Characterization of Dc Plasma Spray Torch and Synthesis of Lanthanum Zirconate for Thermal Barrier Coatings by Ball Milling Method

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Abstract

The Electrothermal efficiency of the DC plasma torch was measured by using energy balance equations. The torch was operated at power levels from 4 to 40 kW in non-transferred arc mode. The plasma torch input power, flow rate of primary gas were optimized for better electrothermal efficiency. Plasma torch has various interesting features such as protective coating to prevent degradation, extremely high temperatures, low environmental impact, short processing time which makes suitable technique for synthesizing composite materials. Thermal barrier coatings (TBCs) are one of the most advanced high temperature protective coatings and being widely used in aeronautic, motor industry and heat power station for their good performance like thermal barrier and oxidation resistance. Recently yttria partially stabilized zirconia (8YSZ) is used as the commercial materials for TBCs applications. However, the major disadvantage of YSZ is the limited operation temperature about 1200 °C for the long-term applications. It is terminate us to identify new and novel materials that can work at higher temperature. Among the interesting candidates for TBCs, Lanthanum Zirconate (LZ) has been proposed as a promising TBCs material for its high melting point, more stable structure and lower thermal conductivity than YSZ. In the present work, LZ was synthesized by method of planetary ball milling. For LZ synthesis, the mixture of La_2O_3 *and* ZrO_2 *powders with 1:2 mole ratios were ball milled for 24 hours. Subsequently, the structural, phase formation and morphological studies were analyzed by XRD and FESEM.*

Keywords: DC plasma spray torch, electrothermal efficiency, $La_2Zr_2O_7$

Introduction

Different types of DC plasma torches operating at power levels between 2 to 6000 kW are used for plasma processing of materials. For spray coating of materials, argon is commonly used as plasma forming gas. The material to be coated will be fed into the plasma jet in the form of powder particles; the particles get melted and projected to impinge on the substrate to form a coating. The thermoelectric efficiency and thermal conductivity are important properties in plasma spray process. Efficiency depends on several parameters such as torch design, plasma gas flow rate, nature of plasma gas, torch input power etc. The torch was operated at power levels from 4 kW to 40 kW. At each power level, total gas flow rate was changed and the properties studied [1].

Pyrochlore-type $La_2Zr_2O_7$ is one of the rare earth zirconate and well-known of its catalytic properties, high melting point (2300 ºC), good phase stability, low thermal conductivity (1.56 W m^{-1} K^{-1}), not oxygen-transparent and very low sintering ability [2,3]. It as a cubic pyrochlore structure which allows operation temperature up to 2200 □C before any phase transformation occurs [4,5]. In view of these remarkable properties, this rare earth oxide has recently found many interesting industrial applications including thermal barrier coating (TBC) [6]. The synthesis of La2Zr2O7 has been achieved by many methods.

Methodology

Electrothermal Efficiency

The electrothermal efficiency of a plasma torch is defined as the percentage of the electric power input to torch, contained in the plasma jet [7]. The electrothermal efficiency of the non-transferred DC plasma torch was calculated by using the energy balance equations. Efficiency is denoted by η is given below,

$$\text{Efficiency } \eta = \left[IP - \frac{Q_{loss}}{IP} \right]$$

Where, IP is the input power to the torch and Q_{loss} is the power dissipated through cooling water.

$$Q_{loss} = 4.18 \times C_p \times V\,(T_2 - T_1)$$

Where, 4.18 is the conversion factor for converting cal/s into watts, C_p is the specific heat capacity of water (1cal/cm^3), V is the amount of cooling water flow rate (cm^3/s), T_1 and T_2 are inlet and outlet temperatures respectively. Electrothermal efficiency was calculated as a function of input power at selected argon gas flow rates.

Experimental Procedure

In this work, commercially available lanthanum oxide (La_2O_3) and zirconium oxide (ZrO_2) were used as raw materials to prepare lanthanum zirconate. The mixture of La_2O_3 and ZrO_2 in the mole ratio of 1: 2 was milled for 24 h with corundum ball mill media by using planetary mill (Insmart, India). The ball to powder weight ratio was maintained at 10:1. The volume of the jar was around 250 ml. The milled powder were sintered at various temperatures 1100 □C and 1400 □C for 4 h using an electric furnace.

La2O3 + 2ZrO2 → La2Zr2O7

Fig. 1 Experimental set-up in a planetary ball milling

Characterization

The crystal structure and phase purity of the LZ powders were examined by X-ray Powder Diffraction (XRD). The overview of the morphology was analysed by using Field Emission Scanning Electron Microscope (FE-SEM).

