ELSEVIER

Journal of Nuclear Materials 283–287 (2000) 1187–1191

journal of nuclear materials

www.elsevier.nl/locate/jnucmat

Section 11. Joining, joints, coatings and corrosion

Characterization of low-activation ferritic steel (JLF-1) weld joint by simulated heat-treatments

N. Inoue [a,*], T. Muroga [a], A. Nishimura [a], T. Nagasaka [a], O. Motojima [a], S. Uchida [b], H. Yabe [b], K. Oguri [b], Y. Nishi [b], Y. Katoh [c], A. Kohyama [c]

[a] *National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan*
[b] *Department of Materials Science, Tokai University, Hiratsuka, Kanagawa 259-1292, Japan*
[c] *Institute of Advanced Energy, Kyoto University, Uji, Kyoto 611-0011, Japan*

Abstract

Characterization of a weld joint of a Fe–Cr–W ferritic steel (JLF-1) has been carried out in comparison with heat-treated specimens. The heat-treatment was carried out to simulate heating history effects of the base metal (BM), the heat-affected zone (HAZ) and the weld metal (WM) of the joint. Change in X-ray diffraction patterns and hardness of the weld joint and the heat-treated samples are compared and discussed. The results of X-ray diffractometry and the hardness measurements suggest that phase transformation should occur around the heat-treatment temperature of 820–830°C, and that the transformation does not necessarily cause hardening. Although the hardness of the HAZ changes with the distance from fusion line, the internal strain and the residual stress do not change significantly throughout the HAZ. The single heat-treatment test seems insufficient to correlate directly to the HAZ of the weld joint, because repeated heating with different maximum temperatures and different cooling rates would have been applied to the HAZ.

1. Introduction

Fe–Cr–W ferritic steels are candidate low-activation materials for fusion reactor structural components. Japanese universities have been promoting a test program of a low-activation Fe–9Cr–2WVTa alloy named JLF-1 [1–4]. For an application of candidate materials to fusion reactors, engineering technologies related to component fabrication are becoming major issues. Characterization and optimization of welding procedures have been considered to be particularly important in the fabrication of complex components such as a fusion blanket support structure. Under this motivation, some of the authors investigated the correlation or relationship between microstructures and hardness at various positions of a tungsten inert gas welding (TIG) weld joint of JLF-1. In that study, the characteristics of base metal (BM), heat-affected zone (HAZ) and weld metal (WM) were examined [5–7].

In this study, X-ray diffractometry and hardness measurements were carried out on JLF-1 after TIG welding or simulated heat-treatment. The heat-treatment was carried out with different temperatures for simulating thermal histories of various locations on the welded joint. The objective of this study is to characterize and analyze the TIG joints of JLF-1 according to the heating history of each position.

2. Experimental

2.1. Sample preparation

A 1.5 ton heat of a low-activation Fe–9Cr–2WVTa was made (JLF-1-HEAT2), and 15 and 25 mm thick plates were distributed to each of participants for surveillance tests [1–4]. The 25 mm thick plates were normalized at 1050°C for 1 h and air cooled, then tempered at 780°C for 1 h followed by air cooling. Two plates were butt-welded by TIG [5]. Chemical composition of

* Corresponding author. Tel.: +81-572 58 2147; fax: +81-572 58 2618.
E-mail address: inoue@LHD.nifs.ac.jp (N. Inoue).

0022-3115/00/$ - see front matter
PII: S0022-3115(00)00293-2

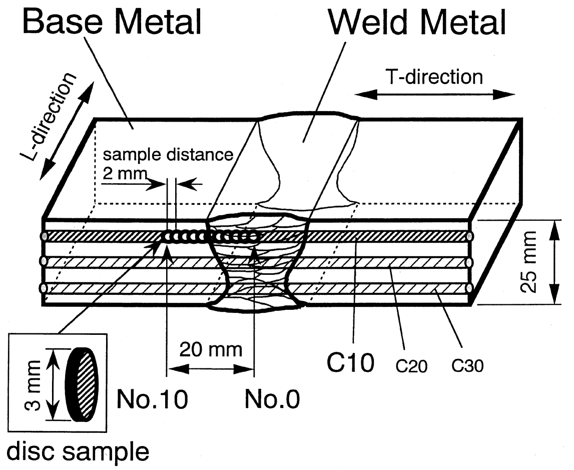

Fig. 1. Scheme for specimen preparation form the weld joints sample.

plates and wire are shown in Ref. [5]. Post-weld heat-treatment was performed at 740°C for 3 h followed by furnace cooling.

