Jurnal Kejuruteraan 36(2) 2024: 837–846
https://doi.org/10.17576/jkukm-2024-36(3)-01

Evaluation of Cutting Parameters on Heat-Affected Zone in Wood Plastic Composites by Pulsed Fiber Laser

Mohd Khairul Domadi[a*], Mohd Idris Shah Ismail[a], Mohd Zuhri Mohamed Yusoff[a,b] & Mohd Hanif Mohd Pisal[c,d]

[a]Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, Malaysia

[b]Institute of Tropical Forestry and Forest Product (INTROP), Universiti Putra Malaysia, Malaysia

[c]Faculty of Chemical Engineering Technology, Universiti Malaysia Perlis, Malaysia

[d]Centre of Excellence for Biomass Utilization (CoEBU), Universiti Malaysia Perlis, Malaysia

[*]Corresponding author: gs61656@student.upm.edu.my

Received 26 July 2023, Received in revised form 20 September 2023
Accepted 30 October 2023, Available online 30 May 2024

ABSTRACT

Biodegradable and environmentally friendly composite materials such as wood plastic composites (WPCs) have gained attention in industrial applications due to environmental concerns and global sustainability goals. However, owing to their unique structures and properties, cutting on WPCs can be challenging. Continuous wave (CW) mode laser may result in heat build-up and easily warp the WPCs during laser cutting. Therefore, minimizing these defects and determining the cutting parameters that influence the heat-affected zone (HAZ) by pulsed mode laser is essential. In this present work, 1 mm thickness of WPC 30 wt.% of wood fiber (WF) filled with recycled high-density polyethylene (rHDPE) has been experimentally cut by single-mode pulsed fiber laser to evaluate the minimum laser energy required to cut the WPC and the influence of cutting parameters on the HAZ. The HAZ was measured using a digital microscope, and the statistical significance of the cutting parameters to HAZ was determined by analysis of variance (ANOVA). The results confirmed that a minimum linear energy of more than 9 J/mm is required to cut the WPC. It has been found that the cutting speed is the major influence on the HAZ, followed by pulse width. Adequate interaction time by cutting speed and duration of the single-laser pulse also significantly affects the cutting process. The higher gas pressure could minimize the HAZ at the surrounding cutting region of the WPCs. Understanding the influence of these parameters could minimize the thermal effect of HAZ and improve the laser cut quality.

Keywords: laser cutting; natural composite; linear energy; ANOVA; material processing

INTRODUCTION

Laser cutting is a thermal material removal process that is widely used in today's manufacturing industries. Owing to its excellent cut quality and efficiency, the ability to obtain complex shapes, flexibility, and speed, laser cutting is proven as one of the attractive and competitive alternatives to conventional manufacturing cutting methods (Tamrin et al. 2020). This method has advantages in cutting for various materials, which can be performed without contact with the workpiece and the absence of tool wear, cutting force, and vibrations. Moreover, laser cutting is highly controllable energy density, efficiently automated, small heat-affected zone (HAZ), rapid cutting process, high-quality finished products, and produces low emission pollution (Bakhtiyari et al. 2021). Fundamentally, lasers can be operated in two distinct modes: continuous wave (CW) and pulsed wave (PW). The versatility of laser modes has enabled precise material processing in various applications, including cutting, welding, engraving, surface ablation, and surface modification (Hamid et al. 2018) (Bhattacharyya & Doloi 2020) (Rohaizar et al. 2020).

In recent years, natural composite materials that are both biodegradable and environmentally friendly have gained positive acceptance due to environmental concerns and global efforts to achieve sustainable goals. In the family of natural fiber-reinforced composites (NFRCs), wood plastic composites (WPCs) stand out as promising eco-friendly composites with significant fabrication demand and potentially replacing natural wood (Koay et al. 2018). WPCs are increasingly being utilized in various industries due to their unique mechanical properties, low cost, and eco-friendly (Shahani et al. 2021). However, cutting these composites can be challenging due to their heterogeneous structure, material sensitivity to thermal operation, and quality variations of the composite material (Jani et al. 2016) (Krishna et al. 2019). Although the fact that laser cutting is widely used, minimizing machining defects is particularly essential in working with different biodegradable and eco-friendly composite materials. The need for characterization, assessing the main effects of laser input parameters, and gaining a deeper understanding of the challenges with laser-materials processing have caused the barrier for industries to implement this method.

Laser cutting of WPC is difficult for the same reason that NFRC is a sensitive material to heat. The cut quality on WPC is determined by the minimum thermal damage, which is the lowest value for both the top and bottom HAZ from the cutting operation. Although HAZ and thermal damage frequently occur in the laser machining of wood and wood composites, it is crucial to minimize HAZ, enhance precision, improve kerf width, reduce material damage at high cutting speed, and improve cut quality. Eltawahni et al. (2011) noted that the laser cutting of MDF wood composite is a complex process because it involves an exothermic chemical reaction and is affected by variables such as composition, density, moisture, thermal conductivity, and internal bond strength between the composite materials. According to Tamrin et al. (2015), the cut quality, size of HAZ, and laser power are also major concern issues in laser cutting of thermoplastics. They used the analysis of variance (ANOVA) to analyze peak power, cutting speed, and gas pressure on a CO_2 laser machine in CW mode and discovered that laser power dominates HAZ. The researchers suggest that more research is necessary to understand the effects of heat input and gas pressure. Tamrin et al. (2020) also evaluated the main parameters for CW laser cutting of composites, such as laser power, cutting speed, stand-off distance, and number of beams passes on HAZ on 0.4 mm cotton fiber laminate reinforced phenolic resin composite by a low power CO_2 laser. The effect of cutting speed on the HAZ was the most significant, and the HAZ depth is inversely proportional to cutting speed. The minimum laser power and maximum cutting speed contribute to the lowest HAZ.

