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MULTI-RESPONSE OPTIMIZATION IN PRECISION CUTTING OF WOOD PLASTIC COMPOSITES BY SINGLE-MODE FIBER LASER

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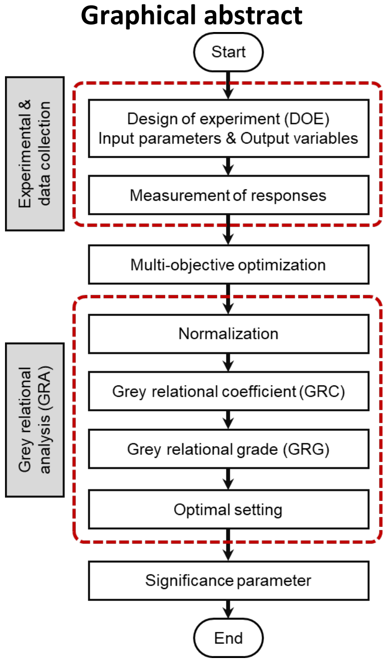
Graphical abstract



Abstract

Environmental and sustainability concerns have driven scientists and engineers to prefer bio-composite materials over synthetic fibers. Wood plastic composites (WPCs) are biobased plastic compounds that have gained much attention in diverse engineering applications as eco-friendly and biodegradable solutions that can support global sustainability objectives. However, the complex structures and properties of these composites make them challenging to cut. This study aims to optimize the multiple-response parameters of laser cutting on WPCs containing 30% wood fiber filled with recycled high-density polyethylene (rHDPE) by single-mode fiber laser. A digital microscope measured the kerf width (KW) and heat-affected zone (HAZ). The material removal rate (MRR) was calculated based on the kerf width, material thickness, and cutting speed. In order to identify the optimal combination of cutting parameters for peak power, pulse width, and cutting speed, grey relational analysis (GRA) was utilized. The results of the GRA analysis confirmed that the best performance characteristics for fiber laser cutting of 1 mm thickness of WPC were achieved at a lower peak power of 80 W, a shorter pulse width of 20 µs, and a slower cutting speed of 2 mm/s. The response table indicates that all cutting parameters significantly affect the cutting process, with the cutting speed being the most crucial parameter, followed by peak power and pulse width. This research revealed that multi-response optimization of pulsed fiber laser cutting can result in higher WPC cut quality and improved productivity.

Keywords: Multi-objective optimization, wood plastic composite, pulsed fiber laser, grey relational analysis, cut quality

1.0 INTRODUCTION

Wood-plastic composites (WPCs) are unique composite materials made by blending wood fibers or agricultural fiber residues with thermoplastic resin and subsequently extruding or molding them into various shapes and sizes. WPCs are designed to capitalize on the advantages of wood and plastic, offering a balance of durability, lighter weight, energy efficiency, aesthetics, and environmental sustainability. WPCs are widely used in various fields, including construction, furniture, automotive, and packaging, due to their strength, cost-effectiveness, and ease of use [1, 2, 3, 4]. However, machining WPCs can be challenging due to their low thermal conductivity, heat sensitivity, and heterogeneous behavior. As natural fiber-reinforced polymer composites (NFRCs), WPCs are difficult to machine using traditional cutting methods. These methods frequently produce significant defects due to unwanted pressure, poor surface quality, slow processing time, constraints for small complex geometries, material damage, and poor dimensional accuracy [5, 6]. Figure 1 depicts the comparison between conventional cutting methods, such as band saw cutting and laser cutting, as identified in the preliminary study. There are obvious distinctions between cutting with a band saw and cutting with a fiber laser. Band saw cutting of WPC creates a larger kerf (≥ 1020 µm) because of the physical size of the blade, while laser cutting produces a much narrower kerf (≤ 780 µm) with a focused beam. In terms of surface finish, band saw cutting results in a rougher surface due to mechanical tearing, delamination, blade wear, and vibration, while laser cutting provides a smoother finish, smaller kerf, and minimal thermal damage through precise and non-contact cutting. Understanding the machining behavior of WPCs is crucial for optimizing the quality of cuts and achieving precise dimensional accuracy. The insights gained from this comparison are important for expanding the range of applications where high-quality and precise cuts are essential. By selecting the appropriate cutting method, manufacturers can ensure superior results in both the aesthetics and functionality of the final products.

