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Reduction of Residual Thermal Stress of CFC Monoblock Target for JT-60SA Divertor

JT-60SAダイバータ用CFCモノブロックターゲットにおける残留応力低減

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This research proposed new structures of the CFC monoblock target for JT-60SA divertor, to reduce residual thermal stress and to depress degradation of heat removal capacity of the targets, toward the mass-production. The following measures were implemented; slitting in the CFC monoblock aside of the cooling tube, replacement of the interlayer material and shifting the position of the cooling tube. The effectiveness of the measures were evaluated by numerical simulations, and infrared thermography inspection and high heat flux test.

1. Introduction

The JT-60SA divertor employed Carbon Fibre-reinforced Carbon composite (CFC) monoblock targets [1, 2], shown in Figure 1. They are under development toward the mass procurement of 1,000 targets, which are required before the full-power operation of the JT-60SA. In the previous trial productions, significant numbers of the targets showed degradation of heat removal capacity, because of cracks of the CFC monoblock around the cooling tube due to high residual thermal stress caused by difference of thermal expansions of the CuCrZr cooling tube and the CFC monoblock.

In this research, effective measures to reduce residual thermal stress and to depress the degradation of heat removal capacity of the targets are developed, and a new structure of targets is proposed based on the measures.

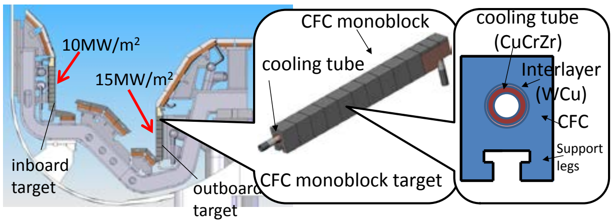

Fig. 1 CFC monoblock target for JT-60SA divertor

2. Residual Thermal Stress of the Target

The targets are manufactured by bonding a CFC monoblock, a CuCrZr cooling tube at the centre of the monoblock and a tungsten copper (WCu) interlayer by vacuum brazing at a maximum of 1,000 ^{0}C. Residual thermal stress of the target was calculated using Femtet® [3]. One CFC monoblock and the corresponding cooling tube were included in the simulation. Residual thermal stress in room temperature is calculated starting from no stress condition at 770 ^{0}C, which the total gap width between the CFC monoblock and the CuCrZr cooling tube is thought to become almost zero, considering thermal expansion coefficients of CuCrZr and CFC. Figure 2 (1) shows the calculated residual thermal stress of the conventional target. In the CFC monoblock, the maximum principle stress reached a peak value near the cooling tube, which is within 80-90 MPa. As the index of the largeness of the residual thermal stress, averaged maximum principle stress in CFC on the bonding surface between CFC monoblock and interlayer within ±45^{0} from the centre of the plasma facing surface where is important for heat removal of targets, E_f, is defined. E_f of the conventional geometry was 85.0 MPa, which is significantly large for CFC. It is necessary to reduce the residual thermal stress of the CFC monoblock target.

