International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:1, No:8, 2007

Influence of Cyclic Thermal Loading on Fatigue Behavior of Thermal Barrier Coatings

Vidyasagar H. N., S. Gopal Prakash, Shivrudraiah, and K. V. Sharma

***Abstract*—**Thermally insulating ceramic coatings also known as thermal barrier coatings (TBCs) have been essential technologies to improve the performance and efficiency of advanced gas turbines in service at extremely high temperatures. The damage mechanisms of air-plasma sprayed YSZ thermal barrier coatings (TBC) with various microstructures were studied by microscopic techniques after thermal cycling. The typical degradation of plasma TBCs that occurs during cyclic furnace testing of an YSZ and alumina coating on a Titanium alloy are analyzed. During the present investigation the effects of topcoat thickness, bond coat oxidation, thermal cycle lengths and test temperature are investigated using thermal cycling. These results were correlated with stresses measured by a spectroscopic technique in order to understand specific damage mechanism. The failure mechanism of former bond coats was found to involve fracture initiation at the thermally grown oxide (TGO) interface and at the TGO bond coat interface. The failure mechanism of the YZ was found to involve combination of fracture along the interface between TGO and bond coat.

Keywords—Thermal barrier coatings, thermal loading.

I. INTRODUCTION

THERMAL barrier coatings (TBCs) have been essential technologies to improve the performance and efficiency of advanced gas turbines in service at extremely high temperatures [1]. TBC protects the metal substrate from high temperature oxidation and environmental attack [1,2]. TBC system consists of three layers: ceramic topcoat, bond coat and metal substrate. TBC system applied to turbine blades made up of titanium base alloy can lower the temperature of metallic substrate of about 100–150°C [4-5], together with active cooling of backside metal, allowing an increase in the turbine entry temperature and as a consequence, in the engine efficiency. The bond coat (BC) deposited between the metallic substrate and the topcoat (TC) to prevent underlying alloy from oxidation and high temperature corrosion and to guarantee the coupling between the ceramic and the airfoil material; during service operations, the oxidation of BC at high temperatures produces a thermally grown oxide (TGO) scale located between BC and TC. The thickness of this layer increases with increasing operation time and this element seems to be almost the most important factor in determining lifetime of a coated component [6-7].

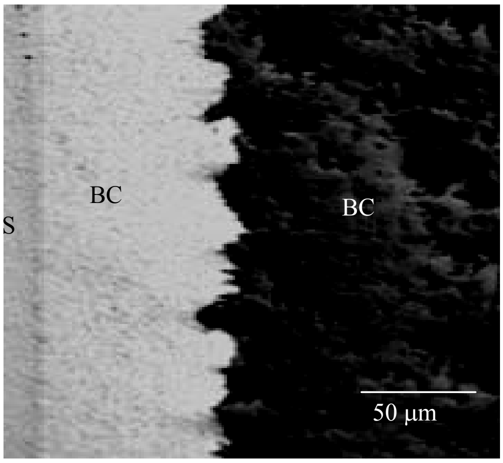

Fig. 1 Microstructures of APS TBC specimens (transition side)

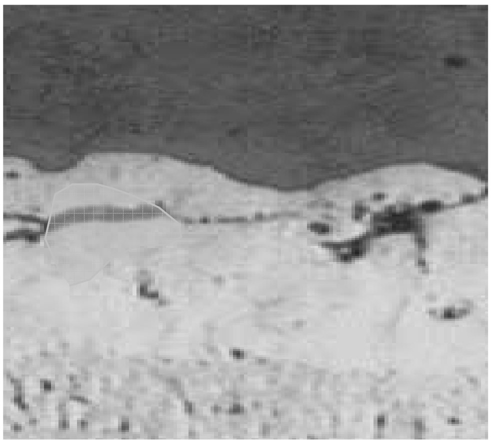

Fig. 2 SEM structure of TBC specimen

Manuscript received October 9, 2001.

Vidyasagar H. N., Senior Lecturer, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore-01, India (e-mail : hnv_sagar@hotmail.com).

S. Gopal Prakash, PhD, Professor, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore.

Shivrudraiah, PhD, Asst., Professor, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore

K. V. Sharma, PhD, Senior Lecturer, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore.

The following objectives of the paper is the measurement of stresses in air spray plasma (ASP) TBC on plate components subjected to cyclic thermal loading fatigue.

II. EXPERIMENTAL STUDIES

The specimens used in this study Air plasma spray (ASP) yttria-stabilized zirconia (YS) TBC systems. The as-processed coatings consisted of a zirconia topcoat layer, plasma-sprayed bond coat layer at low pressure, and a super alloy substrate, as shown in Fig. 1. The TC and BC at form layers on a plate Ti alloy. The thickness of the zirconia topcoat layers ranged from 300–400 *µ*m, and the thickness of the bond coat layer was 100 *µ*m , as seen in Fig. 1. The bond coat in TBC specimens was polished down to reduce surface roughness before deposition of the zirconia coating. The microstructure of the APS specimens is characterized by splats flattered with respect to the surface of Ti alloy. The TBC specimens were subjected to cyclic thermal loading for exposure 100 hours to measure TGO thickness using Scanning Electron Microscope. Fig. 2 shows an SEM photomicrograph of TGO scale of an ASP specimen subjected to 100h of accelerated temperature exposure.

