Measurement Note

NPL REPORT MN 4

Thermographic Evaluation of Thermal Barrier Coatings on Contoured Substrates

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October 2008

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Department for **Innovation, Universities** & **Skills**

Thermographic Evaluation of Thermal Barrier Coatings on Contoured Substrates

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ABSTRACT

The use of Thermal Barrier Coatings is of great industrial relevance to the power generation and aero industries. The added insulation provided by the thermal coating enables the turbine components to operate in environments which are significantly hotter than could previously be achieved. The efficiency gains obtained from higher operating temperatures as well as the increase in component life service represent a considerable economic saving as well as reducing environmental effects.

Steady state thermography has been used for a number of years at NPL to study early delamination signs on flat test coupons which have been aged in electrically heated furnaces. This measurement note reports on the progress towards using a pulsed thermographic technique to study thermal barrier coatings on contoured components. The specimens are aged in furnaces where simulated combustion gases are present.

The contoured specimens have been manufactured and are being coated with a thermal barrier coating at Cranfield University. Preliminary tests on similar specimens from Siemens have shown promising results.

ISSN 1754-2987

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Approved on behalf of the Managing Director, NPL
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1. INTRODUCTION

Test coupons of thermal barrier coatings (TBC's) have been found to fail in ways that suggest the contributions of edge effects. The TBC's are normally applied only to the flat top surface of the coupons, leaving the sides exposed. It has been noted in many cases that the failure through spalling initiates round the perimeter of the coupons and then moves radially inwards until part of the TBC spalls off.

Steady state thermography has been used at NPL to study the onset of the spallation before the TBC actually drops off. Two techniques have been developed; heated thermography and radiated thermography.

In heated thermography the coupon is heated to around 60 °C on a hot plate and then transferred to the thermal camera. Images are acquired in 10 to 15 seconds and then the contrast is stretched manually to highlight the location of the 'cold spots' where the heat from the substrate metal is not conducting well to the TBC. This indicates that there is a sub surface fracture progressing between the TBC and the substrate.

In the radiated thermography technique, the specimen is imaged at room temperature. A source of heat is brought near the object in such a way that the radiation from it falls upon the surface of the TBC. The object is again imaged for approximately 10 to 15 seconds and the contrast is again stretched to search for 'hot spots'. These are areas where the TBC can warm up more than the surrounding parts because it is not adhering fully to the substrate.

The 'hot spots' with the radiative technique correspond to the 'cold spots' obtained with the heated technique. This gives added confidence in the interpretation of the defective region of the TBC.

Pulsed thermography involves imaging the object while applying a sharp radiative pulse of heat on to the surface with the aid of a powerful xenon lamp. Images are then acquired and processed automatically to highlight regions of contrast.
The automatic processing which forms part of the pulsed thermography technique involves calculating the rate of change of temperature of each pixel as well as the acceleration of the temperature change. This offers the potential advantage of making the technique less susceptible to effects due to surface emissivity.

2. SPECIMEN DESIGN AND PREPARATION

Two different specimen designs have been proposed. The first proposal (by NPL - shown in figure 1) makes use of ingots which are 25 mm diameter and 35 cm long.

The ingots would be spark eroded as shown in figure 1 making good use of the material. It should be noted that IN738 cannot be machined with conventional methods as nimonic alloys are very hard.

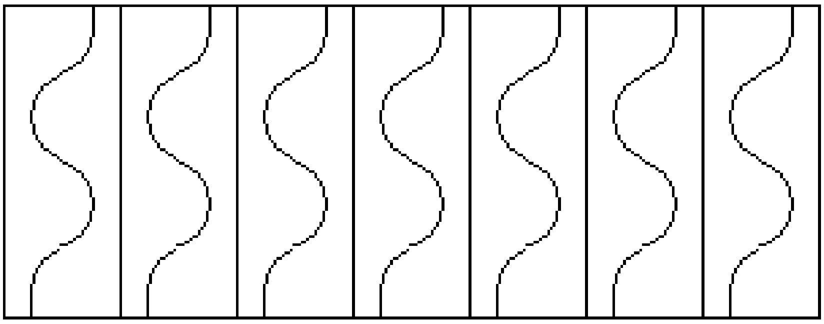

Figure 1. Spark erosion pattern to specimens.

The individual specimen shape is shown in figure 2. The rationale is that it has both concave and convex surfaces which present different challenges to thermography.

