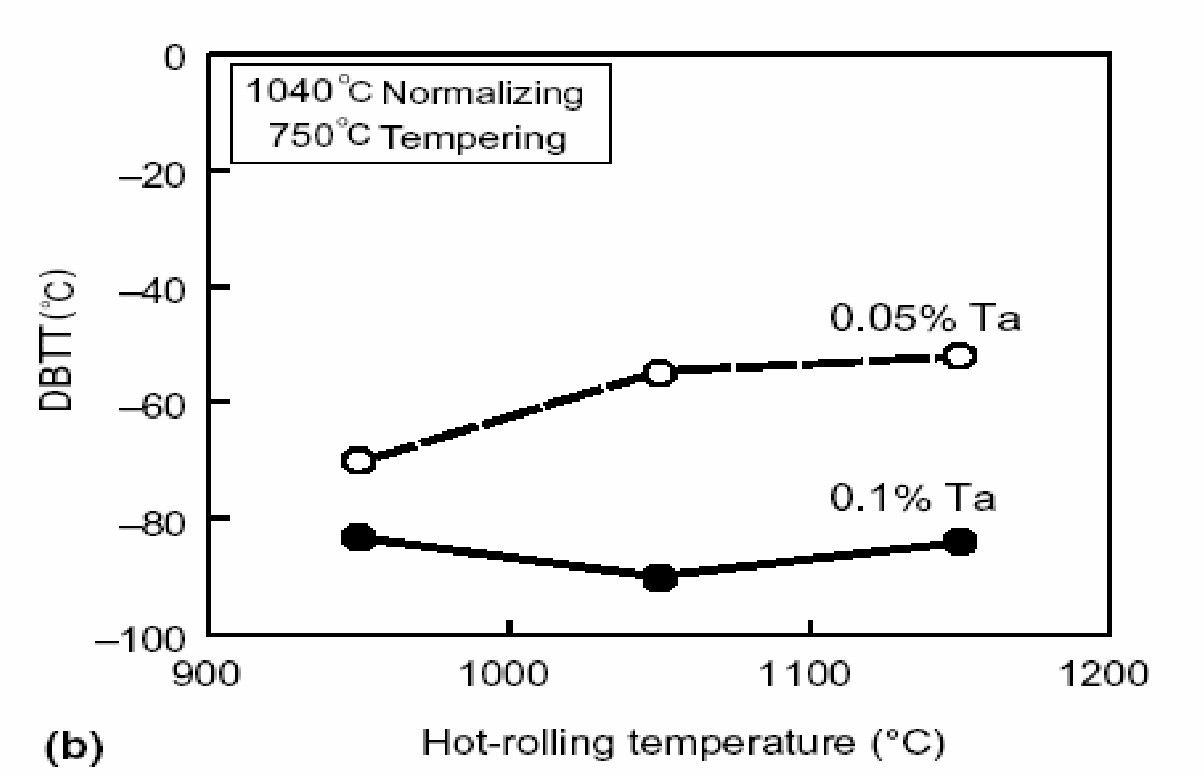
Material: Ferritic Steel: F82H
Property: Hot-rolling temperature (˚C) versus DBTT (˚C)
Condition: Hot-rolled
Data: Experimental

