§7. Developments of Reduced Activation Ferritic/Martensitic Steels for Advanced Blanket Systems

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Reduced activation ferritic/martensitic steels are the most developed candidate materials for fusion in-vessel structures, in terms of industrial experience, mechanical and structural stability after high-fluence exposure to neutrons, etc. One of the major issues for the materials in this class it the enhancement of high temperature strength, primarily for improved power cycle efficiency in fusion energy systems.

The present study is a part of the efforts to develop reduced activation ferritic steels with enhanced heat resistance through straightforward chemistry optimization, namely the enrichment in tungsten to 2.5 to 3.5 mass percent from original 2.0 percent, of the most-proven 9Cr-2W-V,Ta steel (JLF-1). Previous studies successfully designed and trial-fabricated the tungsten-enriched JLS-series alloys and revealed the influence of tungsten content from an aspect of correlation between microstructural evolution and elevated temperature mechanical properties. Meanwhile, it has been pointed out that the enhanced heat resistance might sacrifice the impact property, that leads to raise the minimum operating temperature, while raising the maximum operating temperature of the design window at the same time. The potential impact property degradation in steels is known to be closely related with microstructural instability, for example the precipitation and coarsening of secondary phases, during long-term exposure in high temperatures with and without neutron loadings.

In this particular work, the correlation between the impact properties and microstructural development in JLF-1 and JLS-series alloys by means of long-term heat treatment. The materials were aged at 650C for 1000 and 3000h followed by Charpy impact testing and the secondary electron fractography. The as-normalized and tempered and the aged microstructures were characterized by transmission electron microscopy.

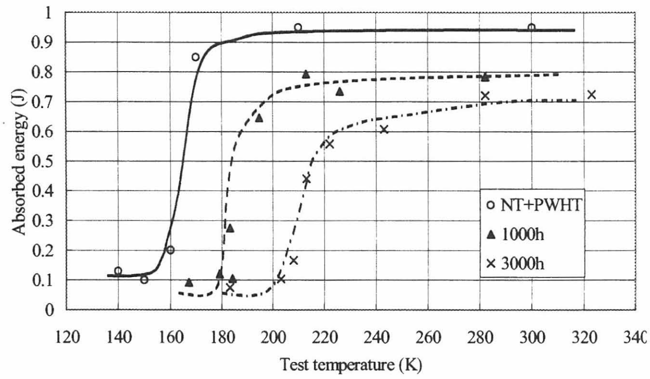
The results of Charpy impact property characterization to the as-normalized and tempered and aged JLF-1 and Fe-9Cr-3.0W-V,Ta JLS-2 steels are presented in Figs.1 (a) and (b), respectively. It is confirmed that the high temperature exposure for longer terms increases the ductile-to-brittle transition temperature (DBTT) and reduces the upper shelf energy. The transmission electron microscopy revealed that the heat treatment enhances the coarsening of $M_{23}C_6$ type precipitates and the precipitation and growth of Laves phase, which is based on Fe_2W composition, both observed mostly on the prior austenitic grain boundaries. The observed impact property degradation is, therefore, likely to be associated with these precipitation behavior.

In the tungsten-enriched JLS-2 steel, the aging-induced degradation in the impact property appeared remarkable at 1000h compared to the JLF-1. However, further degradation by heat treatment to 3000h was not significant and the amount of DBTT shift in JLS-2 was comparable with that in JLF-1.

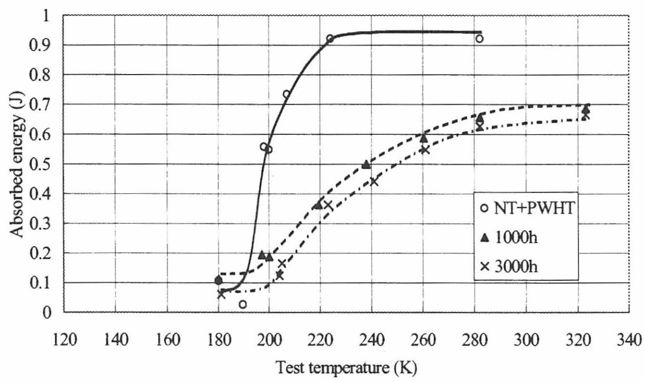
As a conclusion, fundamental knowledge regarding the impact property and its evoluation under high temperature exposure was obtained for the enhanced heat resitance reduced activation ferritic steels. The tungsten enrichment rather simply shifts the design window for the 9Cr-2W-V,Ta steel to the high temperature side. The optimium utilization of comventional and chemical taylored materials should ensure the flexibility and power cycle efficiency in the engineering design of the ferritic steel-based fusion blankets.

Reference

1) H. Sakasegawa, T. Hirose, T. Suzuki, A. Kohyama, Y. Katoh, T. Harada, K. Asakura and T. Kumagai, “Effect of precipitaion morphology on toughness of Reduced Activation Ferritic/Martensitic steels”, Journal of Nuclear Materials, in printing.



(a) JLF-1 (2.0%W)



(b)JLS-2 (3.5%W)

Fig. 1 Charpy impact properties of JLF-1 (a) and JLS-2 (b) reduced activation ferritic steels in standard NT condition and after aging at 650C.