UT-VIV/PFC-Damage

Task Title: STUDY OF DAMAGE MECHANISMS IN PLASMA FACING COMPONENTS

INTRODUCTION

Plasma Facing Components (PFC) for future fusion reactors should withstand high heat flux. The component developed for TORE SUPRA included a high thermal conductivity material (a composite made with carbon matrix reinforced by carbon fibres) mechanically bonded to a copper heat sink and able to remove incident stationary heat flux of 10 MW/m^2 [a]. 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 stress must be increased. Based on the analyses already performed by the TORE SUPRA team and the knowledge of the LCTS laboratory, the objectives of this activity are (i) providing a study of damage mechanisms of the CFC bond, (ii) proposing an optimization of the bond and (iii) possibly giving a tile damage ratio depending on the history of its loading.

2004 ACTIVITIES

During this period the three studies foreseen on the task action sheet were achieved: review of constitutive laws for CFC materials and finite elements simulations at various scales to estimate the stress field in the PFC.

EXISTING CONSTITUTIVE LAWS FOR CFC MATERIALS AND POSSIBLE EXTENSION TO N11 AND NB31 [1]

A literature review was performed to analyse the various constitutive laws, which could be used to describe the mechanical behaviour of a carbon/carbon composite. The damage mechanics theory is well suited to reproduce the non-linear behaviour that results from the well distributed micro-cracks which develop in this kind of material subjected to mechanical loads [2]. As it was previously shown that the damage does not modify the initial orthotropy, a scalar damage model can be used and the relevant identification procedure has been defined.

ANALYSIS OF LOCAL CRACKING MECHA-NISMS [2][3]

At the microscopic scale, it is to be pointed out that the bond between the copper and the composite tile is obtained with the help of an original concept: the tile surface is machined with a laser to produce micro-holes (cone shaped: 300 microns diameter and 500 microns deep) before casting the copper. Computations performed at the microscopic scale reveal that the fabrication phase of the PFC induces (i) a stress concentration in the composite tile ahead of a copper spike, (ii) a positive de-bond stress along the interface between a copper spike and the composite (figure 1). These results correlate well with micrographic observations, which show that damage can initiate within the composite ahead of a copper spike and propagate along the copper/composite interface.

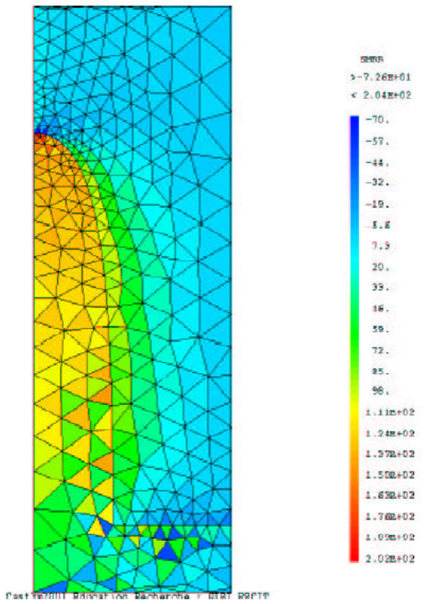

Figure 1 : Radial stress at the microscopic scale during the cooling step from 470°C to 20°C

CALCULATIONS OF RESIDUAL AND UNDER-FLUX STRESSES [4]

At the macroscopic scale (figure 2), the composite tile is mainly submitted to compression as a result of the residual stress field that is induced by the fabrication phase (figure 3). However, a very localised traction component is observed near the edge tile (figure 4) and could give rise to damage initiation within the composite.

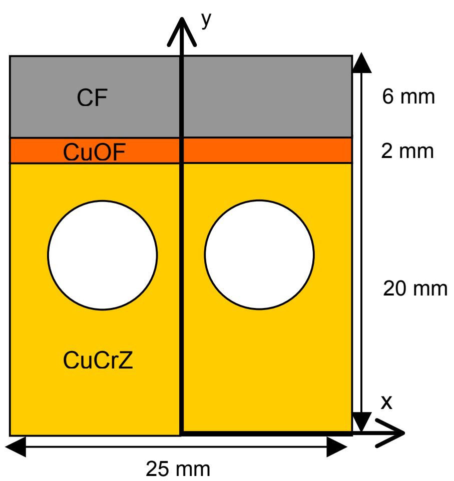

Figure 2 : Geometry of the PFC. The coordinates of the centres of the cooling channels (8 mm diameter) are x = ± 5 mm and y = 13 mm

