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Nano-structured yttria-stabilized zirconia coating by electrophoretic deposition

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ABSTRACT

The most important role of thermal barrier coatings is to reduce the temperature of the substrate in high temperature applications. Nano particle zirconia might be a suitable choice for improving the efficiency of thermal barrier coatings. Nanostructured coatings have lower thermal conduction, higher thermal expansion and lower dimensional variations at higher temperatures in comparison with the microstructured coatings. Electrophoretic deposition has been preferred for thermal barrier coatings due to its simplicity, controllability and low cost. In the present study, three different suspensions of ZrO_2–8 wt%Y_2O_3 (40 nm) made with ethanol, acetone and acetyl acetone were used. Electrophoretic deposition was conducted at a fixed voltage of 60 V for 120 s on aluminized Inconel 738-LC, and then heat treated at 1100 °C for 4 h in air atmosphere.

The coating morphology and elemental distribution were studied using scanning electron microscopy. It was observed that suspension media have an important effect on the quality of the final product. Acetyl acetone showed better dispersion of particles than the other two media. Consequently, deposition from acetyl acetone resulted in uniform and crack-free layers while those from ethanol and acetone were completely non-uniform due to agglomeration and low viscosity, respectively.

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1. Introduction

Thermal barrier coatings (TBCs) are used for high temperature applications such as in steam turbines, jet gas turbines, and combustion chambers. The most important role of TBCs is in reducing the working temperature of substrate (Fig. 1a). TBCs are ceramic materials, along with an intermediate layer known as bond coat (BC), which are mostly used on superalloys. These coatings have been widely used since 1980s. Fig. 1b shows a schematic of turbine blade coated with a bond coat and TBC materials. The bond coat is used for better adhesion between the substrate and the ceramic coating, protection of substrate against oxidation and hot corrosion, and providing a suitable transition between the thermal expansion coefficients of ceramic coating and metallic substrate [1–3]. As for the TBCs materials, 8 wt%Y_2O_3 stabilized zirconia (8YSZ) has been reported as the most desirable ceramic coating [4].

Nanostructured TBCs have recently been used instead of microstructured coatings due to their superior physical properties, e.g., lower thermal conductivity and enhancement of thermal expansion coefficient [5]. Nanostructured zirconia has also been used as TBCs material due to the lack of dimensional variations caused by allotropic changes in upper temperatures [6]. Jing Wu et al. [7] found that nanostructured TBCs have lower thermal diffusion (0.3–0.5 mm^2/s) in comparison with the microstructured ones (0.5–0.7 mm^2/s) in the temperature range of 298–1473 °C. They have reported that nanostructured coatings can cause an extensive temperature variation between internal and external layers [7].

TBCs are usually deposited using plasma spray [8] and vapor deposition techniques [9]. Recently, electrophoretic deposition (EPD) has been recommended due to its simplicity, low cost, no restriction for coating complicated samples, thickness controllability and uniformity of the product [10,11]. Electrophoresis is defined as the movement of charged particles in the presence of an electrical field. In EPD, colloidal ceramic particles are deposited on a

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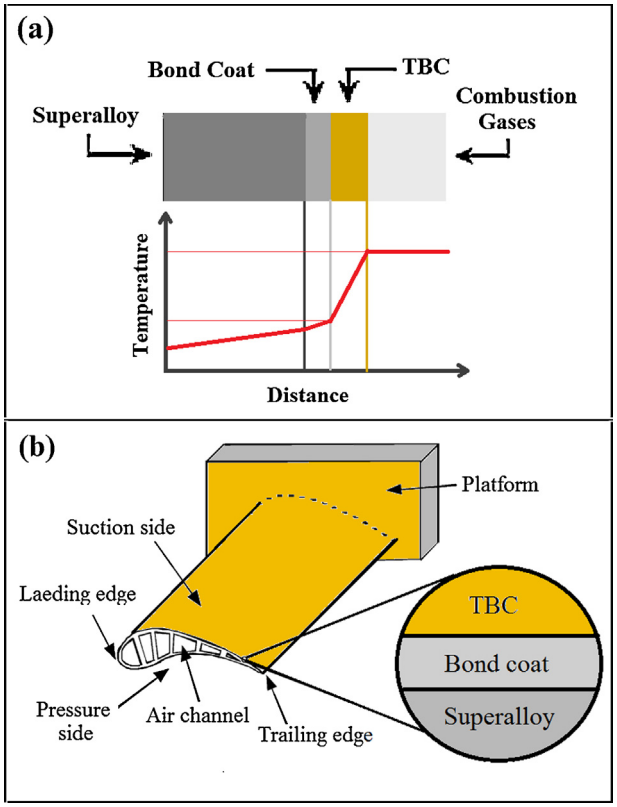

Fig. 1. (a)A schematic of the TBC performance for reduction of the temperature of metallic substrate. (b) Schematic of turbine blade containing intermediate and thermal barrier coating.

conductive substrate in an electric field. Electric field moves charged particles toward the opposite electrode where deposition takes place. Generally, EPD includes two processes, i.e., electrophoresis and precipitation. Precipitation is the formation of a solid condensed bulk [12]. Achieving a successful coating by EPD depends on controlling the suspension media characteristics like the suspension stabilization, particle size, particle concentration, conductivity and deposition parameters of voltage and time [13].