Nugroho and Winarbawa (2018) stated laser cutting requires accurate parameter values to produce high-quality products for composite sheets, and incorrect input parameters could result in low-precision output. According to their results of the signal to noise (S/N) ratio response calculation, gas pressure is the most influential factor for cutting agel leaf fiber unsaturated polyester (ALF/UP) composite with CW CO_2 laser. The effects of cutting speed, laser power, and nozzle distance are ranked second, third, and fourth, respectively. Masoud et al. (2021) studied the HAZ as a response parameter to CW laser power, traverse speed, and gas pressure. The study was conducted on 2 mm, 4 mm, and 6 mm thicknesses of sugar palm fiber-reinforced unsaturated polyester composites by CO_2 laser. For all thicknesses, the effect of gas pressure was the most significant, whereas the contribution of traverse speed increases with material thickness. Furthermore, laser power minimally contributes to the influence on the HAZ.

Most laser cutting of NFRCs and polymer composites was conducted in CW mode. As a result, the laser beam is emitted continuously, which may cause more heat build-up in the composites resulting in thermal damage during the cutting process. According to a study conducted by Leone and Genna (2018), the utilization of a pulsed Nd: YAG laser with high cutting speed and low pulsed energy has demonstrated the potential to decrease the heat-affected zone (HAZ) in CFRP cutting composites. Moreover, Singh et al. (2021) namely gas pressure, cutting speed, pulse frequency and pulse width predictive models were developed. In accordance with Taguchi's L9 orthogonal array (OA) observed that in pulse laser cutting of coir fiber and carbon fiber, the selection of optimal parameter settings plays a crucial role in enhancing the quality of the cut.

Since this is a novel attempt to investigate cutting WPCs with pulsed-mode fiber laser, the primary aim of this preliminary study is to identify the minimum linear energy required to cut through the WPCs and gain a better understanding of the process parameters that influence the HAZ. In this study, the thermal effect of HAZ generated in the cutting process of WPCs using a single-mode pulsed fiber laser was experimentally carried out. The HAZ was measured at the top and bottom of the cut. For evaluating the performance of cutting condition to HAZ, the analysis of variance (ANOVA) method was used to determine the influence of cutting parameters on the HAZ. The findings of this evaluation are essential as the basis for the optimization in pulsed fiber laser cutting of WPCs.

METHODOLOGY

The WPC was used as a specimen in this study. This thermoplastic NFRC is used to make WPC tray for food packaging and its mechanical properties of specimen material are shown in Table 1. The dimensions of each specimen were 40 mm in length, 30 mm in width, and 1 mm in thickness. The WPC was similar material employed by Hanif et al. (2014) because of the widespread interest in wood as a natural reinforcing filler. A significant combination of plastics matrix composite of 30 wt.% short fiber wood fiber (WF) filled with recycled high-density polyethylene (rHDPE) was utilized for specimen fabrication.

A schematic diagram of experimental setup is shown in Figure 1. The wavelength of 1070 nm single-mode fiber laser (SPI: SP-200C) with a maximum peak power of 200 W was used. The laser machine is capable of operating in CW and PW modes. The laser was delivered by optical fiber and focused by a fθ lens of 180 mm in focal length and generates 18 µm of focused beam diameter. Instead of the conventional moving stage, a Galvano scanner was used, and the cutting processes were conducted in argon gas to reduce the impact of oxygen from the surrounding environment. The WPC was clamped using a jig fixture at both ends of the specimen to prevent warpage during laser cutting process.

TABLE 1. Mechanical properties of WPC

Property	Value	Unit
Tensile strength	19.06	MPa
Modulus of elasticity	674.67	MPa
Intensity ratio	0.367	-
Elongation at break	22.73	%
Flexural strength	28.88	MPa
Bend modulus	1124.63	MPa
Impact strength	3820.66	J/m^2

Source: Hanif et al. (2014)

