Development of Nondestructive Evaluation Methods For Ceramic Coatings

W. A. Ellingson, C. Deemer, J. G. Sun,
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439
E:mail: ellingson@anl.gov; Telephone (630)252-5068;FAX (630)252-4798

S. Erdman[+], D. Muliere[+]
and B. Wheeler[+]
Students--Illinois Institute of Technology, Chicago, IL 60616

Introduction

Various nondestructive evaluation (NDE) technologies are being developed to advance the knowledge of ceramic coatings for components in the hot gas-path of advanced, low-emission gas-fired turbine engines. The ceramic coating systems being studied by NDE include thermal barrier coatings (TBCs) and environmental barrier coatings (EBCs). TBCs are under development for vanes, blades and combustor liners to allow hotter gas path temperatures and EBCs are under development to reduce environmental damage to high temperature components made of ceramic matrix composites (CMCs). Data provided by NDE methods will be used to: a) provide data to assess reliability of new coating application processes, b) identify defective components that could cause unscheduled outages c) track growth rates of defects during use in engines and d) allow rational judgement for replace/repair/re-use decisions of components.

Thermal Barrier Coatings

Advances in thermal barrier coatings (TBCs), both electron beam –physical vapor deposition (EB-PVD) and air plasma spray(APS), are allowing higher temperatures in the hot-gas path of gas turbines(1-3). However, as TBCs become “prime reliant”, their condition at scheduled or unscheduled outages must be known. NDE methods are under development to assess the condition of the TBC for pre-spall conditions. One theory being developed for the mechanism for spallation , see Fig.1, is that at the interface between the thermally grown oxide layer(TGO) and the substrate, the topography at that interface changes as a function of the number of thermal cycles(4). If there would be a nondestructive evaluation (NDE) method to interrogate this interface, then perhaps a correlation could be established between the condition of this interface and the potential for spallation. On such NDE method under development is a method called polarized laser back-scatter. The polarized back-scattered laser NDE method, see Fig. 2, is based on a modification of the reflectometry method (5). However, the NDE method under development utilizes two detectors. The polarized laser light is incident on the test specimen and the back-scattered light , which penetrates through the optically translucent coatings reflects back off the interface and is received by two detectors. The difference between the two detectors is that the first detector has a highly polished first-surface mirror in front of it that has a small diameter aperture thereby only allowing light that is back-scattered over a narrow angle to be detected while the second detector has no aperture at all and therefore detects light scattered back over a much larger angle. By taking the voltage output of these two detectors and either adding or dividing in a computer loaded with special software, various features related the scatter pattern can be discriminated. Laser scatter data for an entire test sample are acquired by raster- scanning the sample under computer control. Recently a set of samples were studied that consisted of three 25 mm diameter button samples made with CMSX-4 substrate, plasma sprayed MCrAlY bond coat and a 7YSZ TBC applied using EB-PVD methods. These three samples, all produced at the same time, were thermally treated to various numbers of thermal cycles. Sample GEP had no thermal cycles, sample GEP-9 had 5 thermal cycles and sample GEP-70 had 70 thermal cycles. The thermal cycles were one hour cycles where the hold temperature was 1121 C. Fig. 3 shows resulting back-scattered laser data over a 15mm square region from each sample along with the gray scale histogram for each “image’. What is to be noted in the histogram, is that as the number of thermal cycles increases, the histogram peak shifts to the right showing the larger number of “black’ spots. These “black’ spots correspond to the increased surface roughness at the interface. By tracking such a shift, it may be possible to eventually correlate this to the condition of the interface and thus predict spallation.

Tests have also been conducted with this NDE method on APS TBCs. Results, see Fig. 4, show that pre-spall is detected .

