Status and Key Issues of Reduced Activation Martensitic Steels as the Structural Materials of ITER Test Blanket Module and Beyond

H. Tanigawa 1), K. Shiba 1), T. Hirose 1), R. Kasada 2), E. Wakai 1), S. Jitsukawa 1),
A. Kimura 2), A. Kohyama 2)
1) Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195 Japan
2) Institute of Advanced Energy, Kyoto University, Uji, Kyoto, 611-0011 Japan

e-mail: tanigawa.hiroyasu@jaea.go.jp

Abstract. The status of research and development (R&D) of reduced activation martensitic steels (RAMs) in Japan are reviewed and key issues suggested from recent achievements in Japan since the last conference are highlighted, with the aim of the fabrication for the ITER Test Blanket Module (TBM) and application for the DEMO reactor. It was pointed out that international collaboration would be desirable for research on key issues such as precipitate stability under irradiation or Ta effects which are common for all RAMs and require an extensive research effort.

1. Background and objective

Reduced activation martensitic steels (RAMs) are recognized as the primary candidate structural materials for fusion blanket systems, based on massive industrial experience with ferritic/martensitic steels. The RAM variants are obtained by replacing Mo and Nb in high chromium heat resistant martensitic steels (such as modified 9Cr-1Mo) with W and Ta, respectively[1] . F82H [2] and JLF-1 [3] (see Table 1) are RAMs which have been developed and studied in Japan and various effects of irradiation have been reported [4,5]. F82H was designed with an emphasis on high temperature properties and weldablility, and was provided and evaluated in various countries as a part of the IEA collaboration on fusion materials development. The Japan/US collaboration program also has been conducted with the emphasis on irradiation effects of F82H. Now, among the existing database for RAMs the most extensive one is that for F82H. JLF-1 was designed with an emphasis on creep properties, and irradiation experiments have been conducted up to high dose at temperatures higher than 653K. The properties of JLF1 and F82H are similar in the unirradiated and irradiated conditions, and the R & D of RAMs in Japan is now performed in an all-Japan organization making the most of the advantages of these two RAMs.

It is very important for RAMs to have good toughness properties and high creep strength at the same time for fusion application, and it is also important to have the good aging resistance. W and Ta are the key elements for these properties. It is well known that increasing W will achieve higher creep property but lose the toughness and vice versa. Ta is used in RAMs as it

TABLE 1 CHEMICAL COMPOSITION OF JAPANESE REDUCED ACTIVATION MARTENSITIC STEELS

	C	Si	Mn	Cr	V	W	N	Ta
F82H[1]	0.09	0.07	0.10	7.87	0.19	1.98	0.006	0.04
JLF-1	0.1	0.05	0.45	8.86	0.20	2.0	0.025	0.08

[1] IEA-F82H (IEA heat of F82H, verified under IEA collaboration for Fusion materials development)

Heat Treatment F82H: Normalization;1313K for 38min, Tempering; 1023K for 1h
JLF-1: Normalization;1323K for 1h, Tempering; 1053K for 1h

expected to perform just same as Nb and contribute to have the good toughness and high creep, but it should be recognized that this element is not generally used for commercial alloys and its impacts on steel fabrication is not well known.
The objective of this paper is to review the R&D status of F82H and to identify the key issues for ITER-TBM application and for DEMO application suggested from the recent achievements in Japan.

2. Research and Development of F82H and its key issues as ITER-TBM structural material

It is desirable to make the status of RAMs equivalent to commercial steels in order to use RAMs as the ITER-TBM structural material. This would require proving the reproductively and weldability as well as providing the database. The excellent reproducibility of F82H has been demonstrated with four 5-ton-heats, and two of them were provided as F82H-IEA heats. In addition to the large scale charges, more than twenty laboratory-scale charges have been produced for validating heat treatment response and minor element effects. It has been also proved that F82H could be provided as plates (thickness of 1.5 to 55mm), pipes and rectangular tubes.

