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CO2 Laser Engraving Process of Injection Molded Polycarbonate; Experimental Investigation

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Abstract

In this research, laser engraving process on a 3.2 mm thick polycarbonate sheet by low power CO_2 laser is investigated. For this purpose, the scanning speed, laser power, and laser focal position are considered as laser input parameters. Depth of laser beam penetration, engraving width and heat-affected zone are supposed to be the process output parameters and the measurements of these areas were made by optical microscope. It should be noted that the pressure of laser assist gas is the same in all samples. In this process, in some samples, the quality of the laser engraving was very suitable, with a maximum penetration depth of 1.25 mm. It is shown that the penetration depth of laser engraving increases with increasing laser power and decreasing the laser speed due to increasing heat input. In addition to the heat input, laser focal point is effective on the interaction time of the laser beam with the workpiece. It was supposed that with decreasing or decreasing the laser focal point, the laser speed, the laser beams more interact with the polycarbonate sheet, resulting in more significant amount of evaporation, which increases the penetration depth of the laser beam into the workpiece.

Keywords: Laser engraving; Polycarbonate sheet; CO_2 laser; Optical microscope.

1. Introduction:

Today there is a great deal of variety in the use of lasers in various processes, and it has a progressive trend [1-4]. Different materials and methods in industry, art, and medicine have been affected by this process [5-8]. The process of cutting, drilling, forming, hardening can be exemplified [9-15]. In the process of laser materials processing, in the surface of a material, some changes occur [16-22]. The use of metals, plastics and wood materials is widespread in laser engraving [23-27]. Engraving of signs and images on wood, steel and plastic materials using laser engraving is used by many craftsmen and artists. Small manufacturing companies or even developed industrial factories can engrave the mark of the manufacturer, the required inscriptions and images on their products using laser technology [28]. Laser engraving is done with high speed, accuracy and the error rate in this process is very low [29]. This process is evaluated with specific settings, depending on the consumed materials [30]. A schematic of the laser engraving process is shown in Figure 1. In this process, after that the designer inserts the design into the laser-connected system, by heating the surface of the workpiece with a laser beam, some of the material's surface becomes liquid. The material vaporizes and the laser track is created on the surface of the piece [31, 37].

Figure 1

There has been a great of research in the laser machining area recently. Mathew et al. [38] investigated laser cutting of carbon fiber reinforced plastic composites using a Nd:YAG laser. In this study, the heat-affected zone was investigated in the laser cutting process. Yousef et al. [39] used a neural network model to analyze the process of material removal in laser machining. The results showed that artificial neural networks are capable of predicting the volume of removed materials. Kovar et al. [40] investigated laser micromachining using a Nd:YAG laser source on aluminum metal. Peter et al. [41] performed laser labeling on alumina ceramic using Nd:YAG laser. The results indicated that Nd:YAG laser process performed laser engraving with high accuracy. Carey et al. [42] performed automatic control of laser systems for the laser machining process. In this research, the laser engraving has also been investigated using changes in laser input parameters. Peter et al. [43] optimized the laser labeling process using a Nd:YAG laser on zirconia ceramics. Kotodia et al. [44] investigated the laser machining process of steel sheets using changes in laser power and focal length. The purpose of this work was to analyze the parameters of the laser machining process using CO_2 laser. By using laser engraving process machines, durable and delicate designs can be made on plastic pars [45]. Laser engraving may be a good alternative if the plastic parts are exposed to high friction and can be wiped off the color materials printed on them. Laser engraving can also create beauty, elegance and depth in the desired design. Another case of engraving of plastic parts is for cases where the parts do not have a uniform surface [46]. Various materials, such as polycarbonate, can be considered for this process [32-34]. Polycarbonates are thermoplastic polymers which widely are used in the automotive and household appliances industries [35, 36]. This material due to its properties such as chemical properties, impact and scratch resistance, tensile and bending resistance, thermal insulation, is used in the automotive industry for interior decoration of cars, making dashboards, making shields and interior panels, and modern automotive headlights, in the health and medical industries to make transparent bottles for food and pharmaceutical packaging, to manufacture all kinds of medical and industrial glasses, and in the electrical and computer industries [47].

