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Microstructure and hardness of HIP-bonded regions in F82H blanket structures

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Abstract

Metallurgical examinations and hardness measurements were performed at hot isostatic pressing (HIP)-bonded regions in blanket structures made from F82H alloy in order to investigate the HIP-bondability and the influence on the microstructure due to the HIP and heat treatments which would correspond to the fabrication of an actual blanket. The metallurgical examination showed that the HIP-bonded interfaces were sufficiently diffusion-bonded without significant defects, i.e. voids and/or exfoliations, although grain coarsening was observed at a part of the HIP interfaces. Hardness was nearly equal in the coarsening region and a region without coarsening, but about a 10 Hv increase was found in a boundary in between the regions with and without coarsening. Microcrystallized grains were observed in a region about ~6 μm from HIP interfaces, and the hardness increased by about 0.2 GPa in the region.

1. Introduction

Reduced-activation ferritic/martensitic (RAF/M) steels are primary candidate alloys for breeding blanket structures. F82H alloy (0.1C–8Cr–2W–0.2V–0.04Ta) is a typical RAF/M steel, and has been selected as the candidate alloy for the IEA round robin test on RAF/M steel. When a blanket is fabricated using this alloy, solid hot isostatic pressing (HIP) bonding methods are thought to provide the most promising methods for fabrication of blanket components which have complex shapes and require high mechanical integrity and good dimensional tolerances.

In the past, a HIP joint of F82H alloy was fabricated [1] using small specimens with flat surfaces. In addition, the HIP joining was followed only by tempering after HIP. Thus, the HIP joints could be fabricated for simple configurations and minimum heat treatment. However, an actual blanket has a complex structure, and machining (i.e. bending, grinding and drawing), and several heat treatment variations and times with machining (i.e. stress relieving, normalizing, out gassing and tempering), will be needed in order to fabricate an actual blanket module.

In previous studies [2], box-shaped partial blanket structures made from F82H alloy were fabricated based on fabrication procedures for an actual blanket. The completed structures were given the above-mentioned machining and heat treatments through the fabrication process. There is a possibility that changes in microstructure and/or hardness may have occurred in the HIP-bonded regions in the fabricated blanket structures due to machining and heat treatment. These changes can affect the HIP-bondability, so metallurgical and microstructural observations and hardness testing of the HIP-bonded regions have been performed.

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2. Experimental procedure

The chemical composition for the F82H steel used for fabrication of the blanket structures is given in Table 1. As shown in Fig. 1, the blanket structures are heat-treated using many thermal histories. The first wall of the fabricated blanket structures was cut into testing pieces including HIP-bonded interfaces. The surface of the testing piece for metallurgical observation was wet ground with grits # 4000 (this is finer than F 1200 on ISO 8486-2:1996), polished by buffing with 0.3 μm Al_2O_3 powder, followed by electrolytic polishing at 20–25 V in a solution of 80 vol.% $H_2SO_4 + 20$ vol.% CH_3OH at 0–5 °C, and chemical etching in a solution of 94 vol.% C_2H_5OH + 5 vol.% H_2SO_4 + 1 vol.% $C_6H_3O_7N_3$. Transmission electron microscopy (TEM) observation using a field emission TEM (HF-2000, Hitachi) was also carried out at 200 kV to obtain microstructural information around the HIP-bonded regions. The specimen for TEM observation was surface finished by electrolytic polishing at the above-mentioned conditions, and then microregion transverses to the HIP interface were thinned by focused ion beam (FIB) with a Ga ion gun operated at 30 kV equipped with a micropick up system (FB-2000A, Hitachi). The details of the FIB microprocessing procedure have been explained in a reference paper [3].