Environmental Barrier Coatings for Oxides

Development of oxide/oxide ceramic matrix composites for combustor liners has necessitated the development of a protective coating that can reduce the temperature of the substrate material.. Since these coatings are critical to the materials performance, NDE technologies are under development to detect degradation of these EBCs. While several NDE methods are under development, recent results have demonstrated that NDE thermal image data correctly detected simulated delaminations in an oxide/oxide composite and x-ray computed tomography was used for verification. The thermal imaging method, see Fig. 5, is based on detection of the time-dependent surface temperature when there has been some thermal stimulation (6,7). The high frame rate infrared camera utilizes a focal plane-array with 3 to 5 µm band pass. The flash lamps are powered by a 6.4-kJ power supply. Spectral output of the flash can be customized through use of different gases in the flash tube as well as various external filters.. In our efforts, there are two modes of operation : through transmission where the thermal stimulation is placed on one side of the test sample and the detector on the opposite side and one-sided where the thermal stimulation and the detector are both placed on the same side of the test specimen. In a recent set of experiments, a special cylindrical test specimen, see Fig. 6, was made with intentional delaminations. Results of using one-sided thermal imaging of the entire circumference of the cylinder are shown in Fig.7 By using such methods, with careful attention to the sizes of features , it is possible to calibrate the method and begin to quantify the results.

References

1. North Atlantic Treaty Organization. Advisory Group for Aerospace Research and Development, AGARD. "Thermal Barrier Coatings”, AGARD report, AGARD-R-823, Neuilly-Sur-Seine, France. Dated April 1998.
2. US National Research Council. National Materials Advisory Board. "Coatings for High Temperature Structural Materials", National Research Council report, . National Academy Press, Wash, DC, 1996.
3. US National Aeronautics and Space Administration, NASA. 'Thermal Barrier Coating Workshop", NASA report, NASA Conference Publication 3312, dated 1995.
4. Evans, A. G., Wang, J. S., and Mum, D. “Mechanism-based Life Prediction Issues for Thermal Barrier Coatings’, in Proceeding of the TBC Workshop-1997, pgs 45-52, NASA, 1997
5. Tompkins, H. G. and McGahan, W. A., " Spectroscopic Ellipsometery and Reflectometry", J. Wiley and Sons, Inc. New York, NY, 1999.

6. Sun, J. G., Easler, T. E., Szweda, A., Pillai, T. A. K., Deemer, C. and Ellingson, W. A., “Thermal Imaging and Air-Coupled Ultrasound Characterization of a Continuous Fiber Ceramic Composite,” Cer. Eng. And Sci. Proc., Vol. 20, Issue 3, pp. 200-210, 1999.

7. Deemer, C, Sun, J. G. and Ellingson, W. A., " One-sided thermal imaging for flaw characterization of ceramic matrix composites', Ceram. Trans. 2001, Vol. 124, pgs. 23-240, 2001.

