§10. R&D of Mechanically Joined Module for Divertor Plate of LHD

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Mechanically joined module(MJM)s more than 1700 were installed in the vacuum vessel of LHD as actively-cooled divertor plates at the third campaign for impurity control and wall protection. Each MJM consists of an isotopic graphite(IG-430U) armor tile, copper heat sink, thin graphite sheet, and SS cooling pipe, which are fixed tightly with several SS bolts. The graphite sheet is used to improve thermal transfer efficiency between the armor and heat sink, and between heat sink and cooling pipe. The heat loading test using a facility ACT[1,2] for the module indicates that the thermal performance of the module deteriorates rapidly when heat flux exceeds 0.5 MW/m^2, which is caused by the deformation of the copper heat sink due to high heat loading. To improve the thermal performance, an advanced MJM without a separate copper heat sink, but with a unified armor/heat sink made of isotopic-graphite or carbon composite has been developed. Moreover, a super graphite sheet with a high thermal conductivity of 600W/(m·K) in parallel and strong tensile strength of 19.6N/mm^3 is used as a compliant sheet instead of normal carbon sheet used in the normal MJM. The unification for armor and heat sink simplifies the structure, gives less weight and higher cooling efficiency. Fig.1 shows a schematic view of advanced-MJM. To evaluate the thermal performance of the MJM, steady state high heat flux tests of 2.0 to 4.25MW/m^2 and thermal fatigue test under a heat flux of 2.5MW/m^2 have been carried out using the facility ACT. To evaluate the thermal performance, the temperatures(Ts, Tu, Tl) at the surface, middle and bottom

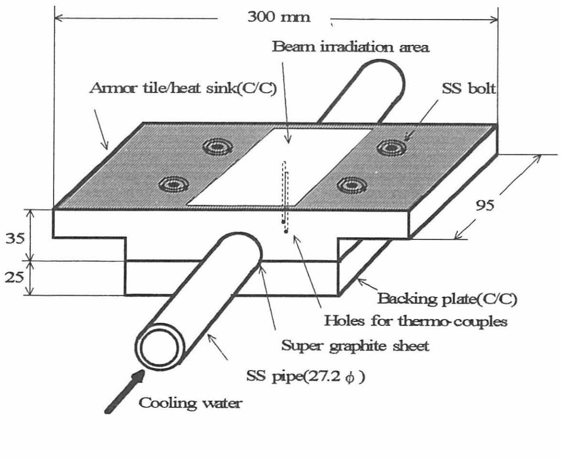

Fig.1 Schematic view of advanced MJM.

of the armor/heat sink were monitored using a pyrometer and two thermo-couples. Fig.2 indicates thermal responses of advanced-MJM with an armor/heat sink made of carbon composite(CX-2002U) and copper cooling pipe measured under steady-state(for 600s) heat flux of 4.0MW/m^2. The saturated surface temperature(Ts) reaches about 1100℃, while the temperature reaches 580℃ at HF=2.0MW/m^2. After the tests, no apparent damage or no loss on the armor/heat sink was observed while a little increase in the surface temperature with shot number occurred during the thermal fatigue test. The increase may be caused by the shrinkage of super graphite sheet or deformation of the armor/heat sink due to cyclic high heat loadings.

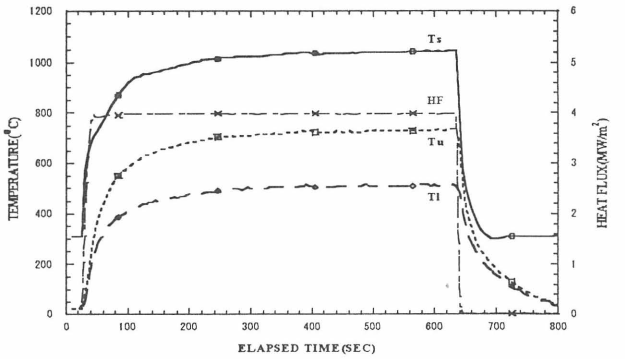

Fig.2 Thermal responses(Ts,Tu,Tl) of advanced-MJM with a super graphite sheet of 0.3mm at HF=4.0MW/m^2.

The dependency of saturated temperature(Tu) on the heat flux is shown in Fig.3 for three kinds of MJMs. The figure indicates that the thermal performance of 3) Unified type of MJM with a super graphite sheet of 0.3mm is superior to those of the other two types.

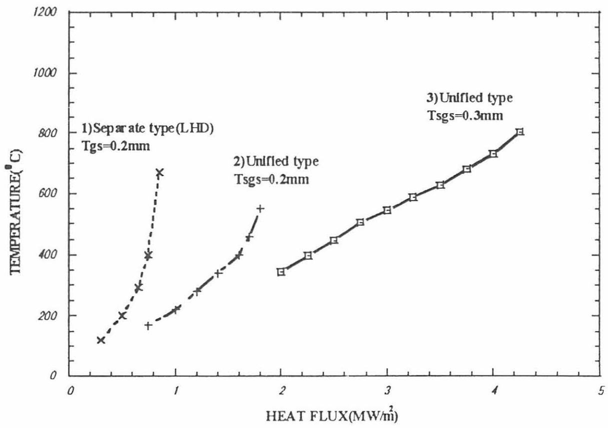

Fig.3 Relationship between the saturated temperatures (Tu) and heat flux for three types of MJMs.

References

1) Kubota,Y.,Noda,N., et al.,NIFS-MEMO-13(1994).

2) Kubota,Y.,Noda,N., et al.,NIFS-MEMO-16(1995).