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Current Status of ITER Full Tungsten divertor technology Development

ITER用タングステンダイバータ開発の現状

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Technology development for ITER full-tungsten (W) divertor outer vertical target (OVT) is in progress in Japan Atomic Energy Agency (JAEA), especially, tungsten monoblock technology that needs to withstand the repetitive heat load as high as 20 MW/m^2. To demonstrate the armor heat sink bonding technology and heat removal capability, 6 small-scale W monoblock mock-ups manufactured by different bonding technologies using different W materials in addition to 4 full- scale prototype plasma-facing Units. After non-destructive test, the W components were tested under high heat flux (HHF) in ITER Divertor Test Facility (IDTF) at NIIEFA. Consequently, all of the W monoblocks endured the repetitive heat load at 20 MW/m2 for 1,000 cycles (requirements 20 MW/m2 for 300 cycles) without any failure.

1. Introduction

After recommendation of the ITER council to develop tungsten (W) monoblock technology for the final decision of the target material of ITER divertor in November 2011, ITER organization (IO) and Japan Atomic Energy Agency (JAEA) as Japanese Domestic Agency (JADA) are actively working on the development and demonstration on the full-W divertor concept under the framework of the task agreement of ITER full tungsten divertor qualification program instead of the CFC/W divertor concept development [1, 2]. JAEA is in charge of technology development and demonstration for manufacturing ITER Divertor Outer Vertical Target (OVT, see Fig 1) together with Japanese industries. In these activities, JAEA has manufactured small-scale mock-ups to examine the durability of the W monoblock itself and the joint of W monoblocks to the Cu-Alloy (CuCrZr) cooling tube trough repetitive high heat flux testing. This paper presents the results of the Full-W Qualification Program conducted by JAEA.

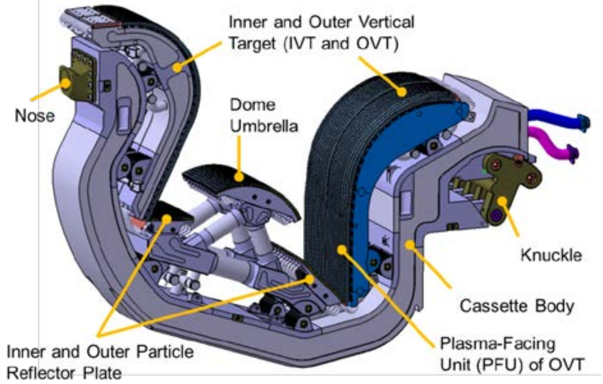


Fig 1. 3D view of the ITER W Divertor

2. Manufacturing Small-scale W-monoblock mock-ups

The small-scale W-monoblock mock-ups that were fabricated in this program are shown in Fig. 2. Prior to bonding the W monoblock to the CuCrZr cooling tube with the outer and inner diameter of 15 and 12mm, the pure copper (Cu) interlayer with the thickness about 1mm is bonded to the hole of the W monoblock. In the present study, the W monoblocks are supplied from the three different manufacturers and they adopted their own bonding technologies for W/Cu interface such as HIPping, Casting, and unidirectional diffusion bonding.

The high temperature brazing for bonding of the W monoblocks with pure Cu interlayer to the CuCrZr cooling tube with Ag-free brazing filler. The brazing filler is Ni-Cu-Mn alloy. The brazing heat cycle is operated at around 980^{o}C, which serves also as solution annealing of CuCrZr, followed by the gas quenching and by the aging heat cycle at 480^{o}C. Before high heat flux testing, the joints for two joint interfaces of W/Cu and Cu/CuCrZr were inspected by Non-destructive examinations i.e. ultrasonic examination and mock-ups passed hydraulic pressure test and cold-He leak test.

3. High Heat Flux Testing on W monoblocks

The high heat flux testing on the small scale W monoblock mock-ups fabricated with the technologies described in Sec. 2.1 were carried out by IO and RFDA at an electron beam facility, ITER Divertor Test Facility (IDTF) at NIIEFA [3]. JADA delivered 6 mock-ups and all of them were tested. The test conditions are as follows; the cooling water at 70^{o}C and 4MPa, the heat load conditions under 10 MW/m^2 for 5000 cycles and 20 MW/m^2 for 300 cycles (IO requirements) and for the additional 700 cycles. The acceptance criteria for successful fatigue performance are defined as follows; (a) No trace of substantial melting at the loaded W surfaces by visual examination, (b) No water leak from the loaded W monoblock/CuCrZr component, (c) No detachment of any W monoblock, (d) No appearance of any "hot spot" during fatigue cycling, and (e) No variation of the maximum surface temperature exceeding 20% between the initial and final thermal mapping. The mock-ups passed the criteria mentioned above throughout the HHF testing, therefore, these tests demonstrate that the W monoblock technologies of Japanese industries and JAEA satisfy the IO requirements regarding heat removal capability and durability against the repetitive high heat loads.