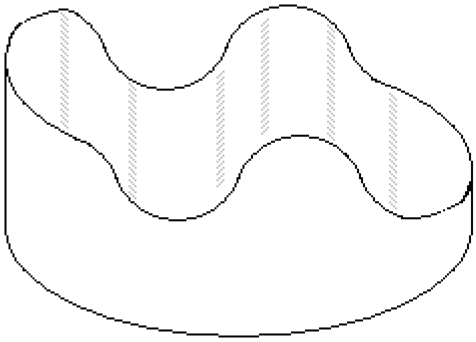

Figure 2. Proposed specimen shape

A simulated aerofoil cross section bar was proposed by Siemens, partner in the Industrial Advisory Group (IAG). It has concave as well as convex surfaces, see figure 3.

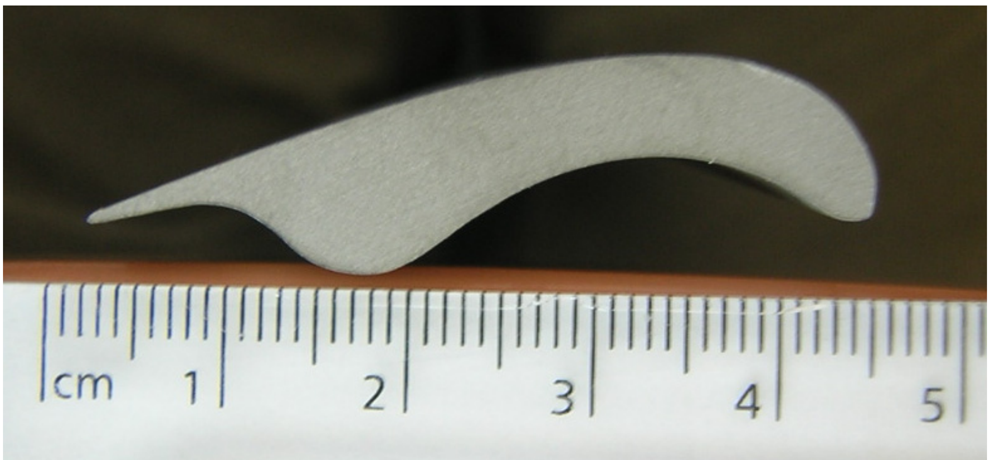

Figure 3. Cross section of the simulated aerofoil test specimen. The 'blade' is approximately 23 cm long.

Although the simulated aerofoil specimen is the more costly of the two options in that it needs to be cast in a mould, it was nevertheless selected for two reasons:

A – It more closely represents the geometry of actual turbine blades used in industry.
B – It does not suffer from the same edge effects alluded to earlier (the TBC coating can be applied all around the contour of the specimen.)

Two substrate materials were considered for the specimens: CMSX4 and IN738. Both have suitable characteristics (high strength at elevated temperatures), but CMSX4 is the more costly.

Since the object of the study is the TBC coating rather than the substrate, and there will be a bond coat applied to the substrate before the TBC is added, there were no compelling arguments towards the use of CMSX4. The material chosen for the specimens was IN738 which is a nickel based super-alloy of common usage in the high temperature industry.

Although the simulated aerofoil specimens were cast in lengths of 23 cm, they may be cut into smaller pieces to generate a larger number of separate specimens if required.

The specimens have already been cast and have now been sent to Cranfield University for bond coat and TBC coating. There are several candidates for the coating, but it is expected that they will be coated with an HVOF Amdry 995 bond coat and an Air Plasma Sprayed (APS) TBC. APS TBC's are by far the more common type because they are much quicker to apply as the specimen can be housed at ambient air pressures during the coating process.

Synergy is being exploited with the Supergen PLE Activity in which NPL and Cranfield are both partners. Cranfield University plan to study specimens made in CMSX4 in conjunction with these IN738 specimens. The main interest of Cranfield University in this work is the study of TBC thickness variations as well as spallation, while NPL's main goal is to test the pulsed thermographic technique on curved TBC specimens.

3. AGEING PROCEDURE

To precipitate incipient failure in the TBC system it is necessary to raise the specimens to high temperatures (typically 1000 °C) and hold them for long periods of time (typically thousands of hours). In order to exploit the synergy with Cranfield University still further, the ageing is to be carried out in their furnaces.