In the present study, the process of low power CO_2 laser engraving on a sheet made of transparent polycarbonate is investigated. The main difference between this study with and previous studies is that use of the range of input parameters which are more effective on the laser engraving process. The scanning speed, laser power and focal length position will be known as laser input parameters. Also, the depth of penetration, the width of engraving, and the heat-affected zone (Figure 2) were measured by optical microscopy and considered as the output parameters of the experiment. According to the output parameters, by decreasing the laser speed, the polycarbonate surface has more interaction time with the laser beam and increases the heat and thus the heat-affected width.

Figure 2

2. Materials and experimental methods

For the experimental tests, a sheet made of polycarbonate with dimensions of 80*175 mm and a thickness of 3.2 mm was prepared by Neco Optimum Machining Company using a plastic injection molding machine. In Figure 3a and b, the injection molding machine and mold used for the production of samples are shown, respectively. Based on some researches, process conditions for injection molding of samples are regulated [47].

Figure 3

The laser focal point method should be used to determine the focal position of the laser. The focal plane of the laser has three positions, as shown in Figure 4a. In this method, a plate of Plexiglas (Acrylic) is mounted 80 degrees relative to the horizon with a stand (Figure 4b) and the laser beam is passed perpendicular to the surface. The laser beam trace falls on the Plexiglass plate, so that the position of the focal point can be measured.

Figure 4

Laser engraving of the samples was performed using CO_2 laser (Optimo model, provided by OPTIMA Industries) with the maximum power of 60 watts. The range of laser parameters includes laser power (4 to watts) and laser scanning speed (7 to 11 mm/s), focal point position (38 to 42 mm), according to ASTM A1069 standard. Table 1 shows the laser parameters in this experiment. By using these parameters, eight laser engraved samples have been created. In Table 1, it is also demonstrated the quality of laser engraved samples.

Table 1

Optical microscopy (Amf4 model, provided by Leica Industries) and Image J software were used for measurements. Figure 5 shows the samples after laser engraving. Laser engraving images of the polycarbonate sheet show that the laser has been able to affect the area of the workpiece well.

Figure 5

3. Results and discussion

In the process of laser engraving, in addition to the width and depth of penetration, good quality of engraving is one of the most critical issues. In this study, according to the setting in Table 1, laser engraving was performed. The results of these experiments, which include penetration depth, width, and heat-affected zone, are listed in Table 1. As shown in Table 1, the highest values of penetration depth belong to sample #4 and #6 that are 1 mm and 1.25 mm, respectively.

The high depth of laser penetration can be attributed to the laser input energy resulting from the high laser power, low laser speed, and the low laser focal length to the surface. In sample #6, laser speed and laser power are the same as in sample #4. So, the amount of heat input, that is calculated by Eq.1 [2, 50] is equal (889 j/m) in both two samples of #4 and #6. However, in sample #6, where the laser focal length is less than sample #4, the amount of input energy to the surface of the polycarbonate sheet is increased, and this causes higher heating.

It had been shown, the laser focal position has a significant effect on penetration depth and quality in the laser material processing [48]. The penetration depth increases, when the laser focal point is decreased below the surface. Because with decreasing the laser focal point, the melt is pushed through the laser joint. Also, reducing the laser focal point lets energy to be absorbed in the melt pool more efficiently, and as a result, the more amount of the base materials melted during the laser processing. Therefore, this heat causes more polycarbonate to evaporate from the surface of the sheet.

$$\text{Heat input} = \text{Laser power}/\text{Scanning Speed} \quad (1)$$

$$\text{Beam density} = \text{Laser power}/\text{Incident beam area} \quad (2)$$

Also, the incident beam area decreases with decreasing the laser focal plane (that means a closer focal plane) [49]. According to Equation 2, with reducing the incident beam area at constant laser power, the beam density is increased and as a result the penetration depth is increased.

