§40. Development of Tungsten Alloys for Divertor of Fusion Reactor

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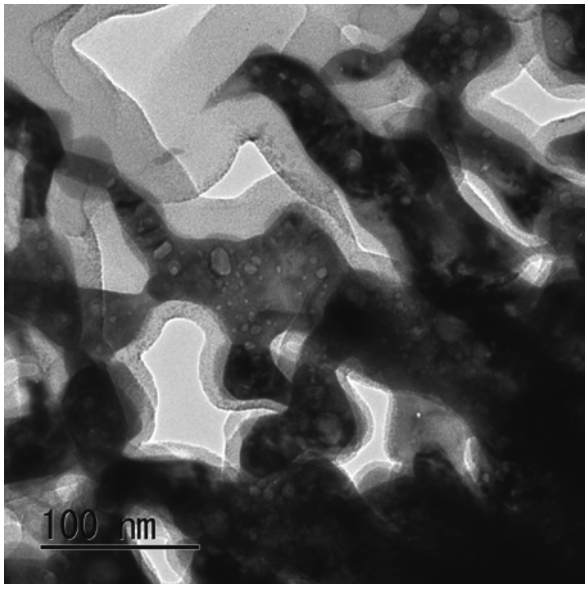
The interaction between tungsten, which is attracted attention as a plasma facing material, and hydrogen, helium has been widely investigated in recent years. However, the study of the interaction between hydrogen, helium and new developed tungsten alloys, which can overcome the problem in tungsten materials, such as low-temperature brittleness, recrystallization brittleness and radiation induced brittleness, has not been performed. In the present study, we developed a new method, which was different one used widely until now, to manufacture a new tungsten alloy with ultrafine crystal grains. We also investigated the damage induced by helium with low energy in pure tungsten.

It is well known that disperse second-phases particles, such as TiC, Y_2O_3 and so on, can effectively solve the embrittlement problems in tungsten. In the present study, 1.0 wt.% nano-sized TiC particles was added into the solution, where oxalic acid ($C_2H_2O_4 \cdot 2H_2O$) was dissolved in deionized water. Ammonium paratungstate ($(NH_4)_{10}H_2W_{12}O_{42} \cdot XH_2O$(APT) was dissolved in the above solution of oxalic acid with TiC particles. The W/TiC precursor was obtained by stirring and evaporating the mixture solution in a methyl silicon oil bath at 438 K. The precursor was ground and then heated in a tubular furnace to 1073 K at a heating rate of 5 K/min, where the isothermal was carried out at 473, 773 and 1073 K for 20, 60 and 60 min respectively. After that, the sample was consolidated using spark plasma sintering (SPS). During the process the pressure staged at 9.6 MPa for 3 min, and then uniformly increased to 47.8 MPa. Simultaneously, the sample was heated to 1623 K at a heating rate of 100 K/min. At the following stage, the sample stayed at 1623 K for 10 min, and subsequently heated to 2023 K at the same heating rate. Finally, the sample was heated to 2073 K for 3 min, and then cooled down to room temperature at a cooling rate of ~100 K/min, the pressure uniformly decreased at the same time.

The density measurement was carried out in the sintered sample. The density is 18.52 g/cm^3, and its relative density is 99.0%. This nearly full dense sample should be owing to the SPS technology. The fracture surface of the sintered sample was observed using scanning electron microscopy (SEM). Trans-granular and inter-granular fractures can be observed on the surface of the sintered samples. Numerous intergranular fracture areas where cracks can be easily formed can be found in the second phase. It was also observed that nano-particles were inserted in W matrix. Therefore, the new developed TiC added tungsten alloy in the present study has a good mechanical property. In addition, the sample was also observed by transmission electron microscopy (TEM). The results show that nano-sized TiC particles exist in the grain interior and at the grain boundary.

To illustrate the high temperature stability of the alloys, the microhardness of the alloy by different temperature heat-treated were evaluated. The microstrohardness of the sintered specimen non-heat treatment is at ~444.2 Hv at room temperature. This value did not significantly decrease even after heat treatment at 1473 and 1573 K. This phenomenon indicates that the sintered specimen has high thermal stability at high temperature.

We also investigated the interaction between helium and pure tungsten using FIB (Focus Ion Beam) and TEM at NIFS. The following figure shows the microstructure of tungsten surface implanted by helium with 100 eV to 10^{26}/m^2 at 1070 K. It is clear that the He bubbles with high density were formed.



Microstructures in pure W implanted by He with 100 eV to 10^{26}/m^2 at 1070 K.

W/TiC nano-particles could be prepared by a chemical method, and the alloy was sintered by SPS. The relative density of W/TiC alloy could reach to 99.0%. Doped TiC nano-particles were detected at the grain interior and grain boundary. Transgranular and intergranular fracture can be observed on the surface of the sintered sample. The W/TiC alloy possesses high thermal stability at high temperature. The interaction between tungsten alloy and hydrogen, helium will be investigated in the next fiscal year using facilities of NIFS.