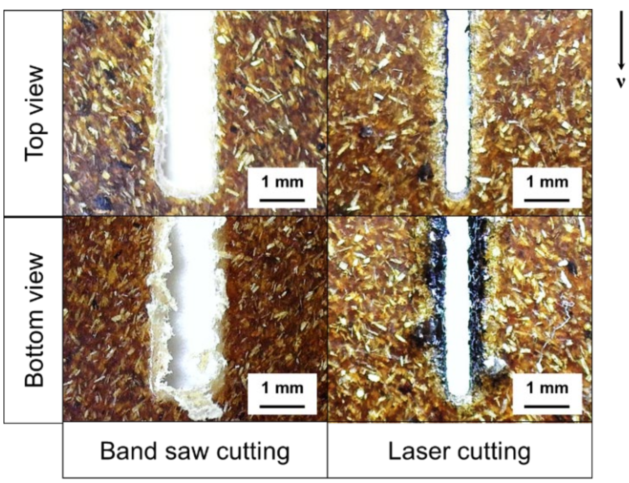


Figure 1 The comparison between band saw cutting and laser cutting of WPC

Thin materials are best cut using laser machines. Laser cutting is a non-contact method used to cut various materials such as metals, ceramics, and composites. It is a process that uses the thermal energy of a laser beam to shape and separate materials into pieces [7]. There usually are two modes of operation for the laser. The modes are pulsed wave (PW) and continuous wave (CW). Cutting with PW laser beams has the potential to provide effective peak power during each pulse for cutting operations, regulate the precision of cutting in complex design applications, and enhance heat management between materials and the laser beam. In addition, laser cutting is characterized by its precision over energy density, efficient automation that enables fast cutting, and low-emission pollution [8]. The majority of thermoplastics are cut by melting the material using the fusion-cutting mechanism [9]. The fusion cutting process employs laser-generated heat energy to liquefy the base material, followed by using a high-pressure, inert gas such as nitrogen, helium, or argon to expel the melted material or debris from the machined kerf. Figure 2 provides a visual representation of this process. Not to be confused with "gas fusion cutting," which entails an exothermic reaction, the term "fusion cutting" refers specifically to inert gas-assisted cutting.

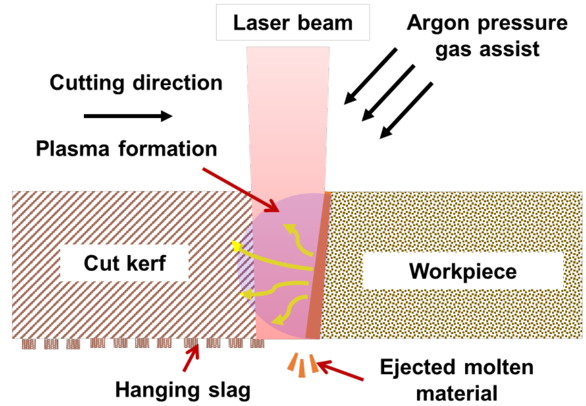


Figure 2 Schematic illustration of fusion cutting of WPC

In general, different types of lasers interacting with different materials could produce diverse laser-material interactions, final outputs, and characterizations. The quality of laser cutting mainly depends on the laser source used, which includes the lasing type, wavelength, mode, and the main working parameters such as laser power, cutting speed, and pulse duration [10]. The quality of laser cutting can be determined by examining several output response parameters such as kerf width (KW), heat-affected zone (HAZ), depth of cut, and dimensional accuracy for each specific material being cut. These parameters provide a detailed assessment of the overall quality of the laser-cutting process. It is crucial to understand the effects of laser-material processing in laser-technology-based manufacturing. Characterizing laser-materials processing, evaluating the primary impacts of laser input parameters, and gaining further insights into the associated challenges are highly relevant for industries involved in machining bio-composites. Notably, there has been no exploration of using a pulsed fiber laser to cut WPC. Despite the practice of laser cutting wood and wood composites since the 1970s, the limited understanding of laser-material processing has hindered industries from adopting this technique. However, with a deeper understanding and further exploration, laser cutting holds immense potential for the bio-composite industry, paving the way for innovative and efficient manufacturing processes.

