TUNGSTEN COATINGS UNDER FUSION RELEVANT HEAT LOADS

C. Thomser[1], J. Linke[1], G. Matthews[2], V. Riccardo[2], A. Schmidt[1], V. Vasechko[1]

[1]Forschungszentrum Jülich EURATOM-Association FZJ, D-52425 Jülich, Germany;
[2]Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, UK
E-mail: c.thomser@fz-juelich.de

Components for first wall applications in future nuclear fusion devices like ITER or DEMO need to fulfill special requirements. Especially transient thermal loads like Edge Localized Modes (ELMs) have a severe impact on the material damage. Tungsten coatings are being assessed for use instead of bulk tungsten. In order to quantify their material degradation, tungsten coatings on a fiber-reinforced graphite substrate were exposed to repeated short fusion relevant thermal pulses in an electron beam material test facility JUDITH 1 (Juelich Divertor Test Facility in Hot Cells).
PACS: 28.52.Fa

1. INTRODUCTION

First wall components for applications in future nuclear fusion devices need to fulfil special requirements, e.g. a good thermal conductivity, a reasonable strength value as well as a good compatibility with a deuterium / tritium plasma. Moreover neutron irradiation has not to lead to an unacceptable activation and a significant degradation of material properties. Especially transient and / or cyclic thermal loads in magnetic confinement experiments like ITER have a severe impact on the material damage of the plasma facing components.

Tungsten coatings are being assessed for use instead of bulk tungsten components. Within the ITER like wall project, realised at JET, a part of the thermally loaded wall will consist of tungsten coated CFC modules.

In order to quantify the material degradation under transient ELM – like heat loads (Edge Localised Modes), tungsten coatings on a fibre-reinforced graphite substrate were exposed to short fusion relevant thermal pulses in the electron beam material test facility JUDITH 1 (Juelich Divertor Test Facility in Hot Cells). In addition the failure mechanism of the coatings was investigated.

2. THERMAL SHOCK TESTS

The applied test parameters for the thermal shock tests in the electron beam facility JUDITH 1 are as follows:

- Sample size: 12 x 12 x 5 mm
- Absorbed power densities: 79…316 MW/m^2
- Electron absorption coefficient: 0.46
- Base temperature: 22…400 °C
- Loaded area: 4 x 4 mm
- Pulse duration: 1 ms
- Inter pulse time: 2 s
- Beam scanning frequency (x / y): 31 kHz / 40 kHz
- Number of pulses: 100
- Electron beam diameter: 1 mm

A picture of the electron beam facility JUDITH 1 is presented in Fig. 1.

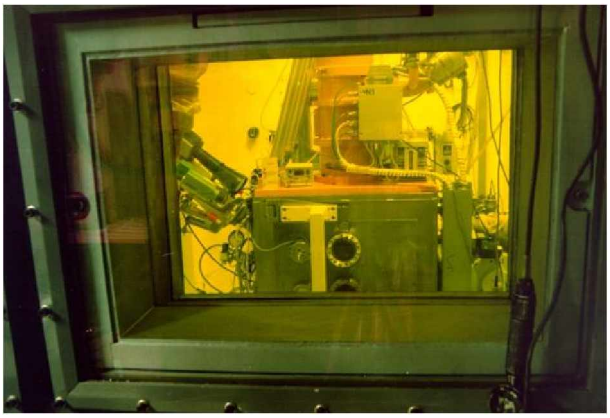

Fig. 1. Electron beam material test device JUDITH 1

3. MATERIAL

A cross – section of the tested coating is presented in Fig. 2. The coating has a total thickness of 20…25 µm and consists of a double layer structure of tungsten and molybdenum. The coating was produced by a Combined Magnetron Sputtering and Ion Implantation (CMSII) coating technique in Romania [1].