Vickers hardness (Hr) was measured with test loads of 9.8 N to examine the hardness change near the HIP interfaces and base metal. The surface was polished electrolytically for observation. Hardness measurements, using an ultra-micro indentation system (UMIS-2000, CSIRO), were carried out to examine indentation hardness change in the region very close to the HIP interface. The indentation hardness was determined using the procedure outlined by Oliver and Pharr [4] with further refinements proposed by Mencik and Swain [5].

3. Results and discussion

A typical macro view of the first wall, shown as a cross section, is shown in Fig. 2(a). The broken lines in this figure show HIP interfaces. As shown in the figure, the first wall has two kinds of HIP interfaces. One is a linear interface between cooling channels and/or between cooling channel and a surface/backing plate, and the other a complex interface made by two cooling channels and a surface/backing plate. Microstructures of a typical complex interface and a linear interface are shown in Fig. 2(b) and (c) respectively. The HIP interfaces can be seen as a result of chemical etching, but the interfaces are also indicated by arrows. Sound bonding without any harmful voids and/or exfoliations can be seen at both interfaces. Fig. 3 shows microstructures in regions near the complex interface and the linear interface and in the standard alloy. The prior-austenite grain size near the linear interface as shown in 3(b) is nearly equal to that of the standard alloy as shown in 3(c). On the other hand, as revealed in 3(a), the prior-austenite grain size near the complex interface is about three to

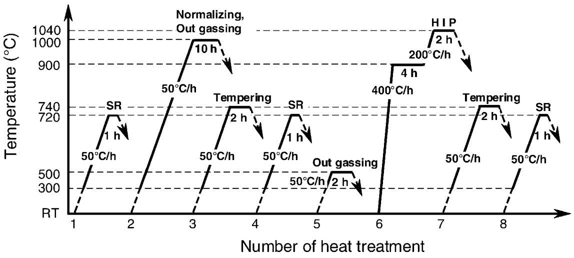


Fig. 1. Heat treatment process used to fabricate blanket structures. Conditions requiring cooling correspond to furnace cooling in all cases.

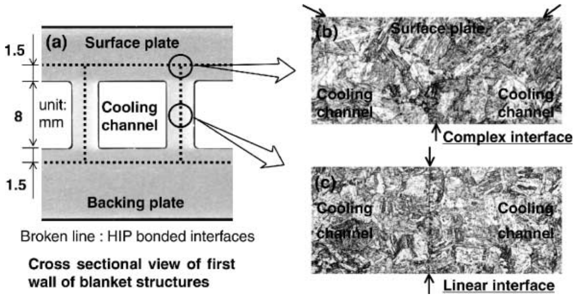
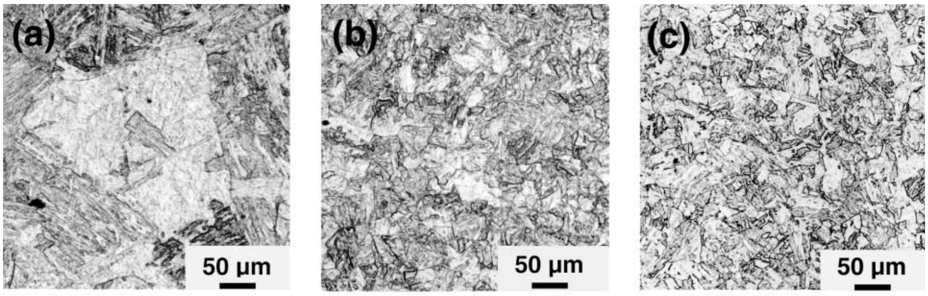


Fig. 2. A typical cross sectional view of first wall of blanket structure fabricated by HIP-bonding and an aspect of a typical HIP-bonding region: (a) shows a cross sectional view of the blanket, (b) shows a complex interface composed of a surface plate and cooling channels, (c) shows a linear interface composed of the cooling channels. Sufficient bonding without any defects is seen in these interfaces.

