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Effect of transient heating loads on beryllium

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HIGHLIGHTS

- We study the effect of transient plasma loads on beryllium erosion and surface microstructure.
- Beryllium targets were irradiated by plasma streams with energy of 0.5–1 MJ/m^2 at ~250 °C.
- Under plasma loads 0.5–1 MJ/m^2 cracking of beryllium surface is rather slight.
- Under 0.5 MJ/m^2 the mass loss of Be is no more than 0.2 g/m^2 shot and decreasing with shots number.
- Under 1 MJ/m^2 maximum mass loss of beryllium was 3.7 g/m^2 shot and decreasing with shots number.

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ABSTRACT

Beryllium will be used as a plasma facing material for ITER first wall. It is expected that erosion of beryllium under transient plasma loads such as the edge-localized modes (ELMs) and disruptions will mainly determine a lifetime of ITER first wall. The results of recent experiments with the Russian beryllium of TGP-56FW ITER grade on QSPA-Be plasma gun facility are presented. The Be/CuCrZr mock-ups were exposed to upto 100 shots by deuterium plasma streams with pulse duration of 0.5 ms at ~250 °C and average heat loads of 0.5 and 1 MJ/m^2. Experiments were performed at 250 °C. The evolution of surface microstructure and cracks morphology as well as beryllium mass loss are investigated under erosion process.

1. Introduction

Beryllium will be used as a plasma facing material for ITER first wall (FW). The primary reasons for the selection of beryllium as an armor material for the ITER first wall are its compatibility with plasma and high oxygen gettering characteristics. In ITER the edge-localized modes (ELMs) will result in large thermal transient loads on beryllium components of first wall. These transient loads cause rapid heating of beryllium surface and can result in some changes in surface and near-surface regions such as material loss, melting, cracking, evaporation and formation of beryllium dust. Erosion of beryllium under transient plasma loads such as ELMs and disruptions will mainly determine a lifetime of ITER first wall.

To obtain the experimental data for the evaluation of the beryllium armor lifetime and dust production under ITER-relevant transient loads, the advanced plasma gun QSPA-Be (quasi-stationary plasma accelerators) was constructed in Bochvar Institute. The QSPA-Be plasma gun facility, a quasi-stationary plasma accelerator, provides hydrogen (or deuterium) plasma heat loads corresponding to ITER ELMs and disruptions in the range of 0.2–5 MJ/m^2 and a pulse duration 0.5 ms [1]. Previous results of heat loading (from 0.5 up to 2.1 MJ/m^2) in QSPA-Be plasma gun which was performed at room temperature (RT) with the Russian beryllium (TGP-56FW ITER grade) have been already presented [2–5].

It is expected that the temperature of heat loading can result in change of beryllium surface microstructure and cracks morphology. Recently new experiments on QSPA-Be plasma gun have been performed with the Be/CuCrZr mock-ups armored by tiles of TGP-56FW beryllium grade. This time Be samples were pre-heated up

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Table 1
Initial characteristics of TGP-56FW grade.

Parameter	TGP-56 FW
Chemical composition (% wt.)	
Be	99.02
BeO	0.95
C	<0.05
Si	0.021
F	<0.001
Fe	0.16
Al	0.018
Ti	0.016
Cr	0.037
Σ (Mn + Mg + Cu + Ni)	0.052
U	n/d
Density (min), % of theoretical value	99.0
Av. grain size (max), μm	25
Mechanical properties	
Ultimate tensile strength (RT), (min), MPa	350
Yield strength (RT), (min), MPa	250
Total elongation (RT), (min), %	2.0

to ~250 °C. The results of new experiments are presented in this paper and compared with the previous ones obtained at RT. The evolution of surface microstructure and cracks morphology and beryllium mass loss/gain under erosion process on the beryllium surface were studied as well as the erosion products.

2. Material and Experimental procedure

Some initial properties of the TGP-56FW beryllium grade are presented in Table 1. The samples of TGP-56FW beryllium in form of tiles were investigated.

Special Be/CuCrZr mockups of the FW have been manufactured for this experiment. Each mockup consisted of the heat sink plate of CuCrZr bronze and 8 beryllium tiles of 8 mm in thicknesses, which were soldered to bronze plate. Among them, the 4 tiles had dimensions of 30 mm × 30 mm and the other 4 tiles were 30 mm × 48.5 mm in dimensions. To prevent damage of the mockup base under the impact of plasma and surface contamination of beryllium samples with foreign materials, the protective beryllium frame with dimensions of 235 mm × 150 mm × 4 mm was applied. A view of mockup is shown in Fig. 1a and b.