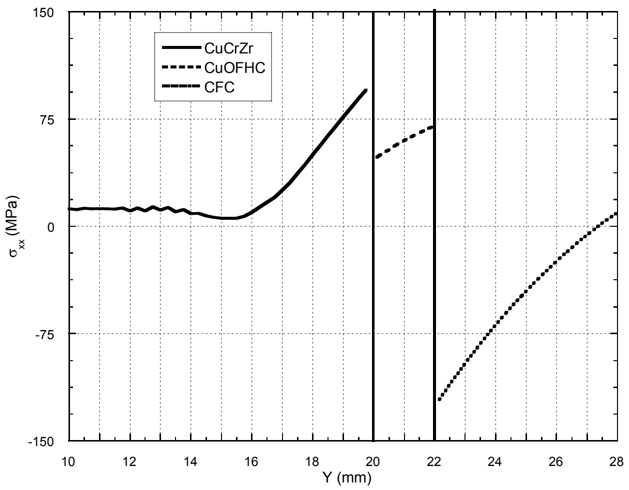

Figure 3 : Longitudinal stress σ_{xx} in the centre of the PFC following a cooling step from 470°C to 20°C

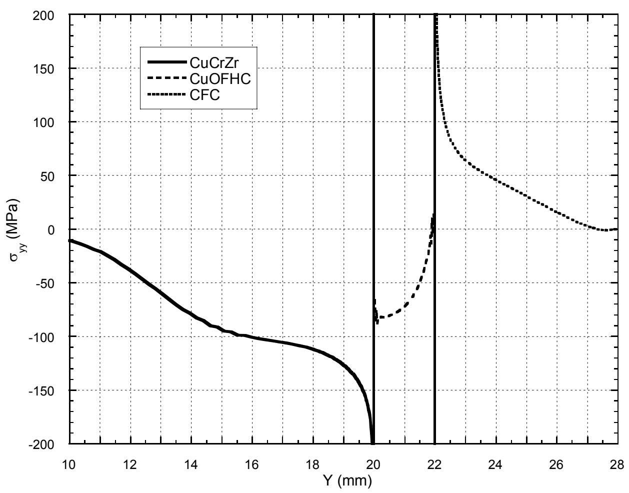

Figure 4 : Longitudinal stress σ_{yy} at the edge of the PFC, following a cooling step from 470°C to 20°C

CONCLUSIONS

The reports corresponding to these activities have been delivered. The work will continue in 2005 with (i) tests on CFC samples to identify a constitutive law, (ii) observations and analyses of damage mechanisms, (iii) optimization of the edge geometry and (iv) modelling of the crack propagation.

REFERENCES

[a] J. Schlosser, P. Chappuis, A. Durocher, L. Moncel, P. Garin - Development of actively cooled components for the Tore Supra toroidal pump limiter - Physica Scripta, TIC 116, 1-4, 2001.

REPORTS AND PUBLICATIONS

[1] G. Camus - Endommagement et rupture dans les assemblages des composants face au plasma, Identification d'une loi de comportement thermomécanique pour composites 3D C/C : application aux matériaux N11 et NB31. Lois de comportement disponibles pour les C/C et extension possible aux matériaux N11 et NB31 - Rapport 1a, Projet P6, 01/12/04.

[2] D. Leguillon, C. Henninger - Endommagement et rupture dans les assemblages des composants face au plasma, Analyse de l'endommagement de la liaison CFC-Cu à l'échelle microscopique : Analyse des mécanismes d'amorçage - Rapport 2a, Projet P6, 20/12/04.

[3] D. Leguillon, C. Henninger - Endommagement et rupture dans les assemblages des composants face au plasma, Analyse de l'endommagement de la liaison CFC-Cu à l'échelle microscopique : Analyse des mécanismes locaux de fissuration - Rapport 2a-bis, Projet P6, 20/12/04.

[4] E. Martin - Endommagement et rupture dans les assemblages des composants face au plasma - Analyse des mécanismes d'endommagement de l'assemblage à l'échelle macroscopique : Calcul des contraintes résiduelles et des contraintes sous chargement de flux thermique - Rapport 3a-bis, Projet P6, 1/12/04.

TASK LEADER

Eric MARTIN

LCTS, UMR 5801 (CNRS-Snecma-CEA – UB1)
Domaine Universitaire
3 Allée de la Boetie
33600 Pessac

Tél. : 33 5 56 84 47 00
Fax : 33 5 56 84 12 25

E-mail : martin@lcts-u.bordeaux1.fr