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Surface Modification on Tungsten Materials by Repeated Pulse High Heat Loading
繰り返しパルス高熱負荷によるタングステン材の表面損傷

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Steady state (1700 ^{o}C, 180 s) and repeated (450 ^{o}C – 1250 ^{o}C, 380 times) heat loading experiments of ITER grade W and Toughened, Fine Grained, Recrystallized W-1.1TiC (TFGR W-1.1TiC) have been performed using an electron beam heat loading system. For ITER grade W, the irradiation around 1700^{o}C caused recrystallization and grain growth up to the average diameters of 50~100 μm. The subsequent repeated irradiations caused significant surface roughening, cracking at the grain boundaries and surface exfoliation. On the other hand, grains of the surface of TFGR W-1.1TiC are clearly observed after the irradiation around 1700 ^{o}C for 180s by steady state heat loading. In addition, TFGR W-1.1TiC did not exhibit any surface roughening and cracking by the repeated heat loading.

1. Introduction

Tungsten (W) is the primary candidate for use as plasma facing materials/components (PFM/PFC). PFM/PFC will be subjected to heavy thermal loads in the steady state or transient mode (disruptions and edge localized modes (ELMs)) combined with high energy neutron irradiation that will cause serious material degradation and transmutation. Material degradation in W mainly comes from recrystallization embrittlement which is the manifestation of brittle fracture at weak, high-energy grain boundaries (GBs) formed by recrystallization: The recrystallization temperature of commercially available pure W plates which are supplied in the stress relieved state is 1200~1300^{o}C, much lower than the melting point of pure W (3410^{o}C).

Recently one of the coauthors has developed nanostructured W-1.1%TiC compacts that exhibit appreciable room temperature ductility even in the recrystallized state (Toughened, Fine Grained, Recrystallized W-1.1TiC: TFGR W-1.1TiC) [1]. Given the recent progress in materials research on the W-TiC alloys, it is very appropriate and meaningful to assess the alloys under closer conditions to the anticipated ambience in fusion reactors. The purpose of this study is to simulate the heat load tolerance capability of TFGR W-1.1TiC and pure W by steady state and repeated heat loading of an electron beam heating device.

2. Experimental

TFGR W-1.1TiC compacts with equiaxed grains were fabricated through the application of superplasticity-based microstructural modification (SPMM) at 1650^{o}C to ultra-fine grained W-1.1TiC. As a precursor for the SPMM treatment, the compacts were produced by powder metallurgical methods utilizing mechanical alloying (MA) and hot isostatic pressing (HIP) at 1350^{o}C for 3 hours. Two kind of TFGR W-1.1TiC (A: High oxygen impurity: 850 ppm, B : Low oxygen impurity: 170 ppm) which have different oxygen content have been prepared to investigate effect of concentration of oxygen impurity. The W-1.1TiC compacts and ITER grade W were machined to the dimensions of 10mm x 10mm x 1mm, followed by mechanical and electro polishing.

All of the polished specimens were placed on a water-cooled Cu block and subjected to high heat load experiments by an electron beam irradiation test simulator of the Research Institute for Applied Mechanics, Kyushu University [2]. The experiments were conducted at two irradiation conditions; (1) surface temperature of around 1700°C, duration of 180 seconds, (2) repeated irradiations of 2 second-irradiation and 7.5 second-rest with one cycle of 9.5 seconds for totally 1 hour. In the case of (2), surface temperature of the samples changes from below 450°C to 1250°C by 2 second-irradiation. Gas emission from the heated sample was measured using QMS. Before and after the irradiation, the specimen surfaces were examined by SEM. Weight loss of the sample was also measured with an electronic balance.

3. Results

For ITER grade W, the irradiation around 1700°C caused recrystallization and grain growth up to the average diameters of 50~100μm. The subsequent repeated irradiations caused significant surface roughening, cracking at the grain boundaries and surface exfoliation as shown in Fig.1. The surface roughening is due to plastic deformation caused by difference in the thermal stresses between the adjacent grains with different orientations.

On the other hand, TFGR W-1.1TiC did not exhibit any surface roughening and cracking as shown in Fig. 2. This can be attributed to the fine grains with dispersoids where the generated thermal stresses are smaller and can also be relaxed by grain boundary sliding which is characteristic of a fine grained structure. These results indicate that TFGR W-TiC has a superior thermal property under repeated high heat load such as ELM heat load conditions.

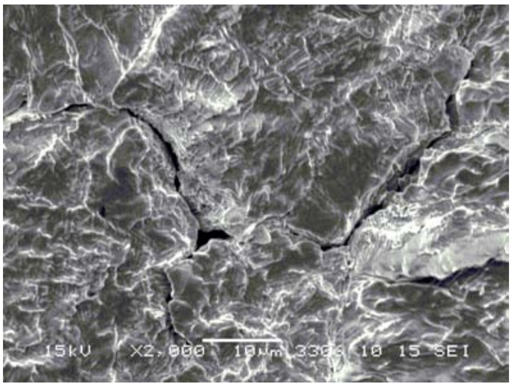

Fig.1. SEM micrograph observed on the surface of ITER grade W, is heated by steady state heat loading at 1700 °C for 180s, and 380 repeated heat loading shots.

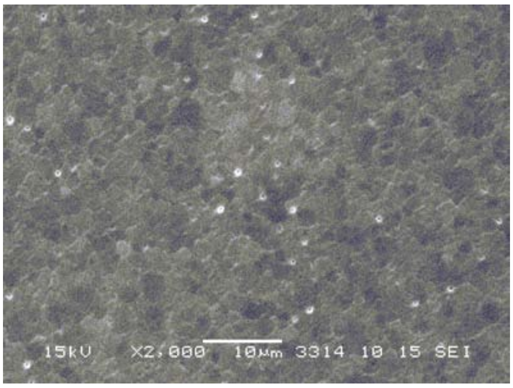

Fig.2. SEM micrograph observed on the surface of TFGR W-1.1TiC, is heated by steady state heat loading at 1700 °C for 180s, and 380 repeated heat loading shots.

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