§5. Development and Synthetic Evaluation of High-Z Plasma Facing Materials

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High Z materials, especially tungsten (W) and its alloys, are very promising for use as PFM and PFC. However, they are known to exhibit significant embrittlment (low temperature embrittlement, recrystallization embrittlement, radiation embrittlement and helium embrittlement) and data on their properties required for PFM/PFC applications are very limited. The objective of this study is to develop advanced W alloys with improved resistance to such embrittlement and evaluate these critical properties, together with baseline properties, for several commercially available W alloys to construct their data base.

i) W alloy development

In order to solve the issues described in the last-year report on W alloy development by mechanical alloying (MA), the followings have been carried out. (1) To produce MA treated powder without both WC/Co impurity contamination and any microstructural heterogeneity, a newly developed 3MPDA (three mutually perpendicular direction agitative ball mill) with pots and balls of TZM was used instead of a planetary ball mill with pots and balls of WC/Co, and the optimum MA condition was established. (2) To eliminate decarburization during vacuum hot pressing for consolidation, HIP with metal encapsulation was applied to 3MPDA-ball milled powder using two-step sintering at approximately 1350 and 1950℃ for 3 h. As a result, it was confirmed that the developed W alloys with 0.3-0.5%TiC additions have no WC/Co contamination, no appreciable microstructural heterogeneity and no appreciable loss of the carbon content. Three-point static bending tests at room temperature showed that the W alloys in the as-forged and as-rolled conditions exhibit appreciable ductility although those in the as-HIPed condition exhibit no appreciable ductility.

Since the room-temperature ductility was found to increase with decreasing grain size between 2 to 0.5μm, efforts to fabricate W alloys with extremely fine grains less than 0.3μm in diameter and a high relative density were made. For this purpose, MA in an atmosphere of purified H_2 and then HIPing at a lower temperature of approximately 1350℃ (0.44Tm; Tm is the melting point of W) were performed. The HIPed bodies showed very small grain sizes of 0.15~0.3 μm depending on TiC contents and relative densities as high as 98~99% in spite of such a lower HIPing temperature. This success in fabrication of W alloys with extremely fine grains and high densities is the first in W and its alloys and should be noticeable. Three-point static bending tests at room temperature conducted for the as-HIPed W alloys showed that the fracture strength is as high as 2000MPa which is close to the yield strength of the alloy, as compared with the fracture strength of 1300MPa for the W alloy with the grain size of 0.5μm. The application of plastic working to the as-HIPed alloys is now in progress, which is expected to significantly increase the ductility of the W alloys.

In addition to the above, another method of recrystallization control by multi-step internal nitriding treatments was applied to achieve microstructures of fine grains and finely dispersed particles of TiN.

ii) Synthetic Evaluation

A systematic study on the relationship between the microstructure and each of the properties needed for PFM/PFC was performed. Three kinds of commercially available W materials, i.e., pure W (99.95%), K-dope W and La_2O_3-dope W, each of which has two different microstructures with stress relief and recrystallization, were subjected to synthetic evaluation of hydrogen and helium retention, blistering, high heat load, erosion, irradiation damage, solid state reaction with carbon, fracture toughness and high temperature creep, in order to correlate microstructures and each property.

It was found that each of the properties is significantly affected by the microstructure of the W materials. Hydrogen and helium retention, blistering, erosion and reaction of carbon layer with tungsten were significantly suppressed for a microstructure with less dislocation density and larger grain size, indicating the significance of recrystallization treatments. K or La_2O_3 doping is not beneficial for these properties, but beneficial for high heat load properties, the resistance to irradiation damage, fracture toughness and high temperature creep. These results tell us that one should choose an optimum microstructure, depending on the location for service, e.g., surface layer or interior of PFM/PFC.