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

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Tungsten and its alloys are potential candidates for 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 on in Japan. Collaborative research on vacuum vapor 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 (UFG W-TiC) are going successfully at Tohoku University. The purpose of the present LHD collaborative reach is to remarkably progress the development of these innovative tungsten alloys by the critical comprehensive evaluations of the material properties required as plasma facing materials. Details of the subjects for each material are following.

(1) VPS-tungsten coated carbon fiber composites:

Resent good improvement of its thermal conductivity encourages R&D studies aiming the practical application. In the present collaborative research, we will examine the measures against damages due to very high flux pulse heat loads and particle loads. The final goal is to propose an innovative VPS-tungsten coating for the next generation divertor of the LHD based on the results of the present collaborative research.

(2) Ultra-fine crystal grain W-TiC alloys:

Mechanical properties such as ductility, resistance to neutron irradiation damage, high flux heat load and high flux plasma particles load will be comprehensively evaluated whether they satisfy the requirements as armor materials under burning plasma conditions.

Development of UFG W-TiC alloys and its evaluations

To find optimum TiC content and alloying atmosphere, 6 different types of alloys between 0.25%TiC and 1.1%TiC were manufactured under argon and hydrogen atmosphere (H. Kurishita, Tohoku Univ.). Remarkable features are followings.

(1) Good plastic deformation at low temperatures where grain growth does not occur is indispensable for practical application. It is very good news that W-0.5TiC alloyed in hydrogen atmosphere showed deformation more than 160% at 1970K, which is lower than the re-crystallization temperature. It is considered that the deformation mechanism is super plasticity. (H. Kurishita, Tohoku Univ.)

(2) It was shown that heavy irradiation of high energy helium ions (3MeV) at 673K and 823K causes surface exfoliation due to blistering. However, the critical dose of the exfoliation in W-TiC alloys is more than ten times higher than that of the usual powder metallurgy tungsten (PM-W). Application as an armor material for high energy alpha loss is promising. (A. Hasegawa, H. Kurishita, Tohoku Univ.)

(3) In case of low energy helium ion irradiation with keV-range energy, accumulation of helium bubbles in matrix was rather inactive compared with PM-W. However, the fine crystal grains at the surface often peeled off. This might be a critical issue as a plasma facing material in the D-T burning condition. (T. Iwakiri, N. Yoshida, Kyushu Univ.)

(4)The W-0.5TiC alloy showed very good performance under hydrogen ion irradiation. Namely, formation of giant blisters, which are commonly observed in PM-W, did not appear. It is considered that ultra-fine grain structure reduce localization of injected hydrogen. (Y. Ueda, Osaka Univ.)

As described in (2)-(4), ultra-fine grain W-TiC alloys showed high irradiation resistance in general. Quantitative understanding of a role of grain boundaries with extremely high density on damage accumulation and behavior of injected hydrogen and helium are going on now.

Evolution of VPS-tungsten coating on carbon materials

Tested materials are vacuum plasma sprayed tungsten deposited on CX-2002U and IG-430U. These test pieces were manufactured by Plansee Co. We have been already confirmed that they showed very good performance under high flux heat load. Irradiation effects of helium plasma and helium ions were mainly studied this year. Important results are followings

(1) It was found that dense nano-size projections are formed at the surface of the VPS-W exposed to helium plasma at 11.3eV up to very high dose ($3.5x10^{27}He^{+}/m^{2}$) at 1250K. Once these fine structure are formed properties of heat load resistance are lowered drastically. Whether this strange phenomenon also occurs in other type of tungsten materials or not is under investigation. (N. Ohno, Nagoya Univ.). TEM observation revealed that fine helium bubbles were formed in the projections. It is considered that formation and migration of helium bubbles under irradiation are the key processes for development of the projections.

(2) In order to evaluate the performance of the VPS-W coated on CX-2002U and IG-430U as divertor materials, plasma exposure experiment was performed in LHD. They were exposed to NBI-heated hydrogen plasma for about 40s at the divertor equivalent position. No cracking and no exfoliations occurred even at the diver-leg position, where heat flux and particle flux are highest. (K. Tokunaga, Kyushu Univ., N. Ashikawa, S. Masuzaki, A. Komori, N. Noda, NIFS)