§18. Post-bond Heat Treatment for a Hot Isostatic Pressed Joint of 9Cr-ODS and JLF-1 Reduced Activation Ferritic/Martensitic Steels

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Reduced activation ferritic/martensitic steels (RAFMs) are candidate structural material for the first blanket in fusion reactors. ODS-RAFM is one of RAFMs strengthened by oxide dispersion. It has excellent high temperature mechanical properties compared with non-ODS RAFMs. Thus it can be used as the high temperature part joining to non-ODS RAFMs to enhance the allowable temperature of fusion blankets to 923 K. Therefore, it is essential to develop bonding techniques for ODS-RAFM and non-ODS RAFM. In this study, 9Cr-ODS and JLF-1 was utilized for dissimilar bonding investigation. The chemical composition is Fe-9.08Cr-0.14C-1.97W-0.23Ti-0.29Y-0.16O-0.013N for 9Cr-ODS and Fe-9.00Cr-0.09C-1.98W-0.20V-0.083Ta-0.015N for JLF-1, respectively. The final heat treatment before bonding was 1323 K × 1h normalization for both, followed by tempering at 1073K × 1h for 9Cr-ODS, and 1053K × 1h for JLF-1. The two steels were hot-isostatic-pressed (HIP) under 191 MPa at 1273 K for 3h. The cooling rate of HIP was 5 K/min.

As shown in Fig. 1, the base metal of 9Cr-ODS as-HIPed was much softened compared with that before HIP; however the JLF-1 as-HIPed was hardened. Microstructural analysis by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) showed that, the microstructure for 9Cr-ODS as-HIPed consists of ferrite; Whereas, the microstructure of JLF-1 consists of quenched martensite. These results indicate that the cooling rate after HIP 5 K/mm was too slow for 9Cr-ODS to induce quenching for martensite transformation, while it was enough for JLF-1. Post-bond heat treatment (PBHT) is necessary to recover the hardness of both the base metals to the levels before HIP. The joint was normalized again at 1323 K×1h with a rapid cooling rate of ~36 K/min. Quenched martensite was induced for both 9Cr-ODS and JLF-1, therefore the materials were hardened. And then, tempering was examined from 993 K to 1093 K for 1h to control hardness and microstructure. As tempering temperature increased, the hardness decreased slightly.

The grain size of 9Cr-ODS was 1.3 μm, and did not changed during HIP and PBHT process, as shown in Fig. 1, because high-density nano-particles in 9Cr-ODS could retard grain growth. However for JLF-1, the grain size increased during HIP and the further PBHT. Grain growth should be minimized because it sometimes induces degradation of strength and toughness. Combining the grain growth with the hardness test result above-mentioned, tempering at 1013-1033 K seems optimal for the joint to recover the hardness to the similar levels before HIP without significant grain growth. After the PBHT with normalization and tempering, the microstructure recovered to that before HIP with tempered martensite and $M_{23}C_6$ particles on the grain boundaries and lath boundaries, though density of nano-particles in 9Cr-ODS slightly decreased during HIP and PBHT.

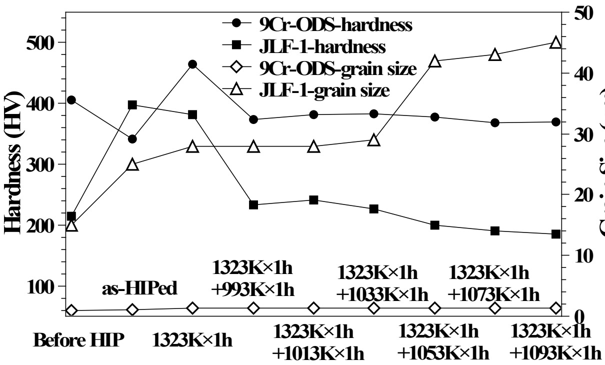

Fig.1 Hardness and grain size of 9Cr-ODS and JLF-1 base metals at different conditions.

All the tensile tests of the joint at as-HIPed and PBHT conditions showed loss of elongation. Fracture stress was lower than yield strength of the base metals. However, SEM still showed dimple pattern in fracture surfaces. Energy dispersive spectrum (EDS) determined that the specimens fractured at the 9Cr-ODS side near the bonding interface, because Ti and Y were detected for the particles in dimples.

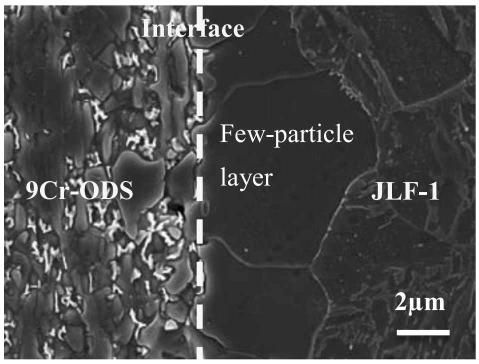

Fig.2 Microstructure of the bonding interface at as-HIP condition.

There is a few-particle layer on the JLF-1 side near the bonding interface at as-HIP condition as shown in Fig. 2. The few-particle layer consists of soft ferrite, and is supposed to be formed by decarburization during heating in vacuum in the HIP process. After the following PBHT with normalization and tempering, the few-particle layer disappeared. Since the fracture surface is always 9Cr-ODS, decarburization should occur also in the 9Cr-ODS and produce soft layer. If 9Cr-ODS is softened to comparable level to JLF-1, fracture of 9Cr-ODS would be earlier due to its lower ductility than JLF-1.

Next, HIP at higher temperature of 1323 K and 1373 K is planned to improve the bonding strength of the joint.