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Zircon dissociation in air plasma through a low power transferred arc plasma torch

S. Yugeswaran[a], P.V. Ananthapadmanabhan[b,*], L. Lusvarghi[c]

[a]Centre for Advanced Coating Technologies, University of Toronto, Toronto, Ontario, Canada M5S 3G8
[b]Laser and Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai 400085, India
[c]Department of Engineering, University of Modena and Reggio Emilia, Via Vignolese, 905, 41125 Modena, Italy

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Abstract

Thermal plasma dissociation offers a convenient and attractive route to prepare zirconium oxide from zircon mineral. Transferred and non-transferred arc plasma torches have been used to study zircon dissociation. The major thrust has been to accomplish complete dissociation and make the process simpler and cost effective. Technologically, this has been attempted in argon-fired plasma reactors using higher electrical power. The present work reports a cost effective low power transferred arc plasma (TAP) processing method for dissociating zircon by using air as the plasma forming gas. Phase composition and microstructure formation of the dissociated zircon were examined by XRD and SEM with EDX. Experimental results showed that the torch input power and processing time strongly influenced the dissociation percentage as well as the microstructure formation. Further, obtained results revealed that the air plasma medium significantly improved the percentage of zircon dissociation rather than argon plasma medium at 10 and 15 kW power levels. The air plasma gives complete zircon dissociation at 10 kW power with 5 min of processing.

Keywords: Dissociation; Microstructure; Plasma torch; Transferred arc; Zircon

1. Introduction

Zirconia (ZrO_2) is used in refractories, pigments, colors, glazes, abrasives and for structural applications in hot extrusion dies, wire drawing dies, cutting tools, automotive engine components and innumerable new areas which are increasing day by day. Zirconia is the starting material for the production of zirconium metal and zircalloy, which is used in the nuclear industry [1]. It is prepared from minerals through various kinds of physical and chemical processes [2–4]. Among the available natural resources, zircon ($ZrSiO_4$) is one of the potent resources for zirconia, zirconia based composites and glass productions [5,6]. Zircon dissociates into ZrO_2 and SiO_2 when heated to temperatures above 1676 °C [3]. Recombination of zirconia and silica to form zircon can be prevented by rapid quenching of the dissociated products. This can be conveniently achieved by thermal plasma processing. Thermal plasma dissociation of zircon and studies on plasma dissociated zircon (PDZ) have been investigated by many authors [7–11]. Thermal plasma processing has several distinct advantages over conventional methods by virtue of the high energy density and high temperatures available in plasma reactors, possibility to control the processing atmosphere, enhanced reaction kinetics, environmental-friendly nature of the process, the rapid quench rate preventing back reaction and adaptability to process a variety of materials.

The first successful preparation of zirconia by plasma dissociation of zircon on a pilot-plant scale was demonstrated by Wilks et al. [12,13], who used a three-phase arc furnace fitted with carbon electrodes for production of zirconia from zircon sands. Ananthapadmanabhan et al. [14,15] have investigated the parametric studies on the plasma processing of

*Corresponding author.
E-mail address: pvapadmanabhan@gmail.com
(P.V. Ananthapadmanabhan).

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Indian zircon. The experiments were carried out in a specially developed non-transferred arc plasma torch based plasma chemical reactor. The authors pointed out that the dissociation percentage was strongly affected by torch input power, plasma and carrier gas flow rate, and location of powder feed port. During the same period, Syamaprasad et al. [16] studied the preparative and microstructural aspects of plasma-dissociated Indian zircon prepared through a transferred arc plasma torch based reactor (20 kW). The process parameters were optimized for achieving high degree of dissociation at zircon feed rate of 4–5 kg/h. The authors reported that they could achieve 90% dissociation with phase separation (ZrO_2 and SiO_2). Yuan et al. [17] produced zirconia from zircon through a 150 kW plasma rotating furnace with N_2 as the plasma forming gas. They studied the effect of furnace temperature, processing time and carbon content on the dissociation process. Similarly, sillimanite ore was converted into mullite, alumina and silicon carbide through a transferred arc plasma torch by a carbothermal reduction route [18].

