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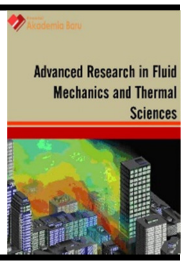

Comparison on Thermal Resistance Performance of YSZ and Rare-Earth GZ Multilayer Thermal Barrier Coating at 1250˚C Gas Turbine Combustor Liner

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Salmi Mohd Yunus[1,*], Azril Dahari Johari[2], Shuib Husin[1]

[1] TNB Research Sdn Bhd, Lorong Ayer Itam, Kawasan Institusi Penyelidikan 43000 Kajang Selangor, Malaysia
[2] TNB Repair and Maintenance Sdn Bhd, Level 23A, PJX-HM Shah Tower, No.16A, Persiaran Barat, 46050 Petaling Jaya, Selangor, Malaysia

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ABSTRACT

Thermal barrier coating (TBC) is used to provide thermal resistance to hot section components in advanced gas turbines. By applying TBC, even at high temperature the durability and efficiency of the turbines can be improved. Yttria stabilized zirconia (YSZ) is the most selected material as the top coat due to its low thermal conductivity and relatively high thermal expansion coefficient. Gadolinium zirconate (GZ) was found to be an alternative material to YSZ due to their good phase stability at high temperature and lower thermal conductivity than the typical YSZ. Multi-layer coatings of GZ/YSZ are being researched in order to take advantage of these materials and improve the durability of the gas turbine combustor liners. This work focused on the study of multilayer (GZ/YSZ) TBC processed by air plasma spraying (APS) and compared with the currently used, standard single-layer of YSZ coating in terms of thermal resistance. The constant variables for both TBC systems are the usage of the bond coat (NiCrAlY), the deposition parameter used and the thickness for the whole TBC system. This thermal resistance test was conducted using a custom-made furnace which imitate almost similar of the GE Frame 9FA combustor liner operating conditions. It was found that than the single layer of YSZ system performed 12 % better rather than the multi-layered TBC system at 1250˚C.

1. Introduction

In decades, high temperature gas turbine components are protected by thermal insulating material, so called thermal barrier coating (TBC) [1]. Those gas turbine components include shroud, combustor liner, transition piece, turbine blades and vanes [2-5]. Typical TBC system consists of a ceramic topcoat and a metallic bond coat [6]. By improving the heat resistance of the exposed gas turbine components, TBC benefits in improving the efficiency, increasing the inlet temperature and/or reducing the usage of cooling air [7]. One of the gas turbine components which typically

* *Corresponding author.*
E-mail address: salmi.yunus@tnb.com.my (Salmi M Yunus)

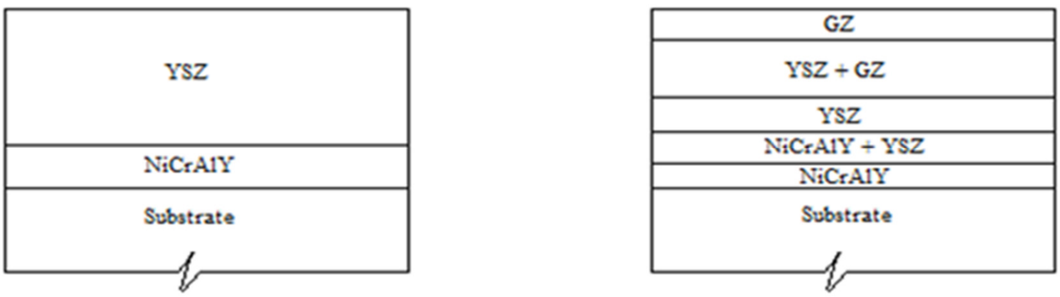
employing TBC is combustor liner with the exposed temperature is up to 1300 °C [3]. They are made of nickel- (Ni-) or cobalt- (Co-) based superalloy to withstand to this high temperature exposure [8]. The employment of typical TBC with the thickness range of 100-500 µm has reduced the surface temperature up to 170 °C [2,9-11].

Under this study, TBC was applied to protect the combustor liners internal surfaces which made of Ni-based superalloy, from high temperature environment of 1250 °C. Ni-based superalloy is a popular choice in gas turbine application due to its ability to withstand high operating temperature up to 1100 °C and resist to creep [2]. However, operating temperature of GE Frame 9FA combustor liner is even higher that reached the substrate melting point.