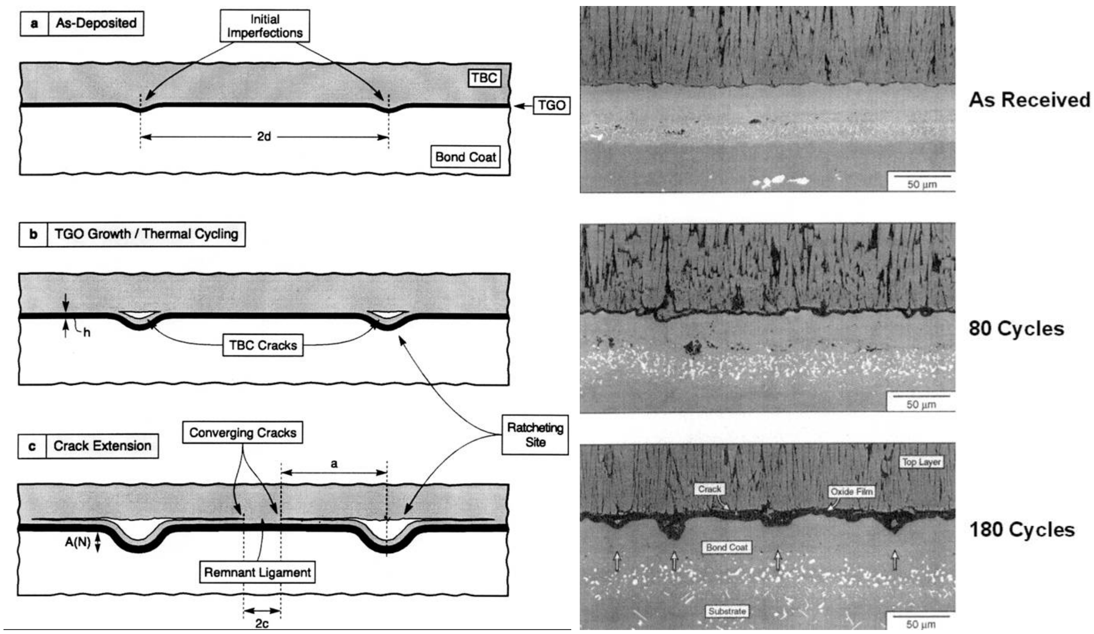


Fig 1. Schematic diagram and optical photomicrographs showing changes in topography between TGO and substrate for EB-PVD TBC(After Evans, et al 1997)

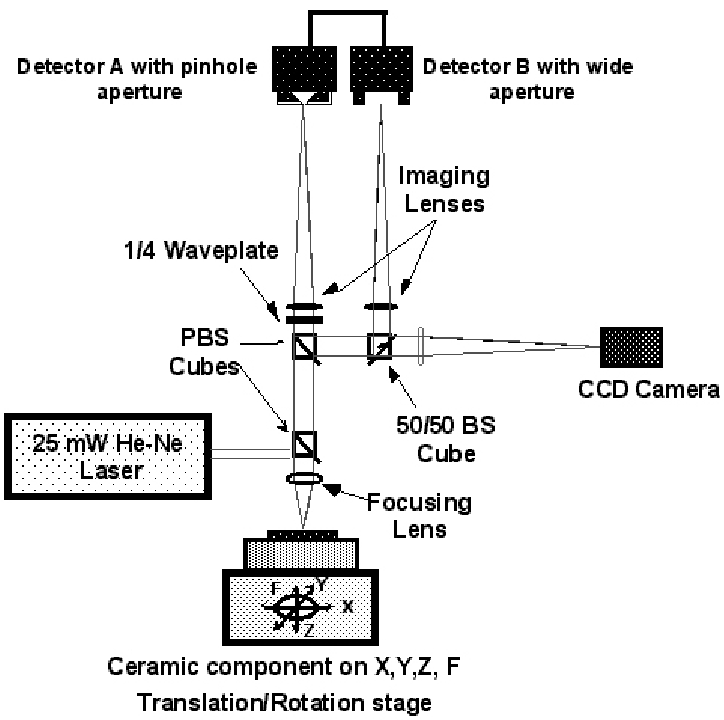
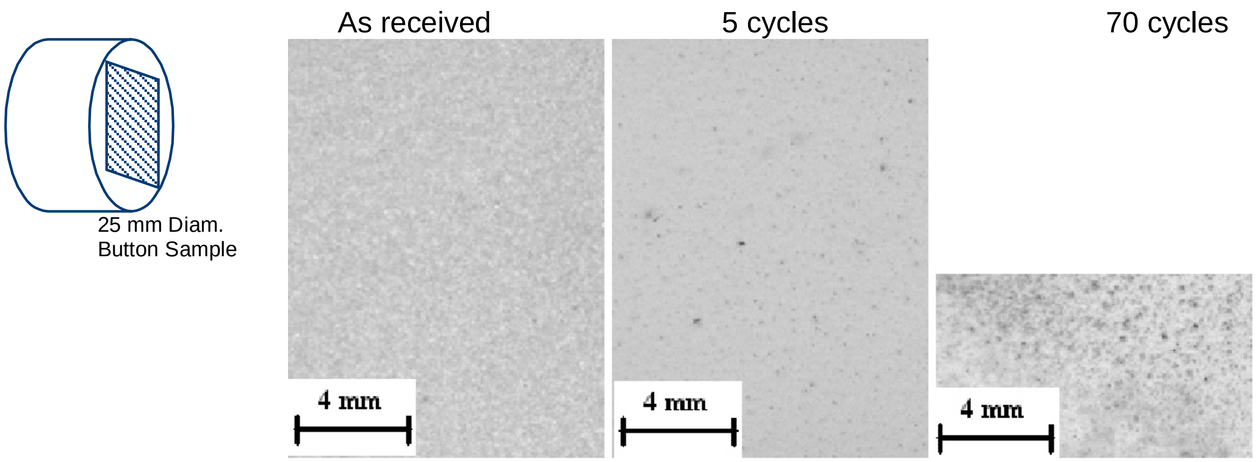
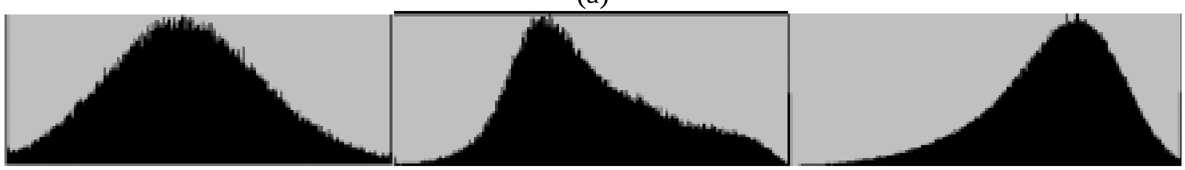


