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The Effect of Small Additional Elements on the Mechanical Properties of 9Cr-1.5W Steel

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1. Introduction

Reduced activation ferritic-martensitic (RAFM) steel is considered a primary candidate for the fusion blanket system owing to its good mechanical properties and excellent irradiation resistance [1-4]. The operational design window for the blanket is limited by the high-temperature creep and low-temperature irradiation embrittlement of the structural material. Accordingly it is essential to develop RAFM steel that is able to withstand high temperatures and high energy neutron irradiation. In this study, an attempt was made to improve the mechanical properties of RAFM steel by the addition of small amounts of boron and/or titanium.

2. Methods and Results

2.1 Experimental Procedure

The materials investigated in this work are 9Cr-1.5W, 9Cr-1.5W-0.005B and 9Cr-1.5W-0.005B-0.005Ti steel. The alloys were prepared by a vacuum induction melting process. The steel ingot was hot-rolled after preheating at 1150℃ for 2h. The hot-rolled plate was normalized at 1050℃ for 50 min, and then tempered at 760℃ for 90 min.

Optical microscopy (OM) and transmission electron microscopy (TEM) were employed to investigate the microstructure of the tempered plate. A chemistry of the precipitates formed in the matrix was quantified by an energy dispersive spectroscopy (EDS) attached to a TEM. A plate-type sub-size tensile specimen with a gage dimension of 2.5 mm in thickness, 6.25 mm in width, and 25 mm in length (ASTM E8) was machined from the tempered plates, and an uniaxial tensile test was performed at 25°C at an initial strain rate of 10^{-3} s^{-1}. A ductile-brittle transition temperature (DBTT) of the tempered plates was determined by a Charpy impact test, for which a full-size notched bar was used according to the ASTM E23.

2.2 Results

Figs. 1 and 2 show the OM and TEM images of the alloys studied. All the samples show a tempered martensitic structure composed of subgrains and martensite laths. Most of the precipitates observed were $M_{23}C_6$ and V-rich MX. The addition of boron or titanium was found to have little influence on the microstructure.


(a) 9Cr-1.5W alloy


(b) 9Cr-1.5W-0.005B alloy

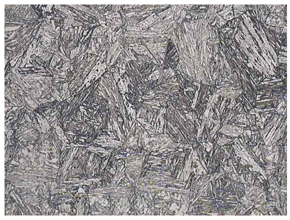
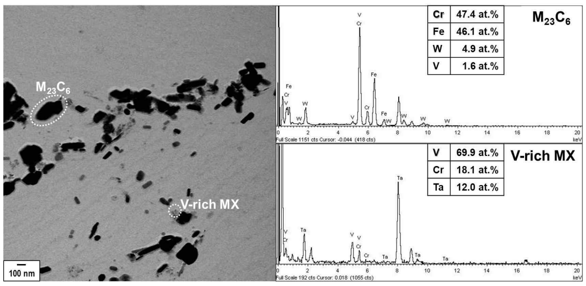
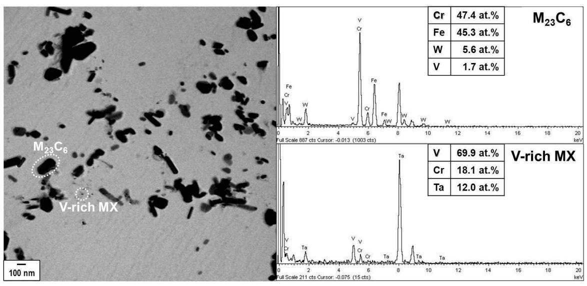

(c) 9Cr-1.5W-0.005B-0.005Ti alloy

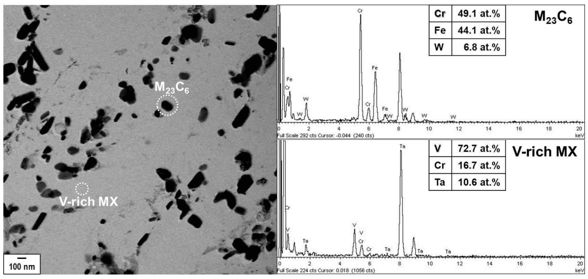
Fig. 1. Optical micrographs of 9Cr-1.5W steels



(a) 9Cr-1.5W alloy



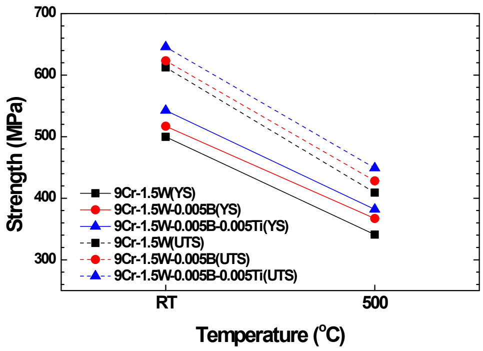
(b) 9Cr-1.5W-0.005B alloy



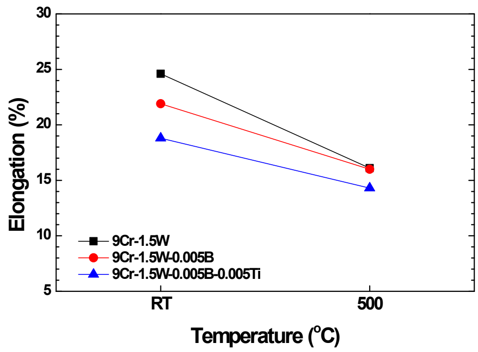
(c) 9Cr-1.5W-0.005B-0.005Ti alloy

Fig. 2. TEM images of the 9Cr-1.5W steels

Fig. 3 shows the tensile properties of the alloys. Both the yield strength and ultimate tensile strength are increased by the addition of boron. A further increase in strength is achieved by the addition of both boron and titanium. Such an increase in strength is attributed to the solid solution hardening of the elements, but is at the sacrifice of ductility. A similar effect was observed for the test at 500°C.



(a) Yield and tensile strength



(b) Elongation

Fig. 3. Tensile properties of 9Cr-1.5W steels

Shown in Fig. 4 are the DBTT and upper shelf energy (USE) of the alloys investigated. The additional decrease in DBTT is observed for the alloy containing both boron and titanium. The USE is found to be less sensitive to the alloying elements. From the mechanical tests, it was concluded that the addition of both boron and titanium enhances the tensile strength and impact resistance.

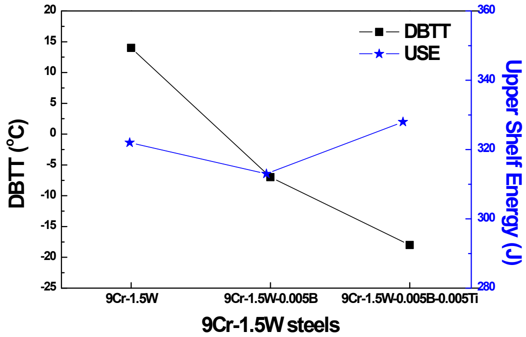


Fig. 4. Impact properties of 9Cr-1.5W steels

3. Conclusions

The addition of a small amount of boron and titanium in RAFM steel enhances both the strength and impact resistance of 9Cr-1.5W based RAFM steel. The increase in strength is attributed to the solid solution hardening effect of the alloying elements, while the role of such elements in improving the impact resistance is unclear.

Acknowledgements

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