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Experimental Study on Inert Gas-assisted Laser Cut Veneer Based on LOM

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Abstract: Based on the LOM (Laminated Object Manufacturing) process, an inert gas-assisted laser method for wood cutting was proposed. The carbonization degree of wood surface was improved by the introduction of helium (He) gas, and the influence of process parameters on the carbonization layer of wood surface was solved, it was significance to reduce the post-processing of LOM and improve the quality of forming workpiece. The cherry wood veneer was used as the experimental material, under the condition of the same process parameters, the wood was cut with or without inert gas-assisted, and the influence factors of kerf quality were studied by variance analysis. The results showed that under the same condition, compared with traditional laser processing, the kerf width was obviously reduced in the inert gas-assisted cutting. Because the He gas had oxygen-isolation and flame retardant effect, which prevented heat accumulation and conduction. The micro morphology of the kerf surface showed that the flatness was better in the inert gas-assisted cutting. As the excess heat was blown out by the cooling and purging of the gas, the phenomenon of oxidation and burning was reduced, the range of HAZ (heat affected zone) was reduced, and the carbonization phenomenon was obviously improved. The surface quality of kerf was improved effectively. According to the analysis of variance, in addition to the effect of laser power, cutting speed and inert gas flow on the cutting width, the interaction between inert gas flow and laser power, laser power and cutting speed were also the main factors which affected the cutting width. The feasibility of the combined inert gas and laser processing to improve wood cutting quality has been verified through experimental research, which provided a certain reference for the follow-up research on improving the wood processing quality.

Keywords: Gas-assisted; laser cutting; cutting width; veneer

1 Introduction

LOM uses thin sheet materials such as veneer and thin wood as raw materials [1,2], the prototype of wood products with external beauty and special quality is produced through the interaction between laser beam and wood [3]. In the new product design verification, modeling evaluation, engineering analysis, functional inspection and other aspects have developed rapidly. The development efficiency of new wood products was improved [4–6], and the development cycle was shortened [7–9].

In the process of laser cutting wood, due to the low ignition point of the wood, when high energy laser beam is irradiated [10], the kerf surface of veneer vaporizes instantly [11], and the processing surface produces ablation and carbonization, which affects the processing accuracy and surface quality [12–14]. Li et al. [15] used CO_2 laser to treat the surface of poplar wood, and measured the influence of laser energy load on chemical composition of wood surface. Barcikowski et al. [16] described the temperature gradient in the kerf and the change of the HAZ on the wood surface during laser cutting of particleboard. Hernandez-Castaneda et al. [17] used laser to cut dry and wet pin respectively, and explored the effect of wood trachea moisture content on the cutting process. Yang et al. [18] used the fraxinus mandshurica as the experimental material, through the nanosecond laser to achieve micron level cutting, explored an effective method to reduce the burn mark. Zhao [19] explored the best process parameters for laser cutting wood by changing the laser parameters which based on experiments, and removed the carbonization layer on the surface by chemical methods.

During laser processing, the area of HAZ and the degree of carbonization were important bases to measure the processing quality [20–22]. The cutting quality was improved by changing the process parameters above the research, but the surface carbonization could only be improved through secondary treatment, which affected work efficiency [23,24]. In this paper, the process method of wood processing with inert gas-assisted laser was proposed, the chemical properties of inert gas were used to reduce the burning and carbonization of wood surface in the processing, and the post-treatment process was instead, and the working time was saved. Since the inert gas neither supported combustion nor oxidized with the substrate. The oxygen was squeezed out of the cutting area by pressure inert gas, and formed an oxygen-isolation zone to prevent combustion and oxidation occurring. At the same time, the ablative products such as residue generated during laser cutting could be taken away by airflow purge, the ablative products were avoided to adhere to the surface of the processed material, and the surface quality of the wood processed by inert gas assisted laser was improved. Through factor test and theoretical analysis, the feasibility of the influence of inert gas on kerf width and processing quality was discussed, and a new way to reduce the carbonization of wood during laser processing was provided.

