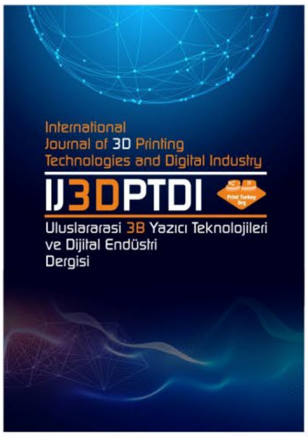

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INVESTIGATION OF THE EFFECTS OF PROCESS PARAMETERS ON MACHINING PERFORMANCE IN LASER CUTTING OF 3D-PRINTED PLA

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ABSTRACT

In the current research, the influences of process parameters on surface roughness and kerf width in CO_2 laser cutting of PLA plates produced by the fused filament fabrication method were experimentally investigated. Laser cutting was performed using three plate thicknesses (2, 3, and 4 mm), three cutting speeds (3, 6, and 9 mm/s), and three laser power levels (90, 95, and 100 W). Surface roughness was determined with a surface roughness tester, and kerf widths were evaluated using a digital microscope. The findings indicate that higher cutting speeds and lower laser power lead to a reduction in both surface roughness and kerf width. Higher cutting speeds combined with lower laser power decreased the thermal effect during cutting by reducing the interaction between the laser and material, resulting in lower surface roughness and narrower kerf width. The effect of plate thickness on surface roughness and kerf width was complex, varying with cutting speed and laser power. The lowest surface roughness (0.951 µm) and kerf width (0.793 mm) values were achieved with a plate thickness of 3 mm, a cutting speed of 9 mm/s, and a laser power of 90 W. This study provides valuable insights into how laser cutting parameters affect the surface quality and dimensional accuracy of PLA plates, contributing to quality improvements in industrial applications. The results highlight the essential influence of cutting speed and laser power on managing surface roughness and kerf width, thus aiding in optimizing the process.

Keywords: Laser cutting, Fused filament fabrication, PLA, Surface roughness, Kerf width.

1. INTRODUCTION

Polylactic Acid (PLA) is a biodegradable thermoplastic polymer sourced from renewable materials like cornstarch, sugarcane, and tapioca roots. Unlike petroleum-based plastics, PLA offers environmental sustainability due to its ability to decompose under industrial composting conditions [1]. Its desirable properties, including mechanical strength, stiffness, and thermal stability, make PLA suitable for diverse applications, such as packaging, biomedical devices, automotive parts, and 3D printing. Additionally, its relatively low melting point and ease of processing have led to widespread adoption in industries aiming to reduce environmental impact [2].

Recently, the use of PLA in additive manufacturing, particularly in Fused Filament Fabrication (FFF), has expanded significantly. Additive manufacturing, or 3D printing, enables the layer-by-layer creation of complex geometries that would be challenging or costly to produce through traditional subtractive methods [3]. In the FFF process, a heated thermoplastic filament, such as PLA, is extruded to form parts from a digital model. This technique provides high design flexibility and minimizes material waste, making it ideal for rapid prototyping and low-volume production [4]. PLA's characteristics—low shrinkage, high dimensional stability, and strong layer adhesion—make it a preferred material for FFF applications [5]. Its ease of handling and relatively low cost further increase its accessibility for both industrial and consumer-level users [6].

Laser cutting has emerged as an essential post-processing technique for materials produced through additive manufacturing, especially for achieving precise and clean cuts [7]. Laser cutting uses a high-energy laser beam to vaporize or melt the material along a specified path, producing clean, accurate cuts with minimal contact. This non-mechanical approach is particularly advantageous for fragile or intricate 3D-printed parts, where traditional cutting methods may introduce stress or damage. For PLA, laser cutting maintains edge quality and dimensional accuracy, reducing the heat-affected zone and minimizing thermal distortion [8]. Additionally, laser cutting facilitates the rapid processing of complex patterns, making it ideal for components with fine details. By preserving both mechanical properties and aesthetic appearance, laser cutting is invaluable for producing functional prototypes and final products [9].

Research on laser cutting as a post-processing method for 3D-printed materials has focused heavily on PLA due to its precision and surface quality enhancement. For instance, Kechagias et al. explored the influence of laser power and cutting speed on surface roughness (Ra) and kerf angle of 3D-printed PLA plates, finding that lower cutting speeds improved surface quality while both speed and power affected kerf geometry significantly [10-11]. Similarly, Moradi et al. [12] optimized the laser cutting process for FDM-printed PLA, analyzing kerf width, taper ratio, and the effects of focal plane position, laser power, and cutting speed. Fountas et al. [10] applied neural networks to predict optimal process settings, examining the effects of laser parameters on kerf angle and Ra in PLA/wood composites. In a related study, Kechagias et al. [13] employed genetic algorithms and neural networks to optimize kerf geometry and Ra during CO_2 laser cutting of PLA, developing predictive models for industrial applications. More recently, Tsiolikas et al. [14] introduced a hybrid approach combining fuzzy logic and grey relational analysis to enhance surface quality and dimensional accuracy in 3D-printed parts.

This study aims to experimentally investigate the impact of process parameters on Ra and kerf width during CO_2 laser cutting of PLA materials produced via fused filament fabrication. It serves as a pioneering contribution to scientific research by examining the effects of cutting conditions to achieve precise and high-quality cuts in the laser processing of 3D-printed PLA materials.

2. MATERIALS AND METHODS

The PLA filament used in this study was supplied by Filameon, featuring a 1.75 mm diameter and recognized for its excellent printability and mechanical properties. Samples were produced using FFF technology on a TEIRA3D 3D printer. The printing settings were as follows: a nozzle temperature of 215°C, a bed temperature of 60°C, a printing speed of 40 mm/s, and a layer height of 0.24 mm. The infill density was set to 100%, with four shell layers applied to both the top and bottom surfaces. The samples, designed in SolidWorks 2020 CAD software, measured 130 × 130 mm and varied in thickness (2, 3, and 4 mm). G-codes for 3D printing were generated using PrusaSlicer 2.6.1. The manufacturing process flow of PLA materials via fused filament fabrication is illustrated in Figure 1.

