§1. Development for Coating/jointing of Tungsten on Structure Materials and Evaluation of Heat Loading Property

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Tungsten is potential candidate for an armor of the first wall and the divertor plate of the fusion reactor because of its low erosion yield and good thermal properties. Joint material with tungsten and cooling channel will be used as the divertor plate. Cu is one of high thermal conductivity material for the cooling channels. In addition, in the case of the fusion demonstration reactor (DEMO), neutron damage will be a critical issue. Structure materials of the first wall/blanket and the cooling channels of the divertor of DEMO will be made by low activation materials. In the present work, W coating/jointing materials on low activation materials such as reduced-activation ferritic/martensitic steel (RAF/M) are tried to fabricated to develop W divertor mock-up for LHD and FFHR and then, heat loading properties of them will be investigated. In this fiscal year, fabrication method of jointing of bulk pure W and reduced-activation ferritic/martensitic steel (RAF/M) was investigated. In addition, heat loading tests of W small samples using electron beam have been carried out and thermal stress has applied on the samples to design evaluation method of heat loading property on small W samples.

The ITER grade W were machined to 10 mm x 10 mm x 1mm, followed by mechanical and electro polishing. Specimens were placed on a water-cooled Cu block and subjected to high heat load experiments by an electron beam irradiation test simulator of the Research Institute for Applied Mechanics, Kyushu University. The electron beam energy used was 20 keV. The beam diameter was 3 mmϕ. Heat flux was evaluated by the beam diameter and net electric current of the electron beam irradiated. The net current was measured by applying a bias voltage to the sample to suppress the secondary electron induced by the electron irradiation. The surface temperature of the center region with a diameter of 1mmϕ of the sample was measured with two-color optical pyrometers (400-1100ºC, 1000-3100 ºC). Before and after the irradiation, the sample surfaces were examined by a scanning electron microscope (SEM). Temperature profile and elastic-plastic analyses were performed for ITER grade W using the finite element code ANSYS. Only 1/4 geometry was considered due to symmetry. The temperature dependence of the materials properties of thermal conductivity, coefficient of thermal expansion (CTE), elastic modulus and Poisson’s ratio and were taken into account. True stress–true strain curves (two straight - line approximation), which were developed by tensile test, has been used in the FEA analyses.

Spark Plasma Sintering (SPS) and Hot Isostatic Pressing(HIP) methods have been designed to joint W bulk and reduced-activation ferritic/martensitic steel (RAF/M). Both methods, crack and exfoliation near boundary between W and RAR/M may be formed during cooling after the jointing due to difference of thermal expansion coefficient. In addition, intermediate layer may be also formed and diffusion of W and constituent elements of RAF/M may occur. As the objective of the work is to evaluate of jointing materials for heat loading, small samples which small stresses will be formed during the cooling after the jointing are going to be fabricated. In the heat loading tests, repeated heat loading which the peak surface temperature of 1250 ºC could be carried out by controlling electric beams current. The tests were conducted at following irradiation conditions: repeated of 2-s irradiation and 7.5-s rest with one cycle of 9.5 s for a total cycle of 200 times. After repeat of 20 time heating, surface was modified and slip lines by plastic deformation were seen. Figure 1 shows the surface after repeating heating of 200 times. After 200 times repeated heat loading, remarkable modification occurred and surface roughened as shown in Fig.1. In addition, cracks and exfoliation along the grain boundaries were also formed on the surface. Figure 2 shows temperature distribution, Mises stress after 2 s electron beams irradiation start by FEM analyses. One corner is the center of the sample because 1/4 model is used. Temperature of surface center is almost agree with the heat loading test result. In center area in the sample surface, stress is released by plastic deformation due to decrease of yield stress at high temperature. This result is agree with the experimental result which slip lines were seen in the center area on the surface of ITER grade W. In addition, the thermal stress analyses indicated that compressional stress and tensile stress is applied on the center area and the out of the center area, respectively, during the heat loading. On the other hand, tensile stress is applied during the cooling. This cyclic stress is considered to cause damage by fatigue. These results also indicate that relation between thermal stress and modification can be revealed by comparing with calculation result of stress by FEM and the heat loading test on the small sample.

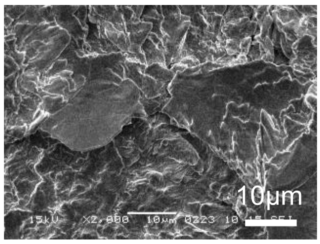

Fig.1 SEM image after heat loading

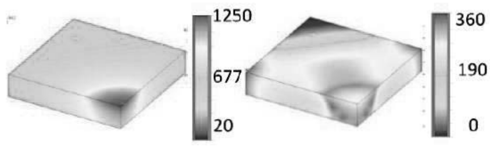

Fig.2 Temperature distribution(ºC) (Left) and Mises stress (MPa) (Right)