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Surface Texturing of Sialon Ceramic by Femtosecond Pulsed Laser

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Abstract

Femtosecond laser surface micromachining is a technique in which an ultrashort pulse laser beam is focused to dimensions of a few microns inside or on the surface of the substrate. In this paper, surface texture transformation behaviour of the SiAlON-Si_3N_4 ceramic using the Ti: Sapphire Femtosecond laser system was investigated. Parametric analysis was conducted using surface drilling, unidirectional and cross-hatching machining procedures performed on the substrate at a varied power and scanning speeds. A linear relation was observed on the microtexturing dimensions and roughness with respect to laser powers and this provided optimum micromachining mechanism at the chosen power of 0.25 W. Two roughness regimes characterised by periodicity and sharp valleys were observed at low pulse overlap and high pulse overlap respectively. Due to the complexity of the surface transformation chemistry, the necessity of a complementary cleaning procedure to remove the silicates retained by the laser treated surface was emphasised.

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Keywords: Femtosecond laser; SiAlON; Silicon nitride; roughness

1. Introduction

Surface texturing of the cutting tools reduces the contact area between the tool and the chip, ultimately reducing the cutting forces. Surface textures have been produced on the cutting tools by different advanced manufacturing methods like focused ion beam machining and laser technology. The focused ion beam machining has been the most preferred method for accurate positioning and dimensions of the surface textures but it is a time consuming process [1]. The developments in ceramics cutting tool such as silicon nitrides has resulted in considerable increase in productivity and an increased applications in the manufacturing industry.

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Silicon Nitride (Si_3N_4) based ceramics have undergone numerous advancements in the past four decades, mainly in an attempt to satisfy the industrial needs for superior structural materials. Some recent advances involve the optimisation of critical sintering parameters such as temperature, pressure and the incorporation of various impurity content combinations to re-enforce micro-structural matrices of the components [1-6]. Silicon nitride materials have further developed through the discovery of the alloys that were possible with alumina (Al_2O_3) known as SiAlONs; the name comes from the combination of Si, Al, O and N. The phase that has found the most use in industry is beta sialon, which has the formula Si6-zAlzOzN8-z, where z ranges from 0 (pure beta Si_3N_4) to 4 [2]. The resulting effects have been characterised by other researchers with their findings revealing apparent improvements in mechanical [5-10], chemical [11] and thermal [12] properties. As a consequence, the attractiveness of Si_3N_4 in tribological [10] and most recently, medical [13] applications has significantly improved. Although these attributes make silicon nitrides one of the most promising engineering materials, Si_3N_4 also exhibit low fracture toughness which is attributed to a combination of high hardness and wear resistance alongside their brittle nature. Hence, this makes traditional mechanical machining difficult, uncontrollable, labour intensive and expensive.

A solution to this problem may be the adoption of Femtosecond laser systems since they offer a non-abrasive material removal mechanism at an energy deposition timeframe smaller than the electron-phonon interaction time, leading to a transient, localised energy propagation profile on the irradiated surface. Due to this unique property, ultrashort laser systems have been found to enable melt free material processing, translating to a highest degree of control with minimal damage to the bulk material layers during micromachining of a variety of engineering materials [14-18]. Like in any laser system, the ease of machining is an intrinsic function of the laser parameters and the thermo-physical properties of the material [19].

This paper aims to characterise the surface transformation of the Si_3N_4 ceramic material using the Ti: Sapphire Femtosecond laser system at various parameters of power and scanning speed (pulse overlap) during a large area cross-hatching micromachining procedure. We attempt to achieve this by performing machining threshold estimation trials using the machining dimensions like the ablation diameter and depth. The full surface texturing of the blank cutting tool was used to identify the evolution of various roughness profile to quantify the machining with respect to the chosen parameters. The results and findings highlighted in this paper are important in the fabrication of engineering tools such Si_3N_4 based cutting inserts.

Nomenclature

D_{av}	Average crater diameter
F_0	Gaussian beam maximum fluence
f	Pulse repetition rate
P	Laser beam power
w_0	Laser beam radius at e^{-2} of the maximum intensity
f_{th}	Micromachining threshold fluence
OV	Pulse overlap
V	Scanning speed

2. Experimental Details

2.1. Material

The commercial sintered SiAlON-Si_3N_4 ceramic (Ceramtec International, Germany) was selected as the test material in this study. The properties of the sample are listed in Table 1. The used 4.8x14x14 mm^3 samples had an average as-received surface roughness of $R_a \sim 0.7 \pm 0.05$ µm (measured using a Confocal Laser Scanning Microscope, CLSM).