4.4 Fabrication of ITER First Wall Mock-ups with Beryllium Armour

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This paper presents the fabricability development for the ITER first wall through the fabrication of a real size first wall panel mock-up without beryllium armor and a partial mock-up of the first wall panel with beryllium armor. Microscopic observation and mechanical test of the HIPped Be/Cu-alloy joints were also performed of which results showed good bondability of the joints. Finally the fabrication procedure of the ITER first wall panel has been established.

1. INTRODUCTION

Beryllium and copper alloy such as DSCu (alumina dispersion strengthened copper: GlidCop® AL-25) or precipitation hardened CuCrZr are candidate materials as the armor and heat sink materials of the first wall in ITER, respectively. Fabrication technologies for the ITER first wall panel with beryllium armor and copper alloy heat sink have been developed. Hot Isostatic Pressing (HIP) has been applied to the bonding of beryllium/copper alloy and also the bonding of copper alloy/stainless steel (SS). The HIP technique realizes satisfactory joints with small deformation and with low residual stress under the condition of high temperature and high bonding pressure even for these dissimilar materials.

The HIP conditions were previously selected by screening tests and high heat flux tests with mock-ups [1, 2]. In case of DSCu as the heat sink material, by applying the selected conditions, i.e. 620℃, 150MPa and 2 hour-holding time with copper interlayer for beryllium/DSCu and 1050℃, 150MPa and 2 hour-holding time without interlayer for DSCu/SS, a partial mock-up of the first wall panel with beryllium armor was successfully fabricated. Also, together with the fabrication of a real size first wall mock-up without beryllium armor, the overall procedure for the fabrication of the first wall panel with beryllium armor has been established. Metallurgical observation of the bonded interfaces were also performed resulting in the confirmation of the fabricability.

2. CONFIGURATION OF ITER FIRST WALL PANEL

A blanket module in ITER consists of four first wall panels facing directly to plasma and one shield block behind the first wall panels so as to protect the outer components from neutron irradiations, of which weight is approximately 4 ton. Figure 1 shows the

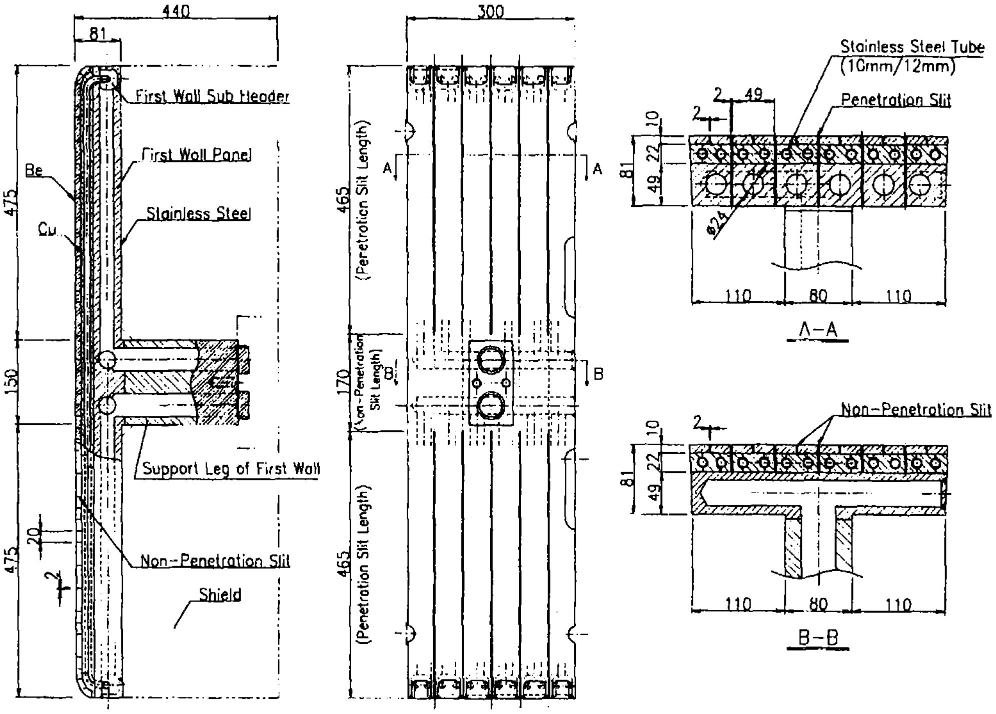

Fig. 1 Configuration of the First Wall Panel

configuration of the first wall panel. The overall dimension of the panel is approximately 300mm^{W} x 1100mm^{H} x 80mm^{t}. A central support leg is extended from the back of the panel to be inserted into the shield block and fixed to the shield block rigidly by welding. The first wall panel consists of beryllium armor, copper alloy heat sink material, SS tubes embedded in the copper alloy, SS backing plate and the support leg also made of SS. It is important for these materials to be bonded metallurgically so that the panel can provide a good performance of heat removable and eventually a good durability against high thermal loads from plasma. There are a lot of slots penetrating through the panel so as to reduce the eddy current and finally the electromagnetic force during plasma disruption. Beryllium armor is especially castellated to reduce thermal stress due to the high thermal loads.

