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先進炉に跨がる材料開発の現状と課題

Present status and issues for material development for advanced reactor

Dissimilar-metals bonding for oxide-dispersion-strengthened steels

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1. Introduction

Reduced-activation ferritic steels and their oxide-dispersion-strengthened (ODS) alloys are promising structural material for fusion blanket [1, 2]. The ODS steels are superior to the non-ODS steels in heat resistance and neutron irradiation resistance, however inferior in mass production. Since high temperature and high neutron dose area is limited at only the surface of the blanket, minimized application of ODS steels there is effective to utilize the advantage of ODS steels. In order to prove the feasibility of this advanced concept, dissimilar-metals joints of them were fabricated and evaluated.

2. Experimental procedure

The dissimilar-metals joint will be used for the first wall structure and for the cooling channel connection near there in the blanket. The former requires large area and three-dimensional-shape bonding, while the latter needs robust welding to resist the coolant pressure. Two bonding processes, hot iso-static pressing (HIP) and electron-beam welding (EBW), are selected in the present study, because they are the most suitable for such structures, respectively. The ODS steel and the non-ODS steel used are 9Cr-ODS [3] and JLF-1 [4]. HIP joints were fabricated at 1000°C, 1050°C, and 1100°C, under a pressure of 191 MPa for 3h with a cooling rate of 5°C/min after the HIP. EBW joints were fabricated with an electron beam output of 15 mA and 150 V and with a welding speed of 2000 mm/min. The bonding atmosphere was vacuum for both the HIP and EBW processes.

3. Results and discussion

Figure 1 (a) plots hardness around the bonding interface of the HIP joints. The HIP at 1000°C induced hardening in the base metal (BM) of JLF-1, while 9Cr-ODS exhibited almost no change in hardness, except the interface region as shown by the large circle in the figure. Both the BMs were hardened during the HIP at 1050°C and 1100°C, though the localized softening was again observed. The hardening is due to the formation of quenched martensite. Since carbon for this phase is supplied from carbides decomposed during the HIP, and contrarily lost by its diffusion and re-precipitation of carbides during the cooling after the HIP, the hardening is increased with increasing HIP temperature and cooling rate after the HIP. The cooling rate after the HIP was 5°C/min and enough for quenching in the BM of JLF-1. While, under the lowest temperature (1050°C) condition with less carbon supply from carbide decomposition, the cooling rate was slow for 9Cr-ODS. According to microstructural analysis, coarsening of carbides was observed after the HIP, and indicates much diffusion of the carbon before quenching with the cooling rate. On the other hand, no-carbide layer was observed in the softening region at the interface, and is attributed to decarburization due to the vacuum atmosphere. Since the softest part is more deformed in the joint, the soft layer with limited volume

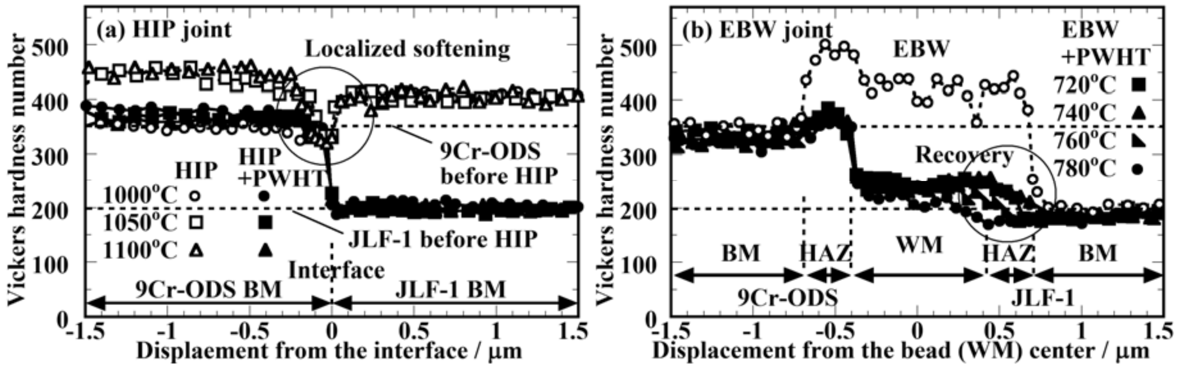

Fig. 1. Hardness around (a) the bonding interface of HIP joint and (b) the weld bead of EBW joint.

leads to very local deformation and loss of elongation. Post-weld heat treatment (PWHT) was examined to recover the hardness and the microstructure. After investigations on effect of PWHT and subsequent cooling rate, normalizing at 1050°C for 1 h with rapid cooling at 36°C/min, and then tempering at 780°C for 1 h is found as the optimum condition for HIP joints. The normalizing refines carbides, and then the tempering changes the quenched martensite into softer tempered martensite. As shown by the closed symbols in the figure, the softest part after the PWHT is JLF-1 BM and is no more limited in volume, the elongation of the joint is improved by the deformation of JLF-1 BM. Tensile strength and elongation after the PWHT were 370 MPa and 0 %, 660 MPa and 11 %, and 580 MPa and 8 %, for 1000°C, 1050°C and 1100°C HIP specimens, respectively. The joint after HIP at 1000°C still fractured at the interface and showed no elongation even after the PWHT. This is probably induced by defects of un-bonded area under less Fe diffusion condition with the lower HIP temperature. Considering that tensile strength of F-1 before HIP is 580 MPa, 1050°C and 1100°C are suitable for HIP temperature to avoid degradation of strength.

In the case of EBW, hardness of weld metal (WM) and heat-affected zones (HAZs) was higher than their BMs. The WM and the HAZs are also quenched martensite phase. As mentioned above, the hardening is accompanied by ductility loss for the joint, therefore PWHT were carried out to relieve the hardening. Due to less heat load on BMs in EBW process than that in HIP process, no carbide coarsening was observed and allowed to skip the normalization in PWHT for carbide refining. Fig. 1 (b) shows the effect of PWHT with only tempering at the temperature range from 720 to 780°C for 1 h. As tempering temperature increased, the hardening of WM and HAZs was relieved. The recovery of hardening is more dependent on temperature in JLF-1 side, as shown by the large circle in the figure. The complete recovery of the hardening there is obtained by tempering at 780°C for 1 h. Tensile strength and of the joint was 580 MPa for the PWHT specimen, and is confirmed to be equivalent to that of JLF-1 before EBW.

4. Summary

In the case of HIP joint, carbide coarsening in the base metals and decarburization around the bonding interface were observed, in addition to the formation of quenched martensite. In order to recover all these microstructural changes, two-step PWHT of normalizing at 1050°C for 1 h and the above-mentioned tempering was required. 1050°C and 1100°C are suitable for HIP temperature to maintain the strength of joint. In the case of EBW joint, hardening occurred in weld metal and heat-affected zones, and in base metals of HIP joint. The complete recovery of hardness was obtained by PWHT of tempering at 780°C for 1 h. Tensile strength of both the HIP and EBW joint was equivalent to that of JLF-1 before the dissimilar-metals bonding.

References

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