Effect of Thermo-mechanical Treatment on Mechanical Properties of Korean RAFM steel

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1. Introduction

Reduced activation ferritic martensitic (RAFM) steel is a candidate structural material for nuclear fusion power systems owing to their high thermal conductivity, and low thermal expansion coefficients outstanding resistance to radiation induced swelling compared to conventional austenitic steels [1-2]. Furthermore, the high-level of technological maturity of these steels acquired from fusion power plants and other advanced technology applications secures them attractive for fusion power applications [3].

Advanced reduced-activation alloy (ARAA) of Korean RAFM steels was developed by Korea Atomic Energy Research Institute (KAERI) and National Fusion Research Institute (NFRI) [4]. Thermo-mechanical treatment (TMT) has been known to be effective to improvement in mechanical properties of several RAFM steels by introducing high densities of dislocations and fine precipitates [5]. This study examines the effect of thermo-mechanical treatment on the microstructure and mechanical properties of ARAA alloy.

2. Methods and Results

2.1 Material Preparation

The chemical composition of ARAA is given in Table I. ARAA was fabricated by vacuum induction melting, hot forging and hot rolling. The hot rolled plates were subjected to various heats as summarized in Table II.

Each heat was divided into two parts. One part of each heat was subjected to normalization (980 °C for 40 min) and tempering (760 °C for 70min) followed by air-cooling. This part of heat is denoted as N&T in the following text. The other part of each heat was subjected to a hot-rolling with a total of 20 % thickness reduction after normalization and before tempering at the same temperature as the N&T condition. This part of heat is denoted as TMT in the following text.

Table I: Chemical compositions (wt.%) (balance Fe).

wt.%	C	Si	Mn	Cr	W	V	Ta	N	Ti	Zr
ARAA	.10	.10	.45	9.0	1.2	.20	.07	.01	.01	.01

Optical microscopy (OM) and transmission electron microscopy (TEM) were employed to investigate the microstructure of the tempered specimens. The etchant used for the metallographic examinations was composed of HF, HNO_3, and H_2O in a volume ratio of 5:10:85.

The mechanical properties of the specimens were assessed by Vickers micro-hardness measurement at room temperature using 0.5 kgf load during the 15 second, and tensile tests at room temperature using a strain rate of 10^{-3} s^{-1}. Ductile-brittle transition temperature (DBTT) of the tempered specimens was determined by the Charpy impact test, for which a full-size notched bar specimens were used according to the ASTM E23.

Table II: Test matrix in this study.

Specimen ID	Normalizing (°C / min)	Hot Rolling (°C / %)	Tempering (°C / min)
N&T	980 / 40	-	760 / 70
TMT		700 / 20	

2.2 Results and Discussion

Fig. 1 shows optical micrographs of ARAA alloy in N&T and TMT conditions. There was little difference in microstructure between the two specimens (Fig. 1).

As shown in Fig. 2, a relatively larger amount of precipitates were observed in the TMT specimen compared to the N&T specimen. Furthermore, the precipitates of $M_{23}C_6$ in the TMT specimen is mostly finer than those in the N&T specimen.

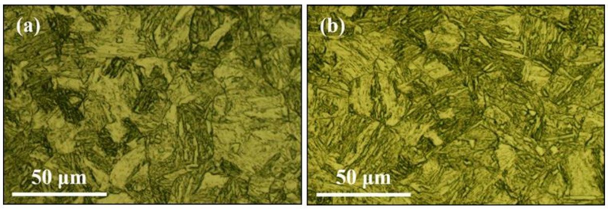

Fig. 1. Optical micrographs of the ARAA alloy in the conditions (a) N&T (b) TMT.