Several studies have sought to improve the precision of laser cutting for composites made from natural fibers. In 2011, Eltawahni et al. [11] conducted a study on CO_2 laser cutting of medium-density fiberboard (MDF) with thicknesses ranging from 4 mm to 9 mm. Their findings indicate that the position of the focal point plays a critical role in determining the dimensions of the upper KW, while laser power and cutting speed have the most significant impact on the lower KW. Increased laser power results in a larger upper and lower KW but a decrease when the focal point, cutting speed, and gas pressure are higher. The lower KW, on the other hand, decreases as the cutting speed rises. Additionally, the study found that as the focal point position and laser power increase, the ratio of the KW decreases. In addition, as material thickness increases, the effect of laser power decreases. According to Nugroho and Winarbawa [12], the gas pressure significantly impacts the cutting quality of unsaturated polyester composite with CW laser. Increasing the gas pressure can improve the efficiency of char removal, allowing the laser beam to penetrate the composite material without obstruction from char deposits. Higher laser power levels transfer more heat energy to the surface, increasing KW. However, increasing the cutting speed may decrease KW as the faster combustion process of the composite restricts the amount of material burned by the laser beam.

Secondary processing is an essential step in achieving nearly net-shaped components for engineering purposes, whether they are made of metal, ceramic, or composites. In this regard, laser machining is an indispensable technique for achieving precision and accuracy in fabricating engineering components. Tamrin et al. [5] investigated the optimization of multi-pass laser cutting of cotton fiber laminate (CFL). In their study, they investigated several factors such as laser power, cutting speed, stand-off distance (SOD), and the number of beam passes. They utilized a low-power diode laser on a 0.4 mm CFL. The findings indicated that cutting speed had the greatest influence on KW and HAZ, while SOD had the least impact. In a recent study conducted by Singh et al. [13], it was found that the cutting speed has the greatest impact on kerf taper (KT) and surface roughness (SR) when considering pulse width, pulse frequency, and gas pressure in the context of pulsed CO_2 laser cutting of hybrid composite sheets made of fabricated coir fiber, carbon fiber, and epoxy. The study utilized sheets with a thickness ranging from 3 to 4.5 mm. Cutting faster resulted in higher KT and lower SR. As pulse width increases and pulse frequency decreases, KT also decreases. SR decreases as pulse width increases, whereas it increases with pulse frequency.

The effectiveness of laser cutting on WPC relies on various factors, including the properties and quality of the wood fibers and polymers, the optical characteristics of the laser beam profile, laser cutting process parameters, and the utilization of a pressure gas-assist system. The outcome can vary greatly depending on the variety of the input responses. Each unique input can significantly impact the final result. Laser cutting of WPCs or bio-composites tends to present challenges in relation to cut quality, including the size of the kerf width (KW), kerf taper, the occurrence of a broader heat-affected zone (HAZ), lengthy machining time, greater hanging slag, and the generation of hazardous chemical decomposition products [14, 15]. In order to produce high-quality WPC products, it is imperative to carefully optimize the laser-cutting process to minimize defects and enhance the precision of the cuts. Therefore, it is crucial to thoroughly assess and fine-tune the laser-cutting procedure to minimize its impact on the final quality of the WPC. The present study aimed to investigate the parametric optimization for fiber laser cutting of WPC through multi-optimization experimental analysis. The study employed grey relational analysis (GRA) to analyze multi-output responses, such as KW, HAZ, and material removal rate (MRR). The GRA methodology is a statistical tool used to evaluate the correlation between multiple input and output variables and predict optimal parameter settings that enhance the desired responses. The study's findings provide valuable insights into optimizing laser-cutting parameters for WPC, which can be utilized to improve the quality and efficiency of fiber laser-cutting processes.

