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Selected Malaysian Wood CO_2-Laser Cutting Parameters And Cut Quality

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Abstract: Laser has been used to cut most non-metallic materials very efficiently and successfully because these materials are highly absorptive by the CO_2 laser wavelength of 10.6µm. Laser cutting process has been found to be reliable in loads of applications, with several advantages over other mechanical means in producing successful cut of even thermally sensitive materials such as wood. Various works which have been conducted to resolve the interaction between laser and wood but an ultimate guideline to produce the best cutting results are still undecided. This latest experiment was performed on Malaysian light hardwood namely, Nyatoh (Palaquium spp.), Kembang Semangkok (Scaphium spp.), Meranti (Shorea spp.) and normal Plywood using low power carbon dioxide laser machine with 500 Watt maximum output. The low power laser machine (Zech Laser model ZL 1010), equipped with a slow flow CO_2 laser producing maximum output power of 500 watt on beam mode of TEM01 is employed. The processing variables taken into investigation were laser power, nozzle-standoff distance (SOD) or focal point position, nozzle size, assist gas pressure, types of assist gas, cutting speed and delay time. The wood properties observed were thickness, density and moisture content of the wood. The analyses considered were of the geometric and dimensional accuracy (straight sideline length, diameter of circle, kerf width, and percent over cut), material removal rate, and severity of burns of the matters upon machining with compressed air or any assist gases. The relationship between processing parameters and types of wood with different properties were outlined in terms of optimum cutting conditions, the minimum burnt-effect achievable and the best cut quality obtained with minimal surface deterioration and acceptable in accuracy. From this present study a guideline for cutting a wide range of Malaysian wood has been outlined.

Key words: Materials processing, laser cutting, wood machining parameters

INTRODUCTION

Laser machining of wood has not been widely accepted by wood industry, although several successful CO_2 laser cutting applications have been reported by Mukherjee *et al*.[1]. An example of CO_2 laser cutting of wood is highlighted by Lum et.al.[2] in their experiment in determining the process parameter settings for the cutting of medium density fibreboard (MDF). Lum et.al. indicated that laser cutting is a type of thermo chemical decomposition (TCD) mechanism. The energy from the laser beam acts to break chemical bonds and thus disrupt the integrity of the material. Khan *et al*[3] have highlighted the importance of parameters like laser power, cutting speed and shield gas to determine the cut quality for both hard and soft timber materials. Both Mukherjee *et al*.[1] and Khan *et al*[3] have also commented on how nozzle design and variation in shield gas velocity could improve the cutting performance of CO_2 lasers on timber-based materials. However, one of the important factors is laser cutting speed because higher cutting speed can achieve lower production as a result of lower cycle time. Shield gas pressure are depended upon the nozzle size and in case of supply gas in cylinder, the amount of gas remaining inside the cylinder can also affects the gas pressure. Barnekov *et al*.[4,5] have twice highlighted on the location of the laser focal point with respect to the workpiece also affecting cutting efficiency. The authors have found that the severance energy which is laser power divide by material thickness for the material is about 1 J mm^{-2}.

The interaction of the laser beam with wood is mainly determined by the type of laser being used. The CO_2 laser beam is absorbed almost completely by wood, as proven by Grad and Mozina[6]. This is the

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reason why most researchers focusing on this type of laser. This is proved by Hattori[7], who discusses the laser processing of wood. There are many types of lasers and Hattori concluded that CO_2 laser is the most suitable for wood processing because different gas has different wavelength and it will results in different energy density and quality of cutting. For example, CO_2 laser has better energy density than YAG laser when interacting with wood and paper.

EXPERIMENTAL DESIGN

Machine specification: The experiments were performed on a low power carbon dioxide laser, equipped with a slow flow CO_2 laser producing maximum output power of 500W. Maximum cutting speed is 7500 mm min^{-1} and mode structure of TEM01. The control of the machine is performed using software provided with the system, named C-Cut.

