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Ceramics International 41 (2015) 11662–11669
CERAMICS INTERNATIONAL
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Protectiveness of Pt and $Gd_2Zr_2O_7$ layers on EB-PVD YSZ thermal barrier coatings against calcium–magnesium–alumina–silicate (CMAS) attack

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Received 6 February 2015; received in revised form 5 April 2015; accepted 22 May 2015
Available online 3 June 2015

Abstract

Thermal barrier coatings (TBCs) are susceptible to degradation caused by environmental deposits mainly composed of calcium–magnesium–aluminum–silicon (CMAS). In this work, the degradation of electron beam physical vapour deposition (EB-PVD) yttria stabilized zirconia (YSZ) TBC due to CMAS attack was investigated. To protect the YSZ coating, a Pt film and a $Gd_2Zr_2O_7$ (GZO) layer were deposited onto the YSZ coating surface by electroplating and EB-PVD, respectively. The coatings were heat treated at 1250 °C for 4 h with CMAS deposits, and their microstructure and chemical composition after CMAS attack were investigated. Electroplating a dense and defect-free Pt film on YSZ coating could provide effective protection from CMAS attack, but EB-PVD GZO coating was unable to prevent molten CMAS infiltration, mainly due to the large inter-columnar gaps. The associated mechanisms were discussed in detail.

Keywords: Thermal barrier coatings (TBCs); Yttria stabilized zirconia (YSZ); Calcium–magnesium–aluminum–silicon (CMAS); Pt film; $Gd_2Zr_2O_7$ layer

1. Introduction

Thermal barrier coatings (TBCs) are widely used to protect the hot-section components of gas turbines from hot gas and to improve the durability and energy efficiency of the turbine [1–3]. TBC systems typically consist of a metallic bond coat and a ceramic top coat. The bond coat provides corrosion and oxidation protection for the substrate and improves the bonding between ceramic top coat and substrate, and the ceramic top coat acts as a thermal insulation layer [3–7]. Currently, the industrial top coat material is 6–8 wt% Y_2O_3 stabilized ZrO_2 (YSZ). Among the methods for depositing the TBC, electron beam physical vapour deposition (EB-PVD) and plasma spraying (PS) are the two most important methods.

The operating conditions of TBC are extremely harsh. In addition to undergoing complicated thermal and mechanical loads, TBC also experiences damage from sand and dust which are ingested into the engine by intake air. The main components of the ingested particles are calcium–magnesium–aluminum–silicon (CMAS). At low temperatures, CMAS particles lead to erosive wear or local spallation of TBCs [8,9]. As temperature increases, CMAS melts and penetrates into the coating, which causes TBC degradation and leads to the loss of insulation efficiency [10–13].

Much attention has been paid to the TBC degradation caused by CMAS deposits. Evans et al. have studied the delamination mechanisms of TBC due to CMAS attack [14]. Hitchman et al. have pointed out that thermal sprayed TBC is susceptible to CMAS attack because of its porous nature [15]. Chen et al. have calculated the energy release rate of a propagating delamination crack by finite element analysis [16]. Witz et al. have investigated the chemical reaction between CMAS and TBC at high temperatures, and focused on the spallation failure resulting from thermal

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http://dx.doi.org/10.1016/j.ceramint.2015.05.128
0272-8842/

stress [17]. Wellman et al. have estimated minimum levels of CMAS required to initiate damage [18]. Krämer et al. have reported that the thermo-chemical interaction between CMAS and YSZ TBC involves dissolution and re-precipitation of metastable tetragonal phase [19]. Our previous studies have shown that CMAS rapidly penetrates to YSZ coating at 1250 °C, causing thermochemical interaction and accelerated sintering of the coatings [20–22]. YSZ dissolves in the molten CMAS and reprecipitates in the form of globular particles depleted in Y, the phase transformation would occur during cooling. Because of the accelerated sintering, the porosity in the coating is significantly reduced, leading to a large degradation in the thermal barrier effect [20–22].

Great efforts have been made to protect TBC against CMAS attack. Julie et al. have shown that the penetration of molten ash in PS $Gd_2Zr_2O_7$ (GZO) or YSZ+Al+Ti TBCs could be largely suppressed by forming an impervious and stable crystalline reaction layer [23]. Krämer et al. have found that the CMAS infiltration in EB-PVD GZO TBC could be arrested by rapid filling inter-columnar gaps with crystalline reaction products [24]. Our previous study has indicated that a dense sealing layer can be formed on the PS $La_2Ce_2O_7$ coating, which effectively prevents CMAS from further penetration. Rai et al. have investigated various CMAS-resistant materials, and pointed out that a reglazed dense Pd film on the coating could provide substantial protection from CMAS attack [26].

