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Experimental Laser Cutting Material Removal Rate for Polymethylmethacrylate in Construction Applications

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Abstract

This research aims to optimize the laser cutting process on polymethylmethacrylate (PMMA) to improve efficiency and quality in construction applications. By exploring the influence of variations in laser current, cutting speed, and material thickness, this study sought to identify the optimal parameters that resulted in the highest material removal rate (MRR) with minimal overcut. Through a series of experiments testing various parameter combinations, the study found that a cutting speed of 40 mm/s, laser current of 80 A, and material thickness of 3 mm yielded the best cutting performance. The results show that optimization of laser cutting parameters can significantly improve the precision, energy efficiency, and quality of PMMA cutting results. The implications of these findings are significant for the development of more efficient and sustainable laser cutting techniques, supporting the use of PMMA in various innovative construction applications such as facades, decorative elements, and architectural prototypes. This research contributes to the understanding of PMMA laser cutting process optimization, with the potential to expand the application of this material in the construction industry through more efficient and quality fabrication methods.

1. INTRODUCTION

In the manufacturing and construction industries, laser cutting has emerged as a revolutionary machining process widely applied for precision cutting and material shaping. This method, particularly CO_2 laser cutting, offers advantages such as low cost, fast processing and high-quality results, making it an ideal choice for applications where accuracy and efficiency are required (Zhou & Mahdavian, 2004).

Laser cutting works by melting or vaporising the material to form precision walls along the cutting path, which can be customised for various material depths or thicknesses. The technology supports a wide range of materials, including metals, polymers and composites, enabling versatile applications in construction, such as intricate panel design, structural prototyping and advanced material customisation (Moradi et al., 2021).

Polymethylmethacrylate (PMMA) is a polymer widely used in construction due to its superior physical properties, such as high transparency, light weight, and ease of moulding, making it suitable for decorative facades, light diffusers, and structural components in modern architecture (Monsores et al., 2019). PMMA material is thermal properties, such as its low thermal diffusion (7×10^{-7} m²/s) and melting range around 300°C, contribute to improved cutting quality and reduced processing time during laser machining (Khoshaim et al., 2021). These qualities make PMMA an excellent candidate for sustainable construction materials where precision and efficiency are critical.

Previous research has shown that laser cutting parameters-such as cutting speed, laser power, and material thickness-play an important role in determining material removal rate (MRR), surface quality, and overall efficiency. Sharifi and Akbari (2019) shows that optimal laser power and speed are essential to achieve smooth cutting on metal alloys, a principle that applies equally to polymers such as PMMA. High cutting speeds

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minimise kerf width, while precise power and speed control ensure heat affected zone (HAZ) reduction and improved edge quality (Moradi et al., 2021). Furthermore, , Moghadasi et al. (2021) PMMA exhibits superior performance in reducing kerf width and HAZ compared to other polymers such as polycarbonate (PC) and polypropylene (PP), making it ideal for construction projects requiring high precision.

However, while previous research has explored the influence of laser cutting parameters on various materials, there are significant gaps in the understanding of CO_2 laser cutting parameter optimisation specific to PMMA in the context of construction applications. In particular, the influence of the combination of cutting speed, laser current and material thickness on MRR and overcut on PMMA, as well as the implications for yield quality and energy efficiency, is less explored in depth. This research aims to fill this gap by systematically investigating the influence of these parameters, with a focus on optimisation for sustainable and innovative construction applications. The results of this research are expected to contribute to the development of more efficient and high-quality laser-cutting techniques and expand the application of PMMA in construction elements such as facades, decorative structures and architectural prototypes.

Laser cutting technology is invaluable in construction to produce complex geometries such as curved panels, decorative facades and modular structural components. Recent advances in CO_2 laser cutting enable efficient material processing while maintaining a high-quality finish, reducing production time and costs. This paper focuses on optimising the laser cutting parameters of PMMA polymers-cutting speed, laser current and material thickness-to increase the material take-up rate and minimise overcut. By addressing these factors, this research aims to support the development of sustainable, efficient and high-precision manufacturing techniques customised for construction applications.

2. METHODS

Polymethylmethacrylate is the material used in this work, a generally applicable material. Figure 1 shows an illustration the laser cutting process on PMMA materials with thicknesses of 3 mm and 5 mm. The process begins with machine control via a computer, which configures parameters such as laser power, gas pressure, and cutting speed. A lens focuses the laser beam to concentrate energy at a specific point on the material's surface, enabling precise cuts. An assist gas, such as nitrogen or oxygen, is directed through a nozzle to clear molten material from the cutting area, ensuring smooth and defect-free cuts. The resulting cut path (kerf) is assessed based on the quality of the top and bottom surfaces, the cut width, and the heat-affected zone (HAZ) to verify the effectiveness of the chosen cutting parameters.