The excellent weldability was revealed through TIG weld tests performed in an air atmosphere, since F82H and its filler wire was designed to have good weldability and good joint property [2, 6]. Charpy impact tests on TIG weld metal show that ductile-brittle transition temperature (DBTT) did not changed from that of base metal, and stayed below 0 degree C (*see FIG.1.*). Creep properties of base metal and weldments obtained from F82H and JLF-1 suggest that there is no large difference between weld joint creep property and that of base metal in both RAMs in low stress region, but the weld joint tend to fracture at smaller Larson Miller parameter in higher stress region. (*see FIG.2.*) This tendency suggests the onset of Type IV fracture which tend to be found on fine-grained HAZ region. Aging tests were also performed on F82H weldments, and it revealed that the Charpy impact property of weld metal did not changed after 10,000 hour aging at 550 degree C (*see FIG..3.*).

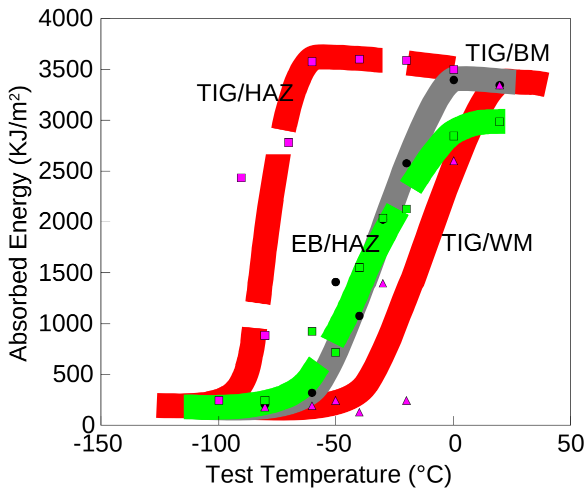

FIG.1 The Charpy impact tests on TIG/EB weldments of F82H. BM: Base metal, WM: Weld metal, and HAZ: Heat affected zone.

