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Correlation between microstructure and hardness of a low activation ferritic steel (JLF-1) weld joint

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Abstract

Fe–Cr–W ferritic steels are candidate low activation materials for fusion reactor structural components. Under a surveillance test program of the Japanese low activation Fe–9Cr–2WVTa steel (JLF-1), JLF-1-HEAT2 was made by Japanese universities. The present paper reports the results of microstructural observation and hardness testing of JLF-1-HEAT2 and its weld joint. The relation of microstructure with local hardness and tensile properties at various positions on the weld joint was investigated, and the correlation qualitatively interpreted in terms of the martensitic lath width.

1. Introduction

Fe–Cr–W ferritic steels are candidate low activation materials for fusion reactor structural components. In comparison with other candidate materials, i.e. vanadium alloys and SiC/SiC composites, the low activation ferritics are recognized to be established industrial materials. For the application of these materials to fusion reactors, technologies relating to component fabrication are becoming major issues. Characterization and optimization of the welding procedures have been considered to be particularly important in the construction of complex components such as the fusion blanket.

Japanese universities have been promoting a test program of a low activation Fe–9Cr–2WVTa alloy named JLF-1 [1,2]. Recently a 1.5 ton heat of JLF-1 was made (JLF-1-HEAT2), and 15 and 25 mm thick plates were distributed to each of the parties for surveillance tests. TIG and EB weld joints of these plates were also available.

The present paper reports the results of microstructural observations and hardness measurements on JLF-1 and its TIG weld joint. Emphasis is placed on the relation of microstructure with local hardness at various positions on the weld joint.

2. Experimental

The chemical compositions of JLF-1-HEAT2 base metal (BM) and weld metal (WM) are shown in Table 1. The 25 mm thick plates were normalized at 1323 K for 1 h and air cooled, then tempered at 1050 K for 1 h followed by air cooling. Two plates were butt-welded by TIG. Table 2 shows the TIG welding condition. Post-welding heat treatment was performed at 1013 K for 3 h followed by furnace cooling. Specimens for testing were prepared from the weld plate shown schematically in Fig. 1.

The surfaces of specimens for optical microscope observations were mechanically polished with #800 wet sandpaper and then chemically etched in a solution of 10% HNO_3 + methanol.

Micro-Vickers hardness measurements were conducted with a hardness tester (MVK-HVL, Akashi) with the testing load of 10 N.

A rod of 3 mm diameter was machined out of the plate as shown schematically in Fig. 1. After machining, the rod was cut into discs for microstructural observations with TEM-2000EX2 and 2000FX transmission electron microscopes at Kyushu University. Microchemical analyses were also carried out with an energy-dispersive X-ray spectrometer (EDS) equipped with the JEM-2000FX TEM. Microstructural and microchemical examinations were made every 2 mm from the center of the weld metal.

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Table 1
Chemical compositions of JLF-1-HEAT2 base metal and weld metal (mass%)

	C	Si	Mn	P	S	Cr	W	V	Ta	Ti
MATRIX	0.10	0.05	0.45	0.003	0.002	8.85	1.99	0.20	0.080	–
WM	0.061	0.13	0.43	0.005	0.003	9.16	1.91	0.25	0.081	0.019

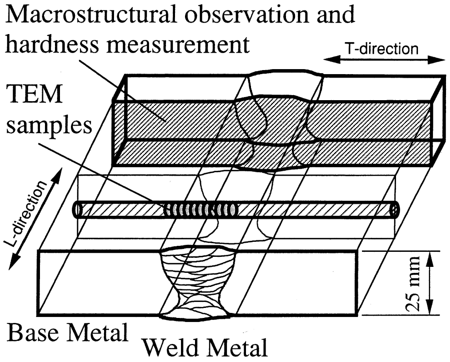

Fig. 1. Scheme for the specimen preparation from a weld joint plate.

Table 2
The TIG welding condition

Plate thickness	25 mm
Current	230–250 A
Voltage	10.5 V
Travel speed	10 cm/min
Heat input	14.5–15.8 kJ/cm
Preheat temp.	<473 K
Interlayer temp.	<473 K
Number of passes	≒25 pass
Wire diameter	1.2 mm
PWHT condition	1013 K