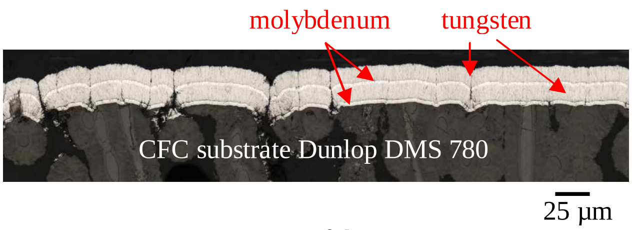

Fig. 2. Cross section of the tungsten coating

4. RESULTS

The delamination of the coating starts at absorbed power densities of about 158 MW/m^2 for nearly the whole range of investigated temperatures. With increasing power density material degradation is increasing. Delamination always begins on the parallel fibers of the CFC substrate, like it is shown in the SEM picture in Fig.3.

PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2010. № 6.
Series: Plasma Physics (16), p. 54-56.

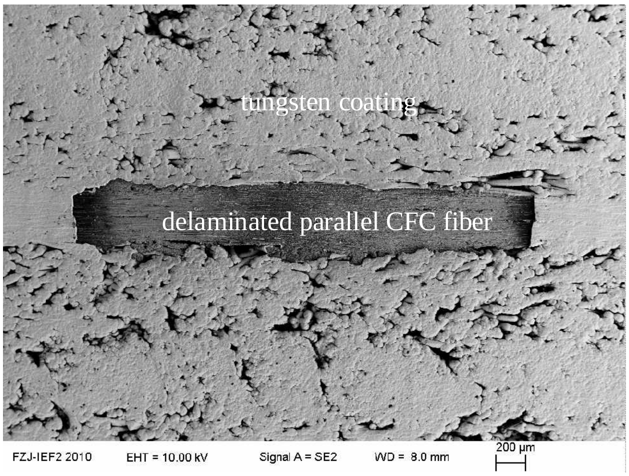

Fig. 3. SEM picture of the delamination of the coating, 158 MW/m^2, 1 ms, 100 shots, room temperature

In Fig. 4 and Fig.5 additionally crack formation and melting for different loading conditions are presented.

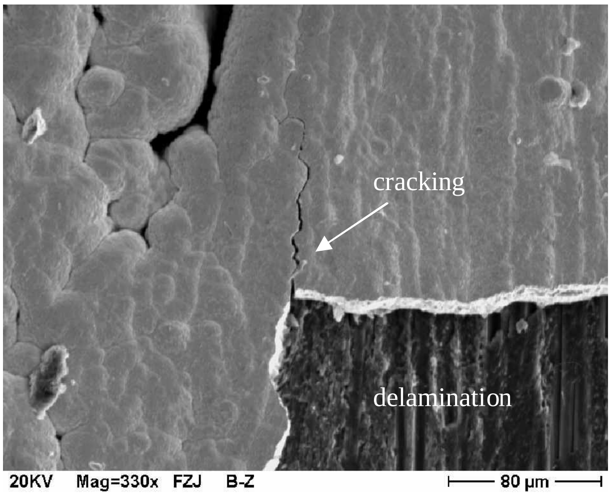

Fig. 4. SEM picture of the failure of the coating, 158 MW/m^2, 1 ms, 100 shots, base temperature 100 °C

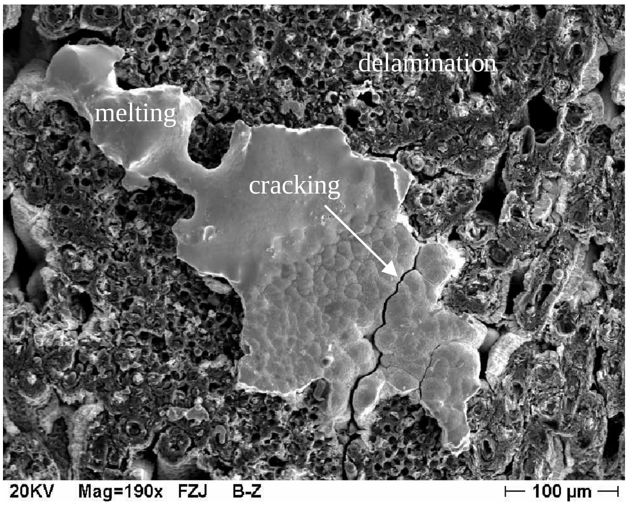

Fig. 5. SEM picture of the failure of the coating, 237 MW/m^2, 1 ms, 100 shots, base temperature 100 °C

An overview about the failure occurrence in dependence on the absorbed power density and base temperature is given in Fig. 6.