2 Experimental

2.1 Process of Inert Gas-Assisted Laser Cutting

The experimental device of inert gas-assisted laser cutting veneer is shown in Fig. 1. The device was equipped with a CO_2 laser generator with a wavelength of 10.6 nm [25], laser power of 80 W, the effective processing area was 900 mm × 600 mm, the focused beam spot size was 0.05 mm. The specimen was fixed on the workbench, and the laser beam movement in the X direction and the Y direction was controlled by the feed system. During the workpiece cutting, the laser was moved to the area to be processed by controlling the feeding system. The inert gas control valve was opened, and the inert gas was injected vertically on the wood surface through the coaxial auxiliary nozzle, due to the oxygen-isolation and flame-retardant effect of inert gas, an effective oxygen isolation layer was formed in the processing area. High energy laser beams were focused on the wood processing area, ultra-high temperature caused the tissue fluid inside the wood cells to vaporize instantaneously, due to effect of thermal stress and heat conduction, the parts that do not vaporize were blown away from the bottom of the kerf by the auxiliary gas, the incisions were formed in the wood surface. The inert gas was the only substance in contact with the workpiece, which could protect the cut surface from oxidation reaction. Meanwhile, the slag was removed by gas purge and the cutting boundary can be cooled to improve the quality of laser cutting.

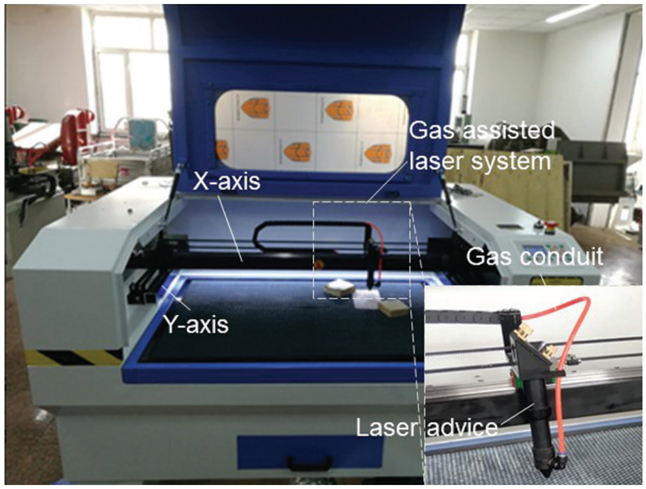

Figure 1: Laser cutting equipment

2.2 Process Method

This experiment used cherry wood (*Prunus serotine*) as the experimental material, which had an air-dried density of 0.85 g/cm^3 and a moisture content of 12.85%, the relative humidity of the environment was 65%. The samples were obtained after processing, and the size was 100 mm × 80 mm × 0.5 mm (length × width × thickness). Helium was selected as the auxiliary gas, and the gas velocity of the inert gas-assisted system was 0.5 L/s. The process direction was perpendicular to the wood fiber, the specimen and process method were shown in Fig. 2. The kerf width and cutting quality with or without inert gas under different laser power and cutting speed were studied. After the completion of the experiment, the kerf width was used as the measurement standard, and were measured at a magnification of 40X through a digital microscope. Because of the irregular shape of the kerf edge, it was necessary to take the average value after several measurements in order to obtain more accurate data.

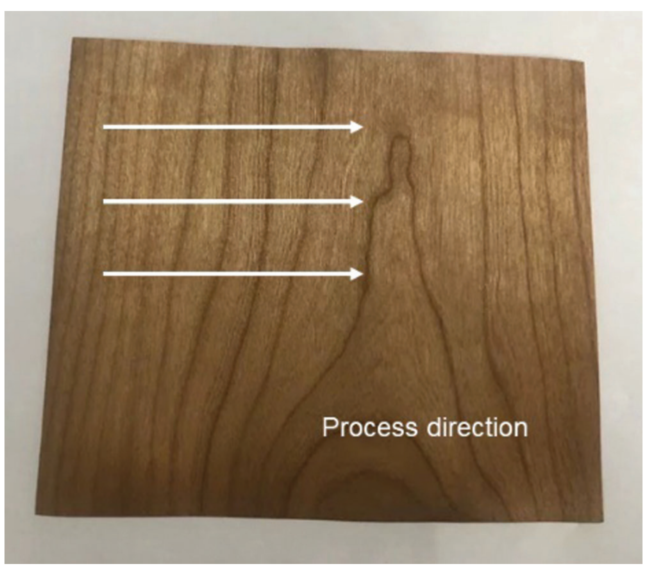

Figure 2: Specimen and process method

2.3 Experimental Design

Factor analysis was used to study the influence rule of parameters variation on the change of wood cutting width. The influence trends of laser power and cutting speed on wood cutting width were investigated respectively by grouping experiments with or without inert gas-assisted system, and the test data were tested by variance analysis. The process parameters of factor experiment are shown in Tab. 1.