Machining parameters: The machining parameters can be divided into two categories, i.e. fixed and variable parameters. The fixed parameters are nozzle diameter, stand off distance, material thickness, assist gas pressure, corner power and time delay whereas the variables are laser power, cutting speed, and types of assist gaseous. Table 1 besides choosing the right

Table 1: Constant and Variable Machining Parameters

Fixed parameters	Variable parameters
Material thickness: 10 mm	Laser power: 100,200,300,400, 500 W
Assist gas pressure: -Gas 1 (1.5 bar)	Cutting speed: 0.2, 0.5, 0.8, 1.2 mm min^{-1}
-Gas 2 (3.0 bar)	
Time Delay: 3 seconds	
Nozzle diameter: 3.0 mm	Assist gaseous: -Compressed air
Nozzle stand-off distance: 1.5 mm	- Nitrogen
Corner power: 70%	

material to be studied, the selection of these parameters were carefully planned in order to highlight the optimum result and to avoid material wastage. For the purpose of the study, only some of the parameters were considered. These parameters are presented in the following section.

DATA COLLECTION AND ANALYSIS

Design of product: The part to be cut consisting of straight lines, a hole and curve geometry is drawn using AutoCAD drafting software. This 2D drawn design was exported into .dxf file format and was used in the Zech Laser machine software in order to generate the cutting path. The design is shown in Fig. 1, whilst being simple and easy to be cut, would also provide ease of analysis.

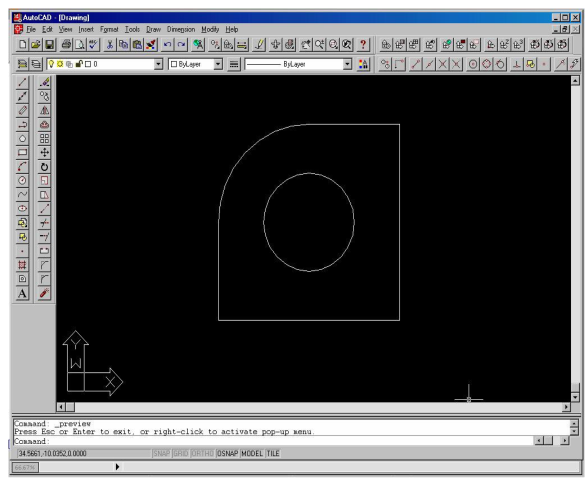

Fig. 1: AutoCAD drawing of the workpiece

Table 2: Physical and Mechanical Properties of the materials

Physical properties			
Types of wood:	Meranti	Nyatoh	Kembang Semangkok
Air-Dry Density (kg m^3):	385-755 ()	400-1,075	515-755
Moisture Content* - Green :	47-102 %	52-79 %	73 %
Moisture Content* - Air-Dry :	14.2-19.7 %	16.5-17.5 %	16.8 %
Shrinkage - Radial :	1.5-2.6 %	1.0-3.0 %	1.2 %
Shrinkage - Tangential :	3.8-7.4 %	1.9-4.3 %	3.0 %
Thickness (mm) :	10	10	10
*based on weight ofwood when dry			
Mechanical properties			
Static Bending (N/mm2)	8,400-13,600	12,200-18,300	15,300-17,000
Compression Strength			
-Perpendicular to grain (N/mm2) :	2.41-2.51	4.48-9.17	N.A
-Parallel to grain (N/mm2) :	34.50-48.20	43.50-48.20	50.20-52.00
Shear Strength (N/mm2) :	6.30-11.00	11.0-11.9	9.10-10.10

Table 3: Graph Plotted

Measured Criteria	Laser Power							
	Air				Nitrogen			
Types of Wood:	M	N	KS	P	M	N	KS	P
Sideline Length (SLL)	Fig. 2 1	11	21	31	Fig. 3 2	12	22	32
Percent Over cut of SLL	Fig. 4 3	13	23	33	Fig. 5 4	14	24	34
Circular Diameter (CD)	Fig. 6 5	15	25	35	Fig. 7 6	16	26	36
Percent over cut of CD	Fig. 8 7	17	27	37	Fig. 9 8	18	28	38
Kerf width	Fig. 10 9	19	29	39	Fig. 11 9	19	29	39
Material Removal Rate (MRR)	Fig. 12 10	20	30	40	Fig. 13 10	20	30	40

