**UT-VIV/PFC-DAMAGE**

# Task Title: STUDY OF DAMAGE MECHANISMS IN PLASMA FACING COMPONENTS

## INTRODUCTION

Plasma facing components (PFC) for controlled fusion machines have to withstand high heat fluxes. In the case of TORE SUPRA, the developed components were made of a high thermal conductivity CFC material (a composite made with carbon matrix reinforced by carbon fibres) mechanically and thermally bonded to a copper heat sink and able to remove incident stationary heat flux of 10 $MW/m^2$ [1]. In order to reach a value of 20 $MW/m^2$ for the divertor component of the ITER machine, the lifetime of this assembly submitted to considerable thermal stresses must be increased.

The objectives of this activity are (i) to provide a study of damage mechanisms of the CFC bond, (ii) to propose an optimization of the bond and (iii) to develop a model for predicting the lifetime of the bond under operating conditions.

## 2006 ACTIVITIES

During this period, the actions foreseen were achieved:

- Identification of the constitutive law of the N11 material [2], [3].

A full set of mechanical tests have been performed to identify the damageable behaviour of a carbon/carbon composite which is similar to the N11 material (figure 1).
After rescaling, this constitutive law was used to estimate the damage of a N11 tile within a PFC submitted to a 10 $MW/m^2$ heat flux (figure 2).

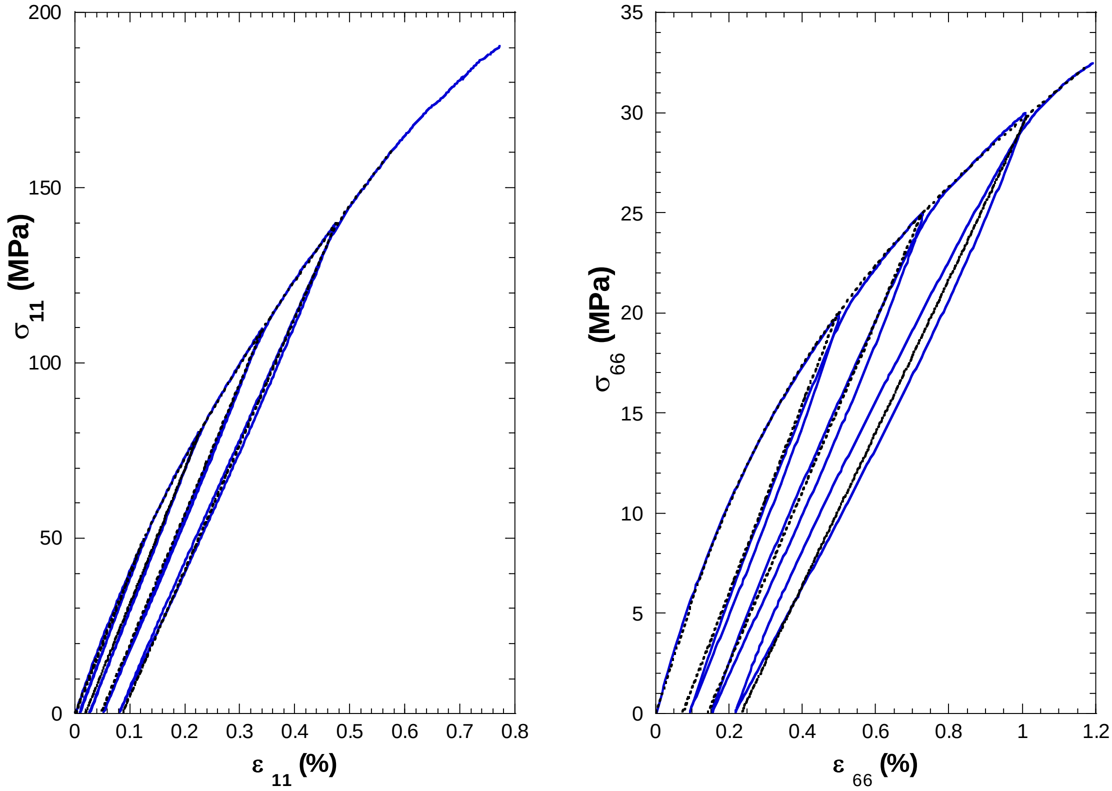


*Figure 1: Comparison between the experimental (blue line) and the simulated (black dotted line) response of a carbon/carbon composite similar to N11*