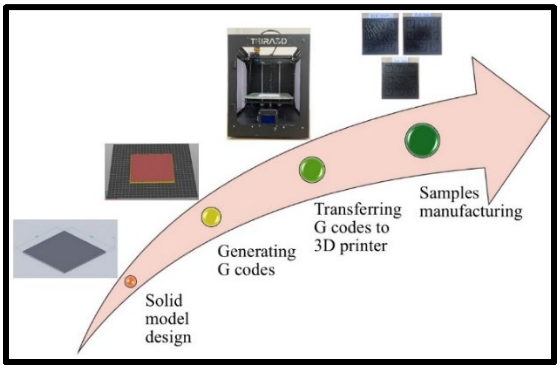


Figure 1. Manufacturing flow of 3D printed PLA with fused filament fabrication.

The CO_2 laser cutting process was conducted using a LazerFix LF7010 Laser Cutting Machine (Figure 2). For all experiments, the laser nozzle was positioned 7 mm above the workpiece. Compressed air was used to expel molten material and to protect the optics from debris. Plate thickness, cutting speed, and power were selected as the experimental parameters for the laser cutting process. Table 1 presents the experimental parameters and their levels. To ensure stability during the process, the samples were securely fixed to the laser cutting table using polypropylene material.

Figure 2. CO_2 laser cutting device.

Laser power levels of 90, 95, and 100 W were chosen based on preliminary experiments to ensure effective cutting of PLA plates across all thicknesses without causing excessive thermal damage. Furthermore, similar power levels have been reported in previous studies [11-12] to yield favorable results for cutting thermoplastic materials, further validating their selection for this study. These selected levels are also relevant to industrial practices, representing typical power settings for CO_2 laser cutting of thermoplastics.

Table 1. Parameters and levels utilized in the laser cutting process.

Factor	Level 1	Level 2	Level 3
Plate thickness (mm)	2	3	4
Cutting speed (mm/s)	3	6	9
Power (W)	90	95	100

Following a full factorial experimental design, 27 experiments were performed. For each plate thickness shown in Figure 3, nine laser cutting trials were carried out on 3D-printed PLA materials, with three different cutting speeds and three power levels. A full factorial experimental design was employed to evaluate the effects of laser power, cutting speed, and plate thickness on kerf width and surface roughness. This design systematically examines all possible combinations of the selected parameters, ensuring a comprehensive analysis of their individual and interaction effects. By testing each combination, the study achieves high statistical reliability and robust conclusions regarding the influence of process parameters. Additionally, the factorial design facilitates the optimization of laser cutting parameters for improving both dimensional accuracy and surface quality, making the findings broadly applicable to various industrial applications.

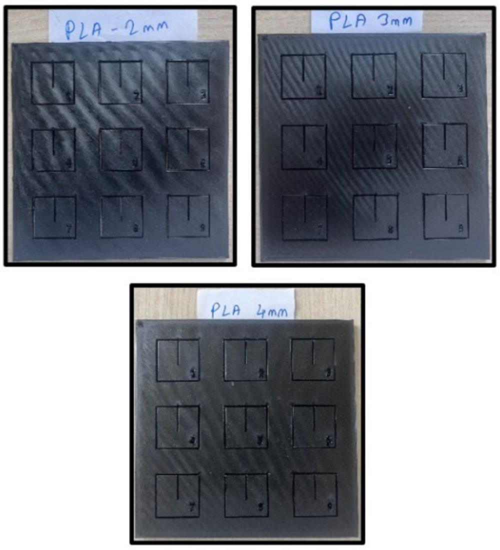


Figure 3. 3D printed PLA materials cut by laser.

Upon completion of the cutting process, the surface roughness (Ra) and kerf width of the cut samples were measured to evaluate the impact of the parameters. Precision instruments were employed to ensure accurate assessments of cut quality. Ra was measured on the cut surfaces using a DAILYAID DR100 model device, with nine readings taken for each experimental condition to calculate an average value. Kerf width was measured using a digital microscope (Dino-Lite AM4113T), with four measurements taken per condition, followed by calculating an average value. Figure 4 shows the surface roughness measurement device and the digital microscope.

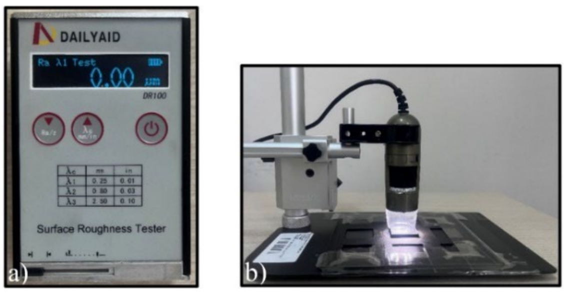


Figure 4. Devices used in measurements a) Surface roughness device b) Digital microscope.

3. RESULTS AND DISCUSSION

3.1. Evaluation of Surface Roughness

The Ra values obtained at a laser power of 90 W, with different plate thicknesses (2, 3, and 4 mm) and cutting speeds (3, 6, and 9 mm/s), are shown in Figure 5. Overall, an increase in cutting speed resulted in a decrease in Ra. This reduction is attributed to the shortened interaction time between the laser and material at higher speeds, which reduces energy accumulation and contributes to a smoother surface [12, 14]. For instance, at a plate thickness of 2 mm, raising the cutting speed from 3 mm/s to 6 mm/s led to an 18.48% reduction in Ra, decreasing from 2.506 µm to 2.043 µm. Increasing the speed further to 9 mm/s lowered Ra by an additional 27.70%, reducing it to 1.477 µm. The reduction in surface roughness at higher cutting speeds can be attributed to the shorter interaction time between the laser beam and the material surface. This limits the accumulation of thermal energy, preventing excessive melting and the formation of surface irregularities. Furthermore, higher speeds reduce the HAZ and material swelling caused by prolonged thermal exposure, resulting in a smoother and more homogeneous surface. These findings align with observations from previous studies [14], which indicate that faster cutting speeds improve surface quality by reducing thermal degradation. By increasing the speed, this localized overheating effect is diminished, resulting in improved surface homogeneity and lower surface roughness. Likewise, for a 3 mm thick plate, Ra at 3 mm/s cutting speed was 2.352 µm; raising the speed to 6 mm/s led to a 47.87% reduction to 1.226 µm, and at 9 mm/s, Ra further decreased by 59.57% to 0.951 µm. These results indicate that increased speed reduces the interaction time between the laser and material, thus decreasing surface roughness and providing a more homogeneous surface. Moradi et al. [12] also observed a decrease in surface roughness with higher laser speeds, achieving optimal cutting quality. For the 4 mm thick plate, surface roughness at 3 mm/s cutting speed was 2.118 µm; increasing the speed to 6 mm/s reduced surface roughness by 37.87% to 1.316 µm, and further to 1.167 µm at 9 mm/s, marking a 44.90% reduction. These findings demonstrate that increasing laser cutting speed reduces surface roughness and minimizes thermal effects during cutting, resulting in a smoother surface. The effect of plate thickness on surface roughness is also noteworthy. In general, thinner plates (2 mm) exhibited higher surface roughness, while increasing thickness resulted in reduced surface roughness values. For instance, at a cutting speed of 3 mm/s, a 3 mm thick plate showed a 6.15% lower surface roughness (2.352 µm compared to 2.506 µm for the 2 mm plate).

