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Effect of microstructural evolution by isothermal aging on the mechanical properties of 9Cr-1WVTa reduced activation ferritic/martensitic steels

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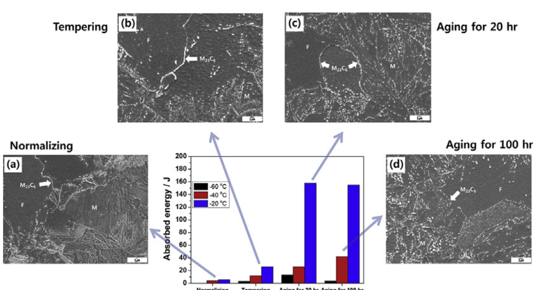
GRAPHICAL ABSTRACT



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ABSTRACT

The influence of microstructural changes caused by aging condition on tensile and Charpy impact properties was investigated for reduced activation ferritic-martensitic (RAFM) 9Cr-1WVTa steels having single martensite and a mixed microstructure of martensite and ferrite. For the mixed microstructure of martensite and ferrite, the Charpy impact properties deteriorated in both as-normalized and tempered conditions due to the ferrite and the accompanying $M_{23}C_6$ carbides at the ferrite grain boundaries which act as path and initiation sites for cleavage cracks, respectively. However, aging at 550 °C for 20–100 h recovered gradually the Charpy impact toughness without any distinct drop in strength, as a result of the spheroidization of the coarse $M_{23}C_6$ carbides at the ferrite grain boundaries, which makes crack initiation more difficult.

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1. Introduction

Reduced activation ferritic-martensitic (RAFM) steels with composition of (8~9)Cr-(1~2)W-V-Ta (in wt%) are a strong candidate material for fusion reactors among the various structural materials such as oxide dispersion-strengthened (ODS) steels, SiC_f/SiC composites, V alloys and W alloys [1–3]. Thus, many countries have developed their own RAFM steels, e.g., Eurofer97 from Europe, F82H from Japan, ORNL3971 from USA, and CLAM from China, etc.

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[4–6]. It has been reported that the RAFM steels have tempered martensite microstructure, Cr-rich $M_{23}C_6$ carbides at the grain, packet/lath boundaries, fine MX precipitates inside the laths, and relatively excellent mechanical properties: a tensile strength of about 650 MPa and ductile-brittle transition temperature (DBTT) of −60 ~ −80 °C [7–12]. Furthermore, there have been many studies to understand the relationship between mechanical properties and the microstructures induced by aging heat treatment [12–18,24–26].

P. Fernandez et al. [16] have reported that $M_{23}C_6$ carbide and MX precipitate were found in as-tempered Eurofer97 steels. Although the slight growth of both types of precipitates was observed after aging treatment at 773 K (500 °C) for 5000 h and 873 K (600 °C) for 1000 h, the aging treatments had no influence in the tensile properties and ductile-brittle transition temperature (DBTT). K. Shiba et al. [24] investigated the aging effect on precipitation behavior in F82H steel. They reported that any other particles such as Laves phase and M_6C except $M_{23}C_6$ and MX precipitated after aging in the range of temperature of 773 K (500 °C) and 873 K (600 °C) for 10,000 h.

However, much attention has not been given to the aging effect in a mixed microstructure of martensite and ferrite as well as the influence of the constituent phases on the mechanical properties. The authors reported the effect of the variation of the constituent phases on the tensile and Charpy impact properties of 9Cr-(1~2)W RAFM steels with a mixed microstructure in both as-normalized and as-tempered conditions [19,20]. This study investigates the effect of aging heat treatment on the microstructural evolution and mechanical properties of 9Cr-1WVTa RAFM steel with a mixed microstructure as an extension of a previous work [19].

2. Experimental procedure

2.1. Materials

The chemical composition of the examined steel is Fe-0.10C-8.96Cr-1.1W-0.21V-0.074Ta-0.41Mn-0.086Si-0.005P-0.004S (in wt.%), which is similar to the composition of Eurofer 97 steel [12]. The steel was prepared using a vacuum induction melting furnace. A 50 kg ingot was hot rolled to a 25 mm thickness and cut into blocks with dimensions of 170 × 70 × 25 mm. The block specimens were homogenized at 1473 K (1200 °C) for 12 h and normalized at 1253 K (980 °C) for 30 min, followed by cooling to ambient temperature at two cooling rates: one was water quenching to form the full martensite microstructure (designated as 'M') and the other was controlled furnace cooling to form the mixed microstructure of martensite and ferrite (designated as 'M + F'). Subsequent tempering treatments were carried out at 1033 K (760 °C) of 1.5 h followed by air cooling, which is a typical tempering condition for Eurofer 97 steel to avoid detrimental precipitates like Laves phases [12]. Finally, isothermal aging at 823 K (550 °C) for a relatively short time in a range of 20–100 h was carried out to simulate thermal exposure at high temperatures.