Table 1
Chemical compositions of F82H steel used (wt%)

C	Si	Mn	P	S	Cr	W	V
0.095	0.1	0.1	<0.005	0.003	7.72	1.95	0.18
Ta	Nb	Ni	Mo	Cu	Al	B	Ti
0.04	0.0001	<0.02	<0.01	<0.01	<0.001	0.00016	0.005



Region near complex interface Region near linear interface Standard alloy

Fig. 3. An aspect of microstructure: (a) and (b) show microstructures near a complex and a linear interface regions, respectively, (c) shows standard alloy. Grain coarsening is seen for the complex interface region in comparison with that of the linear interface region. Grain size at the linear interface region is nearly equal to that of the standard alloy.

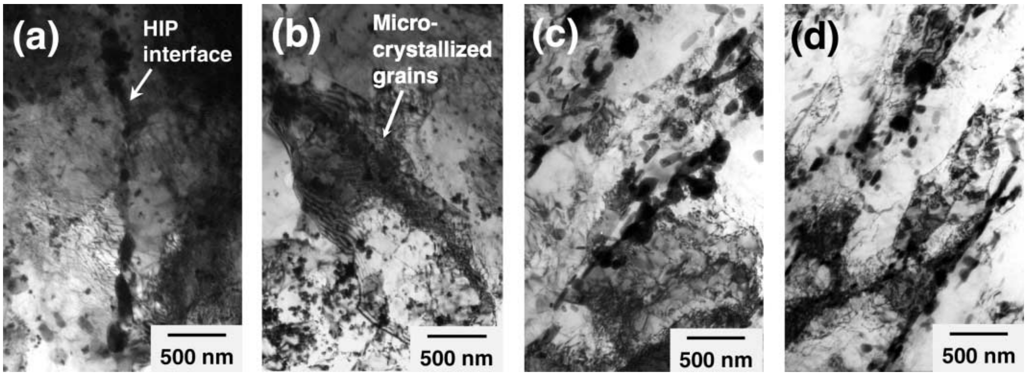


Fig. 4. Typical TEM images at linear interface and standard alloy: (a) HIP-bond interface, (b) region near the interface, (c) a region about 10 μm from the interface, (d) standard alloy. Some microcrystallized grains are observed near the interface. Microstructure in (c) is nearly equal to that of (d).

four-times larger in comparison with that of 3(b) and (c), although the region still features the lath martensite structure. Grain coarsening was also seen near other complex interfaces. Typical TEM images of a HIP-bonded region in the linear interface and the standard alloy are shown in Fig. 4. In Fig. 4(a) the HIP interface is shown. Precipitates are observed in the interface with a size almost the same as that of the standard alloy shown in 4(d). In Fig. 4(b) a region close to the interface is shown. Microcrystallized grains are observed in the region about 6 μm from the interface. A region about 10 μm from the interface is shown in 4(c). The lath structure in 4(c) is nearly equal in comparison with that of the standard alloy in 4(d).

Vickers hardness tests with a test load of 9.8 N were carried out in regions of the linear interface and the complex interface. Measured values in the linear interface region are approximately 225 Hv, which is nearly equal to that of the standard alloy (220 Hv on average). Fig. 5(a) shows hardness change from the complex interface. The figure shows that the hardness changes are

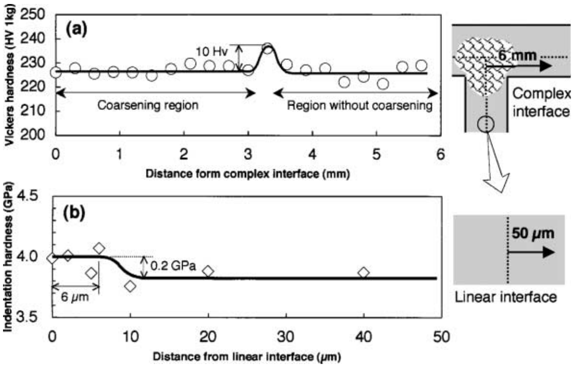


Fig. 5. Hardness change at HIP-bonded regions: (a) Vickers hardness change in region from complex interface in cooling channel, (b) Ultra-micro indentation hardness change at region near linear interface. (a) shows hardness changes are small for coarsening region and region without coarsening, but hardness increased about 10 Hv in a boundary in between regions with and without coarsening. (b) shows that hardness increases about 0.2 GPa in region close to the linear interface.

