§107. Mechanical Property of Plasma Facing Materials Irradiated by Neutron/Ion

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Tungsten (W) is the primary candidate for use as plasma facing materials/components (PFM/PFC). PFM/PFC will be subjected to heavy thermal loads in the steady state or transient mode combined with high energy neutron irradiation that will cause serious material degradation. It is necessary to clarify mechanical strength to evaluate thermal behavior of tungsten materials by high heat loading. In the present works, the tensile testing W material has been performed up to at 1600 °C to obtain stress-strain curves. In addition, observation of fracture surface has been carried out to investigate fracture behavior. In addition, thermoelasto-plastic stress analyses using a finite element analyses (FEA) have been performed to evaluate the thermal behavior and modification of the ITER W divertor mock-up during the high heat loading.

W material used in the present work was ITER grade W. Tensile testing was performed on dog-bone shaped tensile test specimens with an overall length of 16 mm, a gauge length of 5 mm and an effective cross section of 0.6 mm^2. The orientation of the specimens used were parallel (L-R type) and perpendicular (T-R type) directions to rolling direction along rolling surface, respectively. The tests were conducted at RT, 200, 400, 650 (Ar + 4%H_2), 800, 1000 and 1300, 1600 °C (in vacuum: 5 x 10^{-4} Pa). The tests were performed at a strain rate of 2 x10^{-4} s^{-1}. By SEM investigations of the fracture surfaces, the different failure modes dependent on temperature were characterized. The stress-strain curves of ITER grade W obtained in the tensile testing has been used in the FEA analyses to quantitative evaluation of thermoelasto-plastic stress due to high heat loading.

Steady-state temperature and thermal stress profiles for a three dimensional model of the ITER W monoblock divertor mock-ups have been calculated using the finite element analysis code ANSYS. Heat transfer from the mockup to the coolant water via forced convection has been computed by using a film code, which calculated the heat transfer coefficient as a function of wall temperature.

Figure 1 shows stress-strain curves of L-R type W. Brittle fracture occurs both L-R and T-R type specimens at RT. On the other hand, ductile fracture occurs on L-R type specimen but not T-R type specimen at 200 °C. This result means that DBTT of the specimen is around at 200 °C in the case of this strain rate. Yield strength decreases and total elongation increases with increasing test temperature. There is difference of about 100 MPa between L-R and T-R type specimens on tensile strength at RT and 200 °C, however, there is no difference between them above 400 °C. The reason for this is because migration of dislocation do not occurs at low temperature, and shape of grain boundary for direction of stress influence tensile strength. On the other hand, there is difference between L-R and T-R type specimens on total elongation, even if high temperature which ductile fracture occurs, and total elongation of L-R type specimen is higher than that of T-R type specimen. These stress-strain curves of ITER grade W obtained in the present works has been used in the FEA analyses to quantitative evaluation of modification of the ITER W divertor mock-up due to high heat loading.

Figure 2 shows temperature distribution (a) and equivalent stress (elastic analyses(b), elasto-plastic analyses). Results from the FEA analyses indicate that in the case of heat flux of 10 MW/m^2, temperature changes from the heat loaded surface to cooling tube and temperature gradient occurs. The elastic stress analyses show stress is generated by the temperature gradient and difference of thermal expansion coefficient near interface of W and Cu buffer layer/CuCrZr cooling tube. In addition, principal stress distribution indicates that tensile stress is applied to tangential direction in W near Cu buffer layer and compressive stress is also applied to normal direction in Cu buffer layer near W. The elasto-plastic stress analyses also indicate that stress relaxation occurs in the part of W which the stress is concentrated. This is considered to be due to plastic deformation at high temperature. This plastic deformation at high temperature may cause crack formation during temperature decreasing because yield stress decreases with increasing temperature. In the present works, temperature and stress distribution of the ITER W monoblock divertor mock-up at steady state heat loading condition have been evaluated. In particular, the result of the FEM analyses indicates that large stress is applied and plastic deformation occurs in interface of W, and Cu buffer layer/CuCrZr cooling tube at 10 MW/m^2.

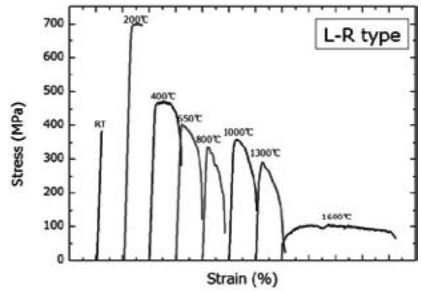

Fig. 1. Stress-strain curves of L-R type W.

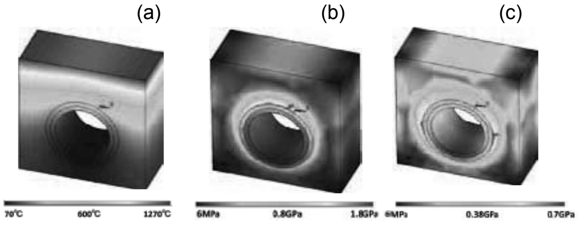

Fig. 2. Temperature(a) and equivalent stress (elastic analyses(b), elasto-plastic analyses)