Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Microstructure and mechanical properties in the weld heat affected zone of 9Cr-2W-VTa reduced activation ferritic/martensitic steel for fusion

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1. Introduction

Reduced activation ferritic/martensitic (RAFM) steel has been developed as a potential candidate for the first wall and blanket of fusion reactor [1,2]. RAFM steel demonstrated excellent resistance to the neutron irradiation and mechanical properties [2]. The investigation of weldability in company with the development of RAFM steel is essential for construction of the fusion reactor. Generally, the superior mechanical properties of the RAFM steel can be upset during welding process due to microstructural change by rapid heating and cooling in the weld heat affected zone (HAZ) [3].

Therefore, this paper studied the microstructure and mechanical properties in the weld HAZ of RAFM steel. The mechanical properties of the HAZ were evaluated using a Vickers hardness test and Charpy impact test, and then discussed the relationship between the microstructure and mechanical properties in the weld HAZ.

2. Methods and Results

2.1 Experimental procedure

An ingot of the 9Cr-2W-VTa RAFM steel having 9.03Cr, 2.03W, 0.18V, 0.043Ta and 0.1C (all in wt %) was fabricated using a commercial vacuum-induction melting furnace. The ingot was initially hot-rolled into a plate with a thickness of 15 mm, after which the base steel was produced through normalizing at 1,000℃ for 30 min and tempering at 750℃ for 2 hours.

Specimens of the HAZs were prepared using a Gleeble simulator at different peak temperatures and heat inputs. The welding thermal cycle for simulating HAZs was calculated based on Rosenthal's heat –flow equation [4]. The microstructures of the base steel, HAZs and tempered HAZs were observed using a scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Finally, the strength and impact properties were evaluated using a Vickers hardness test and Charpy V-notch impact test.

2.2 Results

2.2.1 Microstructure of the base steel

Fig. 1 shows the SEM micrograph of the base steel. Through the normalizing and tempering heat treatment, the base steel consisted of tempered martensite with two types of carbides which were coarse $M_{23}C_6$ particles along lath boundaries and fine MX particles within the laths.

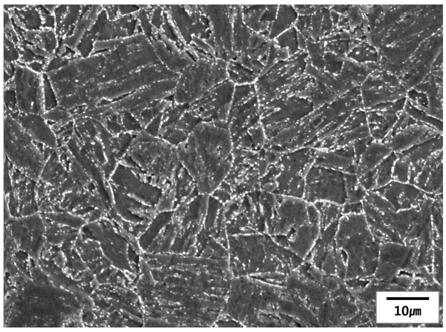

Fig. 1. SEM micrograph of the base steel

2.2.2 Microstructures in the weld HAZs

Fig. 2(a) is the SEM micrograph in the HAZ with welding condition of 1200℃ peak temperature and 30 kJ/cm heat input. As shown in Fig. 2(a), the HAZs consisted of martensite and δ-ferrite, and then the fraction of δ-ferrite increased with increase in the peak temperature and heat input. In addition, the prior austenite grain size and lath size of martensite in the HAZs increased with increase in the heat input.

Meanwhile, we carried out the tempering in order to simulate the post weld heat treatment (PWHT). Fig. 2(b) shows the SEM micrograph of the tempered HAZ, simulating with welding condition of 1300℃ peak temperature and 30 kJ/cm heat input. As shown in Fig. 2(b), the tempered HAZs consisted of tempered martensite and δ-ferrite. In addition, $M_{23}C_6$ particles and MX particles precipitated along lath boundaries and within laths of the tempered HAZ, which was similar to the base steel.

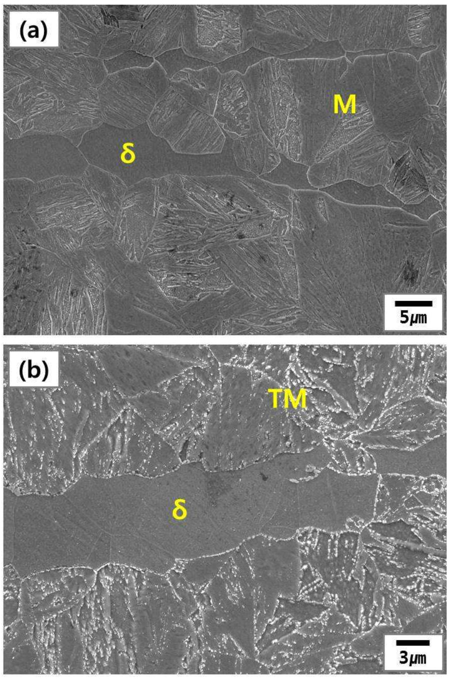

Fig. 2. SEM micrographs of the HAZ: (a) before PWHT and (b) after PWHT. δ: δ-ferrite, M: Martensite and TM: Tempered Martensite

2.2.3 Mechanical properties in the weld HAZs

The strength of the base steel and the HAZs were evaluated using a Vickers hardness test. The Vickers hardness of the HAZs was even higher than that of the base steel due to the formation of martensite. Meanwhile, the impact property of the base steel was the most excellent among the specimens, while the HAZs had the lowest impact property. These results can be attributed to the fact that the base steel consisted of tempered martensite, whereas the HAZs consisted of martensite and δ-ferrite. Finally, the impact properties of the HAZs were improved by PWHT, but the impact properties of the tempered HAZs were still lower than that of the base steel.

3. Conclusions

The phase transformation and mechanical properties in the weld HAZ of RAFM steel were investigated. The base steel consisted of tempered martensite and two carbides. During rapid welding thermal cycle, the microstructure of the base steel was transformed into martensite and δ-ferrite. In addition, the volume fraction of δ-ferrite and grain size increased with increase in the peak temperature and heat input. The strength of the HAZs was higher than that of the base steel due to the formation of martensite, whereas the impact properties of the HAZs deteriorated as compared with the base steel due to the formation of δ-ferrite. The PWHT improved the impact properties of the HAZs, resulting from the formation of tempered martensite.

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