LEGEND : - M = Meranti, N = Nyatoh, KS = Kembang Semangkok and P = Plywood

PARAMETERS OF STUDY

Sideline length: The sideline length was measured using digital caliper and the obtained lengths were shown in Table 2. The measured length was the straight section of the workpiece which resulted from laser cutting. Since there were many work pieces to be measured, the measurement of sideline length was only considered at the cut surface parallel to grain distribution of the wood.

Circular diameter: This dimension was also measured using digital caliper.

Percentage of Over cut: Over cut was obtained from the percentage over cut of the measured length or diameter of the part geometry using the following equation;
Over cut (%) = {(Measured dimension-Actual dimension)/(Actual dimension)}
Over cut and its percentage were represented with a negative (-) sign if it was smaller than the actual dimension and with a positive form if the obtained measurement was larger than the actual dimension.

Kerf width: Measurement for kerf width was performed at the straight section cut by the laser. Kerf widths were measured by measuring the inner length of the work material and subtracting it with the outer length of the produced part. This value was then divided by 2 to obtain the mean value of kerf width from both sides of the kerf.

Material removal rate (mrr): Material removal rate was calculated using the following functions;
Material Removal Rate, MRR (m^3 min^{-1}) = thickness x cutting speed x kerf width

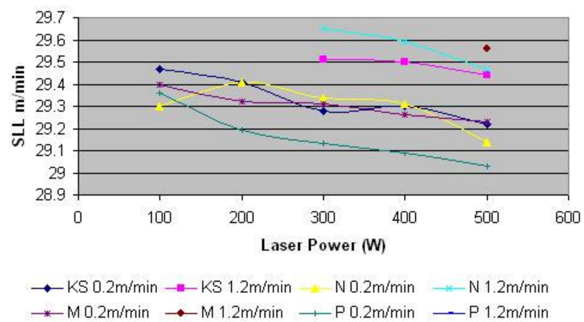

Fig. 2: Chart A1-Sideline length against laser power (compressed air)

RESULTS AND DISCUSSIONS

There were forty graphs plotted in total from the experiments with different parameters as shown in Table 3 and for clarity, are presented in twelve groups. For example, Chart A1in Fig. 2 is the plot for the results of maximum and minimum cutting speed (0.2 m min^{-1} and 1.2m min^{-1}) using compressed air (prefix 'A') and Chart N1 in Fig. 3 when Nitrogen gas was used (prefix 'N'). All measurable values i.e. sideline length, percent over cut of SLL, circular diameter, percent over cut of CD, Kerf width and material removal rate were presented against the laser power, varying from 100 W to 500 W. There were no results for some experiments at maximum cutting speed of 1.2 m min^{-1} because cutting was not completed or there have been no penetration on the material at all.

Sideline length and percent overcut: Figure 2, showed that as the laser power increases, the sideline length obtained decreases, at all cutting speeds. With compressed air assisting the cutting operation, it was

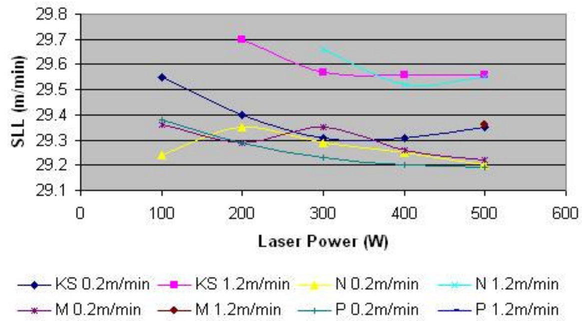

Fig. 3: Chart N1-Sideline length against power (nitrogen)

also observed that all work pieces were cut successfully at the cutting speeds of 0.2m min^{-1} for all laser power, whereas only some were possible to be cut using input power of 300 watt and above at cutting speeds of 1.2m min^{-1}. It can be said that as the cutting speed increases, there were considerably less time for laser beam exposure to the workpiece, disabling the laser beam's ability to initiate penetration in order to produce a successful cut.