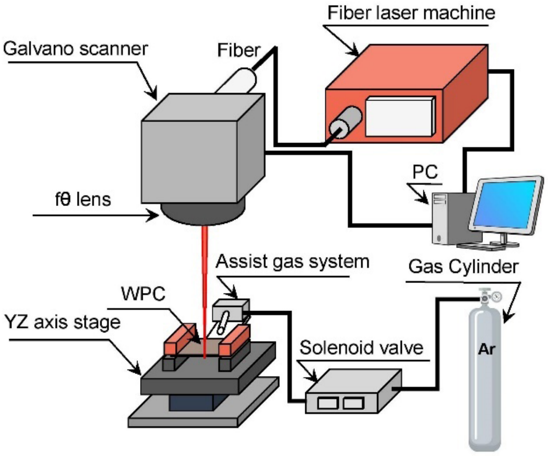

FIGURE 1. Schematic diagram of experimental setup

In this study, four main cutting parameters are considered from the literature review, i.e., peak power, pulse width, cutting speed and gas pressure. 81 cutting conditions with three levels for each parameter were used to establish the experimental design as listed in Table 2. For the effective analysis, the frequency was kept constant at 25 kHz. In order to ensure accuracy and reliability, it is advisable to rerun the experiment if the readings for the HAZ of the pulsed fiber laser are found to be inconsistent. The full factorial of Design of Experiments (DOE) was used to evaluate the influence of cutting parameters and ANOVA method was adopted to determine the contribution of each parameter to the HAZ. The statistical analysis was generated by Minitab software.

After the laser cutting process, the output response of HAZ was observed and measured at both the top and the bottom cutting region using a digital microscope. The HAZ for WPC refers to the region of the base material that contains burn marks and charred edges, melted and vaporized elements close to the cutting kerf, and localized thermal damage near the cutting region. The mean HAZ was calculated by averaging the results of three measurements taken from the center of cut for both kerf sides and extending out every 4 mm (3 locations with perpendicular to cutting direction) for both the top and bottom surfaces of the specimens as shown in Figure 2. The methodology to measure the dimension of HAZ was adopted from Leone et al. (2021) and Tamrin et al. (2020). In addition, each cutting condition was also observed either the laser cutting could perform the cut through or incomplete cut the WPC material.

TABLE 2. Laser cutting parameters and their levels

Factor	Parameter	Level		
		1	2	3
A	Peak power, P_p (W)	80	90	100
B	Pulse width, τ (μs)	15	25	35
C	Cutting speed, ν (mm/s)	2	4	6
D	Gas pressure, p (kPa)	300	500	700

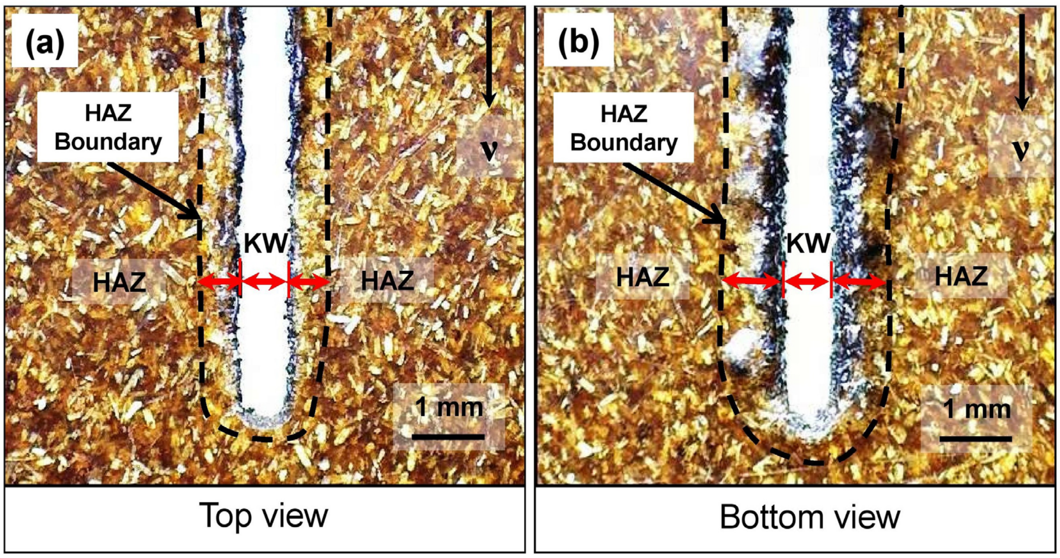

FIGURE 2. Optical micrograph of HAZ at (a) top and (b) bottom of cutting region

RESULTS AND DISCUSSION

The pulsed mode laser has the capability of energy efficient in producing high peak power, while its average power is relatively low. Pulsed laser is designed to achieve high peak power because its duration (pulse width) limits the heat build-up and is suitable for laser cutting of WPCs with less damaging the materials. Figure 3 shows the laser cutting of WPCs with cut through, which sufficient energy is supplied to the workpiece and incomplete cut (or grooving) due to insufficient energy. In laser cutting, the amount of energy input per unit length to the workpiece (i.e., linear energy) directly impacts to the cutting quality and researchers used linear energy to show the combined effect on process performances (Li et al. 2019; Riveiro et al. 2017). Since sometimes it is difficult to understand and control the many parameters individually, instead of these parameters, a combination of cutting parameters can be advantageous. The linear energy E_l (J/mm) for pulse mode laser can be expressed as:

$$E_l=(P_p\times f\times\tau)/v \qquad (1)$$

where P_p is the peak power, f is the pulse frequency, τ is the pulse width, and ν is the cutting speed.

In this study, the linear energy required to cut the WPC is determined using the relationship between peak power, pulse width, and the cutting speed, while the frequency is kept constant. The influence of linear energy with difference cutting speeds on cutting condition to WPC material is depicted in Figure 4. With this configuration, the laser cutting process could only completely cut through 69 of the total runs, while 12 runs could not be cut through due to poor heat generation resulting from insufficient linear energy and less interaction time.

