LASER DRILLING BY Nd: YAG OF COMPOSITES: A REVIEW

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Abstract

Laser beam drilling (LBD) is one of the advanced machining processes that are used for the machining of such materials like metals and its alloys, non-metals, composites, ceramics because of its precision, low cost and high speed of operation which cannot be machined with the conventional machining processes. This paper is focused the effect of Nd:YAG laser on the hole quality of composites materials. Moreover, the review paper has been more emphasized on increasing the productivity of the drilled hole by using the solid-state laser without changing the drilled hole. This paper is shown the future scope in the area of solid-state drilling through laser of composites. This review paper may be beneficial for the researchers who are working on the laser drilling of composites.

Keywords: Nd:YAG laser, Laser drilling, Hole quality features, Composite

1. Introduction

Desired size and shape of the materials can be obtained through the machining of the workpiece i.e. advanced engineering materials. Mainly conventional and unconventional machining processes are widely used in manufacturing sectors. Quality and precise products can be obtained through the unconventional machining process i.e. laser beam machining, Abrasive water jet machining, Electric discharge machining, Ultrasonic machining, electrochemical machining etc. Out of various unconventional machining processes laser machining is highly suitable for the advanced engineering materials i.e. ceramics, composites and superalloys. Industrial demand can be fulfill through laser machining.

Laser is a non contact type process so that it can be produced a better hole quality i.e. drilling in various advanced engineering materials. Laser is also suitable for the cutting, grooving, marking etc. in difficult –to-cut materials.

Laser beam drilling is highly suitable drilling technique as compared to other alternatives for the advanced engineering materials.

Laser beam drilling is the type of laser beam machining process which is moving in a 1-D and beam is stationary against the materials. It is widely useful for making thousand of narrow holes in the turbine blades and hot chamber.

Percussion drilling process is given in Figure 1. Drilling with laser has many advantages like more production rate, non contact type process so that no tool wear and it is suitable for thermally conductive and non-conductive materials. Hole quality at low cost can be improved by the laser drilling process. Metallurgical properties of the materials have changed in very less amount so that less heat affected zone on surrounding the drilled hole [1].

There are many numbers of quality characteristics would be affected in laser drilling like hole circularity, recast layer, hole taper etc [2]. The percussion drilling is applicable for the smallest size holes i.e. 0.12 mm to 1.20 mm. Percussion drilling are not suitable for more than 1.20 mm diameter hole.

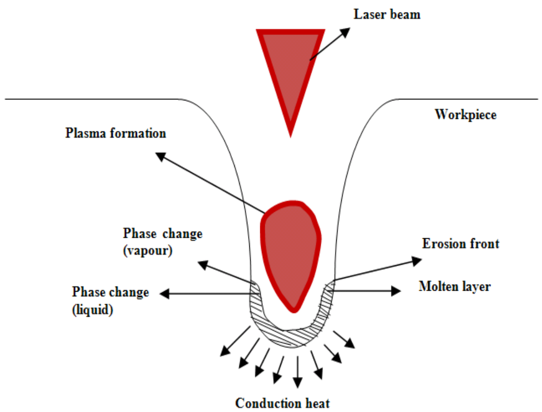

Fig 1. Laser percussion drilling

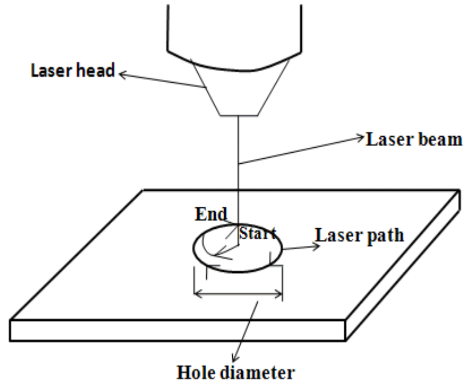

Fig 2. Laser trepan drilling [9]

Hence trepanning is the suitable drilling process for drilling hole more than 1.20 mm along the periphery of the hole as shown in Figure 2. Laser trepanning process is more suitable for making hole with less defects on advanced engineering materials [3].

In present scenario laser drilling is applicable for almost all advanced industries like automobile, shipping, aerospace, heavy equipments and chemical due to its properties like high production rate, more flexibility, more accuracy etc [4 -7]. For obtaining better results Nd:YAG laser is used as compared to other lasers.

