Lifetime Assessment and Shock Behavior of TBC in Gas Turbine Blades: Experimental and Numerical Investigations

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ABSTRACT

In this study, the thermal shock behaviour of a thermal barrier coating system of a gas turbine engine's turbine blade of the space and aircrafts are evaluated. The thermal shock behaviour of the thermal barrier coating system was investigated. Computer-assisted thermal (ANSYS) and crack growth (FCPAS) analyses were carried out with the help of the obtained information. Thermal barrier coating system consists of nickel based superalloy substrate, ytria stabilized zirconia (%8 YSZ) ceramic top coat and NiCrAlY bond coat. Plasma spray method was used for coatings. Damages that occurred in the specimens were assessed according to cycle numbers, thermal stress and heating time. With the aid of the experiments, stress analyses of the modelled TBC were performed. The crack profiles and crack progression rates were determined. Finally the coating life was determined.

1. Introduction

To protect turbine blades in hot working conditions from thermal stresses and other effects, TBC was applied on to the structure of the blade. Different types of coating technologies are widely used for turbine blades. Thermal barrier coating (TBC) systems, consisting of yttria partially stabilized zirconia (YSZ), thermally grown oxide (TGO) and a metallic bond coat, are used in applications for thermal protection of hot-section parts in gas turbine engines [1-5].

The interface regions undergo high stresses due to the mismatch of thermal expansion between BC and TBC. Additionally, growth stresses due to the development of thermally grown oxide (TGO) at the interface and stresses caused by interface roughness are superimposed. Stress relaxation generally leads to a reduction in stress levels at high temperature, but can also give rise to enhanced stress accumulation after thermal cycling, which results in early crack initiation at the bond coat/alumina interface and spallation failure afterwards [6-12].

It is clear that thermal barrier coatings have an important role in current applications and in the new generation of engines that are being designed. In addition to this, durability and reliability limits the benefits of thermal barrier coatings. Due to the lack of a reliable lifetime assessments, full use of the potential of these coatings is not possible. Proper understanding of damage mechanisms in thermal barrier coatings is a key factor for increasing the durability and reliability of the coating. [13].

In this study, cracks that formed on the coatings due to thermal stress were investigated experimentally, and a finite element model was developed based on the results obtained from the experiments. For the base blade material, Nickel base alloy substrate was used. As a bond coating material NiCrAlY was preferred. YSZ was selected for the top coating layer. See table 1 for materials' details. For the TBC used geometry, the turbine blade was covered with a 150 micron thickness of a super alloy bond coating (NiCrAlY). For over the bond coating layer, 350 micron thickness of YSZ (ytria stabilized zirconia) was used as a top coating.

Table 1: Material properties of substrate, bond coat and top coating

Material	Thermal Conductivity [W/m°C]	Thermal Expansion 10-6 [1/°C]	Density [kg/m3]	Specific Heat [J/kg°C]	Poisson's ratio	Young's Modulus [GPa]
Ni-base alloy	19	15	8190	575	0,3	18
NiCrAlY	20,7	15,4	7710	567	0,25	16,8
YSZ	1	10.8	5240	582	0,25	50

2. Experimental Study

In the literature, for thermal and structural analysis of the turbine blade, a small segment of the turbine blade is obtained and subjected to thermal shock tests. The front surface temperature of the test sample was raised to 1250°C and maintained at this temperature for 5 minutes. While heating, the rear side of the test sample was cooled with a high flow of air to obtain a controlled temperature gradient. In this way, the temperature of the base was maintained at 800°C. After completing the heating process, burning gas was removed automatically from the coating surface which was then cooled from both sides with pressurized air for 2 minutes.

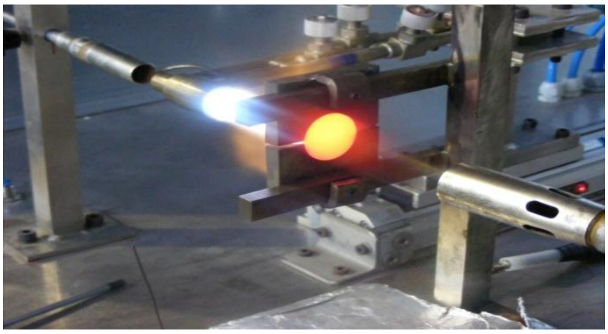

Figure 1.Sample view at the time of experiment

The samples were taken for macro evaluation at the end of every 50 cycle, and for micro evaluation at the end of every 500 cycles. Samples for micro analysis were obtained by cutting the cross-sections, and cracks that formed were identified with the aid of a Scanning Electron Microscope (SEM).