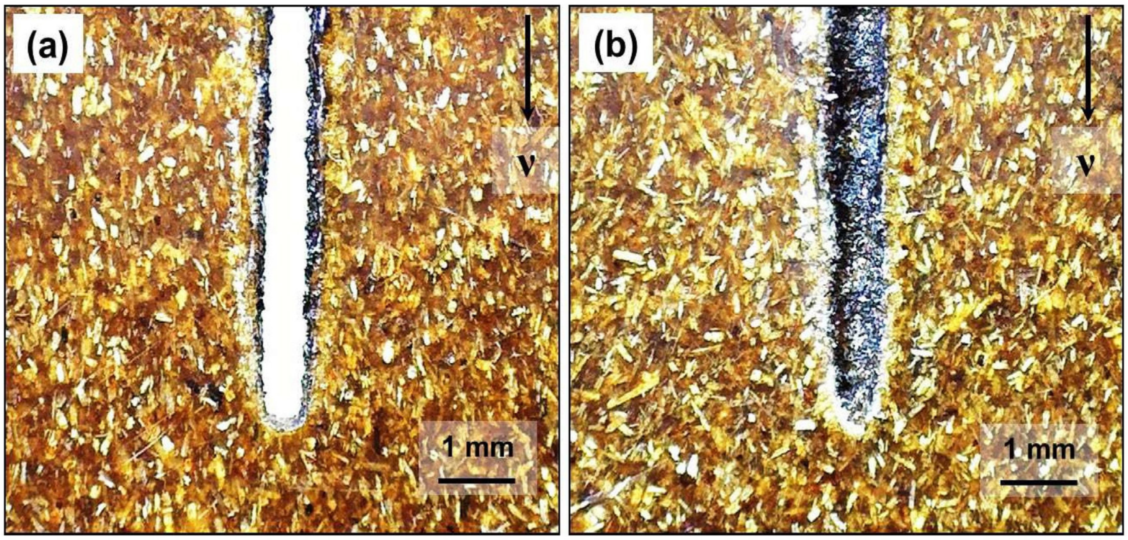

FIGURE 3. Laser cutting condition of (a) cut through and (b) incomplete cut (groove)

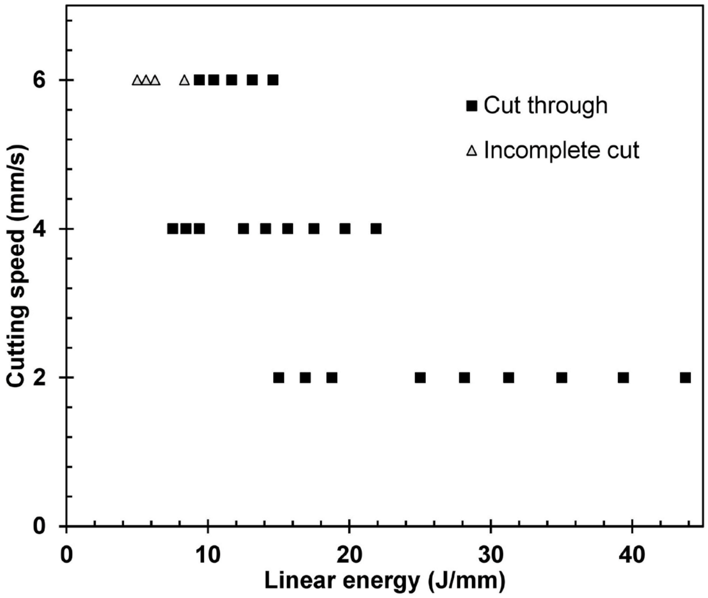

FIGURE 4. Feasibility map of linear energy and cutting speed on cutting condition

It can be seen that linear energy greater than 9 J/mm can be considered as the starting level of adequate energy to perform completely the material removal process on WPC. Despite this, with enough interaction time and a cutting speed of 4 mm/s and a linear energy of 8 J/mm, the WPC material can be completely removed. This is because interaction times greater than or equal to 4.5 ms are considered possible exposure times required to perform the cutting process (Kannatey-Asibu 2009). It can be noted that to cut through the 1 mm thickness of WPC in a single pass, it required sufficient energy to heat up, melt, and vaporize the material, which is the linear energy should be more than 9 J/mm. However, if the low linear energy is applied, it may only produce a partial cut, leaving a groove or indentation on the surface of the WPC.

This study utilizes ANOVA to effectively evaluate and quantify the statistical significance of every process parameter. The second-order regression analysis of ANOVA result of HAZ under different peak power, pulse width, cutting speed and gas pressure is shown in Table 3. In this table, the presented parameters of DF, SS, and MS are the abbreviation of the degree of freedom, the sum of squares, and mean squares, respectively. The DF is determined by the number of observations in the sample.

