THE EFFECT OF CO2 LASER ENGRAVE PARAMETERS ON SURFACE ROUGHNESS ON POLYMETHYLMETHACRYLATE (PMMA)

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ABSTRACT

The investigation of the laser engraving process has been the focus of a significant amount of research in the field of laser machines. On the surface of the material, gaps and imperfections will appear as a natural result of the engraving process. It is widely held that the surface texture of a material has a significant impact on the material's mechanical qualities, as well as its functional performance and aesthetic appeal. As a result, the purpose of this study is to investigate the influence that different process parameters have on the PMMA (polymethylmethacrylate) surface during the engraving process. PMMA was used throughout this investigation in the engraving process, which was carried out by a machine equipped with a 40W CO2 laser tube. In order to explore the effect that laser engraving has on materials, a total of 25 separate experiments were carried out in line with the Taguchi design principles. It has been investigated how surface roughness (Ra), as well as total machining time, is affected by the laser power, scanning speed, scan gap, and nozzle distance that are considered to be input factors. According to the findings, the surface roughness of the sample had a value that varied from 0.810 to 5.159 micrometres when measured in terms of distance. The factor that has the greatest influence on the Ra value is the scanning speed, which is followed by the nozzle distance, laser power, and scan gap. On the other hand, the amount of time necessary for the machine to finish engraving on the sample can range anywhere from 58 to 135 seconds, with the scanning speed being the characteristic that has the most influence on this figure.

Keywords: CO2 laser engrave, PMMA, surface roughness, optimization.

1.0 INTRODUCTION

The application of laser technology in non-traditional machining processes, particularly in the fields of cutting, marking, and engraving [1-5], has made the technology well-known in recent years. The whole phrase "Light Amplification by Stimulated Emission of Radiation" is where the abbreviation "laser" comes from [6-8]. Because the aforementioned method required a significant quantity of energy or power, the laser was able to successfully sever and remove the material. Subsequently, over the course of the marking process, it was seen that the material underwent very little changes in terms of the inherent attributes it possessed [3,5,17]. In the context of the technique of engraving, it has been found that variations in the characteristics of the material and the structure of the material are more prominent and visually evident.

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According to Ninikas et al. (2016), the selection of appropriate process parameters is essential because various materials have varying capacities of absorption, which results in changes in the quality of material surfaces. This makes it necessary to account for these differences when designing the process. Previous research [12-17] has provided a summary of the factors that might impact the surface roughness. These factors include scanning speed, focal distance, scan gap, and laser power. A research study on laser engraving of PMMA using a CO2 laser was carried out by Hubeatir et al. [5] with the intention of utilising the Taguchi approach in order to conduct an analysis of the pertinent parameters. The results of the research show that there is a link between the growth in surface roughness value and the increase in scanning speed and laser power. This correlation is a positive one.

The surface roughness of a product is an important factor when evaluating the surface's finish [14-18, 26-28]. This is because the surface roughness of a product serves as an indicator of the product's overall quality. When determining the quality of the final product, it is not appropriate to take into consideration the degree to which the level of surface polish changes from one area to another inside the product itself. On the other hand, the exploration of surface roughness has generally focused on individual values rather than analysing the interplay between components and their effect on the outcomes. This is in contrast to the research that has been done on the roughness of surfaces. According to Imran et al. [4] and Nguyen et al. [7], researchers have shown that laser engraving has a high level of sensitivity to the input process parameters. This is something that was not previously known. These results are based on research that was carried out on the subject in question.

Therefore, the aim of this work is to investigate the influence that the characteristics of the laser parameters effect on the surface roughness. The Taguchi approach was utilised in order to conduct an investigation into the impact that the laser engrave parameter had on the responds that were involved.

2.0 METHODOLOGY

2.1 CO2 Laser Engrave Machine

During the course of the experiment, a CO2 Laser Engrave Machine with a power output of 300W was utilised. This machine was demonstrated to be compatible with the K40 Whisperer programme, as illustrated in Figure 1. The gadget has a working surface that is 300 millimetres by 200 millimetres, which allows for the nozzle to be moved about freely. The software for the system is only capable of reading files in two different formats—specifically, .svg and .dxf. The machine successfully severed non-metallic materials with a maximum thickness of five millimetres, demonstrating its competence to cut through materials of this thickness range. Both the speed of the cutting and engraving processes achieved their utmost potential, with the former reaching 50 mm/s and the latter reaching 300 mm/s.