Table 1: Process parameters of factor experiment

Number	1	2	3	4	5	6	7	8
Laser power(W)	15	20	25	30	35	40	45	50
Cutting speed(mm/s)	20	30	40	50	60	70	80	90

3 Results and Discussion

3.1 Effect of Laser Power and Cutting Speed on the Cutting Width of Wood

The cherry veneer was processed by laser with or without the inert gas-assisted system, and the cutting width under different laser power and cutting speed was measured. Due to incomplete combustion which caused the irregular shape of kerf edges, in order to obtain more accurate data, five points from large to small were selected at each kerf to measure and take the average value. Through the data processing and the change trends were shown in Fig. 3. In the case of the inert gas-assisted system, the cutting width of cherry veneer was smaller than that without the inert gas-assisted system.

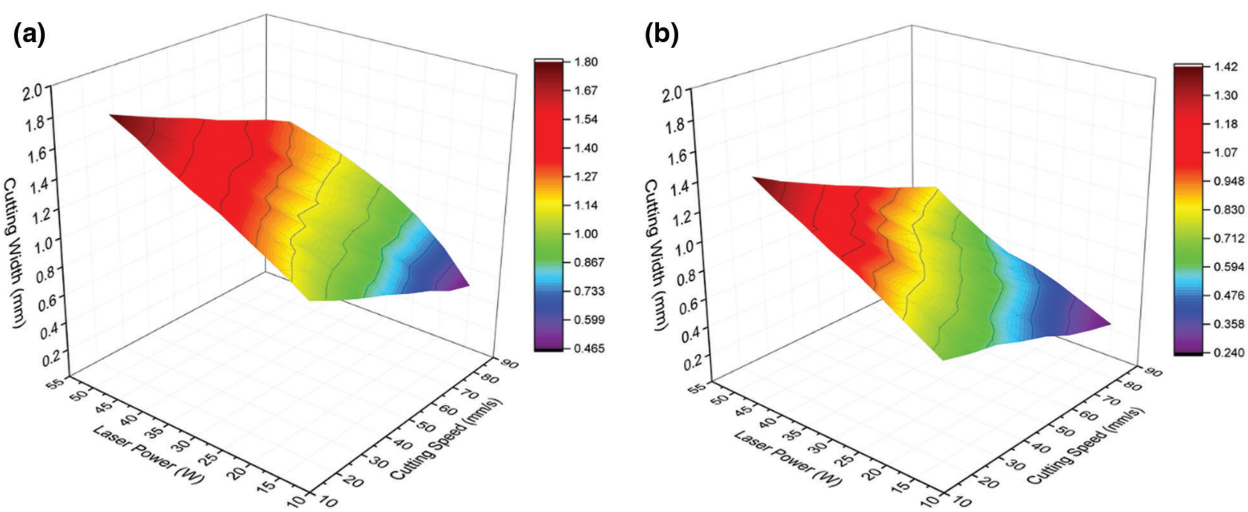

Figure 3: Effect of process parameters with or without inert gas-assisted on cutting width, (a) without or (b) with the gas-assisted system

