§12. Trial of Brazing of Tungsten Mono-block and Copper Alloy Tube for the Divertor Plate for FFHR

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In fusion reactors, the divertor plate will be irradiated to high heat and particle load. For the stable operation of the reactors, the life time of the plate should be long, and the material of the plate is required to have high melting point and low sputtering rate. A possible material for the plate is tungsten (W). For the heat removal from the plate, pressurized water is a candidate of coolant in FFHR-d1 as in ITER. In the case of the ITER outside divertor plate, cooling tube made of copper alloy (CuCrZr) is brazed to carbon and W mono-blocks. In tokamak-type fusion reactor, neutron flux to the divertor will be so large that any copper alloy cannot be used[1]. However in FFHR-d1, the neutron flux could be much smaller than that in tokamak-type reactor because of the difference of the divertor plate position, and copper alloys could be used as the cooling tube in the divertor in FFHR-d1[2]. Thus, we conducted a trial of brazing of tungsten mono-block and copper alloy tube to develop the divertor plate for FFHR-d1.

The differences of the brazing between ITER and this work are the sizes of the W mono-block and the cooling tube made of CuCrZr and the brazing filler material as shown in Table1. The sizes of the W mono-block and cooling tube in this work are larger than the size of them in ITER. The size of the cooling tube is same as that in LHD, and we plan to install the test divertor plate in LHD after basic examination such as heat load examination. In this work, MBF-20 (Ni bal%, Si 4.5%, Fe 3%, B 3.2%) was utilized as the brazing filler material, though Nicuman37 (Ni-Cu-Mn) is utilized in ITER, because MBF-20 is cheaper than Nicuman37.

Figure 1(a) shows the schematic view and dimensions of the test module in this work. Oxygen free high conductivity (OFHC) copper was casted inside the W mono-block hole as shown in Fig. 1(b) as the buffer. MBF-20 foil (38 μm) was inserted between the OFHC copper and the cooling tube.

Table 1. The differences of the brazing between the ITER outer vertical target[3] and this work.

	Size of a mono-block	Cooling tube size	Brazing filler material
This work	50mm cube	27mmϕ	Ni-Si-Fe-B (MBF-20)
ITER (OVT)	~30x30x10mm	15mmϕ	Ni-Cu-Mn (Nicuman37)

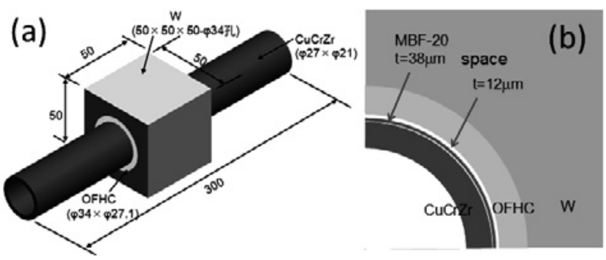

Fig.1. (a) Schematic view and the dimensions of the test module in this work. (b) Cross-section of the module.

The heat treatments, brazing and aging, were carried out in the high-vacuum furnace in Metal Technology Co. Ltd. Figure 2 shows the time evolutions of the W mono-block temperature during the heat treatments. The temperature was kept to be 950 °C for 60 min. for the isothermalization in the furnace. For the brazing, the temperature was kept to be 1050 °C for 45 min., and was rapidly cooled by nitrogen gas injection from 1000 °C. After the brazing, the aging with 480 °C was carried out for 240 minutes to recover the hardness of the cooling tube.

Figure 3 shows the photos of the test module before and after the heat treatments. The W mono-block was cracked, and gaps appeared between the cooling tube and OFHC copper. Both defects are considered to be caused by the rapid cooling from 1000 °C. The surface of the W mono-block was rapidly cooled, and the stress by the local heat shrinking caused the crack. The solidus temperature of MBF-20 is 969 °C, though the rapid cooling with N2 gas injection was started from 1000 °C. Therefore, the heat shrinking of the cooling tube was started before MBF-20 changed to solid phase, and that caused the generation of the gap.

1) Tokitani, M.: in this annual reports.
2) Tanaka T. et al.: J. Plasma Fus. Res. to be published.
3) Ezato, K. et al.: 22nd Fusion Energy Conference IT/P7-17 (2008).

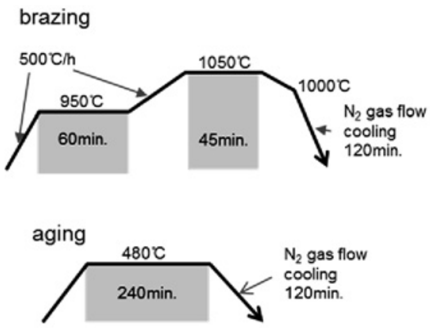

Fig. 2. Heat treatment for the brazing and the aging.

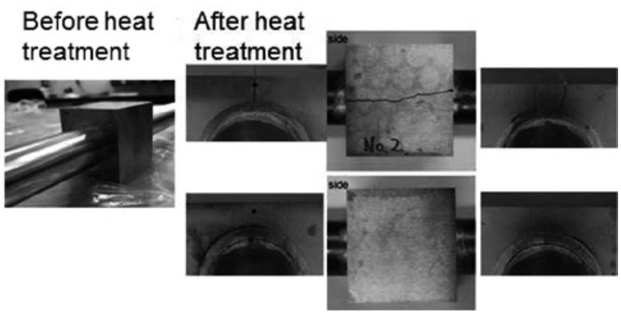

Fig. 3. Photos of the test module before and after the heat treatments.