In TBC technology, yttria-stabilised zirconia (YSZ) is the most used top coat material [12]. It has many advantages such as high melting point which up to 2700 °C, low thermal conductivity, and good adherence when in contact with metallic substrate/bond coat [11,13]. Pure zirconia (Zr) experiences 5 % volume expansion at 1170 °C due to phase transformation [3]. This undesirable volume change is avoidable with the additional of yttria (Y_2O_3) thus stabilised the thermal barrier coating structure, where this produced TBC material so-called YSZ [2]. Recent technology in TBC is researching and developing the alternative materials for YSZ such as rare-earth zirconates. Theoretically, they have better properties than typical YSZ material such as lower thermal conductivity, longer cyclic life, lower sintering rate, etc. [12,14]. A drawback of these rare-earth zirconates is their low mismatch in thermal expansion coefficient thus their applications should be in multilayer system [15]. Gadolinium zirconate (GZ) is among the excellent candidates nowadays that being studied by others [14,16-18]. However, not only in the actual gas turbine application, literatures also revealed that no study on the oxidised GZ system has been made. There is a need to study their performance in high temperature exposures.

2. Methodology

Two TBC powders used in this study; typical YSZ and GZ. They were deposited onto Ni-based superalloy samples which similar to the actual GE Frame 9FA combustor liner material, via air plasma spray (APS) technique. The deposition parameter used was also similarly used in the actual gas turbine application, as tabulated in Table 1. The thickness of the samples was 5 mm. The thickness of the TBC systems which included the bond coat was 775±75 µm. Multilayer coating system was applied on the samples. For typical YSZ powder, two-layer system has been chosen (sketch in Figure 1a), which consists of bond coat and YSZ top coat. For GZ powder, 5-layer coating system has been chosen (sketch in Figure 1b) to improve the mismatch of thermal expansion between GZ and the bond coat [6]. Bond coat used for both systems was a metallic type of NiCrAlY.



(a) 2-layer TBC system (b) 5-layer TBC system

Fig. 1. Sketches of TBC systems used, where (a) for typical YSZ powder and (b) for GZ powder

Table 1
Parameter used for thermal barrier coating deposition

Parameter	Bond coat	Top coat
Spray distance, inches	3.5-4.0	3.5-4.0
Voltage, V	68-72	72-76
Current, A	550	575

The samples were oxidised via high-temperature heat treatment which at 1100 °C for 100 hours. The main objective was to characterise both TBC systems in long-term exposures, with less time and cost consumed. After the isothermal heat-treatment test, the samples were cooled down to ambient temperature inside the furnace to avoid thermal shock on the samples. At 1000 °C, aging effect is usually temperature-independent, thus this temperature is sufficient enough to age the samples [17].

A series of test was carried out on each TBC system. Microstructures were captured via Scanning Electron Microscopy (SEM). The microstructure changes and any difference between both TBC systems were discussed. These micrograph images had also been used to measure the porosity distribution in the TBC systems. General measurement of the porosity was carried out via Image J analyser software. Thermal resistance test was carried out via a custom-made furnace which had imitated the actual conditions of GE Frame 9FA combustor liner. The soaking temperature used was 1250 °C with the cooling air of 300 °C. The objective of the test was to determine the insulation property of the TBC systems in the actual gas turbine combustor liner's condition. The insulation property for both TBC coating systems was determined through their temperature reduction (using Equation 1). Higher temperature reduction indicated better insulation property of the TBC system. The recommended and reliable temperature reduction by TBC is about 170 °C [2,9-11].

$$\text{Temperature reduction, } \Delta T_{\text{TBC system}} = \Delta T_{\text{coated sample}} - \Delta T_{\text{uncoated sample}} \tag{1}$$

where,
$\Delta T_{\text{coated sample}} = T_{\text{inner surface with TBC}} - T_{\text{outer surface}}$,
$\Delta T_{\text{uncoated sample}} = T_{\text{inner surface}} - T_{\text{outer surface}}$

