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Feasibility Study on Laser Cutting of Phenolic Resin Boards

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Abstract

Laser cutting is the most widely implemented application of lasers in industry. The many advantages of this process stimulate users in industry to cut many different materials, such as wood and wood composites –particleboard, plywood, etc.–, which are being cut with excellent results and productivity. Phenolic resins boards are a new substitute of wood in highly aggressive environments. In the present work we study the feasibility of CO_2 lasers to cut phenolic resin boards and assess the potential health hazards of the vapours and residues produced, since its thermal degradation may produce toxic organic vapors.

Keywords: Laser cutting; wood substitute; phenolic resin board

1. Introduction

Laser cutting is the most widely implemented application of lasers in industry. This is due to the great advantages of this technique over traditional cutting methods and its versatility [1] since lasers can produce narrower kerfs and higher cut quality than most of other cutting techniques. It is also one of the faster cutting processes, can produce cuts in any direction with sharp corners and it can be easily automated, what confers a great flexibility on it. Another important characteristic is its capability to cut almost any material. All these reasons together stimulate users in industry to try this technique to cut anything they may need. Some of these materials are different kinds of wood and wood composites which are cut with excellent results and productivity. In fact, CO_2 laser cutting of plywood die boards was one of the first commercial uses of these lasers in 1971 [1, 2]. The radiation of CO_2 lasers is highly absorbed by cellulose of woods, so the main cutting mechanism is thermo-chemical degradation of this organic constituent by the laser radiation, producing a sharp cut at high velocity with some carbon residues in the cut edges. But laser cutting of wood and wood composites involves serious health hazards since laser induced thermal decomposition of cellulose and lignin produces aerosols and organic vapours which may include cyclic compounds, acrolein or butadiene [3-5]. According to the International Chemical Safety Cards (ICSC) 0090 and 0015, acrolein is severely irritating to the eyes, the skin and the respiratory tract, and among the serious hazards of cyclic compounds, such as benzene, we must point out that it is carcinogenic. For this reason, present installations for laser cutting of wood and wood composites must include a fumes extraction equipment incorporating suitable air filters to remove particles and organic vapors [4].

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In the last years phenolic resin boards (PRB) were introduced as new wood substitutes for highly aggressive environments. Phenolic resins are the main constituent of this kind of composite, which is formed by a thick board of this resin covered by a thin sheet of melamine resin imitating the aspect of natural wood. Boards made of phenolic resins are denser and harder than wood or particleboard. Therefore, they are very difficult to cut using saws or milling cutters. Based on the intrinsic characteristics of laser cutting, this technique seems to be a good alternative to mechanical means to cut PRB. Most likely, the cutting mechanism for these resins may be a thermo-chemical degradation or combustion by the heat absorbed from laser radiation. Laser induced thermal degradation of these resins may produce two kinds of byproducts: on one hand are volatile compounds, such as carbon dioxide, carbon monoxide, and organic vapors which may include the monomers formaldehyde and phenol, together with aromatic hydrocarbons [6]. On the other hand, charring of the cut edges may also produce condensed residues with oily or char texture depending on the grade of decomposition. According to the International Chemical Safety Cards (ICSC) 0275 formaldehyde is carcinogenic, while ICSC 0070 states severe health hazard for phenol. Unfortunately, information about decomposition byproducts of these resins under laser irradiation are not available, so chemical safety cards may not be very useful.

The objective of the present work is to study the feasibility of conventional CO_2 laser cutting machines to cut PRB. With this aim we analyzed the cut quality and speed, as well as the gaseous and condensed by-products generated. All these results are compared with those from laser cutting of particleboard, which serves as a reference material.