In pulsed mode Nd:YAG laser produces better performance on thicker materials also due to its good focusing characteristics for different materials [8 – 11]. Nd:YAG laser used for many other applications in manufacturing areas [12]. Figure 3 shows the various types of engineering materials.

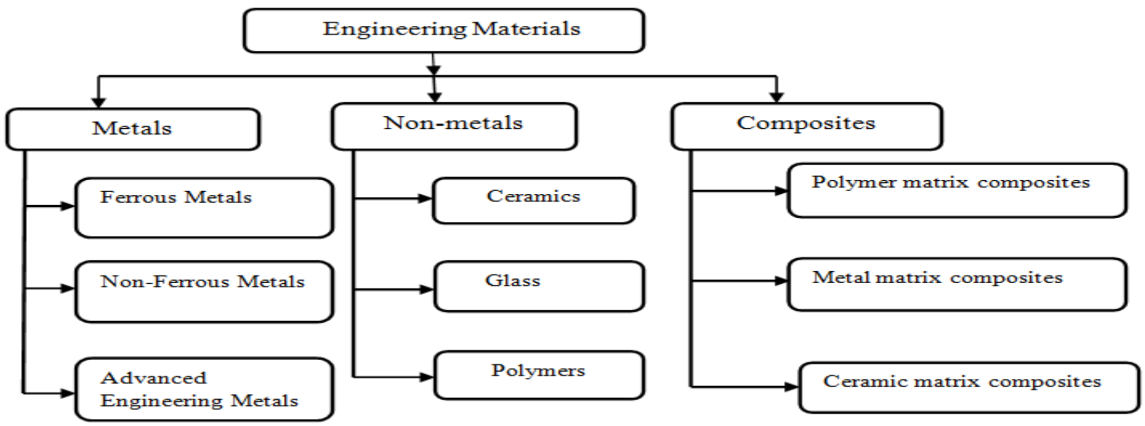

Fig 3. Types of engineering materials [12]

In this review paper, the effect of input process parameters on different quality characteristics in Nd:YAG laser beam drilling process of materials i.e. composites. It shows the effect of solid-state laser beam drilling on the composite materials so that its help the better understanding of the laser process.

2. Drilling System of pulsed Nd:YAG laser

Figure 4 shows the drilling system of Nd:YAG laser. In this system laser which is focused on the work surface through generation unit. Obtained hole through the laser can be changed by adjusting focal length. Quality of drilling hole can be obtained by proper controlling of the input process parameters [13 - 14].

3. Performance characteristics in laser beam drilling

Figure 5 shows the different characteristics of laser drilling. Laser power, focal length, distance between the nozzle and the workpiece, hole of nozzle, used gas pressure and pulse duration etc. are input process parameters in laser drilling. While some output quality characteristics like spatter formation, recast layer, hole circularity, material removal rate and heat affected zone (HAZ) etc [4, 5].

Hole at the entrance side, outer side, barreling etc. are given in Figure 5. Due to convergent and divergent shape of the laser beam profile taper generation is always found [8, 9]. Positive taper will occur when the entrance side hole diameter is more than the outer side diameter. Taper less circular drilled hole is desirable for getting quality precise hole on the workpieceb[15].

