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Hole qualities in laser trepanning of polymeric materials

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ABSTRACT

The present study focuses the effect of four input controllable laser cutting variables on the hole taper and hole circularity in laser trepan drilling of polymeric materials. Experiments have been conducted on acrylonitrile butadiene styrene (ABS) and polymethyl methacrylate (PMMA) polymer sheets. Laser power, assist gas pressure, cutting speed and stand-off distance were selected as independent process variables. Three different holes of diameters 2 mm, 4 mm and 6 mm were drilled in these work materials of 5 mm thickness. A Taguchi L9 orthogonal array with four factors and three levels of each factor was used to plan and conduct the experiments in order to obtain required information with reduced number of experiments. The process performance was ascertained in terms of hole taper and hole circularity. Initial analysis involved in determining the effect of the four process variables on hole taper and circularity for these two polymers at three different hole diameters. From ANOVA analysis, the optimum levels of the four process variables with respect to materials and hole diameters were evaluated. As it was found that the optimum levels of four process variables were different for different hole size and materials, additional analysis was conducted to incorporate the effect of material and hole diameter on the hole taper. From the analysis, the optimum combinations were obtained at compressed air pressure of 2.0 bar, laser power of 500 W, cutting speed of 0.6 m/min, stand-off distance of 5.0 mm, hole diameter of 2.0 mm and material of PMMA. These combinations produced the minimum taper in the hole. The circularity of the hole was more at the entrance than the exit when ABS polymer was laser drilled while in PMMA, the hole was more circular at the exit than the entrance.

1. Introduction

The laser drilling process is one of the most widely used thermal energy based non-contact type advance machining process which can be applied across a wide range of materials. Nowadays laser drilling is finding increasingly widespread application in the industries. Laser beam machining is based on the conversion of electrical energy into light energy and then into thermal energy to remove the material from work piece. The material removal process is by focusing laser beam onto the work material for melting and vaporizing the unwanted material to create a hole. CO_2 laser drilling has been widely used in industries because of its high production rate and abilities on rapidly varying holes size, drilling holes at shallow angle, and drilling hard-to-work material such as high strength materials, ceramic and composite. Laser drilled holes are inherently associated with a number of defects. Circularity of hole, spatter thickness, and hole taper are some defects associated with laser drilling. As a result, the quality of the drilled holes is the main issue in the laser drilling process. There are two types of laser drilling: trepan drilling and percussion drilling. Trepan drilling involves cutting around the circumference of the hole to be generated, whereas percussion drilling is carried out by utilizing a focused laser spot to heat, melt and vaporize the target material such that a desired hole is formed through the work piece with no relative movement of the laser or work material [1,2]. Fig. 1 shows a schematic of laser beam drilling [2].

Ghoreishi et al. [3] investigated the relationships and parameter interactions between laser peak power, laser pulse width, pulse frequency, number of pulses, assist gas pressure and focal plane position on the hole taper and circularity in laser percussion drilling of stainless steel and mild steel. The central composite design was employed to plan the experiments in order to obtain required information. The process performance was evaluated in terms of equivalent entrance diameter, hole taper and hole entrance circularity. They found that the pulse frequency had a significant effect on the hole entrance diameter and hole circularity in drilling stainless steel unlike the drilling of mild steel, where the pulse frequency had no significant effect on the hole characteristics. Eltawahni et al. [4] investigated the effect of laser power, cutting speed, and focal point distance on the cutting edge quality parameters in CO_2 laser cutting of ultra-high performance

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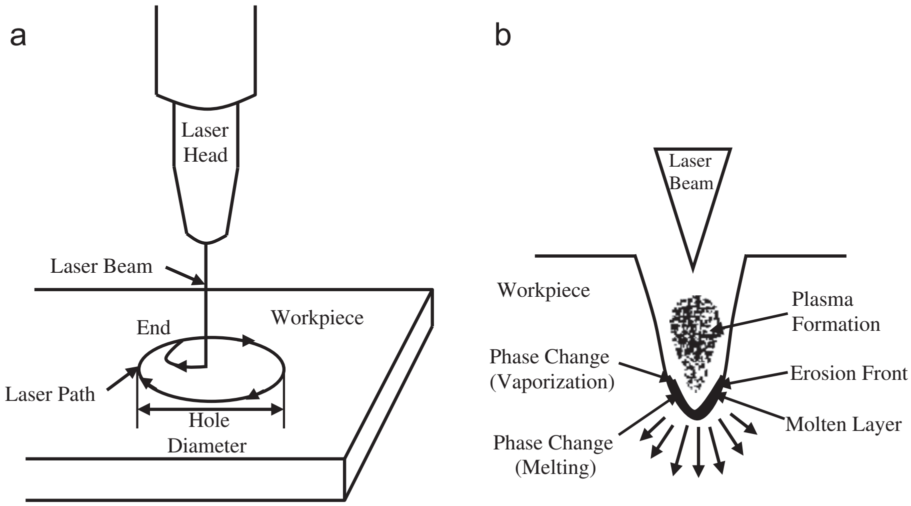