It can be seen from Fig. 3, when the laser power was constant, with or without He gas-assisted, the variation trend of cutting width under the action of different cutting speeds was basically similar, and the cutting width was decreased with the increase of cutting speed. It was due to the laser beam interacted with the veneer for a long time when the cutting speed was slow, the HAZ was expanded because of the heat accumulation at the kerf, and a large amount of slag was produced by incomplete vaporization at the kerf, so the cutting width was large and presented irregular jagged shape. With the gradual increase of the cutting speed, the interaction time between laser beam and wood was shortened, the accumulated heat of laser beam on the wood surface was reduced in unit time, the fusion speed of wood at the kerf was lower than the moving speed of laser beam, so the cutting width was correspondingly reduced, and even the phenomenon of impenetrability was appeared. When the cutting speed was unchanged, with or without He gas-assisted, the variation trend of cutting width under the action of different laser power was basically similar, and the cutting width was increased with the increase of laser power. It was due to less heat was generated and transferred by the laser acting on the surface of the veneer when the laser power was low, sublimation and combustion was reduced, and the removal of wood was relatively less, so the cutting width was small. With the gradual increase of laser power, the heat which generated on the surface of the veneer was rapidly accumulated in the same time, and the temperature rapidly increased to its own boiling point, so more wood was consumed in the kerf, and the cutting width also increased.

In the case of the inert gas-assisted system, the cutting width of cherry veneer was smaller than that without the inert gas-assisted system. It was because He gas as a protective gas, an oxygen-free zone was formed on the surface of the workpiece and inside the kerf, which obstructed the oxygen in the air, destroyed the basic conditions of wood combustion, and played the role of oxygen isolation and flame retardant. At the same time, the heat in the ablation area within the kerf and the residue generated by incomplete vaporization were taken away by gas purge, so that the heat could not be further transmitted to the inside of the workpiece, which reduced the heat accumulation temperature and the range of HAZ, the amount of wood ablation was reduced. Therefore, the cutting width was smaller and the kerf parallelism was better.

3.2 Analysis of Variance of Factors Affecting Cutting Width

In the above experiments, the cutting width which obtained by changing the laser power and cutting speed was different. Through factor experiment design, inert gas flow, laser power and cutting speed were selected as independent variables, and cutting width as dependent variables. The influence rule of different process parameters on the surface quality of kerf was studied through variance analysis. The factor level table of cherry wood veneer specimens is shown in Tab. 2. According to the experimental scheme, the interaction between various factors was ignored, and the experimental data was measured and recorded. The measured value of cutting width is shown in Tab. 3.

Table 2: Factors and levels of factorial design

Factors Levels	A Inert gas flow (L/s)	B Laser power (W)	C Cutting speed (mm/s)
1	0 (A_1)	15 (B_1)	30 (C_1)
2	0.5 (A_2)	25 (B_2)	50 (C_2)
3	–	35 (B_3)	70 (C_3)

SPSS software was used for variance analysis of the experimental results. It can be seen from Tab. 4, the general significance level was taken as $\alpha = 0.05$, A*C ($F = 1.228$, Sig. $= 0.305 > \alpha = 0.05$), and A*B*C ($F = 1.861$, Sig. $= 0.139 > \alpha = 0.05$), which had no significant effect on the cutting width. However, the other factors (A, B, C), the interaction between (A*B) and (B*C) were considered to be the main effects on the cutting width of cherry wood. Because the absorption of laser energy would be affected by the addition of inert gas, the interaction between inert gas and laser energy was the main factor affecting the cutting width. At the same time, the reasonable matching relation between laser power and cutting speed was the main factor to determine the cutting width. Since the gas flow rate was small, there would be no cutting

Table 3: Experimental results of the factors for cutting width of cherry wood

A × B		C_1			C_2			C_3		
B_1	A_1	0.98	0.97	0.93	0.71	0.69	0.72	0.64	0.59	0.62
	A_2	0.86	0.85	0.84	0.66	0.65	0.64	0.56	0.54	0.55
B_2	A_1	1.09	1.04	1.08	0.94	0.86	0.85	0.76	0.75	0.76
	A_2	0.96	0.95	0.93	0.72	0.71	0.70	0.66	0.60	0.64
B_3	A_1	1.31	1.32	1.39	1.01	0.98	1.04	0.89	0.92	0.91
	A_2	1.22	1.21	1.23	0.90	0.88	0.88	0.79	0.81	0.82

Table 4: Analysis of variance for cutting width

Source	Sum of Squares	Degrees of freedom	Mean square	F	Sig.
Corrected model	2.274	17	0.134	245.670	0.000
Intercept	40.059	1	40.059	73577.554	0.000
A	0.166	1	0.166	304.085	0.000
B	0.864	2	0.432	793.881	0.000
C	1.197	2	0.599	1099.656	0.000
A*B	0.009	2	0.004	8.085	0.001
A*C	0.001	2	0.001	1.228	0.305
B*C	0.032	4	0.008	14.789	0.000
A*B*C	0.004	4	0.001	1.861	0.139
Error	0.020	36	0.001		
Total	42.352	54			
Corrected total	2.293	53			

resistance, so the interaction between cutting speed and inert gas was not the main factor affecting the cutting width.