2.0 METHODOLOGY

This research utilized a composite material that consisted of 30% wood fiber and recycled high-density polyethylene (rHDPE) to achieve the best mechanical strength and physical properties. According to Kosior and Mitchell [16], rHDPE has properties that are nearly identical to the virgin HDPE. The wood fiber has an average diameter of 199 µm and is made from pulverized mixed-grade wood. The mixture was compressed into a thin plate measuring 1 mm in thickness using an electrically heated hydraulic press machine. The dimensions of each sample were standardized to 40 mm in length, 30 mm in width, and 1 mm in thickness. Table 1 shows the mechanical and thermal properties of WPC.

Table 1 Mechanical and thermal properties of WPC

Property	Value	Unit
Tensile strength	19.06	MPa
Modulus of elasticity	674.67	MPa
Intensity ratio	0.367	-
Poisson's ratio	0.3	-
Final decomposition temperature	530.96	°C
Thermal conductivity	0.637	$Wm^{-1}K^{-1}$
Specific heat capacity	1.775 (at 39.97°C) and 327.7 (at 389.2°C)	J/g°C
Density	546	kg/m^3
Interparticle spacing	3.9125	nm

Figure 3 shows the schematic diagram of the experimental setup for the laser-cutting process. A single-mode fiber laser (SPI SP-200C) with a wavelength of 1070 nm and a maximum of 200 W peak power was used. The laser beam was delivered through optical fiber and focused using a 180 mm focal length of fθ lens, which resulting a focused beam diameter of 18 µm. A Galvano scanner was employed to control the speed and direction of the laser beam, while argon gas was used to create an inert environment [17]. The exhaust fan was placed near the processing area to remove harmful fumes and maintain safety effectively.

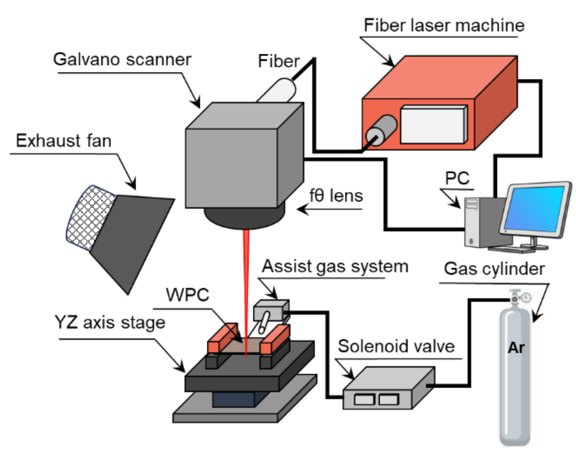


Figure 3 Schematic diagram of laser cutting of WPC

In this study, a full factorial design of experiments (DOE) was utilized, which involved 27 unique cutting conditions, each replicated three times. The pulsed laser cutting main input parameters include three levels of peak power (P_p), pulse width (τ), and cutting speed (v), as listed in Table 2. Combining different cutting parameters can be advantageous as it simplifies the process of laser material cutting. These ranges are carefully chosen based on the minimum linear energy E_l (J/mm) required to completely cut through the 1 mm WPC specimen (i.e., E_l > 9 J/mm)[18]. An E_l of a pulse mode laser can be expressed in equation (1). The pulse frequency was fixed at 25 kHz for a 14 mm laser cutting length, and gas pressure was set at a constant 700 kPa (7 bar), which gave better results than the preliminary experiment.

As shown in Figure 4, three measurements were taken of the top and bottom surfaces of the specimens at intervals of 4 mm, at three locations perpendicular to the cutting direction, starting from the center of the cut for both kerf sides. These measurements were then averaged to calculate the mean KW and HAZ using equations (2) and (3). The method for measuring KW and HAZ was adopted from studies conducted by Tamrin et al. [19] and Leone et al. [20]. Finally, the MRR is calculated by using equation (4). This methodology provides a thorough understanding of the impact of each parameter on the cutting process' performance, which is crucial for optimizing the process and achieving the desired outcomes.

