EXPOSURES OF EU W-CFC COMBINED TARGETS WITH QSPA Kh-50 PLASMA STREAMS SIMULATING ITER ELMS

V. A. Makhlaj[1], I.E. Garkusha[1], J. Linke[2], G. Pintsuk[2], V.I. Tereshin[1], A.N. Bandura[1], V.V. Chebotarev[1], V.V. Staltsov[1]

[1]Institute of Plasma Physics, NSC Kharkov Institute of Physics and Technology, Kharkov, Ukraine;
[2] Forschungszentrum Jülich, IEF 2 D-52425 Juelich, Germany

Repeated load tests of special combined W-CFC samples were performed with QSPA plasma streams either resulting in strong melting of W surface layer or below the melting, but above the cracking threshold. Experiments show that in result of target exposures with heat load of 0.4 MJ/m^2 (no melting) only cracks formation was found on both tungsten and CFC surfaces. It is obtained that enhanced evaporation of CFC results in additional shielding of tungsten surface by C cloud and protects W surface from evaporation even for essentially increased energy density in impacting plasma. Exposures of combined target with heat loads of 0.82 MJ/m^2 resulted in strong melting of tungsten. Meshes of macro-cracks and micro-cracks as well as ripple structures are appeared on the resolidified surface.
PACS: 52.40.Hf

1. INTRODUCTION

Important issue for ITER divertor targets is determination of surface erosion under Edge Localized Modes (ELM) of (1…3) MJ/m^2 during (0.1…0.5) ms for each event [1]. Simulation experiments with large numbers of plasma impacts at different energy densities are required for estimation of tolerable size of ELMs and identification of main erosion mechanisms of tungsten and carbon-fiber composites (CFC) targets that is relevant to ITER conditions.

A number of powerful test facilities are available to provide the examinations of different materials under such short transient events. Fig. 1 shows experimental data points for transient load tests of tungsten samples in a number of different test facilities, namely the electron beam facility JUDITH [2] in Juelich, Germany, the quasi-stationary plasma accelerator QSPA Kh-50 [3] in Kharkov, Ukraine, the plasma gun MK200-U [4] in Troitsk, Russia, and the Repetitive High Energy Pulsed Power ion source RHEPP-1 [2] in Albuquerque, USA.

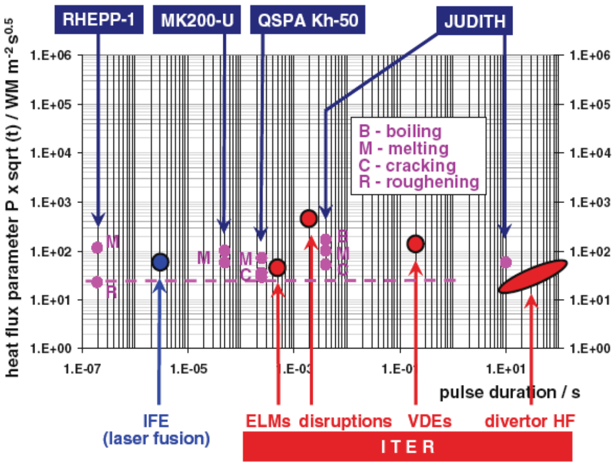

Fig. 1. Simulation of short transient events with tungsten test specimens in a number of different electron, plasma and ion beam test facilities

These tests cover a rather wide range of various pulse durations, nevertheless, the observed threshold values for different damage factors (R – roughening, C – cracking, M – melting, B – boiling) appear at similar heat flux parameters (P×t$^{0.5}$) [2]. It should be noted that this plot contains only preliminary results which have been obtained from different test specimens (i.e. tungsten with different grain size and orientation etc.). Nevertheless, this first attempt to compare data from a number of very different test facilities using electron, plasma or ion heating might be a basis for a combined effort to tackle the material issues under very short thermal exposure.

Therefore repeated load tests of special combined W-CFC samples with QSPA plasma streams were performed as a part of round-robin tests of identical materials with different experimental devices (plasma focus, pulsed plasma gun, e-beam, i-beam, QSPA). The experiments include the investigation of tungsten and CFC damages under irradiation with the same number of QSPA plasma pulses but with different heat loads.

