§31. Development and Evaluation of Tungsten-coated Ceramics as First Wall Material of Helical Reactor

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In a helical fusion reactor, it is favorable to employ plasma facing walls with a thin thickness, in order to obtain a desirable magnetic configuration and easy access of plasma heating.

Tungsten has been regarded as candidate plasma facing material since the erosion yield owing to plasma sputtering is very small. In addition, the tritium inventory in the wall is low. However, the weight of tungsten is significantly large and the cost is expensive, if the bulk tungsten is used as the wall material. In the case of maintenance and replacement for cassettes of tungsten wall, it takes a time since the cassette is heavy.

The cassette weight becomes significantly light if the tungsten coated ceramics material is employed. The cost of the plasma facing material also becomes inexpensive. As the candidate of ceramics, there may be carbon fiber composite (CFC) and SiC/SiC composite material. The thermal conductivity of CFC is highest among the plasma facing materials, so that we here consider the tungsten coated CFC.

Tungsten coatings on bulk graphite have been conducted so far by using vacuum plasma spray (VPS) and chemical vapor deposition (CVD). In the case of VPS, the bulk density of tungsten is not high, so that the thermal conductivity is low. In the case of CVD, the coating layer easily cracks owing to the difference of thermal expansion coefficient between the coating layer and the bulk graphite.

Recently, spark plasma sintering (SPS) has been applied to prepare a thin and high density tungsten material, by Toyo Tanso Ltd. This tungsten was brazed on CFC by using hot pressing. As the CFC, CX-2002U was employed. Figure 1 shows the tungsten- coated CFC. The tungsten layer has a quite large bulk density, 16.54 g/cm^3, close to the pure tungsten density, 19.3 g/cm^3. The estimated porosity is only 14.5 %. The thermal diffusion rate was measured as D = 0.74 cm^2/s. The thermal conductivity was obtained from both the bulk density and the thermal diffusion rate. The thermal conductivity, k, is given by

$$k = \rho C D , \qquad (1)$$

where ρ is the bulk density, C the specific heat and D the thermal diffusion rate. In the case that $\rho = 16.5 \times 10^3$ kg/m^3, C = 132 J/kg K and D = 7.4×10^{-5} m^2/s, the thermal conductivity becomes k = 161 W/m K. This value is quite close to that of pure tungsten, 171 W/m K, and highest among the tungsten coating materials.

The thickness of brazing layer is approximately 100 μm. The density and the thermal conductivity in X direction of CX-2002U are 1.65 g/cm^3 and 422 W/mK at RT, respectively. As the thermal stress test, this tungsten coated CFC heated up to 1073 K was suddenly dropped to water, and after that the damage owing to the thermal stress was examined. No failure was observed for this test.

The above data show that the present tungsten-coated CFC has a quite high potential on the thermal properties and then this material may be suitable for the plasma facing wall in both the helical and tokamak reactors.

Further investigations on the fuel hydrogen retention and the performance to the high heat load are required in order to design the plasma facing wall and the cassette structure. This brazing material at least has to endure to the heat flux of 10 MW/m^2 without melting of tungsten layer. The tritium inventory of this brazing material has to be comparable with that of bulk tungsten even if the graphite is employed. The tritium inventory may be kept low, since the carbon dust[1)] is little produced. These issues will be continuously investigated.

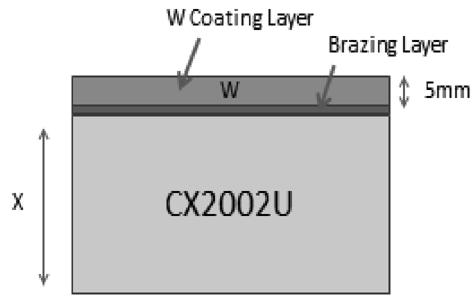

Fig. 1 Tungsten-coated CFC with high thermal conductivity.

1) Hino, T. et al: Nucl. Fusion 45 (2005)894.