The SS states the total variation that can be attributed to various factors. The parameter of MS is used to determine whether factors are significant. The F-value is used to calculate the P-value. A sufficiently large F-value shows that the parameter is significant. Moreover, if P-value does not exceed from 0.05 means the input parameter effect on output is significant. As can be observed from Table 3, the cutting speed has the most significant impact to both top and bottom HAZ and followed by the pulse width. In addition, two-way interaction control factors also confirmed that top and bottom HAZ strongly correlates with the combination of cutting speed and pulse width. The combination of the peak power with either cutting speed or pulse width is also substantially affect to HAZ.

Figure 5 illustrates the top and bottom surfaces of cutting region at difference level of cutting speed at constant for other parameters (P_p: 80 W, τ: 35 μs, p: 700 kPa). It can be seen that working with low cutting speed increases the heat accumulated during the laser cutting of WPC by allowing the laser to employ more time in cutting through the composite. This results in a larger size of bottom HAZ. However, under low cutting speed the top HAZ indicates a smaller size. It can be noted that since the laser movement is relatively slow, the laser energy is sufficiently penetrated to the bottom surface of WPC and generates larger HAZ at the bottom compared to the top surface. Subsequently, cutting speed with higher level shows smaller HAZ at the bottom surface and larger HAZ at the top surfaces of WPC. This is due to the laser energy being mostly supplied to the top side and partially transfer to the bottom side of materials under rapid process.

As can be observed from Figure 6 (other parameters are kept constant; P_p: 90 W, ν: 2 mm/s, p: 700kPa), as one of the most significant parameters to HAZ, the relationship of pulse width with HAZ is non-linear. The longer pulse width may expose the cutting zone to more heat for an extended duration, resulting in a larger HAZ. It may also cause thermal damage to the WPC and increase the tendency of melting and spattering of this composite, and subsequently directly affect the incremental of kerf width. As obtained from ANOVA that the combination of pulse width and cutting speed has a strong correlation with HAZ, Figure 6 also shows the size of top HAZ is smaller compared to bottom HAZ. This confirmed that under low cutting speed (ν: 2 mm/s) and at any levels of pulse width, the larger HAZ is generated at the bottom surface and smaller HAZ at the top surfaces of WPC. Furthermore, a combination of long pulse width with slow cutting speed is not preferable for minimizing the bottom HAZ. This could happen because heat accumulation at the bottom side of WPC is more sensitive to heat build-up, and the cutting region is less exposed to cooling airflow. The shorter pulses allow the laser energy to be delivered to the material faster, allowing for a more controlled cut with less thermal damage to the surrounding area. In the case of long pulse width, it can be used with a faster cutting speed.

TABLE 3. ANOVA results for HAZ in laser cutting of WPC

Source	DF	Adj. SS	Adj. MS	F-value	P-value
(a) Top HAZ					
P_p	2	0.2540	0.12699	1.47	0.240
τ	2	3.4538	1.72692	19.97	0.000
ν	2	6.5359	3.26794	37.78	0.000
p	2	0.2880	0.14400	1.66	0.200
$P_p\ \tau$	4	1.3636	0.34090	3.94	0.008
$P_p\ \nu$	4	1.6051	0.40128	4.64	0.003
P_p p	4	0.0535	0.01338	0.15	0.960
$\tau\ \nu$	4	10.1520	2.53801	29.34	0.000
τ p	4	0.1070	0.02674	0.31	0.870
ν p	4	0.1216	0.03041	0.35	0.842
Error	48	4.1515	0.08649		
Total	80	28.0861			
(b) Bottom HAZ					
P_p	2	0.4455	0.22277	3.02	0.058
τ	2	5.7863	2.89317	39.28	0.000
ν	2	18.8040	9.40199	127.65	0.000
p	2	0.5895	0.29477	4.00	0.025
$P_p\ \tau$	4	1.0588	0.26471	3.59	0.012
$P_p\ \nu$	4	1.6366	0.40914	5.55	0.001
P_p p	4	0.1043	0.02607	0.35	0.840
$\tau\ \nu$	4	6.8388	1.70970	23.21	0.000
τ p	4	0.0384	0.00961	0.13	0.971
ν p	4	0.1620	0.04051	0.55	0.700
Error	48	3.5353	0.07365		
Total	80	38.9997			