Results and discussion

Electrothermal Efficiency

The electrothermal efficiency was calculated as a function of input power at selected argon gas flow rates. Efficiency decreases with increases in power from 5kW to 35kW is observed. Efficiency was 72%, 72% and 79% at 7kW power level for primary gas flow rates 20, 25 and 30lpm respectively. We observed that higher Efficiency is 79% at 30lpm than 20, 25lpm gas flow rates. Further it is seen that efficiency is 61, 62 and 65% at higher input power is 30 kW for primary gas flow rates 20, 25 and 30lpm respectively. The same was observed at all different input power levels. The variation of electrothermal efficiency with increase in input power at various argon gas flow rates is shown in Fig.2.

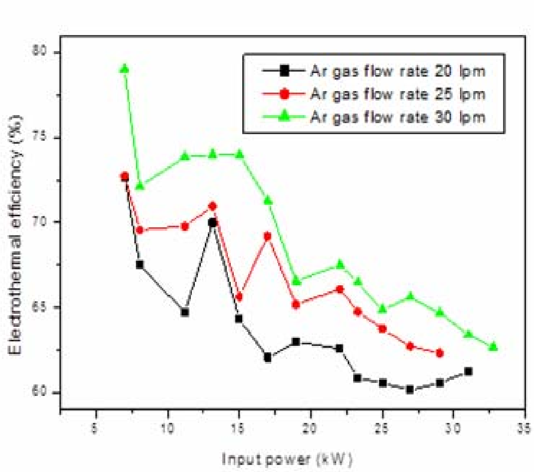

Fig.2 Variation of electrothermal efficiency with increase in input power at different argon gas flow rates

XRD Analysis

Fig. 3 shows the XRD patterns of the samples prepared at1100 ^{0}C and 1400 ºC for 4 h, to determine the crystalline phases. It is reported in Ref. [5] that the binary oxides of rare earths with zirconia have two types of structures, i.e. pyrochlore and fluorite. The fully crystallized LZ as a pyrochlore structure which is very similar to that of the fluorite structure and the two weak peaks of 2è between 36º peak of [3 3 1] and 46º peak of [5 1 1] are the indication of pyrochlore structure [6,8]. Which implied that LZ powders had a phase-transition when the temperature reached to 1400 ºC. The diffraction peaks can be readily indexed to the pyrochlore crystal system $La_2Zr_2O_7$ (JCPDS: 73-0444). As shown in the magnified peak of [2 2 2] and [4 0 0] the peaks of LZ powders shift to the low degree side with the increase of temperature, implying that the lattice parameter increases with the increase of the nano-grain size.

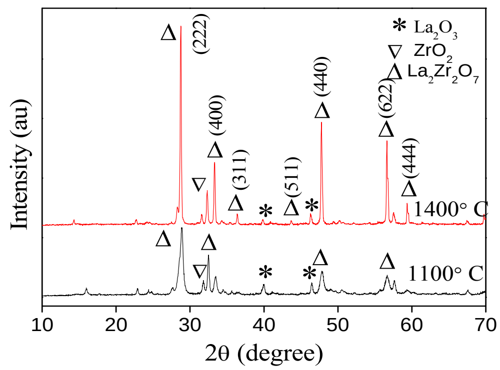

Fig. 3 XRD profiles of the powders after sintering at 1100 □C and 1400 □C for 4 h

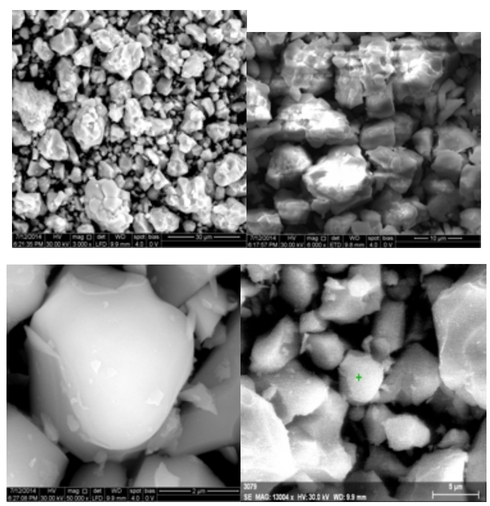

Fig.4 SEM image of $La_2Zr_2O_7$ powders sintering at 1400 ºC for 4 h

The morphology of as-prepared $La_2Zr_2O_7$ particles has a blocky irregular shape (Fig. 4). It is also interesting to see that each particle surface contains a large number of pores [9].

Conclusions

Electrothermal efficiency of the DC plasma spray torch was studied by using energy balance equation. Lanthanum zirconate was successfully synthesized by ball milling method. This method is easier, low cost and simplicity which is dominant the other methods of synthesis. The synthesis condition for Lanthanum zirconate is optimized and its morphological analysis implies that after milling the size of the particles are reduced greatly. By further processing, the process parameters can be optimized such that it can be used for the application of thermal barrier coating using the same method. We can use this composite which acts as a good thermal barrier on the coated material.

The procedure is facile and suitable for the synthesis of $La_2Zr_2O_7$ powders, and the most important thing is that it will be an excellent method for the preparation of other pyrochlore type of rare earth zirconate ($Re_2Zr_2O_7$, Re = rare earth).

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