Figure 1: CO2 Laser Engrave.

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Table 1 provides details on the parameter setting settings that have been taken for the CO2 laser equipment over the course of this investigation. The controller software was responsible for setting the scanning speed and the value of the scan gap; yet, the hardware of the machine was the one that was in charge of controlling the laser power. The sample of PMMA was placed in a position that it was directly below the nozzle of the machine.

Table 1: Laser Engrave Parameter List and Level.

PARAMETER	LEVEL 1	2	3	4	5
Laser Power	10% (4W)	25% (10W)	50% (20W)	75% (30W)	100% (40W)
Scanning Speed (mm/s)	100	150	200	250	300
Scan Gap (Dots Per Inch, DPI)	125	200	333	500	1000
Nozzle Distance (mm)	2	3	4	5	6

2.2 Surface Roughness Experiment

As shown in Figure 2, the Surface Roughness Tester Machine was utilized in order to establish the roughness level of the engrave surface. This was done in order to ensure that the engraving would turn out correctly. Table 2 provides a rundown of the parameters that make up the machine setting values as a summary.

Table 2: Surface Roughness Tester Machine Setting.

PARAMETER SETTING	VALUE
λs	2.5µm
N	20
Standard	ISO1997
λc	0.25mm

Figure 2 shows as the sample was positioned such that it lay just beneath the probe of the tester machine. This allowed for the surface roughness to be measured, analyzed, and determined. The probe will go in a straight line down the engraved line, and the value of the engraved roughness will be shown on the screen of the tester machine as it moves down the line.

The Taguchi method (L25) orthogonal array was used and was subsequently shown in Table 3 as a result. During the process of engraving, a timer was used to record the amount of time spent on the machining operation for each of the samples, and a machine was used to assess the roughness of the engraving surface. Additionally, a timer was employed to record the amount of time spent on the machining operation for the whole process. Data was collected on the surface roughness as well as the engraving times from the responses.

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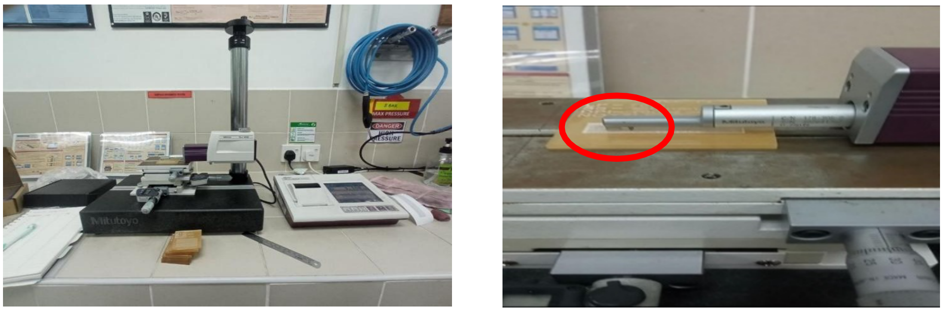

(a) **(b)**

Figure 2: (a) Surface Roughness Tester Machine (b) Sample on Surface Roughness Machine.

Table 3: Engraving Parameter and Responses.

Run No	Laser Power (%)	Scanning Speed (mm/s)	Scan Gap (DPI)	Nozzle Distance (mm)	Responses	
					Surface Roughness, Ra (µm)	Engrave Time (s)
1	10	100	125	2	1.887	133
2	10	150	200	3	1.887	103
3	10	200	333	4	1.484	82
4	10	250	500	5	1.435	68
5	10	300	1000	6	1.713	60
6	25	100	200	4	1.394	133
7	25	150	333	5	1.560	104
8	25	200	500	6	2.344	82
9	25	250	1000	2	1.466	69
10	25	300	125	3	1.372	60
11	50	100	333	6	5.159	132
12	50	150	500	2	1.429	105
13	50	200	1000	3	1.450	84
14	50	250	125	4	1.621	68
15	50	300	200	5	1.557	59
16	75	100	500	3	4.162	72
17	75	150	1000	4	2.444	104
18	75	200	125	5	2.783	82
19	75	250	200	6	3.005	68
20	75	300	333	2	0.810	59
21	100	100	1000	5	4.216	135
22	100	150	125	6	3.522	105
23	100	200	200	2	1.385	81
24	100	250	333	3	1.821	67
25	100	300	500	4	1.147	58

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4.0 RESULTS AND DISCUSSION

4.1 Mean and S/N Ratio Surface Roughness Analysis

Table 4 presents the summary of the mean value for surface roughness at each level of the parameter, and a graph that represents these data has been constructed. Table 4 is located here. A high value of delta [7-8] indicates that there is a significant change in one of the parameters that impacts the surface roughness of the laser engrave. Figure 3 depicts the graph that was plotted for the mean, and it reveals that the scanning speed parameter is ranked as first, followed by nozzle distance and laser power. This can be seen by looking at the graph. The relevance of the scan gap value was the lowest of any of the other parameters.