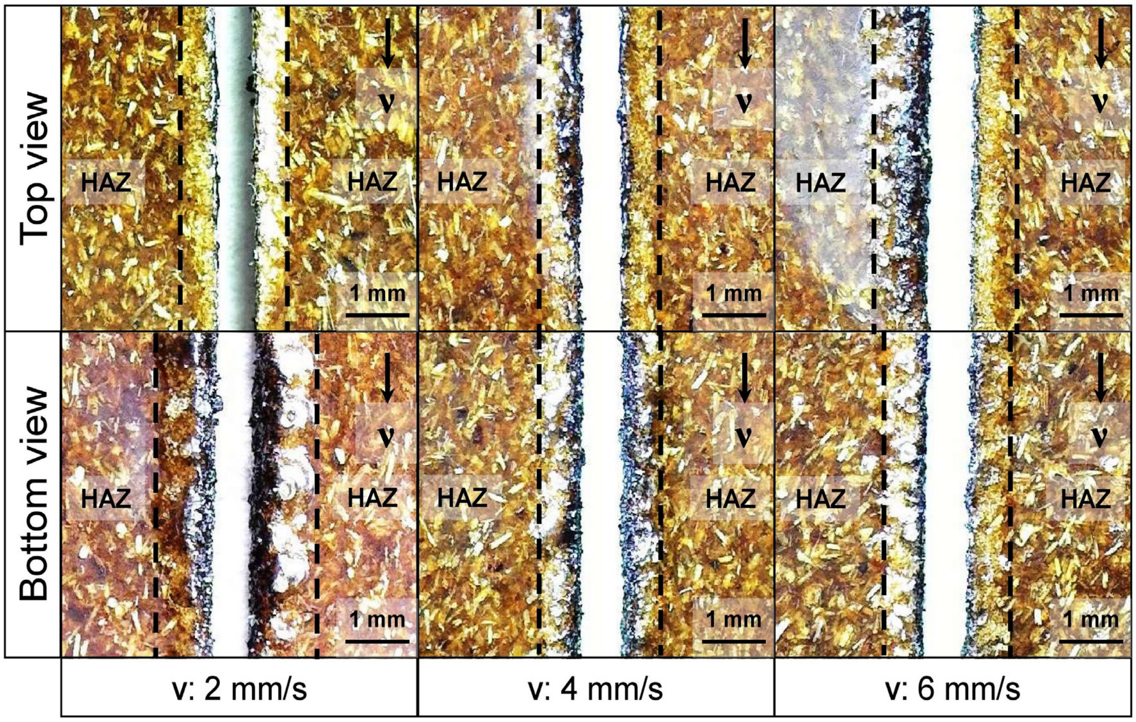

FIGURE 5. Effect of cutting speed on HAZ

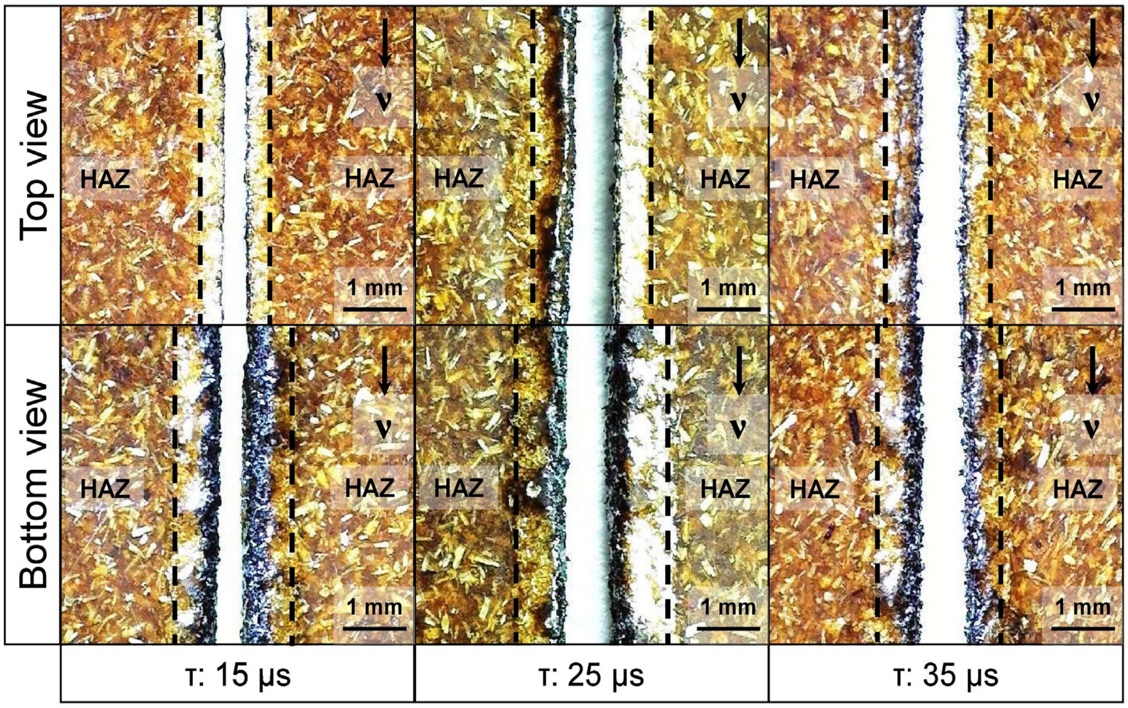

FIGURE 6. Effect of pulse width on HAZ

Gas pressure is required to remove the molten material from the cutting area, prevent the kerf's debris from damaging and degrading the cutting region, and provide a cooling process to both WPC surfaces. Figure 7 illustrates the top and bottom surfaces of cutting region at difference level of gas pressure at constant for other parameters (P_p: 90 W, τ: 15 µs, and v: 2 mm/s). It can be observed that the smallest HAZ at both top and bottom side of WPC is generated under higher 700 kPa of gas pressure. Reduction of gas pressure leads to increase the HAZ size. For the top HAZ, the gas pressure appears to yield no significant results. Therefore, maintaining a constant gas pressure during laser-cut is preferable. Compared to the top HAZ, the bottom HAZ exhibits a significant value for gas pressure. As can be seen in Table 3, from ANOVA results confirm the HAZ is more significant at the bottom surface of WPC due to the narrow kerf, which restricts the amount of gas that can reach the bottom region. In contrast, the peak power does not thoroughly change the HAZ since the small difference between low and high levels. Moreover, it has observed from ANOVA result that the peak power minimally contributes to the effect on the HAZ.

