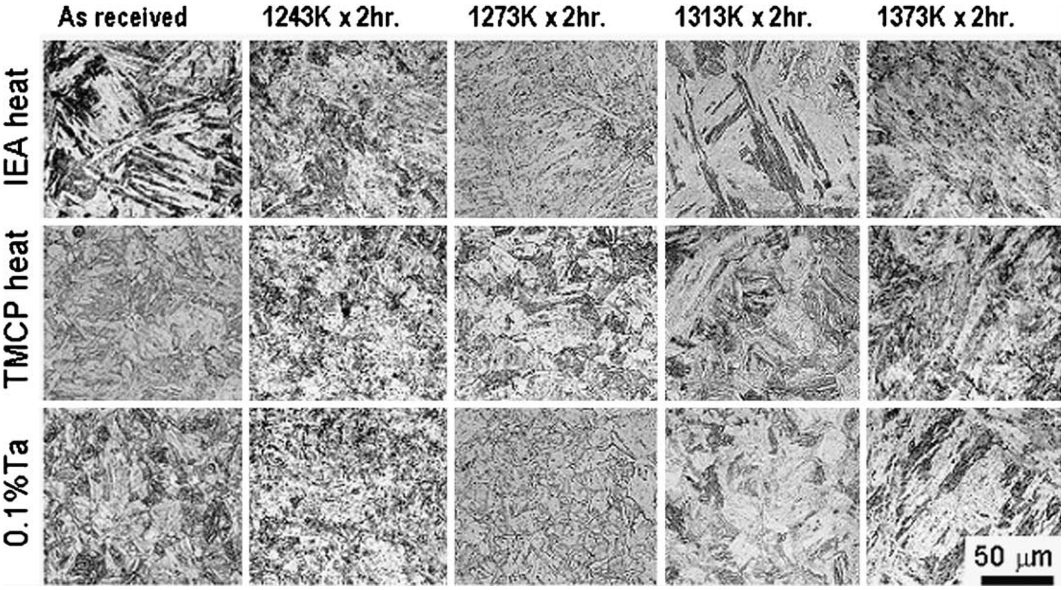

Fig. 1. Microstructure of F82H IEA heat after HIP simulating heat treatment.

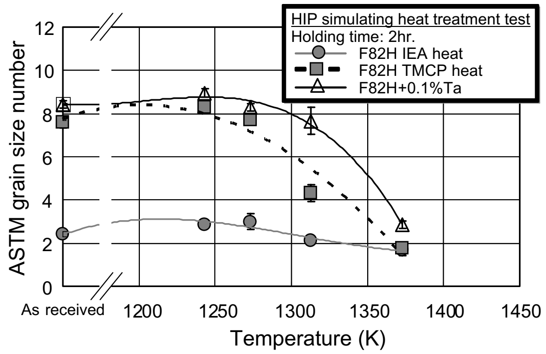

Fig. 2. ASTM grain size change induced by HIP simulating heat treatment.

The grain coarsening is believed to be proceeded by dissolution at grain boundaries. Fig. 2 shows that the threshold temperature of PAG coarsening depends on Ta contents. TaC is the most stable carbide in F82H steel. Tamura et al. determined the solubility of TaC in F82H steel [10]. The TaC solvus curve calculated from the solubility is presented in Fig. 3. As shown in this figure, the TaC in conventional F82H with 0.05%Ta is soluble at 1300 K and the TaC in F82H + 0.1%Ta is soluble at 1363 K. These solvus temperatures show good agreement with the results of the isochronal heat treatment test. Although HIP at 1273 K could avoid grain coarsening, the bonding surface must be finished by fine polishing to obtain good bonding properties.

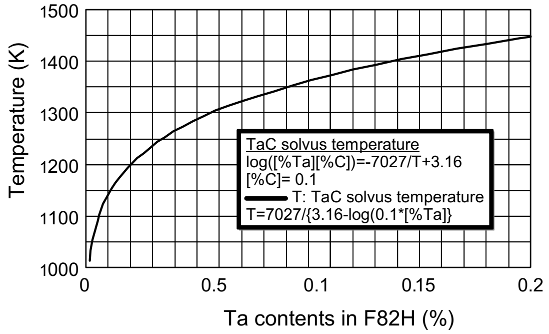

Fig. 3. TaC solvus temperature calculated from the solubility product.

3.2. *Grain fining*

Homogenizing, which dissolves precipitates and normalizes the grain size for the two steels, requires heating above 1373 K. However, the gamma to delta ferrite transformation temperature is reported to be >1473 K in F82H, so the homogenizing should be carried out below 1473 K [11]. Normalizing around the temperature at which transformation of ferrite into austenite is completed upon heating, A_{C3} was also performed to determine the heat treatment conditions to obtain a fine grain size. Optical micrographs after homogenizing and low-temperature normalizing are shown in Fig. 4. As shown in this figure, although the A_{C3} of F82H was reported to be 1173–1183 K [12], alpha-ferrite phase emerged after 1193 K normalization. On the other hands, no ferrite phase was observed after 1203 K normalization and a fine grain (ASTM grain size number 7) was kept after 1243 K normalization.