Fig 2. Schematic diagram of the polarized laser back-scatter NDE method for studying the topography of the TGO-substrate interface.

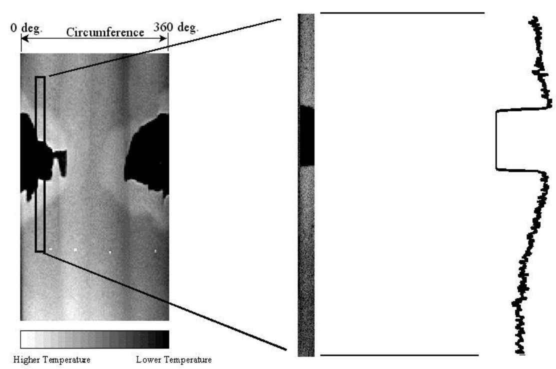


(a)

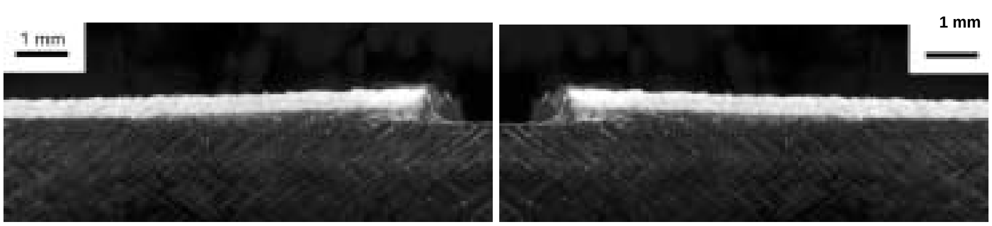


(b)

Fig 3. Polarized laser back-scatter data from thermally cycled EB-PVD samples.
a) data
b) scale histograms



(a) (b) (c)



(d)

Fig 4. Example of polarized-laser back scatter for detection of de-bonds in APS TBC. a) One-sided thermal image showing delamination and laser scan position, b) laser scan data, c) line plot of laser scan data, d) optical photomicrographs of delaminated region.