2. EXPERIMENTAL SETUP

The exposed samples, which were prepared in Forschungszentrum Jülich (Germany), consisted of cylinder of deformed tungsten, made by PLANSEE, were cut from a 10 mm long rod of 12 mm in diameter embedded into the CFC coupon of 25x25x10 mm. CFC part of combined target was manufactured from 2-directional carbon fibre composite DMS 704. All the samples have been slightly polished to guarantee an identical surface finishing for all test coupons; in addition, this simplified the post-irradiation laser profilometry on the test coupons.

Molybdenum diaphragm with diameter of 12 cm and square hole of 25 mm with slightly rounded corners was flush mounted to the target surface (Fig. 2). Thus, due to rounded corners, 1…2 mm of each corner of target was protected by diaphragm to provide the reference line for laser profilometry. Surface analysis of exposed samples was carried out with an optical microscope MMR - 4, equipped with CCD camera and also with Scanning Electron Microscopy (SEM). Measurements of weight losses are performed also.

Earlier it was shown, that onset of tungsten surface melting for W-C target was not achieved under the plasma exposures with fixed energy densities in comparison with similar measurements for pure tungsten samples, which start to melt at surface load of (0.55…0.6) MJ/m^2 [5]. Enhanced evaporation of CFC (carbon evaporation threshold (0.4…0.45) MJ/m^2) results in additional shielding of tungsten surface by C cloud and protects W surface from evaporation even for essentially increased energy density in impacting plasma. The peak heat load to W surface are decreased from 1.1 MJ/m^2 to 0.8…0.85 MJ/m^2 and tungsten evaporation threshold was not achieving [5].Therefore, these combined targets have been exposed 10 QSPA pulses of the duration 0.25 ms and the heat loads ≤ 0.6 MJ/m^2 and ≥ 0.82 MJ/m^2, which is respectively below and above the melting threshold for these experimental conditions.

3. EXPERIMENTAL RESULTS

Experiments show that in result of target exposures without melting only cracks formation was found. Cracks are developed on both tungsten and CFC surfaces (Fig. 3).

Exposures of the target with heat loads resulting in melting (≥ 0.82 MJ/m^2) lead to appearance of ripple structures on the resolidified tungsten surface. Strong melting of tungsten results in the intensification of the droplets splashing (Fig. 4). Meshes of major-cracks and micro-cracks are observed also on tungsten and CFC surfaces Average cell of major crack mesh in tungsten ~ 0.5 mm. Mesh size of micro-cracks is about 30 µm. It corresponds to the grain size of material. The width of the major cracks in a both tungsten and CFC is achieved 3…4 µm after 10 pulses.

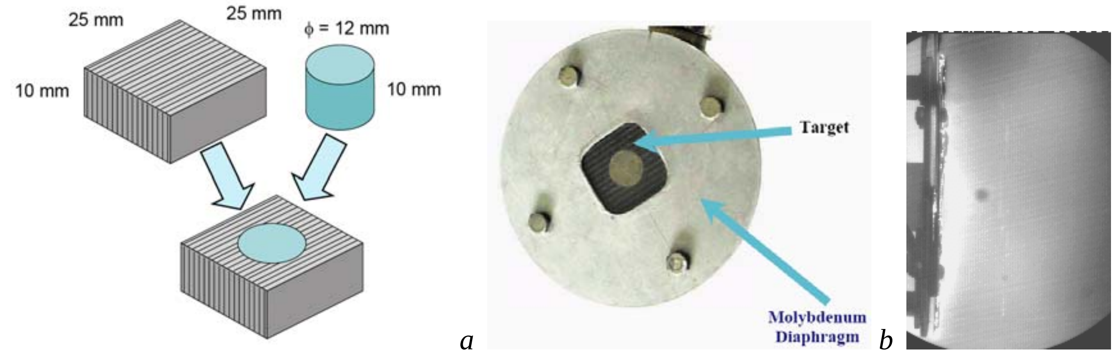

Fig.2. Scheme (a), general view (b)of combined target and image of QSPA plasma stream interaction with the target (c)