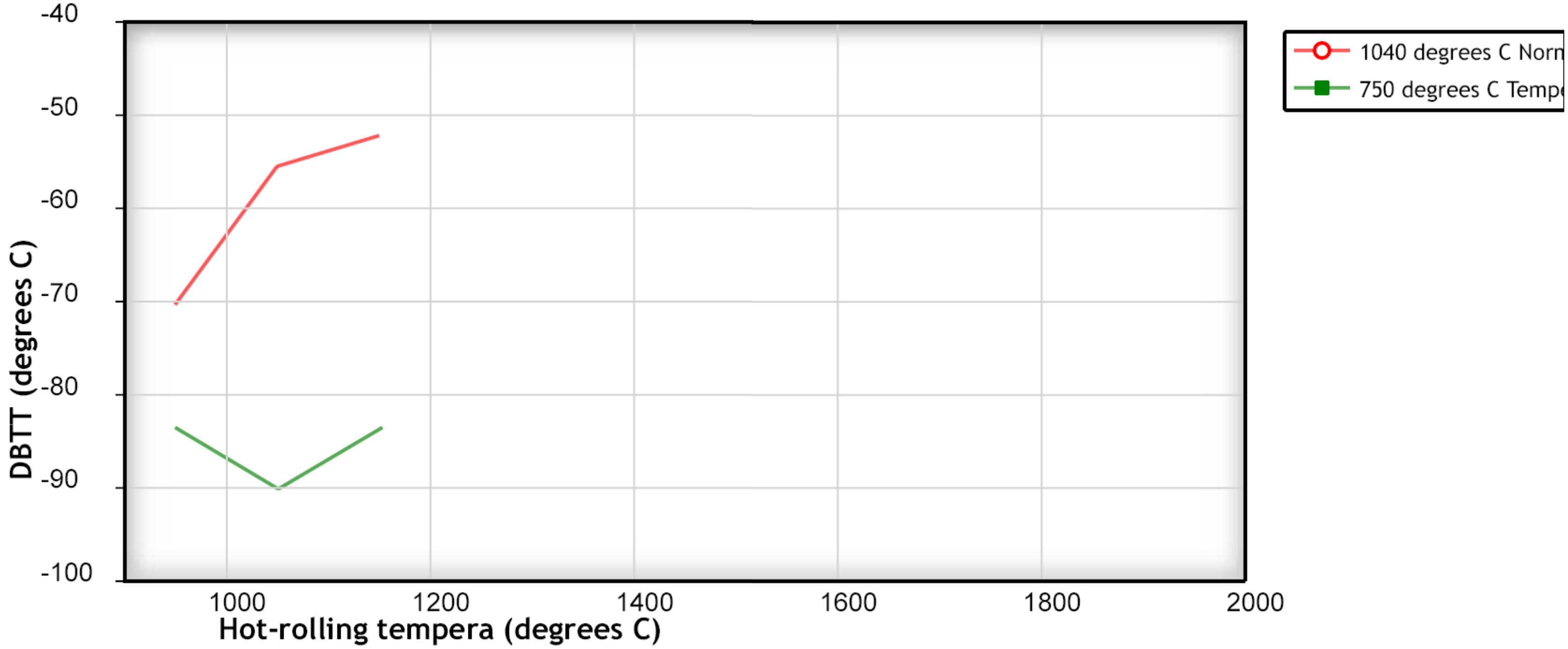


Source:
Journal of Nuclear Materials, 329-333, (2004), 243-247

Title of paper (or report) this figure appeared in:
Reduced Activation Martensitic Steels as a Structural Material for ITER Test Blanket

Author of paper or graph:
K. Shiba, M. Enoeda, J. Jitsukawa

Caption:
Charpy DBTT of Ta-modified F82H with different Hot-rolling and Normalization temperatures.



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Plot Format:

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

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Reduced activation martensitic steels as a structural material for ITER test blanket

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Abstract

A Japanese ITER test blanket module (TBM) is planed to use reduced-activation martensitic steel F82H. Feasibility of F82H for ITER test blanket module is discussed in this paper. Several kinds of property data, including physical properties, magnetic properties, mechanical properties and neutron-irradiation data on F82H have been obtained, and these data are complied into a database to be used for the designing of the ITER TBM. Currently obtained data suggests F82H will not have serious problems for ITER TBM. Optimization of F82H improves the induced activity, toughness and HIP resistance. Furthermore, modified F82H is resistant to temperature instability during material production.

1. Introduction

In the long-term R&D program of the blanket established by the Fusion Council of Japan in 1999, a ceramic breeder blanket with reduced-activation ferritic/martensitic (RAF/M) steel is regarded as the near-term candidate concept of the blanket for a fusion power demonstration plant in Japan [1]. In the program of the blanket development, a blanket module test in the ITER is scheduled from the beginning of the ITER operation. It is recognized to be one of the most important milestones. The RAF/M steel F82H is a candidate material for the Japanese ITER test blanket module (TBM) to obtain the data for the DEMO blanket design. Major parameters at the first wall for the testing of the test blanket module in ITER are 0.78 MW/m^2 as the neutron wall loading and 0.25 MW/m^2 as the surface heat flux [2]. In the case of a water-cooled system, ITER TBM will be irradiated to less than 3 dpa at temperatures ranging from 280 to 330 °C during the basic performance stage, and possibly to about 10 dpa in the extended performance stage. The feasibility of using reduced-activation martensitic steel F82H is discussed in this paper.

2. Materials

Most of the data have been obtained using F82H-IEA heat material, which was melted into two different 5 ton ingots. Some irradiation data was obtained using F82H pre-IEA heat material. Chemical compositions of these steels are listed in Table 1. F82H-IEA heat was normalized at 1040 °C for 38–40 min followed by air-cooling (AC) and tempered at 750 °C for 60 min followed by AC.

