§13. Fabrication of Divertor Mock-up by ODS-Cu and W by Improved Brazing Method for FFHR-d1 Divertor

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It is known that a Reduced Activated Ferritic/Martensitic Steel (RAFM) would not withstand in a reactor divertor, because of its high self-induced internal thermal stress [1]. Under such a condition, copper alloy with high thermal conductivity has a large advantage. In fact, copper alloy has been considering of using as a divertor cooling tube in not only helical reactor FFHR-d1 but also tokamak DEMO reactor [2),3)]. The CuCrZr is a precipitation hardened copper alloy (PH-Cu), which was selected as a cooling pipe of the ITER divertor. In the selection of the ITER divertor material, the lower fracture toughness of the ODS-Cu after neutron irradiation at 250°C for a dose ~2.5 dpa, was concerned [4)]. However, the toughness of the CuCrZr at a high temperature over 450˚C is dramatically decreased [5)]. On the other hand, one of the ODS-Cu of GlidCop® has a superior high temperature strength over 300 MPa even after an annealing up to ~1000˚C [5)]. This characteristics provide two important advantages. The first advantage is that ensure the redundancy of the temperature margin of the divertor operation even when an unexpected temperature excursion occurs. The second one is the brazing procedures itself, since rapid cooling down phase does not need at the final stage of the brazing heat treatment. The rapid cooling down phase would be considered giving an undesired thermal stress to the material. From the recent assessment of the neutronics environment, copper alloys could be available in a divertor heat sink in both FFHR-d1 and DEMO reactor [3),6)]. A primary dose limit is determined by radiation induced hardening/softening which occurs ~0.2 dpa/1-2 dpa, and it has a temperature dependence. If the temperature of the GlidCop® is completely kept at 300 ˚C, radiation induced hardening/softening would be moderated. According to the above evaluation, the GlidCop® can be selected as the current best candidate material in the commercial base of the divertor heat sink, and its temperature should be kept at 300 ˚C as possible during operation.

Brazing test between tungsten and GlidCop® was carried out by using three kinds of filler materials as listed in table 1. In the first test, BNi-6 showed the best joint strength of around 200 MPa among three filler materials. However, its stress-strain curve showed brittle fracture properties [1)]. Then, we tried to find and test the better brazing condition. Fig. 1-(a) and -(b) shows the heat treatment procedures of the first and the improved second brazing test. The improvement points are (1) treatment temperature was decreased from 980˚C to 960˚C, (2) Treatment time was reduced from 45 min to 10 min, and (3) Slow cooling rate was adopted. The point (3) cannot apply in CuCrZr. As the results, ductile fracture properties were obtained as shown in Fig. 2. Since yield strength of GlidCop® is over 300 MPa, deformed regions in those specimens are concentrated on the filler material. This fact deserves to surprise, because this means that actual deformation of the brazed filler material is quite larger than the strain rate of Fig. 2.

Then, the small-scale divertor mock-up of the W/BNi-6/GlidCop® was successfully fabricated by the improved brazing method as shown in Fig. 3. Taking into account of the applicability for the three dimensional helical divertor, the flat plate tungsten armour has been considered. The heat loading test was carried out by electron beam device ACT2 in NIFS. Fig 4 shows the temperature profile of the mock-up during steady sate heat loading. The highest temperature under 8 MW/m^2 is ~350˚C in the tungsten plate. The temperature profile is quite reasonable by modelling calculation by a finite element method (ANSYS). The design of the W/BNi-6/GlidCop® showed an excellent potential for using in the FFHR-d1 divertor.

Filler materials	Solid phase [˚C]	Liquid phase [˚C]	Cr	Cu	Mn	Ni	P	Si	Fe	B
MBF-20	969˚C	1024˚C	7			bal.		4	3	3
BNi-6	875˚C	875˚C				bal.	11			
Nicuman37	880˚C	925˚C		52.5	38	9.5				

Table 1. Chemical composition [%] and solid/liquid phase temperature of the selected filler materials.

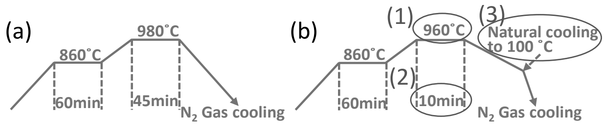

Fig. 1. Procedures of the brazing heat treatment of (a) first test and (b) improved second test.

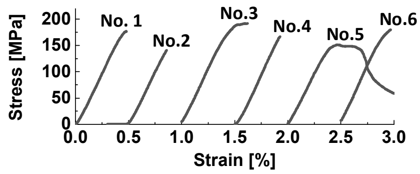

Fig. 2. Stress-strain curves of W/BNi-6/GlidCop® brazing specimens. (6 pieces of specimens)

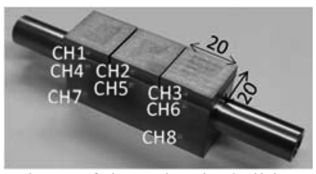

Fig. 3. Divertor mock-up of the W/BNi-6/GlidCop®.

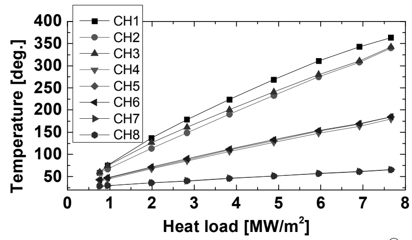

Fig. 4. Temperature profile of the W/BNi-6/GlidCop® mock-up in Fig. 3 during a steady state heat loading.

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