3. FABRICATION OF FULL-SCALE FIRST WALL PANEL MOCK-UP WITHOUT BERYLLIUM ARMOUR

3.1 Mock-up Configuration and Bonding Method

The full-scale first wall panel mock-up includes all elements shown in Figure 1 except beryllium armor. For fabrication of this complex component, a major issue is to obtain good joints in the surface-to-surface bonding of dissimilar materials with complicated 3D shape. It would be very hard by conventional bonding method, such as brazing, fusion welding and explosion bonding etc.

In this study, a new bonding technique, Hot Isostatic Pressing (HIP), is applied. HIP method is based on the principle of diffusion bonding that occurs under the conditions of high temperature and high bonding pressure. In this first wall fabrication, by using thin SS plates to cover grooved copper alloy plates sandwiching the SS tubes, high bonding pressure was imposed to the bonding surface. HIPped joints have low residual stress due to non-fusion welding. This would be a big advantage to reduce the deformation that affects the final configuration.

3.2 Fabrication

Fabrication procedure applied for this mock-up is based on the overall fabrication procedure of the first wall panel shown in Figure 2. As the heat sink material, DSCu was used here.

(1) Assembly before HIP

In the assembly before HIP, SS tubes

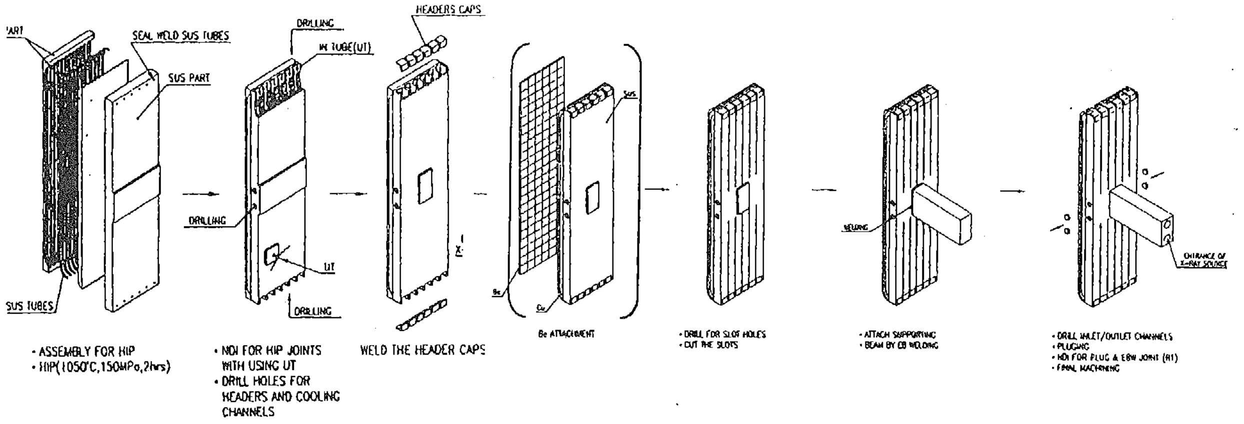

Fig.2 Fabrication Flow of Separable First Wall in ITER

(10 mm inner diameter, 1 mm thickness) and blocks, and DSCu plates which had been machined to correct configuration were assembled as shown in Figure 3 and covered by thin SS plates. The SS tubes, blocks and thin plates were welded at their edges to form the boundary for imposing the bonding pressure during HIP treatment.

(2) HIP treatment

The applied HIP bonding conditions for DSCu and SS were 1050℃, 150MPa, 2 hour-holding time [2, 3].

(3) Drilling and assembly of header

After machining to eliminate the SS thin plates, six coolant holes were drilled through the SS backing plate and first wall sub-headers were machined at both edges of the backing plate, and caps of the sub-headers were welded with TIG welder.