A rod 3 mm in diameter was machined out of the joint plate as shown schematically in Fig. 1. After machining, the rod was cut into small discs. The cross sectional macrostructure showed that Nos. 0–3, 4–7 and 8–10 correspond to the WM, the HAZ and the BM positions, respectively. Samples for the heat-treatment test were prepared from the base metal of the plate. The size was 8 mm square and 3 mm thickness. The heat-treatment was performed by a gold image furnace (QHC-E410P/TPC, Ulvac Co.). The temperature was reached and held for 10 min in vacuum followed by a quick cooling by flowing N_2 gas. The typical cooling rate was 8.5°/s.

2.2. Measurements

Micro-Vickers hardness measurements were carried out by a hardness tester (MVK-HVL, Akashi) with a testing load of 10 N for thermally treated samples, and 5 N for weld joint disc samples. The structures of the samples were examined by means of X-ray diffractometry (Rigaku Denki RU-200B). The residual stress measurements were conducted with an X-ray residual stress measurement apparatus (Rigaku, PSPC; Cr target. V filter; 40 kV, 30 mA. DS = 1 mm). The residual stress was measured within an area 1 mm in diameter.

3. Results

3.1. X-ray diffractometry

Fig. 2(a) shows X-ray diffractometry of the samples heat treated at various temperatures. The lattice spacing

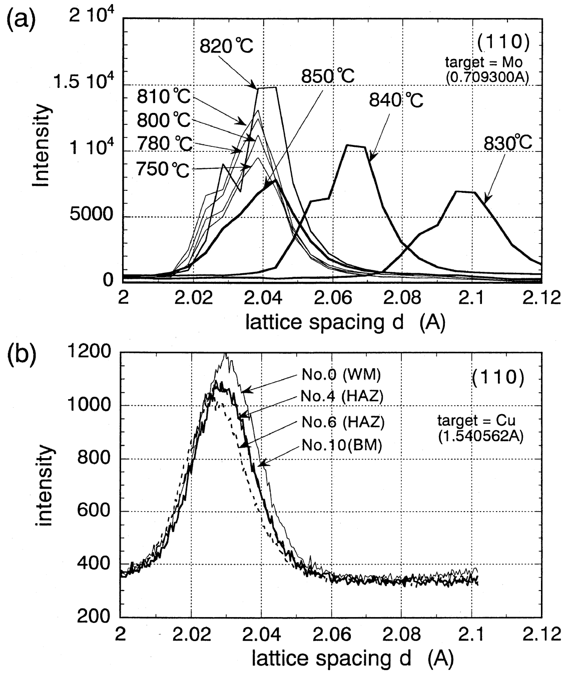

Fig. 2. X-ray diffraction spectra of JLF-1. (a): the heat-treated samples, and (b): BM, HAZ and WM extracted from the weld joint.

is not dependent on the heat-treatment temperature below 810°C. The lattice spacing increases significantly at 830°C followed by a gradual decrease. This result suggests that these transformation should occur around 820–830°C.

Fig. 2(b) shows the X-ray diffractometry of the weld joint sample. The changes in the lattice spacing of the weld joint are smaller than that of the heat-treated samples.

The results of X-ray diffractometry, hardness, the full width of half maximum intensity (FWHM) and the residual stress of the heat-treated samples and the weld joint samples are reported in Figs. 3 and 4, respectively.

3.2. Hardness

Fig. 3(a) shows the change of Vickers hardness (Hv) of the heat-treated samples. The heat-treatment below 820°C does not change the hardness (Hv 210–220). The change of hardness is found at the heat-treatment temperature over 830°C, and the lattice spacing also changes at the sample temperature. The change occurs at the same temperature as that for the lattice spacing. It is, however, to be noted that a small amount of softening occurred at 830°C in spite of the significant

