§21. Evaluation of Advanced Tungsten Materials as Plasma Facing Materials

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1. Introduction

Tungsten and tungsten based alloys are potential candidates as the plasma facing materials in the next generation fusion experimental devices aiming the steady state operation and D-T burning. The advantages of refractory metals such as tungsten were recognized earlier in Japan. Collaborative research on vacuum plasma sprayed tungsten has been carried on among NIFS and Kyushu University. On the other hand, R&D of ultra-fine crystal grain tungsten alloys dispersed fine TiC particles are going successfully at Tohoku University. The purpose of the present LHD collaborative reach is, therefore, to progress the development of these innovative tungsten based alloys furthermore by the collaborative comprehensive evaluations of the material properties required as plasma facing materials.

2. Experimental Results and Discussion

2.1 Development and evaluations of W-TiC alloys

We could successfully fabricate W-TiC alloy with the target ductility. This result owed to the development of ultra-fine grain W-TiC, discovery of its super plasticity and the special deformation process utilizing the super plasticity. Excellent properties of the newly developed W-1.1%TiC are followings. (1) Residual porosity is negligibly low. (2) Strength of the grain boundaries is very high even re-crystallized state. Its fracture strength reaches 4.4GPa and ductile even at room. (3) Fractured surfaces are in the crystal grains but not along the grain boundaries. These results indicate that development of W materials with good ductility at room temperature even after re-crystallization is promising. We could have outlook for development of W materials with high resistance for thermal fatigue and DBTT lower than room temperature. A most important future issue is scale up of the samples.

2.2 Test of VPS-W coated divertor tiles in LHD

Divertor plasma exposure test carried out last year showed that VPS-W coated graphite tile fabricated by Plansee Co. has enough resistance for heat load and plasma particle load to use as the divertor tiles of LHD. On the other hand recent plasma study indicates that accumulation of high-Z impurities in the core plasma is low in LHD. Base on these good results it was decided to install VPS-W coated test divertor tiles in LHD. The base material of the tile is isotropic graphite (IG430U) and the W of 0.1mm-thick was deposited by means of VPS technique. The tiles were set near I port (two tiles), O port (one tile) and L port (one tile) of the 1st session of LHD. After completion of the experimental cycle (cycle 13), the tiles were taken out and were examined by using an optical microscope and a scanning electron microscope. It was found that some parts of the surface became smooth due to sputtering erosion and other parts were cover by thick depositions. However, no cracking and no exfoliation occurred as expected. Nano-scale internal damage such as formation of He bubbles and micro-cracks will be studied by picking up micro-samples by using FIB technique. These data will be very important to discuss the stability of the tungsten coating. It is worth to note that accumulation of W impurities in the core plasma was not detected.

2.3 Fundamental Studies on plasma irradiation effects in tungsten based materials

(1) Simultaneous irradiation effects of hydrogen and He

In case of burning plasma condition, plasma facing materials will be bombarded by mixed plasma of hydrogen isotopes and helium. The synergistic irradiation effects of hydrogen and helium on W were examined by using plasma source. Large blisters of about 100~200μm in diameter are formed by heavy irradiation of pure hydrogen plasma (1.5keV H_3^+). By adding helium only 0.05% (1.0keV), however, formation of the blisters was strongly suppressed. With decreasing the energy of the helium plasma, the inhibitive action diminishes. It is speculated that sub-surface layer of about several 10nm containing very dense nano-size helium bubbles acts as barrier for hydrogen diffusion from the surface to the deeper part where blistering occurs due to accumulation of hydrogen gas.

(2) Heavy irradiation effects of low energy He plasma

In case D-T burning very high flux of He plasma less than 100eV bombard the armor of divertors. Our systematic studies on the heavy irradiation effects of W by low energy helium plasma have revealed that formation of He bubbles strongly degrade material properties. For example, migration and coalescence of helium bubbles above 1000ºC, results in the formation of meso-scale long projections at the irradiated surface. It was confirmed that thermal shock comparable to that of ELM can easily melt these projections. Modification of surface morphology by helium at high temperatures is a large concern as divertor armor.

3. Final remarks

Most of the planed research programs have been carried as expected. Especially development of the ultra fine grain W-TiC alloys with ductility even at room temperature is a highlight. We could successfully confirm that the VPS-W coated isotropic graphite can be use as divertors of LHD. It is planning that summary report of the present collaboration research program will be published in journal.