CORRELATION OF CUTTING SPEED ON KERF WIDTH AND HAZ DURING CO_2 LASER CUTTING OF ALUMINA

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ABSTRACT: Alumina is widely used in the automotive, aviation and electronics industries due to its advantages such as high hardness, high melting temperature, and high corrosion resistance. One of the crucial methods to process alumina in those applications is the cutting process. Achieving the right equilibrium between cutting speed and cut quality is crucial, as it directly influences another vital aspect of the cutting process: material removal rate (MRR). The objective of this study is to investigate the correlation between cutting speed and cut quality during CO_2 laser machining of alumina. The research involves varying the cutting speed in the range of 500 mm/min to 800 mm/min and measuring the kerf taper angle and heat affected zone (HAZ). The measurements were taken from micrographs obtained using a Stereo Microscope. Regression analysis was performed using Minitab software to assess the strength and significance of the correlation between cutting speed and kerf taper angle and HAZ. The results indicate a strong and significant correlation between cutting speed and HAZ, with an R^2 value of 0.8432 and a P-value of 0.011. Conversely, the study found a weak and insignificant correlation between cutting speed and kerf taper angle, with an R^2 value of 0.1540 and a P-value of 0.344.

KEYWORDS: *Laser Cutting; Kerf taper angle; HAZ; Alumina Ceramic*

1.0 INTRODUCTION

Alumina finds extensive utilization across the automotive, aviation, and electronics sectors. It serves as an effective electrical and thermal insulator, ignition system component, and bearing material. This is owed to its notable properties, including high hardness, a high melting point, and remarkable resistance to corrosion [1-3]. However, the conventional machining of alumina presents challenges due to its brittle structure, high toughness, and extreme hardness, leading to rapid tool wear [4,5]. Practical applications necessitate alumina machining, such as drilling or sawing. The processing of a high-intensity laser beam is one of the alternative machining techniques [6]. Compared to conventional machining techniques, laser machining offers several advantages, such as non-mechanical contact between the cutting tool and workpiece, high precision, localized treatment, and cost-effectiveness [7,8]. However, laser machining requires high temperature processing, which produces high temperature gradients along the cutting edges and a high thermal stress in the cutting section[9,10]. Once the thermal stress levels reach the critical values, it is impossible to prevent the formation of cracks at the cutting edges, which limits the practical applications of the machined components.

Study of the laser cutting process and the effect of cutting speed on the kerf taper angle, HAZ, and surface roughness is crucial to determining the quality of the final product [11]. Laser ablation is an alternative method for cutting alumina characterized by minimal mechanical impact. In this technique, material is vaporized with minimal impact on the surrounding area [12-16]. Various laser machining processes exist, including fiber laser, CO2 laser, and Nd:YAG. CO2 lasers are often preferred for macro processing applications due to their high power and superior beam quality [17].

There are studies on laser cutting of alumina relating the laser machining process parameters and the quality characteristics of the machined specimen such as HAZ, surface roughness, kerf width, and microcracks. It was reported that the length of the HAZ is positively correlated with laser power and inversely correlated with cutting speed [18]. The same study also revealed that that microcracks can form in the

HAZ due to the reattachment of the molten alumina matrix to the base material and thermal stress that generates microcracks below the surface [19]. Further research has indicated that an increase in laser power, gas pressure, and cutting speed increases kerf width [20,21]. The surface roughness of the cutting surface is significantly influenced by the gas pressure, gas composition, and cutting speed, as indicated by previous research. However, the relationship between cutting speed and surface roughness is not linear, and inefficient cutting and a rougher surface finish can result from cutting speeds that are either too high or too low [22].

Most of the studies done on this subject matter were done on thin alumina plate with thickness of less than two millimeters. There is lack of study of CO2 laser machining of alumina on thicker alumina plates. This research explored the relationship between cutting speed and both kerf width and heat-affected zone (HAZ) when employing CO2 laser technology for cutting of alumina plate of three millimeters thickness.

2.0 METHODOLOGY

For this project, the CO2 Laser Machining model MHL2512HV2-R PLUS was utilized to cut a 99.7% alumina (Al2O3) ceramic plate measuring 80mm x 80mm x 3mm. During the experiments, the cutting speed values were varied between 500 to 800 mm/min, with an increment of 50 mm/min between each trial. The remaining CO2 laser cutting parameters were fixed according to published studies [17-21] related to cutting of alumina and shown in Table 1. The experimental setup and cutting conditions are shown in Figure 1.