This fact was more obvious at low laser power, especially below 300 watt, at which no full through cut (FTC) could be made at all, for all types of wood.

The difference between the actual dimension and the producible length was found to be in the range of 0.35mm to 0.97mm less than the actual length of 30mm. The closest achievable length was at the cutting speed of 1.2m/min for an input power of 300 watt; which is 0.35mm less than the actual length (corresponding for 1.17% less in terms of percentage over cut); while the furthest was at the cutting speed of 0.2m/min, at 500 watt input power which is 0.9mm less or approximately 2.86% less in terms of percentage over cut. Besides the figures stated above, other readings fell in the range of 1.37 to 2.87% less in terms of percentage over cut.

Figure 3, with nitrogen as the assist gas in cutting, generally exhibit a similar trend to those obtained when cutting with compressed air. As the laser power increases, the over cut becomes worsens with the decreasing of cutting speed. Similarly, the results showed the same pattern and correlation between the producible length and the actual dimension drawn in AutoCAD. However, it was also found that the number of work pieces which were successfully cut was lower when compared with the numbers obtained with compressed air-assisted cutting. For example, at cutting speed of 0.5m/min, for the same input power of 100 watt, there was no cut that can be made when nitrogen

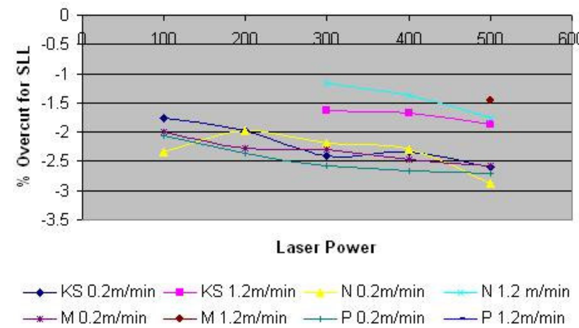

Fig. 4: Chart A2-Percent over cut against Power for SLL (Compressed air)

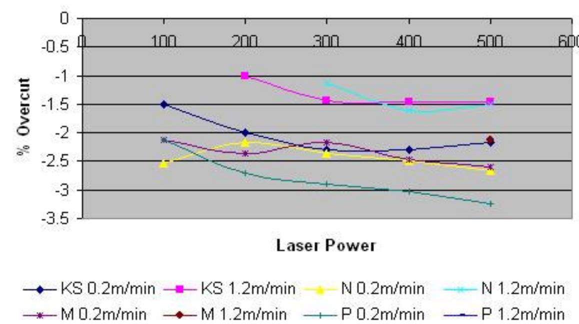

Fig. 5: Chart N2-SLL Percent over cut against Power (Nitrogen)

was assisting the process. This reason solely, cannot be taken for conclusion. Even though nitrogen may limit the ability of the laser beam to cut successfully, the producible cuts were the same as when cutting with compressed air, if other combinations of cutting speeds and input power were considered.

Figure 5, showed more practical relationship between laser power and cutting speed than those obtained when cutting with compressed air as shown in Fig. 4. The inert environment offered by nitrogen might be considered as the reason in creating stable conditions in the cutting process, resulting in proper relationship between laser power and cutting speed. This fact is also supported by the sideline length obtained and numbers of workpiece producible throughout the experiment.

