ARTICLE IN PRESS

Ceramics International (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Fabrication of micro-scale textured grooves on green ZrO_2 ceramics by pulsed laser ablation

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ARTICLE INFO

Keywords:
Laser machining
Green ceramics
Surface quality
Micromorphology of laser ablation

ABSTRACT

The green ZrO_2 ceramics were fabricated by cold isostatic pressing. Pulsed laser ablation with a wavelength of 1064 nm was performed to fabricate micro-scale textured grooves on the surface of green ZrO_2 ceramics. The influence of laser parameters on surface quality was studied. The heat-affected zone around the machined grooves and micromorphology of laser-irradiated surface were investigated. Results showed that micro-scale textured grooves with a width of 30–50 µm and a depth of 15–50 µm on the green ZrO_2 ceramic surfaces were successfully fabricated by pulsed laser ablation. The laser parameters had a profound influence on the surface quality of micro-scale textured grooves. Better surface quality could be obtained with frequency below 40 Hz, power below 6 W, and scanning velocity above 200 mm/s. A sintering layer was found on the laser-irradiated surfaces when frequency was above 60 Hz, power was above 10 W, and scanning velocity was below 150 mm/s. Analysis of this sintering layer revealed clear melting and resolidification of ZrO_2 particles.

1. Introduction

Advanced ceramics are preferable for kinds of strategic application [1], low thermal conductivity, low coefficient of friction, excellent corrosion and wear resistance, high fracture toughness, and good thermal shock resistance make zirconia suitable for the use in engineering applications [2]. In order to improve tribological properties of ceramic surface, surface textures as an effective approach have been applied in bearings [3,4], mechanical seals [5] and engine cylinder liners [6]. Meanwhile, because of excellent tribological, electrical, and optical properties, ceramics with textures are also widely used in engineering applications such as cutting tools [7,8], solar receiver applications [9], and electronic component [10]. However, the properties of ceramics have difficulties with respect to its engineering fabrication through traditional approaches [11]. Available literatures showed that the high strength and hardness of ZrO_2 ceramics made it difficult to fabricate micrometer-sized structures on the surface of zirconia effectively, especially with conventional cutting tools, severe tool wear and excessive processing time significantly reduced the productivity of ceramic parts [12–14]. So no-traditional machining processes are alternative at present such as electrical discharge machining (EDM), laser beam machining (LBM), ultrasonic machining and so on [15]. The ceramics machining by laser has been an advanced manufacturing method in many areas such as cutting tools, electronics and material processing [16–19]. Xing et al. fabricated micro-scaled textures on surface of Al_2O_3/TiC ceramic by laser [8]. Sciti et al. drilled holes on the SiC ceramics through a pulsed CO_2 laser and investigated the surface modification in relationships with the laser processing parameters [20]. However, these no-traditional machining processes are a time consuming and expensive technique and surface quality obtained is not so good [21,22].

Because of the inherent of hardness and brittle nature of sintered ceramics, and problems associated with poor thermal shock resistance leading to initiation and propagation of micro-cracks induced by laser machining process, researchers had turned to the study the machining of the green ceramics (unfired) [23,24]. After the green ceramics processing, green ceramics will be sintered into products. Ahn, et al. fabricated micro-scaled structures successfully on a stainless steel green body without damaging the green body [25]. Investigations were conducted to discover the laser micromachining processes for green ceramics which had different composites of micro particles and polymer binders [23,26]. The results showed that the main removal mechanism of ceramics is ablation of the polymer binder at low laser fluence. Micro-patterning of green alumina compacts was also carried out successfully via contact (turning, drilling and milling) and non-contact machining (laser machining), the results indicated that better

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http://dx.doi.org/10.1016/j.ceramint.2017.02.074
Received 12 January 2017; Received in revised form 17 February 2017; Accepted 17 February 2017
0272-8842/

Table 1
Chemical analysis of zirconia powder.

Oxides	ZrO_2	Y_2O_3	HfO_2	Al_2O_3	SiO_2	CaO	Er_2O_3	SrO	Fe_2O_3	CuO	As_2O_3
wt%	88.22	8.30	1.51	1.11	0.27	0.27	0.18	0.07	0.05	0.02	83PPM

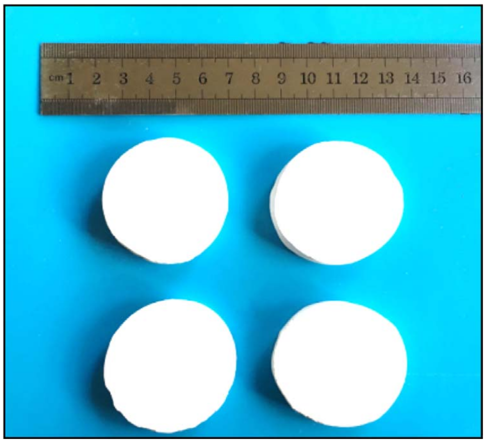

Fig. 1. Optical image of green ZrO_2 ceramics.

