Material performance of tungsten coatings under transient heat loads

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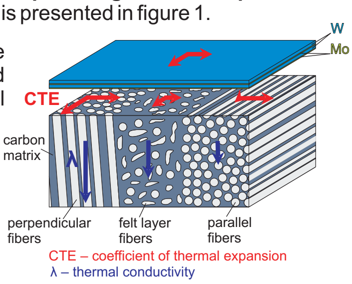
Introduction

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 carbon fiber composite (CFC) substrate were exposed to short fusion relevant thermal loads in the **electron beam material test facility** JUDITH 1 (Juelich Divertor Test Facility in Hot Cells). A schematic drawing of the coating and substrate, which was produced by a combined **Magnetron Sputtering and Ion Implantation** (CMSII) coating technique in Romania [1], is presented in figure 1.

Fig. 1 / Table 1: Schematic drawing of the tungsten coating on the CFC substrate and summary of relevant thermal material properties

Material	CTE (K^{-1})	Thermal conductivity ($Wm^{-1}K^{-1}$)
W	$4\text{-}5 \times 10^{-6}$	168
Mo	7.2×10^{-6}	138
CFC fiber (axial direction)	0.1×10^{-6}	high
CFC fiber (radial direction)	$10\text{-}12 \times 10^{-6}$	low
CFC (felt layer)	5×10^{-6}	middle



Experiment

A picture of the electron beam material test facility JUDITH 1 is shown in figure 2. The applied test parameters for the thermal shock tests in JUDITH 1 are as follows:

Absorbed power densities: 79 – 316 MW/m^2
Electron absorption coefficient: 0.46
Base temperatures: RT - 400 °C
Acceleration voltage: 120 kV
Pulse duration: 1 ms
Inter pulse time: 2 s
Number of pulses: 100
Sample size: 12 x 12 x 5 mm^3
Loaded area: 4 x 4 mm^2

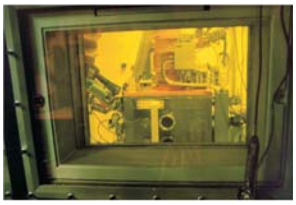


Fig. 2: Electron beam material test facility JUDITH 1 (Juelich Divertor Test Facility in Hot Cells)

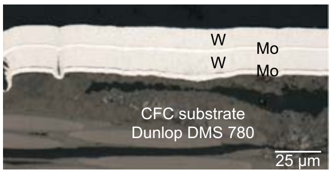


Fig. 3: Microscopic image of the cross section of the tungsten coating on the CFC substrate

Results

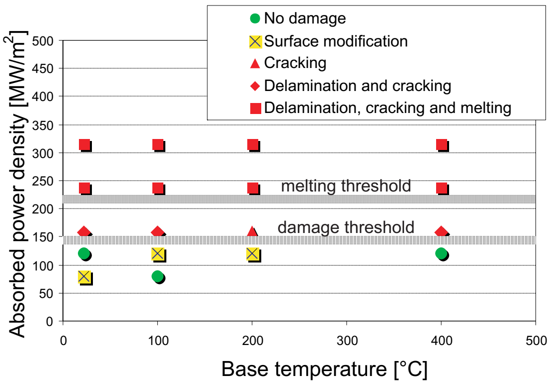


Fig. 4: Overview about the damage mechanisms of the tungsten coating in dependence on base temperature and absorbed power density

An overview about the **failure occurrence** in dependence on the **absorbed power density** and base **temperature** is given in figure 4. Only a small influence of base temperature can be observed especially for the highest absorbed power density. With increasing temperature the delaminated area is slightly decreasing (figure 5). **Brittle destruction** at room temperature for different power densities is presented in figures 6 - 8.

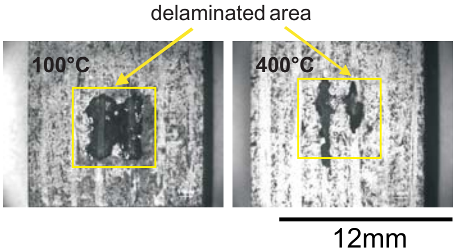


Fig. 5: Delamination of tungsten coating at 316 MW/m^2 after 100 shots at different temperatures

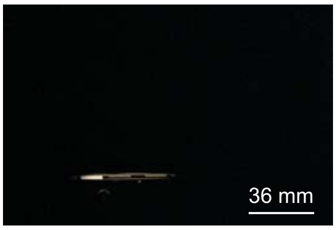


Fig. 6: No brittle destruction, absorbed power density 121 MW/m^2, 1 ms, first shot, room temperature

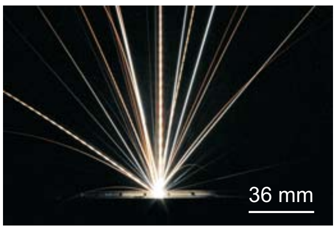


Fig. 7: Brittle destruction, absorbed power density 237 MW/m^2, 1 ms, first shot, room temperature

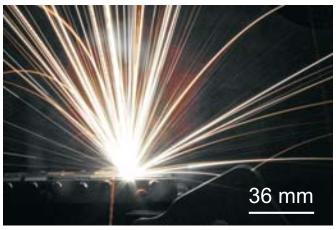


Fig. 8: Heavy brittle destruction, absorbed power density 316 MW/m^2, 1 ms, first shot, room temperature

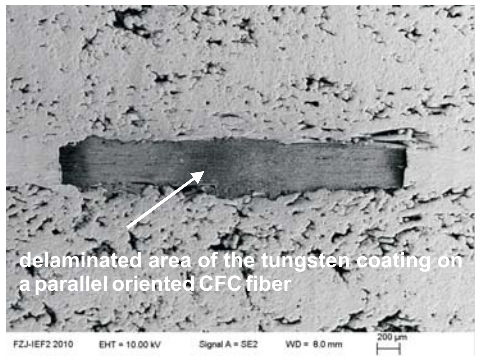


Fig. 9: SEM picture of the delamination of the coating, 158 MW/m^2, 1 ms, 100 shots, room temperature

Delamination of the coating starts always on the **parallel oriented fibers** of the CFC substrate (figure 9) since this particular fiber orientation has the **worst thermal conductivity** as well as the **highest mismatch in thermal expension coefficients** between fiber and substrate. Failure occurrence in depency on fiber orientiation is shown in table 2 in detail.

		Base temperature, °C			
		RT	100	200	400
APD, MW/m^2	316	par. felt per.	par. felt per.	par. felt per.	par. felt per.
	237	par. felt per.	par. felt per.	par. felt per.	par. felt per.
	158	par. felt per.	par. felt per.	par. felt per.	par. felt per.
	121	par. felt per.	par. felt per.	par. felt per.	par. felt per.
	79	par. felt per.	par. felt per.	par. felt per.	par. felt per.

APD - absorbed power density
par. - parallel oriented fibers
felt - felt layer
per. - perpendicular oriented fibers
green - no damage; orange - moderate damage; red - heavy damage.

Table 2: Failure occurrence in dependence on the CFC substrate fiber orientation

Conclusion

The coating degradation due to thermal shocks is mainly dependent on the absorbed power density, meanwhile only a very small influence of temperature can be observed. The parallel fiber orientation of the CFC substrate is the preferred region for the start of delamination of the coating due to the bad thermal conductivity and the high mismatch of CTE coefficients.

Source
[1] C. Ruset et al., Fusion Engineering and Design 84, (2009), p. 1662

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