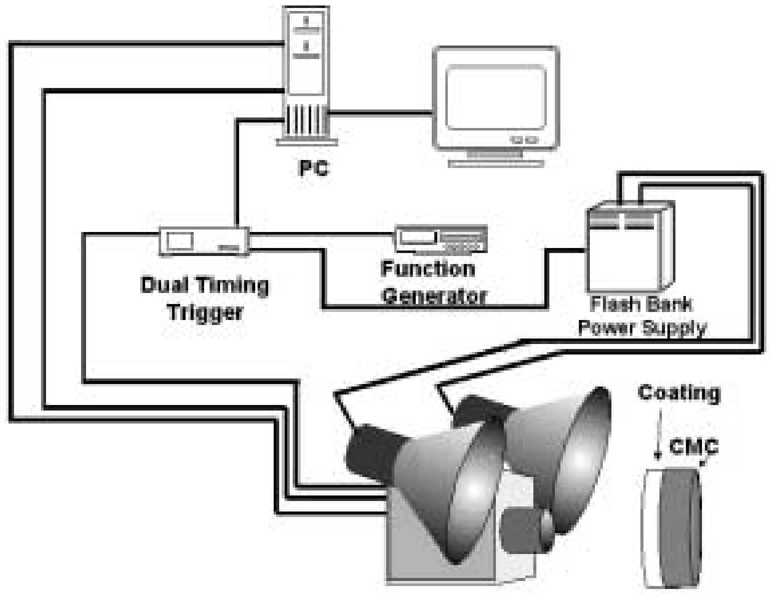
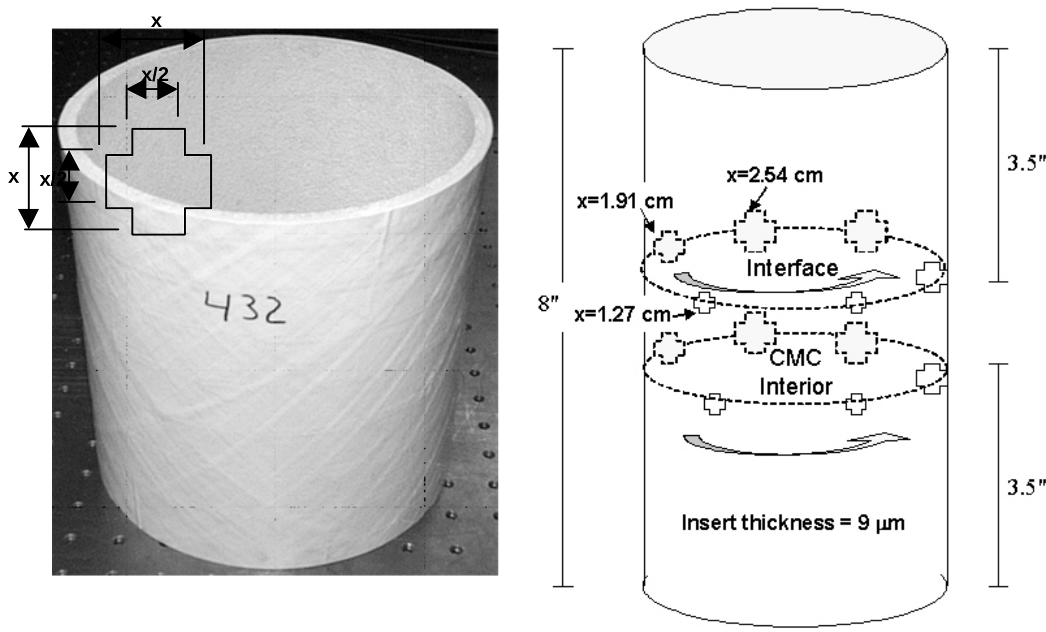


Fig 5. Schematic diagram of the one-sided thermal imaging NDE method for delamination detection for EBC.



(a) (b) (c)

Fig 6. Oxide/oxide delamination test sample. a) photo of cylinder test sample
b) schematic diagram showing position of delams, c) size description of intentional delams.