Table 1: Laser cutting condition

Cutting Speed (mm/min)	Laser Power (W)	Frequency (Hz)	Nozzle Gap (mm)	Nozzle Diameter (mm)	Gas Pressure (Bar)
500-800	1500	500	1.5	1	7

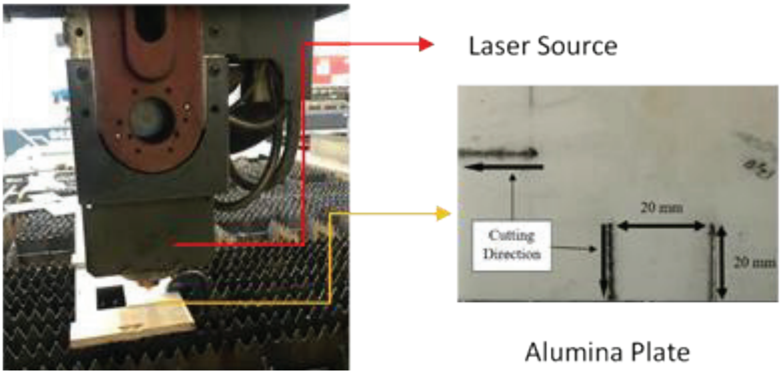


Figure 1: Experimental Setup

The micrograph images of the samples were taken and measured using Stereo Microscope, as shown in Figure 2. The HAZ is identifiable through noticeable discoloration, indicating alterations in material properties attributed to thermal effects. Equation 1 and Equation 2 were used to calculate the HAZ and kerf taper angle, respectively, where t is the thickness of the alumina plate. Three readings were taken for each measurement, and the averages were calculated.

$$\text{HAZ} = \frac{\text{HAZ width - Kerf width}}{2} \tag{1}$$

$$\text{Kerf Taper Angle } (\theta) = \text{Arctan } \left(\frac{\text{Kerf width entrance - Kerf width exit}}{2\text{t}}\right) \tag{2}$$

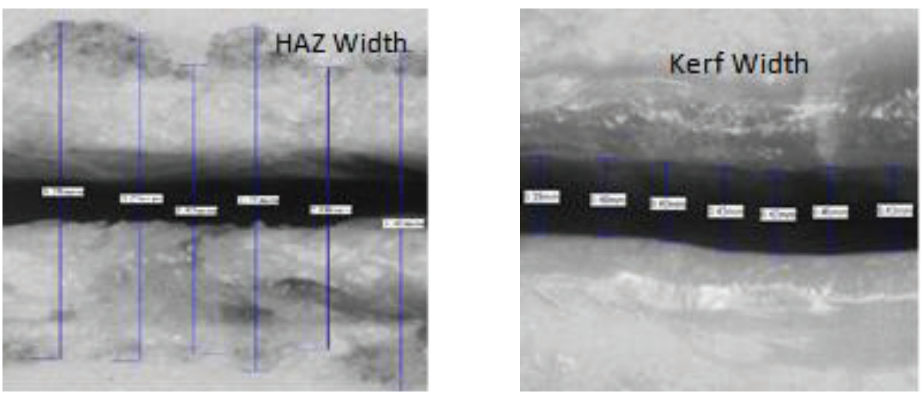


Figure 2: Micrograph image (a) HAZ width (b) Kerf width

The regression analysis to establish the R2 values for the relationship between cutting speed and the kerf taper angle, heat affected zone (HAZ), and surface roughness were done using Minitab software.

During the regression analysis, scatter plots, P-values, and R2 analyses were conducted. P-values were used as a statistical measure to determine whether there was a significant correlation between cutting speed and the three output responses. A P-value less than 0.05 indicates a significant correlation.

3.0 RESULT AND DISCUSSION

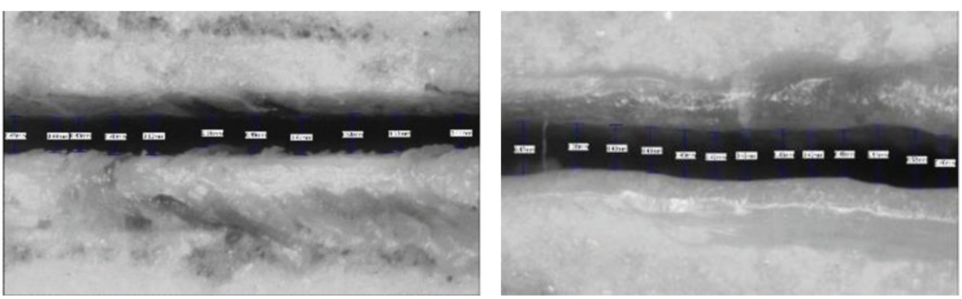
The outcomes of the laser cutting experiment, comprising of HAZ and kerf taper angle data for different cutting speeds, are presented in Table 2.