Table 2 Laser cutting parameters and their levels

Label	Parameter	Levels
A	Peak power, P_p (W)	80, 90, 100
B	Pulse width, τ (μs)	20, 25, 30
C	Cutting speed, v (mm/s)	2, 3, 4

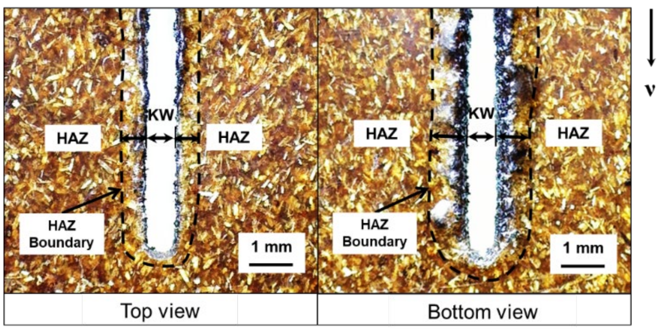


Figure 4 The optical micrograph of measuring KW and HAZ

$$E_l = \frac{P_p \times f \times \tau}{v} \quad (1)$$

$$KW = \frac{KW_1+KW_2+KW_3}{3} \quad (2)$$

$$HAZ = \frac{HAZ_1+HAZ_2+HAZ_3+HAZ_4+HAZ_5+HAZ_6}{3} \quad (3)$$

$$MRR = KW \times h \times v \quad (4)$$

Grey relational analysis (GRA) is a useful technique for analyzing multi-objective optimization problems where several competing objectives must be considered simultaneously. The approach utilized in this study for conducting GRA was derived from the methodology outlined by Mohd Radzman et al. (2023)[21]. Prior to calculating the performance criteria, the mean KW, top and bottom HAZ, and MRR were normalized between 0 and 1 since these values represent the idealized parameters [22]. The normalization of data is done with the help of equations (5) and (6). In this research, for precision cutting, the normalized value of the original sequence for KW, top and bottom HAZ, which are smaller-the-better performance characteristics, can be expressed as:

$$x_i^*(k) = \frac{x_{i\,max}(k)-x_i(k)}{x_{i\,max}(k)-x_{i\,min}(k)} \quad (5)$$

Where $x_i^*(k)$ and $x_i(k)$ are the normalized sequence and the observed sequence respectively, with the k^{th} response of i^{th} specimen. While the normalized value of the original sequence for material removal rate, which is bigger-is-better performance characteristics can be expressed as:

$$x_i^*(k) = \frac{x_i(k)-x_{i\,min}(k)}{x_{i\,max}(k)-x_{i\,min}(k)} \quad (6)$$

After obtaining the normalized data, the grey relational coefficient (GRC) is calculated using equation (7). The GRC, $\xi_i(k)$ represents the relationship between the ideal response and the experimental data.

$$\xi_i(k) = \frac{\Delta_{min}-\zeta\Delta_{max}}{\Delta_i(k)+\zeta\Delta_{max}} \quad (7)$$

Where $\Delta_i(k)$ was the deviation sequence between the reference and comparability sequence $x_0^*(k)$ and $x_j^*(k)$ respectively. As shown in equation (8), Δ_i is the absolute value of the difference between $x_0^*(k)$ and $x_j^*(k)$. While Δ_{min} and Δ_{max} were the minimum and maximum value of Δ_i respectively, as shown in equation (9) and (10). The distinguishing coefficient, ζ (where, ζ∈[0,1]) is typically set to be 0.5 in general and most situations [23].

$$\Delta_i = \left|x_0^*(k) - x_j^*\right| \quad (8)$$

$$\Delta_{min} = min_{(\forall j \in i)} min_{(\forall k)} \left|x_0^*(k) - x_j^*\right| \quad (9)$$

$$\Delta_{max} = max_{(\forall j \in i)} max_{(\forall k)} \left|x_0^*(k) - x_j^*\right| \quad (10)$$

As the final step, the optimum combination parameter was determined by referring to the higher value of grey relational grade (GRG), γ_i. Equation (11) averages the GRC of each response by *n*. The higher value of GRG corresponds to the experimental value that is closer to the ideal normalized value. Thus, a higher GRG indicates that the corresponding parameter combination is closer to the optimal condition.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (11)$$

