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

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1. Introduction

W and W based alloys are potential candidates of plasma facing armor materials in the next generation fusion experimental devices aiming the steady state operation and D-T burning. Advantages of refractory metals such as W were recognized earlier in Japan. Collaborative research on vacuum plasma sprayed W (VPS-W) has been carried among NIFS and Kyushu University. On the other hand, R&D of ultra-fine crystal grain W alloys dispersed fine TiC particles are going successfully at Tohoku University. The purpose of the present LHD collaborative reach program is, therefore, to progress the development of these innovative W based alloys furthermore by the collaborative comprehensive evaluations of the material properties required as plasma facing materials. In this fiscal year each research group continued their activity to finalize this research program. A study meeting was held in November at Kyushu University to discuss new results and research direction in future.

2. Summary of the research program

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

Based on the good results of fundamental heat load tests and divertor plasma exposure test in LHD with the retractable material transfer system, 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 on it by means of VPS technique. The tiles were set near inner port (two tiles), outer port (one tile) and lower port (one tile) of the 2008FY campaign (12th cycle) of LHD. After completion of the experimental cycle (12th cycle), the tiles were taken out and were examined comprehensively by using an optical microscope, SEM, TEM, EDS, RBS, ERD and so on. In case of the tile placed at near inner port, the incident surface strongly hit by the strike point became smooth due to sputtering erosion but no cracks and no exfoliation were observed. It was found that large spherical He bubbles of 2-10 nm in diameter were formed in the sub-surface region. This fact indicates that the surface temperature reached about 1000°C often. Impurities such as C, O and Fe penetrated in the matrix of W but not formed deposition layer. It is interesting that penetration of C was especially deep. We should pay more attention to the behavior of He and C, because both of them may degrade ductility of W. On either side of the eroded area the incident surfaces were covered by thick co-deposition layer of about 1μm thick composed of C, O, W and Fe. Understanding the role of the co-deposition in the recycling and retention of hydrogen isotope is important. The condition of the incident surface also depends strongly on the position of the tiles. In case of the near lower port tile, strike point region are not eroded but covered by a thick co-deposition layer composed of C, W and a little Fe. Present work indicates that surface condition of the W divertors changes from place to place depending on the impurity transport and change of heat flux. It should be emphasized that W emissions were not observed. We could confirm that the VPS-W coated graphite divertor developed by NIFS can be used as W divertor of LHD.

2.3 Fundamental studies on plasma irradiation effects in W 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 H isotopes and He. Effects of their synergistic irradiation on W were examined by using plasma source. Large blisters of about 100~200μm in diameter are formed by heavy irradiation of pure H plasma (1.5keV H_3^+). By adding He only 0.05%, however, formation of the blisters was strongly suppressed. With decreasing the energy of the He plasma, the inhibitive action diminishes. It is speculated that very dense He bubbles formed in the sub-surface region and nano-cracks connecting the bubbles and the surface acts as barrier for H penetration into the matrix and short-cut paths to the surface, respectively.

(2) Heavy irradiation effects of low energy He plasma

In case of D-T burning very high flux of He plasma less than 100eV bombard the armor of divertors. Systematic studies on the heavy irradiation effects of low energy He plasma on W have revealed that formation of He bubbles strongly degrade material properties. Due to thermal migration and coalescence of He bubbles above 1000ºC results in the formation of meso-scale long projections at the irradiated surface. Thermal vacancies enhanced the phenomenon.