§12. Optimization of the Brazing Conditions of Copper Alloy Heat Sink to Tungsten Armor for FFHR-d1 Divertor

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The divertor armour material of the helical reactor FFHR-d1 is considering of tungsten block because tungsten has important advantage for low hydrogen isotope retention, low sputtering yield. On the other hand, material selection of the divertor heat sink and bonding technique between armour and heat sink is currently under investigation. Under heavy neutron irradiation environment in a fusion reactor, reduced activation feritic/martensitic steel (RAFM), such as F82H, is one of the candidate materials for the heat sink [1], because it has robust resistivity against a neutron irradiation. However, F82H would not be able to withstand the heat load of the FFHR-d1 divertor over 10MW/m^2, because of the high self-induced internal thermal stress. Under such a condition, copper alloys with high thermal conductivity has a large advantage for the FFHR-d1divertor. However, they cannot be acceptable under heavy neutron irradiation because the remarkable degradation of the material properties, such as toughness and thermal conductivity, occurs at a wide temperature range. However, from the assessment of the neutronics environment at the divertor of the FFHR-d1 to date, copper alloys could be used for a heat sink especially at the outer divertor of the torus [2]. An oxide dispersion-strengthened copper alloy (ODS-Cu) such as GlidCop® (Cu-0.3wt%Al_2O_3) could be the most superior copper alloys among the commercial alloys. In fiscal year 2013 (FY2013), we tried to find the reliable brazing method between tungsten armor and GlidCop® by a brazing test with three kinds of filler materials (MBF-20, BNi-6, Nicuman37). Consequently, it was concluded that the most superior fracture strength among the three filler materials was BNi-6 with GlidCop® [3], and its brazing strength reached to around 250 MPa. However, the brazing conditions still remained some problems, because some cracks were initiated in the tungsten blocks. Such cracks would cause degradation of the brazing strength. Therefore, a brazing technique conducted in FY2013 should be improved. The possible points to be optimized, can be considered as tungsten size and heat treatment conditions.

According to the above experience, we tried to optimize the brazing condition of between tungsten and GlidCop® by using BNi-6 (P: 11.5%, Ni: bal.) filler material (W/BNi-6/ GlidCop®). The main optimized points are roughly categorized for two part. The first part is the heat treatment conditions. Fig. 1 shows the heat treatment procedures in (a) FY2013 and (b) FY2014 brazing experiment. The improved points of the procedures from FY2014 to FY2014 are indicated in (1), (2), and (3) in (b) FY2014. First, (1) treatment temperature of brazing was decreased from 980 ˚C to 960 ˚C. Second, (2) treatment time was reduced from 45 min to 10 min. Then, (3) cooling rate was changed to slowly. The second part of the main optimized point is that size of the tungsten brock was reduced from 30×30×18 mm^3 to 20×20×5 mm^3. The plane of the 30×30 mm^2 and 20×20 mm^2 are the brazing surface. With optimizing above four points, brazing test of the W/BNi-6/ GlidCop® divertor mockup was conducted. The CAD image of the fabricated mockup is shown in Fig. 2. Consequently, we successfully fabricated the W/BNi-6/ GlidCop® mockup without any serious damages. Fig. 3 shows the Photo of the fabricated mockup of the W/BNi-6/ GlidCop® by optimized brazing condition. In the heat treatment, other brazing samples of the W/BNi-6/ GlidCop® were also treated together. Not only mockup but also all of other brazing samples were successfully fabricated without any damages.

The optimized brazing technique was demonstrated for obtain the nice brazing without any serious damages.

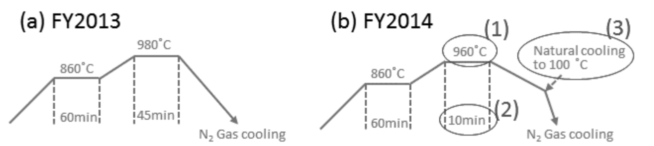

Fig. 1. Heat treatment procedures for brazing of the W/BNi-6/GlidCop® in the (a) FY2013 and (b) FY2014 case.

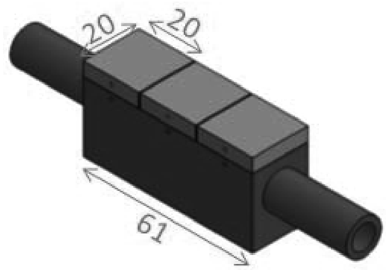

Fig. 2. CAD image of the fabricated mockup of the W/BNi-6/ GlidCop® by optimized brazing condition.

Fig. 3. Photo of the fabricated mockup of the W/BNi-6/ GlidCop® by optimized brazing condition. It has very good brazing without any damages.

1) S. Suzuki et al., Fusion Eng. Des. 81 (2006) 93.
2) T. Tanaka et al., Fusion Eng. Des. 89 (2014)1939.
3) M. Tokitani et al., Plasma Fusion Res. 10 (2015) 3405035.