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Review article

# Laser drilling of structural ceramics—A review

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A B S T R A C T

Structural ceramics are becoming widely popular in numerous fields because of high mechanical and physical properties. It is of great difficulty for conventional techniques to machine brittle and hard materials. As one of nontraditional machining methods, laser beam machining has emerged as an effective technique for drilling of ceramics. This paper reviews the research work on laser drilling of structural ceramics from its different pulse width. Lasers have been discussed to understand effects of critical experimental parameters on the quality characteristics and physical mechanisms involved in drilling ceramics. In addition, it is held that heat and liquid-assisted laser processing serves as a useful method to improve processing quality. Computational approaches of ANSYS and COMSOL are used to predict laser input parameters' effects on quality of hole and describe the physical phenomena during processing. Comments on laser drilling of ceramics developments and future directions are provided at the end.



**Contents**



## 1. Introduction

Structural ceramics play an important role in several applications due to their excellent properties like high hardness, high strength, good thermal resistance and chemical stability [1,2–5]. However, it is difficult to machine due to the brittle and hard nature of ceramics. Traditional processing ways of ceramics are not only time-consuming but also laborious. Under such circumstances, various nontraditional machining methods have been adopted in processing ceramics, including ultrasonic machining (USM) [6], electrical-discharge machining (EDM) [7], laser beam machining (LBM) [8] and laser assisted machining (LAM) [9–11].

As one of the advances machining methods, LBM is considered a desired machining technique on account of non-conduct processing, low production costs, flexibility and its ability to process variable parameters with high accuracy [12]. LBM has been applied in many aspects of industry and life [13]. The schematic of LBM is shown in Fig. 1 [14]. Pulsed lasers have been used in drilling of structural ceramics. Fig. 2 presents laser-material interaction of a pulsed laser beam [15]. The circularity, taper angle of hole and heat affected zone (HAZ), cracks at surface and wall near hole are often used to characterize the quality of hole. To obtain the desired hole, laser drilling generally involves a great many of controllable parameters such as pulse width, energy density, repetition frequency and

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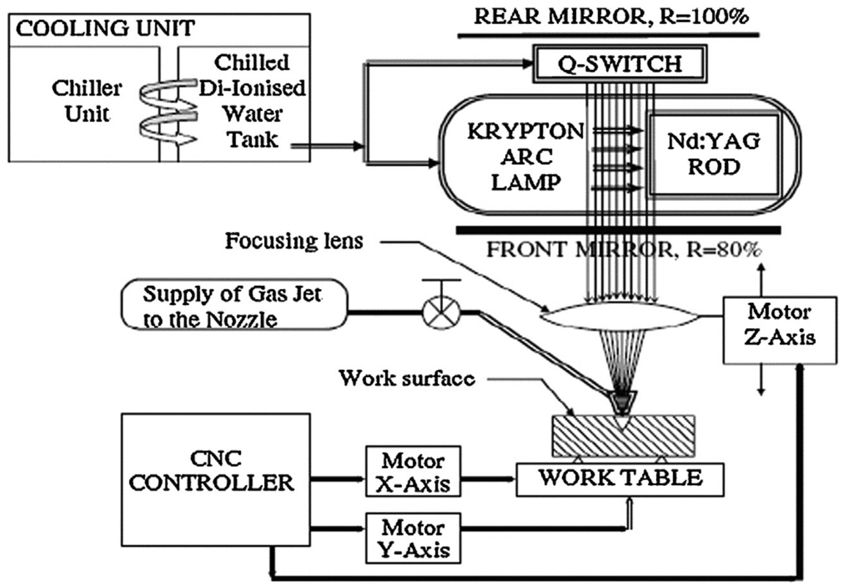