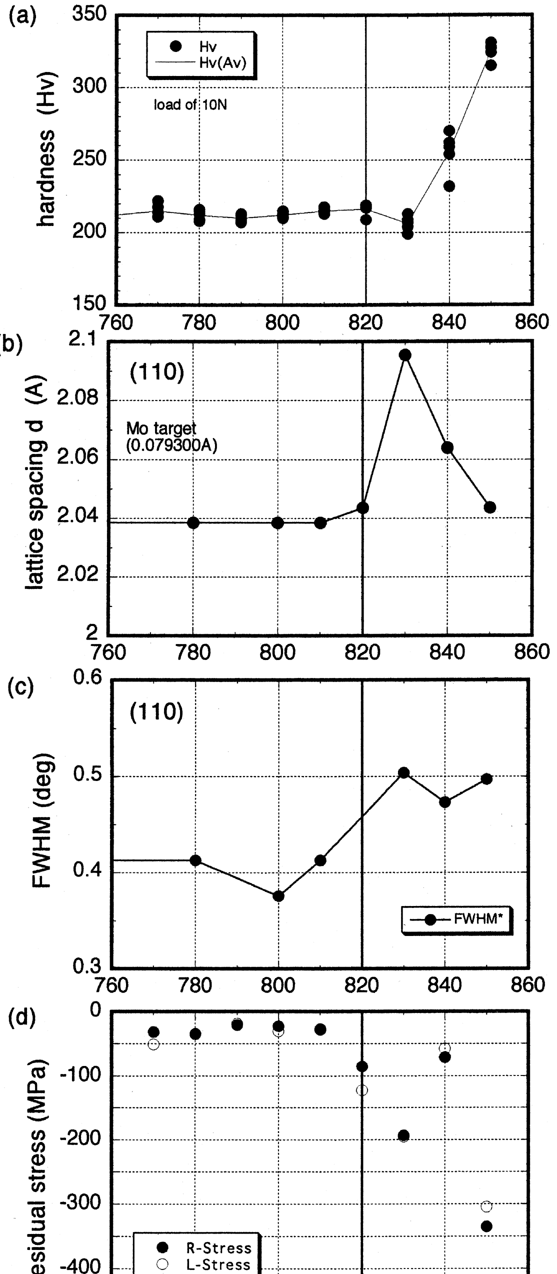

Fig. 3. Change of the hardness (a), the lattice spacing (b), the FWHM (c) and the residual stress (d) at various heat-treatment temperatures.

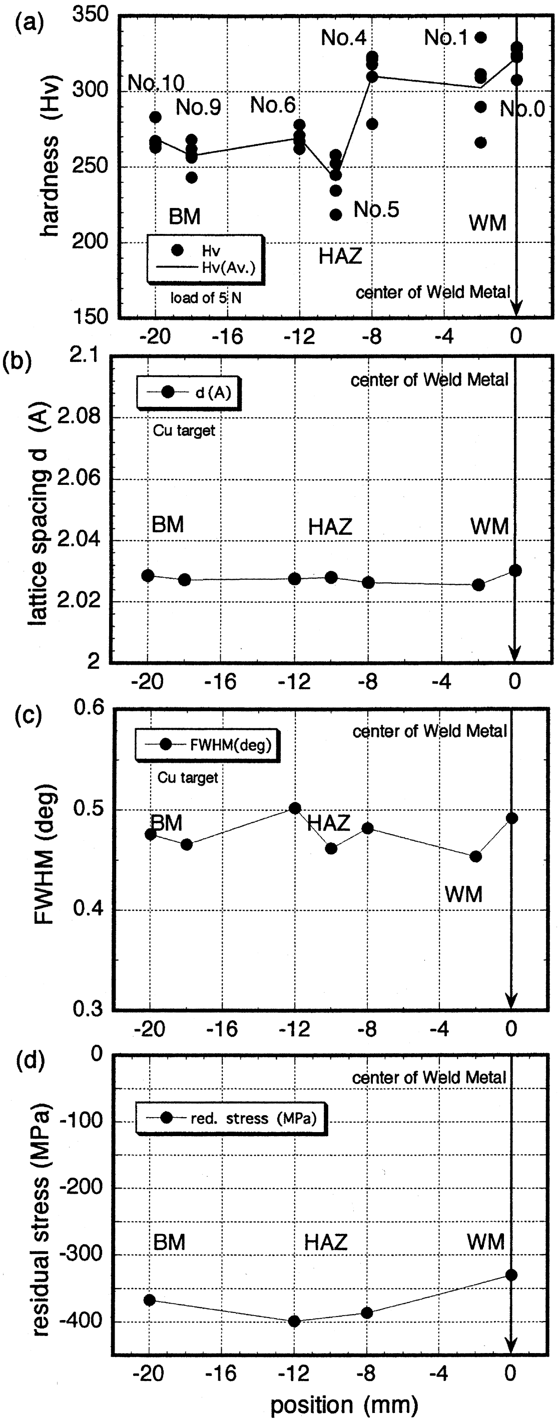

Fig. 4. Change of the hardness (a), the lattice spacing (b), the FWHM (c) and the residual stress (d) at various position of the weld joint.

change in the lattice spacing, suggesting that the transformation does not necessarily cause hardening. The hardness increases at 840°C and 850°C. Fig. 4(a) shows the hardness change of the weld joint samples. The hardness of HAZ changes with the distance from the fusion line.