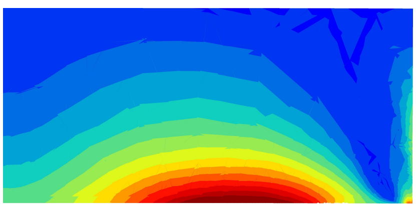

*Figure 2: The simulated damage in a N11 tile submitted to a 10 $MW/m^2$ heat flux*

**-** Influence of the edge geometry on the stress singularity at the interface [4].
Different geometries of the CuOFHC/CFC interface (near the free edge) were computed. The results show that intersecting the free edge with a 90° angle provides the most severe singularity. A 120° angle between the free edge and the interface is proposed in order to lower the singularity and to limit the crack initiation under thermal loading.

**-** Thermal expansion tests [5].
The thermal expansion mismatch between the CFC and the copper is of prime importance to evaluate the stress level in a PFC submitted to a heat flux. N11 and CuCrZr samples have been cut from a PFC to be tested under inert atmosphere in a dilatometer. Consistent values of thermal expansion coefficient were obtained for the copper alloy but variability is observed as a consequence of the small size of the composite samples.

**-** Modelling of the monoblock geometry [6].
In order to transpose the results obtained on the flat tile concept, the modelling of the monoblock geometry designed for ITER has started. Preliminary results show that after the elaboration phase, the composite is submitted to a complex stress state near the interfacial region (figure 3).

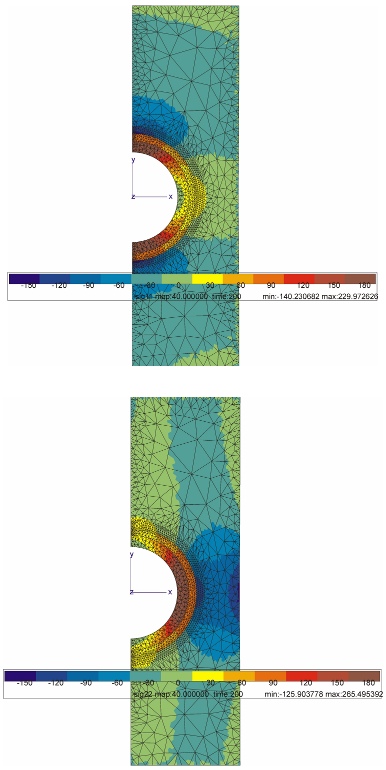

*Figure 3: Modelling of the monoblock geometry: isovalues of $\sigma_{xx}$ (a) and $\sigma_{yy}$ (b) stresses the after the elaboration phase*

## CONCLUSIONS

The reports corresponding to these activities have been delivered.

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**UT-VIV/PFC-Pyro**

# Task Title: APPLICATION OF A TRICOLOUR PYROREFLECTOMETER TO PLASMA FACING COMPONENTS IN-SITU INFRARED MONITORING

## INTRODUCTION

In the course of the development of a concept for a spectrally resolving thermography diagnostic for the ITER divertor using optical fibres [3] multicolour pyroreflectometry is being developed towards tokamak applicability in a collaboration between the CNRS-PROMES (Odeillo) and the CEA/DSM/DRFC. The CNRS-PROMES has developed two colour [1] and three colour versions [2]. This method allows to measure temperature under conditions of wavelength dependent emissivities. and with the advent of more reflecting wall surfaces in tokamaks it is of increasing interest to have this possibility also in that environment. This collaboration has reached its third year [4], [5], [6], [7].