(4) Slotting

Electrical discharge machining was applied to fabricate 70mm-deep penetration slots shown in Figure 1, and a circular saw were used for 22mm-deep non-penetration slots. Figure 3 shows the

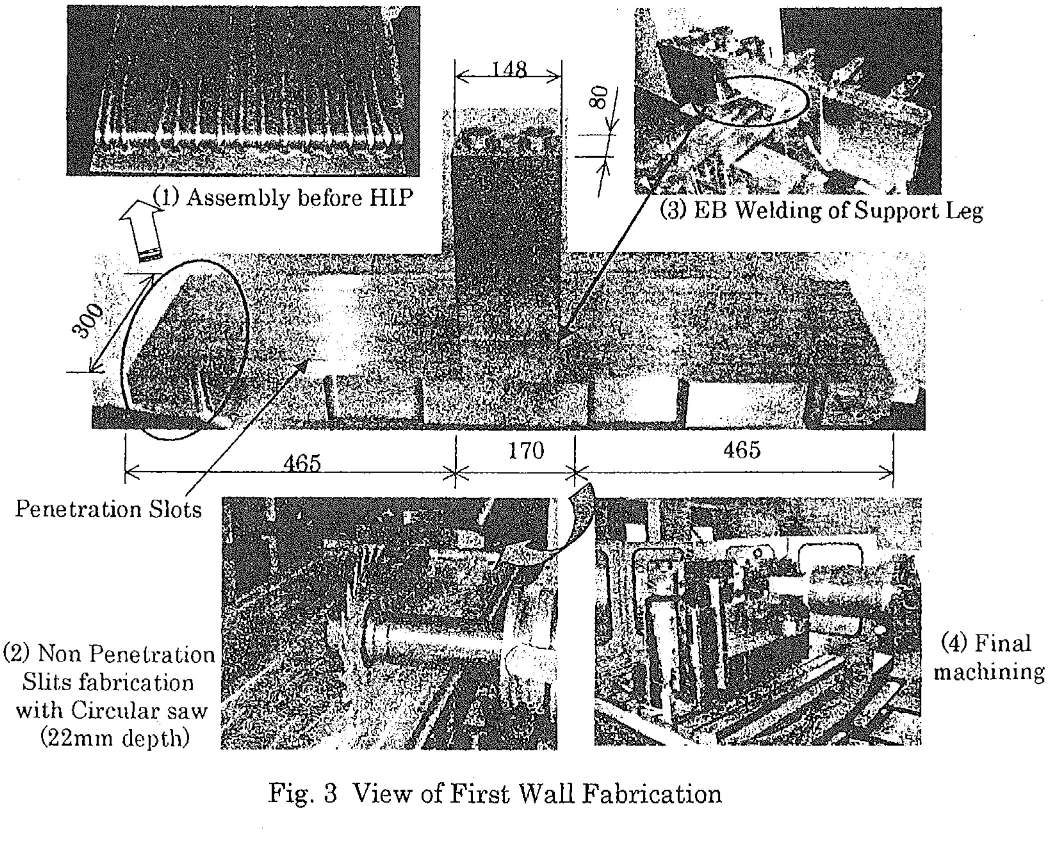

Fig. 3 View of First Wall Fabrication

slotting with the circular saw.

According to the results obtained from dimensional measurement after the slotting, the panel could be fabricated within the accuracy of 300 ± 1.0mm in panel width、2±0.5mm in slot width and < 0.7mm in the step between adjacent surfaces across the slots.

(5) EB welding of support leg

Electron beam welding (EBW) was applied to the joining of the support leg of which cross-section was 150mm x 80mm to the back of the panel. In order to reduce the angular distortion by welding, welding from both sides was selected. The appearance after EBW is shown in Figure 3.

From the results obtained from dimensional measurement after the welding, the deformation due to the angular distortion was 0.69 mm at maximum.

(6) Final machining and inspection

The soundness of the fabricated mock-up was confirmed by pressure test and He leak test etc. Figure 4 shows the final appearance of the full-scale first wall panel mock-up without the beryllium armor set up into a full-scale mock-up of 1/2 shield block.

