Recent developments in thermal barrier and thermo-mechanical screening coatings for high thermal loading applications

G. Diaconu[1], D. Girardin[2], J.J. Serra[3], L. Autrique[3], F. Rezai-Aria[1], G. Dour[1]

1- ***CROMeP, École des Mines d'Albi-Carmaux, route de Teillet, 81 013 Albi Cedex 09***
2- *Centre de R&D, St Gobain PAM, BP109, 54 704 Pont à Mousson Cedex*
3- *DGA - GHF Odeillo*

E-mail : dourdour@enstimac.fr
http://www.enstimac.fr/recherche/mat

Introduction

The targeted application is centrifugal casting of cast iron in which thermal loadings have been evaluated to be between 1 and 5 MW /m^2 depending on the casting conditions. As a result of these large heat fluxes the tools tend to crack in a bi-dimensionnal network (heat checking). Subsequent loss in productivity forces the user to change to a new die or repair it. The growing competition in this industry pushes industrials to search for innovative solutions to extend the life of their tools. Among the foreseen solutions, coatings constitute the most promising alternative.

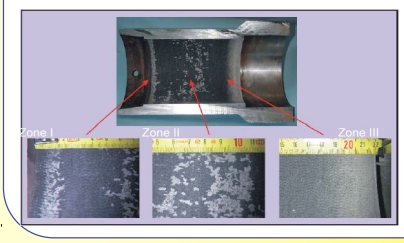
Several coatings have been investigated on a small scale centrifugal casting equipment. The coatings were either plasma sprayed functional graded cermets or gun sprayed refractory alloys. Some of the results in terms of thermal barrier and of wear are given. The coated dies were instrumented with thermocouples and an inverse modelling enabled us to find out the thermal loadings in each conditions. This was later used in a simulation of the thermo-mechanical behaviour of the FGM coating, using thermal and mechanical properties from literature. With the other coatings, we didn't find any reported data about its properties. We managed to measure its thermal properties using a photo-thermal microscope developed at GHF Odeillo.

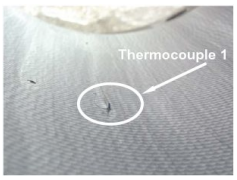
The simulation of thermal stresses in the FGM coating brought us to study the interaction that a single coating and its substrate have during thermal loading. With two hypothetical examples, we show the effect of thermo-mechanical screening. In a further development using a normalized model of the coating/substrate structure, we find one condition in which a given thermal load (flux density, duration) would bring no stress at the surface of the die where the heat checking cracks always start. A materials selection using this criterion shows that a few materials could satisfy this thermo-mechanical screening condition.

Experimental set up

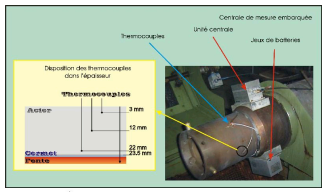
A. Several coatings tested during investigation

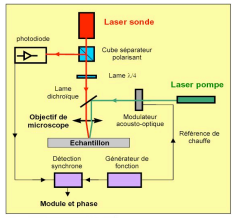
-Mono coating obtained by welding of refractory alloys
-FGM cermet coating obtained by thermal spray
-Metallic coating (WCCO) obtained by gun spray
+ painted NB layer

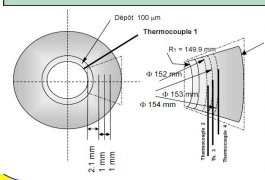


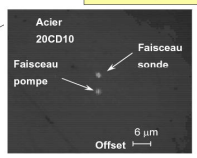


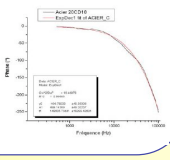
B. Some new measurement methods





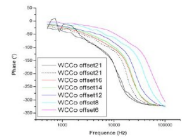






Some results

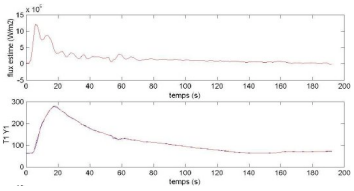
Thermal micro-measurement on WCCo and NB



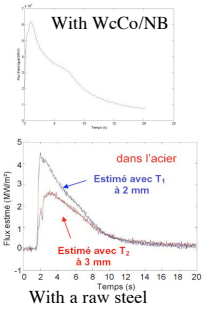
Positionnement offset	WCCo	NB
6	0.37	-
8	0.30	-
12	0.33	0.5
14	0.28	-
16	0.27	-
18	-	91.58
21	0.22	3.69

* 10^{-5} m^{2}s^{-1}

Inverse modeling for some centrifugal castings



With a cermet coating



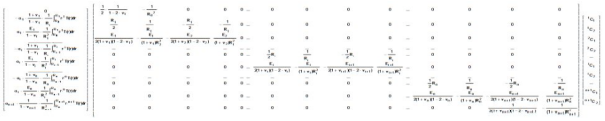
With a raw steel

Some thermal stresses model

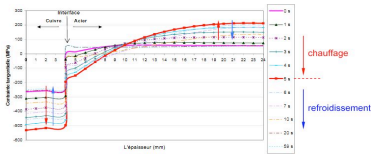
$$\sigma_{rr}^{i} = -\alpha_i \cdot \frac{E_i}{1-\nu_i} \cdot \frac{1}{r^2} \int_{R_{i-1}}^{r} r \cdot T(r,t)\,dr + \frac{E_i \cdot C_1(t)}{2(1+\nu_i)(1-2\cdot\nu_i)} - \frac{E_i \cdot C_2(t)}{(1+\nu_i)\cdot r^2}$$

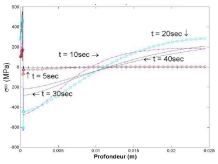
$$\sigma_{\theta\theta}^{i} = \alpha_i \cdot \frac{E_i}{1-\nu_i} \cdot \frac{1}{r^2} \int_{R_{i-1}}^{r} r \cdot T(r,t)\,dr - \frac{\alpha_i \cdot E_i}{2\cdot(1-\nu_i)} \cdot T(r,t) + \frac{E_i \cdot C_1(t)}{2(1+\nu_i)(1-2\cdot\nu_i)} + \frac{E_i \cdot C_2(t)}{(1+\nu_i)\cdot r^2}$$

Boundary conditions leads to



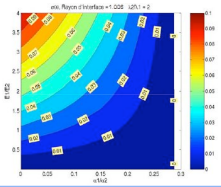
Application to bi-metal die or FGM coating

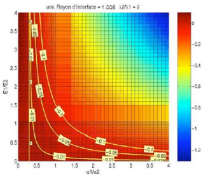




Thermo-mechanical screening

Is there a couple of substrate/coating that would lead to a reduction of thermal stresses in a given thermal loading ?





Maximum Thermal stresses = function of $(E_1/E_2, \alpha_1/\alpha_2, \lambda_1/\lambda_2)$

and proportionnal to the ratio $\frac{E_2 \cdot \alpha_2}{(1-\upsilon_2)} \cdot \frac{\phi_{max} R_0}{\lambda_2}$

Conclusion

- A method had been developped to measure thermal properties at microscale for the coating and has been successfully applied here
-Temperature measurements and their exploitation has been improved and applied to coated dies
-Thermal stresses are analysed taking into full account the coating
-Normalized analysis is performed that give indications about thermal screening conditions

Future works

-Test of thermal fatigue behavior of some of the substrate/coating combinaisons
-Test cold spray deposition method
-Apply micro thermal measurement to other coatings