Development of Reduced Activation Ferritic-Martensitic Steels in South Korea

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1. Introduction

In the mid-1980s research programs for development of low activation materials began. This is based on the US Nuclear Regulatory Commission Guidelines (10CFR part 61) that were developed to reduce long-lived radioactive isotopes, which allows nuclear reactor waste to be disposed of by shallow land burial when removed from service. Development of low activation materials is also key issue in nuclear fusion systems, as the structural components can became radioactive due to nuclear transmutation caused by exposure to high-dose neutron irradiation. Reduced-activation ferritic-martensitic (RAFM) steels have been developed in the leading countries in nuclear fusion technology, and are now being considered as candidate structural material for the test blanket module (TBM) in the international thermonuclear experiment reactor (ITER). South Korea joined the ITER program in 2003 and since then extensive effort has been made for developing the helium-cooled solid-breeder (HCSB) TBM which is scheduled to be tested in the ITER program. However, there has been no research activity to develop RAFM steels in South Korea, while all the participants in the ITER program have developed their own RAFM steels [1-5]. It is recently that the Korea Atomic Energy Research Institute (KAERI) started the Korean RAFM steel research program, aiming at an application for the HCSB-type TBM structure in ITER. In what follows, the current status of RAFM steels and the R&D program led by KAERI to develop Korean RAFM steels are summarized.

2. Current Status of RAFM Steels for Fusion Reactor Application

When ferritic-martensitic steels were considered as structural materials for fusion reactors in the late 1970s, 9Cr-1Mo steel was the first candidate in the US [6]. This is because the alloy exhibit good strength, high thermal conductivity and relatively good resistance to irradiation-induced swelling. In the mid-1980s, the idea of low activation materials was introduced, and the calculation of radioactivity decay suggests that reduced activation status could be achieved if typical alloying elements exhibiting high induced-radioactivity (e.g., Ni, Mo, Nb, Cu and N) were eliminated or restricted [7]. This leads to development of RAFM steels in which such elements in 9Cr-1Mo steels are replaced by the elements like W, Ta, V and Mn. International research programs carried out in the US, Japan and Europe settled on ORNL 9Cr-2WVTa, F82H, EUROFER97, respectively.

Table I: RAFM steels developed in the leading countries in fusion technology

Country	Institute	Alloy	Composition
Japan	JAEA	F82H	8Cr-2W-0.2V-0.04Ta
EU	CEA FZK	EUROFER97	9Cr-1W-0.2V-0.12Ta
US	ORNL	ORNL 9Cr-2WVTa	9Cr-2W-0.25V-0.08Ta
India	IGCAR	Indian RAFM	9Cr-1W-0.2V-0.07Ta
China	IPP	CLAM	9Cr-1.5W-0.2V-0.15Ta
Russia	Bochvar	RUSFER EK-181	11Cr-1.2W-0.6V-0.2Ta

Among various RAFM steels (Table I), F82H and EUROFER97 were produced in large scale in the mid-1990s, and then distributed worldwide for performance evaluation as a part of International Energy Agency collaboration, which allows the alloys to establish the world’s largest database. Round-robin tests performed on F82H and EUROFER97 reveal that both alloys have adequate strength, acceptable resistance to irradiation swelling and He embrittlement, and good compatibility with aqueous, gaseous and liquid coolants which allows for various design options. Accordingly, these alloys are currently considered as the primary structural materials for the ITER-TBM systems. There are, however, several issues remaining with such RAFM steels. These include a limited creep resistance at high temperatures and irradiation-induced embrittlement at low temperatures, which limit the operating temperature window to 250~550°C. Additional issues are production of He and H under high-dose irradiation conditions, relatively poor weldability and a limited database at high irradiation doses. The operating conditions in the TBM system in ITER and the properties required for the RAFM steel are summarized in Table II.

Table II: Operating conditions of the TBM system in ITER and the properties required for RAFM steels [8]

Temperature window	250~550°C
Max. irradiation damage	~150 dpa
Yield strength	> 500 MPa at RT; > 350 MPa at 500°C
Creep strain (irradiated)	< 1%
Irradiation swelling	< 2%
DBTT (irradiated)	< 50°C
Toughness of weldments	> 70% of matrix

3. R&D Program for the Korean RAFM Steels

The R&D program for the Korean RAFM steels began in the early 2012. The purpose of the program is to develop Korean own RAFM steels and to provide large-scale RAFM steel plates for fabrication of TBM mockup. The development procedure for the Korean RAFM steel is schematically shown in Fig. 1.