3.0 RESULTS AND DISCUSSION

The following section presents the results obtained through the methodology discussed in the previous section. Table 3 presents the experimental conditions that were used for the single-mode pulsed fiber laser cutting of WPC, along with the mean values for kerf width (KW), top heat-affected zone (HAZ_T), bottom heat-affected zone (HAZ_B), and material removal rate (MRR) for each experimental trial. The mean values of KW, HAZ_T, HAZ_B, and MRR obtained from the three replications are listed in columns 6 to 9 of Table 3. It should be noted that the linear energy (E_l) range of the laser, specifically between 10 – 37.5 J/mm, is used to ensure that the laser cutting process has enough amount of energy and sufficient interaction time (t_i) to cut through the WPC effectively [24].

Identifying the optimal process parameters to minimize thermal damage and maximize productivity is a challenging task. However, normalizing experimental outcomes utilizing GRA can identify the optimal process parameters that adhere to equation (5) in minimizing KW and HAZ and equation (6) in maximizing MRR. Columns two to four of Table 4 show the processed experimental data after normalization. The normalized values can be seen to range from zero to one. Following normalization, the reference and comparison sequences are denoted as $x_0^*(k)$ and $x_j^*(k)$ respectively. A normalized score of one signifies optimal performance, with higher normalized scores indicating superior performance. In this study, equation (8) is used to govern the absolute value of deviation sequence of $\Delta_i(k)$. The KW, HAZ, and MRR are equally influenced by all the process parameters. To calculate the GRC values listed in columns six to nine of Table 4, the distinguishing coefficient (ζ) in equation (7) was replaced with ζ = 0.5 to give equal weightage to all process parameters.

Table 3 Full factorial design of experiment and response data

Exp. No.	Input parameters A (W)	B (μs)	C (mm/s)	E_l (J/mm)	Output responses (Mean) KW (mm)	HAZ_T (mm)	HAZ_B (mm)	MRR (mm³/s)
1	80	20	2	20.0	0.453	1.151	1.514	0.906
2	80	20	3	13.3	0.608	1.201	1.648	1.824
3	80	20	4	10.0	0.652	1.414	1.569	2.608
4	80	25	2	25.0	0.525	1.169	1.607	1.051
5	80	25	3	16.7	0.642	1.268	1.901	1.926
6	80	25	4	12.5	0.718	1.370	1.803	2.872
7	80	30	2	30.0	0.473	1.075	1.604	0.947
8	80	30	3	20.0	0.489	1.293	1.633	1.468
9	80	30	4	15.0	0.700	1.380	1.911	2.800
10	90	20	2	22.5	0.588	1.133	1.669	1.176
11	90	20	3	15.0	0.668	1.232	1.655	2.004
12	90	20	4	11.3	0.768	1.322	1.719	3.072
13	90	25	2	28.1	0.600	1.129	1.661	1.200
14	90	25	3	18.8	0.600	1.254	1.693	1.799
15	90	25	4	14.1	0.756	1.462	1.735	3.024
16	90	30	2	33.8	0.550	1.067	1.640	1.099
17	90	30	3	22.5	0.568	1.237	1.803	1.703
18	90	30	4	16.9	0.646	1.350	1.643	2.584
19	100	20	2	25.0	0.594	1.158	1.751	1.188
20	100	20	3	16.7	0.674	1.332	1.653	2.022
21	100	20	4	12.5	0.740	1.306	1.665	2.960
22	100	25	2	31.3	0.666	1.212	1.938	1.332
23	100	25	3	20.8	0.736	1.270	1.893	2.208
24	100	25	4	15.6	0.780	1.316	1.659	3.121
25	100	30	2	37.5	0.656	1.127	1.693	1.312
26	100	30	3	25.0	0.616	1.250	1.653	1.848
27	100	30	4	18.8	0.648	1.368	1.751	2.592

The GRG values were calculated using equation (11), and the experiments were organized based on their values. The order of experiments can be determined by referring to column 3 of Table 5, where their respective GRG values are listed. The maximum attained GRG value was 0.759, indicating that the corresponding experimental data is more closely aligned with the ideal experimental data. Experiment number 1 achieved the highest GRG value, indicating that it is the most optimal sequence for the multi-response optimization of the single-mode pulsed fiber laser cutting process. Figure 4 depicts a visual representation of the GRG value for each specimen, showing the rankings of different parameter combinations in relation to their performance characteristics. The full factorial DOE allows for observing changes in the response when factors vary between different levels. As per the findings in Figure 5, it is evident that the highest GRG value is attained through experiment number one. Thus, it has been shown that all 27 runs possess an optimal configuration of process parameters that yield the most favorable multi-performance characteristics.