3.3 The Microscopic Morphology of the Kerf Surface

The quality of incision section of cherry wood veneer with or without inert gas-assisted system was analyzed by digital microscope. It can be seen from Fig. 4a, When the cutting speed V = 20 mm/s, the HAZ on the kerf surface was large in the traditional laser processing, and the carbonization around the kerf was serious or even produced slag. It was due to the mixing of oxygen around the workpiece, the excess heat made the wood which could not reach the vaporization condition would interact with oxygen and produce combustion reaction, the phenomenon of wide range of HAZ and serious ablative were caused. It can be seen from Fig. 4b, when the cutting speed V = 20 mm/s, the cutting width was obviously reduced and the parallelism was better with the inert gas-assisted system, the HAZ was smaller, and the carbonization around the kerf was obviously improved, and the kerf quality was better. It was due to the inert gas was sprayed onto the surface of the veneer through the nozzle and formed airflow beam, which blew away the excess heat through the kinetic action of the airflow, the cutting boundary was cooled and the phenomenon of high concentration of the HAZ was reduced. As an auxiliary gas, helium

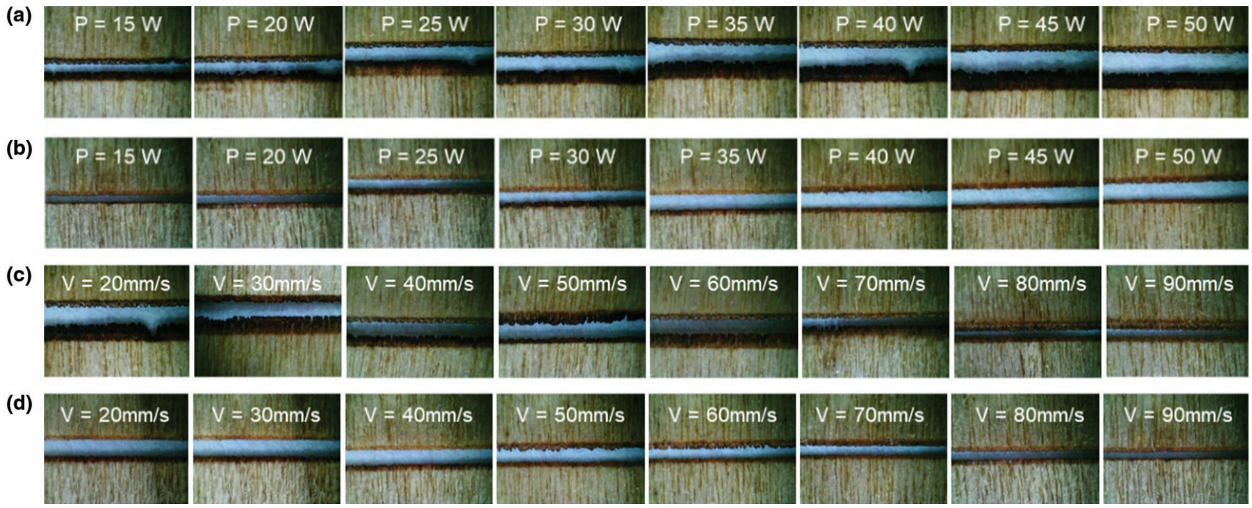

Figure 4: Micrographs of the kerf under different laser power. (a) without inert gas-assisted V = 20 mm/s; (b) with inert gas-assisted V = 20 mm/s; (c) without inert gas-assisted P = 40 W; (d) with inert gas-assisted P = 40 W

had the function of oxygen isolation and flame retardant, which could protect the material properties from changing in the kerf, reduce the carbonation phenomenon and improve the processing quality.