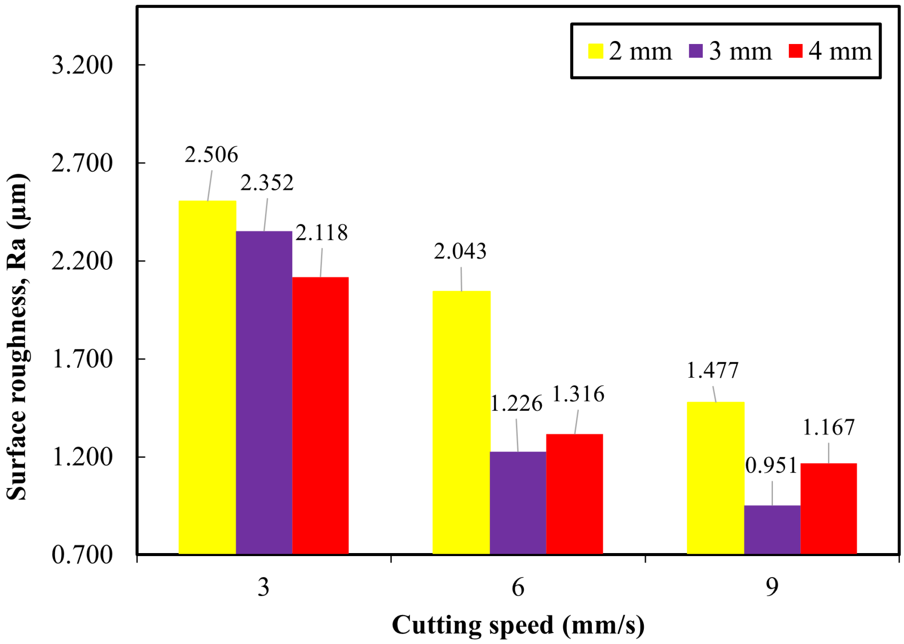


Figure 5. Surface roughness depending on cutting speed and plate thickness at 90 W power.

Similarly, for a 4 mm thick plate at the same speed, surface roughness further decreased by 9.95% to 2.118 µm, providing a smoother surface. At a cutting speed of 6 mm/s, surface roughness for a 2 mm thick plate decreased by 18.48%, from 2.506 µm to 2.043 µm. A 3 mm thick plate showed a 47.87% reduction (from 2.352 µm to 1.226 µm), achieving a lower surface roughness. For the 4 mm thick plate, surface roughness decreased by 37.87% from 2.118 µm to 1.316 µm. At the highest cutting speed (9 mm/s), surface roughness for a 2 mm thick plate dropped by 41.06%, from 2.506 µm to 1.477 µm, while a 3 mm thick plate achieved a 59.57% lower surface roughness (2.352 µm to 0.951 µm). For a 4 mm thick plate, surface roughness decreased by 44.90%, from 2.118 µm to 1.167 µm. This trend suggests that thicker plates produce a more uniform cut when interacting with the laser beam. As noted by Tsiolikas et al. [14], thicker plates processed by laser tend to exhibit lower surface roughness due to more homogeneous energy distribution and transfer. Moradi et al. [12] also emphasized that energy absorption in thicker materials is more uniform, resulting in reduced surface roughness. Surface roughness values obtained at a laser power of 95 W across different plate thicknesses (2, 3, and 4 mm) and cutting speeds (3, 6, and 9 mm/s) are shown in Figure 6. A clear reduction in surface roughness was observed as cutting speed increased.

For instance, with a 2 mm thick plate, increasing the cutting speed from 3 mm/s to 6 mm/s resulted in a 47.64% decrease in surface roughness, from 2.758 µm to 1.444 µm. Further raising the speed to 9 mm/s reduced surface roughness by an additional 11.91%, bringing it down to 1.272 µm. For a 3 mm thick plate, the surface roughness at 3 mm/s was 2.596 µm. Increasing the speed to 6 mm/s led to a 47% reduction to 1.376 µm, and at 9 mm/s, surface roughness further dropped by 54.28% to 1.187 µm. For the 4 mm thick plate, surface roughness at 3 mm/s was 2.443 µm. Increasing the speed to 6 mm/s reduced it by 41.55% to 1.428 µm, and at 9 mm/s, it further decreased by 47.32% to 1.287 µm. The impact of plate thickness on surface roughness is also noteworthy. In general, thinner plates (2 mm) exhibited higher surface roughness, while an increase in thickness tended to result in lower surface roughness values. For instance, at a cutting speed of 3 mm/s, a 3 mm thick plate achieved a 5.87% lower surface roughness (2.596 µm compared to 2.758 µm for the 2 mm plate). Similarly, a 4 mm thick plate showed an additional 5.89% reduction in Ra (from 2.596 µm to 2.443 µm), producing a smoother surface. When the cutting speed was set to 6 mm/s, surface roughness values for the 2-, 3- and 4-mm plates were measured at 1.444 µm, 1.376 µm, and 1.428 µm, respectively, with the 3 mm plate exhibiting the lowest surface roughness.