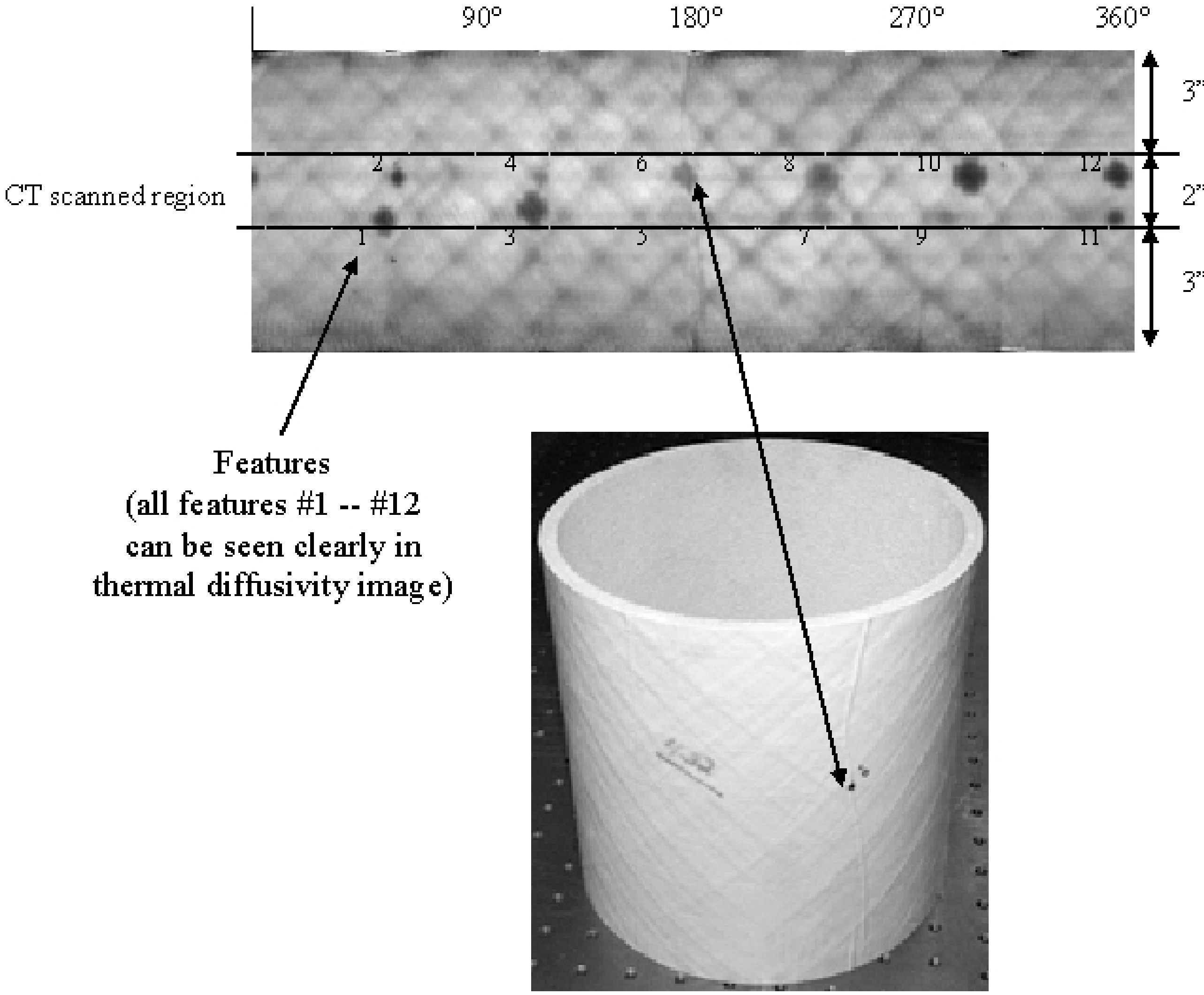


Figure 7. Example of detection of delaminations of sample shown in Fig 6.
The thermal image data are obtained using one-sided acquisition parameters