The temperatures will be 900, 950 and 1000 °C and the atmosphere will be a simulated combusted natural gas environment. The nominal composition of this gas is 15 vol % O_2 – 3.4 % CO_2 – 6 % H_2O -1 % Ar – balance N_2. This may discolour the surface of the TBC somewhat, but that is part of what this study is intended to investigate. The furnaces are heated electrically at 5 °C per minute to the holding temperature and cooled at a maximum rate of 5 °C. The holding periods will be a flexible 250 hours, slightly longer or shorter to ensure that the ends of cycles always take place on working days so that the specimens can be studied before the next cycle starts.

A schematic diagram of the furnace and gas supply system is shown in figure 4 and the temperature cycles are shown in figure 5. In preliminary tests at 900 °C and 950 °C some specimens have survived ~ 2500 hours, so it is envisaged the tests will need a considerable time at temperature.

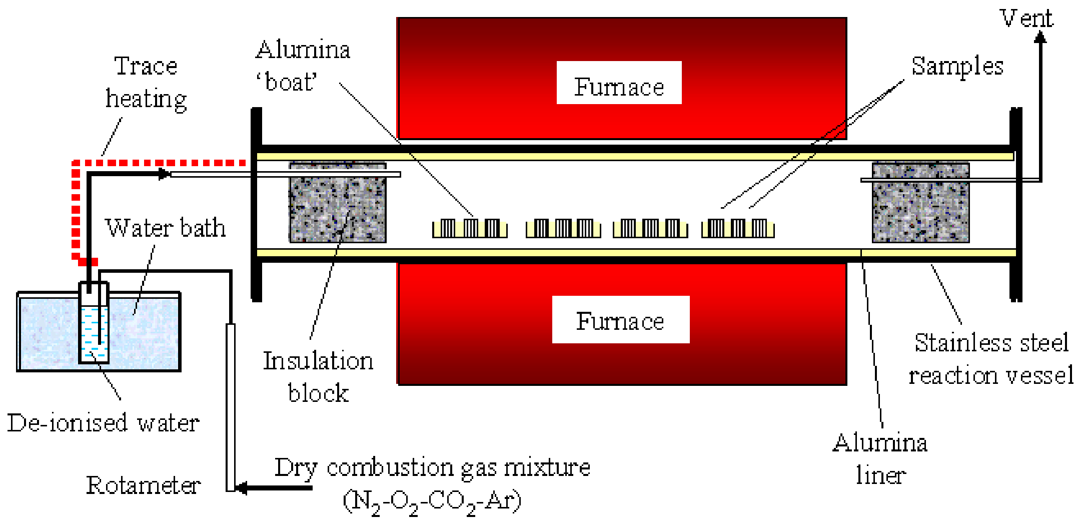

Figure 4. Schematic diagram of the electrically powered furnace and gas supply system

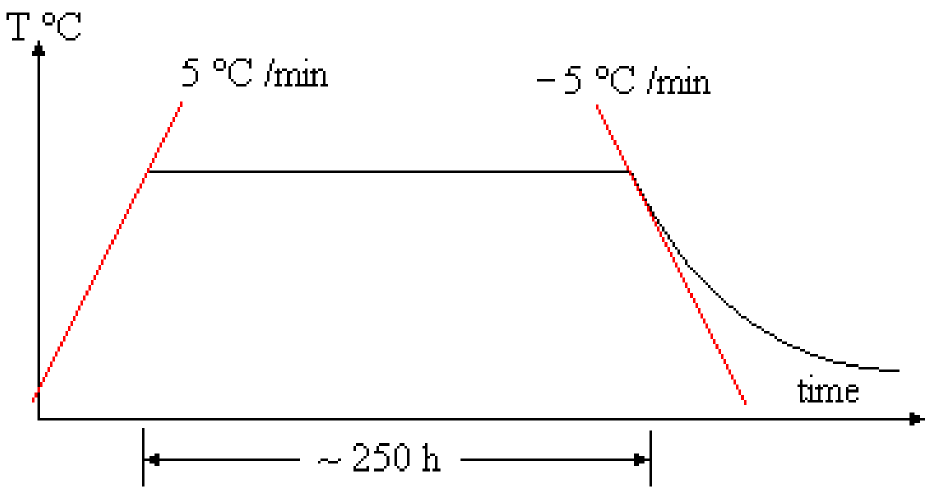

Figure 5. Graphical representation of the temperature cycles to be used.