Fig. 1. Schematic of laser beam: (a) trepan drilling and (b) percussion drilling [1].

polyethylene of various thickness from 6 mm to 10 mm. They conducted the experiments by implementing the Box–Behnken design and measured upper kerf, lower kerf, ratio of upper kerf to lower kerf and cut edge surface roughness. They developed model equations relating the input processing parameters with the output or response they had measured. They found that the upper kerf decreased as the focal position and the cutting speed increased, and it increased as the laser power increased. The roughness decreased as the focal point increased from its lowest level till its central level and then it increased as the focal distance increased above its central level. The roughness decreased as the laser power increased and it increased as the cutting speed increased. Higher cutting speed did not always improve the efficiency of the laser cutting process. Benyounis and Olabi [5] did a comprehensive literature review of the applications of design of experiments, evolutionary algorithms and computational networks on the optimization of different welding processes through mathematical models. According to their review of various literatures, they were of the opinion that there was considerable interest among the researchers in the adaption of response surface methodology (RSM) and artificial neural network (ANN) to predict responses in the welding process. For a smaller number of experimental runs, they noted that RSM was better than ANN and genetic algorithm (GA) in the case of low order non-linear behavior of the response data. In the case of highly non-linear behavior of the response data, ANN was better than other techniques. They also observed that the Taguchi approach of SN ratio might lead to non-optimal solutions with less flexibility and the conducting of needless experiments.

Yilbas [6] studied the effect of the laser parameters and the material properties on the hole quality in laser hole drilling. A statistical approach, referred to as factorial design, was used to test the significance level of the factors that affect the hole quality. Three materials, stainless steel, nickel and titanium, were considered. The experimental study yields tables of significance of each factor on the aspects that determine the quality of the holes. The parameter which was found to be very significant in most cases was the workpiece thickness. The first-order interaction of pulse length–thickness was the most significant, whilst pulse length–focus setting was significant for all of the materials examined. For the second-order interactions, only pulse length–focus setting–thickness was found to be significant. Yilbas and Kar [7] experimentally conducted thermal and efficiency analysis of the CO_2 laser cutting process to cut mild-steel samples of 0.8–2.0 mm thicknesses. They also considered the effects of momentum and gas–liquid interface shear stress due to an assisting gas jet. The approximate magnitude of the heat absorbed was estimated and the thickness of the melting layer was predicted. The theoretical predictions were compared with the experimental findings. The liquid-layer thickness measured experimentally was found to be in good agreement with the theoretical predictions. The variation of first and second law efficiencies with jet velocity for different cutting speeds showed increasing trend with increasing jet velocities and cutting speeds. Yilbas [8] examined the laser gas assisted cutting process. A statistical method based on factorial analysis was used to identify the influence of cutting parameters on the resulting cut quality. It was found that increasing laser beam scanning speed reduces the kerf width while with the increase of laser power, kerf width increases. The main effects of all the parameters employed have significant influence on the resulting cutting quality.

Choudhury and Shirley [9] investigated laser cutting qualities of polypropylene (PP), polycarbonate (PC) and polymethyl methacrylate (PMMA) with a view to evaluate the effect of the main input laser cutting parameters (laser power, cutting speed and compressed air pressure) and develop model equations relating input process parameters with the output. The experiments were carried out according to the central composite first-order design based on response surface methodology. The output quality characteristics examined were heat affected zone (HAZ), surface roughness and dimensional accuracy. It was found that the response was well modeled by a linear function of the input parameters. From the analysis, it has been observed that PMMA has less HAZ, followed by PC and PP. For surface roughness, PMMA has better cut edge surface quality than PP and PC. However, all three polymeric materials showed similar diameter errors tendency in spite of different material properties. French et al. [10] investigated the effects of seventeen factors at two levels and their first-order and second-order interactions on the hole taper and circularity in Nd:YAG laser percussion drilling. They found that pulse shape, energy, peak power, focal position, gas pressure and Nd:YAG laser rod were the most effective factors affecting the hole taper and circularity. Kamalu and Byrd [11] studied the effects of focal length of lens, position of the focal plane with respect to the material surface and laser energy on laser drilling performance. They measured drilling performance by diameter of laser-drilled holes. The three factors were studied at two levels and two sets of 2^3 factorial designs were analyzed.

Negarestani et al. [12] developed a 3D model for simulating the heat flow and material removal rate in laser machining of