The mockups were irradiated by deuterium plasma streams (5 cm in diameter) with pulse duration of 0.5 ms and average heat loads of 0.5 and 1 MJ/m^2. The angle between plasma stream direction and target surfaces was 30°. Relative distribution of absorbed energy density on the surface of beryllium target at both heat loadings is shown in Fig. 2. The temperature of Be tiles has been maintained about 250 °C during all the experiments.

The samples were exposed to up to 100 shots at each energy density. After 10, 40, 60 and 100 shots, the evolution of the surface macro- and microstructure was investigated and beryllium mass loss/gain measurements were performed.

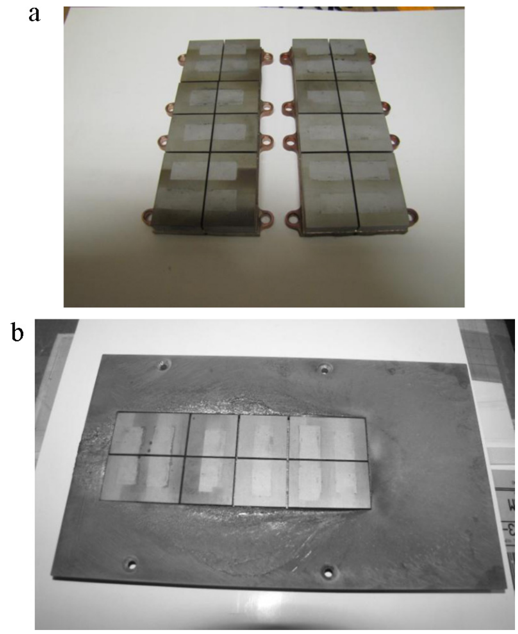

Fig. 1. A view of the Be/CuCrZr mockups (a) and mockup assembly with a protective Be frame (b) for experiments in the QSPA-Be plasma gun facility.

Microstructure of the samples was studied both by optical microscopy and SEM. The measurements of weight were carried out using an analytical balance Precisa ES2200 with an accuracy of 1 mg. Mass loss (Q) was calculated by the equation: $Q = \Delta m/SN$, where $\Delta m = m_i - m_k$ is the mass change of the two Be tiles between shots (i) and (k), S is the total surface area of the eight Be tiles (160 mm× 60 mm); $N = N_i - N_k$ – number of shots with (i) = 10, 40, 60, 100 and (k) = 0, 10, 40, 60, correspondingly.

3. Experimental results and discussion

3.1. Evolution of surface structure at 250 °C

The value of heat load at 250 °C strongly influences the evolution of the surface structure with increasing number of shots.

3.1.1. Surface structure of Be irradiated at heat load 0.5 MJ/m^2

As well as it was shown earlier in [3,4] with Be samples tested at RT, at 250 °C and heat load of 0.5 MJ/m^2 several processes take place simultaneously on the surface subjected to plasma stream loading:

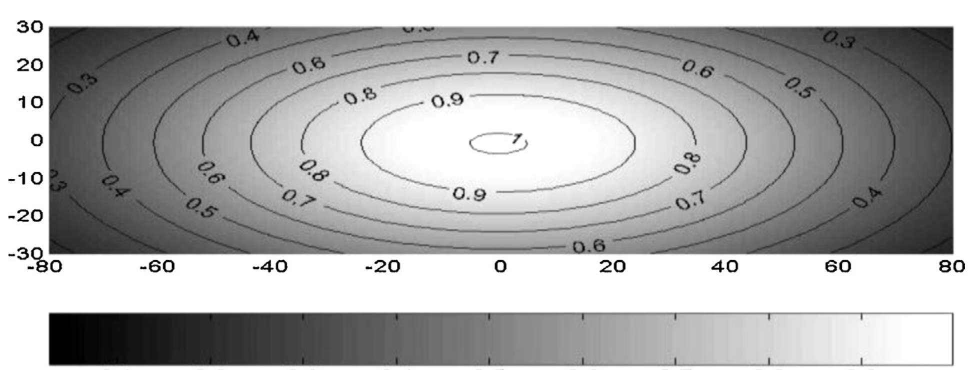

Fig. 2. Relative distribution of absorbed energy density on the surface of beryllium target.