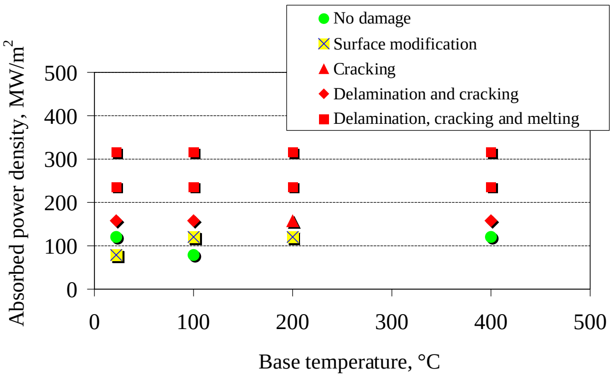

Fig. 6. Overview about the damage mechanisms of the tungsten coating

Only a small influence of base temperature can be observed especially for the highest absorbed power density. With increasing temperature the delaminated area is decreasing (two samples are shown as an example in Fig. 7). However, the temperature influence seems not to play the major role for the degradation of the coating.

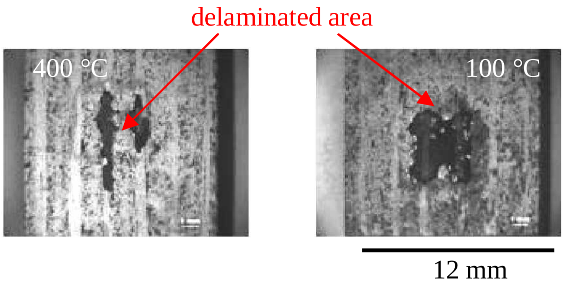

Fig. 7. Influence of temperature on the delamination of the coating, 316 MW/m^2, 1 ms, 100 shots

Moreover, spark erosion is documented by an optical camera in the first shot of the experiments. The exposure time was 5 s, i.e. the trajectories of all ejected particles are recorded in the photographs. Almost no erosion can be found at power densities below 158 MW/m^2. For higher power densities heavy spark erosion is observed, which a hint for the delamination of the coating is. The magnitude of spark erosion is dependent on the absorbed power density, like it is presented for two examples in Fig. 8 and 9.

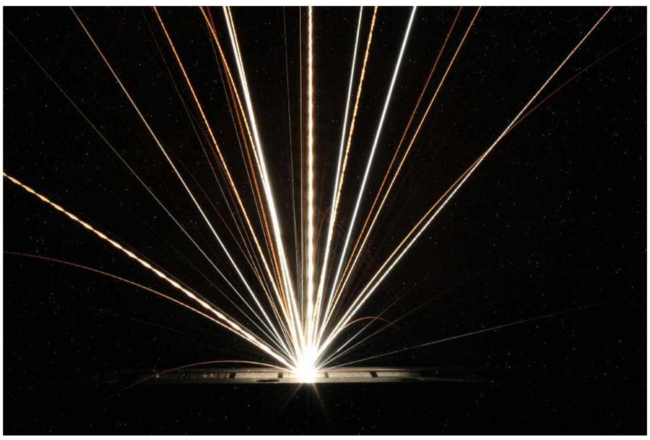

Fig. 8. Spark erosion, absorbed power density 237 MW/m^2, 1 ms, 100 shots, room temperature