The figure 3 shows the overview of the surfaces of the W monoblocks after 1000 cycles at 20 MW/m2. Although during the additional 700 cycles, the heated surface of the W monoblocks show the progress of the plastic deformation caused by high thermal stress, no macroscopic crack at the W surface after the test was observed.

Fig 4 (a) Full-scale PFU prototype as test assembly and (b) W surface after 5000 cycles at 10 MW/m^2 and 1000 cycles at 20 MW/m^2.

In parallel to the full-W qualification program, JAEA has tested the full-length PFU prototype based on the previous ITER divertor design with CFC and W monoblocks as shown in Fig.1. Because these prototypes have a short W straight part

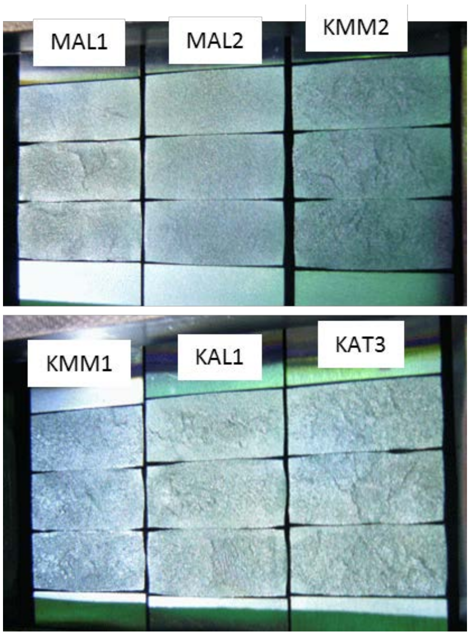


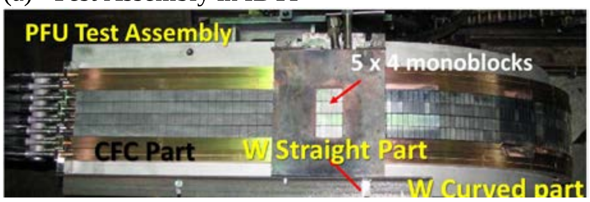
Fig. 3. W monoblock surface of the small-scale mock-ups after 5000 cycles at 10 MW/m^2 and 1000 cycles at 20 MW/m^2 in IDTF. KMM1, KAL1 etc show mockups' IDs.

with the same dimensions as those of the current reference W monoblock, this part was tested. The four PFU prototypes were mounted on a test frame dedicated to IDTF, called Test Assembly as shown in Fig 4 (a). In this activity, 5x4 W monoblocks withstood against 5000 cycles at 10 MW/m^2 and 300 plus 700 cycles at 20 MW/m^2 without any failure such as water leak from the cooling tube and the substantial W monoblock melting. The surface of W monoblocks after the repetitive high heat loads are shown in Fig. 4 (b). Although the crystal growth of W occurs, the no macroscopic crack at the surface is observed. Comparing the results from the small scale mock-ups case, the plastic deformation of the W surface is suppressed. This might be ascribed to the overheating occurred in the small-scale mock-up case because of the water chemistry problem, that is, thermal barrier was formed at the cooling tube by deposition of the impurity during the coolant boiling. This is discussed elsewhere [4]. From the both results of high heat flux testing mock-ups and prototypes, JADA can draw the conclusion that that W monoblock technology including material production and manufacturing is available.

References

[1]T. Hirai et al., Fus. Eng. & Des.88 (2013) 1798– 1801.
[2]T. Hirai et al., Phys. Scr. T159 (2014) 014006.
[3]K. Kuznetsov, et al., Fus. Eng. & Design 89 (2014) 955–959.
[4]G. Pintuk et al, Characterization of ITER tungsten and CFC qualification mock-ups exposed to high cyclic thermal loads, (P2-088) in Symp. Fus Tech (SOFT) 2014.

(a) Test Assembly in IDTF



(b) W surface after HHF testing in IDTF

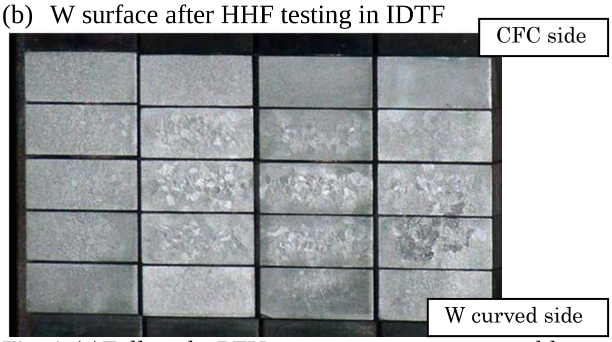


Fig 4 (a)Full-scale PFU prototype as test assembly and (b) W surface after 5000 cycles at 10 MW/m^2 and 1000 cycles at 20 MW/m^2.