Table 4: Mean Value of Surface Roughness.

Level	Laser Power	Scanning Speed	Scan Gap	Nozzle Distance
1	1.681	3.364	2.237	1.395
2	1.627	2.168	1.846	2.138
3	2.243	1.889	2.167	1.618
4	2.641	1.87	2.103	2.310
5	2.418	1.32	2.258	3.149
Delta	1.014	2.044	0.412	1.753
Rank	3	1	4	2

It is achievable to identify the differences in response (surface roughness) that may be seen in Figure 3 to any combination of the elements. At the scanning speed section, the values 1.32 m and 3.364 m were revealed as having the lowest and largest values of average surface roughness, respectively. These values were demonstrated to be at the extremes of the distribution. Both of these values were discovered on Level 5, and Level 1 respectively. While the value of surface roughness was plotted at Level 4 with a value of 2.641 m, the mean surface roughness for laser power was plotted at Level 2 with a value of 1.627 m. The value of the surface roughness was greatest at Level 4, with Level 2 having the lowest value possible. When the proportion of laser power has been raised to more than 75%, the value of the surface's roughness starts to decrease. This is as a result of an increase in the ablation process that occurs as a consequence of an increase in laser power, and this discovery has a good agreement with the work that was done by Imran and his colleagues [4, 19, 20, 27].

Hasan et al. [9] discovered that when the scanning speed increased, low laser-matter contact time occurred. This led to a reduction in the surface area of the material that was vaporized as a result of the interaction between the laser and the material. Because the ablation process is so dominant, the value of the material's surface roughness will decrease as the length of time spent between the laser and the material reduces. This is owing to the fact that the ablation process takes precedence. On the other hand, a lengthier melting process resulted in the formation of bulges [4, 13-15], which led to a larger degree of surface roughness (at Level 1) being formed as a result of the process. This was the case because the bulges caused the surface to be less level.

The laser power as well as the scanning speed value that is used in combination with its value are what define the scan gap characteristic [21-25]. The value of the surface roughness was determined to be at its lowest when the nozzle gap was adjusted at a measurement of 2 mm. On the other hand, it was discovered that the nozzle spacing needed to be adjusted at 6 mm in order to get the highest possible degree of surface roughness. A surface that has a lower value of surface roughness is one that has a lower overall value of surface roughness. Khan et al. and Xie et al. [10,13] conducted research that was very similar to what we did, and they came to the same

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conclusion: the surface quality can deteriorate with increasing distance from the laser defocus, but a smoother surface can be achieved by reducing the amount of time that the laser beam is focused on the material. Xie et al. [10,13] came to the same conclusion.

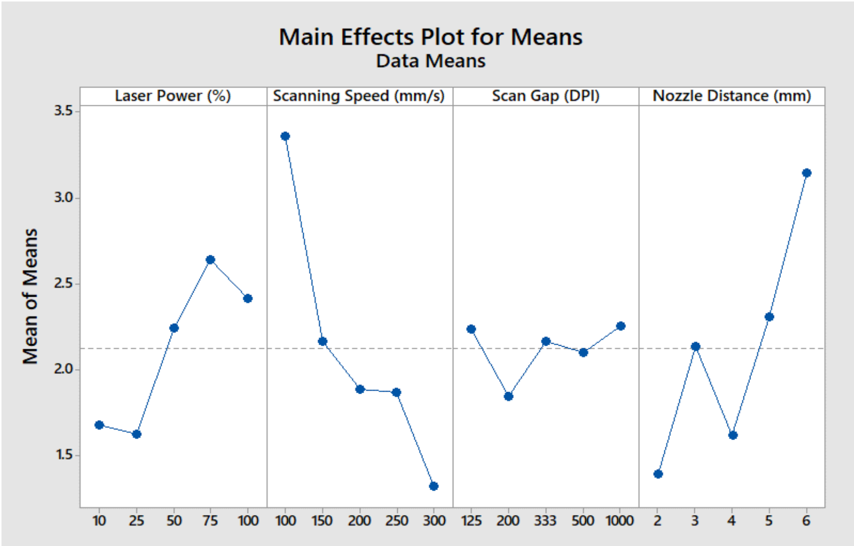

Figure 3: Mean Graph of Surface Roughness.