The major limitation of EPD process is the low cohesion of green coating. This limitation may be ameliorated by subsequent sintering procedure. The application of nano-particles not only makes a suitable condition for production of nano structured coatings, but also it reduces the sintering temperature in comparison with samples coated using micro-particles [14]. However, high surface area of nano-particles enhances the tendency of particles to join together in the suspension and make agglomerates. Then the agglomerates reduce the probability of coating to become uniform. Therefore, controlling the size of agglomerates plays an important role in the production of a uniform dense coating. Controlling the size of agglomerates in EPD requires selection of a suitable suspension medium [15].

The aim of this study is electrophoretic deposition of 8YSZ coating on Inconel superalloy substrate.

2. Materials and methods

2.1. 8YSZ powder synthesis

Nano-powder of 8YSZ was synthesized via Combustion Gel Method as following.

Table 1
Optimum composition for powder cementation process.

(wt%)	Composition of powders	
	Grain size (μm)	Raw materials
15	50 μm	Al (99.9%, Merck)
4	–	NH_4Cl (99%, Merck)
81	30 μm	Al_2O_3 (99%, Merck)

$ZrOCl_2{\cdot}8H_2O$ was dissolved in nitric acid producing zirconium oxy-nitrite:

$$ZrOCl_2{\cdot}8H_2O + 2HNO_3 \rightarrow ZrO(NO_3)_2 + 8H_2O + 2HCl$$

Y_2O_3 was dissolved in nitric acid while heating and stirring producing yttrium nitrite:

$$Y_2O_3 + 6HNO_3 + 3H_2O \rightarrow 2Y(NO_3)_3 + 6H_2O$$

In these reactions, water was added to the reaction chamber in order to optimize the dissolution process.

The two nitrides produced were mixed while heating and stirring during which glycine was added to the mixture for combustion reaction to take place. It is important to note that glycine reacts with each of $ZrO(NO_3)_2$ and $Y(NO_3)_3$ as:

$$ZrO(NO_3)_2 + 10/9NH_2CH_2COOH \rightarrow ZrO_2 + 20/9CO_2 + 14/9N_2 + 25/9H_2O$$

$$2Y(NO_3)_3 + 10/3NH_2CH_2COOH \rightarrow Y_2O_3 + 20/3CO_2 + 14/3N_2 + 25/3H_2O$$

Stoichiometric amount of each compound was added for obtaining stoichiometric final product [16–18]. After completion of the gel combustion reaction a gray spongy gel remained in the chamber. The spongy mass was then powdered and calcined at 700 °C.

2.2. Aluminizing (BC)

Aluminized coating, to be used as the BC, was produced using cementation process. High activity aluminum process was utilized for coating the BC layer. According to Mevrel [19] and Meier et al. [20], the optimum powder products as shown in Table 1 was chosen. Powder cementation was done in a tube furnace of Argon atmosphere at 850 °C for 90 min.

2.3. EPD cell and suspension preparation

Three suspensions were prepared using ethanol, acetone and acetyl-acetone solvents as reported in Table 2. Three grams of 8YSZ were added to 100 ml of each solvent. 0.1 g/L of CoO was added as sintering aid agent [21]. Moreover, 0.6 g/L iodine was added as a dispersive agent. Solvents were stirred for 24 h on a magnetic stirrer (Alfa D-500, Iran) and 4 h in an ultrasonic bath (Hielscher UP 100H, Ultrasound Technology, Germany). Conductivity and operational pH of suspensions were measured using 712 conductometer, and 827 pH lab, (both Metrohm, Switzerland).

The electrophoretic cell had a 20 mm × 10 mm × 2 mm plate of stainless steel as anode and Inconel 738-LC as cathode set 15 mm apart. The surfaces of electrodes were polished and then cleaned with acetone and alcohol in the ultrasonic bath. The EPD process was performed at 60 V (DC power supply Mastech, HY30001E, 9225, USA) for 120 s. Variations in electrical current was monitored using a dual display multi-meter (Escort, 3146A, Taiwan) during deposition process. Samples were dried in air atmosphere for 24 h after the completion of coating process.

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