Table 2: Result of Experiment Output

Run	Cut Speed (mm/min)	Kerf Taper Angle (Degree)	HAZ (mm)
1	500	0.29	1.20
2	550	0.43	1.07
3	600	0.36	0.94
4	650	0.86	0.89
5	700	0.14	1.35
6	750	0.07	0.83
7	800	0.14	0.85

3.1 Correlation between cutting speed and kerf taper angle

Figure 3 shows the sample of micrographs of the kerf width measurement for entrance and exit. As reported by other study [12,13], the kerf width at the entrance is larger than that at the exit. This is due to the larger removal of materials at the entrance compared to the exit. The kerf taper angle was calculated based on Equation 2 and tabulated in Table 2.



(a) (b)

Figure 3: Kerf width at cutting speed of 700 mm/min. (a) Kerf width (entrance)-0.46 mm (b) Kerf width (exit)- 0.44 mm

The regression analysis for cutting speed and kerf taper angle is shown in Figure 5. The analysis indicates that there is no statistically significant relationship between the Kerf Taper Angle and cutting speed because the P-value is greater than 0.05, specifically 0.344. Furthermore, the R2 value is only 1.54%, which is extremely low.

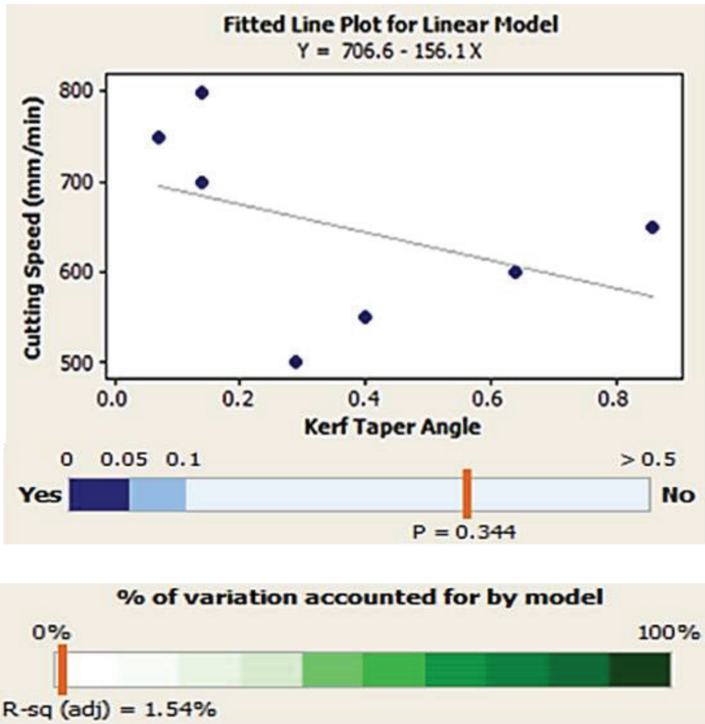
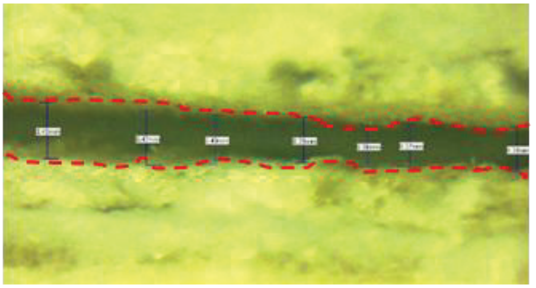
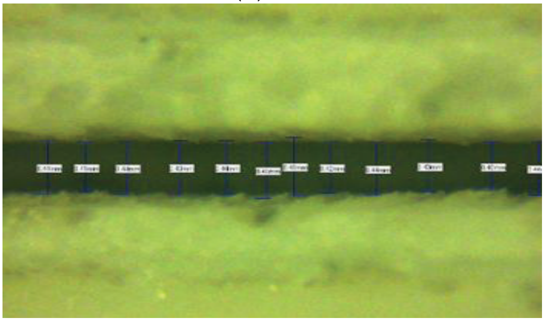


Figure 4: Regression analysis for cutting speed and kerf taper angle

A positive linear correlation was observed between cutting speed and kerf taper angle within the range of 500 mm/min to 650 mm/min. However, beyond this cutting speed, the kerf taper angle decreased abruptly to less than 0.14. At high cutting speed, the rapid movement of the high-temperature laser beam prevents the formation of a large amount of recast layers at the kerf width entrance resulting in better cuts and minimizes the difference between the entrance and exit kerf width. This is evidence as shown in Figure 5 where at a higher speed of 750 mm/min, the edge of the cut is much straighter and cleaner compared to the more undulating cutting edge of that of 500 mm/min cutting speed. This finding is consistent with previously reported study [21].



