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Thermal properties of glass-ceramic bonded thermal barrier coating system

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Abstract: The thermal properties of a thermal barrier coating (TBC) system comprised of BaO–MgO–SiO_2 based glass-ceramic bond coating, 8% (mass fraction) yttria stabilized zirconia (8YSZ) top coating and nimonic alloy substrate were evaluated. The thermal diffusivity and thermal conductivity of the TBC coated substrate were lower than those of bare substrate and glass-ceramic coated substrate under identical conditions. The specific heat capacity, thermal diffusivity and thermal conductivity of the TBC coated substrate increase with the increase of the temperature. Further, it is observed that the thermal conductivity of the TBC system decreases with the increase in the top coating thickness.

Key words: glass-ceramic coating; thermal barrier coating; thermal properties; yttria stabilized zirconia

1 Introduction

Thermal barrier coatings (TBCs) are widely applied to protect the hot-section components of modern gas turbine engine from the aggressive environments. The oxidation resistance, thermal shock resistance and thermal insulation capacity of the TBCs are of primary importance among their thermo-mechanical properties related to the high temperature applications [1]. The basic function of a TBC is to restrict the heat transfer from the hot gas in the engine to the surface of the coated alloy component [2].

Generally, TBC system consists of a ceramic top coating, a metallic bond coating and a metallic substrate [3]. Usually, M-NiCrY type bond coating is applied to assist the adherence and stress relaxation. However, exposure of the TBC system to elevated temperatures leads to the development of a thermally grown oxide (TGO) layer between the bond coating and top coating [4]. TGO has a major influence on the TBC durability. As the TGO layer thickness increases with the operation time, high stresses are generated at the bond coating/TGO interface due to the volume increase, thermal expansion misfit and applied loads. As a consequence, crack initiates and propagates, leading to the spallation of the ceramic top coating, finally resulting in the failure of the TBC system [4,5]. Thus, the bond coating is the most critical component of the TBC system. The chemistry and microstructure of bond coating affect the durability through the structure and morphology of the developed TGO [6,7].

Glass-ceramic coatings possess excellent chemical inertness, low thermal conductivity, high temperature stability and superior mechanical properties. Because of the excellent combination of these properties, glass-ceramic coatings can efficiently be utilized to reduce high temperature degradation of the structural materials [8]. Further, glass-ceramic coating is also conceived as cheap but effective alternative thermal barrier coating. 3% yttria doped zirconia dispersed in a high temperature resistant alumino-borosilicate glassy phase showed good performance as a thermal barrier coating [9]. The inherent low thermal conductivity of the glass-ceramic based bond coating can reduce the metal substrate temperature and thereby protect the substrate from oxidation and creep failure. Therefore, glass-ceramics may be an ideal bond coating in a TBC system. Potential of glass-ceramics as good oxidation and thermal shock resistant bond coating in the conventional thermal barrier coating system has been already established [10,11].

The thermal properties of the TBCs have been extensively studied by the researchers as these coatings are used at the elevated temperatures [12–17]. The thermal insulation property of the TBCs is determined by their thermal conductivity, which plays an important role in the heat transfer processes [14]. In the present work, an attempt was made to carry out in-depth study for the

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evaluation of thermal conductivity of a glass-ceramic bonded TBC system.

2 Experimental

BaO−MgO−SiO_2 based glass-ceramic coating (thickness ~100 μm) was applied on the nimonic alloy (AE 435) substrate by conventional enameling technique. The glass and substrate composition has been reported elsewhere [10]. Nimonic alloy substrate with dimensions of 10 mm × 10 mm × 2 mm was used for the present work. 8% YSZ (8YSZ) powder was air plasma sprayed on the glass-ceramic coated substrates using a METCO-F4 plasma gun. The thermal spraying parameters for YSZ top coating are shown in Table 1 and the porosity of YSZ coating is 8%−12%. The thickness of 8YSZ top coating varies from 200 μm to 400 μm.