As can be seen in Equation 1, the heat input is increased by increasing the laser power and decreasing the scanning speed [50-52]. In Figure 6a, the variation of the engraving laser width parameter with laser power change is shown. It can be seen that by increasing the laser speed, the interaction time of the laser effect with the surface of the polycarbonate sheet increase. This increases the heat at the sheet surface and thus evaporates more profoundly, and as a result, the depth of the laser track is increased. It is crystal clear that the width of the laser engraving process is one of the importance criteria and a proper size of this parameter is important. Not only can save the suitable size of this parameter by testing some laser engraving process, but also it can decreases the amount of heat-affected zones based on Figure 5. Figure 6b shows the curve of the depth changes due to the laser speed changes. According to the equation 1, with increasing the laser power in laser materials processing, the heat input increases, and it causes increasing the width of the laser track.

Figure 6

In sample #2, the laser power and focal length position are constantly compared to sample #3, but the laser speed in sample #2 is higher than sample #3, which causes less penetration. Because the higher speed reduces the penetration of the laser beam with the surface, as a result the input energy is reduced and the surface is not heated well.

The Quality of the engraving and the maximum reduction of HAZ are another parameter which have a significant role in the engraving process because of the more precise the target area, the better the process. In Figure 7, it is clear that by increasing scanning speed the quality of sample #1 declined. The causes of this phenomenon is that the laser beam interaction time reduced, and the interaction time is not adequate for fulfilling the process.

Figure 7

4. Conclusion

This research deals with laser engraving operation by low power CO_2 laser on a 3.2 mm thick polycarbonate sheet. The effect of changing input parameters including scanning speed, laser power, and laser focal position on the amount of penetration depth, width heat-affected zone, and quality of laser engraving area was investigated. By measuring the geometrical dimensions of the laser affected area, it was found that the laser penetration depth increased to 1.25 mm by decreasing the laser focal point. Also, it was shown that by increasing laser power and decreasing the laser speed and as a result increasing the heat input, the depth and quality of laser engraving. As the laser speed decreases, the laser beam interacts with the polycarbonate sheet, resulting in a higher amount of evaporation, which ultimately increases the penetration depth of the laser beam. Increasing of laser interaction time is also adequate for fulfilling the process and quality of laser engraving process. Due to the output results and obtained quality of the engraved surfaces, the low CO_2 laser is suitable and reliable for this process.

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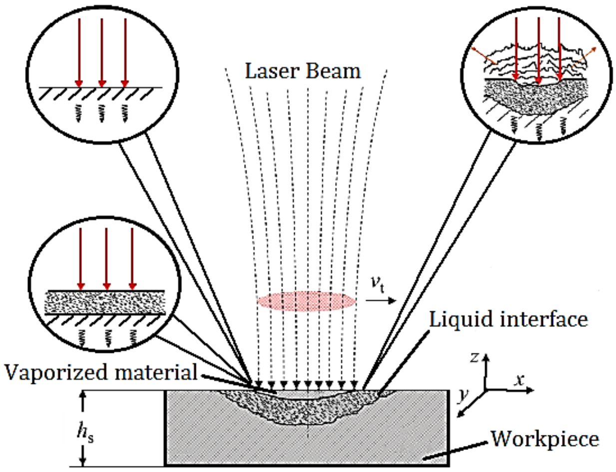


Figure 1- Laser engraving schematic [28]

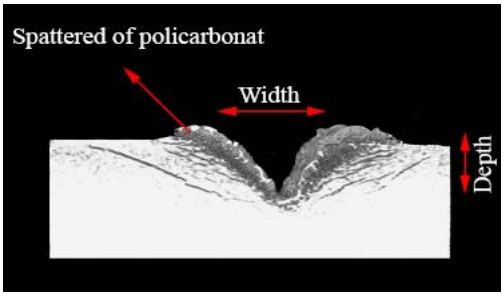


Figure 2- Schematic of geometric dimensions in the laser engraving process [28]