In the present work, zirconia was prepared from zircon through low power transferred arc plasma (TAP) processing. The unique feature of the process is that it uses air as the plasma forming gas with a view to make the process cost-effective because argon, which is usually used, is quite expensive. The present investigation was focused on optimizing the torch operating parameters involved in the process for completely removing silica *in situ*. X-ray diffraction (PW Philips with CuKα radiation), scanning electron microscopy (Philips XL40) and Energy dispersive X-ray spectroscopy (INCA, Oxford Instruments) were used to characterize the phase, extent of dissociation and microstructure. The dissociation percentage (DP) of the processed zircon was estimated by the following expression [10]:

$$\mathrm{DP}\ (\%) = \frac{I_b}{I_Z + I_b} \times 100 \qquad (1)$$

where I_z and I_b are the intensities of the most intense diffraction peaks of zircon and zirconia respectively.

2. Experimental set up and procedure

The low power transferred arc plasma torch used in the present study is shown in Fig. 1. The torch consists of a graphite bowl (diameter; 70 mm, height; 100 mm), which served as the anode. The top side diameter of the anode is 60 mm and the bottom side diameter is 40 mm. The bottom of the anode was connected to the positive terminal of the power supply. The graphite cathode is 250 mm long and 50 mm in diameter with a 5 mm central hole and conical tip at one end. The top of the cathode was connected to the negative terminal of the power supply through a water cooled hollow brass cylinder (600 mm length) fitted with flanges and suitable mechanism for up/down movement. Plasma forming gas was injected through the 5 mm central hole in the graphite cathode. The end of the cathode tip has a central hole (5 mm) and 2 mm holes (4 numbers) at the sides in order to ensure the uniform distribution of plasma forming gas.

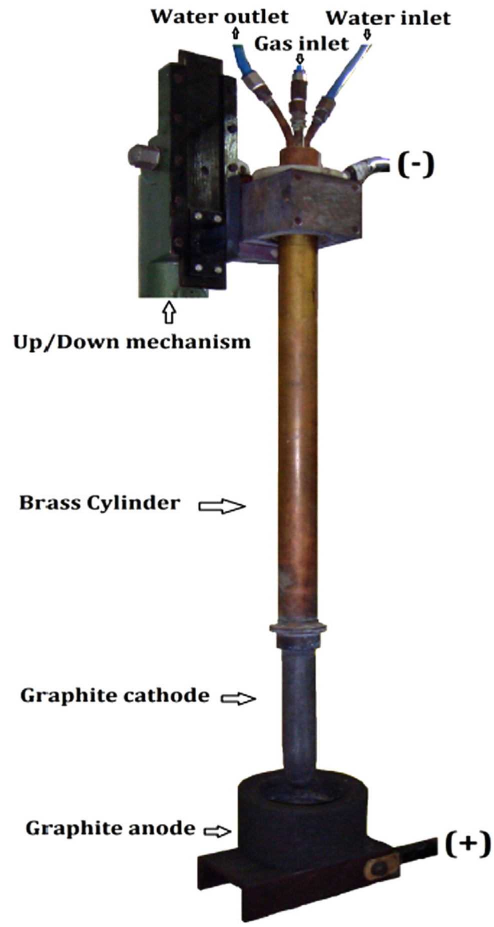

Fig. 1. Low power transferred arc plasma torch.

A 25 kW IGBT based DC power supply was used for generating the plasma. The plasma arc was initiated between the electrodes by high frequency pilot arc ignition system. Raw zircon powder was kept in the anode bowl. The plasma arc was struck initially between the cathode tip and the wall of the graphite anode and then slowly moved to all parts of the anode crucible for a few minutes duration until the zircon powder melted. The resulting hemispherical shaped molten slag was cooled by forced air for about 10 min duration and the product was characterized by XRD, SEM and EDX. Zircon dissociation was carried out at different TAP operating conditions and the range of operating parameters is presented in Table 1. In order to avoid electrode erosion and damage, the entire experiment was carried out intermittently with proper cooling.

3. Results and discussion

3.1. Raw powder

Commercially available Indian zircon was used for the present study and it contained 62 wt% ZrO_2, 35 wt% SiO_2, 1 wt% Al_2O_3, 0.15 wt% TiO_2 and 0.015 wt% Fe_2O_3. The XRD pattern of the raw zircon powder is shown in Fig. 2. All the diffraction peaks corresponding to zircon can be identified. The morphology and particle size distribution of the raw zircon