2. Experimental

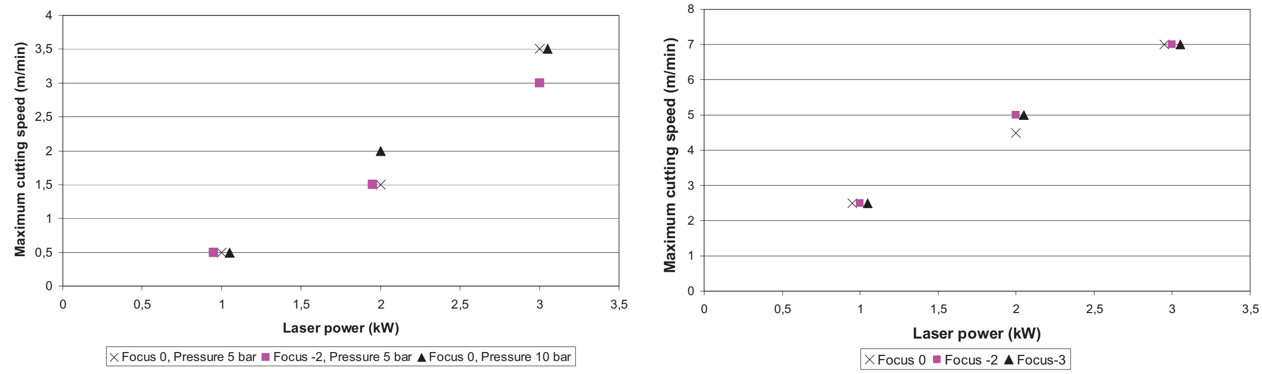
Two kinds of materials were processed for comparison: particleboard pieces with thickness of 19.3 mm covered in both faces with a melamine sheet imitating beechwood, and full phenolic resin boards with thickness of 14 mm covered with a layer of melamine imitating oak wood.

A high power CO_2 laser (Rofin-Sinar DC 035) was employed to perform the cuts. The laser was operated to emit a continuous beam with powers ranging from 1 to 3 kW. The laser beam was focused on the workpiece using a convergent lens with focal distance of 190.5 mm. The cutting head incorporates a conical converging coaxial nozzle which exit diameter was fixed to 2 mm. The exit nozzle can be adjusted to keep the stand-off distance between the exit nozzle and workpiece invariable (set to 1 mm) while changing the position of focus. Compressed air and argon were used as assist gas at pressures ranging from 4 to 20 bar. The cut width was measured using an optical microscope incorporating a X-Y micrometer table and surface roughness of the cut edges was evaluated using a TESA Rugosurf 10G surface roughness gauge.

Two different procedures were employed to analyze the condensed residues and the volatile compounds produced during the cuts. The procedure to analyze the vapours and smokes in the environment of the cut process, together with the calculus to compare the results with the exposure limits was carried out according to the corresponding standards published by the United States National Institute for Occupational Safety and Health (NIOSH): NIOSH 2546, 2016, 2018, 2532, and 1501. They essentially consist of pumping a specific flow of the atmosphere close to the cutting area through the proper tube sampler containing the filtering material which adsorbs the vapours or gases to be screened. Then, the vapours and gases in the sampler are desorpted using a precise protocol and measured by the technique recommended. On the other hand, a particular method was developed to analyze the condensed residues produced during laser cutting since no other standard procedure was found. The experimental set-up included a small piece of the material to be cut into a vacuum chamber. The vacuum chamber has two inlets at opposite faces, one is a chocked entrance for atmospheric air and the other is connected to a rotary vacuum pump passing through a cold finger to trap the volatile compounds. This set-up avoids the accumulation of vapors and fumes in the vacuum chamber and permits the collection of the condensed residues under atmospheric conditions. The residues were analyzed by gas chromatography (Agilent 6890N), incorporating a fused-silica capillary column HP-5 (5% Phenyl Methyl Siloxane) having a length of 30 m and diameter of 250 μm.

3. Results and Discussion

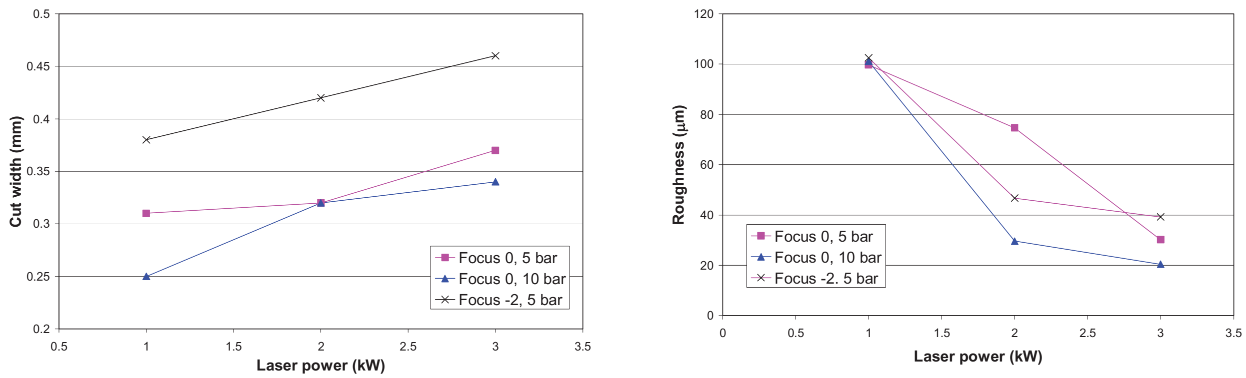
The graphics in Figures 1.a and 1.b present the results of the maximum cutting speed as a function of laser power for different focus positions relative to the surface of the piece and for two different assist gas pressures –just compressed air was used in this case. The maximum cutting speed is obtained when the beam is focused on the surface of the piece (focus 0) for both types of material. Laser cutting of the particleboard pieces can be achieved at notably higher cutting speeds than the PRB, due to the higher density and thermal stability of phenolic resin.