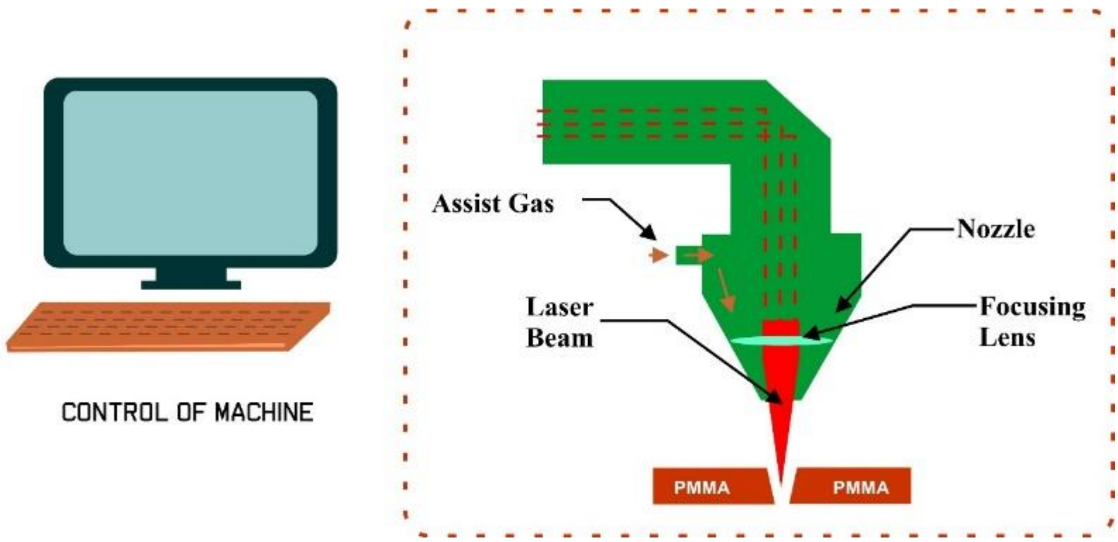

Figure 1. Illustration of laser cutting used PMMA

The parameters used in this work are shown in Table 1. while the PMMA cutting illustration, showing the difference in size at the top and bottom as well as the material thickness, can be seen in Figure 2.

Table 1. Parameters used in research

No	Parameter Process	Units	Process Parameter Value		
			Low	Medium	High
1	Laser cutting	Ampere (A)	60	70	80
2	Cutting speed	mm/s	20	30	40
3	Thickness	mm	3	-	5

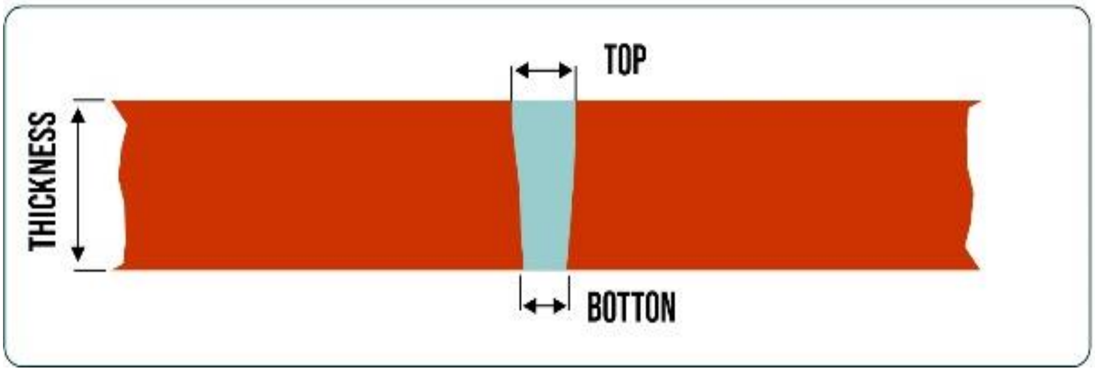

Figure 2. Illustration of PMMA cutting profile of 3 mm and 5 mm thickness

Table 2. Properties of PMMA (Khoshaim et al., 2021)

No	Properties	Values
1	Density	1188 kg/m^3
2	Thermal conductivity	0.193 $W.m^{-1}K^{-1}$
3	Heat capacity	1.42 $kJ\ kg^{-1}\ K^{-1}$
4	Flammability UL94	HB
5	Thermal expansion coeffisient	$7 \times 10^{-5} K^{-1}$
6	Thermal diffusivity	$7 \times 10^{-7} m^2/s$
7	Melting temperature	433 K
8	Water absorption	0.3 %
9	Ultimate strength	72.4 MPa

3. RESULT AND DISCUSSION

This section presents the research results and analyses obtained based on the specified parameters. The discussion focuses on the interpretation of data from the PMMA cutting process, by analysing the influence of variables on the Material Removal Rate (MRR) and overcut produced.

