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Fundamental Study on Dissimilar Metal Joining with Vanadium and Austenitic Stainless Steel

バナジウムとオーステナイトステンレス鋼の異材接合に関する基礎研究

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The mechanical and metallographical properties of the electron beam weld joint with the pure vanadium and SUS316L austenitic stainless steel and the effect of post welding heat treatment (PWHT) at 600°C and 1000°C were investigated. The electron beam was positioned just on the butt joint, shifted by 0.2 mm and 0.4 mm on the SUS316L side. Much higher hardness was observed in the weld metal (WM) of the as-welded joints than that of base metals (BMs), which might be attributed to the solution hardening and the formation of σ-phase of the Fe-V system. No reduction of the higher hardness of the WM and interlayer (IL) occurred due to the PWHT at 600°C and 1000ºC regardless of the electron beam position in the welding. Generally, the PWHT enhanced the formation of σ-phase of the Fe-V system and precipitates of Ni_2V_3 and NiV_3. As a result, the hardness of WM and IL grew up to approximately Hv900–1000, which was 5–10 times higher than that of the BMs.

1. Introduction

Vanadium (V) alloy is recognized as a promising low activation structural material for fusion reactor blanket because of its good high temperature strength and resistance to neutron irradiation [1]. The self-cooled liquid-lithium (SCLL) blanket is one of the blanket designs using the V-alloy as a structural material. Since the peripheral component of the SCLL blanket such as the heat exchanger will be fabricated using austenitic stainless steel, the joining technology with those materials should be developed [2].

The objective of this study is to investigate the mechanical and metallographical properties of the EBW joint with the pure-V and SUS316L austenitic stainless steel and the effect of PWHT on these properties.

2. Experimental

Pure-V and SUS316L austenitic stainless steel were employed for the welding. Electron beam butt-welding (EBW) was carried out using flat plates in dimension of 50 mm × 50 mm × 4 mm. The acceleration voltage, the beam current and the welding speed were 150 kV, 12 mA and 1000 mm/min, respectively. The electron beam was positioned just on the butt joint (EB00), shifted by 0.2 mm (EB02S), 0.4 mm (EB04S), and 0.6 mm (EB06S) on the SUS316L side to evaluate the effect of melting behavior of Fe, Cr and Ni.

The PWHT was performed in vacuum at 600°C and 1000°C for 1 h. Vickers hardness measurement of the weld joint was performed using a Vickers hardness tester. The observation and compositional analysis of the EBW joints were performed using a scanning electron microscope with energy dispersive spectroscopy system (SEM/EDS). Identification of the phase and precipitate was conducted using an x-ray diffraction device (XRD).

3. Results and Discussion

No significant defects were observed in the as-welded EB00, EB02S and EB04S joints, whereas non-welded region was formed in the as-welded EB06S joint. The as-welded EBW joint was distinguished into the BM of V (V-BM), weld metal (WM) and BM of SUS316L (SUS316L-BM).

Fig. 1 shows the PWHT temperature dependence of hardness for the EB00, EB02S and EB04S joints. Much higher hardness was observed at the as-welded WM than the BMs. The σ-phase of the Fe-V system and the fcc-Fe were detected in the WM of as-welded EB00 joint and in the WM of as-welded EB02S and EB04S joints, respectively. Therefore, it was possible that the solution hardening and the formation of σ-phase of the Fe-V system were the dominant factor for the higher hardness of the WM of as-welded joints.

The hardness change in the WM of the EB00 joint was relatively small due to the PWHT at 600°C, whereas significant increment was observed due to the PWHT at 1000°C. Based on the EDS analysis and the phase diagrams, the matrix phase of the WM of post-welding heat treated EB00 joint was the σ-phase of the Fe-V system. The possible dominant factor of the higher hardness after the PWHT at 600°C would be the solution hardening and formation of σ-phase of the Fe-V system, and further increment of the hardness at 1000°C might occur due to the formation of Ni_mV_n precipitates.