3. Results and Discussion

3.1 Evaluation on The Microstructures

Plasma sprayed coating has pores and cracks in microstructures [2,12]. This was similarly found as in Figure 2, where the microstructure of both TBC systems exhibited a huge number, random of pores and voids with a range of sizes and shapes. The large pores observed within the typical YSZ microstructure was probably induced by the unmelted powder particles during air plasma spray. For the GZ/YSZ system, the microstructure also exhibited smaller pores with an unclear, not sharp interface between the layers. This was due to the induction of each layer with the intermixed materials of its top and bottom layer [16]. Researchers found that the hairline cracks will be developed during the deposition of the feedstock ceramic particles onto the substrate, where they were cooled from their melting temperature to contact temperature6. This also supported the hairline cracks that occurred on the top coat/ceramic-contained region of both samples.

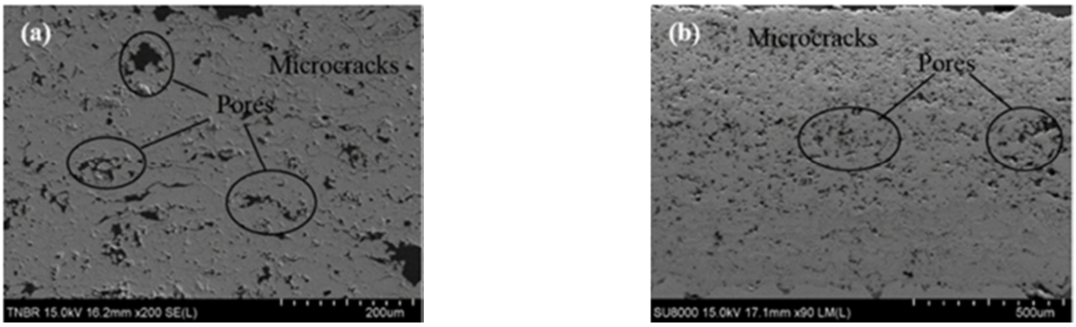


Fig. 2. Micrographs of the as-sprayed samples of (a) typical YSZ system, and (b) GZ/YSZ system

Isothermal heat treatment at the temperature of 1100 °C brought to the development of thermally growth oxides (TGO) in the metallic layer(s) and sintering in the ceramic layer(s). Referring to Figure 3, both oxidised microstructures exhibited TGO in the layer(s) that contained NiCrAlY. For typical YSZ system, the microstructure of this oxidised sample was more homogenous and denser which highly due to the sintering. In contrast with the oxidised microstructure of GZ/YSZ sample, the pores and microcracks seemed visible. The existence of those pores and microcracks hypothesised that the tested GZ/YSZ system will not perform as better as the typical YSZ oxidised system.

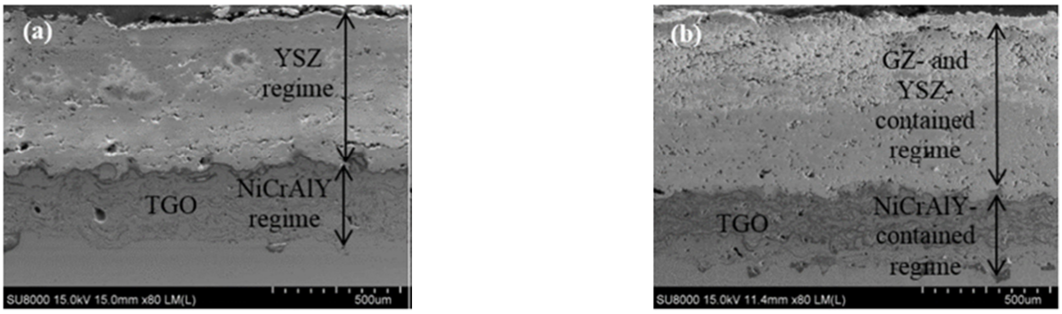


Fig. 3. Micrographs of the oxidised samples of (a) typical YSZ system, and (b) GZ/YSZ system

3.2 Evaluation on The Porosity Changes

TBC which produced via plasma spray technique has the porosity in the range of 3 – 20 % [2]. This has been found on the measured porosity of both as-sprayed samples as shown in Figure 4. After heat treatment applied, the porosity of typical YSZ system decreased while the porosity of GZ/YSZ system increased specifically in GZ-contained layers. These indicated that GZ-contained layers had experienced stress which might due to thermal expansion thus exhibited microcracks. This met an agreement with the study that carried out by other researcher where thick TBC system also tended to experience microcracks that parallel to the surface [6]. These findings were also relevant to the discussions made in their microstructure changes.