a) b)

Figure 1. Maximum cutting speed as a function of laser power: a) PRB, b) Particleboard.

The graphics in Figures 2.a and 2.b present the cut width and roughness of the cuts performed in the PRB as a function of laser power for different focus positions and assist gas pressures. They show that the cut width in PRB is between 0.2 and 0.5 mm and increase with laser power. The focus position has also a noticeable influence on the cut width, yielding best results with focus on the surface of the piece. These results are, in any case, well bellow the cut width obtained using disc saws or other traditional methods. The surface roughness of the cut edges is specified using the Rz5 normalized parameter. The results show that it strongly decreases with laser power. Comparatively, they are higher than that obtained with a disc saw –our measurements of this are close to Rz5 ≈ 17 µm, however it can be observed that laser cut roughness can be reduced to the order of Rz5 ≈ 20 µm adjusting focus position on the surface and using high assist gas pressure.



a) b)

Figure 2. Cut quality results in PRB as a function of laser power: a) cut width, b) roughness.

All cuts present a thin layer of carbonized material on the surface of the cut edge with typical thickness between 200 and 300 μm. This layer is essentially independent of the type and pressure of the assist gas, as demonstrated in exploratory cutting trials using compressed air at pressures up to 12 bar and argon at pressures from 4 up to 20 bar. All these cuts carried out to explore the influence of the assist gas exhibited same appearance and similar cut width and speed. The use of argon instead of air did not show any influence on the formation of the layer of carbonized residues on cut edge since the oxygen of carbonyl groups in char may come from auto-oxidation of hydroxymethyls in the inert atmosphere, consequently, the residual products of thermal degradation of phenolic resins under inert or oxidizing atmospheres are very similar [6].

On the other hand, the formation of a condensed residue with oily or carbonaceous aspect on the top edge of the cuts, together with the high amount of vapors and fumes produced are other side-effects which deserve more attention. The condensed residues appear mainly in the cuts of the phenolic resin boards and in a much lower amount in the particleboard cuts. They show an oily aspect predominantly in incomplete cuts, on the contrary, if the cut is complete it has a char texture, probably because it underwent a more intense combustion and more severe degradation to cinders. Figures 3.a and 3.c show the appearance of the upper surface of the cuts where these condensed residues can be observed in two cuts carried out using air as the assist gas at different pressures: a) 5 bar, c) 10 bar. Both cuts were performed using a laser power of 3 kW and cutting speed of 3.5 m/min. A clear reduction in the layer of the condensed residue is observed with the increase of the assist gas pressure. The adjacent pictures show the appearance of the cuts after cleaning the charcoal; the cuts present a sharp edge showing a reduction of the affected zone with the increase of the assist gas pressure.

The condensed residues were analyzed and the main compounds found are listed in Table 1. Several heavy alkanes were found among the major constituents of the residues from particle board, these compounds do not represent any health hazard. On the other hand, the oily residues are more abundant in the cuts of the phenolic resin boards. Moreover, the major constituents of this residue are phenols and cresols which may constitute a serious health hazard. Consequently, careful manipulation of the cut edge of the phenolic resin boards must be recommended in order to avoid skin contact with these residues.

