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Transferred arc plasma processed mullite from coal ash and bauxite

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

[a] Joining and Welding Research Institute, Osaka University, 11-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

[b] Laser and Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai, 400 085, India

[c] Department of Materials and Environmental Engineering, University of Modena e Reggio Emilia, Via Vignolese, 905, Modena, 41100, Italy

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Abstract

Coal ash disposal is one of the main problems in thermal power plant unit. Currently, a number of waste management systems are being tried for effective disposal of coal ash. In this paper, coal ash from thermal power plant unit was successfully utilized for synthesis of mullite ceramic by using transferred arc plasma processing (TAP) technique. For this purpose, bauxite was added with coal ash by 0, 25, 50 and75 weight ratio. The compositions were thoroughly mixed by ball milling and were melted in the transferred arc plasma torch at 10 kW input power level for 3 min. Argon was used as plasma forming gas. The phase and microstructure formation of the melted samples were investigated by XRD and SEM images. The results show that the additions of bauxite greatly influenced the phase formation of mullite during the processes.

Keywords: D. Mullite; E. Refractories; Coal ash; Arc plasma

1. Introduction

The possibility of utilization of industrial waste materials such as fly-ash, red mud rejected from aluminium industry, mud from hydrometallurgy zinc plants, etc. has assumed increased research and development thrust. Development of new glass–ceramic products by re-use of fly-ash from domiciliary waste incinerators and coal power plants has been the subject of many investigations [1–9]. Conversion of coal ash to ceramic bricks and zeolites has been studied by various investigators [6–10]. A number of researchers have used coal ash for devitrifying bulk glass samples by a two-stage heat treatment. However, all these conventional methods take long time to produce the composites and also their power consumption is high.

Transferred arc plasma processing is an effective and efficient technology for melting and vitrification of hazardous wastes due to the high temperatures and energy density available in transferred arc plasma (TAP) torch. The present paper deals with transferred arc plasma processing of coal ash to produce mullite-based ceramics for high temperature applications. Mullite ceramics have been extensively studied because of their excellent properties of high melting point (1830 °C), moderate thermal expansion coefficient, high resistance to thermal shock, good chemical stability in various corrosive environments, low thermal conductivity, low dielectric constant, excellent creep resistance and sufficient mechanical strength [11].

There are numerous advantages of the application of TAP for processing of materials and waste utilization. The process is characterized by extremely high temperatures (up to 20,000–30,000 K), excellent arc stability and low environmental impact (low oxides emissions, low percentage of ultra-fine powder). Another advantage of the process lies in the simplicity of generation and control. High power density allows high production rate with evident time savings [12–15]. Also, it is highly cost effective compared to the conventional methods. In this study, coal ash waste from thermal power plant was successfully utilized to prepare mullite ceramic.

2. Experimental procedure

The coal ash used in this investigation was obtained from the Neyveli Lignite Corporation (NLC), Tamilnadu, India and the bauxite was purchased from Carborundum Universal (CUMI) India (P) Ltd. The phase and chemical compositions of the coal ash and bauxite were analyzed by X-ray diffraction (XRD) and

* Corresponding author. Tel.: +81 6 6879 8694; fax: +81 6 6879 8694.
E-mail address: kobayasi@jwri.osaka-u.ac.jp (A. Kobayashi).

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Table 1
Chemical composition of raw materials.

Constituents	Bauxite	Coal ash
Al_2O_3	57.5	28.97
SiO_2	5.1	60.44
TiO_2	6.4	1.97
Fe_2O_3	3.7	4.49
MgO	1.55	1.03
K_2O	0.21	1.08
P_2O_5	0.33	0.37
CaO	0.59	0.77
Na_2O	0.29	0.27
Others	Balance	Balance

spectroscopic analysis by induction coupled plasma (ICP) method. The chemical compositions of coal ash and bauxite are given in Table 1.