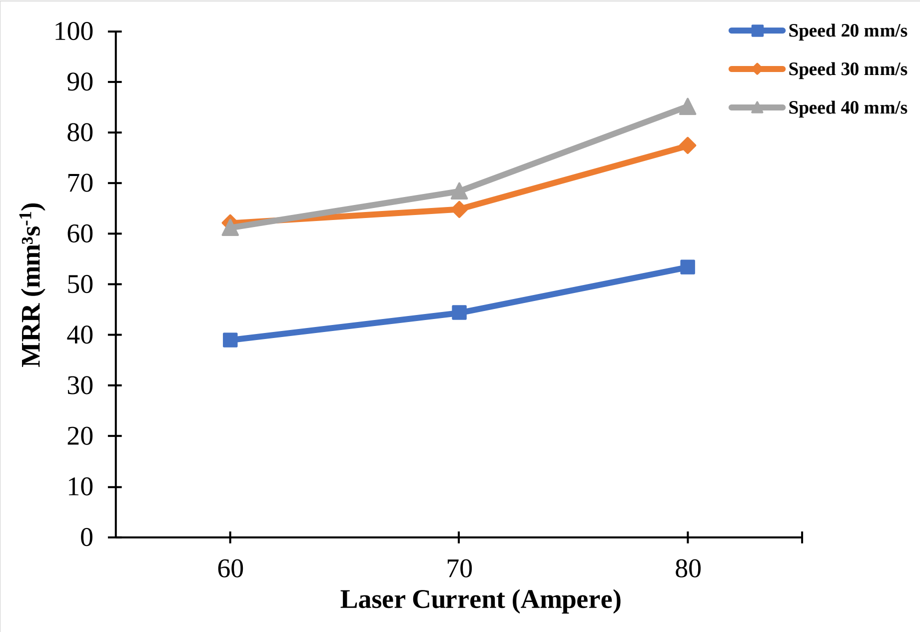

Figure 3. The result Material Removal Rate (MRR) of thickness 3 mm

The graph illustrates the relationship between laser current and Material Removal Rate (MRR) at varying nozzle speeds of 20 mm/s, 30 mm/s, and 40 mm/s. Figure 3 presents a linear trend, indicating that the MRR value rises proportionally with an increase in laser current and nozzle speed during the laser cutting process. Based on the results obtained, it can be seen in Figure 3. the movement of the nozzle displacement with a speed of 20 mm/s obtained an MRR value of 39 mm^3s^{-1} with a laser current of 60 A. While the maximum value is obtained from the use of a speed of 40 mm/s with an MRR value of 86 mm^3s^{-1} with a laser current of 80 A. It can be assumed that higher nozzle speeds also produce greater MRR at large laser current levels, resulting in the efficiency of laser energy distribution in removing material. This finding is in line with a study by Choudhury and Shirley (2010) which confirmed that a significant increase in laser power and travelling speed would increase MRR without affecting the quality of the cut if the parameters are within optimal limits. A high increase in MRR indicates the successful efficiency of the manufacturing process. However, it is likely to affect decreasing surface quality if the parameter selection is not set appropriately (Wang et al., 2021).