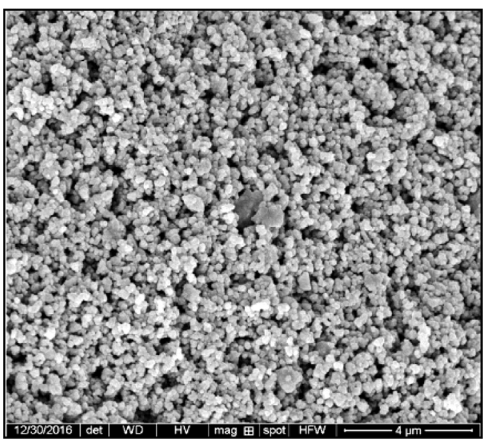

Fig. 2. SEM micrographs of the fracture surfaces of green ZrO_2 ceramics.

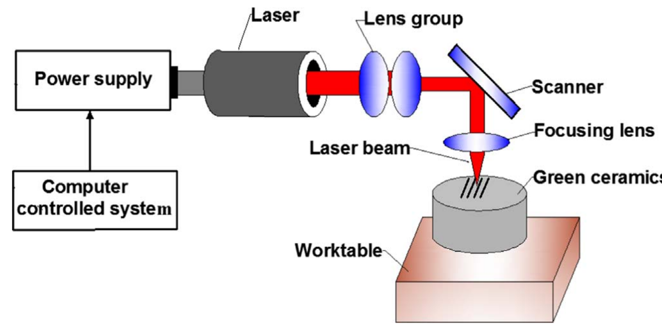

Fig. 4. Schematic diagram of laser processing green ceramics.

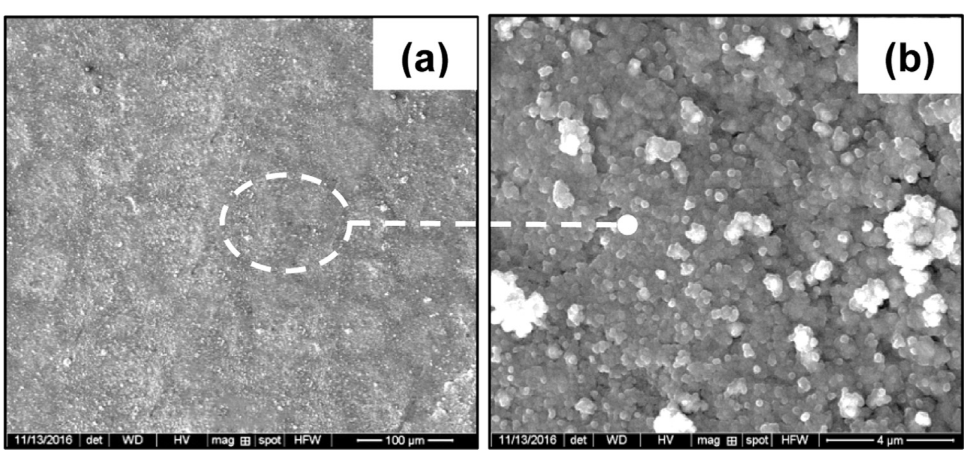

Fig. 3. SEM micrographs of the polished surfaces of green ZrO_2 ceramics, (a) the polished surface, (b) enlarge SEM micrograph corresponding to (a).

machining quality will be got with the combination of contact and non-contact machining [27].

However, the pulse laser interactions with green ZrO_2 ceramics are not well understood. Few literatures had investigated the influences of laser parameters on the formation of micro-scaled structures, the heat-affected zone around the machined area and the modification in laser-irradiated surface. In this paper, the green ZrO_2 ceramics were fabricated by cold isostatic pressing. The mechanisms of green ZrO_2 ceramics by laser machining with regard to different laser parameters including laser frequency, laser power, and laser scanning velocity were revealed. The influences of laser parameters on the formation of micro-scale textured grooves, the heat-affected zone around the machined area, and the modification in laser-irradiated surface were investigated.

2. Materials and experimental procedures

2.1. Preparation of green ZrO_2 ceramics by isostatic cool pressing

The green ZrO_2 ceramic compacts were fabricated with nanoscale zirconia powder (particle mean size 100 nm). Chemical analysis of zirconia powder was listed in Table 1. Green ZrO_2 compacts were fabricated by isostatic cool pressing which has the advantage of compaction's high strength, high and uniform density. A cold isostatic press (KJYs-300, Shanxi Jinkaiyuan Co., Ltd., China) was used with maximum pressure of 200 MPa. Green compactions were being pressed as pressure increasing evenly up to 110 MPa, then maintaining at a pressure of 110 MPa for 10 s. After that, the pressure was released evenly. Fig. 1 shows the optical image of green ZrO_2 ceramics. The mean dimensions of green ZrO_2 ceramic compacts were Φ 45×9 mm.