Effects of Heat Treatment Conditions on the Mechanical Properties of RAFM Steel

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1. Introduction

In the mid-1980s, research programs for the development of low activation materials began. This is based on the US Nuclear Regulatory Commission Guidelines (10CFR part 61) developed to reduce long-lived radioactive isotopes, which allows nuclear reactor waste to be disposed of by shallow land burial when removed from service. The development of low activation materials is also a key issue in nuclear fusion systems, as the structural components can became radioactive due to a nuclear transmutation caused by exposure to high-dose neutron irradiation. Reduced-activation ferritic-martensitic (RAFM) steel has been developed in leading countries for nuclear fusion technology [1], and is now being considered as a primary candidate material for the test blanket module (TBM) in the international thermonuclear experiment reactor (ITER).

The mechanical properties of RAFM steel are strongly affected by microstructural features including the distribution, size as well as the type of the precipitates, dislocation density and grain size [2,3]. Such microstructural characteristics are determined mainly by the thermo-mechanical process employed to fabricate the final product. Accordingly, the final heat treatments are the key steps to control the microstructure and mechanical properties. In the present work, we investigated the mechanical properties of the RAFM steel with a particular attention being paid to the effects of the normalizing and tempering conditions on the mechanical properties.

2. Methods and Results

2.1 Experimental procedures

A total of 37 alloys were designed where the amounts of alloying elements such as V, Ta, Ti and Zr vary systematically in 9Cr-1W based RAFM steel. Rectangular shaped ingots were produced by vacuum induction melting (VIM), and were hot rolled at 1200°C to 15 mm-thick plates. The first batch of model alloys (with 22 different compositions) were normalized at 1050°C, while the second batch of alloys (with 15 different compositions) were normalized at 980°C. The normalizing and tempering conditions employed are summarized in Table I.

Table I: Heat treatment conditions employed in the present work

	Normalizing	Tempering
Batch 1	1050°C/30m	760°C/50m
		760°C/90m
		760°C/180m
Batch 2	980°C/40m	760°C/50m
		760°C/70m
		760°C/100m

Plate-type sub-size tensile specimens with a gage dimension of 2.5 mm in thickness, 6.25 mm in width and 25 mm in length (ASTM E8) were 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 creep rupture test was conducted at 550 °C under an applied stress of 240 MPa, using a rod-type specimen with a gage dimension of 6 mm in diameter and 28 mm in length. 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 and Discussion

The yield strength (YS) and total elongation (TE) of the program alloys determined at room temperature are shown in Fig. 1. The batch 1 alloys normalized at 1050°C (Fig. 1(a)) exhibits a large scatter in the tensile properties: the YS and TE vary between 700 and 420MPa, and 14-29%, respectively, depending on the tempering condition. When normalized at 980°C (i.e., batch 2 alloys), the samples show a much smaller scattering in the tensile properties (Fig. 1(b)). The tensile properties of the F82H alloy lie on a trade-off line between the YS and TE of the batch 2 alloys.

A decrease in the normalizing temperature leads to an improvement of impact resistance. For the batch 1 alloys, the ductile-brittle transition temperature (DBTT) is far above -40°C (Fig. 2(a)) whereas more than half of the batch 2 alloys show a DBTT of less than -40°C.

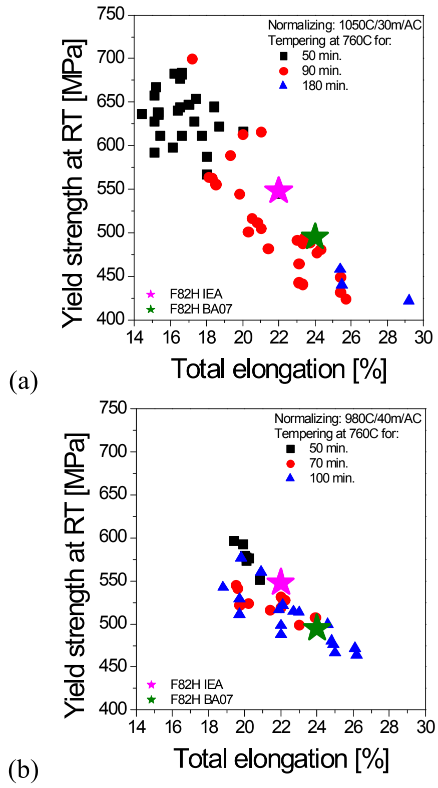

Fig. 1. The tensile properties of (a) batch 1 and (b) batch 2 alloys at room temperature.

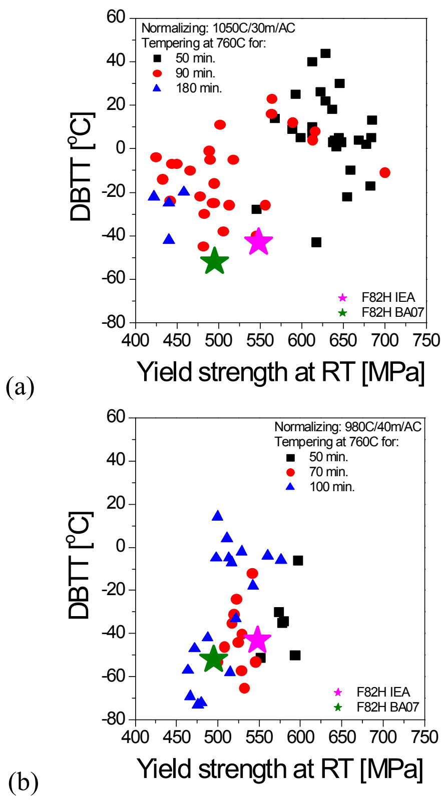

Fig. 2. Plots of the DBTT against the yield strength at room temperature: (a) batch 1 and (b) batch 2 alloys.

The enhanced impact resistance found in batch 2 alloys is attributed to the refined prior austenite grains (PAG), which in turn are attributed to the reduced normalizing temperature.

A correlation is made between the creep rupture time and the DBTT of the selected alloys in Fig. 3. It is a general trend that the under-tempered samples show a better short-term creep resistance. Some of the batch 2 alloys are found to exhibit a much better resistance to the impact and creep than the F82H alloy.

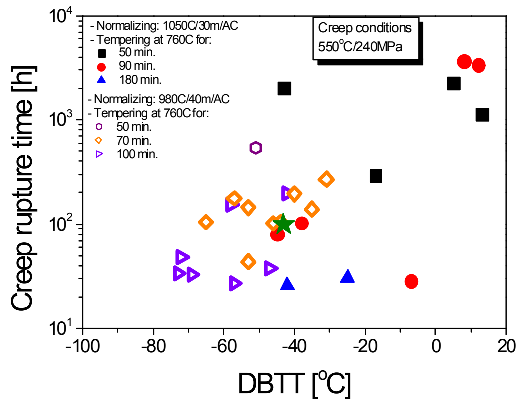

Fig. 3. A plot of creep rupture time against the DBTT of the selected alloys.

3. Conclusions

From a statistical analysis made on the mechanical properties of the RAFM steels designed, it was found that a reduction in the austenitization temperature results in a refinement of PAG, which in turn leads to an improvement of the impact resistance. The short-term creep resistance is enhanced as the tempering time decreases. Accordingly, it is concluded that for a given alloy composition, an improvement of both creep and impact resistance can be achieved by an optimization of heat treatments.

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