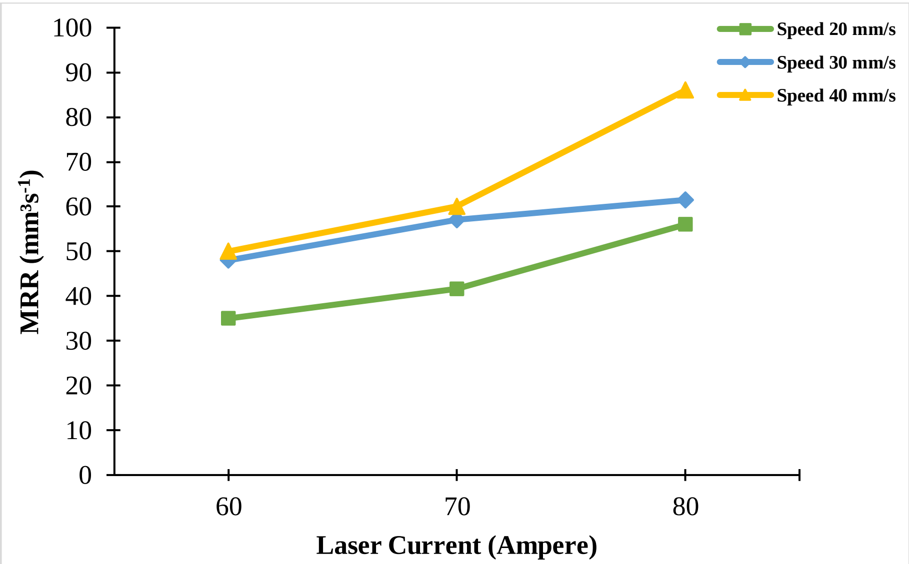

Figure 4. The result Material Removal Rate (MRR) of thickness 5 mm

Based on the graph shown in Figure 4, increasing the Laser Current from 60 A to 80 A provides a consistent increase in the MRR at cutting speeds. This indicates that the thermal energy generated by the laser increases with high current, accelerating the ablation process of PMMA material more efficiently. High cutting speed (40 mm/s) with 80 A current achieved the highest MRR. This is because the laser interaction time with the material is short enough that the energy generated is focused on material removal, without causing heat accumulation that can reduce efficiency. Meanwhile, at low speed (20 mm/s) with a current of 60 A, it is only 35 mm^3s^{-1}, where longer laser exposure causes melting of excess material that accumulates on the surface, thus inhibiting maximum material removal (Kumar & Babu, 2024). It should be noted based on the low laser current parameter graph that the energy generated is not large enough to optimally support high speeds. As a result, the MRR between speeds (20 mm/s, 30 mm/s, and 40 mm/s) shows an insignificant difference. However, at low laser current, as shown in the graph, 80 A, the MRR increases, especially at high speed, indicating that the combination of high current and high speed is an efficient relationship with PMMA thickness around 5 mm.

Based on the MRR results with graphical comparison Figure 3. is the MRR result with a PMMA cutting thickness of 3 mm while Figure 4 shows at a cutting thickness of 5 mm, there is a significant difference from the resulting MRR value which has decreased. The MRR value obtained tends to decrease as the material thickness increases (Hashemzadeh & Pourshaban, 2020). This is due to the process of material removal in PMMA due to the absorption of laser energy which causes the material to evaporate and melt quickly so that the level of cutting efficiency is affected by the laser energy absorbed by the material.