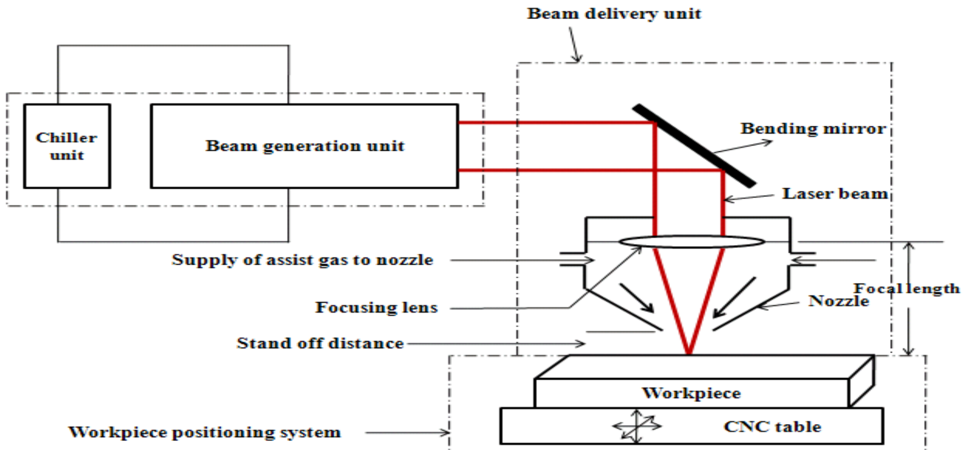

Fig 4. Schematic of Nd:YAG laser beam drilling system

3.1 Recast layer thickness

When the work surface melt through the thermal energy of the laser beam and re-solidify on the worksurface due to poor vaporization process of the some material. After re-solidification of the molten material and form a layer on the work surface known as recast layer.

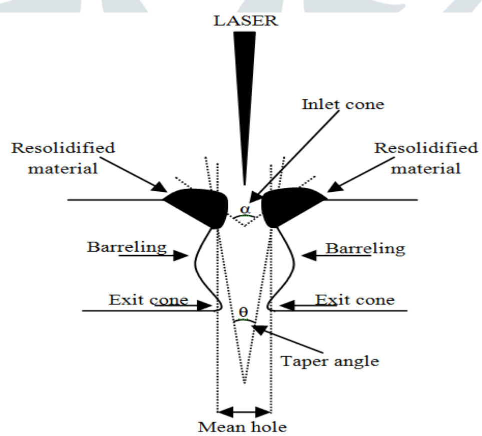

Fig 5. Image of hole made by laser [9]

3.2 Hole taper

Hole inclination (θ) is highly affected by the various factors i.e. quantity of pulses, focus of lens and pulse energy. Eq. 1 is generally used for finding the tapering hole. Here, θ is the taper angle and D_t, D_b and t

is the circumference of the top hole, bottom hole, and width (thick) of the material, respectively. Figure 6 shows the assessment of hole taper.

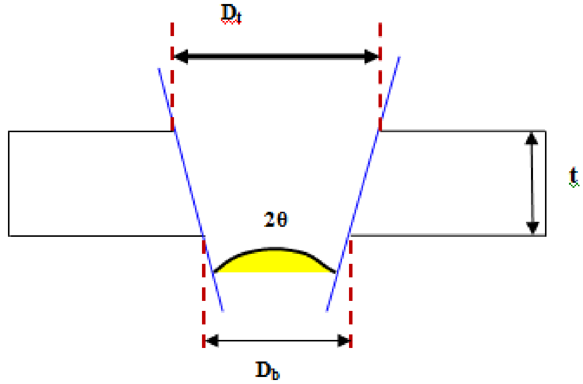

Fig 6. Assessment of hole taper

$$\tan\theta = \frac{D_t - D_b}{t} \quad (1)$$

3.3 Hole circularity

Very important quality characteristic i.e. Hole perfection is common measurement in process. Roundness of the drilled hole is known as hole circularity which is shown in Figure 7. Eq. 2 is commonly used for calculating the HC. $D_{minimum}$, $D_{maximum}$ are the minimum and maximum hole dimension of the drilled hole surrounding the circle.

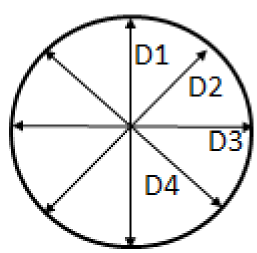

Fig 7. Perfection of the drilled hole

$$Hole\ Circularity = \frac{D_{minimum}}{D_{maximum}} \quad (2)$$

3.4 Heat affected zone

Due to the thermal properties of the laser beam, metallurgical properties of the materials have been affected. A zone due to high heat has to be formed around the drilling hole of the workpece known as heat affected zone (HAZ). It has been observed through SEM images that microstructure of the workpiece has been changed. The depth of HAZ is shown in Figure 8 (a) and (b).