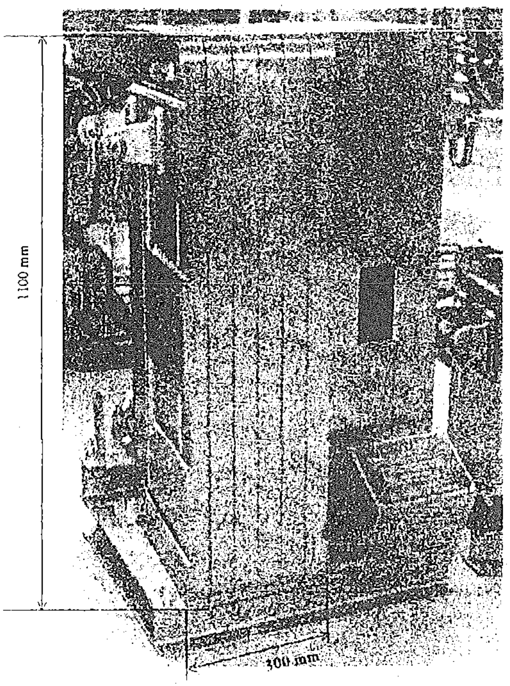

Fig. 4 Final Configuration of Separable First Wall real size Mock-up

4. FABRICATION OF FIRST WALL PARTIAL MOCK-UP WITH BERYLLIUM ARMOUR [4]

4.1 Mock-up Configuration

The configuration of the first wall partial mock-up with beryllium armor is $300\text{mm}^W \times 280\text{mm}^H \times 100\text{mm}^t$ keeping the width to be the same as the full-scale panel.

4.2 Materials and HIP Conditions

The materials used in this fabrication were vacuum-hot-pressed beryllium (S-65C) and the same materials used for the full-scale first wall panel mock-up, i.e. DSCu as heat sink and SS as tubes and backing plate. For interlayer materials between beryllium and DSCu, pure copper was selected from the results of previous screening tests [1]. The interlayer was coated about 20 μm thick onto the surface of DSCu by physical vapor deposition (PVD).

The selected HIP bonding conditions for beryllium and DSCu with copper interlayer were 620 ℃, 150MPa, 2 hour-holding time[1].

4.3 Fabrication

Since the fabrication procedure and method for assembly and HIPping of DSCu and SS were the same as above-mentioned in Section 3.2, the fabrication of beryllium armor onto the HIPped DSCu/SS block is mainly described here.

(1) Machining to shape beryllium tile

After the shaped tiles were cut out from beryllium S-65C block by wire electrical discharge machining, jig grinding machine was applied to finish the surface to be bonded. The surface roughness after finishing was less than 1.6μm.

(2) PVD coating of interlayer

After an alkali cleaning of DSCu surface, a copper plating treatments was carried out by using an ARC type ion-plating equipment. The thickness of coated copper was 20μm.

(3) HIP treatment

Thin SS plates were also used for covering the surfaces to be bonded and

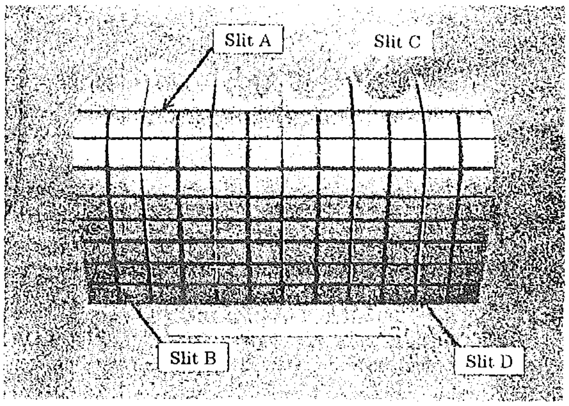

Fig. 5 Procedure of Castellation and Slotting for Beryllium Armor

imposing the bonding pressure during HIP treatment. The selected HIP bonding conditions for beryllium and DSCu with copper interlayer were 620℃, 150MPa, 2 hour-holding time with 425 ℃ , 4 hour-holding time in its cooling down process. The 4 hour-holding at 425℃ was to reduce thermal stress and thus to avoid thermal crack within the temperature range in which thermal expansion coefficient of beryllium becomes high [5, 6].

(4) Castellation and slotting

After eliminating the thin SS plates by machining, the castellation of beryllium tile and the slotting penetrating through beryllium tile, DSCu heat sink and SS backing plate were performed by electrical discharge machining. Electrodes of shaped copper plate and copper wire were used for castellation along curved surface, and castellation along straight surface and slotting, respectively.

Figure 5 shows the procedure of castellation and slotting. The castellation with 10mm depth along straight surface shown with symbol A in the figure were first cut by wire electrical discharge machining. Then the castellation with same depth along curved surface shown with symbol B were cut by electrical discharge machining with shaped electrode. Penetration slots shown with C were made by wire electrical discharge machining. The slots shown with D are also electrical discharge machined but peculiar only to this mock-up.