When the cutting process was assisted with nitrogen, the highest portion of material loss was found to be 0.8mm or 2.67% less in terms of percentage over cut and was observed at the cutting speed of 0.2m/min and input power of 500 watt for Nyatoh. The smallest was 0.3mm or approximately 1.0% less in terms of percentage over cut. This data however, showed some difference when compared to cutting with compressed

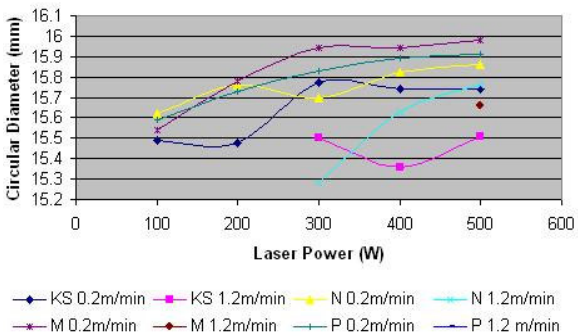

Fig. 6: Chart A3-circular diameter (cdiam.) against power (compressed air)

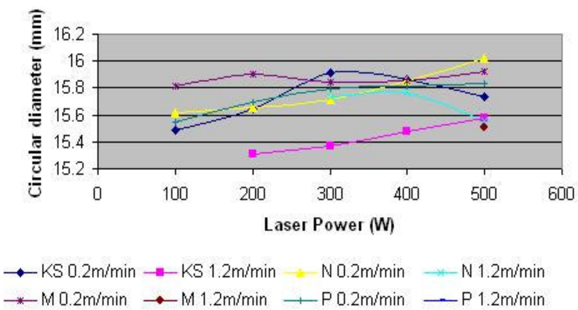

Fig. 7: Chart N3-circular diameter against power (nitrogen)

air as the assisting gas. It was found that the length was little shorter, which is 0.01mm less (0.03% more in terms of percentage over cut) when cutting assisted with nitrogen.

Circular diameter (Cdiam.) and percent overcut: Figure 6, indicated that as the laser power increases, the circular diameter produced becomes larger, especially at low cutting speed. The reason behind this was that, when lower speed or lower feed was applied to the process, heat input into the workpiece accumulated longer in the cut zone, added with the longer time for it to be dissipated rapidly; hence causing more portions of the material to vaporize and burned, thus resulting in larger diameter holes.

The highest portion of this was evident when cutting Nyatoh at the lowest speed of 0.2m min^{-1} with highest input power of 500 watt, producing a diameter of 16.02mm or 5.73% more in terms of percentage over cut. While, the smallest over cut was found to be 0.28mm larger than the actual dimension or representing 1.87% more in terms of percentage over cut. Generally, the range of material loss due to over cut

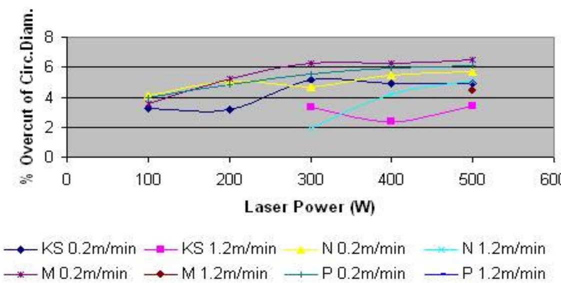

Fig. 8: Chart A4-Cdiam. Percent over cut against Power (Compressed air)

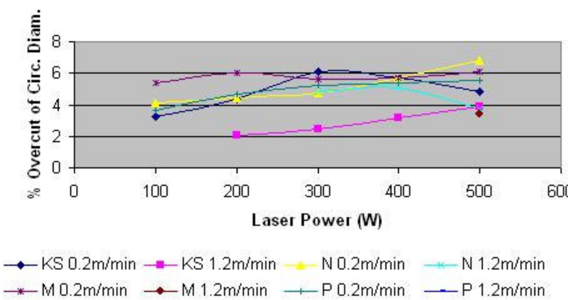

Fig. 9: Chart N4-Cdiam. Percent over cut against Power (Nitrogen)

in terms of diameter and percentage of over cut are, 0.28mm to 0.98 mm and 1.87 to 6.53%, respectively.

Similarly, the relationship between increasing the circular diameter upon increasing laser power and decreasing cutting speed was also found to be the same when cutting with nitrogen as the assist gas. Referring to Fig. 7, the highest over cut was found to be at the cutting speed of 0.2m min^{-1} with 500 watt laser power, indicating hole of 1.02mm larger than the actual diameter or 6.8% more in terms of percentage over cut; while the lowest over cut obtained is 0.31mm larger or corresponded for 2.07% more in terms of percentage over cut. This reading was reported when cutting at the speed of 1.2m min^{-1} with input power of 200 watt.