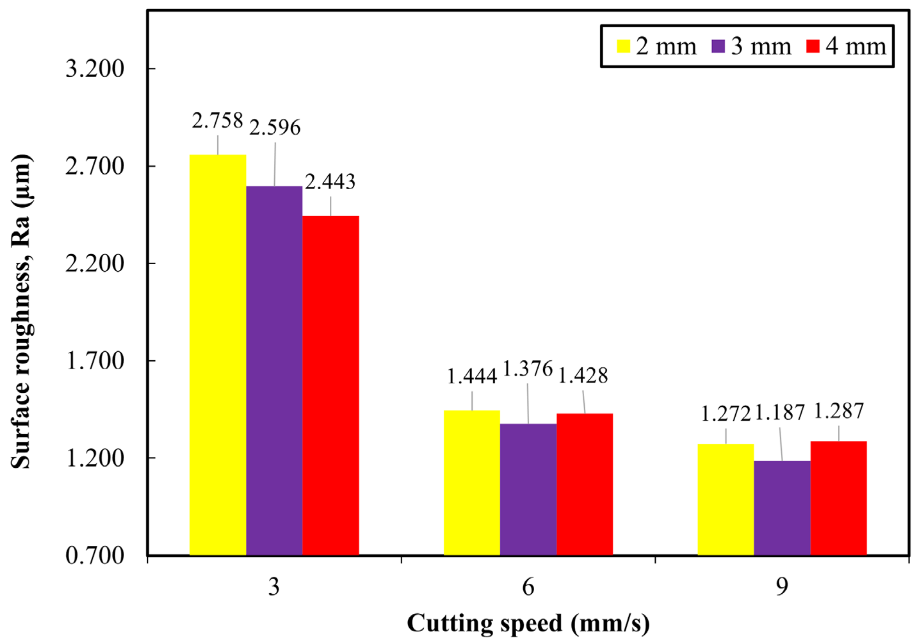


Figure 6. Surface roughness depending on cutting speed and plate thickness at 95 W power.

At an increased cutting speed of 9 mm/s, surface roughness further decreased across all thicknesses, with values recorded at 1.272 µm for the 2 mm plate, 1.187 µm for the 3 mm plate, and 1.287 µm for the 4 mm plate. These results indicate that increasing laser cutting speed reduces surface roughness, contributing to a smoother finish by minimizing thermal effects during cutting. Additionally, the trend of decreasing surface roughness with increasing plate thickness suggests that thicker plates allow for a more uniform surface under the laser beam, thereby enhancing surface quality. Figure 7 shows the Ra values measured for 3D-printed PLA materials at a constant laser power of 100 W with varying parameters. Surface roughness decreased with increasing cutting speed. For instance, with a 2 mm thick plate, increasing the cutting speed from 3 mm/s to 6 mm/s reduced Ra by 43.95%, from 2.983 µm to 1.672 µm. A further increase in speed to 9 mm/s lowered surface roughness by an additional 8.07%, reaching 1.537 µm. Similarly, for a 3 mm thick plate, surface roughness at 3 mm/s was 2.758 µm; raising the speed to 6 mm/s resulted in a 41.44% reduction to 1.615 µm, and at 9 mm/s, Ra decreased by 49.60% to 1.390 µm. For a 4 mm thick plate, surface roughness at a cutting speed of 3 mm/s was 2.691 µm; increasing the speed to 6 mm/s reduced it by 41.32% to 1.579 µm, and at 9 mm/s, Ra was further reduced by 51.77% to 1.298 µm.

The influence of plate thickness on surface roughness is evident when evaluated alongside cutting speed. In general, thinner plates (2 mm) exhibited higher surface roughness, while an increase in plate thickness correlated with lower surface roughness values. For example, at a cutting speed of 9 mm/s, comparing Ra values for the 2 mm and 3 mm thick plates showed a reduction of 9.56%, from 1.537 µm to 1.390 µm. Similarly, comparing the 3 mm and 4 mm thick plates at the same speed, the 4 mm thickness showed an additional 6.62% reduction in Ra, from 1.390 µm to 1.298 µm. These results suggest that thicker plates and higher cutting speeds enable a more uniform interaction with the laser beam, thereby enhancing surface quality. Figure 8 shows cross-sectional images of surfaces obtained at different cutting speeds with a plate thickness of 3 mm and a laser power of 90 W. The images reveal a noticeable improvement in surface quality as cutting speed increases. At the lowest cutting speed of 3 mm/s, distinct irregularities and surface unevenness are observed. Due to the longer interaction time between the laser and the material at this speed, energy accumulation on the surface increases, resulting in a higher Ra of 2.352 µm. At a cutting speed of 6 mm/s, there is a moderate improvement in surface quality, as the shorter interaction time reduces energy accumulation on the surface, bringing the surface roughness down to 1.226 µm.

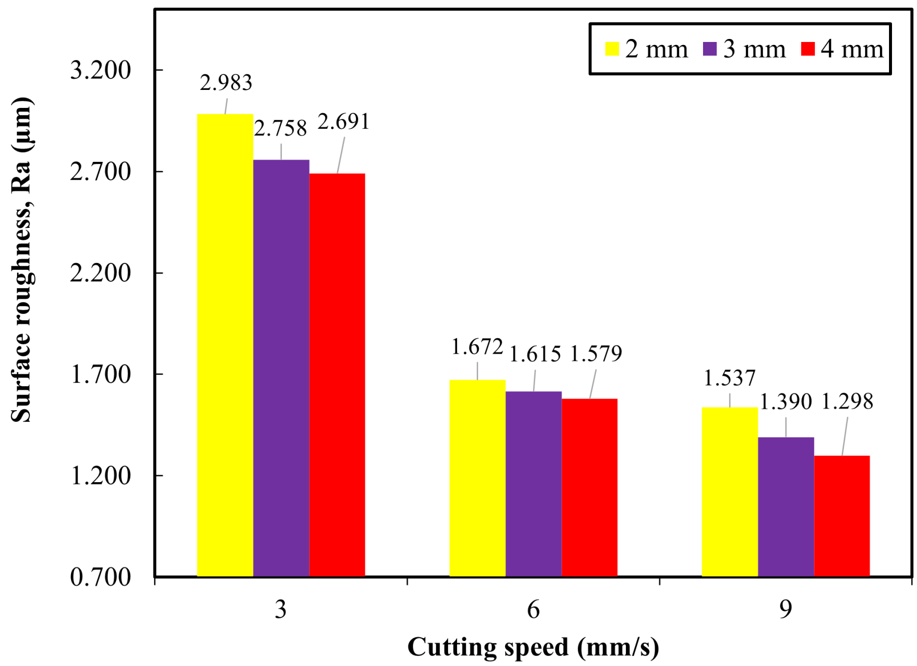


Figure 7. Surface roughness depending on cutting speed and plate thickness at 100 W power.