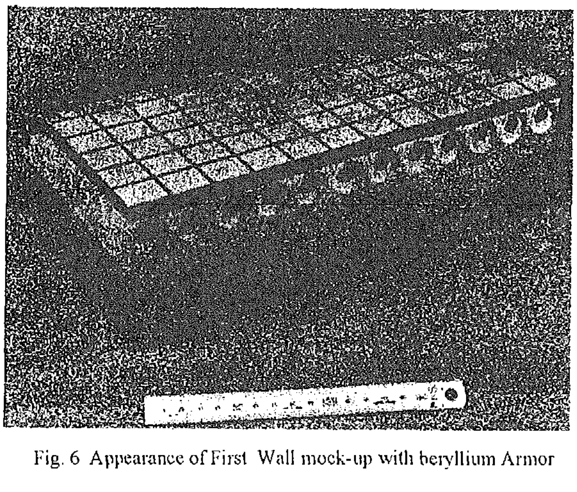

Fig. 6 Appearance of First Wall mock-up with beryllium Armor

Dimensional measurement by means of digital vernier calipers and 3D measuring system found the maximum increase of castellation/slot width and deformation of the curved surface as 0.2mm and 0.058mm, respectively.

Figure 6 shows the final appearance of the first wall partial mock-up with beryllium armor.

4.4 Metallurgical Observation and Mechanical Tests

(1) Metallurgical observation

Figure 7 shows an example of macroscopic observation of beryllium/ DSCu bonded interface. No cracks and exfoliation are observed at the interface. It confirms the soundness of the HIP bonding and harmless influence of the castellation and slotting on the joint.

From the results of microscopic observation and analysis, i.e. SEM and EPMA, some eutectoids are formed at the interface such as Be_2Cu(δ phase) about 1 μm thickness、 BeCu(γ phase)about 6 μm、 BeCu(γ phase)and solid solution of copper(α phase) about 10μm.

(2) Four-point bending test

Four-point bending test was carried out with test specimens sampled from the fabricated mock-up. The bending strengths obtained were 187.3MPa, 247.1MPa and 293MPa (242.7MPa in average). As these results are comparative with those of previous tests, 231.2MPa and 258.1MPa (244.7MPa in average), it can be confirmed that the reproducible bonding techniques has been established.

5. DISCUSSION

Taking account of the deformation measured with the full-scale first wall panel mock-up and the partial first wall mock-up with beryllium armor, total deformation of the first wall panel with beryllium armor would become ±1.7mm for 300 mm panel width, ±1.2mm for 2 mm slit width and < 0.9mm in the step between adjacent surfaces across the slots. In order to provide higher accuracy if necessary, the following procedure can be applied. Before the HIP bonding of beryllium onto DSCu, non-penetration slots are machined from the back side of the panel on the same position of penetration slots remaining a certain thickness of DSCu. After the HIPping of beryllium/DSCu, the remained DSCu is slotted with the bonded beryllium. By this procedure with decreased bonding area, the residual stress and finally the deformation would be further reduced.

Taking account of the curtailment of the total manufacture cost for ITER which has become the serious issues in Japan, a few proposals are shown in the followings in order to reduce the first wall fabrication cost of which the beryllium bonding cost and material one occupy about 40%. At first, it is suggested to reduce the total number of the beryllium castellation. For example, if the size of castellation which has 25mm squire is changed to 50mm one, the total number of castellation and slots fabrication is reduced to half, from about 50 to 24. As the total cutting length of castellation and slots also become half, the big effects of cost reduction can be expected.

The other proposal is a reduction of beryllium purity. Though the beryllium materials in ITER grade is required more than 99.0% of pure beryllium, taking the level of the thermal stress in in-situ thermal load distribution into account, it has the possibility to use the more than 98.5% of beryllium.

6. CONCLUSION

The first wall panel of real size mock-up without beryllium armor and that of partial curved mock-up with beryllium were successfully demonstrated, and the methods and procedure for fabrication of first wall of which joints had the good performance without any cracks and exfoliation have been established.

REFERENCES

[1] T.Hatano et al, Development of Be/DSCu HIP Bonding, 5th IEA International workshop on Beryllium Technology for Fusion, Moscow in Russia (2001)
[2] T. Hatano et al, Fusion Eng. Des., 39-40, 363-370 (1998)
[3] Y. Kosaku et al., Fabrication of the Full Scale Separable First Wall of ITER Shielding Blanket, JAERI-Tech 2002-078 (2002)
[4] Y. Kosaku et al, Fabrication of Prototype Mockups of ITER Shielding Blanket with Separable First Wall, JAERI-Tech 2002-063 (2002)
[5] ITER Document No. S 74 RE 1B, ITER Material Properties Handbook (1998).
[6] P. Lorenzetto et al., "THERMAL FATIGUE TESTING OF A ITER PRIMARY WALL SMALL SCALE MOCK UP", 4th SOFT, Tokyo, April 06-11, 1997.