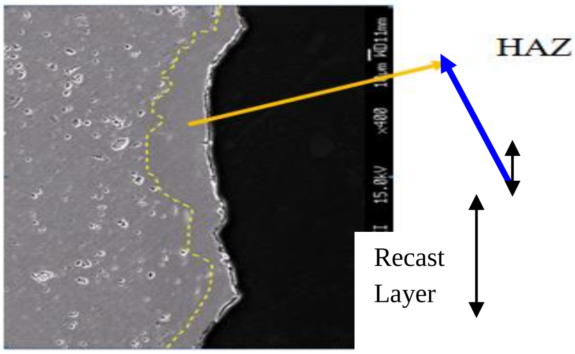

Fig 8 (a) HAZ in laser cutting of Al-Sheet [17]

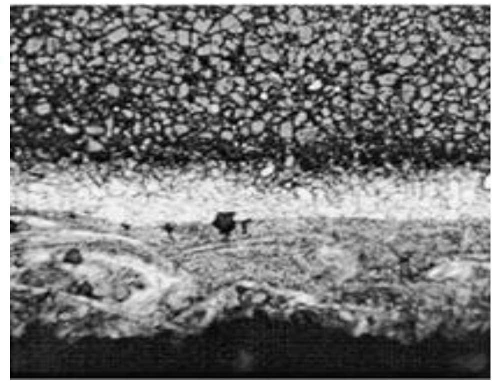

Fig 8 (b) HAZ and Recast layer [16]

4. Studies on Composites

Composite are a mixture of two or more materials in a certain ratio. There are generally two parts in composites and they are in fibers and particle forms. Free drilling of composite is found in laser drilling [18]. Very important and useful research has been mentioned in the following points.

4.1 Polymer Matrix Composites

There are wide applications of polymer matrix composites (PMC) in the many industries i.e. aerospace, automobile and electronics, shipping etc due to its characteristics. Laser drilling process is suitable for the drilling of various PMC like duplex-s polyimide, aramid/epoxy and epoxy / glass etc.

Cheng et al.[19] have been investigated that the molten composite was minimum and swelling has been found 50% higher in carbon fibers due to high heat or development of HAZ. Poor hole quality has been found surrounding the drilling hole of the resin due to the high heat [20].

Salama et al. [21] have been investigated the laser machining / drilling on mild steel and composite (CFRP). It shows the MRR and depth of machining.

Yung et al.[22] have shown a effect on material surface. It has also been investigated that residues not found on the inlet side workpiece.

4.2 Metal- Matrix Composites

Advanced engineering materials i.e. metal – matrix composites (MMCs) are very hard and difficult to machine due to its properties. MMCs are used for making turbine blades, hot chamber.

It is investigated that effect on Al-MMCs surfaces of beam of laser. It has also been found that lower re-solidified layer with respect to others Lau et al. [23].

Padhee et al. [24] have been investigated the RSM and GRA approaches for obtaining the
Optimized results of composite materials i.e. silicon carbide and aluminium based and optimize HAZ and taper.

4.3 Ceramic Matrix Composites

It is widely used for the optical and storage devices due to its very special properties of the ceramic matrix composites [CMCs] material like highly thermally conductive, higher melting point, stable at higher temperature and chemical, more hardness etc

A composite (titanium nitride–alumina) of micro size drilled hole has been obtained at negative focal length at entrance side and positive focal length at bottom side of the hole on different process parameters [25]. In this study authors employed RSM technique for optimization and ANN technique for modeling of process parameters for circularity at the entrance and exit hole taper.

Sola et al. [26] have been investigated the micro-machining efficiency of Nd:YAG laser on ceramic plate via tape casting process.

5. Future Scope of Research

Some possible future research areas are mentioned below:

1. The development of economical hybrid drilling processes with LBD process with better hole geometry and high-speed drilling will remain a key research area.
2. Few efforts have been made to identify theeffect of beam angle on hole geometry, keeping in view with mechanical properties of materials.
3. Few studies have been conducted on measuring the thermal stress distribution in HAZ of nonmetals and composites.
4. Not many studies have been conducted on the Nd:YAG LBD of fiber reinforced composites like GFRC and CFRC.

The advent of newer and more interesting difficult-to-drill materials that are productive in a wide variety of applications has challenged the feasibility of Nd:YAG LBD.

6. Conclusions

The conclusions are mentioned below.

1. Mainly hole of drilling geometry effected by pulse width (PW), pulse frequency (PF), cutting speed (CS) etc.
2. Geometrical characteristics of drilled hole are very for different materials with the same set of process parameters and thickness of the workpiece.
3. Hole inclination between top and bottom and HAZ output parameters have reduce.
4. Improve hole quality and minimize drilling time.

It is also concluded that applications of LBD are increasing rapidly in the various area

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