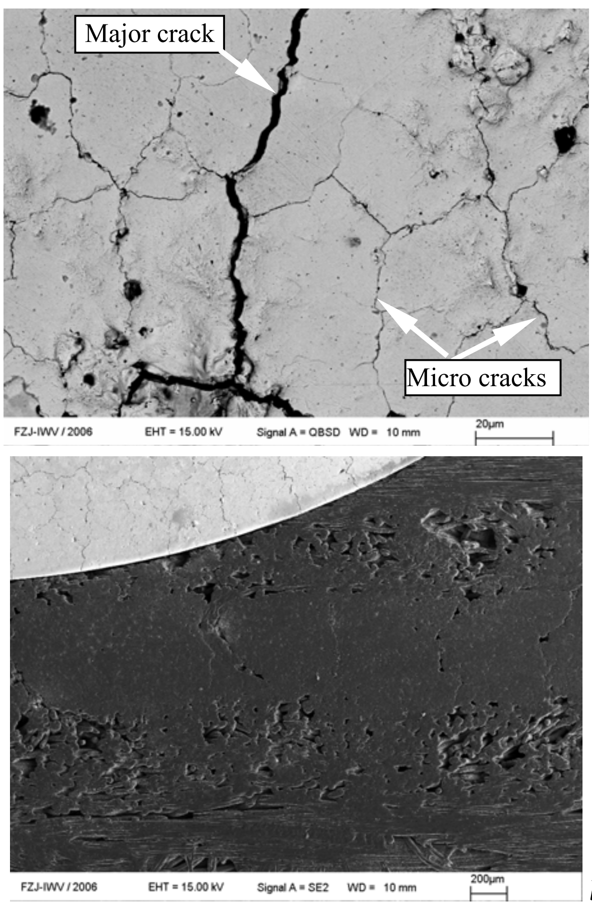

Fig.3. SEM images of W-C target surface after 10 plasma pulses of 0.6 MJ/m^2: a - tungsten, b - CFC

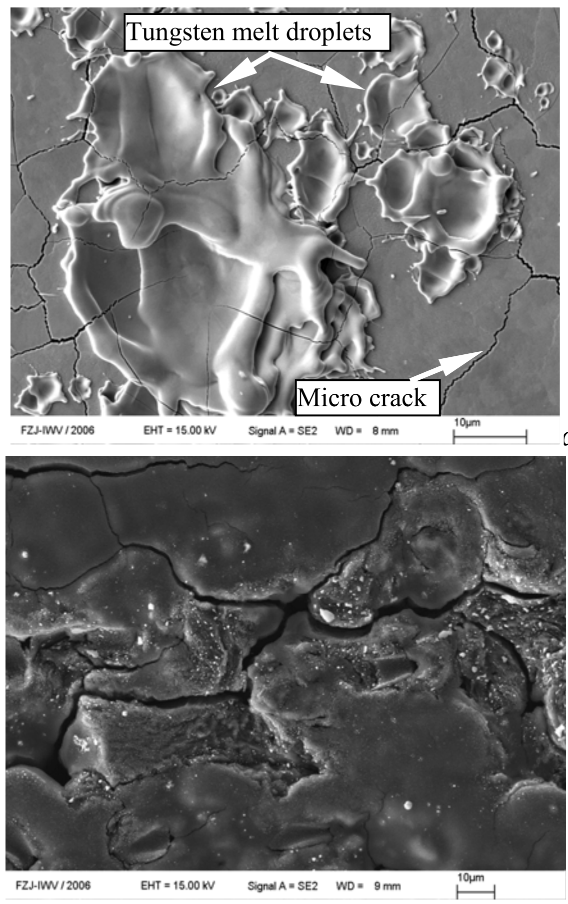

Fig.4. SEM images of W-C target surface after 10 plasma pulses of 0.82 MJ/m^2: a - tungsten, b - CFC

The width of intergranular cracks is not exceeded 1 μm. As it is seen from Fig. 5, such fine cracks are developed in surface layer ~ (50…100) μm. Major cracks are much deeper. Appearance of pores in surface layer can be caused by expansion of macro-cracks mesh and losses of tungsten grains in result of plasma impacts.

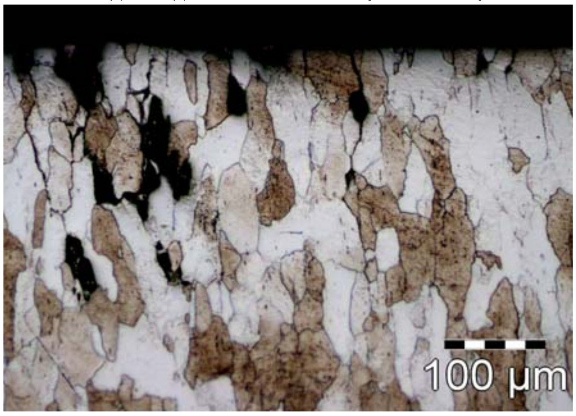

Fig.5. Cross-section of tungsten target after 10 plasma pulses of 0.82 MJ/m^2

CONCLUSIONS

Plasma exposures of EU combined tungsten – CFC targets are performed with QSPA Kh-50 pulses of varied energy density as part of round-robin tests [2].

