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Laser machining of Al_2O_3–ZrO_2 (3%Y_2O_3) eutectic composite

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Abstract

In this work we present the study of the interaction between NIR pulsed laser and Al_2O_3–ZrO_2 (3%Y_2O_3) eutectic composite. The effect produced by modifying the reference position as well as the working conditions and laser beam features has been studied when the samples are processed by means of pulse bursts.

The samples were obtained by the laser floating zone technique using a CO_2 laser system. The laser machining was carried out with a Q-switched Nd:YAG laser at its fundamental wavelength of 1064 nm with pulse-widths in the nanosecond range.

Geometric dimensions, i.e. ablated depth, machined width and removed volume as well as ablation yield of the resulting holes have been studied. We have described and discussed the morphology, composition and microstructure of the processed samples.

Keywords: Laser machining; Al_2O_3; ZrO_2; Wear resistance; Functional applications

1. Introduction

Laser processing is of great interest in the field of optics, electronics, microelectronics, aerospace and medicine. This technique is cost-effective compared to traditional methods and it may be applied to a wide range of substrates, such as metals, ceramics and semiconductors.[1] In the field of materials processing by laser, several methods, such as laser machining, micromachining, marking, drilling and pulsed laser deposition, have been developed along the last two decades.[2,3]

The appearance of techniques for generating short and ultra-short laser pulses, ranging from tens of nanoseconds to a few femtoseconds without variation of other parameters such as pulse energy or the working frequency, have allowed the availability of more powerful systems, with power densities that can reach TW/cm^2. These laser systems, with better features and lower prices, offer a high-speed/high-quality tool for laser machining, which is of great interest in both basic and applied research for scientific and technological purposes.[3,4]

However, the foundations of the mechanisms involved in laser ablation are far from being well established. It is known that laser ablation depends on laser wavelength, optical features of laser beam, pulse-width regime and optical-thermal-mechanical properties of the substrate. Some theoretical descriptions have been developed by many authors to generalize the stages of the ablation process.[4–19]

Directionally solidified eutectic ceramics are commonly employed for functional and structural components because of their features, amongst which is worthy of mentioning their lightness, hardness, wear resistance and chemical stability at high temperature.[20–22] In particular, the eutectic composites based in Al_2O_3 are of great interest because of the properties derived from the distribution of the phases after solidification which can provide them with high flexural strength, toughness and creep resistance at high temperature and structural stability up to temperatures close to melting point, making them good candidates for applications such as gas turbines or systems for energy generation.[23,24]

In this work the interaction between NIR pulsed laser in the nanosecond range and the Al_2O_3–ZrO_2 (3%Y_2O_3) eutectic composite, directionally solidified, has been investigated to modified the surface in order to improve the wear behavior. The role the topography of the surface plays is of paramount

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Table 1
Laser output parameters.

	Working frequency				
	1	2	5	10	40
Pulse energy (mJ)[a]	2.7	2.45	1.6	0.9	0.5
Pulse length FWHM (ns)[a]	8	10	12	20	40
Peak power (kW)[a]	300	260	120	45	2
Pulse irradiance (GW/cm^2)	226	196	90	34	1.5
Optical absorption $\alpha\|_{1064\,\mathrm{nm}}$ (cm^{-1})	2.4	2.4	2.4	2.4	2.4
Absorption length $L_\alpha\|_{1064\,\mathrm{nm}}$ (cm)	0.42	0.42	0.42	0.42	0.42
Thermal diffusion length L_{th} (μm)	0.21	0.23	0.26	0.33	0.47

[a] Data provided by the laser manufacturer.

importance in aspects of great significance such as friction or wear resistance. The tribological behavior of a system can be improved by machining the surface in order to avoid a flat morphology.[25] The geometry of the machined zones, in cavity or groove shape, and their distribution on the surface are some of the key factors to take into account in the tribological behavior.[26]

The geometrical dimensions and the ablation yield have been investigated since they depend on the reference position, on the laser working conditions as well as in the method of machining.[27]

2. Experimental

2.1. Sample fabrication

The precursor rods were obtained from commercial powders of Al_2O_3 (99.99%, Aldrich), ZrO_2 (3%Y_2O_3) (99.99%, Tosho TZ3YS) and Mn_2O_3 (99.99% Aldrich). The powders were ground in a planetary mill with acetone in an alumina container. They were fired in air for 1 h, hand milled in an agate mortar to eliminate agglomerates and mixed in the eutectic composition: 62% Al_2O_3, 36.9% ZrO_2 and 1.1% of Y_2O_3, expressed in mol%. The resulting powders were isostatic pressed at 200 MPa for 2 min obtaining ceramic rods which were sintered at 1500 °C for 12 h.

The samples that will be tested for wear resistance will be produced by the laser surface melting technique using a focussed diode laser system that emits in 940 nm. To favour the absorption of the laser irradiation, a 0.9% of Mn_2O_3 is incorporated to the eutectic composite. The influence the addition of this oxide to the ceramic composite produces has been investigated by machining samples with and without Mn_2O_3.

The laser floating zone system include a CO_2 semisealed laser of 600 W (Electronic Engineering Blade 600) emitting in 10.6 μm and an in-house built growth chamber with gold coated metal mirrors for the beam focussing and two vertical axis for the cylinder displacement. Both axes have independent rotation and translation movement. A more detailed description of this technique can be consulted elsewhere.[20–24,28–30]

Finally, before the laser machining process, the eutectic fibers were flattened using a rotating sander machine.

2.2. Laser processing

A commercial diode-pumped Nd:YAG laser has been used in this work (Rofin-Sinar E-Line 20). The laser system operates at its fundamental wavelength of 1064 nm with a maximum mean power of 11 watts, in a Gaussian beam mode TEM_{00} with a beam quality factor $M^2 < 1.3$. The opto-acoustical Q-Switch commutator controls the cavity output in continuous and pulsed mode, generating pulses as short as 8 ns with a frequency range of 1–40 kHz.

The beam is deflected by a programmable galvanometer scanner controlled by CAD software, making a bidirectional movement in such a way that any predefined pattern and processing procedure can be performed. The system is equipped with a beam expansor 5× before the galvanometric mirrors and a convex lens with focal length f of 100 mm. Thus, using the equations[1]:

$$D_{bw} = \frac{4FM^2\lambda}{\pi D_0} \quad (1)$$

$$R = \left(\frac{\pi D_{bw}^2}{4M^2\lambda}\right) \quad (2)$$

where D_0 is the diameter of the laser beam before the optical lens, the diameter at the focal point D_{bw} and the Rayleigh range R for this system are, approximately, 13 μm and 96 μm, respectively.

The laser processing was carried out by means of pulse bursts, irradiating with a series of between 5 and 150 laser pulses according to the laser output parameters given in Table 1 and modifying the reference distance.

2.3. Characterization techniques

The microstructure and composition has been determined by means of scanning electron microscopy (SEM) using a JEOL JSM6400 with EDX analysis. Superficial topography, profile and removed volume measurements have been carried out with an optical confocal microscope Nikon Sensofar Plμ2300. Absorbance spectrum was measured using a double beam spectrophotometer UV–Vis–IR Cary 500 Varian.