F82H pre-IEA heat was normalizing at 1040 °C for 40 min followed by AC and tempered at 740 °C for 120 min followed by AC.

3. Material properties data

Several kinds of properties of F82H steel have been obtained. There is not enough space to explain all of the properties data. Detailed data can be found in references

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Table 1
Chemical composition of F82H-IEA heat and pre-IEA heat (mass %)

	Fe	Cr	W	V	Ta	C	B
F82H IEA heat	Bal.	7.71	1.95	0.16	0.02	0.090	0.0002
F82H pre-IEA heat	Bal.	7.46	2.10	0.21	0.03	0.097	0.0004
	Si	Mn	P	S	Al	N	
F82H IEA heat	0.11	0.16	0.002	0.002	0.003	0.006	
F82H pre-IEA heat	0.09	0.07	0.002	0.003	0.025	0.002	

[3–6]. Elastic modulus, modulus of rigidity, and Poisson's ratio were measured as elastic properties at temperatures ranging from room temperature to 700 °C. Thermal conductivity and thermal expansion coefficients were obtained as thermal properties at temperatures ranging from room temperature to 900 °C. As a magnetic property, magnetic hysteresis curves were obtained at temperatures ranging from room temperature to 400 °C. As mechanical properties, tensile properties, Charpy impact properties, fracture toughness, fatigue properties, creep properties were obtained. Tensile tests were conducted at temperatures ranging from −100 to 700 °C, and true stress–true strain diagrams were produced. Isothermal fatigue test were carried out at RT, 300, 400 and 550 °C with strain range between 0.5% and 1.5%. Creep tests have been finished to 30 000 h and continued to 100 000 h at temperatures ranging from 500 to 650 °C. Thermal aging has been completed to 30 000 h at 500, 550, 600 and 650 °C and continued to 100 000 h, either. Tensile, Charpy, fracture toughness and precipitation analysis were conducted on thermally aged materials. These data have been complied into a database to supply the data for blanket design.

4. Weld and HIP joining

TIG and electron beam (EB) welds have been fabricated and characterized on F82H-IEA heat. Tensile, Charpy impact, fracture toughness specimens have been tested after post-weld heat treatment (PWHT) and after thermal aging at 550 °C up to 10 000 h [6]. Tensile and Charpy impact properties of a TIG-welded joint were carried out after HFIR irradiation. The weld metal region hardens and the toughness degrades in the PWHT condition in both TIG and EB welds. On the other hand, heat affected zone (HAZ) softens in TIG, but not in EB. After neutron irradiation to 8 dpa at 300 °C, the weld metal (WM) revealed the same level of irradiation hardening as base metal, but it was about half of the base metal and WM [7]. Therefore, the irradiated TIG weld joint deformed at the HAZ. The ITER TBM will be fabricated by HIP method, and a demonstration module has been fabricated without obvious defects [8]. Irradiation of HIP joints is being conducted in the HFIR, and tensile and toughness data will be obtained.

5. Corrosion

The data on corrosion behavior is quite limited. Corrosion loss of F82H-IEA in high-temperature water has been measured, but the test was carried out for only one test condition [5]. The corrosion tests of F82H in supercritical water are being prepared at JAERI, Naka site. An irradiation induced stress corrosion cracking (IASCC) test, slow strain rate tensile test (SSRT) of F82H irradiated to 2 dpa at 250 °C in JRR-3M has been conducted [9]. This SSRT test caused no cracking in both oxygen- and hydrogen-addition water conditions, in spite of the large irradiation hardening. This result suggests IASCC susceptibility of F82H is low.

6. Irradiation behavior

Several research groups have obtained data on irradiated F82H steel, but most data are tensile and Charpy impact data. Some of the irradiation data, mainly HFIR and JAERI reactors irradiation data, are also included in the material database on RAF/M steels mentioned above. Fig. 1 is the dose dependence of yield stress of F82H after irradiation [10]. As shown in this figure, heavy irradiation hardening occurs around 300 °C, while almost no hardening happens above 400 °C. In the case of the water-cooled system of ITER TBM, it will be irradiated to 3–10 dpa at around 300 °C, which increases the yield stress to 700–800 MPa. However, F82H still has a capability for more hardening as shown in Fig. 1, and irradiation results indicate F82H still retains its ductility.