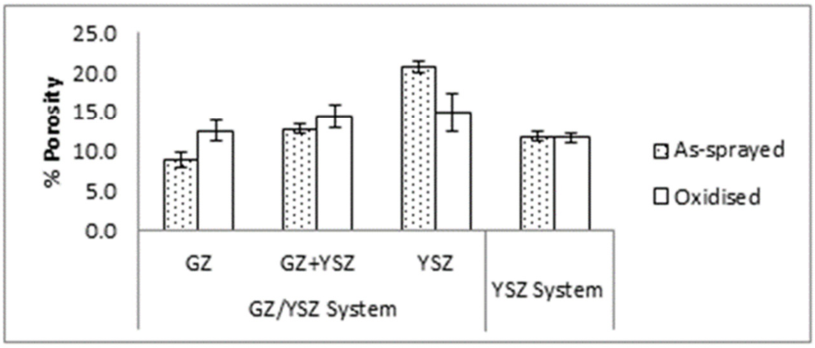


Fig. 4. Measurement of porosity on both samples in as-sprayed and oxidised conditions

3.3 Thermal Resistance Analysis

From Figure 5, the typical YSZ system was performed well as the temperature reduction had reached about 190 °C. In vice-versa, GZ/YSZ system only reached the temperature reduction of 145 °C. It was attributed to the microcracks that exhibited and highly expected will decrease the life of the system. As the most vital property, the low temperature reduction reached by the GZ/YSZ system; which even less than the recommended of 170 °C absolutely indicated that the typical YSZ system remain better in actual application of 1250 °C gas turbine combustor liner.

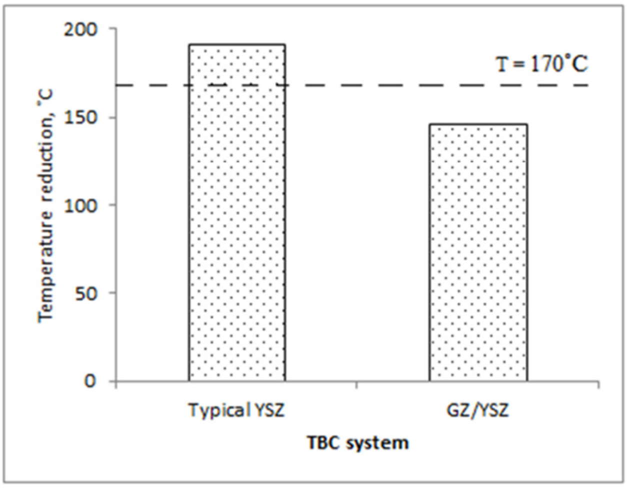


Fig. 5. Temperature reductions by both TBC systems at 1250°C

4. Conclusion

The selected TBC has been evaluated via microstructures changes, porosity and on the imitation of the actual gas turbine combustor liner's operating conditions. It was found that the YSZ system performed 12 % better than the multi-layered GZ/YSZ system at 1250 °C. As-sprayed condition of both samples was similar to the typical air plasma sprayed coatings but the performance of the oxidised samples was different. Oxidised GZ/YSZ sample experienced the exhibition of microcracks thus brought to the increment of porosity and lower temperature reduction of 145 °C, which 15 % worse than the recommended temperature reduction. Further study on the appropriate GZ/YSZ system in term of thickness, deposition parameter, etc., is needed before they are capable to be applied in the actual gas turbine application.

References

[1] Lee, Woo Y., David P. Stinton, Christopher C. Berndt, Fazil Erdogan, Yi-Der Lee, and Zaher Mutasim. "Concept of functionally graded materials for advanced thermal barrier coating applications." *Journal of the American Ceramic Society* 79, no. 12 (1996): 3003-3012.

[2] Khosravy el_Hossaini, M. *Review of the New Combustion Technologies in Modern Gas Turbines, Progress in Gas Turbine Performance, Edited by Ernesto Benini*. ISBN 978-953-51-1166-5, 268 pages, Publisher: InTech, Chapters published June 19, 2013 under CC BY 3.0 license DOI: 10.5772/2797, 2013.