(a) (b)

Figure 3- a) Injection machine used in research, b) Mold used to produce polycarbonate samples

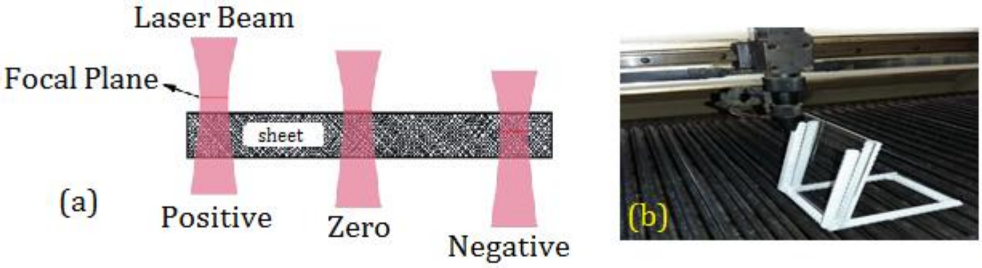


Figure 4- Determine the focal plane of the CO_2 laser used in the experiments

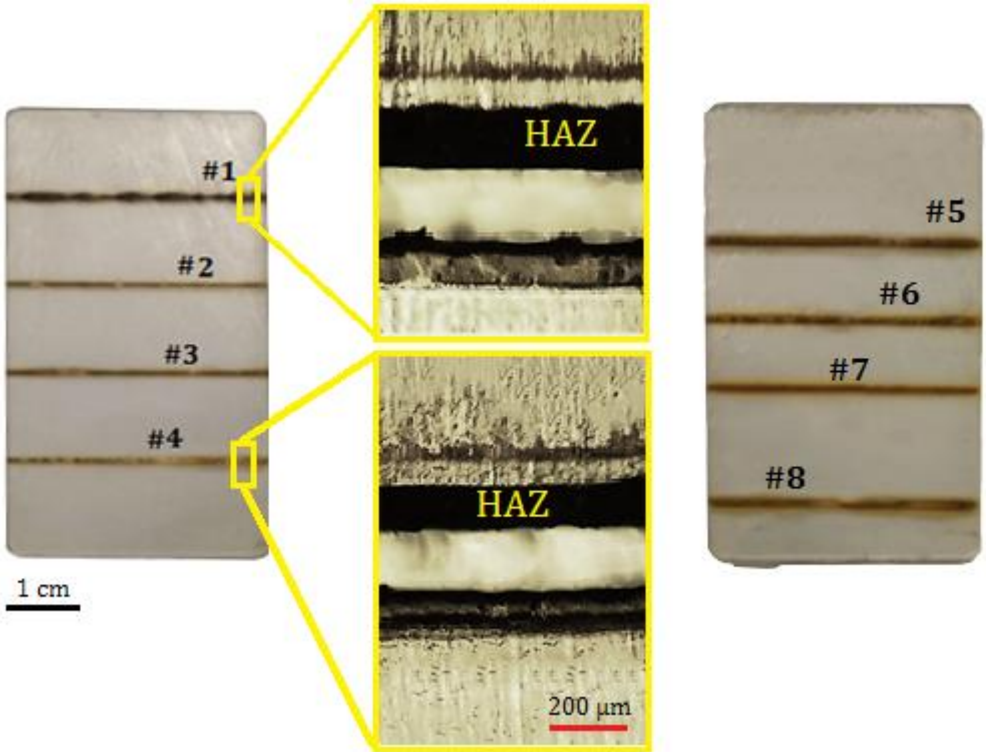
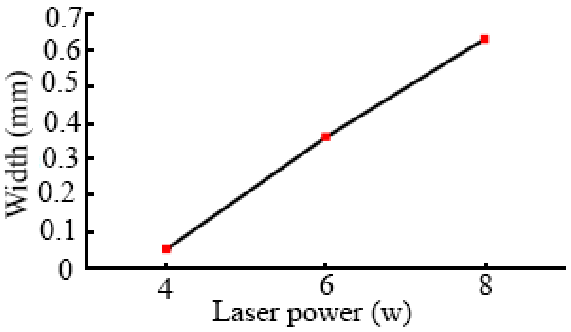
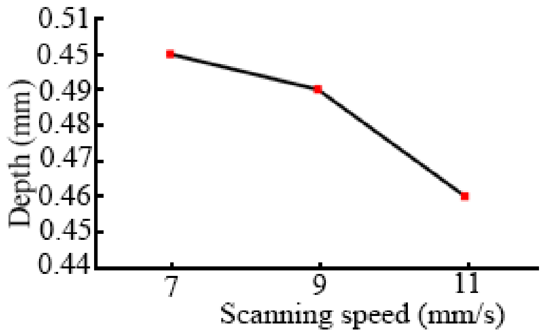