Macro-Ruby fluorescence spectroscopy (MRFS) analysis was used to study the evolution of hydrostatic stresses in the YZ scale of TBC specimen as a function of thermal cycles. The spectra were excited with 50-100 mW of 476-nm radiation from a krypton ion laser and analyzed with a spectrometer equipped with a charge coupled devise detector. In the macro experiments, the incident beam was focused down to a relatively broad spot size and the scattered light was collected along the surface normal with an f/1.4 lens. MRFS ruby experiments were done both through the zirconia topcoat and also on the polished cross-section. Because the topcoat is translucent, a small fraction of the scattered light comes from the ruby crystallites in the oxide scale. Thus, analysis of the scattered radiation through the topcoat in the macro mode provides information about the residual hydrostatic stress in the oxide scale, averaged over the effective activation volume of the scale, the dimensions of which are expected to be slightly greater than the beam size. The macro mode on the polished cross-section provides information about mean stresses in a given length (i.e., 7 mm) of the scale encompassed by the laser spot. The micro-fluorescence spectra were acquired in the backscattering mode through a microscope that allowed the laser to be focused to 2 µm for more details please refer Singh et al. [8].

III. RESULTS AND DISCUSSION

The results, shown in Fig. 3**,** indicate that the average hydrostatic compressive stress in the scale increases significantly, from -0.2 to -1.7 GPa, as the TBC damage increases during thermal cycling. This result can be regarded as the overall effect of the creep related localized phenomenon. TGO observation is also implying that the increased damage in the topcoat results in decreased residual stress at initial thermal loading cycles. The trend in the data shown in Fig. 3 was consistently observed for all of the coating thickness that was investigated and is similar to that seen for oxidization specimen with minimum stress observed at initial cycles. This trend seems similar in all thickness TBC specimens that were subjected to thermal cycling. In that later case, maximum stresses were observed. The trend may be due to the extent of scale damage introduced [9-10], the specimen clearly shows the damage in the topcoat. Scale damage leads to modified state of stress in the scale.

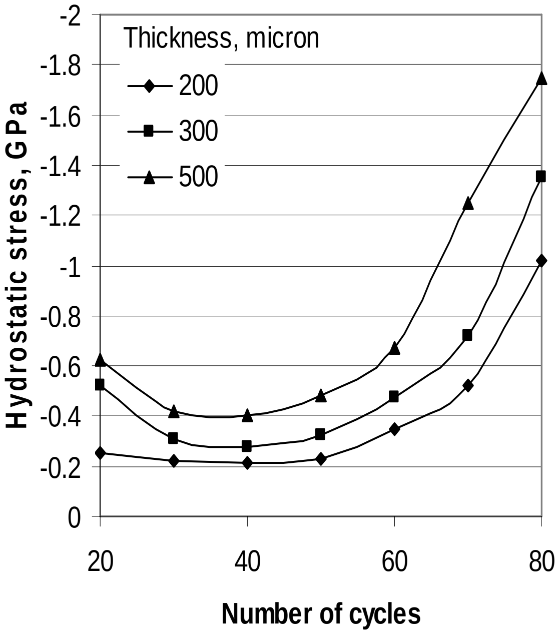

Fig. 3 Hydrostatic stress in TBC specimen measured through topcoat by macro-ruby fluorescence spectroscopy as a thermal cycles (Room temperature to 750 °C)

IV. CONCLUSION

The BC stress is depending on TGO thickness i.e thicker TGO layer increase the BC stress along cooling from room temperature to 20°C temperatures to 750 °C. It is repeating in re-heating to maximum peak temperature results in topcoating residual stress, which can be so high to produce reverse yielding in the topcoatings. Damage evolution in the topcoat TBC system subjected to simulated service environment is closely related to stresses developed in system. The damage in the means of residual stresses was measured by MRFS. Damage and stress evolution were studied as function of number of thermal cycles. The thermal stresses were observed to strongly influence the nature and evolution of hydrostatic stress in the topcoat and TGO.

REFERENCES

[1] M. Martena, D. Botto P. Fino S. Sabbadini. M.M. Gola, C. Badini, 13 (2006) 409–426.
[2] B. G. Nair, J. P. Singh and M. Grimsditch, ceramEngr. Sci. Proc. 21 (3) (2000), 133–141.
[3] C. Hsueh, J. A. Haynes, m. J. Lance, P. F. Becher, M. K. Ferber, E. R. Fuller, A. Langer, W. C. Carter and W. R. Cannon, J. AmerCeram. Soc. 82(4) (1999) 1073.

[4] M. J. Lance, J. A. Haynes, W. R. Cannon and M. K. Ferber, "Ceram. Trans. Nondestructive evaluation of Ceramics," edited by c. H. Schilling and J. N. Gray vol. 89, p. 229.

[5] K. W. Schlichting, k. Vaidyanathan, Y. H. Sohn, E. H. Jordan, M. Gell and N. P . Padture, Mater. Sci. Engr. A291 (2000) 68.

[6] A. M. Limarga, S. Widjaja, T H. Yip and L. K. Teh, Surf. Coat. Tech. 153 (2002) 16.

[7] K. Sfar, J. Aktaa and D. Munz, Mater. Sci. Engr. A333 (2002) 351.

[8] J. P. Singh, B. Nair, D. Renusch, M. Sutaria, and M. Grimsditch, *Journal of the American Ceramic Society* (84[10]2385-93(2001)).

[9] Gell, M., K. Vaidyanathan, B. Barber, J. Cheng and E. Jordan, *Metall. Mater. Trans A,* 30A, 427-35 (1999).

[10] Evans, A. G., G. B. Crumley and R. E. Demaray, *Oxidation Met*., 20 [5/6], 193-216 (1983).