At the highest speed of 9 mm/s, surface quality reaches its optimal level; the brief contact between the laser and the material results in minimal energy build-up and reduced thermal impact, lowering surface roughness to its minimum level of 0.951 µm. These observations align with previous findings, confirming that increased cutting speed reduces surface roughness and enhances surface quality.

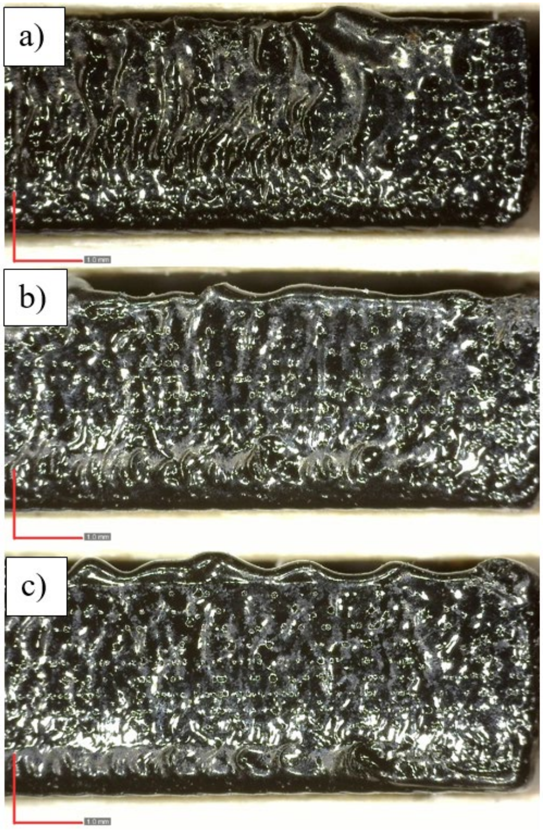


Figure 8. Laser cutting at different speeds for 3 mm thickness and 90 W power a) 3 mm/s, b) 6 mm/s and c) 9 mm/s.

Figure 9 illustrates the effect of laser power (90, 95, and 100 W) on average surface roughness. A notable increase in Ra was observed with rising laser power. For example, the average Ra at 90 W was 1.684 µm, which increased by 4.22% to 1.755 µm at 95 W and further by 10.94% to 1.947 µm at 100 W. These findings indicate that higher laser power leads to greater energy density on the surface, resulting in more pronounced melting and surface irregularities in the material. Increased laser power causes greater energy accumulation on the surface, which raises the extent of melting and leads to a significant increase in surface roughness. These results demonstrate that higher laser power reduces surface quality, as the increased energy density negatively impacts surface roughness.

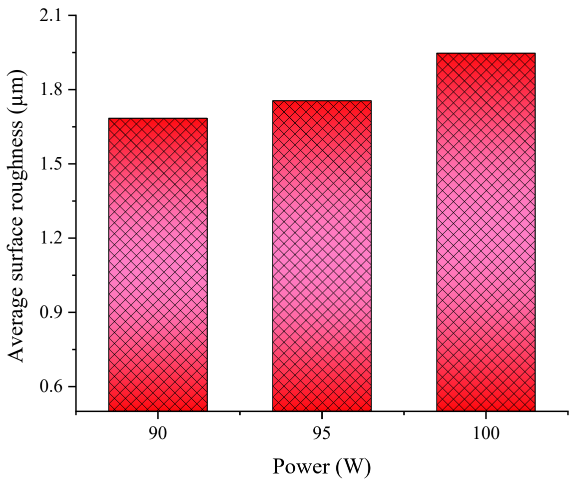


Figure 9. Average surface roughness at different powers.

3.2. Evaluation of Kerf Width

The kerf widths of 3D-printed PLA material were examined by cutting it at 90 W power with three different plate thicknesses and three different cutting speeds; the results are shown in Figure 10. The highest kerf width, measured at 1.071 mm, was observed with a plate thickness of 2 mm and a cutting speed of 3 mm/s. When the cutting speed was increased to 6 mm/s and 9 mm/s, the kerf width for the 2 mm thick plate decreased by 12.89% and 24.09%, respectively. At the same laser power, the kerf width for a 3 mm thick plate at a cutting speed of 3 mm/s was 0.979 mm, reaching the lowest value of 0.793 mm at 9 mm/s. At lower cutting speeds, the prolonged interaction time between the laser and the material allows for significant heat accumulation, particularly in thicker plates. This increased heat transfer leads to a wider kerf width due to greater melting of the material. In contrast, thinner plates exhibit narrower kerf widths at the same cutting speed, as the heat dissipates more quickly. As the cutting speed increases, the interaction time decreases, limiting heat accumulation and minimizing the influence of plate thickness on kerf width. These trends highlight the critical role of optimizing cutting speed and thickness to achieve precise kerf dimensions. In general, increasing the cutting speed for all plate thicknesses reduced the energy transfer in the cutting zone by decreasing the interaction time between the laser beam and material, which in turn reduced melting and led to narrower kerf widths [15-16]. At a low cutting speed (3 mm/s), variations in kerf width were observed with increasing plate thickness.