3.3. FWHM

Figs. 3(c) and 4(c) show the change of the FWHM, which is the result of internal strain. These data are reproduced from X-ray diffractometry in Fig. 2(a) and (b). The FWHM in Fig. 4(c) is modified for the X-ray target difference (copper and molybdenum). Fig. 3(c) shows the enlarging of FWHM when the heat-treatment temperature exceeds 820°C. The strain is induced when fresh martensitic phase appears owing to the high temperature heat-treatment. The change of FWHM in the weld joint is not significant.

3.4. Residual stress

Figs. 3(d) and 4(d) show the variation on residual stress. A significant change appears at a heat-treatment temperature beyond 820°C. In the heat-treated specimens, the residual stress (negative) increases according to an increase of the lattice spacing and the FWHM. The residual stress is almost the same throughout the HAZ, although the hardness is significantly changed.

4. Discussion

4.1. Effect in HAZ

The microstructure of the BM was found to be tempered martensite [3]. Fig. 3 implies that the heat-treatment below 820°C would not change that phase. The drastic change in the lattice spacing at 830°C suggests that the transformation, namely austenization followed by martensitic transformation occurred during the heat-treatment. Thus the A3 temperature of JLF-1 is estimated to be 820–830°C. However, the transformation does not necessarily cause hardening, as shown by a comparing of Fig. 3(a) and (b). The tempered martensitic phase seems to be maintained in the softer part of the HAZ (No. 6) which shows a small change of lattice spacing. The hard part of the HAZ (No. 4) also shows a small change of lattice spacing. One possible explanation of this would be that the hard part of the HAZ reached very high temperature where only a small change in the lattice spacing is induced as seen at 850°C in Fig. 3(b).

4.2. FWHM and residual stress

The FWHM indicates the regulation of lattice structure. The larger the internal strain, the larger the FWHM becomes. The heat-treatment at higher temperature increases the FWHM and the residual stress. It is supposed that the increase in the strain occurred as a result of the phase transformation, coinciding not with the hardness change but with the change in the lattice spacing.

4.3. Repeated heat-treatment

When the hardness of the HAZ (Hv 330, No. 4 position) is compared with that of the heat-treated sample, it may be deduced that the position corresponds to an 840–850°C heat-treatment temperature. However, the single heat-treatment test is not sufficient to indicate its influence on the HAZ of a weld joint, because repeated heating with different maximum temperatures and different cooling rates would be applied to a real HAZ. The repeated heating may exert a complicated influence on the HAZ and the WM. The small change in Figs. 4(c) and (d) with position in the HAZ may be caused by this.

5. Conclusion

The change of X-ray diffraction patterns and hardness are compared and discussed for a TIG weld joint and heat-treated samples of JLF-1. The X-ray diffractometry showed that the structural change (lattice spacing, internal strain, residual stress) occurs at a heat-treatment temperature of 830°C. This result suggests that a phase transformation occurs and thus the A3 temperature should be around 820–830°C. The hardening, on the other hand, commences at 840°C suggesting that the transformation does not necessarily cause the hardening.

The internal strain and the residual stress do not change through the HAZ, in spite of a large variation in hardness with the distance from the center of weld metal. Probably, a single heat-treatment cannot simulate correctly the HAZ of the welded joint, because repeated heating with the different maximum temperatures and different cooling rates have been applied to the HAZ.

Acknowledgements

The authors wish to thank Mr K. Hoshino and Mr T. Hirose of Rigaku for his support in the X-ray diffractometry. They also acknowledge Dr T. Hasegawa of Nippon Steel Co. for supplying the weld joint plates.

References

[1] A. Kohyama, Y. Kohno, K. Asakura, H. Kayano, J. Nucl. Mater. 212–215 (1994) 684.
[2] A. Kohyama, A. Hishinuma, D.S. Gelles, R.L. Klueh, W. Diets, K. Ehrlich, J. Nucl. Mater. 233–237 (1996) 138.
[3] T. Hasegawa, Y. Tomita, A. Kohyama, J. Nucl. Mater. 258–263 (1998) 1153.

[4] A. Kohyama, Y. Kohno, M. Kuroda, A. Kimura, F. Wan, J. Nucl. Mater. 258–263 (1998) 1319.
[5] N. Inoue, T. Muroga, A. Nishimura, O. Motojima, J. Nucl. Mater. 258–263 (1998) 1248.
[6] A. Nishimura, N. Inoue, T. Muroga, J. Nucl. Mater. 258–263 (1998) 1242.
[7] N. Inoue, T. Muroga, A. Nishimura, O. Motojima, K. Oguri, Y. Nishi, Y. Katoh, A. Kohyama, in: Proceedings of International Symposium on Environment-Conscious Innovative Materials Processing with Advanced Energy Sources, 24–27 November, 1998, Kyoto, Japan.