## 2006 ACTIVITIES

In the previous years the pyroreflectometric method developed at the CNRS/PROMES had been used to measure true temperatures and optical properties of solid tungsten samples over short working distances (cm-range) at high temperatures. The aim for the year 2006 had been to measure over distances of the order of 1m inside the high power electron-beam facility FE200 of FRAMATOME in Le Creusot. This work-program was accompanied by new thermo optical measurements on tokamak exposed samples and control-measurements in the laboratory with thermocouples.
The principle of the method (explained in detail in [1] and [2]) is the following: of two parallel optical fibres with largely overlapping viewing areas one serves for the illumination of the target and the other for detection of the thermal and the reflected light from the target. The illumination is provided by pulsed laser diodes working at 1.3 µm and 1.55 µm. It is so weak that it does not heat up noticeably the target. This light is reflected off the target. The reflected light and the intrinsic thermal emission of the target at the 2 wavelengths are distinguished by synchronous detection tuned into the pulse of the illuminating diodes. From the reflected light the emissivities $\varepsilon$ at both wavelengths are determined – as well as the diffusivity factor $\eta$ which corresponds to the ratio of bidirectional to hemispherical reflection, which is assumed to be constant for the two wavelengths of interest. In installations with 3 colours this hypothesis can be tested and an eventual error can be quantified [2]. These values known, the absolute temperature of the target can be deduced from the passive measurements. To follow the temperature evolution of these values over a large temperature range the solar furnace and the MEDIASE facility of the CNRS-PROMES were used [4]. We had investigated earlier solid tungsten samples with different surface roughness [6]. The temperature range from 700°C – 1500°C was accessible in these experiments. Between 1000°C and 1200°C there was a noticeable change in the emissivity and the diffusivity of the target but the ratio of the reflectivities $\rho_r/\rho_b$ at the two wavelengths (1.55 µm and 1.3 µm) stayed rather unaffected. Depending on the roughness, the useful cone for measurements had a width of 20-30 degrees. These results have been published [8].
Meanwhile the BRDF (Bidirectional Reflectivity Distribution Function) for normal incidence was measured on tungsten coated graphite samples obtained from ASDEX UPGRADE (courtesy of A. Herrmann, IPP-Garching). The absolute values of the reflectivity changed significantly (figure 1) during a heating cycle whereas the relative angular distribution did not change.

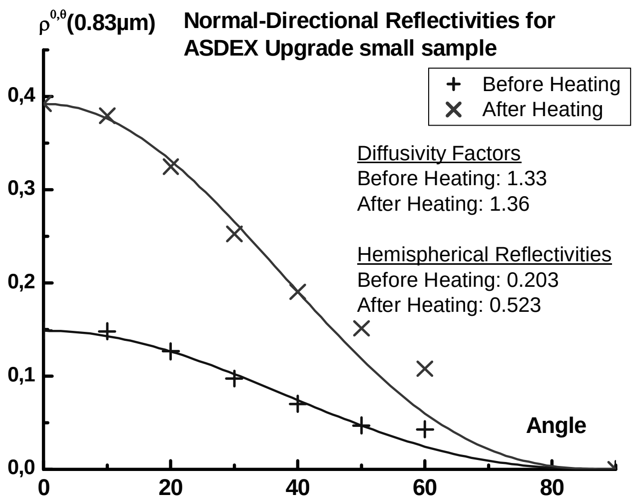


*Figure 1: B.R.D.F. for ASDEX UPGRADE sample before and after heating*

The quality of the pyro-reflectometric measurements was demonstrated (figure 2) by inserting a thermocouple in a 3 mm thick tungsten sample and measuring at different temperatures. The sample was heated from one side by the solar furnace and the pyroreflectometer measured on the other side. The temperature measured by the thermocouple $T_{th}$ is almost the same as the results $T^*(T_{Rr},T_{Rb},\rho''_r,\rho''_b)$ from the pyroreflectometric measurements except for an offset of a few degrees that is likely to be due to the thermal gradient in the sample. Also shown in figure 2 are the apparent temperatures at 1.3 µm and 1.55 µm ($T_{Rb}$ and $T_{Rr}$) the respective emissivities and the colour temperature $T_C$ calculated with the assumption that the emissivities are identical at both wavelengths. The latter illustrates well the shortcoming of this often made assumption in comparison with the pyroreflectometric approach.