Fig. 2 shows the dose dependence of the Charpy ductile-to-brittle transition temperature (DBTT) of F82H-IEA and the TIG-welded joint with 1/3 V-notched specimens irradiated in the HFIR up to 20 dpa at 300 °C [11,12]. DBTT increases rapidly at the beginning of the irradiation, but it saturates after about 5 dpa. As shown in this figure, DBTT of base metal stays around room

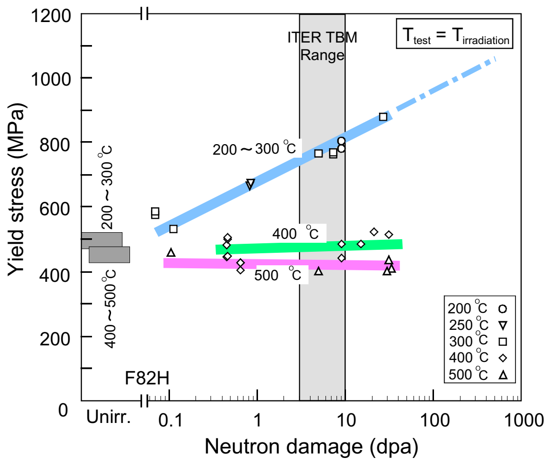

Fig. 1. Yield stress of F82H after neutron irradiation as a function of irradiation damage.

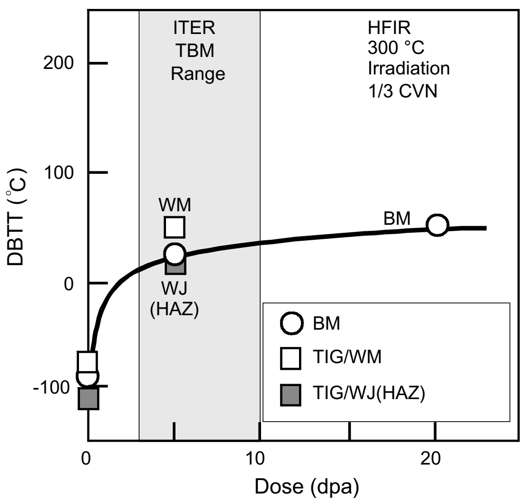

Fig. 2. Dose dependence of Charpy DBTT of F82H-IEA and TIG-welded joint after neutron irradiation.

temperature, and even the TIG weld metal DBTT remains below 100 °C.

Fig. 3 shows the helium effect on fracture toughness using the boron-doping method. In this study, 0.18T DCT specimens of B-doped F82H with different $^{10}B/^{11}B$ ratio were irradiated in the JMTR to 1 dpa at 250 °C [13]. ^{10}B-doped, ^{11}B-doped and $^{10}B+^{11}B$-doped F82H generates about 300, 0 and 150 appm of helium during irradiation, respectively. DBTT of ^{11}B-doped F82H raised to about 50 °C and $^{10}B+^{11}B$ F82H, which contains 150 appm He, increased DBTT about 50 °C additionally. To take account of the helium effect, the toughness of F82H may be modified to lower the DBTT.

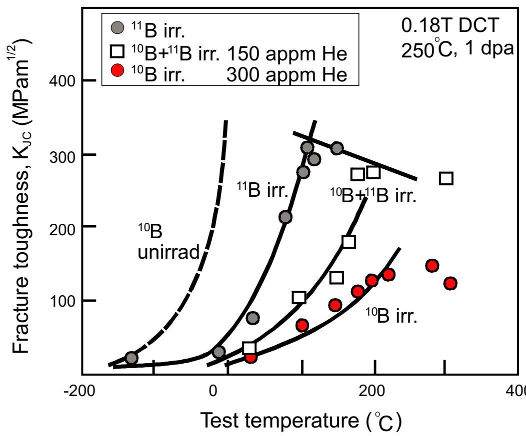

Fig. 3. Fracture toughness transition curves of B-doped F82H after neutron irradiation.

7. Issues to be investigated

The data accumulated on RAF/M steels suggests F82H will not have serious problems for the ITER test blanket module. However, some additional researches and data are needed to confirm the reliability of F82H steel.

(1) Quality control of material properties

Fabrication condition should be strictly defined to guarantee the material properties.

(2) Helium and hydrogen effect

Simulation irradiations using B-doping, Ni-doping and ^{56}Fe-doping have been conducted to investigate He and H effects [11,14–20]. In these simulation methods, Ni-doping has some side effects, so that it is difficult to evaluate the helium effect itself [11,16,17]. B-doping results suggest He up to 300 appm does not affect hardening, but it does increase the DBTT. However, the ITER TBM will be irradiated to 3–10 dpa, so that the helium generation during operation is up to only 100–150 appm. B-doping and other results suggest helium effect is not serious at this helium level.