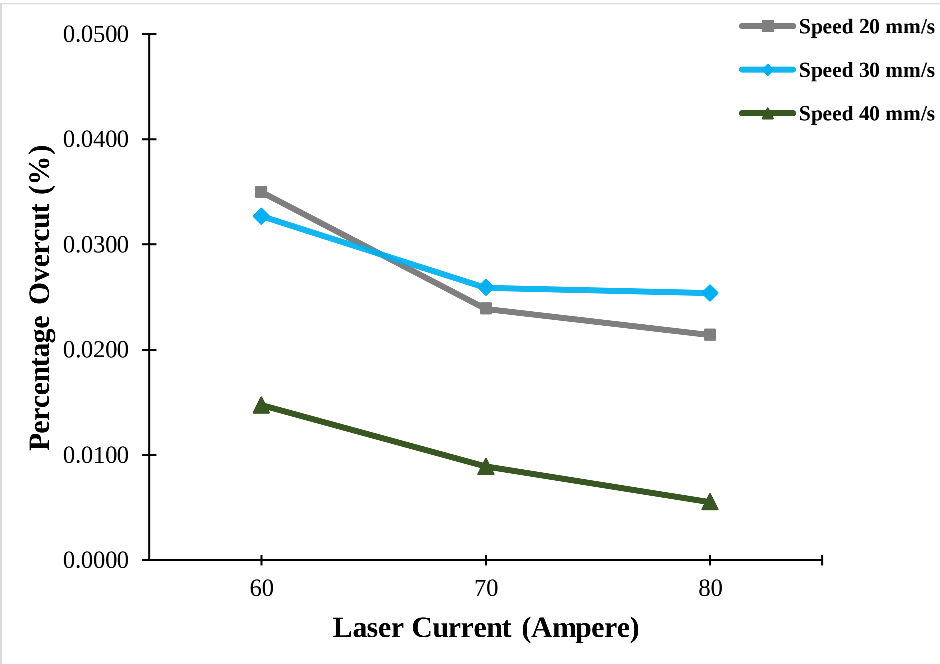

Figure 5. The result Overcut of thickness 3 mm

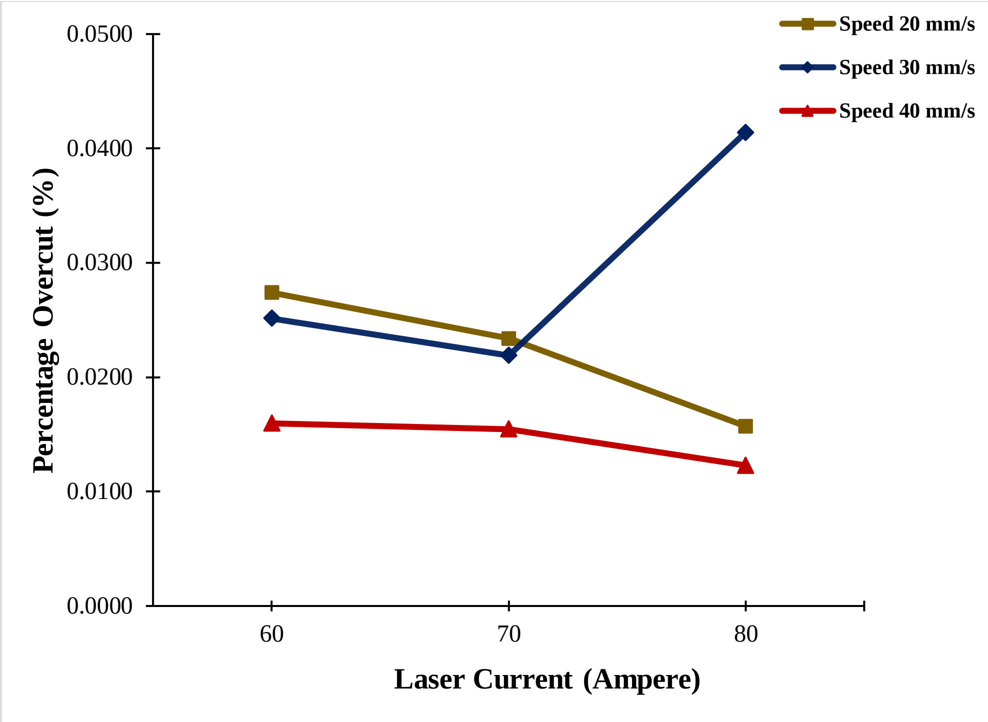

Figure 6. The result Overcut of thickness 5 mm

The cutting speed significantly affects the occurrence of the overcut phenomenon in the process. Based on the data shown in the graph, increasing the cutting speed significantly reduces the overcut value. At low speeds, such as 20 mm/s, the overcut reaches 0.0350% at a current of 60 A, while at a high speed of 40 mm/s, the overcut value decreases drastically to 0.0055%. This occurs because low speeds provide longer laser exposure times, causing excessive melting around the cut area, while high speeds limit such melting. In addition, increasing the laser current from 60 A to 80 A also resulted in a decrease in overcut as the greater thermal energy helped to remove material in a more efficient and focused manner. The material thickness affects the overcut results, where PMMA a thickness of 5 mm produces a lower overcut than PMMA with a thickness of 3 mm. This is because the thermal energy distribution in thicker material does not reach the bottom kerf area, so the material is not completely cut and results in a smaller overcut. In contrast, thinner materials have more significant melt due to wider energy distribution.

The findings of a study conducted by Yusuf (2024) confirmed that higher amperage can improve the precision of the cut, which can reduce the occurrence of overcut. Therefore, based on the findings of this study, the optimal parameter combination—high cutting speed (40 mm/s) and high laser current (80 A) was found to be effective in reducing overcut and improving the efficiency of the laser cutting process, particularly for PMMA.

4. CONCLUSIONS

This study shows that the optimal laser cutting parameters for Polymethylmethacrylate (PMMA), such as a cutting speed of 40 mm/s, a laser current of 80 Ampere, and a material thickness of 3 mm, resulted in an excellent Material Removal Rate (MRR) of 86 mm^3/s, with a minimum overcut of 0.0055%. These parameters not only improve material removal efficiency but also ensure precise cutting, which is critical for construction applications requiring high-quality PMMA components. This study highlights the importance of controlling the laser speed and current to reduce excessive melting and maintain a clean, high-precision cut, making these findings highly relevant to manufacturing in the construction industry where precision and material integrity are important.

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