[3] Beele, W., G. Marijnissen, and A. Van Lieshout. "The evolution of thermal barrier coatings—status and upcoming solutions for today's key issues." *Surface and Coatings Technology* 120 (1999): 61-67.

[4] Gurrappa, I., I. V. S. Yashwanth, I. Mounika, H. Murakami, and S. Kuroda. "The importance of hot corrosion and its effective prevention for enhanced efficiency of gas turbines." In *Gas Turbines-Materials, Modeling and Performance*. InTech, 2015.

[5] Dorfman, M., M. Stapgens, J. Medrano, and D. Sporer. "Takeoff with advanced coatings: Improving thermal protection through new material solutions." *Sulzer Tech. Rev* 3 (2013): 8-12.

[6] Koolloos, Martijn Frans Jan. "Behaviour of low porosity microcracked thermal barrier coatings under thermal loading." (2001).

[7] SwadŸba, L., G. Moskal, B. Mendala, and T. Gancarczyk. "Characterisation of APS TBC system during isothermal oxidation at 1100 C." *Archives of Materials Science* 758 (2007): 758.

[8] Gurrappa, I., and A. Sambasiva Rao. "Thermal barrier coatings for enhanced efficiency of gas turbine engines." *Surface and Coatings Technology* 201, no. 6 (2006): 3016-3029.

[9] MOSKAL, G., and A. ROZMYSLOWSKA. "Microstructure and Thermal Diffusivity of Ni (Co) CrAlY Powders for Bond Coat Applications." In *Thermal Conductivity 30: Thermal Expansion 18: Joint Conferences: August 29-September 2, 2009, Pittsburgh, Pennsylvania, USA*, vol. 30, p. 441. DEStech Publications, Inc, 2010.

[10] Mouritz, Adrian P. *Introduction to aerospace materials*. Elsevier, 2012.

[11] Xu, Huibin, and Hongbo Guo, eds. *Thermal barrier coatings*. Elsevier, 2011.

[12] Clarke, David R. "Materials selection guidelines for low thermal conductivity thermal barrier coatings." *Surface and Coatings Technology* 163 (2003): 67-74.

[13] Padture, Nitin P., Maurice Gell, and Eric H. Jordan. "Thermal barrier coatings for gas-turbine engine applications." *Science*296, no. 5566 (2002): 280-284.

[14] Hailin Zhang, Lei Guo, Yue Ma, Hui Peng, Hongbo Guo and Shengkai Gong. "Thermal cyclic behaviour of $(Gd_{0.9}Yb_{0.1})_2Zr_2O_7$/8YSZ gradient thermal barrier coatings deposited on Hf-doped NiAl bond coat by EB-PVD." *Surface & Coatings Technology* 258 (2014): 950 – 955.

[15] Bobzin, K., N. Bagcivan, T. Brögelmann, and B. Yildirim. "Influence of temperature on phase stability and thermal conductivity of single-and double-ceramic-layer EB–PVD TBC top coats consisting of 7YSZ, Gd2Zr2O7 and La2Zr2O7." *Surface and Coatings Technology* 237 (2013): 56-64.

[16] Ramachandran, C. S., V. Balasubramanian, P. V. Ananthapadmanabhan, and V. Viswabaskaran. "Influence of the intermixed interfacial layers on the thermal cycling behaviour of atmospheric plasma sprayed lanthanum zirconate based coatings." *Ceramics International* 38, no. 5 (2012): 4081-4096.

[17] Zhong, Xinghua, Huayu Zhao, Xiaming Zhou, Chenguang Liu, Liang Wang, Fang Shao, Kai Yang, Shunyan Tao, and Chuanxian Ding. "Thermal shock behavior of toughened gadolinium zirconate/YSZ double-ceramic-layered thermal barrier coating." *Journal of Alloys and Compounds* 593 (2014): 50-55.

[18] Limarga, Andi M., Samuel Shian, Mor Baram, and David R. Clarke. "Effect of high-temperature aging on the thermal conductivity of nanocrystalline tetragonal yttria-stabilized zirconia." *Acta Materialia* 60, no. 15 (2012): 5417-5424.