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The effects of laser-induced modification of surface roughness of Al_2O_3-based ceramics on fluid contact angle

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Abstract

Laser surface treatment of Al_2O_3-based refractory ceramics, by melting and re-solidification, can be successfully applied to producing surfaces that are pore-free, homogeneous and crack-free. Such treated surfaces can lead to an increase in the corrosion and erosion resistances of the materials, due to lower permeability to corrosive species and higher surface hardness, respectively. Furthermore, the corrosion resistance can be influenced by the wetting characteristics of the treated surfaces in service environment. Therefore, it is important to investigate the effect of laser treatment of ceramic materials on the interaction of the surface with the various environmental elements. This work is concerned with an experimental investigation of the effects of laser surface treatment, by melting and re-solidification, on the fluid contact angles of Al_2O_3-based refractory ceramics. These effects are examined by the modification of the surface roughness characteristics induced by laser treatment. Laser-treated surfaces, both containing cracks and crack-free, are compared with untreated surfaces and the results are reported. The untreated surfaces demonstrated considerable non-uniformity in wetting, in contrast to the treated surfaces. The extent of wetting of the laser-treated surfaces containing cracks was proportional to laser power density. This is due to wetting being enhanced, among other factors, by surface roughness, which increased with power density. The crack-free surfaces were the most smooth and, thereby, exhibited the smallest extent of wettability variations. The reduction in wettability after the laser treatment (crack-free) may have an advantage for corrosion resistance.

Keywords: Laser; Ceramics; Roughness; Contact angle; Wetting

1. Introduction

The properties of laser-treated ceramic surfaces are very important in determining the effectiveness of the treatment of such materials for industrial applications, e.g. as linings in high-temperature waste incinerators. The surface roughness and wetting characteristics influence the interaction characteristics of the treated surfaces with the corrosive species. In general, the effects of laser treatment on the wetting characteristics of ceramics have not been fully explored yet, with only limited research work being conducted [1,21–23]. The main factors that affect the wetting characteristics of a surface are its composition, the content of O_2, the surface morphology, surface energy and the temperature [1,23]. Laser surface treatment by melting and re-solidification of oxide ceramics, such as those based on Al_2O_3, does not generally result in significant changes in the composition and O_2 content, compared with the untreated surfaces [2]. Therefore, the main characteristic of laser-treated oxide ceramics that affects their wetting properties is the change in surface morphology, induced by the laser treatment. The morphological modifications (pore-sealing, elimination of surface flaws and cracks, homogenisation) are expressed through changes in

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surface roughness; therefore, this can be identified as one of the prime factor that affect the wetting characteristics of laser-treated oxide ceramic surfaces compared to the untreated surfaces, under identical environmental conditions. This paper reports the modification of the wetting characteristics of laser-treated ceramic surfaces by considering the effects of surface roughness. The importance of surface roughness on wetting characteristics has been reported in numerous publications [3–10].

Surface roughness is generally decreased by laser surface treatment, due to densification and elimination of surface defects. An increase in surface roughness increases the wettability of a surface [3–10]. To enhance corrosion resistance, hydrophobic surfaces are desirable. Thus, a reduction in wetting generally leads to increased corrosion resistance when the surface is in contact with liquid corrosive species (e.g. molten slags in incinerators), since penetration through access sites, and chemical degradation, are limited due to a decrease in the effective contact area between the corrosive species and the ceramic surface; for example, Kashcheev and Semyannikov [11] have derived an expression that relates the volume of molten slag penetrating a refractory ceramic surface to the contact angle between the surface and the slag. Therefore, the wetting properties of the surface can become critical in determining the corrosion of refractory ceramics in their application environments, influencing their service lifetimes.

2. Experimental procedures

2.1. Materials

The materials under study were three types of commercial Al_2O_3-based refractory ceramics (commercial names: KR85B, KR85C and SR60C), manufactured by RHI Dinaris GmbH. Their chemical compositions are shown in Table 1. These ceramics are used as internal linings in a commercial waste incineration plant, in the rotary kiln and the secondary combustion chamber. In fact, the KR85C refractory ceramic is currently used in the main part of the rotary kiln and secondary combustion chamber and the SR60C refractory ceramic is used in the upper part of the secondary combustion chamber, where there are lower thermal loads and erosion conditions.

Table 1
The chemical compositions of the Al_2O_3-based refractory ceramics [20]

Constituent	Content (wt.%)		
	KR85B	KR85C	SR60C
Al_2O_3	83	82	60
SiO_2	8.5	8.5	35.5
Cr_2O_3	4.5	5.5	–
P_2O_5	1.9	1.9	1.7
Fe_2O_3	0.4	0.4	0.9

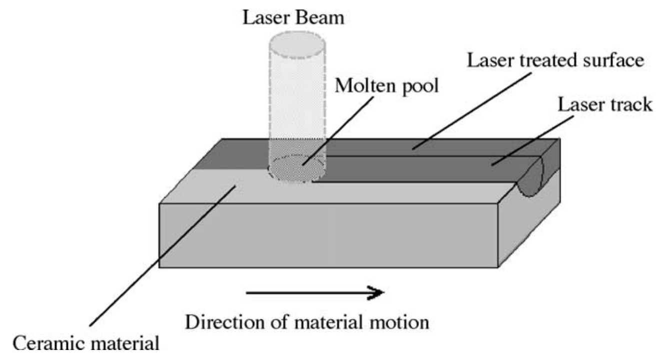

Fig. 1. Schematic diagram of laser surface treatment by melting and re-solidification.

2.2. Laser treatment

The three ceramic materials were surface treated using a 1.3 kW Rofin–Sinar CO_2 laser, emitting at 10.6 μm and operating in the continuous TEM^*_{01} mode. The samples, cut approximately to dimensions 70 mm × 70 mm × 50 mm, were positioned on a CNC *x*–*y* translation table, and moved underneath the stationary laser beam with the aid of a computer connected to the control system of the table. The processing gas was Argon at 5 l/min. Overlapping tracks, at 50% of the beam diameter, were used for large area treatment, to develop uniform depth profiles. The process of melting and re-solidification is schematically illustrated in Fig. 1.

The thermal energy density incident on the ceramic surface at any time is a function of the laser power density and processing speed. A range of laser power density values and processing speeds were used to treat the ceramic surfaces. Effective treatment, i.e. formation of pore-free and homogeneous surfaces, was achieved using a laser power density between 5×10^2 W/cm^2 and 90×10^2 W/cm^2 and a processing speed between 0.2 and 45 mm/s for the KR85B and KR85C ceramics, while effective treatment was possible for the SR60C ceramic using a laser power density between 5×10^2 W/cm^2 and 100×10^2 W/cm^2 and processing speed between 0.2 and 40 mm/s (Figs. 2 and 3).

Processing of the ceramic surfaces at low traverse speeds within the above ranges produced homogeneous and pore-free surfaces, that were also crack-free. Such surfaces were developed using a power density of 6×10^2 W/cm^2 at a processing speed of 0.4 mm/s for the KR85B and KR85C ceramics, while, for the SR60C ceramic, crack-free surfaces were produced using a laser power density of 4×10^2 W/cm^2 at a processing speed of 0.4 mm/s. The laser beam diameter for crack-free treatment was kept constant at 12 mm.

2.3. Surface roughness

The surface roughness was estimated from the mean value (Ra). Measurements were carried out using a Taylor–Hobson Surtonic 3+ surface profilometer, along a set distance of 8 mm. The roughness values for large laser-treated surface