Table 4 Normalized values and GRC

Exp. No.	Normalized KW (mm)	HAZ_T (mm)	HAZ_B (mm)	MRR (mm³/s)	GRC KW (mm)	HAZ_T (mm)	HAZ_B (mm)	MRR (mm³/s)
1	1.000	0.787	1.000	0.000	1.000	0.701	1.000	0.333
2	0.526	0.660	0.685	0.414	0.514	0.596	0.613	0.461
3	0.392	0.122	0.871	0.768	0.451	0.363	0.795	0.683
4	0.779	0.742	0.782	0.065	0.694	0.659	0.696	0.348
5	0.423	0.492	0.086	0.460	0.464	0.496	0.354	0.481
6	0.190	0.233	0.317	0.888	0.382	0.395	0.423	0.817
7	0.938	0.981	0.787	0.018	0.890	0.963	0.701	0.337
8	0.889	0.429	0.720	0.254	0.818	0.467	0.641	0.401
9	0.245	0.207	0.062	0.855	0.398	0.387	0.348	0.775
10	0.588	0.833	0.634	0.122	0.548	0.750	0.578	0.363
11	0.343	0.584	0.667	0.496	0.432	0.546	0.600	0.498
12	0.037	0.356	0.517	0.978	0.342	0.437	0.508	0.958
13	0.552	0.844	0.653	0.132	0.527	0.762	0.591	0.366
14	0.552	0.528	0.577	0.403	0.527	0.514	0.542	0.456
15	0.074	0.000	0.478	0.956	0.351	0.333	0.489	0.920
16	0.705	1.000	0.702	0.087	0.629	1.000	0.626	0.354
17	0.650	0.569	0.317	0.360	0.588	0.537	0.423	0.439
18	0.411	0.284	0.696	0.757	0.459	0.411	0.622	0.673
19	0.570	0.771	0.441	0.127	0.538	0.686	0.472	0.364
20	0.325	0.330	0.672	0.504	0.425	0.427	0.604	0.502
21	0.123	0.396	0.644	0.928	0.363	0.453	0.584	0.873
22	0.350	0.634	0.000	0.192	0.435	0.578	0.333	0.382
23	0.135	0.487	0.104	0.588	0.366	0.494	0.358	0.548
24	0.000	0.370	0.658	1.000	0.333	0.443	0.594	1.000
25	0.380	0.849	0.578	0.183	0.446	0.768	0.542	0.380
26	0.502	0.538	0.673	0.425	0.501	0.520	0.605	0.465
27	0.404	0.238	0.441	0.761	0.456	0.396	0.472	0.677

Table 5 GRG and rank

Exp. No.	GRG	Rank
1	0.759	1
2	0.546	12
3	0.573	7
4	0.599	4
5	0.449	25
6	0.504	20
7	0.723	2
8	0.582	6
9	0.477	24
10	0.560	11
11	0.519	17
12	0.561	10
13	0.561	9
14	0.510	19
15	0.523	15
16	0.652	3
17	0.497	22
18	0.541	13
19	0.515	18
20	0.490	23
21	0.568	8
22	0.432	27
23	0.442	26

24	0.593	5
25	0.534	14
26	0.523	16
27	0.500	21

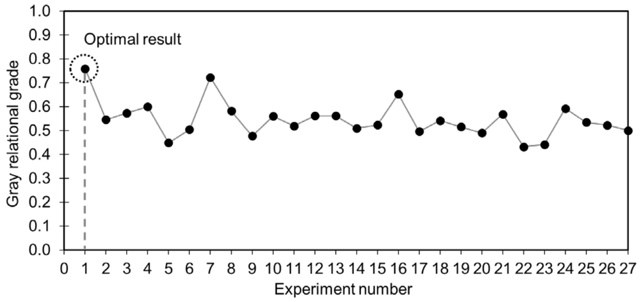


Figure 5 Grey relational grade for multi-response optimization of single-mode pulsed fiber laser cutting of WPC

