SI-8

ダイバーター開発の進展
Progress on the development of the ITER divertor

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1. Introduction

JAEA, assigned as Japanese Domestic Agency (JADA), is currently manufacturing various components for the ITER construction. The ITER divertor components are being manufactured by 3 parties (EUDA, RFDA and JADA). JADA is responsible for the manufacturing of the divertor outer vertical target.

The divertor has a role to exhaust impurities which come from plasma. The divertor is subjected to the high heat flux from the impact of the impurities. To withstand the high heat flux, the surface of the divertor is covered with refractory materials. The inner and the outer vertical target where the severe heat flux is subjected are covered with carbon fiber composite and pure tungsten, and the dome components are fully covered with pure tungsten in the current baseline design. These armor materials are metallurgically bonded to the copper alloy (CuCrZr) cooling tubes to achieve high heat removal capability. Figure 1 shows the schematic drawing and the procurement sharing of the ITER divertor components. Unique technologies, which have been independently developed by the 3 parties, are utilized for the bonding of the armor materials and the cooling tubes. JADA currently uses "brazing" technology for the bonding.

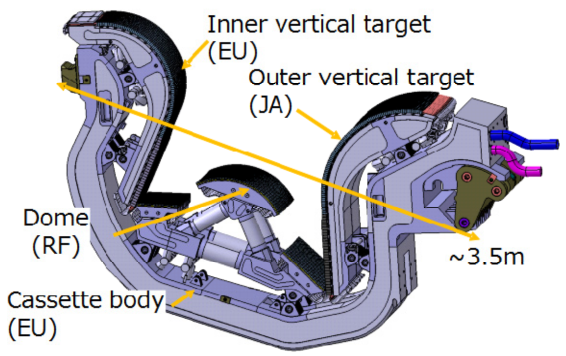

Figure 1　Schematic and procurement sharing of ITER divertor components (1 cassette, current)

On the other hand, ITER organization (IO) has proposed to start with a fully tungsten-armored divertor targets since 2011, in terms of cost saving and relevancy of DEMO divertor design. This proposal is still in review at the IO's advisory committees (STAC and MAC). And the final decision on the armor material selection of the divertor targets will be made by the ITER Council within 2013. As a result, JADA has started R&D's on the fully tungsten-armored divertor target. In this paper, latest progress on the R&D's on the fully tungsten-armored divertor target in JADA is presented.

2. Small-scale tungsten divertor mock-ups

JADA and IO have placed the contract to develop tungsten-armored divertor targets since the end of 2012. Based on this contract, JADA has provided more than 10 small-scale divertor mock-ups with pure tungsten armor tiles for high heat flux testing in order to investigate the thermal performance and the durability. Figure 2 shows a schematic drawing and the photo of the small-scale tungsten divertor mock-ups.

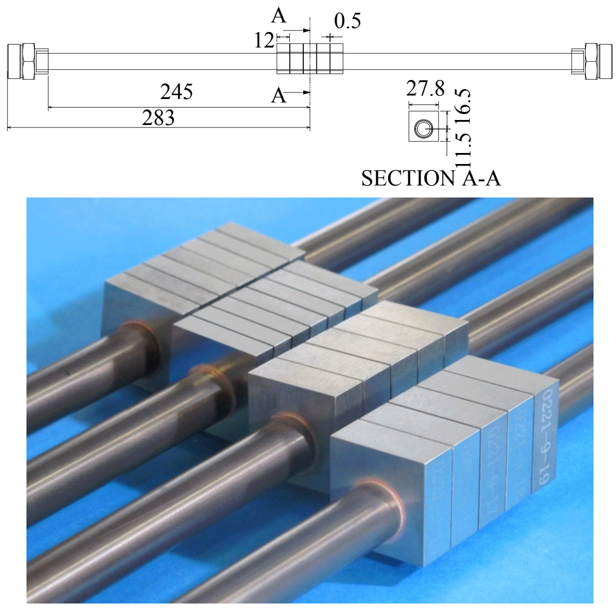

Figure 2 Schematic drawing and photo of small-scale tungsten divertor mock-ups (unit: mm)

The cross section of the mock-ups is similar to that of the divertor outer vertical target in the current design. The tungsten monoblock armor is bonded onto the pure copper interlayer prior to the brazing process. And then, the pure copper interlayer and the cooling tube made of CuCrZr are brazed with Ni-Cu-Mn based braze filler material. Table 1 shows the bonding method of the mock-ups.