**Fig. 1.** Schematic of laser beam machining system [14].

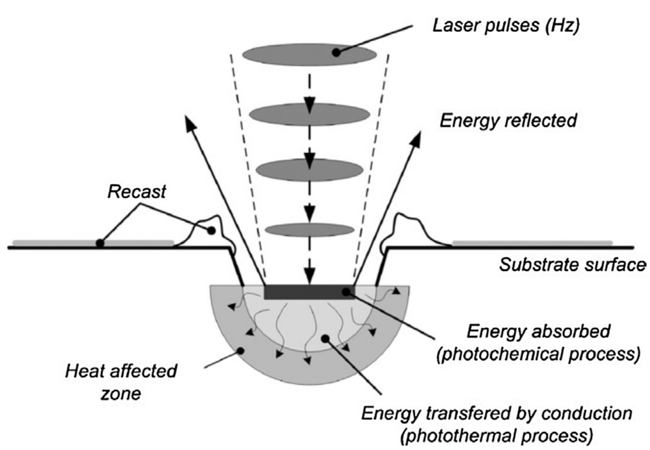


**Fig. 2.** Laser-matter interaction of a pulsed laser beam [15].

focal plane position. For optimization purposes, modelling and simulation is indispensable [16], such as experimental methods [14], analytical methods [17] and artificial intelligence methods [18].

This paper provides a review on laser drilling of structural ceramics with millisecond (ms), nanosecond (ns), picosecond (ps) and femtosecond (fs) lasers in order to predict the significant factors and effects on the quality characteristics. Heat and liquid-assisted laser drilling techniques are discussed. Computational approaches with ANSYS and COMSOL for the determination of optimum laser drilling have also been described. The paper is ended with concluding the laser drilling of ceramics developments and outlining the trend for future research.

## 2. Laser drilling of structural ceramics

Laser drilling produces better quality with shorter pulse width and higher peak intensity due to the change in mechanism of material removal [19]. Ultrashort pulse laser has less thermal damage to material because the thermal diffusion depth is equal to or less than optical penetration depth [13]. The experiments have been conducted by various researchers with different laser parameters using ms, ns, ps and fs lasers. Shorter pulse laser is helpful to improve the quality of machining but at higher cost. Auxiliary method assisted LBM is a very efficient processing way [20]. The results obtained are used to investigate the effect of each factor on the quality of hole.

### 2.1. Laser drilling with millisecond (ms) laser

Sciti and Bellosi [21] have performed the experimental study for laser drilling of silicon carbide (SiC) using $CO_2$ laser with laser power (0.5 and 1 kW), pulse duration (0.5–2 ms), lens focal length (95.3, 63.5, 31.8 mm) taken as process variables. Their study revealed that SiC can be removed by melting and vaporization through various reactions [22]. The center distance of micro-holes achieved about 200 μm on the sample surface. The desired effects of holes in the range of 80–100 μm were obtained at 0.5 kW of laser power and 1 ms of pulse duration. They also found that the relationship among microstructural and pulse duration, energy density. As shown in Fig. 3a, the regular circle hole were obtained. The section of hole tended to be cylindrical rather than conic with the increasing pulse duration (Fig. 3b). Silicate-like dendrite crystals can be observed evidently on the wall surface at the high energy density but not at low energy density (Fig. 3c) and the inner wall was covered glassy-like bubbles (Fig. 3d).

Kacar et al. [23] have experimentally investigated the effect of variation of pulse duration (0.5–8 ms), peak power (0.5–11 kW) on the holes of the alumina ceramic substrates. Their work found that the average taper angle would change from positive to negative value with the increase peak power and pulse duration (Fig. 4). The diameters of exit hole proportionally change with the pulse duration at fixed peak power, but the diameters of entrance hole do not have this tendency (Fig. 5). Results showed that higher value of pulse duration would lead to cause more resolidified material. The thickness also affects the amount of resolidfied materials by influencing the time of drilling. Millisecond pulsed Nd:YAG laser drilling of different thickness (5 and 10.5 mm) of alumina ceramics by varying laser peak power (5–9 kW), pulse duration (1–6 ms), number of pulses (10–100), repetition rate (5–20 Hz) and focal plane position (0–4 mm) was investigated by Hanon et al. [24]. Their experimental results showed that the depth of hole and the recast layer at the wall and the entrance of hole increase with increasing number of the pulses. They also found that columnar grains face towards the hole walls and that stress of columnar structures accelerates the cracking of materials when at cooling.

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