As shown in Table 6, the GRG response table can be used to assess the various effects of each input parameter on the performance characteristics of pulsed fiber laser cutting for this biodegradable composite. The average GRG is calculated based on the associated parameters and level. The difference between the highest and lowest response values for each characteristic is called delta (δ). The parameters are prioritized according to δ values, with a higher δ value indicating a more significant impact on the process. A greater sensitivity to various parameter levels is implied by a high δ value, rendering it a valuable means of determining parameter significance. This study confirms that the most important parameter in cutting WPC using a single-mode fiber laser is the cutting speed, which ranks the highest δ. The subsequent two major parameters are peak power and pulse width, respectively. In comparison to previous investigations, the obtained results were consistent [13, 18].

Table 6 Response table for grey relational grade

Level	A (W)	B (µs)	C (mm/s)
1	0.579	0.566	0.593
2	0.547	0.513	0.506
3	0.511	0.559	0.538
δ	0.068	0.053	0.087
Rank	2	3	1

Figure 6 displays the main effects plots of each laser-cutting parameter level on multiple responses. From the analysis of Table 6 and Figure 5, it has been determined that the A1 (80 W), B1 (20 µs), and C1 (2 mm/s) characterize the highest value of GRG for peak power, pulse width, and cutting speed respectively. Hence, the optimal combination of process parameters in fiber laser cutting of WPC is A1 - B1 - C1, as shown in Figure 7. These parameters include lower peak power, moderate pulse width, and the lowest cutting speed at linear energy (E_l) of 20 J/mm. These settings lead to improved cut quality by minimizing thermal damage (KW and HAZ) and maximizing productivity (MRR).

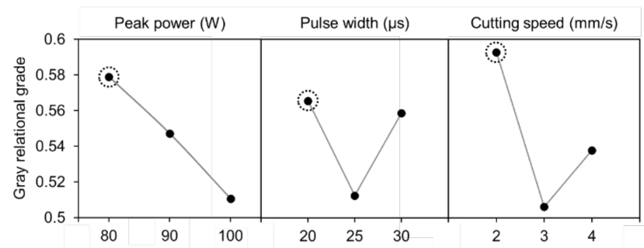


Figure 6 Main effects plot of pulsed fiber laser cutting on multi-response

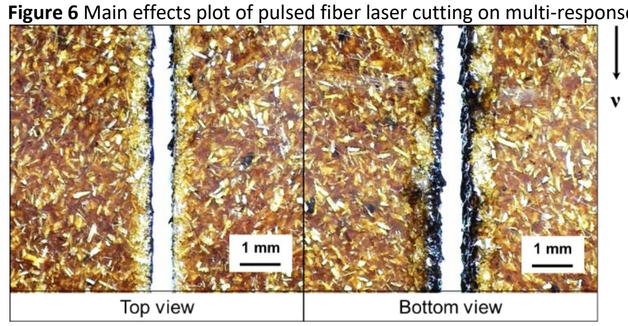


Figure 7 Microscopic view of the laser cut for WPC at A1 – B1 – C1

4.0 CONCLUSION

An experimental investigation was conducted on optimizing the cutting process of wood-plastic composites (WPC) using a single-mode pulsed fiber laser. To achieve the best cutting parameters, the grey relational analysis was used to analyze the performance characteristics of minimizing KW and HAZ to improve cut quality and maximize MRR to increase productivity. The optimal combination of parameters was determined to be a lower peak power of 80 W, a shorter pulse width of 20 µs, and a slower cutting speed of 2 mm/s. This combination was found to have the most favorable effect on the fiber laser cutting performance. The study also revealed that all cutting parameters significantly affect the laser cutting process, with cutting speed being the most influential parameter, followed by peak power and pulse width. The response table and main effects plot have been used to verify the data obtained through calculation.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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