The hardness of the WM of EB02S joint significantly increased due to the PWHT above 600°C, and was almost independent of the PWHT temperature. Based on the XRD and EDS analysis and the phase diagrams, the matrix phase of the WM of post-welding heat treated EB02S joint was the fcc-Fe, and the possible dominant factor of the higher hardness of the WM would be the solution hardening and formation of Ni_mV_n precipitates.

The WM of EB04S joint showed almost no change of the hardness due to the PWHT at 600°C and 1000ºC. Since no precipitate was formed in this WM, the possible dominant factor of the higher hardness of the WM would be the solution hardening. The interlayer (IL) was formed at the edge of the WM of V side only in the post-welding heat treated EB04S joint. The IL showed much higher hardness than the BMs and WM, and the hardness of the IL tended to increase with PWHT temperature. Based on the EDS analysis and the phase diagrams, the matrix phase of the IL of post-welding heat treated EB04S joint was the σ-phase of the Fe-V system, and the possible dominant factor of the higher hardness of the IL would be the solution hardening, formation of σ-phase of the Fe-V system and formation of Ni_mV_n precipitates.

4. Conclusion

The mechanical and metallographical properties of the EBW joint with the pure-V and SUS316L steel and the effect of PWHT was investigated. The results are summarized as follows:

(1) Much higher hardness was observed in the WM of the as-welded EB00, EB02S and EB04S joints than the BMs, which might be attributed to the solution hardening and the formation of σ-phase of the Fe-V system.

(2) The hardness change in the WM of EB00 joint was relatively small due to the PWHT at 600°C, whereas significant increment was observed due to the PWHT at 1000°C, which might be attributed to the solution hardening, formation of σ-phase of the Fe-V system (≥600°C) and the formation of Ni_mV_n precipitates (1000°C).

(3) Significant increment of the hardness in the WM of EB02S joint occurred due to the PWHT at 600°C and 1000°C, which might be attributed to the solution hardening and formation of Ni_mV_n precipitates.

(4) Almost no change of the hardness due to the PWHT at 600°C and 1000ºC occurred in the WM of EB04S joint. The IL was formed at the edge of the WM of V side only in the post-welding heat treated EB04S joint. The IL showed higher hardness than the BMs and WM, which might be attributed to the solution hardening, formation of σ-phase of the Fe-V system and formation of Ni_mV_n precipitates.

References

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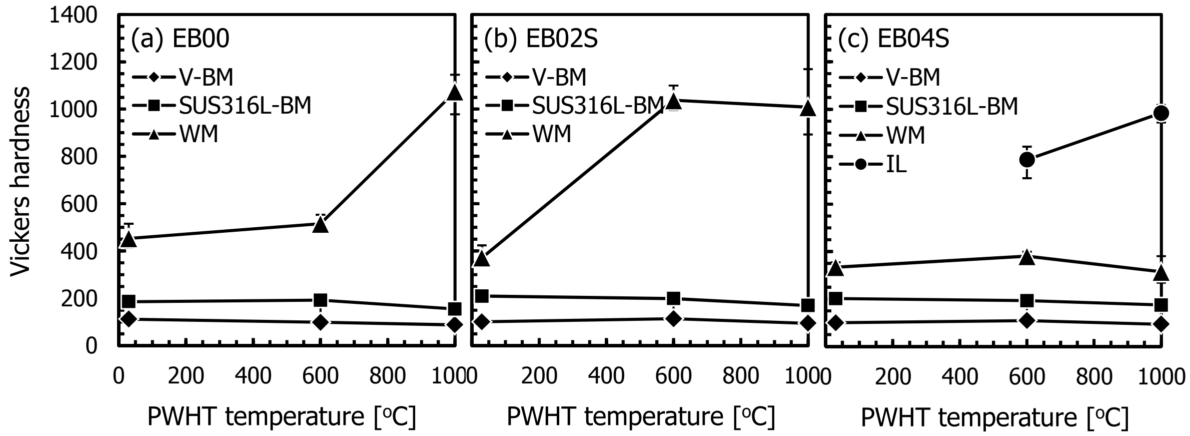

Fig. 1 PWHT temperature dependence of hardness in V-BM, WM, IL and SUS316L-BM for the (a) EB00, (b) EB02S and (c) EB04S joints (PWHT: 600°C and 1000°C for 1 h)