(a)

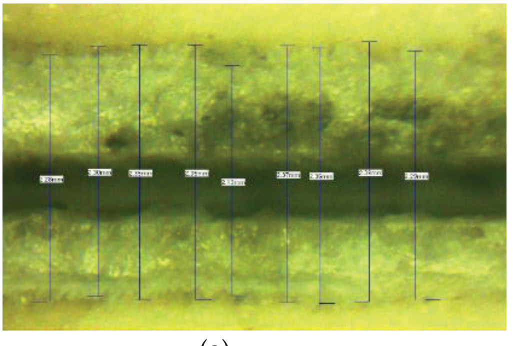


(b)

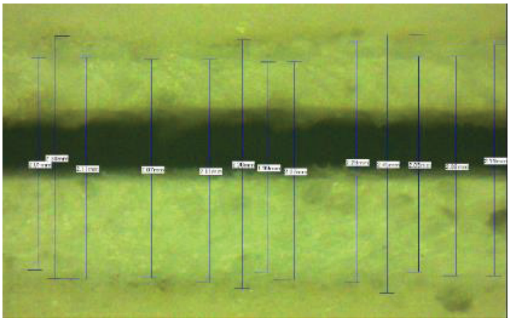
Figure 5: Micrographs of kerf width at the cutting speed of (a)500 mm/min and (b) 750 mm/min

3.2 Correlation between cutting speed and HAZ

The micrographs of the HAZ measurements for cutting speeds of 600 mm/min and 800 mm/min are shown in Figure 6. The HAZ width values were determined based on the average of nine measurements for each



(a)



(b)

Figure 6: Micrographs HAZ cutting speed (a) 600 mm/min and (b) 800 mm/min

Figure 7 presents the regression analysis results between cutting speed and HAZ. The analysis shows that there is a statistically significant relationship between the two variables, as evidenced by a P-value of 0.011, which is less than acceptance limit of 0.05. The quadratic equation $y = 4684 - 7487x + 3355x^2$ provides a good fit for the data and can be used to predict the HAZ value for a given value of cutting speed. The R^2 value of 84.32% indicates a strong quadratic correlation between cutting speed and HAZ, meaning that 84.32% of the variation in HAZ can be explained by the quadratic model based on cutting speed.

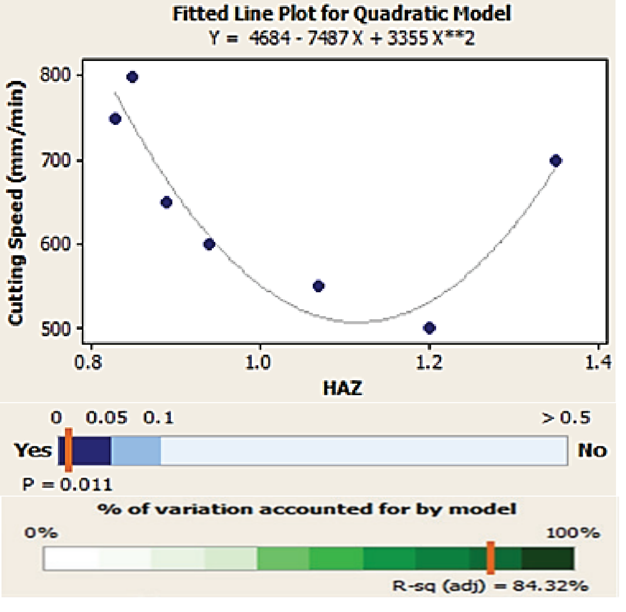


Figure 7: Regression analysis for cutting speed and kerf taper angle

A lower HAZ value indicates better cut quality. The HAZ refers to the area affected by high heat, which can cause changes in material properties and reduce the strength of the alumina substrate. Previous studies have shown that micro cracks in alumina ceramics typically begin in the HAZ region [23]. The HAZ values were found to be lowest at cutting speeds of 750 and 800 mm/min. However, at moderate cutting speeds of 500 mm/min and 550 mm/min, higher HAZ values of 1.20 mm and 1.07 mm were obtained, respectively. The heat transfer rate to the alumina surrounding the cut is lower at higher cutting speeds, resulting in lower HAZ values.

4.0 CONCLUSION

This study concluded that there is strong correlation between cutting speed and HAZ, indicated by the low P-value of 0.011 and high R^2 value of 84.323%. However, there is no significant correlation between cutting speed and kerf width taper angle, indicated by a high P-value of 0.344 and a low R^2 value of 1.54 %.

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AUTHOR CONTRIBUTIONS

B. Umroh: Writing-Original Draft Preparation; M. N. A. Rahman: Supervising and Writing-Reviewing and Editing; M. Solihin: Data Collection and Data Analysis; A.A.M. Sultan: Reviewing and Editing, Z. Ebrahim: Reviewing and Editing; R.L. Muhamud: Industry input & reviewing; A. Ginting: Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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