Figure 5- laser engraving image of sample #1 to #4.



(a)



(b)

Figure 6- a) The effect of Laser power changes on width of laser engraving, b) The effect of laser speed changes on depth penetration of laser engraving.

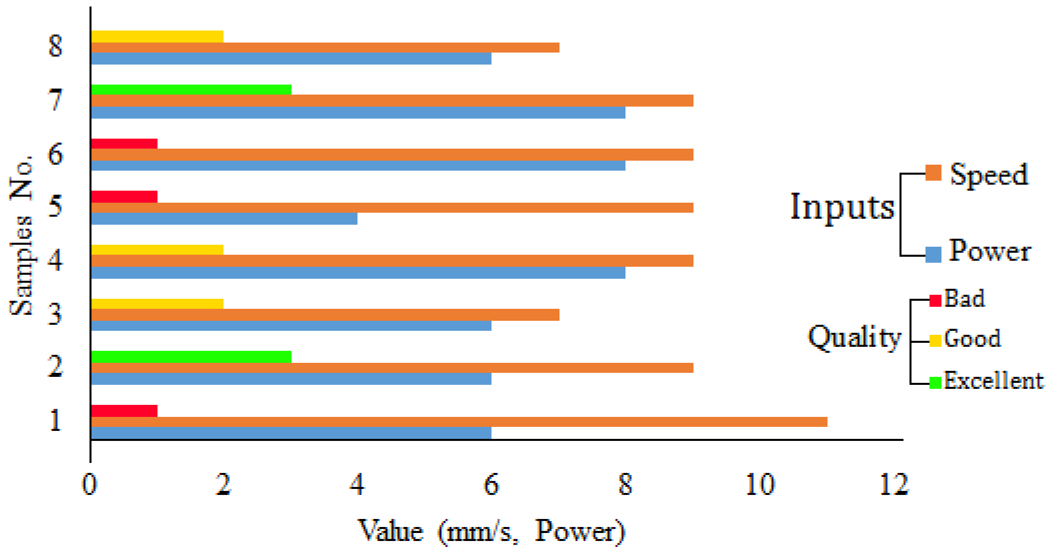


Figure 7. Evaluation of quality engraved kerf based on scanning speed and laser power inputs

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Table 1- Input parameters for the laser engraving process

No	Power (W)	Speed mm/s	Focal plane position (mm)	HAZ (mm)	Width (mm)	Depth (mm)	Quality
1	6	11	40	0.06	0.25	0.50	BAD
2	6	9	40	0.17	0.31	0.49	EXCELLENT
3	6	7	40	0.49	0.98	0.46	GOOD
4	8	9	40	0.14	0.58	1.00	GOOD
5	4	9	40	0.12	0.40	0.85	BAD
6	8	9	38	0.18	0.50	1.25	BAD
7	8	9	42	0.25	0.68	0.95	EXCELLENT
8	6	7	42	0.52	1.12	0.38	GOOD