(3) Fatigue properties after/under irradiation

The ITER test blanket will be operated with pulse operation, so that fatigue properties are relatively important. However, irradiation data on fatigue properties of RAF/M steel is quite limited [21,22]. Therefore, after/under irradiation fatigue properties have not been understood yet. Particularly, helium effects should be confirmed.

(4) Corrosion behavior after/under irradiation

The specification for the requirement for corrosion has not been defined. Some data suggest the loss of the thickness may be small [5]. Estimation of the amount of radioactive products deposited into cooling water is necessary. Evaluation of the coating is also important relating with the tritium permeation and inventory.

(5) Inspection method for HIP joining

It is not a material issues, but it is important to develop the optimum HIP process condition, and non-destructive inspection method.

8. Material optimization

As describe in the irradiation results section, DBTT-shift has a trend of saturation with the irradiation damage, but helium gives additional degradation to toughness. Therefore, toughness of F82H should be modified to increase the margins for low-temperature irradiation embrittlement, particularly for helium embrittlement. Additionally, further reduction of activity is expected for safety and maintenance viewpoint. Harmful elements on radiation-induced activity are W, N and Nb [23]. Reduction of W is difficult, because W maintains the high-temperature strength of the material. Nb can be reduced to 0.5 ppm by the raw material selection and care of the environment during melting. N can be reduced to 20 ppm; however, N reduction increases phase instability during material fabrication, and material properties become unstable. To maintain the stable material properties, lower hot-rolling temperature (950 °C) and normalizing temperature (1000 °C) is effective. High-purity F82H (14 ppm N and 0.001% Ti) with low-temperature rolling/normalizing has fine grain (ASTM 6) and better toughness than F82H-IEA heat. Furthermore, the material is heated to high-temperature during the HIP joining process. This heating causes coarsening of microstructure at the joining region and degrades the toughness. The HIP process is operated usually at 1050 °C, but a higher temperature is favorable to obtain good joints. To increase the resistance to the heating during the HIP process modified F82H with 0.1% Ta (14 ppm N and 0.001% Ti) was examined. As shown in Fig. 4, this Ta-modified F82H has a fine grain microstructure (ASTM 9.5) and excellent toughness (−90 °C of Charpy DBTT). This alloy is quite stable for the temperature instability during material fabrication, and a heat treatment simulating the HIP process at 1050 °C does not cause coarsening of grains. Neutron irradiation of Ta-modified F82H is being conducted in the HFIR.

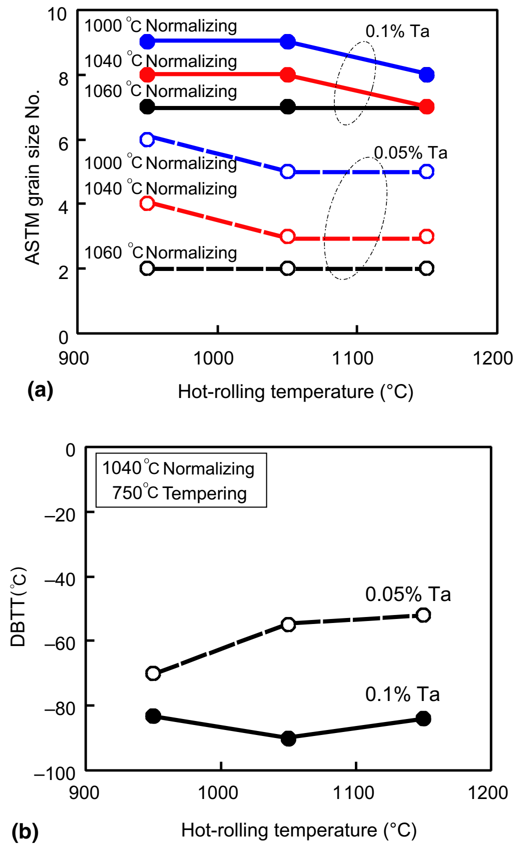

Fig. 4. (a) Grain size and (b) Charpy DBTT of Ta-modified F82H with different hot-rolling and normalization temperature.

9. Summary

The Japanese ITER test blanket module is planed to using reduced-activation martensitic steel F82H. Feasibility of F82H for ITER test blanket module was discussed and summarized as follows:

(1) Properly data of F82H to be used for the designing of the ITER TBM are complied into a database. The database includes physical properties, magnetic properties, mechanical properties and neutron irradiation data.
(2) Data suggest that F82H will not have serious problems for ITER TBM.
(3) Optimization F82H improves the induced activity, toughness and HIP resistance. Furthermore, modified F82H is stable to temperature instability during material production.

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