4 PRELIMINARY RESULTS

Early pulsed thermography tests have been carried out on similar simulated aerofoil specimens in collaboration with Siemens. The specimens were cut to sections approximately 3 cm in length and drilled through to provide a mechanism for easy mounting in the coating chamber. Figure 6 shows an APS TBC coating all around the simulated aerofoil.

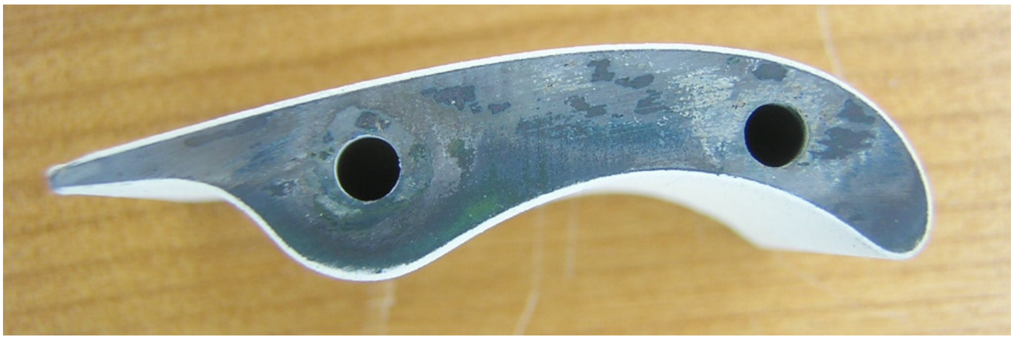

Figure 6. APS TBC coating fully covering the surface around the simulated aerofoil (Siemens)

These specimens were aged for different lengths of time at various temperatures to suit the internal testing procedures at Siemens. Pulsed thermography was then applied to the convex and concave surfaces of the specimens.

The method was able to highlight debonded regions of the TBC, see figure 7.

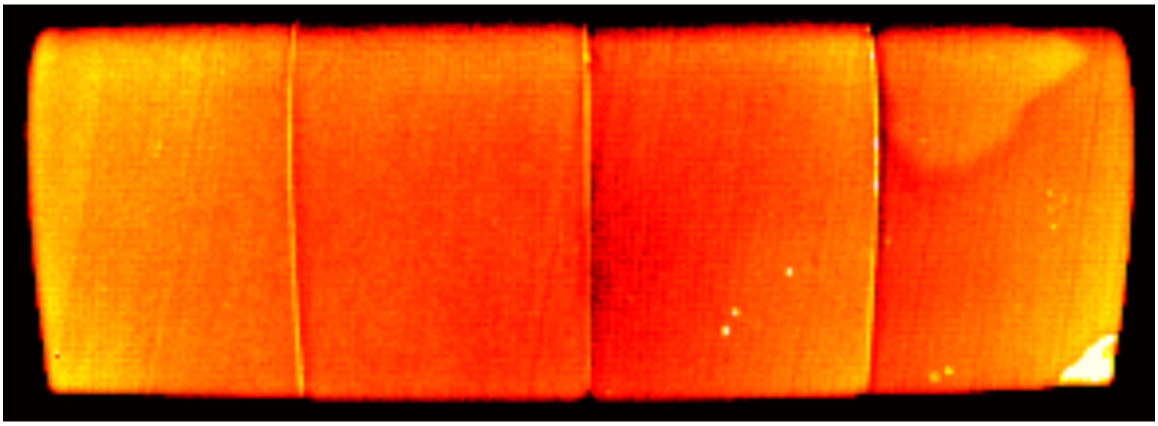

Figure 7. Pulsed thermogram of TBC coated specimens after 125 hours of exposure at temperatures of 930, 990, 1050 and 1100 °C respectively

Notice that the TBC on the bottom right hand corner of the specimen on the right hand has spalled off. Thermography reveals that there was also a large area at the top left hand corner of the same specimen that has become detached from the substrate.

It is hoped that halting the ageing regime at regular intervals before large scale spallation occurs will enable pulsed thermography to detect smaller areas of delamination before they become so large that they can be detected by other optical techniques.

ACKNOWLEDGMENTS

The work reported in this measurement note was funded by the Department of Industry Universities and Skills (DIUS). Contributions of specimens from Siemens are also gratefully acknowledged. The author is also thankful for ongoing collaborative work on coatings and ageing in furnaces carried out by Cranfield University.