3. Modelling and analysis

The "Solid-90" used for thermal analysis and the "solid-186" element type used for structural analysis were generated by sweep meshing the hexagonal shape that provided the best result. Mesh was performed in a sequential and correct manner according to material characteristics and element type that were entered to the finite element model formed on ANSYS. All parameters necessary for thermal and structural analysis were entered to the crucial points formed after meshing. Data was formed on the FCPAS program using the results obtained from these analyses. FCPAS is an interface, based on finite elements method that can perform the three dimensional breaking analysis for engineering materials and crack progression analysis for cylindrical models with a plate. By using ANSYS in the crack progression analysis, the horizontal cracks in the three dimensional coating were modelled, parametric macros were generated under thermal loads, and individual analysis were performed.

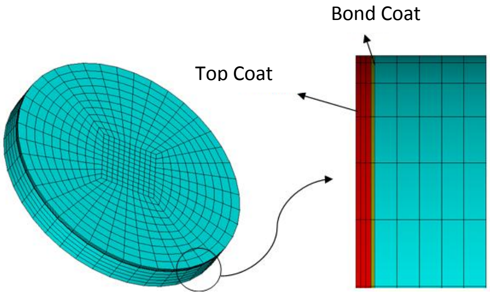

Figure 2. Finite element model of the experimental sample

4. Results and discussion

In the experiments, the sample heating rate was 20 ºC/s, and cooling rate was 10 ºC/s. İt was determined that the experimental data and numerical results for the heating and cooling times overlapped with1.2% deviation. As a result of the analyses that were performed, it was calculated that when the upper surface temperature reached 1232 ºC, the base temperature was 990 ºC. It was hence determined that the TBC with YSZ provided 19.6% thermal protection by reducing the base temperature by 242 ºC.

In the life estimates that were performed, it was calculated that, as shown in Figure 3, the crack size progressed 1 mm from the side towards the center at the end of 1500 cycles, 1.45 mm at the end of 1750 cycles, and 2.6 mm at the end of 2000 cycles. At the end of 2300 cycles, the crack size reached 20% of the radius, which corresponds to 3 mm. It was observed that the experimental data and numerical results overlapped with 3.6% deviation at most.

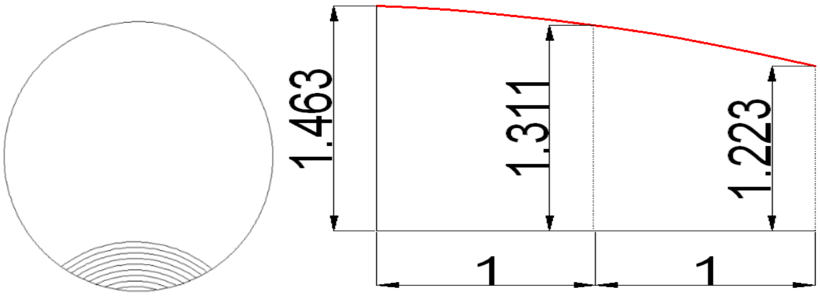

Figure 3. Graph of crack length according to the number of cycles obtained experimentally and numerically

As seen on Figure 4, it was determined that the crack profile is epileptic and that it overlaps with the numerical results with a 1% deviation.

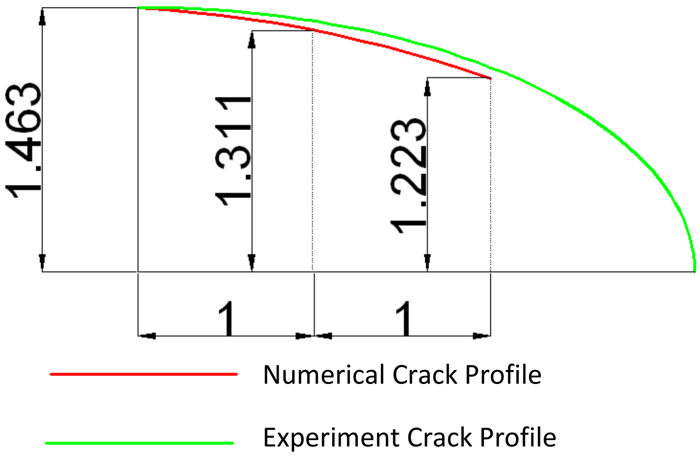

Figure 4. Crack profiles obtained experimentally and calculated numerically

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