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Analysis on solidified surface of melted Toughened, Fine-Grained Recrystallized tungsten exposed to TEXTOR edge plasma

TEXTORプラズマ曝露させたTFGRタングステンの溶融・凝固層の解析

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TFGR W (Toughened, Fine-Grained Recrystallized Tungsten) has been developed to improve poor mechanical properties of W. In order to evaluate applicability of TFGR W as plasma facing material, two TFGR W samples (TFGR W-1.1wt%TiC and TFGR W-3.3wt%TaC) were exposed to TEXTOR edge plasma. The surfaces on each sample were melted and the melting layers were re-solidified after the exposure. The structure of the solidified layer was specifically different between TFGR W-1.1wt%TiC and TFGR W-3.3wt%TaC. In the un-molten part of both samples, the grain growth was observed. The XRD composition analysis revealed that the amount of TiC and TaC dispersoids decreased and, instead, tungsten carbide (W_2C) increased.

1. Introduction

Tungsten (W) is a leading candidate for use as a plasma-facing material in a fusion reactor, and will be used in the divertor of ITER. To improve the poor mechanical properties of W (room temperature brittleness and neutron irradiation embrittlement), TFGR W (Toughened, Fine-Grained Recrystallized W) was developed by Kurishita et al. at Tohoku University [1, 2]. TFGR W has an average grain size of ~1 μm with a small amount of TiC or TaC dispersoids which enhances toughness and increases ductility. However, the performance in the edge plasma environment such as erosion and melting behavior by high heat and particle flux is not well known.

In our previous study [3], TFGR W samples were exposed to the edge plasma of tokamak TEXTOR under non-melting conditions (sample temperature of ~ 1300 ^{o}C) to investigate the erosion behavior. We observed the slight grain growth and the erosion of TiC dispersoids on the surface after exposure. In order to evaluate applicability of TFGR W as plasma facing material, further investigations are needed on the melting behavior and characterization of solidified layers after the material was loaded by much higher heat and particle fluxes.

2. Experimental

Surface melting experiments on TFGR W samples by plasma exposure were conducted in the Plasma-Material-Interaction-Test facility at TEXTOR. These samples were exposed to the TEXTOR edge plasmas with the available limiter lock system [4-6]. Two types of TFGR W samples (TFGR W-1.1wt%TiC and TFGR W-3.3wt%TaC) were installed on the roof limiter, as shown in Fig. 1(a). The plasma parameters are I_p = 350 kA, B_t = 2.25 T and n_e = 3.5 x 10^{19} m^{-3}. The position of the roof limiter is near Last Close Flux Surface (46.4 cm).

During the exposure, the temperature of the sample surface increased up to ~ 3000 ^{o}C, measured by 2D IR camera. The surfaces on each sample were melted. After the exposure, the melting layers were re-solidified, as shown in Fig. 1(b).

Following exposure, post-mortem analyses were conducted on the samples including the solidified layers. Surface morphology and roughness profiles were observed by digital microscope. The microstructure was also observed by SEM (Scanning Electron Microscope). In addition, Composition analysis was conducted by XRD (X-ray diffraction).

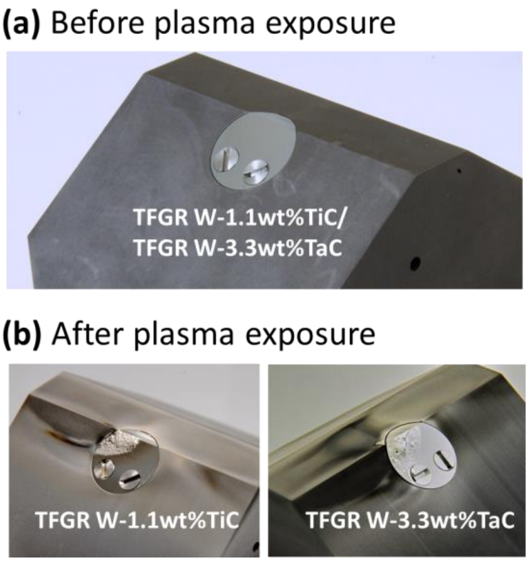

Fig.1. TFGR W-1.1wt%TiC and TFGR W-3.3wt%TaC samples installed at graphite limiter (a)before plasma exposure and (b)after exposure.

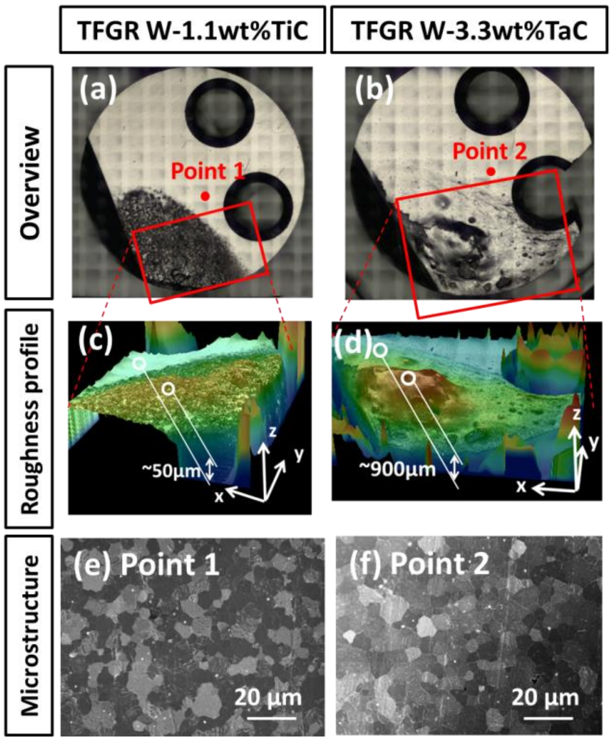

Fig.2. Surface condition after plasma exposure. TFGR W-1.1wt%TiC (a) overview, (c) roughness profile observed by digital microscope and (e) microstructure observed by SEM. TFGR W-3.3wt%TaC after plasma exposure; (b) overview, (d) roughness profile and (f) microstructure.

3. Results

The structures of the solidified layers differed between TFGR W-1.1wt%TiC and TFGR W-3.3wt%TaC. The overviews of the samples are shown in Fig. 2(a) and (b). Roughness profile revealed that the solidified layer of TFGR W-1.1wt%TiC had a number of small pores with size of ~ 1 μm and the layer was raised up by ~ 50 μm (Fig. 2(c)). In contrast, the solidified layer of TFGR W-3.3wt%TaC had a dome-like structure with a height of 900 μm and a few cracks with length of ~ 1 cm (Fig. 2(d)).

In the un-molten part of TFGR W-1.1wt%TiC and TFGR W-3.3wt%TaC samples (point 1 in Fig. 2(a) and point 2 in Fig. 2(b), respectively), the grain growth was observed. Before exposure, the average grain size in TFGR W was ~ 1 μm [1, 2]. After exposure, the size increased up to ~ 10 μm, as shown in Fig. 2(e) and (f). This may be due to annealing effect by elevated surface temperature (~ 3000 ^{o}C) during plasma exposure.

XRD composition analysis showed that, in comparison to the non-melted samples [3], the amount of TiC and TaC dispersoids decreased and, instead, tungsten-carbide (W_2C) increased. This may be attributed to the decomposition of dispersoids to C atoms and their combination with the parent phase of W.

In the presentation, we will also discuss the role of dispersoids in the melting behavior and formation of solidified layer on TFGR W material.

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