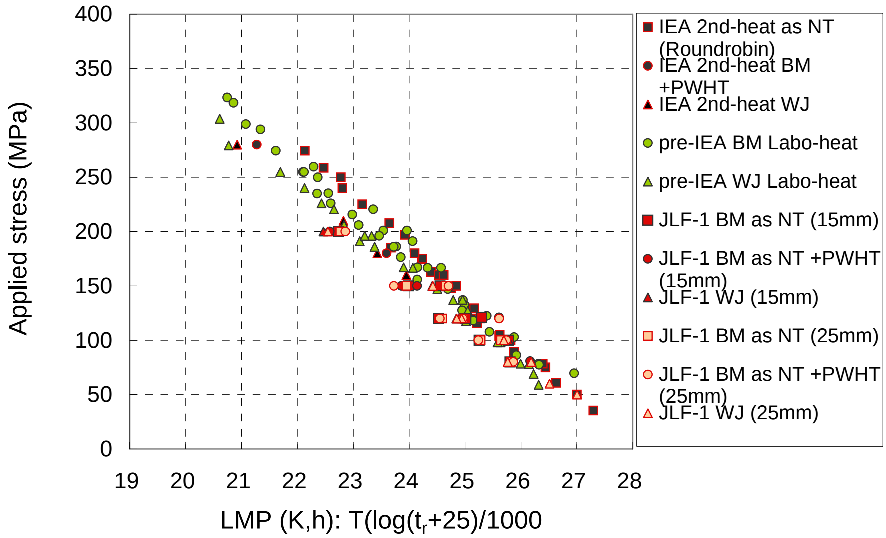

FIG.2. The creep tests on base metal and TIG weldments of F82H and JLF-1

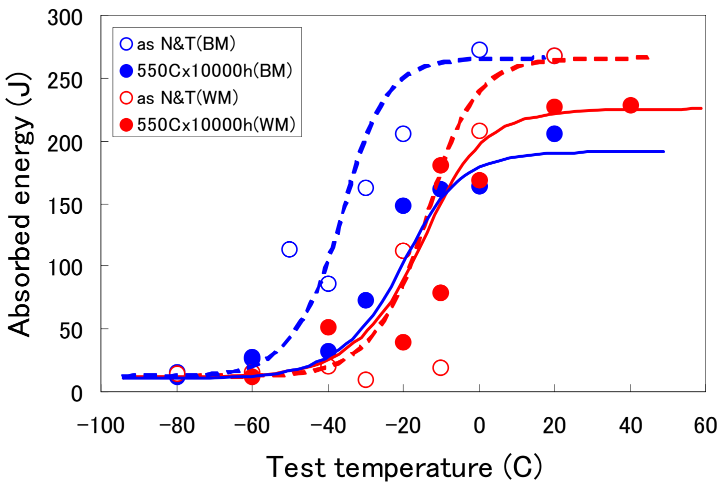

FIG.3. The Charpy tests on aged base metal and TIG weldmetals of F82H

Although F82H is currently perceived as a prime RAM for the ITER-TBM structural material, some issues remain to be examined to assure its applicability even under the most severe operation scenario. ITER will be operated in the pulsed mode with cycles up to 30,000, and severe plasma disruptions are expected to occur 100 times per year, suggesting that the structural materials will experience fatigue and/or creep fatigue loading under irradiation. The fatigue softening has the potential to degrade the strength of RAMs during the ITER operation.

Another issue would be the lost of uniform elongation appearing in irradiated RAMs[7], which could lead to component failure in case of the most severe plasma disruption. To overcome these issues, it is essential to obtain a good understanding of the detailed mechanical properties and to carefully design the TBM based on that information.

3. Key issues of RAMs for DEMO application

The potential of RAMs for DEMO application has been proved through high dose irradiation experiments such as the FFTF/MOTA program [5], but some key issues, such as the microstructure stability under/after high dose irradiation below 673K and the effects of transmutation elements, are necessary to resolve before RAMs are put into practical use. Fine tuning of elemental composition and production processes should be carried out in consideration of these issues. Recent studies revealed that the stability of precipitates under irradiation plays one of the key roles [8], and the heat treatment conditions affect the stability.

The effects of Ta are recognized to be another key issue. Ta is added to all RAMs to improve creep strength as well as fracture toughness. For example, the effect of Ta on creep property appears on minimum creep rates. As it shown in *FIG.4.*, stress exponents of F82H mod3 (F82H with 0.1Ta) is the same as that of F82H at lower temperature and higher stress level, but it become larger at lower stress level, and this suggest the effect of Ta, as it is the only difference between theses RAMs. On the other hand, Ta is also the element which decrease the mechanical property of weldment[6]. Ta is also decrease weldability. *FIG. 5.* show the results of the trans-varestraint test performed on F82H and its Ta concentration variation. The plot indicate that the hot cracking susceptibility increased as Ta concentration increased. These effects are quite depended on how Ta present in RAMs. It has been believed that Ta form MX just as Nb do [9], but recent XRD analyses study on extraction residue sample obtained from F82H show no MX peaks [9]. Detailed microstructure analyses of F82H with the emphasis on inclusion has recently found that Ta did form complex oxide (Ta oxide with aluminum) (*see FIG.6.*), and this has been suspected to have some impact on mechanical property. To understand these problems, it is necessary to understand the Ta effects on phase stability in the steel, and it is desirable to summarize the status of Ta from each RAM, because Ta is not used in commercial steels and only used in RAMs for fusion application,