Therefore a HIP process to secure both good bonding properties and grain size should be carried out as follows: HIP at > 1373 K + Normalizing at < 1273 K + Tempering. Alternatively conventional HIP processing using 0.1%Ta steel can also obtain these features.

4. Summary

To clarify the effect of thermal history on the metallurgical properties of F82H, metallurgical analysis on

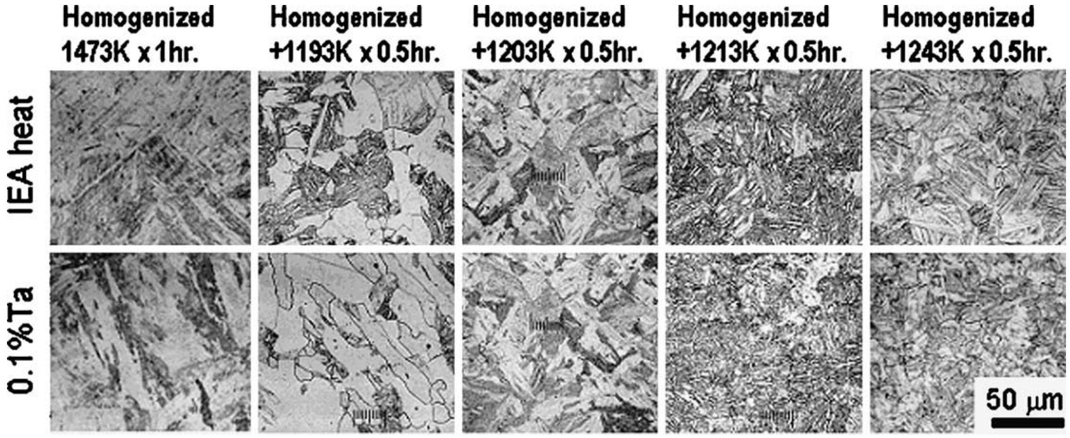

Fig. 4. Optical micrographs after homogenizing following low-temperature normalizing.

heat-treated steels has been carried out. The following conclusions were obtained.

1. F82H showed grain coarsening after heat treatment at temperatures where tantalum carbide dissolves. Tantalum additions to F82H maintain fine grain sizes after conventional HIP conditions.
2. A conventional normalizing temperature of 1313 K was not enough to normalize the prior grain size of F82H. To normalize the grain size homogenizing heat treatments above 1373 K were required.
3. F82H with coarse grains were recovered by the homogenizing the steel at 1473 K followed by low temperature normalizing below 1273 K.
4. To obtain both bonding properties and fine grained structures, the following thermal process is recommended: HIP at > 1373 K + Normalizing at < 1273 K + Tempering.

References

[1] R.L. Klueh, D.S. Gelles, S. Jitsukawa, A. Kimura, G.R. Odette, B. Van der Schaaf, M. Victoria, J. Nucl. Mater. 307–311 (2002) 455.

[2] S. Jitsukawa, M. Tamura, B. van der Schaaf, R.L. Klueh, A. Alamo, C. Petersen, M. Schirra, P. Spaetig, G.R. Odette, A.A. Tavassoli, K. Shiba, A. Kohyama, A. Kimura, J. Nucl. Mater. 307–311 (2002) 179.

[3] A. Hishinuma, A. Kohyama, R.L. Klueh, D.S. Gelles, W. Dietz, K. Ehrlich, J. Nucl. Mater. 258–263 (1998) 193.

[4] H. Kawamura, M. Kato, E. Ishitsuka, S. Hamada, K. Nishida, M. Saito, Fusion Eng. Des. 29 (1995) 475.

[5] M. Enoeda et al., JAERI-Tech 2001-078, 2001.

[6] T. Hatano, S. Suzuki, K. Yokoyama, T. Kuroda, M. Enoeda, J. Nucl. Mater. 283–287 (2000) 685.

[7] K. Furuya, E. Wakai, M. Ando, T. Sawai, K. Nakamura, H. Takeuchi, A. Iwabuchi, J. Nucl. Mater. 307–311 (2002) 289.

[8] Standard Test Methods for Determining Average Grain Size, Annual Book of ASTM Standards, 2001.

[9] K. Shiba et al., these Proceedings. doi:10.1016/j.jnucmat.2004.04.018.

[10] M. Tamura, K. Shinozuka, K. Masamura, K. Ishizawa, S. Sugimoto, J. Nucl. Mater. 258–263 (1998) 1158.

[11] E. Wakai et al., these Proceedings. doi:10.1016/j.jnucmat.2004.04.037.

[12] A. Alamo, J.C. Brachet, A. Castaing, C. Lepoittevin, F. Barcelo, J. Nucl. Mater. 258–263 (1998) 1228.