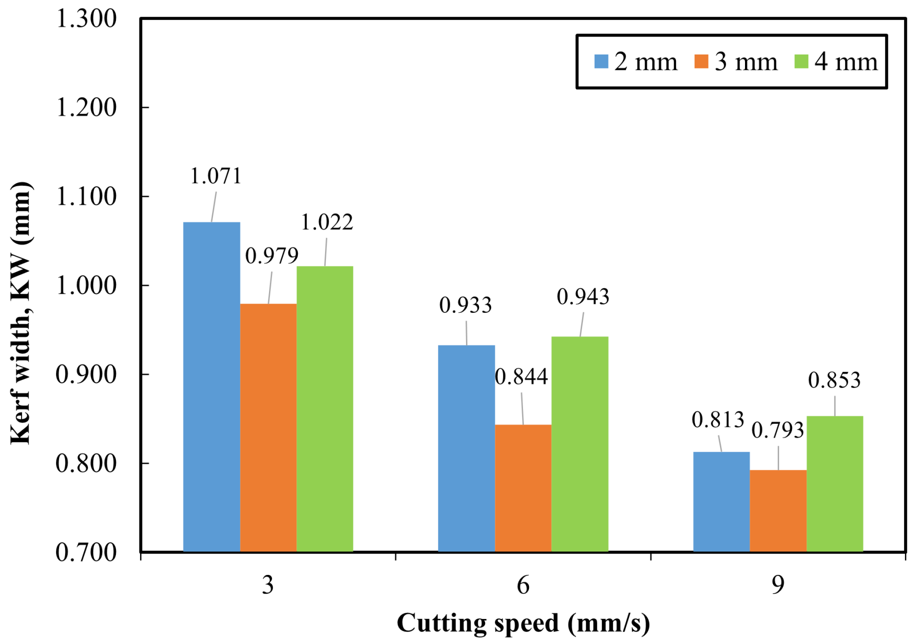


Figure 10. Kerf widths depending on cutting speed and plate thickness at 90 W power.

As the plate thickness rose from 2 to 3 mm, the kerf width contracted by 8.59%. However, when the thickness advanced further from 3 to 4 mm, the kerf width expanded by 4.39%. These findings align with literature suggesting that thicker plates at lower cutting speeds absorb more heat, leading to increased melting [11]. At cutting speeds of 6-9 mm/s, the widest kerf values were observed for 4 mm thick plates [12, 17]. This trend of increasing kerf width with plate thickness at lower speeds can be attributed to thicker plates spreading the laser beam's effect over a larger area, enhancing heat distribution. It is emphasized that laser processing parameters have a significant impact on cutting operations and should be optimized according to plate thickness and cutting speed [12, 18]. These results indicate that careful selection of process parameters is critical to improve laser cutting quality. Figure 11 presents the kerf widths obtained at a laser power of 95 W for three different plate thicknesses and cutting speeds. A clear reduction in kerf width was observed across all plate thicknesses as cutting speed increased. For example, with a 2 mm thick plate, increasing the cutting speed from 3 mm/s to 6 mm/s reduced the kerf width by 14.47%, from 1.099 mm to 0.940 mm. Further increasing the speed to 9 mm/s led to an additional 21.20% reduction, yielding a kerf width of 0.866 mm. Similarly, for a 3 mm thick plate, increasing the cutting speed from 3 mm/s to 6 mm/s reduced the kerf width by 10.57%, from 0.946 mm to 0.846 mm, and further increasing the speed to 9 mm/s resulted in a 12.05% reduction, reaching 0.832 mm. For a 4 mm thick plate, the kerf width was 1.043 mm at a cutting speed of 3 mm/s. Raising the speed to 6 mm/s decreased the kerf width by 6.33%, bringing it to 0.977 mm, and further increasing to 9 mm/s led to a 15.34% reduction, resulting in a kerf width of 0.883 mm. At a low cutting speed (3 mm/s), variations in kerf width were observed with increasing plate thickness. Increasing the thickness from 2 to 3 mm led to a 13.92% decrease in kerf width (from 1.099 mm to 0.946 mm), while increasing thickness from 3 mm to 4 mm caused a 10.25% rise, reaching 1.043 mm. These results indicate an overall trend of decreasing kerf width with higher cutting speeds; however, variations in kerf width were seen at lower speeds depending on plate thickness. This can be attributed to the laser's larger area of influence on thicker materials and the extended interaction time at lower speeds, resulting in a wider kerf. Figure 12 shows the kerf widths obtained from the laser cutting process conducted at a power level of 100 W, using different plate thicknesses and cutting speeds. Generally, an increase in cutting speed led to a reduction in kerf width. For instance, for a 2 mm thick plate, increasing the cutting speed from 3 mm/s to 6 mm/s reduced the kerf width by 18.64%, from 1.164 mm to 0.947 mm. Further increasing the speed to 9 mm/s decreased the kerf width by an additional 22.34%, resulting in a final width of 0.904 mm.

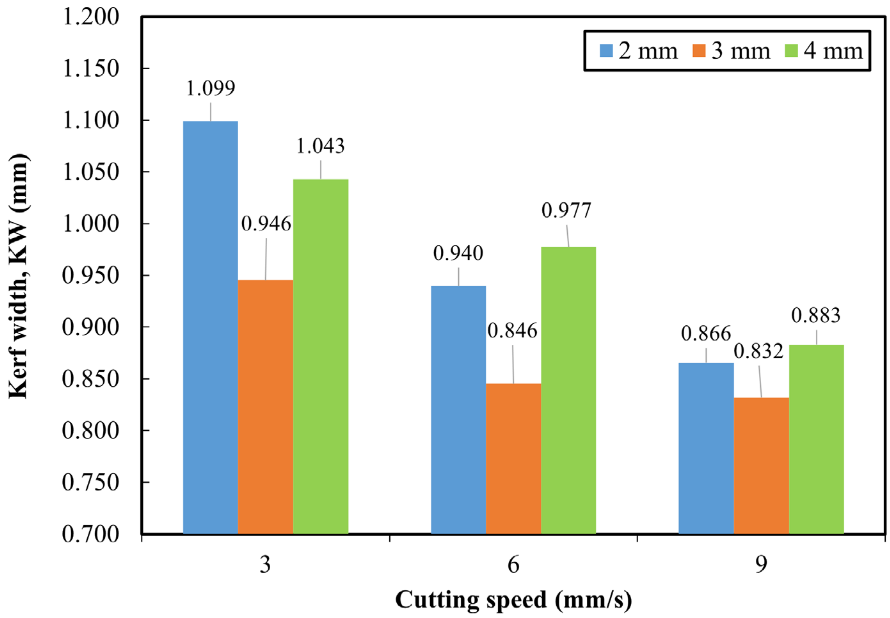


Figure 11. Kerf widths depending on cutting speed and plate thickness at 95 W power.