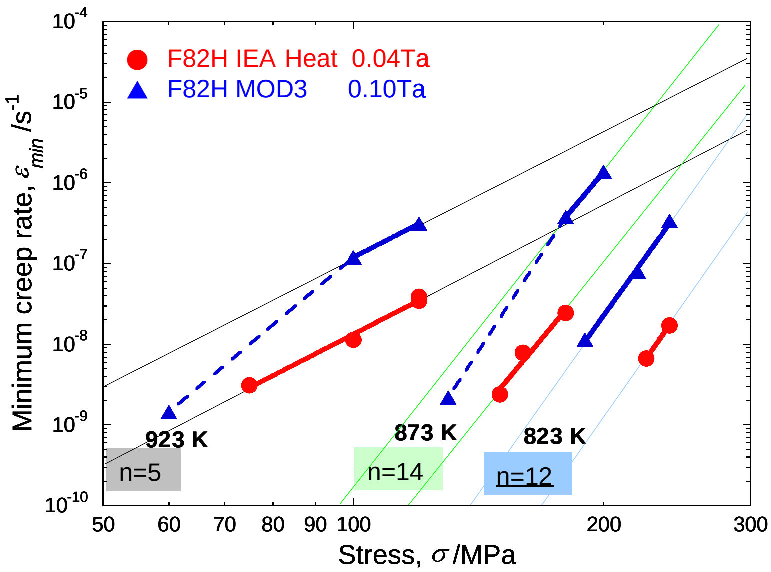

FIG.4 Stress dependence of minimum creep rate of F82H-IEA heat and F82H Mod3 (F82H with 0.1Ta, low Ti, N). $\varepsilon_{min} = A\sigma^n$ *, where A is constant, s is stress, and n is stress exponent.*

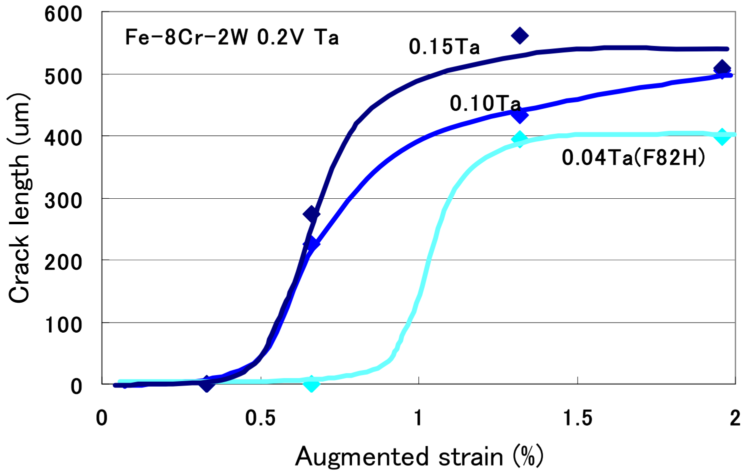

FIG..5. Ta concentration dependence of hot cracking susceptibility obtained by trans- varestraint tests

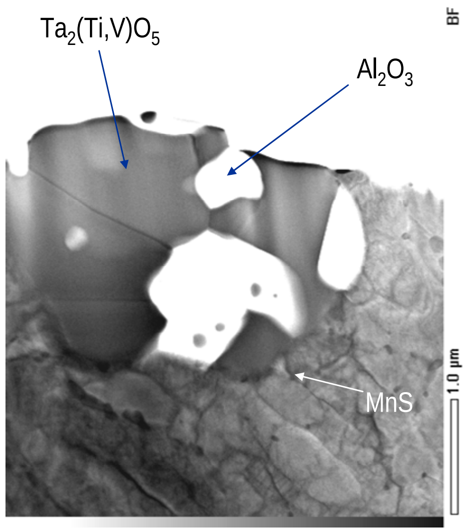

FIG.6. Cross sectional bright field STEM image of complex inclusion found in F82H

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and as the result, there is not quite enough information on Ta for steel fabrication. This is common issues for all type of RAMs but requires an extensive research effort, thus, it is desirable to be carried out effectively utilizing an international collaboration of the parties developing the RAMs .

4. Summary

(1) Progress on RAM R&D in Japan has reviewed with the emphasis on fabrication technology. It was indicated that the mechanical properties of Japanese RAMs weldments are quite acceptable for TBM fabrication.
(2) The Ta effects are indicated as the key issues for all RAMs. It was indicated that even though Ta is the essential element for RAMs but very minor element as the additive for commercial steels and behave quite different from Nb. Necessity of international collaboration on Ta problem are suggested.

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