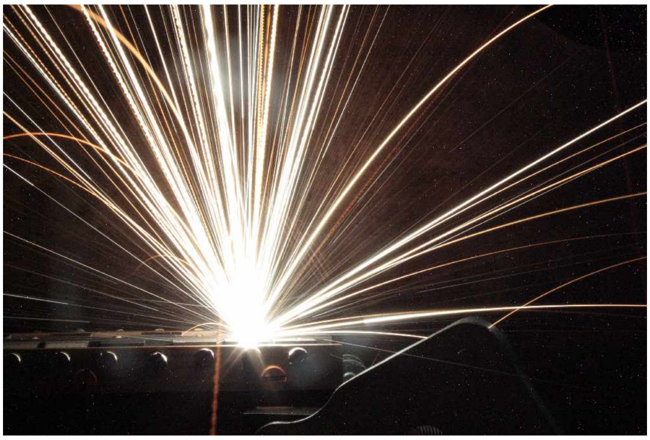

Fig. 9. Spark erosion, absorbed power density 316 MW/m^2, 1 ms, 100 shots, room temperature

5. CONCLUSIONS

The damage threshold and the failure mechanism of tungsten coatings under transient fusion relevant heat loads were characterised in an electron beam facility. The delamination of the coating is mainly dependent on the absorbed power density. Only a very small influence of temperature can be observed. The parallel fiber orientation of the CFC substrate is the preferred region to start the delamination of the coating due to the bad thermal conductivity and the high mismatch in thermal expansion between the coating and the substrate.

ACKNOWLEDGEMENTS

We acknowledge G. Knauf, G. Böling, T. Flossdorf, E. Wessel, M. Diederichs, M. Hühnerbein and M. Wirtz for their assistance with the experiments and investigations.

This work, supported by the European Communities under the contract of Association between EURATOM/Forschungszentrum Jülich, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

REFERENCES

1. C. Ruset, et al.// *Fusion Engineering and Design*. 2009, v. 84, p. 1662.

Article received 13.09.10

ПОВЕДЕНИЕ ВОЛЬФРАМОВЫХ ПОКРЫТИЙ В УСЛОВИЯХ, ИМИТИРУЮЩИХ ТЕРМОЯДЕРНЫЕ ТЕПЛОВЫЕ НАГРУЗКИ

К. Томсер, Й. Линке, Г. Маттеус, В. Рикардо, А. Шмидт, В. Васечко

Компоненты первой стенки в будущих реакторах типа ITER или DEMO должны удовлетворять специальным требованиям. Особое разрушительное воздействие на материал оказывают переходные тепловые нагрузки типа граничных локализованных мод (ELM). Вместо монолитного вольфрама рассматривается использование вольфрамовых покрытий. Для того, чтобы оценить деградации материала вольфрамовые покрытия на подложке графита, армированного волокнами, были подвержены многократному воздействию коротких импульсов с величиной энергонагрузки, ожидаемой в реакторе, на электронно-пучковой имитационной установке для тестирования дивертора в горячей камере (JUDITH 1 в г. Юлих).

ПОВОДЖЕННЯ ВОЛЬФРАМОВИХ ПОКРИТТІВ В УМОВАХ, ЩО ІМІТУЮТЬ ТЕРМОЯДЕРНІ ТЕПЛОВІ НАВАНТАЖЕННЯ

К. Томсер, Й. Лінке, Г. Маттеус, В. Рікардо, А. Шмідт, В. Васечко

Компоненти першої стінки в майбутніх реакторах типу ITER або DEMO повинні задовольняти спеціальним вимогам. Особливий руйнівний вплив на матеріал роблять перехідні теплові навантаження типу граничних локалізованих мод (ELM). Замість монолітного вольфраму розглядається використання вольфрамових покриттів. Для того, щоб оцінити деградації матеріалу вольфрамові покриття на підкладці графіту, армованого волокнами, піддаються багаторазовому впливові коротких імпульсів з величиною енергонавантаження, очікуваного в реакторі, на електронно-пучковій імітаційній установці для тестування дивертора в гарячій камері (JUDITH 1, в м. Юліх).