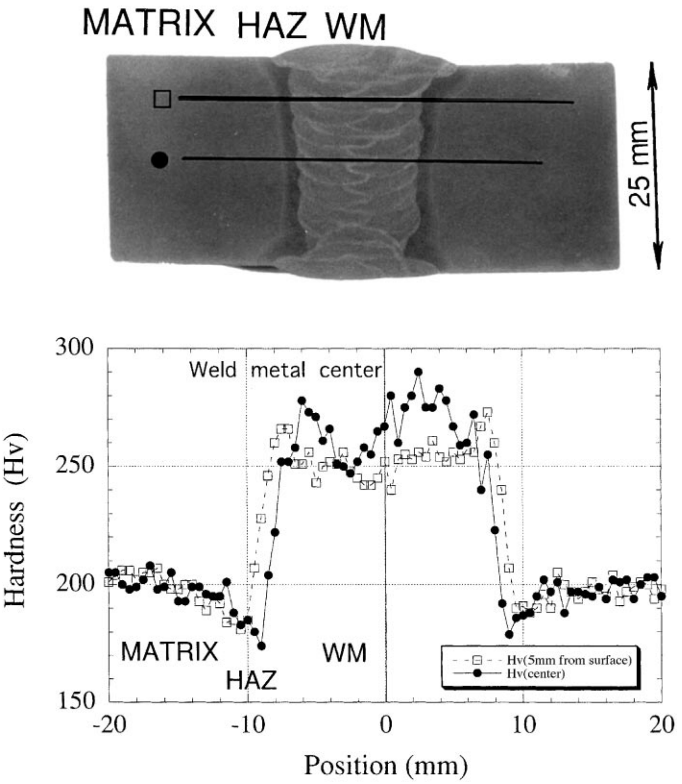

Fig. 2. Cross sectional macrostructure and hardness distribution across the weld joint.

3. Results and discussion

3.1. Macrostructure and hardness distribution

Fig. 2 shows the macrostructure of a cross section of the weld joint and hardness distributions at two depths. The macrostructure shows clearly the distribution of the base metal, the heat affected zone (HAZ) and the weld metal. In the weld metal, the fine structure reflects the heating history during the repeated welding passes. The vickers hardness (Hv) is highest (Hv240–Hv290) in the weld metal and lowest in the heat affected zone.

Details of the hardness distribution in the weld metal across the plate is shown in Fig. 3 together with the higher magnification macrostructure of the corresponding area. The figure shows that local hardness at the white lines observed is higher than that in the surrounding area. This hardening seems to be due to rapid cooling after the next adjacent pass of the welding.

3.2. Microstructural observations

Fig. 4 shows the microstructures at various distance from the center of the weld metal. Fine lath structure of moderately-tempered martensitic phase and well-tempered martensitic phase are observed in the weld metal and the base metal, respectively. In the heat affected zone, coarsened lath structure of deeply-tempered martensitic phase is observed. Precipitates of 200–500 nm diameter were observed in all specimens. The EDS analysis and electron diffraction showed that the precipitates observed were Cr-carbides ($M_{23}C_6$).

3.3. Lath width and hardness

Distribution of lath width with position of the weld joint is shown in Fig. 5. The lath width was estimated from TEM micrographs as an average separation of the boundaries. Thus the values represent average of the thickness and the width without any contribution from the length. The hardness data at identical positions to the full points shown in Fig. 2 are also reproduced. The figure clearly indicates a relation between the hardness and the lath width.

The results of the tensile tests of the same materials are reported in Ref. [3]. The yield stress was estimated as a 0.2% proof stress at room temperature. The yield

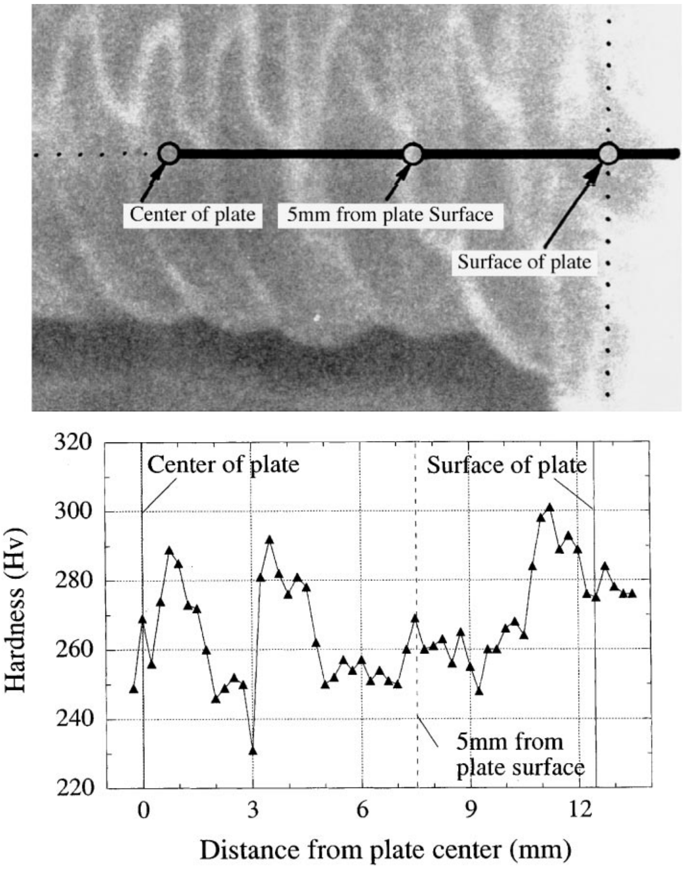

Fig. 3. Details of hardness distribution in the weld metal.