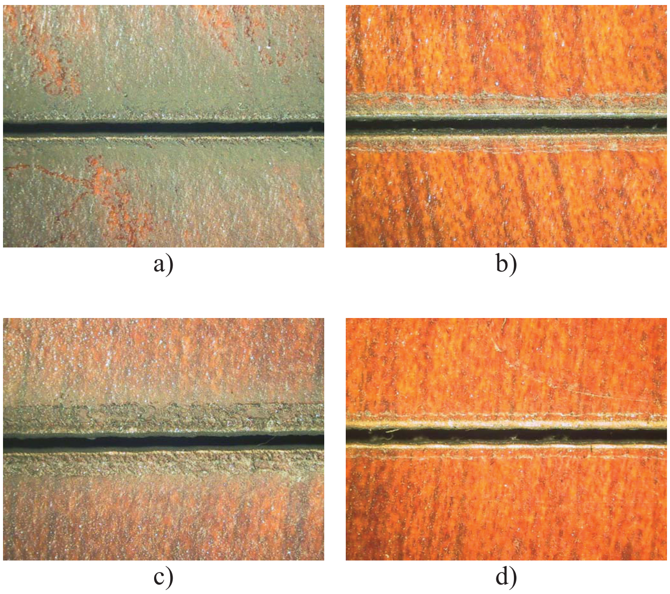


Figure 3. Optical images of the top surface of the cuts before and after cleaning the deposited residues. The cuts were performed using a laser power of 3 kW and cutting speed 3.5 m/min but different assist gas pressure: a) and b) at 5 bar; c) and d) at 10 bar.

Table 1. Main compounds detected in the condensed residues.

		Compounds
Particleboard	Major	Heavy alkanes
	Minor	Phenol, m-cresol, 3-phenyl-acrolein, phenolic ethers
PRB	Major	Phenol, cresols
	Minor	Phenanthrene

Table 2 summarizes the most abundant and hazardous compounds detected in the fumes produced when cutting the PRB and particleboard for comparison. Together with the identification of the compounds their concentration is reported and comparison with the legal limits for concentrations of hazardous compounds in workplace air according to the Permissible Exposure Limits (PEL) as stated in the standards of the United States Occupational Safety and Health Administration (OSHA). The exposure index is the quotient of the measured concentration by the PEL, it indicates the level of danger for the corresponding compound.

Table 2. Main compounds detected in the vapours and fumes from the cuts.

MATERIAL	COMPOUND	OSHA - PEL (mg/m^3)	CONCENTRATION (mg/m^3)	Exposure index OSHA
PRB	ACROLEIN	0.8	0.01	0.013
	FORMALDEHYDE	2.46	0.04	0.016
	PHENOL	19	1.12	0.06
	BENZENE	3.19	2.00	0.627
Particleboard	ACROLEIN	0.8	0.02	0.03
	FORMALDEHYDE	2.46	0.16	0.065
	PHENOL	19	0.83	0.044
	BENZENE	3.19	2.3	0.72

The concentration levels of the majority of the compounds are well below the threshold limit values but for benzene, which is one of the most dangerous. The concentration level of benzene in the atmosphere during the laser cutting process is slightly below the Permissible Exposure Limit established by the OSHA. Therefore this substance deserves special consideration to reduce the health hazards that can cause and must be periodically checked to beware of its concentration levels. On the other hand, the concentration levels of all substance but phenol are higher in the particleboard fumes than in the fumes generated by the cuts in the phenolic resin boards. The result for the concentration of phenol is predictable taking into account that it is one of the monomers of the resin which constitutes the core of this material. The higher concentration of the rest of substances in the fumes from the particleboard cuts must arise mainly from the decomposition of the wood chips, since it is the major constituent in this material. The reason for this higher concentration may come from the higher cutting speed for this material, producing a higher rate of material removal and decomposition and therefore a higher amount of fumes. In any case, we can state that the health hazards due to contamination of the atmosphere at the working place is similar during laser cutting of the very usual particleboard covered with the melamine layer and the phenolic resin boards. Consequently, special protective measures, i.e. personal protection such as adequate masks and local reduction of the substance by a proper fumes extraction equipment; together with regular assessment of the concentration levels are strongly recommended during CO_2 laser cutting of both materials.

As a conclusion, we demonstrated the feasibility of CO_2 laser cutting of phenolic resin boards, obtaining good cutting speed and cut quality. Current conventional CO_2 laser cutting equipments can be employed with just special attention to fumes extraction, incorporating suitable air filters to remove organic vapors, similar to those employed for laser cutting of wood, wood composites and other polymers. Additionally, personal protective measurements must be implemented to avoid contact with condensed residues in the cut edges.

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