For a 3 mm thick plate, the kerf width at a cutting speed of 3 mm/s was 0.938 mm; raising the speed to 6 mm/s reduced the kerf width by 10.55% to 0.839 mm, and a further increase to 9 mm/s reduced it by 12.05%, bringing it down to 0.825 mm. For a 4 mm thick plate, the kerf width measured 1.030 mm at a cutting speed of 3 mm/s. Increasing the speed to 6 mm/s lowered the kerf width by 6.89%, reducing it to 0.959 mm, while a further increase to 9 mm/s resulted in a 16.70% reduction, bringing the kerf width down to 0.858 mm. Overall, at a laser power of 100 W, higher cutting speeds resulted in narrower kerf widths across all plate thicknesses.

This outcome can be attributed to the reduced interaction time between the laser beam and the material, which decreases the amount of melting and produces a narrower kerf. Additionally, an increase in kerf width was observed with greater plate thicknesses at lower cutting speeds, likely due to higher heat absorption in thicker plates. Figure 13 shows the microscope images and measurement pictures of the kerf widths after laser cutting at 2 mm plate thickness, 90 W power and three different cutting speeds (3, 6 and 9 mm/s).

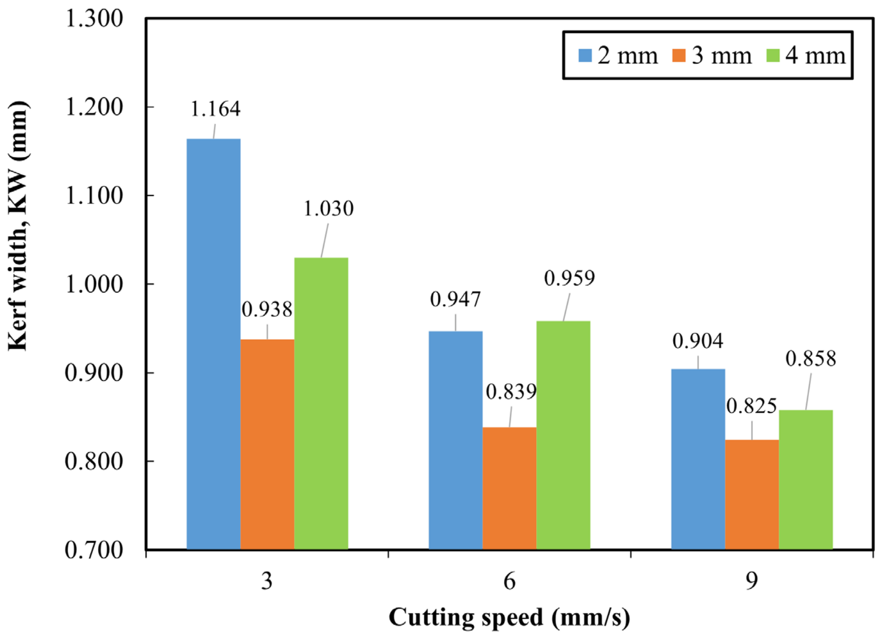
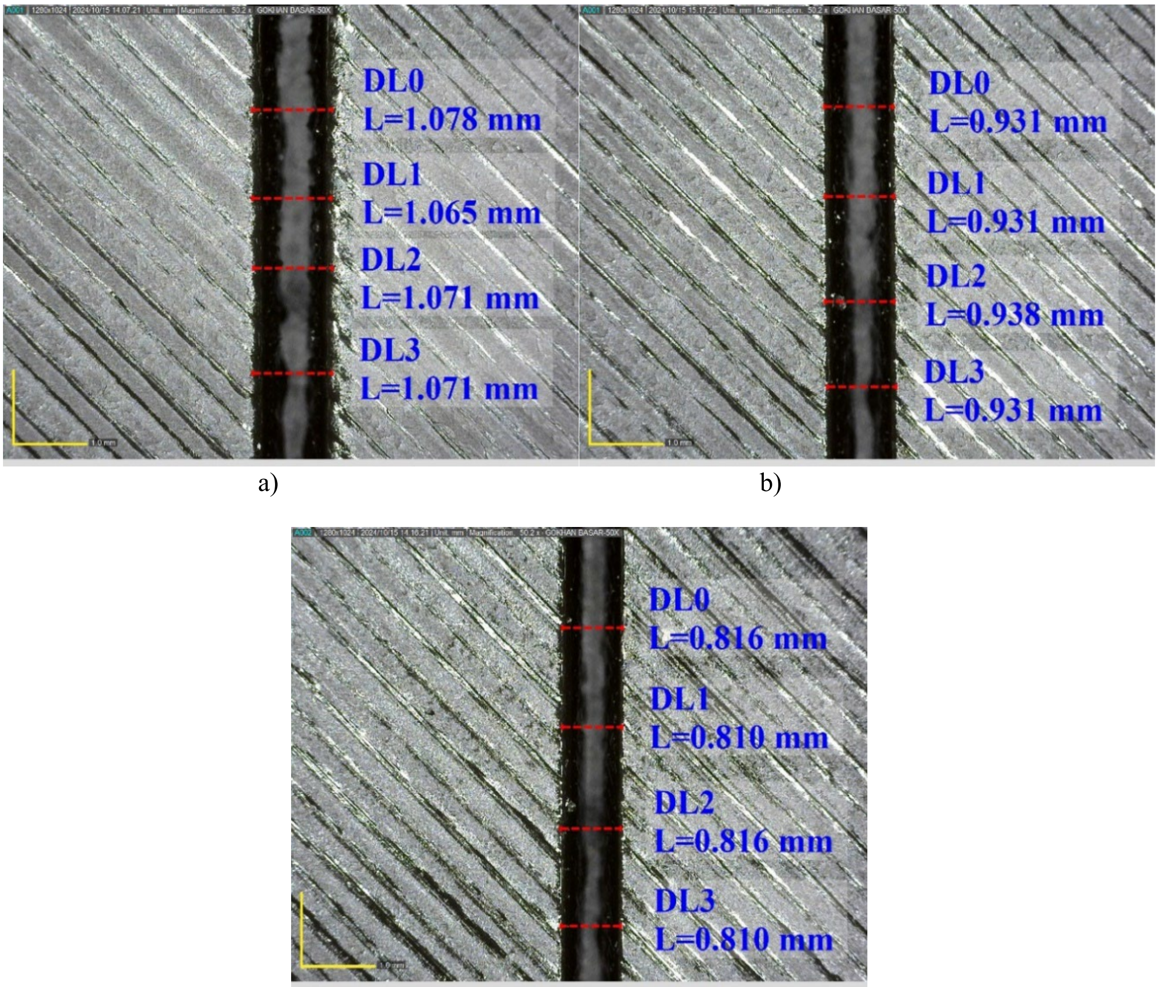


