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Droplet assisted laser micromachining of tungsten carbide

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Abstract
Hard ceramic materials like tungsten carbide (WC) are extensively used in high value manufacturing, and micromachining of these materials with sufficient quality is essential to exploit its full potential. A new micro-machining technique called droplet assisted laser micromachining (DALM) was proposed and demonstrated as an alternative to the existing nanosecond (ns) dry pulse laser ablation (PLA). DALM involves injecting liquid micro-droplets at specific frequency during the nanosecond laser micromachining to create an impulse shock pressure inside the laser irradiation zone. The impulse shock pressure is generated due to the explosive vaporisation of the droplet, during its interaction with high temperature laser irradiation zone. The droplet assisted laser micromachining process exploits the combined potential of conventional ns laser processing, shock processing and wet processing, through the use of fine liquid droplets of size 150µm. This is the first attempt to exploitation of laser induced shock pressure to aid the laser micromachining of hard ceramic materials. In this paper, the DALM uses a nanosecond pulsed Nd:YAG laser to generate shock pressure and to machine the tungsten carbide substrate. The results suggest that the impulse shock pressure generated during DALM process can transforms the melt ejection mechanism of the conventional dry ns laser micromachining process. The change in ejection mechanism results in a 75% increase in material removal rate compared to conventional dry ns laser micromachining.

Keywords: Assisted; Ceramics; Droplet; Liquid; Laser; Micromachining.

1. Introduction

Hard, advanced ceramic materials such as tungsten carbide (WC) have excellent mechanical and thermal properties, such as hardness, wear resistance and retention of strength at elevated temperatures, making them highly desirable and suitable for a wide range of applications from aerospace to tooling [1]. Micromachining using short (microsecond-nanosecond) and ultra-short (picosecond-femtosecond) pulsed lasers is becoming an important process to machine hard materials like WC. Dry pulse laser ablation (PLA) by nanosecond lasers is extensively used across range of industries [2], however their material removal rate (MRR) is currently limited and result in significant spatter re-deposition with some thermal damage [3]. Ultrashort pulse laser machining using picosecond (ps) and femtosecond (fs) lasers is portrayed as an alternative to ns laser machining, however its MRR is extremely low and is used mostly for micromachining of thin materials [4]. Current dry ns PLA involves substrate absorption of laser photon followed by melt pool formation, partial vaporisation and ejection of meltpool by vapour pressure. In dry PLA only part of the melted material is vaporised or ejected and the rest resolidify inside the laser irradiated zone as a recast layer. Also, most of the ejected material gets redeposit around the edge of the micromachined region as spatter (over the material surface) [5]. This paper will concentrate on investigation the potential of droplet assisted laser micromachining (DALM) process for micromachining of WC material. DALM is expected to address the disadvantages of conventional nanosecond pulse laser ablation including low material removal rate and spatter redeposition.

2. Experimental Procedure

Tungsten carbide blocks (P10 grade) of dimension 50mm × 40mm × 10mm were used as test samples. Laser micromachining experiment was performed with and without liquid droplet, so as to evaluate the performance of DALM based micromachining compared to conventional dry PLA process. Conventional dry PLA experimental setup is same as the one discusses in previous literatures [3]. A schematic diagram of the DALM setup is shown in Figure 1. Compared to the Conventional dry PLA experimental setup, the DALM based micromachining system has an additional micro-dispenser capable of delivering a controlled volume of liquid at a specific frequency and time. The micro-dispenser was used to inject the liquid droplets over the laser irradiation zone (to induce shock and remove the dross and recast). The frequency of the laser beam and micro-dispenser were synchronised to work in sequence. The laser source used for this experiments is a LITRON frequency tripled Q-switched Nd:YAG laser with a wavelength of 355nm and a pulse duration of 8ns. Water was used as the liquid medium. 355nm laser wavelength was chosen, due to its low absorption with water. A three axis linear stage was used to move the sample relative to the droplet/laser focus.

For all experiments, the size of the droplet and the frequency of the laser were maintained at 150µm and 10Hz respectively. The laser fluence was varied from 0.1-6J/cm^2 and the number of pulse per position was varied from 25 to 500, so as to understand the significance of DALM and the conventional dry PLA process. All experiments were performed with stationary laser beam and stationary work piece. Finally, the laser micromachined samples

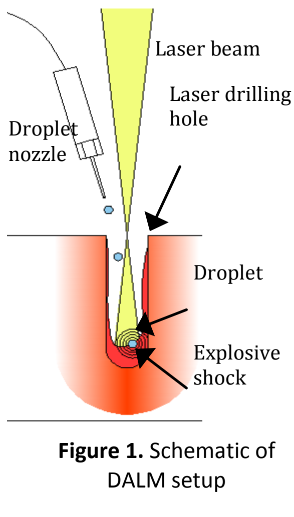


Figure 1. Schematic of DALM setup

were analysed using optical microscopy, scanning electron microscopy (SEM), elemental energy dispersive spectroscopy (EDX) and a white light interferometer.