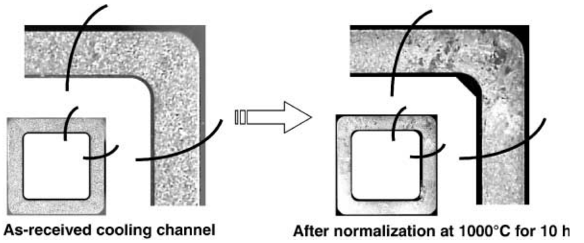


Fig. 6. Cross sectional view of an as-received rectangular cooling channel and after normalization. The as-received channel has fine and homogeneous structure in before Normalizing. After the normalizing, Grain coarsening at corners of the channel is found following normalizing.

small at regions with coarse grains as well as with a grain size nearly equal to that of the standard alloy, but hardness increased about 10 Hv in a boundary in between regions with and without coarsening. For more detailed information on hardness, a region that included the linear interface was measured by ultra-micro indentation system with a testing load of 15 mN. The hardness, shown in Fig. 5(b), given as 'indentation hardness [4,5]' is in units of 'GPa'. The hardness measurement shows that the hardness increases by about 0.2 GPa (or 5%) in the region about 6 μm from the interface, which corresponded to the region in which microcrystallized grains were observed. The hardness of the region away from the interface was similar to that of the standard alloy (3.8 GPa in average [3]). As for the complex interface, a detailed analysis will be reported in a JAERI internal report.

Hardening was seen in the region very close to the linear HIP interface, probably because of microcrystallized grains that develop in the region. The grains seem to be formed due to HIP, although further analysis is needed. Grain coarsening was seen around the complex interface bonds. In order to confirm the cause, an as-received rectangular cooling channel was heat treated in the normalizing/out gassing condition (at 1000 °C for 10 h) shown in Fig. 1. The cross sectional views of the cooling channel and one after the heat treatment are shown in Fig. 6. As revealed in this figure, enhanced grain growth can be seen at the corner following the heat treatment. Therefore, it is thought that enhanced grain coarsening occurred at the corners preferentially during the normalizing/out gassing treatment before HIP. Hence, one of the causes for enhanced grain coarsening in the channels appears to be the normalizing/out gassing treatment. However, the coarsening was also seen in the region in surface/backing plate. This requires further study.

4. Summary

Partial blanket structures made from F82H steel were fabricated by applying the HIP-bonding method. The components of the blanket structures were subjected to machining and several heat treatment variations and times during fabrication in addition to HIP. Metallurgical and microstructural observations and hardness measurements were performed in HIP-bonded regions of the blanket structures in order to investigate HIP bondability. Properties of microstructure and hardness for the HIP-bonded regions were compared with that of the standard alloy, and the following results were obtained:

1. Sufficient diffusion bonding without any harmful defects was found in the HIP-bonded interfaces in the partial blanket structures.
2. The microstructure in the region near the linear HIP interface was similar to that of the standard alloy, both of the microstructures exhibited lath martensitic structures.
3. Hardness increased by about 0.2 GPa (5%) in a region about 6 μm from the linear interface in comparison with that of the region away from the interface; microcrystallized grains were observed in the hardening region.
4. Grain coarsening was seen at all complex interface bonds. Hardness changes were small for the coarsening region and a region without coarsening, but a 10 Hv increase was found in a boundary in between the coarsening regions and the region without coarsening.
5. It was found that the grain coarsening had already occurred at corners of the rectangular cooling channels in the normalizing step before HIP.

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