It can be seen from Fig. 4c, when the laser power P = 40 W, the carbonization area on the kerf was large in the traditional laser processing, and the cutting width decreased with the increase of the cutting speed. It was because when the cutting speed was slow, the heat was transferred to the uncut base material, which could only reach the wood ignition point. The combustion reaction with oxygen occurred and generated heat, which resulted in carbonization of the cutting surface and rough quality. It can be seen from Fig. 4d, when the laser power P = 40 W, the carbonization area on the kerf decreased and the surface quality was improved with the inert gas-assisted system. It was because the introduction of inert gas made the surface of the processed material covered with helium, combustion reaction in contact with the air was avoided, the formation of residue of molten material was reduced, the HAZ was effectively reduced, and thus the processing quality of the material was improved.

The carbonization degree of the veneer surface was observed by scanning electron microscope (SEM) in the microscopic environment, which provided guidance for analyzing the destruction morphology of wood fiber. It can be seen from Fig. 5a, after traditional laser processing, the slag could not be blown away in time, the surface of the kerf was severely ablated or even charred due to the accumulation of excess heat, a large

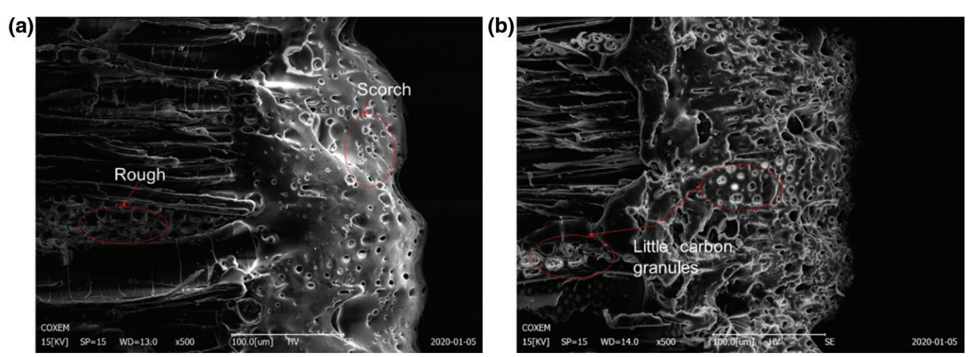

Figure 5: Microtopography of cutting kerf (a) without gas-assisted; (b) with gas-assisted

number of carbon particles existed in the trachea, and the processing quality was poor. It can be seen from Fig. 5b, under the laser processing by the inert gas-assisted, the kerf flatness was good, and there were only a few carbonized particles in the inner wall of the trachea. It was due to the airflow generated by the inert gas coaxial with the beam, which blew out the vaporized material and excess heat from the kerf, prevented the further transfer of heat, cooled the kerf surface, and reduced the HAZ. At the same time, the property of oxygen isolation of the inert gas prevented the wood from burning even if it reached the ignition point, which effectively guaranteed the quality of the kerf.

4 Conclusions

Laser cutting was the key process of LOM, the cutting quality directly affected the surface effect of hot-pressing workpiece, and the improvement of carbonization could reduce the process of secondary treatment. An inert gas-assisted system was introduced to explore the effects of different process parameters on the cutting width and kerf quality, in order to minimize the carbonization and burning problems, and improve the processing quality.

1. An inert gas-assisted laser cutting process was used on thin wood veneer, the experimental results showed that when the cutting speed was constant, the cutting width was proportional to the laser power. When the laser power was constant, the cutting width was inversely proportional to the cutting speed. Due to the cooling and flame retardant effect of inert gas, the cutting width generated by the inert gas-assisted laser cutting was obviously smaller than that of the traditional laser.
2. Through the variance experiment and factor analysis, it could be seen that inert gas, laser power, cutting speed, the interaction between inert gas and laser power, and the impact of laser power and cutting speed had significant effects on the cutting width.
3. The cutting width of inert gas-assisted system was obviously smaller than the traditional laser through the microscopic, and the carbonization phenomenon was well improved. The kerf surface was observed by SEM, without the inert gas-assisted system, the kerf surface was rough, carbonization phenomenon was serious or even charring. With the inert gas-assisted system, the carbon particles on the kerf surface were less, the carbonization phenomenon was obviously improved, and the kerf quality was better.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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