Figure 8 and 9 exhibited that both of these highest and lowest values of over cut, showed different values obtained when cutting with compressed air, in which less over cuts were produced when assisting the cutting process with nitrogen. Again, this supports the fact that nitrogen did manage to control heat input in cutting process, thus producing the desired features with acceptable dimensions.

Kerf width: Comparing the width of the cut or kerf width, generally, it was found that the widths obtained

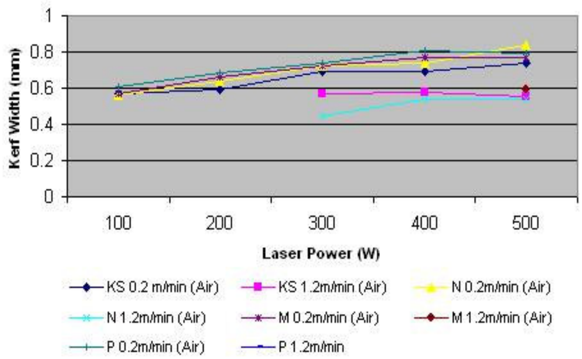

Fig. 10: Chart A5-Kerf width against power (compressed air)

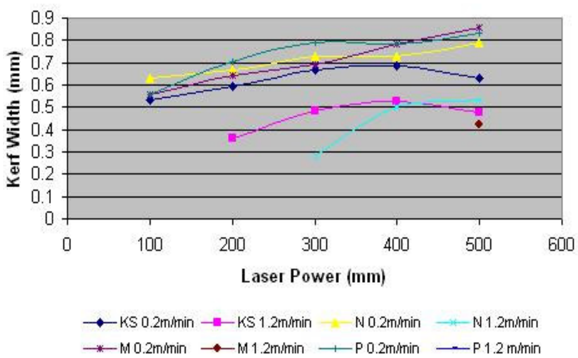

Fig. 11: Chart N5-Kerf width against power (nitrogen)

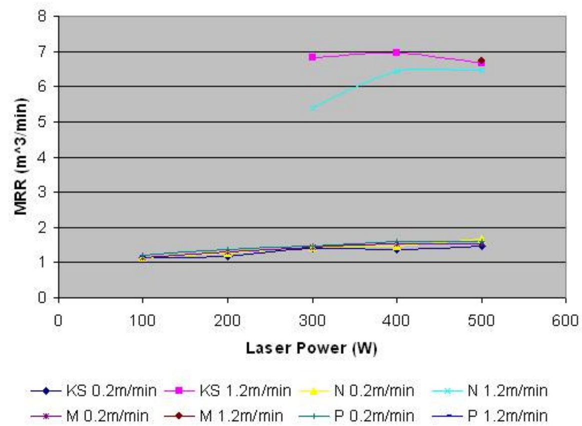

Fig. 12: Chart A6-MRR against power (compressed air)

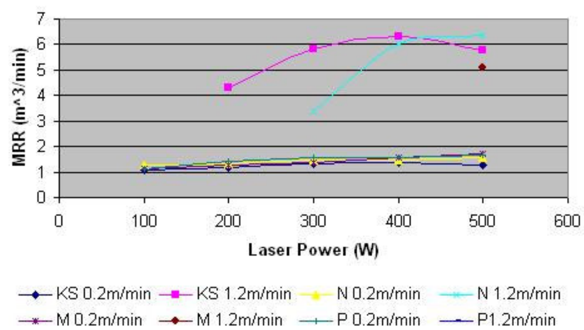

Fig. 13: Chart N6 - MRR against Power (Nitrogen)

when cutting with compressed air-assisted were larger than that of when cutting with nitrogen.