Table 1 Bonding method of small-scale tungsten divertor mock-ups

	Tungsten /Cu interlayer	Cu interlayer /CuCrZr tube
Type A	Direct casting of Cu	Ni-Cu-Mn brazing
Type B	Diffusion bonding	
Type C	HIP bonding	

As shown in the table, three kinds of bonding methods between the tungsten armor and the pure copper interlayer have been tested to qualify as suitable bonding techniques for the manufacturing of the ITER divertor targets.

3. Results of high heat flux testing

High heat flux testing of the small-scale tungsten divertor mock-ups has been carried out in the test facility at JAEA and in the ITER Divertor Test Facility (IDTF) at Efremov Institute in Russia. The maximum heat flux of 20 MW/m^2 was cyclically applied to the plasma-facing surface of the mock-ups to simulate the slow-transient heat flux of ITER. In this thermal cycling experiment, the maximum surface temperature of the tungsten armor reached over 2000^{o}C, which exceeds the recrystallization temperature of pure tungsten (=~1300^{o}C). The trace of recrystallization of the tungsten armor was found in all mock-ups. Although 1 out of 8 mock-ups tested showed surface cracking, the other 7 mock-ups demonstrated sufficient thermal performance and durability without any failure up to 300 cycles. In particular, 6 mock-ups tested in IDTF withstood without any failure not only for 1000 cycles at 20MW/m^2 but also for additional 5000 cycles at 10MW/m^2 to simulate normal operation of the ITER divertor targets, which strongly encourages IO's design change proposal described in the previous section. Figure 3 shows the surface of the tungsten armor of the mock-ups after 1000 cycles at 20MW/m^2.

Summary

JADA has successfully developed small-scale tungsten-armored divertor mock-ups which can fulfill the acceptance criteria for the ITER divertor target part in preparation for the final decision on the armor material selection of the divertor targets by ITER Council. In addition, high heat flux test results obtained so far suggest that the current material specification on tungsten is sufficient for the steady-state heat flux toward the ITER divertor targets. Those results also indicate that the current tungsten monoblock technology including the bonding techniques is acceptable for the requirements of the full-tungsten divertor vertical targets for ITER.

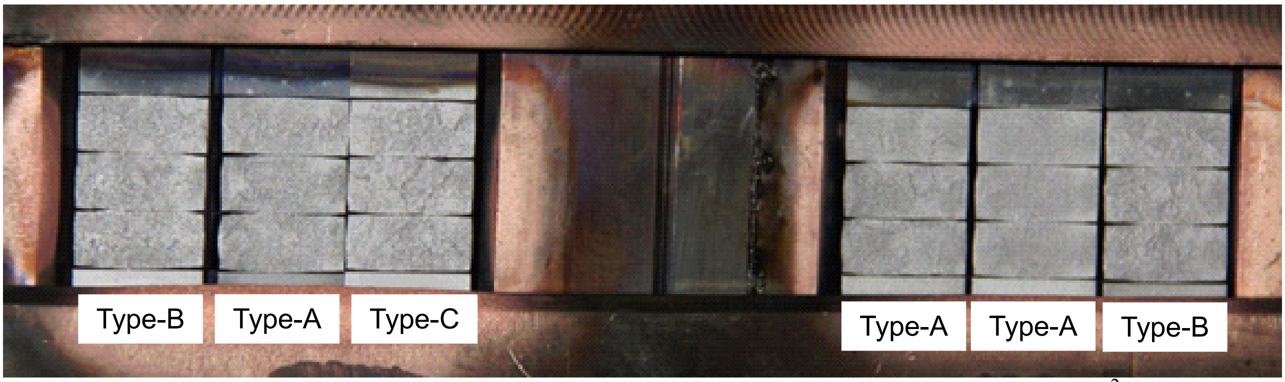

Figure 3 Small-scale tungsten divertor mock-ups after 1000 thermal cycles at 20MW/m^2 in IDTF