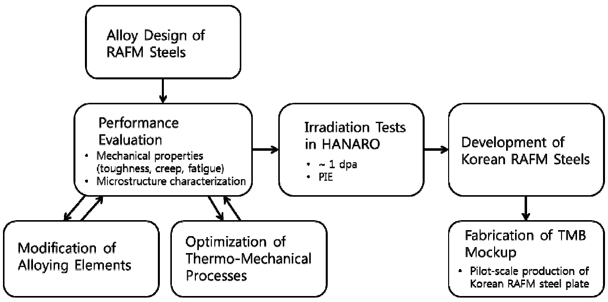

Fig. 1. Development procedure for the Korean RAFM steels

Alloy design of more than 60 preliminary compositions has been completed, the strategy of which focusing on the improvement of toughness and creep resistance. Some (Batch 1) of preliminary alloys were already produced in POSCO, and the tensile, creep, and impact tests of the alloys are currently under way. Based on the test results, both alloy compositions and thermo-mechanical processes (TMP) employed to produce plate will be modified, and the performance of the alloys thus prepared (Batch 2) will be evaluated again. Such fine tuning of composition and process will be repeated until the properties of program alloys meet the requirements as the TBM structural material. For two program alloys qualified for the requirements, the neutron irradiation tests up to 1 dpa in HANARO and the post-irradiation examination (PIE) will be carried out in 2014-2015. Based on the PIE results, one of two candidate alloys will be selected as the Korean RAFM steel, and the alloy will be produced in a pilot-scale (~1 ton) in POSCO Specialty Steel Company for fabrication of the TBM mockup. Under a good scenario, the HCBS TBM system (a TMB concept which is being led by the National Fusion Research Institute in South Korea) would be fabricated with the Korean RAFM steel and then installed in ITER in 2020.

4. Summary

The current status of RAFM steel and the research plan to develop the Korean RAFM steels are briefly summarized. Both F82H and EUROFER97 have an adequate experience base to be used as TBM structural material. The program to develop the Korean RAFM steel commenced in the early 2012. The development structure includes alloy/process design, performance evaluation, irradiation test in HANARO and PIE. The program alloy exhibiting the best performance will be chosen as the Korean RAFM steel and then produced in a large-scale for TBM mockup fabrication in 2016.

REFERENCES

[1] R.L. Klueh, E.E. Bloom, The development of ferritic steels for fast induced-radioactivity decay for fusion reactor applications, Nuclear Engineering and Design. Fusion, Vol. 2, p. 383, 1985.
[2] M. Tamura, H. Hayakawa, M. Tanimura, A. Hishinuma, T. Kondo, Development of potential low activation ferritic and austenitic steels, Journal of Nuclear Materials, Vol. 141-143, p. 1067, 1986.
[3] K. Ehrlich, S. Kelzenberg, H.D. Rohrig, L. Schafer, M. Schirra, The development of ferritic-martensitic steels with reduced long-term activation, Journal of Nuclear Materials, Vol. 212-215, p. 678, 1994.
[4] B. Raj, K. Bhanu, S. Rao, A.K. Bhaduri, Progress in the development of reduced activation ferritic-martensitic steels and fabrication technologies in India, Fusion Engineering and Design, Vol. 85, p. 1460, 2010.
[5] Q. Huang, J. Li, Y. Chen, Study of irradiation effects in China low activation martensitic steel CLAM, Journal of Nuclear Materials, Vol. 329-333, p. 268, 2004.
[6] S.N. Rosenwasser, P. Miller, J.A. Dalessandro, J.M. Rawls, W.E. Toffolo, W. Chen, The application of martensitic stainless steels in long lifetime fusion first wall/blankets, Journal of Nuclear Materials, Vol. 85-86, p. 177, 1979.
[7] E.E. Bloom, R.W. Conn, J.W. Davis, R.E. Gold, R. Little, K.R. Schultz, D.L. Smith, F.W. Wiffen, Low activation materials for fusion applications, Journal of Nuclear Materials, Vol. 122, p. 17, 1984.
[8] P.M. Raole, S.P. Deshpande, Structural materials for fusion reactors, Transactions of The Indian Institute of Metals, Vol. 62, p. 105, 2009.