Under exposures of target with heat load of 0.4 MJ/m^2 (no melting) only cracks formation was detected.

The measured heat load to W-C surface became decreased in comparison with that for W surface due to carbon vapor shield formation.

Onset of tungsten surface melting under plasma impacts is observed when absorbed energy density achieved ≈0.6 MJ/m^2. Cracks are developed on both tungsten and CFC surfaces.

Plasma exposures with heat loads of 0.82 MJ/m^2 led strong melting of tungsten. Mesh of macro-cracks and micro-cracks as well as ripple structures are detected in result of exposures.

This work was initiated in frame of IAEA Expert Meetings on Materials Irradiation. It was supported in part by STCU project # 4155

REFERENCES

1. G. Federici et al // *Plasma Physics Controlled Fusion.* 2003, v. 45, p. 1523–1547.
2. J. Linke et al // *Journal of Nuclear Materials*. 2007,v. 367-370, p. 1422-1431.
3. V.I. Tereshin et al // *Plasma Physics Controlled Fusion*. 2007, v. 49, p. A231-A.239.
4. G. Federici et al // *Journal of Nuclear Materials*. 2005, v. 337-339 , p. 684-690.
5. V.A. Makhlaj et al // *Problems of Atomic Science and Technology. Series "Plasma physics" (12).* 2006, N6, p. 74-76.

Article received 10.10.08

ОБЛУЧЕНИЕ ЕС W-CFC КОМБИНИРОВАННЫХ МИШЕНЕЙ ПЛАЗМЕННЫМИ ПОТОКАМИ КСПУ Х-50, МОДЕЛИРЮЩИМИ ELM В ИТЭРе

В.А. Махлай, И.Е. Гаркуша, J. Linke, G. Pintsuk, В.И. Терешин, А.Н. Бандура, В.В. Чеботарев, В.В. Стальцов

Проведены циклические испытания специальных комбинированных образцов W-CFC с использованием плазменных потоков КСПУ с варьируемыми энергетическими нагрузками, которые приводят к развитому плавлению поверхностного слоя W, либо находятся ниже порога плавления, но выше порога растрескивания. Экспериментально показано, что в результате облучения мишеней плазменными потоками с плотностью энергии 0,4 МДж/м^2 (отсутствие плавления) было зарегистрировано лишь растрескивание поверхностей CFC и вольфрама. С увеличением плотности энергии в плазменном потоке развитое парообразование CFC приводит к дополнительной экранировке поверхности вольфрама облаком углеродной плазмы и предохраняет поверхность W от испарения даже при существенно возросшей плотности энергии налетающей плазмы. Облучение мишеней с тепловыми нагрузками 0,82 МДж/м^2 приводит к интенсивному плавлению вольфрама. Сетки макро-трещин и микро-трещин, а также волновые структуры появляются на повторно затвердевающей поверхности.

ОПРОМІНЕННЯ ЄС W-CFC КОМБІНОВАНИХ МІШЕНЕЙ ПЛАЗМОВИМИ ПОТОКАМИ КСПП Х-50, ЯКІ МОДЕЛЮЮТЬ ELM В ІТЕРі

В.О. Махлай, І.Є. Гаркуша, J. Linke, G. Pintsuk, В.І. Терешин, А.М. Бандура, В.В. Чеботарьов, В.В. Стальцов

Проведено циклічні іспити спеціальних комбінованих зразків W-CFC з використанням плазмових потоків КСПП з варійованими енергетичними навантаженнями, які приводять до розвитого плавлення поверхневого шару W, або знаходяться нижче порога плавлення, але вище порога розтріскування. Експериментально показано, що в результаті опромінення мішеней з густиною енергії 0,4 МДж/м^2 (відсутність плавлення) було зареєстровано тільки розтріскування поверхонь CFC і вольфраму. Зі збільшенням густини енергії розвинуте паротворення CFC приводить до додаткового екранування поверхні вольфраму шаром вуглецевої плазми і захищає поверхню W від паротворення навіть при істотно збільшеній густині енергії в плазмі, що налітає. Опромінення мішеней з тепловими навантаженнями 0,82 МДж/м^2 приводить до інтенсивного плавлення вольфраму. Сітки макро-тріщин і мікро-тріщин, а також хвильова структура з'являються на повторно затверділій поверхні.