Figure 12. Kerf widths depending on cutting speed and plate thickness at 100 W power.



a) b)

c)

Figure 13. Laser cutting at different speeds for 2 mm thickness and 90 W power
a) 3 mm/s, b) 6 mm/s and c) 9 mm/s.

An examination of the figure shows that kerf widths decrease as the speed rises. In the first image, kerf width measurements for a speed of 3 mm/s range from 1.078 mm to 1.071 mm, reflecting the relatively wide kerf width expected at low speeds. As the cutting speed increased, the kerf width consistently declined, as illustrated in the second image (6 mm/s), where the kerf width fell between 0.931 mm and 0.938 mm, and in the third image (9 mm/s), where it ranged from 0.810 mm to 0.816 mm. These trends are consistent with the literature where studies by Kechagias et al. [11] and Sabri et al. [19] similarly reported that increasing cutting speeds resulted in more consistent and narrower kerf widths. Figure 14 shows the average kerf widths resulting from laser cutting at different power levels. The average kerf widths for 3D-printed PLA cut at 90, 95, and 100 W were calculated as 0.917, 0.937, and 0.940 mm, respectively. An increase in kerf width was observed with rising power levels, with the lowest kerf width occurring at 90 W and the highest at 100 W. However, the increase in kerf width with higher power levels was not significant, suggesting that the limited laser cutting time, combined with a certain level of energy density, was sufficient to achieve adequate melting without further widening the kerf. While an upward trend in average kerf width was observed with increasing laser power, this increase was minimal. This result can be attributed to the accumulation of more energy on the material surface as laser power increases, leading to a greater amount of melted material. The increase in the amount of melting widens the kerf. These findings align with other studies on the effect of laser power on kerf width and are consistent with the work by Moradi et al., which also examined the relationship between laser power and kerf width [12].

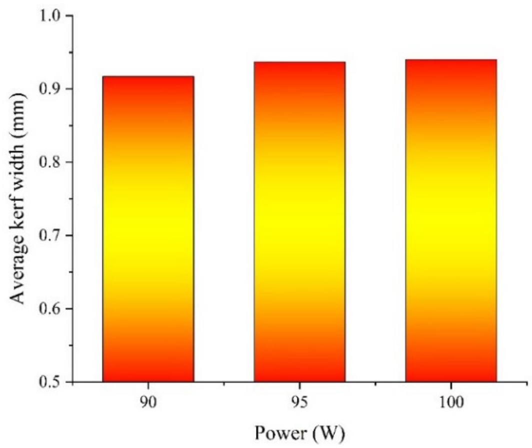


Figure 14. Average kerf widths at different powers.

4. CONCLUSIONS

The influence of cutting parameters—plate thickness, cutting speed, and laser power—on surface roughness and kerf width in CO_2 laser cutting of PLA materials made by fused filament fabrication was examined through experimental investigation. The findings obtained from the investigation are summarized below:

- Ra reduced with rising cutting speed at for all laser power levels.
- In laser cutting operations performed at low cutting speeds, Ra decreased as plate thickness increased. Moreover, at these low cutting speeds, surface roughness values rose with an increase in laser power.
- The lowest Ra (2.118 µm) at low cutting speed (3 mm/s) was measured with a plate thickness of 4 mm and the lowest laser power (90 W).
- The lowest surface roughness observed in laser cutting processes conducted at 90 and 95 W laser power and cutting speeds of 6 and 9 mm/s was achieved with a plate thickness of 4 mm.
- Across all laser cutting conditions, the lowest surface roughness (0.951 µm) was achieved with a plate thickness of 3 mm, cutting speed of 9 mm/s, and laser power of 90 W, whereas the highest surface roughness (2.983 µm) was obtained with a plate thickness of 2 mm, cutting speed of 3 mm/s, and laser power of 100 W.
- Kerf width was reduced with higher cutting speeds and lower laser power across all plate thicknesses.
- At the lowest cutting speed (3 mm/s), the smallest kerf width was achieved with a 2 mm plate thickness regardless of laser power. Under these conditions, kerf width increased as laser power increased.
- When all cutting conditions are considered, kerf width decreased when plate thickness increased from 2 mm to 3 mm, whereas a further increase in plate thickness to 4 mm resulted in an increase in kerf width.
- Under all laser cutting conditions, the minimum kerf width of 0.793 mm was achieved with a 3 mm plate thickness, a cutting speed of 9 mm/s, and a laser power of 90 W. In contrast, the maximum kerf width of 1.164 mm occurred with a 2 mm plate thickness, a cutting speed of 3 mm/s, and a laser power of 100 W.

This study demonstrates the importance of carefully selecting cutting parameters to achieve optimal surface quality and minimum kerf width in CO_2 laser cutting. Increasing cutting speed, adjusting laser power, and optimizing plate thickness play critical roles in achieving high precision and quality surfaces in industrial applications. The findings of this study hold significant potential for various industrial applications. In rapid prototyping and additive manufacturing, the optimized laser cutting parameters enable precise and high-quality processing of 3D-printed PLA components, reducing post-processing needs. In biomedical applications, the results facilitate the accurate fabrication of complex geometries, critical for implants and custom prosthetics. Additionally, the packaging industry can use these findings to enhance the efficiency of eco-friendly PLA product manufacturing. By reducing kerf width and surface roughness, the study's optimized parameters improve manufacturing efficiency, minimize material waste, and lower production costs, making the approach applicable across multiple industries requiring precision and sustainability.

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