As the power increases, the kerf width increases with the decreasing cutting speed and showed its widest kerf on Nyatoh at cutting speed of 0.2m min^{-1} at input power of 500 watt for compressed air-assisted cutting. The reading recorded was 0.835mm. However, when nitrogen was used, the largest width produced was 0.855mm using Meranti at the cutting speed of 0.2m min^{-1} and input power of 500 watt. These figures alone do not represent the overall conditions of the analysis regarding kerf width since they only corresponded to cutting at 0.2m min^{-1} cutting speed and 500 watt input power. Interestingly, other data were found to behave oppositely.

Figure 10 and 11 showed for comparison, by selecting a couple the narrowest kerf width obtained at the same cutting speed of 0.5m/min and input power of 200 watt, they were found to be 0.49 mm and 0.485mm for both cutting process with compressed air and nitrogen-assisted, respectively. Once more, the kerf widths obtained show a slight difference in which the width obtained with nitrogen-assisted cutting is relatively smaller.

Overall, the range of kerf width for compressed air-assisted cutting falls within 0.45mm to 0.835mm while for nitrogen-assisted it ranges within 0.28mm to 0.855mm.

Material removal rate (mrr): As a function of cutting speed, kerf width and material thickness; referring to previous data on kerf width, it can be said that the material removal rate when cutting with compressed air is higher than that of when cutting with nitrogen as the assisting gas.

Through examination of Fig. 12, Fig. 13, and analyzing all data, it was found that the maximum material removal rate for cutting with compressed air is $6.84m^3\ min^{-1}$ while the minimum is $1.13m^3\ min^{-1}$. As for nitrogen-assisted cutting, the maximum material removal rate is 6.36m3 min^{-1} while the minimum is 1.07m3 min^{-1}.

Even with higher rate of material removal, it does not always means that the process is utmost efficient. In order for the process to be efficient and versatile, all cutting characteristics consideration has to be priorities. This is vital since to the objective of the final product must be properly defined. For example, the final dimension might be vital to the finished product whilst the finished quality is not, and vice versa, according to the actual function of final part produced.

CONCLUSION

An initial study on laser cutting of wood has been described in this report. It is concluded that:

- Selection of cutting parameters for laser cutting of wood is governed by material's moisture and air content, workpiece thickness and density
- For material thickness of 10mm for all wood samples, it is not possible to achieve a successful cut using laser power of 100 watt at 1.2m min^{-1} cutting speed
- Due to exothermic reaction, cutting with compressed air exhibits severe burns and charring, larger kerf width and over cuts, and higher portions of material loss
- The use of nitrogen is proven to be reliable in reducing material loss and over burning due to the compensation of heat accumulation. Nitrogen offers cooler and inert environment to the cutting process
- Closer dimensional accuracy and acceptable surface finish in laser cutting of wood are able to be obtained when nitrogen is used in assisting the cutting process as compared to the use of compressed air instead
- Suitability of wood for laser cutting for these few selected materials was found to be in the order of

Plywood	Meranti (Shorea spp.)	Nyatoh (Palaquium spp.)	Kembang Semangkok (Scaphium spp.)
→			
Least	Suitability		Best

For further works, the current research will be carried out in a slightly more conclusive ways. This will hopefully include a survey on types of suitable materials to be used. With this, further systematic investigations are to be conducted and a comprehensive guideline for laser cutting of Malaysian wood can be drawn.

A few other problems which should be taken into considerations are the effect of moisture content, due to the fact that water is highly absorptive to CO_2 laser radiation and might reduce the cutting efficiency. From the initial experiments conducted, the main issue to be solved in this area is how to simplify the process of selecting the correct parameters to ease cutting and to reduce the effects of black char due to over burning of the work material. It was also shown that the use of an inert gas such as nitrogen might be beneficial in creating inert and cooler environment, thus resulting in a final product with better appearance and acceptable in dimensions. However, this hypothesis still needs to be proven theoretically and to identify whether the cost incurred can be justified.

From any studies to be conducted in the future, it is hoped that a new method of wood processing can be introduced to achieve better quality with lower production cost especially for potentially commercialized Malaysian wood products.

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