§ 8. 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, it is known that they exhibit significant embrittlment (low temperature embrittlement, recrystallization embrittlement, radiation embrittlement and helium embrittlement) and the data on a variety of properties required for PMC/PFC are very limited. This project is aiming at developing advanced (W) alloys with improved resistance to such embrittlement and at evaluating the properties, together with baseline properties, for several commercially available W alloys to construct their data base.

i) W alloy development

In order to improve the resistance to embrittlement, tungsten alloys of W-0.3wt%TiC with the microstructure of fine grains (~1 μm grain size) and finely dispersed particles of transition metal carbide with several nm diameter were fabricated by mechanical alloying (MA) with planetary ball mill and vacuum hot pressing (VHP) and HIP, followed by hot forging and rolling. The developed alloys were subjected to impact three-point bending and static tensile tests, X ray diffraction (XRD) analysis and TEM observations. As a result, the alloys showed much improved ductility compared with commercially available pure tungsten, but considerable difference in ductility was recognized between the developed alloys. It was considered that such difference may be attributed to three issues. The first is that brittle W_2C precipitates are formed during VHP by reaction of W with WC impurity contaminated from pots and balls made of WC/Co used for MA and have the detrimental effect of promoting the embrittlement, even when they are very fine and undetectable by XRD. The second is that there often occurs heterogeneity in grain size and particle distribution. This heterogeneity may come from the heterogeneity in MA treated powder, which is closely related to the use of planetary ball mill. The third is the occurrence of decarburization during VHP due to reaction of carbon with oxygen impurity contained in power, resulting in significant loss of carbon content necessary for carbide formation. In order to solve these issues, the followings are being carried out. To produce MA treated powder without WC/Co impurity and any microstructural heterogeneity, a newly developed 3MPDA (three mutually perpendicular directions agitative ball mill) with pots and balls of TZM was used and. the optimum MA condition was established. To eliminate decarburization, HIP with a metal capsule was applied to 3MPDA-ball milled powder using two-step sintering at 1350 and 1950℃ for 3 h. As a result, it was recognized that there is no appreciable microstructural heterogeneity, no appreciable loss of carbon content. A very high density of transition metal carbide precipitates of 7 nm in average diameter.was observed.

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

ii) Synthetic Evaluation

In order to clarify how the properties needed for PFM/PFC depend on the microstructure of tungsten material, two kinds of pure-tungsten (99.95%) specimens with different microstructures, i.e., stress relieved and recrystallized specimens, were subjected to synthetic evaluation of hydrogen and helium retention, blistering, high heat load, .erosion, irradiation damage, reaction of carbon with tungsten, fracture toughness and high temperature creep, etc.

It was found that the effect of the microstructure is different, depending on each of the properties. For example, the hydrogen and helium retention, blistering, erosion and reaction of carbon layer with tungsten were significantly suppressed in the recrystallized specimens, indicating that dislocations may give the detrimental effect. On the other hand, high heat load properties, the resistance to irradiation damage and mechanical properties such as fracture toughness were better in the stress relieved specimens than in the recrystallized ones. These results tell us that one should choose the different microstructure, depending on the location, surface layer and interior of PFM/PFC. A systematic study on the relationship between the microstructure and each of the properties needed for PFM/PFC should be performed and are now in progress.