2.2. Mechanical testing

Tensile and Charpy impact properties were evaluated for the block specimens which were heat treated. Tensile tests were performed with sub-size test coupons (4ϕ × 60 mm) following ASTM E8M using a universal tensile test machine (INSTRON 5882, INSTRON). The test were conducted at a cross head speed of 2 mm/min

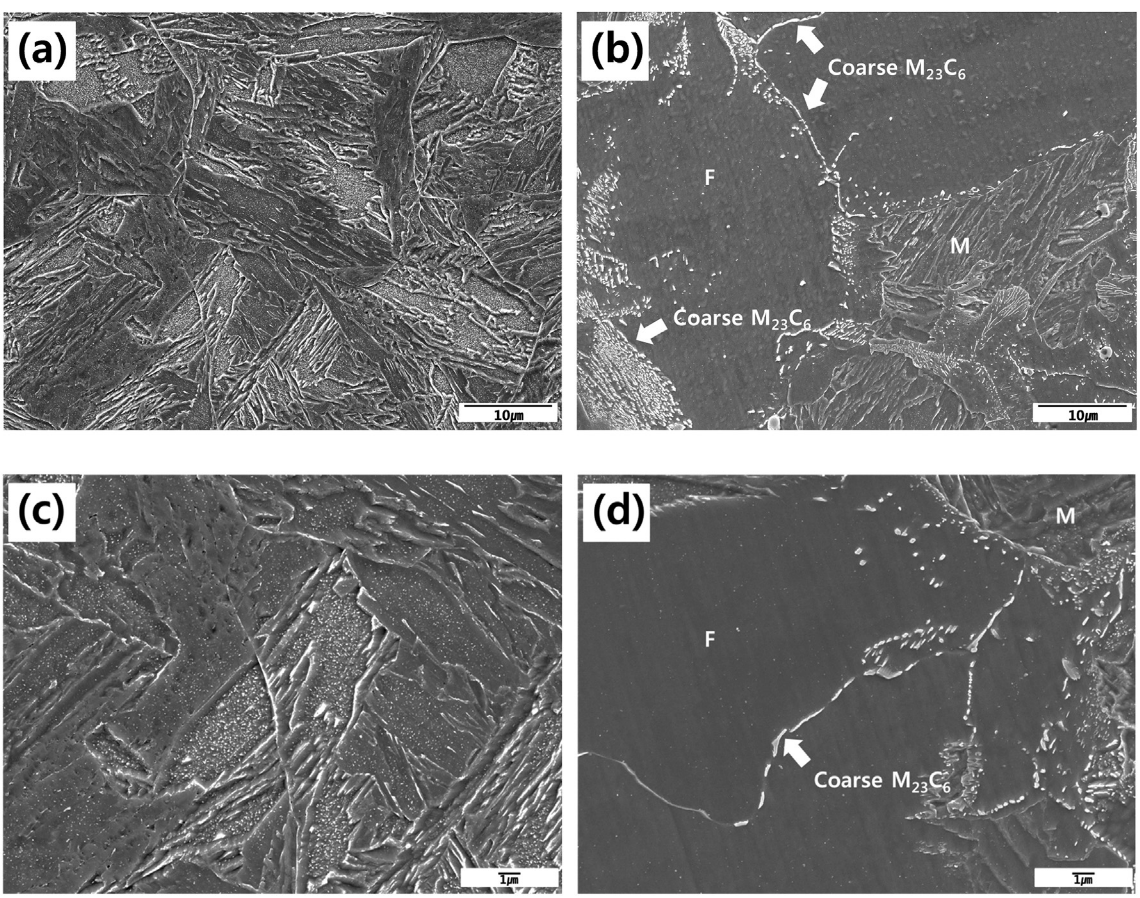

Fig. 1. SEM micrographs of the as-normalized specimens: (a) M specimen, (b) M + F specimen, (c) M specimen at high magnification, and (d) M + F specimen at high magnification.

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