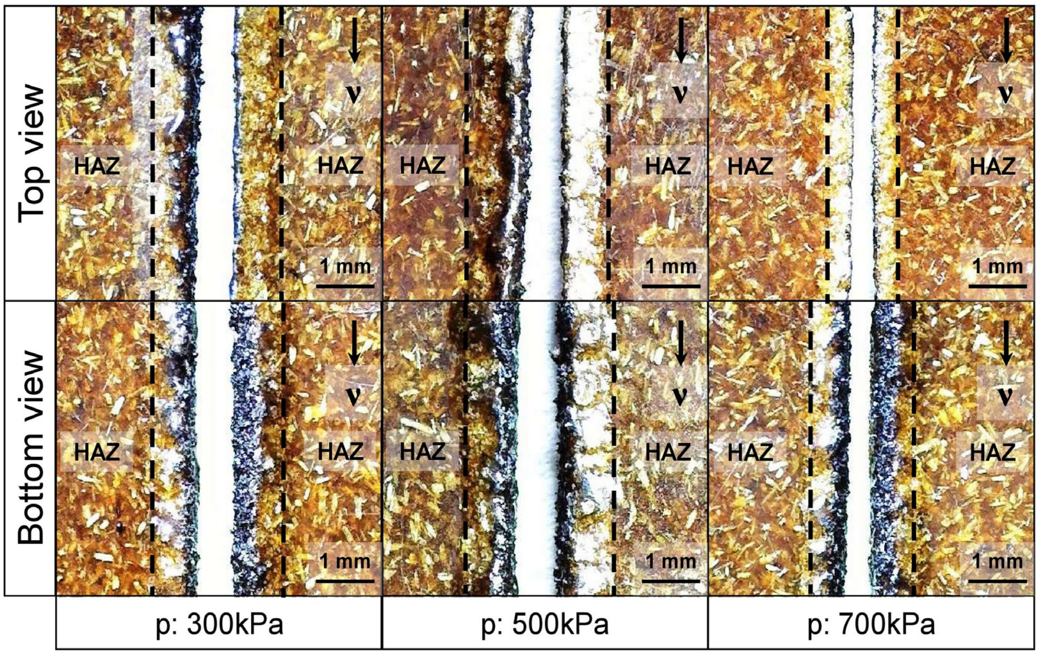

FIGURE 7. Effect of gas pressure on HAZ

CONCLUSION

The aim of this preliminary research is to determine the minimum linear energy needed to cut through WPCs and understand the impact of different process parameters on the HAZ. The cutting of WPCs using single-mode pulsed fiber laser has been experimentally carried out and the influence of cutting parameters on HAZ at the top and bottom of cutting region were evaluated. Main conclusions obtained in this study are as follows:

1. The minimum linear energy required by a pulsed fiber laser to achieve full cutting through the 1 mm thickness of WPC should be greater than 9 J/mm for sufficient laser energy and interaction time.
2. The primary factor influencing the HAZ in pulsed fiber laser cutting is cutting speed, with pulse width ranking second in significance.
3. Cutting speed, pulse width and combination of both parameters significantly affect HAZ. It is recommended to combine longer pulse width with faster cutting speed for minimizing the HAZ.
4. A gas pressure of 700 kPa produces less HAZ compared to lower level of gas pressure and provides a cooling effect within the cutting region during laser cutting process.
5. The combination of peak power and cutting speed, or pulse width, has been found to be significantly more effective in minimizing the HAZ compared to utilizing peak power alone.

These findings suggest that a strategic combination of these factors should be considered in order to achieve further optimal results for pulsed fiber laser cutting processes of WPCs.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Universiti Putra Malaysia for financial support through the Putra Grant (GP-IPS/2018/9608000) and to the Centre of Excellence for Biomass Utilization (CoEBU) of Universiti Malaysia Perlis for their assistance with specimen preparation.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Hamid, S. N. F. A., Sepeai, S., H. Zaidi, S., & Ahmad, S.

M. 2018. Pulsed Laser Annealing of Ag-Paste on n -Doped Emitter. *Jurnal Kejuruteraan SI 1*(3): 57–62. http://dx.doi.org/10.17576/jkukm-2018-si1(3)-08

Bakhtiyari, A. N., Wang, Z., Wang, L., & Zheng, H. 2021. A review on applications of artificial intelligence in modeling and optimization of laser beam machining. *Optics and Laser Technology* 135: 106721. https://doi.org/10.1016/j.optlastec.2020.106721

Bhattacharyya, B., & Doloi, B. 2020. *Modern Machining Technology: Machining Processes Utilizing Thermal Energy.* Academic Press.