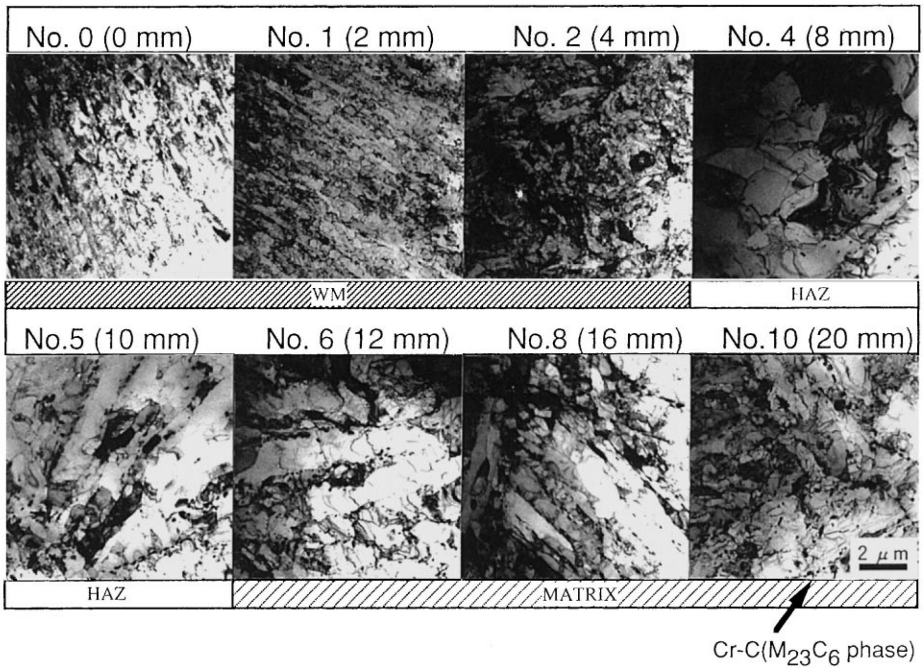

Fig. 4. Microstructures at various distances from the center of the weld metal.

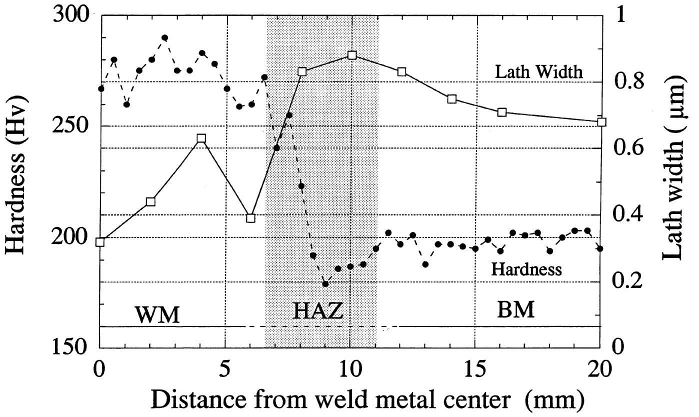

Fig. 5. The lath width as a function of distance from the weld metal center. Hardness data at identical position shown in Fig. 2 are also reproduced.

stresses of the weld metal, measured for a tensile specimen cut along the weld band bead, was 687 N m^{-2} (70.1 kg/mm^2). The yield stress of the base metal was measured for two types of specimens: parallel (L-direction) and perpendicular (T-direction) to the weld line. The yield stresses of L-direction and T-direction were 452 N m^{-2} (46.1 kg/mm^2) and 457 N m^{-2} (46.6 kg/mm^2), respectively.

Fig. 5 and the tensile data imply qualitative relationships between lath width, hardness and yield stress; with the decrease in lath width, both hardness and yield stress increase. However, it was shown that in the martensitic steels, not only TEM-observable defects such as grain (lath) boundaries, precipitates and dislocations but also TEM-invisible defects such as substitutional and carbon atoms contribute to the mechanical properties [4]. Further characterization of microstructure is needed in order to establish the correlation.

4. Conclusion

The microstructures and hardness were estimated at the weld metal, the heat affected zone, and the base metal of the JLF-1 weld joint. The microstructure was qualitatively correlated with the hardness and the yield stress using the lath width as a parameter. Further characterization of microstructures including TEM-invisible defects is needed in order to establish a quantitative microstructure-mechanical property correlation.

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