According to the patents presented by Hasz et al., the protective coatings against CMAS attack can be classified into three types, i.e. impermeable, sacrificial, and nonwetting types [27–29]. Interestingly, Platinum has the features of both impermeable and nonwetting. It has been reported that GZO coating can stop CMAS infiltration effectively [24]. In view of the above facts, Pt and GZO were selected as protective materials in the present work. Pt film was produced onto EB-PVD YSZ coating by electroplating, and GZO layer was deposited onto YSZ coating by EB-PVD. The potential properties of the Pt film covered YSZ coating and the

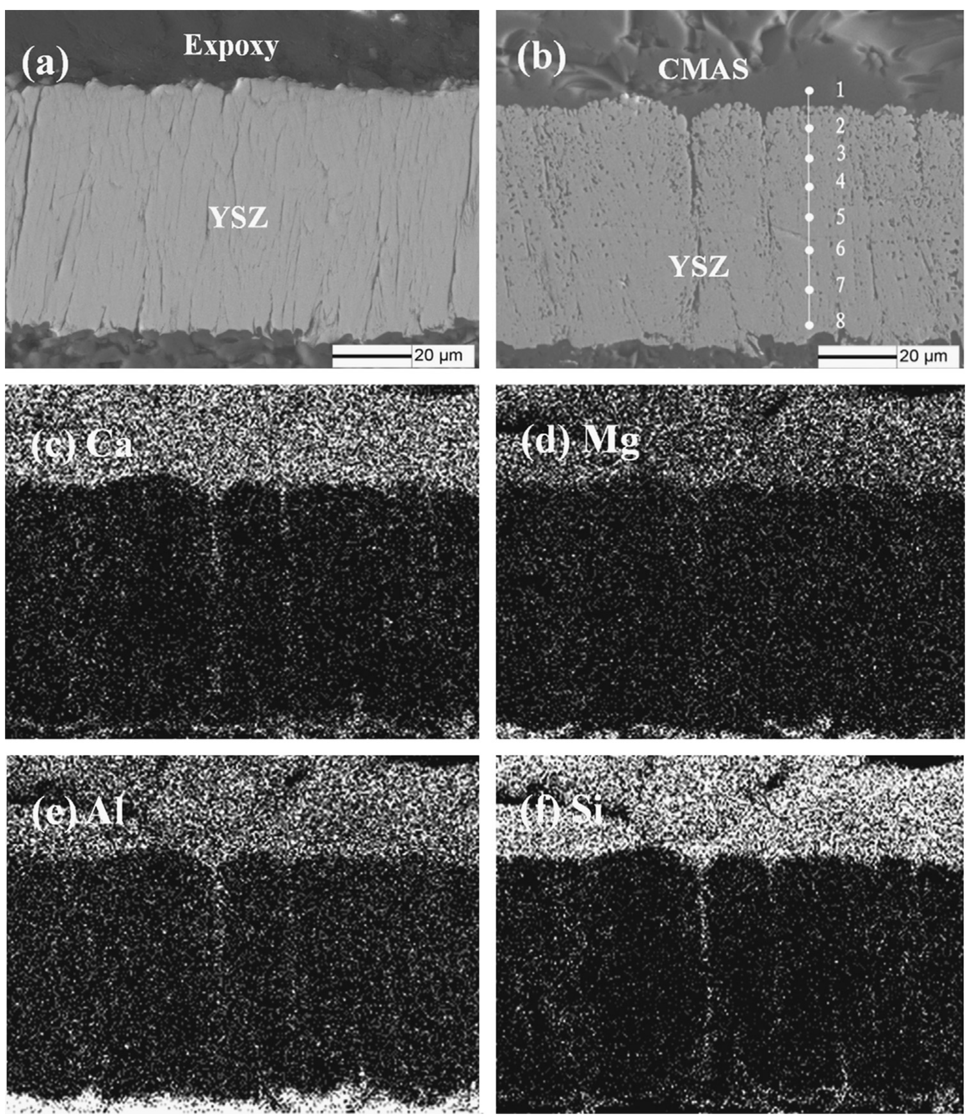

Fig. 1. Cross-section images of YSZ coatings after heat treatment at 1250 °C for 4 h without (a) and with (b) CMAS deposits, (c)–(f) show the element maps of the YSZ coating after CMAS attack.