Eltawahni, H. A., Olabi, A. G., & Benyounis, K. Y. 2011. Investigating the CO_2 laser cutting parameters of MDF wood composite material. *Optics and Laser Technology* 43: 648–659. https://doi.org/10.1016/j.optlastec.2010.09.006

Hanif, M. P. M., Supri, A. G., & Zainuddin, F. 2014. Effect of wood fiber treated with salicylic acid/ ethanol on tensile properties and thermal stability of recycled high density polyethylene/wood fiber composites. *Applied Mechanics and Materials* 679: 132–136. https://doi.org/10.4028/www.scientific.net/amm.679.132

Kannatey-Asibu, E. J. 2009. *Principles of Laser Materials Processing: Background on Laser Processing*. John Wiley & Sons Ltd. https://doi.org/https://doi.org/10.1002/9780470459300

Jani, S. P., Kumar, A. S., Khan, M. A., & Kumar, M. U. 2016. Machinablity of hybrid natural fiber composite with and without filler as reinforcement. *Materials and Manufacturing Processes* 31(10): 1393–1399. https://doi.org/10.1080/10426914.2015.1117633

Koay, S. C., Subramanian, V., Chan, M. Y., Pang, M. M., Tsai, K. Y., & Cheah, K. H. 2018. Preparation and characterization of wood plastic composite made up of durian husk fiber and recycled polystyrene foam. *MATEC Web of Conferences*, *152*, pp. 1–7. https://doi.org/10.1051/matecconf/201815202019

Krishna, V., Kate, K. H., Satyavolu, J., & Singh, P. 2019. Additive manufacturing of natural fiber reinforced polymer composites: Processing and prospects. *Composites Part B* 174: 106956. https://doi.org/10.1016/j.compositesb.2019.106956

Leone, C., & Genna, S. 2018. Heat affected zone extension in pulsed Nd:YAG laser cutting of CFRP. *Composites Part B:* 140: 174–182. https://doi.org/10.1016/j.compositesb.2017.12.028

Leone, C., Mingione, E., & Genna, S. 2021. Laser cutting of CFRP by Quasi-Continuous Wave (QCW) fibre laser: Effect of process parameters and analysis of the HAZ Index. *Composites Part B: Engineering*, *224*. pp. 109146 https://doi.org/10.1016/j.compositesb.2021.109146

Li, M., Li, S., Gan, G., Zhang, Y., Liang, Z., & Yang, X. 2019. Experimental study on hole quality and tensile progressive failure following fiber laser cutting of multidirectional carbon fiber reinforced plastic laminates. *Journal of Laser Applications* 31(1): 012004. https://doi.org/10.2351/1.5046549

Masoud, F., Sapuan, S. M., Ariffin, M. K. A. M., Nukman, Y., & Bayraktar, E. 2021. Experimental analysis of heat-affected zone (HAZ) in laser cutting of sugar palm fiber reinforced unsaturated polyester composites. *Polymers* 13(5): 1–12. https://doi.org/10.3390/polym13050706

Nugroho, G., & Winarbawa, H. 2018. Investigation of Agel Leaf Fiber/Unsaturated Polyester Composite Cutting Parameters Using CO_2 Laser. *Proceedings - 2018 4th International Conference on Science and Technology, ICST 2018*, pp. 2–6. https://doi.org/10.1109/ICSTC.2018.8528630

Riveiro, A., Quintero, F., Lusquiños, F., del Val, J., Comesaña, R., Boutinguiza, M., & Pou, J. 2017. Laser cutting of Carbon Fiber Composite materials. *Procedia Manufacturing* 13: 388–395. https://doi.org/10.1016/j.promfg.2017.09.026

Rohaizar, M. H., Sepeai, S., Ahmad Ludin, N., Ibrahim, M. A., Sopian, K., & Zaidi, S. H. 2020. An improved efficiency by surface modification using pulse laser for partial transparent bifacial solar cell. *Jurnal Kejuruteraan* 32(4): 715–721. https://doi.org/10.17576/jkukm-2020-32(4)-22

Shahani, S., Gao, Z., Qaisrani, M. A., Ahmed, N., Yaqoob, H., Khoshnaw, F., & Sher, F. 2021. Preparation and characterisation of sustainable wood plastic composites extracted from municipal solid waste. *Polymers* 13(21). https://doi.org/10.3390/polym13213670

Singh, Y., Singh, J., Sharma, S., Aggarwal, V., & Pruncu, C. I. (2021). Multi-objective Optimization of Kerf-taper and Surface-roughness Quality Characteristics for Cutting-operation On Coir and Carbon Fibre Reinforced Epoxy Hybrid Polymeric Composites During CO_2-Pulsed Laser-cutting Using RSM. Lasers in Manufacturing and Materials *Processing* 8(2): 157–182. https://doi.org/10.1007/s40516-021-00142-6

Tamrin, K.F., Moghadasi, K. & Sheikh, N.A. 2020. Experimental and numerical investigation on multi-pass laser cutting of natural fibre composite, *The International Journal of Advanced Manufacturing Technology* 107(3-4): 1483–1504. https://doi.org/10.1007/s00170-020-05121-3.

Tamrin, K.F., Zakariyah, S.S. and Sheikh, N.A. 2015. Multi-criteria optimization in CO_2 Laser Ablation of multimode polymer waveguides, *Optics and Lasers in Engineering* 75: 48–56. https://doi.org/10.1016/j.optlaseng.2015.06.010.