The signal-to-noise ratio, often known as the S/N ratio, is a measurement that indicates the level of quality in a process. Therefore, a higher value of the signal-to-noise ratio might potentially result in a system that is more dependable [7,21,22]. The significance of the S/N ratio was examined by using the criterion "the lower, the better," which reads as follows: "the smaller, the better." This is because a smoother surface implies a better representation for the display product, and a lower value of surface roughness formed in the laser engraving process indicates a smoother surface. Additionally, this is because a smoother surface indicates a lower value of surface roughness created in the laser engraving process. The findings of this analysis of the S/N ratio data were shown in Table 5. It was established that the factor that had the most influence on the surface roughness was the scanning speed. This was followed by the nozzle distance, laser power, and scan gap as the factors that had the next highest influence.

Table 5: S/N Ratio Value of Surface Roughness.

Level	Laser Power	Scanning Speed	Scan Gap	Nozzle Distance
1	-4.454	-9.507	-6.457	-2.587
2	-4.043	-6.235	-4.926	-5.816
3	-5.724	-5.155	-4.984	-3.893
4	-7.353	-5.084	-5.443	-6.447
5	-6.532	-2.126	-6.297	-9.364
Delta	3.31	7.381	1.53	6.776
Rank	3	1	4	2

Figure 4 shows that the highest mean for S/N ratio calculated for the surface roughness is created at scanning speed Level 5 with a value of -2.126 decibels (dB). This was determined by the data presented in the figure. The computations shown in the figure led to this conclusion being reached. In contrast, it was discovered that the mean value of the S/N ratio was the lowest when the scanning speed was set to level 1, with a value of -9.507 dB. This was the case when the value was measured.

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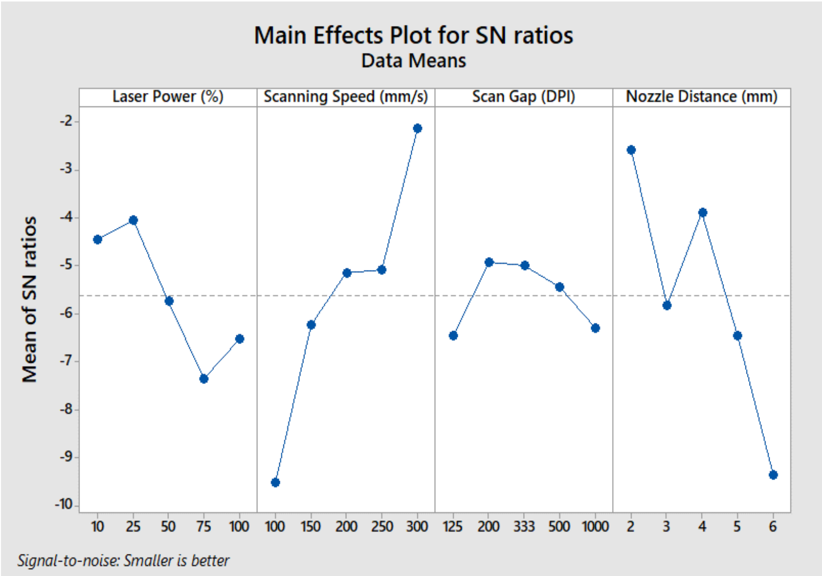

Figure 4: S/N Ratio Graph of Surface Roughness.

5.0 CONCLUSIONS

In the present investigation, the Taguchi approach was utilized to explore the link between surface roughness and the effects of four elements connected to laser engraving: laser power, scan speed, scan gap, and nozzle distance. Both the mean and the signal-to-noise ratio were utilized in the analysis of the experimental data on the impacts and responses. During the course of the analysis that was carried out as part of the research project, it was discovered that the scanning speed was the characteristic that had the most significant influence on the response (surface roughness). It was determined that this is the case as a result of the influence that the temperature of the laser had on the surface of the PMMA material. The scan gap and the nozzle distance, on the other hand, had the least significant of an influence on the surface roughness.

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