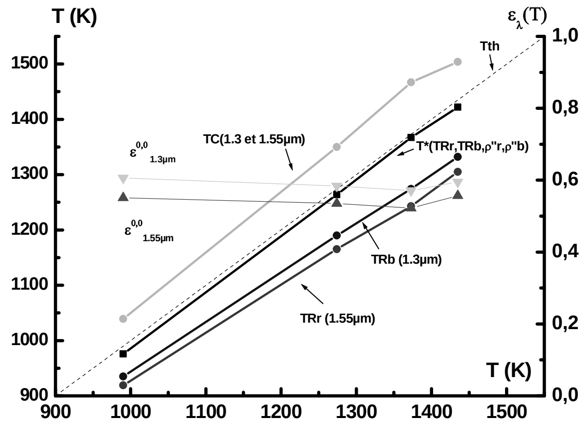


*Figure 2: Comparison of thermocouple temperature $T_{th}$ with pyroreflectometer temperature T**

Lens constructions were manufactured (figure 3) to increase the working distance from a few mm to about 1m. These setups were successfully used in the FE200 facility of FRAMATOME on tungsten samples under high heat load from an intense electron beam. Typical measurements are shown in figure 4. $T_b$, $T_r$ and $T_c$ are respectively the apparent temperatures at 1.3 µm and 1.55 µm and the associated colour temperature. Also shown are the reflectivities ρ at these two wavelengths.

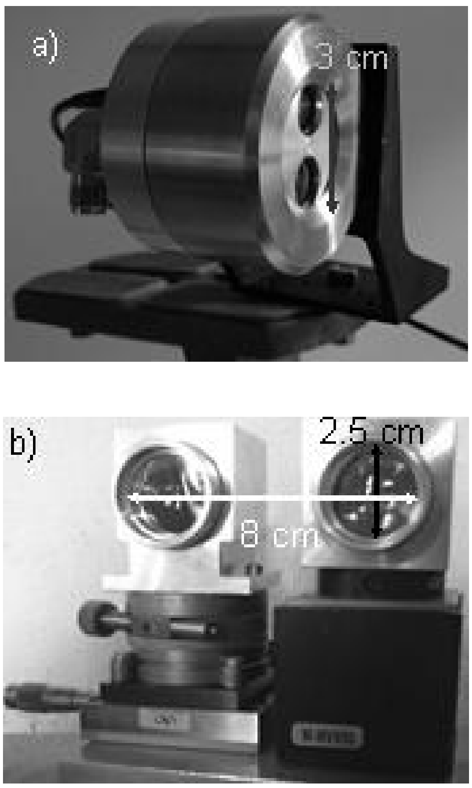


*Figure 3: Lens constructions for measurements inside FE 200 (a) and from outside (b)*

On the strength of these positive results two new contracts were started with the CNRS-PROMES, one for the permanent implementation of this method at the FE 200 facility and the other for the investigation of the possibility to install such a system at JET.

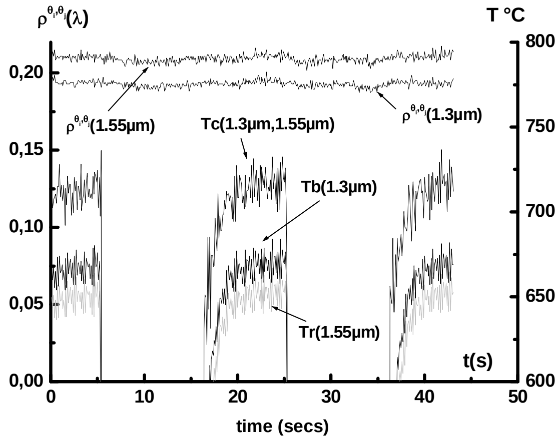


*Figure 4: Measurements taken with the pyroreflectometer at the FE200 facility*

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