The objective of the present work is to convert coal ash to mullite. Muliite is $3Al_2O_3$:$2SiO_2$ and therefore, the molar ratio of alumina to silica required for mullite formation is 3:2. Coal ash contains about 30 wt.% of alumina and 60 wt.% of silica which correspond to alumina-to-silica molar ratio of 0.3:1. Therefore, the yield of mullite resulting from transferred arc plasma processing of coal ash alone without any addition of alumina is expected to be very low. The idea of adding bauxite is to bring the alumina–silica ratio closer to 3:2. Since coal ash contains about 30% of alumina, the amount of bauxite required to bring the alumina–silica molar ratio closer to 3:2 would be about 50 wt.%. In view of the considerable loss of silica (by volatilization as SiO gas) during transferred arc plasma processing, it was decided to see the effect of lower and higher alumina additions on the phase composition. The amount of bauxite additions was worked out with this logic. Free energy minimization plots for the alumina–silica system illustrates the significance of the relative amounts of alumina and silica on the formation of mullite. It is also seen from free energy minimization studies that the by proper control of alumina–silica ratio, mullite formation can be accomplished.

Transferred arc plasma processing was carried out using coal ash and coal ash mixed with 25, 50 and 75% of bauxite powder. The different samples were designated as T1 (100% coal ash), T2 (75% ash + 25% bauxite), T3 (50% of ash + 50% bauxite) and T4 (25% ash + 75% bauxite). The powder mixture containing different percentages of bauxite was thoroughly mixed in a planetary ball milling for 2 h. The ball to mixture weight ratio was kept at 10:1. The milled powders were melted in the transferred arc plasma torch at 10 kW input power level for 3 min and cooled by a jet of air directed towards the molten sample. The schematic diagram of the TAP system is shown in Fig. 1.

The transferred arc plasma system consists of plasma torch, power supply, gas and water lines. The cathode of the plasma torch is made of a graphite rod 250 mm long and 50 mm diameter. Its end tapers to a conical shape for better electron emission. The cathode is enclosed in a hollow brass cylinder and provisions are made for water circulation (for cooling) and gas flow. The system has multiple inlets for plasma gas at the

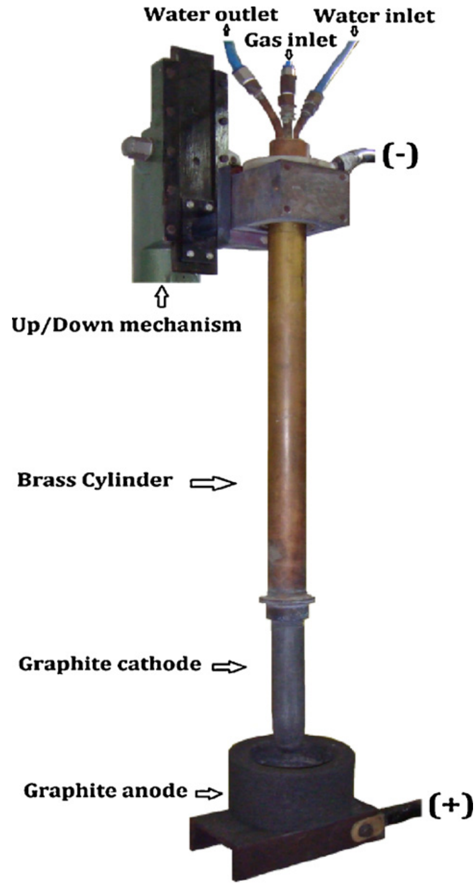

Fig. 1. Sehamatic of TAP torch.

cathode end. A graphite bowl of 100 mm depth and 50 mm inner diameter serves as the anode and melting bed. The samples were placed in the anode bed and DC arc was struck. The melted samples were cooled by forcing a jet of air on the molten sample. The operating parameters for the experiments are given in Table 2. The different compositions of coal ash–bauxite mixture are labeled as T1, T2, T3 and T4. The weight % of bauxite was 0 in T1; 25 in T2; 50 T3; and 75 in T4.

The TAP processed samples were milled down to a few micrometer size powders in agate mortar prior to X-ray diffraction (XRD) analysis. For scanning electron microscope (SEM) investigation, the samples were polished beginning with a set of silicon-carbide papers and final polishing with diamond paste. Then the samples were chemically etched using 30 wt.% HF solution for 30 s. The XRD pattern of the sample was performed using a PW Philips X-ray diffractometer with Cu Kα

Table 2
Operating parameters.

Input power	10 kW
Plasma gas and flow rate	Argon; 10 lpm
Cooling water flow rate	10 lpm
Processing time	3 min
Cooling time	10 min
Cooling medium	Forced air