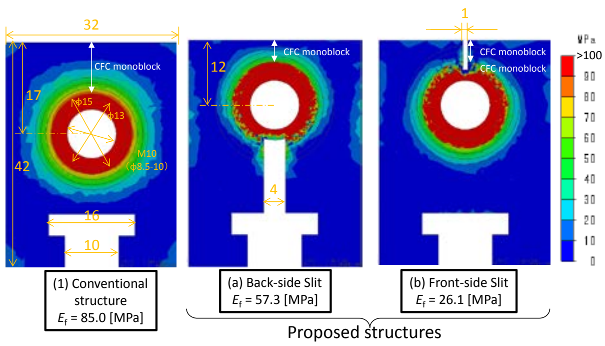

Fig. 2. Contour plot of residual thermal stress

3. Reduction of Residual Thermal Stress

The following measures were proposed to reduce the stress; (i) making a slit in the CFC monoblock aside of the cooling tube, (ii) changing the harder WCu interlayer of 1.0mm thickness to softer oxygen-free copper (OFCu) interlayer of 1.5mm thickness, and (iii) changing the position of the cooling tube. The result of the parameter study is shown in Figure 3. E_f is plotted against position of the cooling tube, x, i.e., distance between the plasma facing surface and the centre of the cooling tube. The case with slit in support-leg-side ((a) backside slit case), the case with slit in plasma facing surface side ((b) front-side slit case), and the case with no slit ((c) no slit case) are plotted in the same graph. In addition to the OFCu interlayer cases, the WCu interlayer cases with three slit cases are also plotted as (d), (e) and (f). Summarizing the parameter study, residual thermal stress of the CFC monoblock target is expected to be reduced by the following measures; (i) making a slit in front-side (plasma-facing-side) or back-side (support-leg-side), (ii) employing soft OFCu as the interlayer material, and (iii) locating cooling tube near the plasma facing surface.

New structures for reduction of residual thermal stress are proposed as follow; two types of slit condition, i.e., (a) back-side slit type and (b) front-side slit type, OFCu interlayer, x = 12 mm (avoiding too small x considering manufacturability), as shown in Figure 2 (a) and (b), in which the residual thermal stress in the CFC monoblock on the bonding surface is 30-70 MPa in (a) back-side slit type and 0-40 MPa in (b) front-side slit type. The E_f of the proposed structures are 57.3 MPa for (a) back-side slit and 26.1 MPa for (b) front-side slit, respectively, which are both drastically reduced from that of the conventional structures.

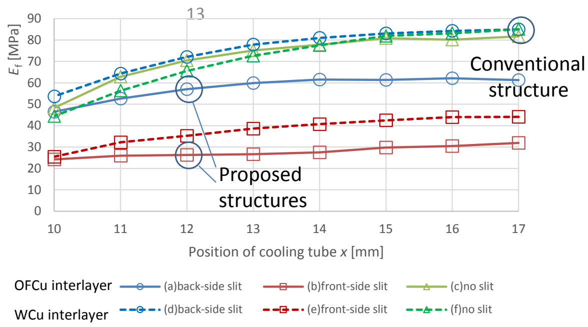

Fig. 3. Parameter study on residual thermal stress

4. Tests on Target Mock-ups

In order to evaluate heat removal capacity of the mock-ups with the proposed structures, infrared thermography inspection using the FIND facility [4, 5] was carried out, which can evaluate cooling performance by thermal response during quick change of water temperature in the cooling tube from hot water (95 ^{0}C) to cold water (5 ^{0}C). The cooling time of each block is normalized by that of the reference block, block #1 of (a) back-side slit type in this test, as summarized in Figure 4. All mock-ups have good cooling performance in the front side (measuring position ②, ③ and ④) where is important for cooling of actual target.

High heat flux test of 15 MW/m^2 (a) back-side slit target was carried out by JEBIS (JAEA Electron Beam Irradiation System) [6]. The maximum temperature is 1,631 ^{0}C, which is below the temperature limit of the targets, 1,800 ^{0}C.

Considering the results of the infrared thermography inspection and the high heat flux test, the heat removal capacities of the proposed structures are confirmed.

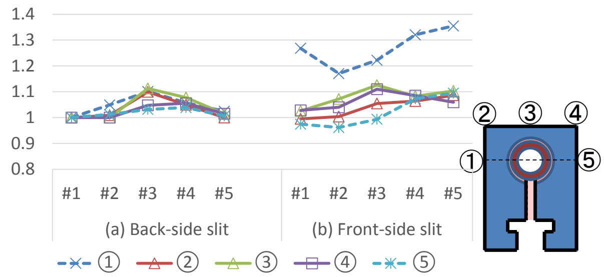

Fig. 4. Result of infrared thermography inspection

5. Conclusion

New structures of CFC monoblock target for the JT-60SA divertor were proposed, in which effective measures to reduce residual thermal stress and to improve heat transfer capacity were developed and implemented. Effectiveness of the new structures was confirmed by infrared thermography inspection and high heat flux test.

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