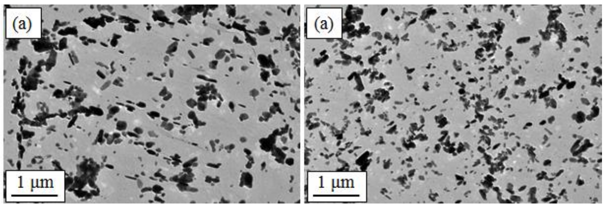

Fig. 2. TEM images of the ARAA alloy in the conditions (a) N&T (b) TMT.

Fig. 3 shows the Vickers micro-hardness of the ARAA alloy in the N&T and TMT conditions. Each data represents the average value of ten measurements made on the plane-view (i.e., longitudinal / rolling direction) and cross-section (i.e., transverse direction) specimens. As shown in Fig. 3, the TMT specimen significantly increases in hardness compared to the N&T specimen. It is well known that the TMT condition with refined prior-austenite grains showed a larger increase in hardness than the N&T condition [4].

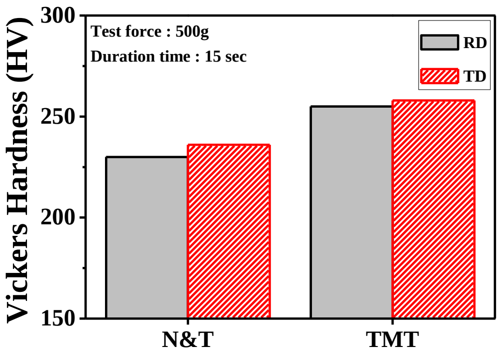

Fig. 3. Vickers micro-hardness of the ARAA alloy in the N&T and TMT conditions.

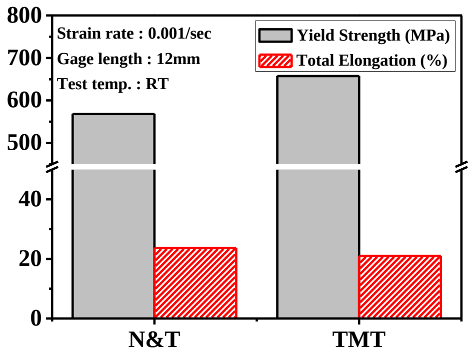

Fig. 4. Room temperature tensile properties of the ARAA alloy in the N&T and TMT conditions.

Fig. 4 shows the room temperature yield strength and total elongation of the ARAA alloy in the N&T and TMT conditions. Two specimens in the plane-view orientation, with specimen length along the rolling direction, were tested for each condition. The Yield strength of the specimens shows the same trend as their Vickers micro-hardness shown in Fig. 3. This is consistent with the observation of a positive proportional relationship between Vickers micro-hardness and yield strength [7]. ARAA alloy in the TMT condition showed a similar total elongation (~2.7% decrease) but significantly greater yield strength (~15.7% increase) compared to the N&T condition.

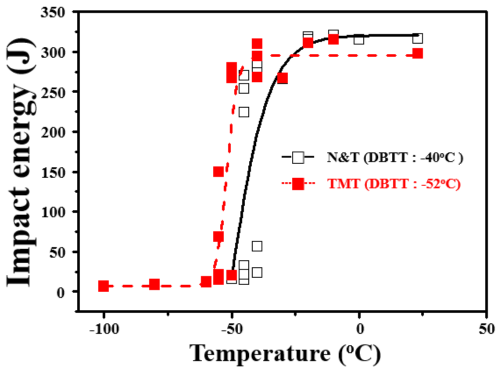

Fig. 5. Charpy impact properties of the ARAA alloy in the N&T and TMT conditions.

Fig. 5 shows the Charpy impact property of ARAA alloy in the N&T and TMT conditions. The TMT specimen leads to an improvement of impact property, reducing the DBTT from -40 to -52 °C.

3. Conclusions

The effects of thermo-mechanical treatment on microstructure and mechanical properties were studied. TMT consisting of austenitizing and 20% hot-rolling at 700 °C significantly enhances both tensile strength and impact property of ARAA, which suggests that a TMT is a promising way of improving mechanical properties of RAFM steels.

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