3. Results

The ablation rate of DALM based laser micromachining process, performed on a flat WC plate is shown in Fig. 2. As can be seen from the figure, a positive correlation was observed with increase in fluence; however the variance is extortionate at the high fluence range at the fluence range of 2-5 J/cm^2. As elucidated from the figure, the ablation threshold of the WC with DALM based laser micromachining process is close to 2 J/cm^2. A fluence of 5 J/cm^2 was chosen for further experiments due to its high material removal rate compare to the threshold ablation fluence. Also noticed from the figure is that the ablation rate gets saturated above 5 J/cm^2, which should be due to plasma shielding effects. The ablation trend of DALM based laser micromachining is similar to the one observed with dry PLA process, however, the magnitude of removal rate is significantly higher in DALM based process compared to conventional dry PLA [2,5].

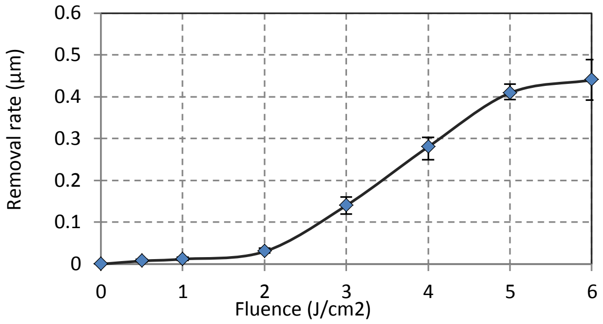
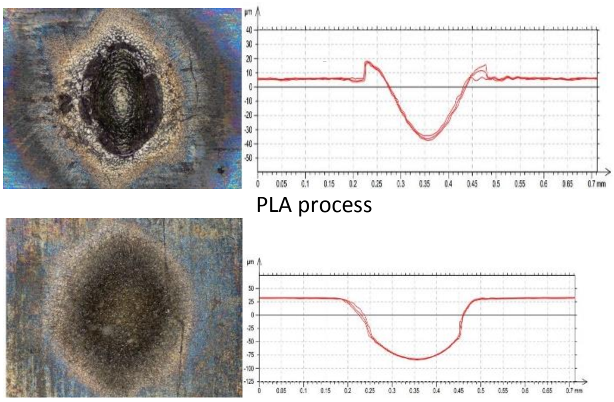


Figure 2. Graph showing effect of laser fluence on removal rate for DALM (No of laser and droplet pulse = 250; Laser frequency = 10Hz; Droplet frequency = 10Hz).

Figure 3 shows a typical comparison of WC micromachining performed using conventional dry laser ablation process and the droplet based micromachining process. As can be seen from the figure, DALM process shows high penetration and significant reduction in spatter redeposited over the edge of the hole and.

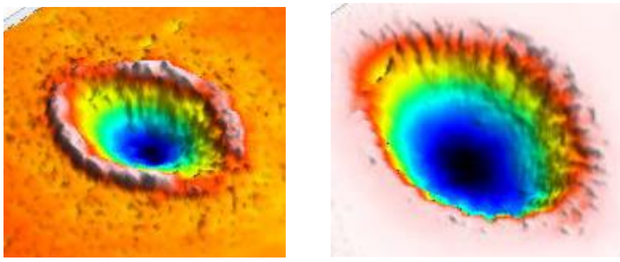


PLA process

DALM process

Figure 3. Images taken by the infinite focus optical microscope (Number of laser and droplet pulse = 125; Laser frequency = 10Hz; Droplet frequency = 10Hz; Laser fluence = 5J/cm^2).

Figure 4 shows the 3d profile of the laser micromachined hole with DALM and dry PLA process. As can be seen from the figure, a significant spatter was deposited over the dry PLA hole compared to DALM hole. The increased melt ejection improves the material removal rate of the DALM based process. As can be seen from Table 1, there is around 75% overall increase in material removal rate with the DALM process, a significant part will be due to the improved melt ejection mechanisms resulting in a minimal recast layer. It was clear from the optical microscopy that the addition of the liquid droplet had significantly inhibited the spatter formation around the perimeter of the laser irradiated zone.



(a) PLA process (b) DALM process

Figure 4. 3d profile of the hole machined with PLA and DALM.

Table 1. Effect of number of pulse per position on MRR for DALM and PLA (Fluence = 5J/cm^2; Frequency = 10Hz).

No of pulses	Material removal rate (µm^3)		% change
	PLA	DALM	
100	6166.4	9913.4	60%
125	6280.5	11685.7	88%
250	5895.7	12707.6	124%

4. Conclusions

Experimental investigations were carried out to demonstrate and to understand the mechanism of droplet assisted laser micro-machining process. Droplet assisted laser processing can be used to achieve high quality and high material removal rate in laser micromachining of hard ceramic materials. Compared to dry PLA process, DALM process can result in around 75 % increase in material removal rate. The improvement observed with the DALM system is attributed to the change in melt ejection phenomena, in particular, the explosive vaporisation of the droplet that helps to efficiently remove the melt layer at the side walls of the irradiated zone. The shock pressure generated during explosive vaporisation of the liquid droplet increases the melt ejection velocity, thereby reducing the spatter deposited over the ablated surface.

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