§4. Dissimilar-metals bonding between Oxide-Dispersion-Strengthened (ODS) and Non-ODS Reduced-activation Ferritic Steels

Nagasaka, T., Fu, H.Y., Muroga, T., Tanaka, T., Sagara, A., Guan, W.H., Nogami, S., Hasegawa, A. (Tohoku Univ.),
Serizawa, H. (JWRI, Osaka Univ.),
Kimura, A. (IAE, Kyoto Univ.),
Ukai, S. (Hokkaido Univ.)

Reduced-activation ferritic steels and their oxide-dispersion-strengthened (ODS) alloys are promising structural material for fusion blanket. 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 the most effective to utilize the advantage of ODS steels. For this concept, the purpose of the present study is to develop dissimilar-metals joint between the ODS and non-ODS ferritic steels.

Two bonding processes, hot iso-static pressing (HIP) and electron-beam welding (EBW), are selected in the present study. The ODS steel and the non-ODS steel used are 9Cr-ODS and JLF-1. 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 a welding speed of 1000 mm/min. The bonding atmosphere was vacuum for both the processes.

Figure 1 (a) plots hardness around the bonding interface of the 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, which is super saturated solid solution of Fe-C alloy. 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 enough for quenching before the carbon diffusion 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 too 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 (5°C/min). 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 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 the tensile properties, 1050°C and 1100°C are suitable for HIP temperature.

In the case of EBW, hardness of weld metal (WM) and heat-affected zones (HAZs) was much 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 of the joint was 580 MPa for the PWHT specimen, and is confirmed to be equivalent to that of JLF-1 before EBW.

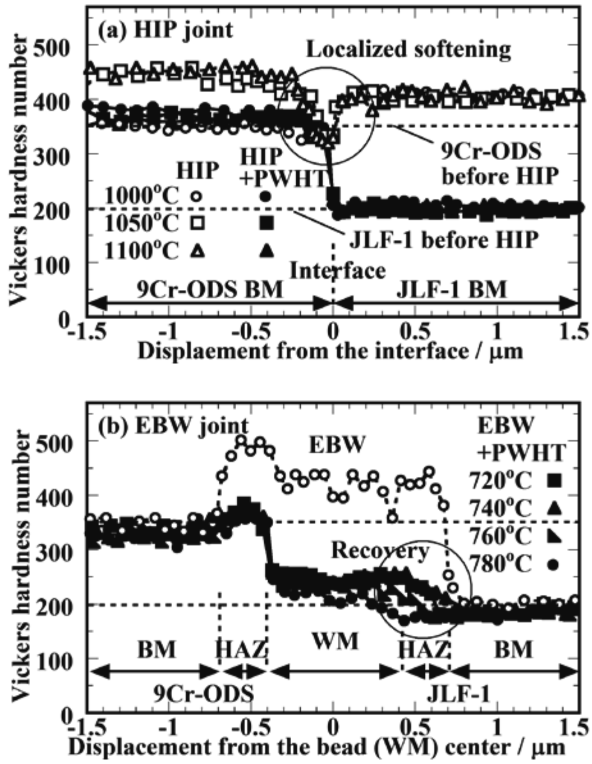

Fig. 1 Hardness around the bonding interface of the joint.