Table 1 Thermal spraying parameters for YSZ top coating porosity of YSZ coating

Spraying parameters	Value
Powder injection	Outside nozzle 6 mm
Power input/kW	40
Primary (Ar)/secondary (H_2) gas flow in plasma/(L·min^{-1})	35, 10
Carrier gas (Ar) flow in feeder nozzle/(L·min^{-1})	2.6
Stand-off distance/mm	120

Laser-flash technique was utilized to measure the specific heat capacity and thermal diffusivity of the uncoated, glass-ceramic and TBC coated substrates as a function of temperature using a thermal diffusivity measuring system (FLASHLINE^{TM}4010, Anter Corporation, USA). High intensity laser pulse (Nd:glass laser, average pulse width −300 μs) was absorbed at the front surface of the specimen and the temperature increase of the rear surface was measured by a thermocouple (type S thermocouple). The thermal diffusivity was determined by the shape of the temperature versus time curve at the rear surface. The specific heat capacity was determined by the maximum temperature indicated by the thermocouple and the thermal conductivity was estimated by the product of the thermal diffusivity, specific heat capacity and density [17]. Thermal diffusivity measurements were made in a vacuum chamber from the room temperature to 1000 °C. Prior to application of the laser pulse, the specimen was coated with gold and subsequently with graphite thin films on the surfaces on which the heating was conducted by the laser pulse and temperature increment was monitored. Coating was necessary to absorb the laser pulse. Coating also ensures the heat flow by conduction method.

3 Results and discussion

3.1 Microstructural characterization

Figure 1 shows the surface microstructures of nimonic alloy substrate, glass-ceramic bond coating and 8YSZ top coating. It can be seen that the surface microstructures of substrate, bond coating as well as top coating are almost devoid of any defects like pores and microcracks. Figure 2 demonstrates the fractured cross-sectional micrographs of 8YSZ top coating. The cross-sectional images show the single splat, splat/splat interface, inter-lamellar pore, globular pore, intra-splat crack and columnar structure of the top coating. Based on the microstructural observations, small pores and cracks are presented in the top coating.

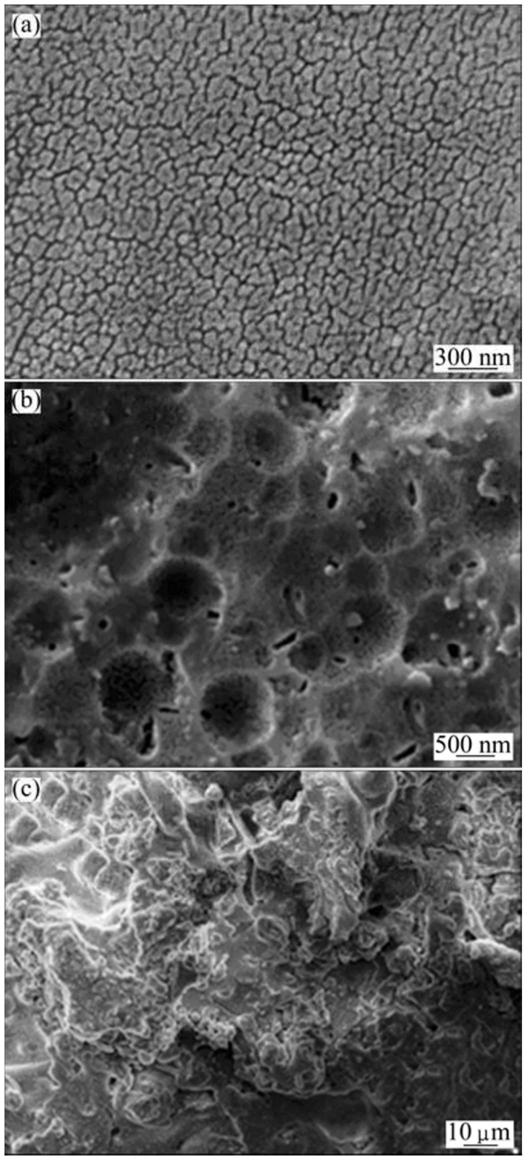

Fig. 1 SEM images of substrate (a), glass-ceramic bond coating (b) and 8YSZ top coating (c)