CO_2 laser machining of wood, perspex and glass with and without use of assist gas

Wairimu G., Ikua B.W. and Kioni P.N.

Abstract—*In this paper, we investigate the effect of CO_2 laser machining on wood, perspex and glass. These materials are very important due to their wide applications and thus there is need to machine them as desired. Glass is a hard, optically transparent and used for a variety of purposes such as eyewear, bottles, windows and even certain types of furniture. Perspex is the clear, light weighted, hard and thick plastic, widely used for watch glasses, advertising signs, domestic baths, motorboat windscreens, aircraft canopies, and protective shields. To eliminate the possibility of the CO_2 light being diffused by dirt/dust particles on the surface of these materials being experimented on, thorough cleaning of the surfaces is done and these specimens left to dry before use. A continuous wave (cw) CO_2 laser beam with an estimated power of 35 Watts is then focused on the surfaces of the specimens. Machining time and the number of scans are varied and their effect on depth, hole diameters, kerf widths, taper, aspect ratio and heat-affected-zone (HAZ) investigated. Effect of compressed air as the assist gas on hole profiles and the point at which glass cracks was also investigated. During these experiments, the machining velocity, laser and optics parameters were kept constant. Results showed that in an increase in the input parameters resulted in an increase in the features under investigation.*

Keywords—CO_2 laser, continuous wave, laser ablation, quality machining, machining time.

I. INTRODUCTION

PLYWOOD is one of the most widely used wood structural products due to its flexibility, low cost, workability, re-usability, resistance to cracking, shrinkage, splitting and twisting/warping, and its general high degree of strength, and can be locally manufactured. It is used in many applications that need high-quality, high-strength sheet material. Lasers offer a number of attractive advantages for the cutting of timber, plywood, and particleboard. In particular, it provides narrow kerfs of 0.3-0.8 mm, the absence of sawdust and minimum or no noise. While the use of a laser eliminates rough, torn-out and fuzzy edges which are common with conventional sawing techniques, it is characterized by burned edges produced by the laser heat. Greater amounts of charring will result when the material thickness is increased, thereby necessitating the use of small cutting feed-rates. CO_2 laser has been commonly used to machine most non-metallic materials like wood because these materials highly absorb the CO_2 laser wavelength of 10.6 μm. Conventional glass cutting is done by scoring and breaking which produces microcracks and splinters, and leaves cutting oil residues. These microcracks and oil residual lead to lowered strength and pollution of the glass sheets respectively. If the glass has to be bent or tempered, further grinding, polishing and washing processes become necessary. Most types of glass are prone to thermal shock and are therefore laser is generally not suitable for cutting. The instantaneous heat of the laser beam provides cutting action by both vaporization and the blowing away of molten glass from the cut zone [1].

There are many parameters which influence laser machining and therefore have to be considered for quality machining to be achieved. These input parameters include [2]:

- Laser parameters such as laser power, wavelength, depth of focus (DOF), focal length, beam diameter
- Material parameters such as thermal diffusivity, thermal conductivity, reflectivity, absorptivity, material thickness, initial temperature and humidity
- Machining parameters such as scanning speed, positioning of the focal point, incidence angle, type and pressure of the assist gas.

Nukman et al. [3] investigated the effects of CO_2 laser cutting parameters on the cut quality of several selected Malaysian wood. The processing variables taken into investigation were laser power, nozzle stand-of distance (SOD) or focal point position, nozzle size, assist gas pressure, types of assist gas and cutting speed. These were their observations:

- Cutting parameters selected for laser cutting of wood were the materials moisture and air content, workpiece thickness and density.
- For material thickness of 10 mm for all wood samples, it was not possible to achieve a successful cut using laser power of 100 W at 1.2 m/min cutting speed.
- Due to exothermic reaction, cutting with compressed air exhibited severe burns and charring with larger kerf widths, over cuts and higher portions of material loss.
- Use of nitrogen was reliable in reducing material loss and over burning due to the compensation of heat accumulation by offering cooler and inert environment to the cutting process.
- Closer dimensional accuracy and acceptable surface finish in laser cutting of wood were obtained when nitrogen was used in assisting the cutting process as compared to the use of compressed air.

Szymani et al. [4] investigated on modern cutting techniques in wood machining processes by evaluating three new approaches to kerfless wood cutting. These are the use of

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cutters, high-velocity liquid jet and laser beam. It was apparent that the high-velocity liquid jet and laser beam offer great potential in secondary manufacture, in particular for cutting of intricate contours and complex computer-controlled operations.

Migliore et al. [5] observed that with an assist gas, factors to be considered include the type, flow rate and purity. These influence the speed of machining and surface finish. For instance, when oxygen is used as an assisting gas, the exothermic reaction results in reduction of machining time.

Begic et al. [6] noted that some gaseous impurities can modify the characteristics of the beam generated by a CO_2 laser and cause some nonreproducible performances such as loss of power, reduced stability of the laser beam and shorter service life for electrodes and delivery mirrors.

Yilbas [7] assessed cutting quality and thermal efficiency of a laser gas assisted cut- ting process. He found that increasing laser beam scanning speed reduced the kerf width and that the kerf width increased with increasing laser output power. The main effects of all the parameters employed had significant influence on the resulting cutting quality.

In alloys, assist gases are used in industrial laser machining to protect the laser optics by blow back of ejected debris and to allow a chemical reaction between the substrate and assist gas in order to generate more energy as noted by Voisey et al. [8]. These authors investigated the effects of using assist gases in the drilling of different substrates with the aim of investigating whether assist gases are beneficial to the laser drilling of superalloys. No noticeable variation in the mass of substrate removed per hole was observed for either assist gas used to drill both the blind and through holes. Changing from an oxidising (oxygen) to an inert assist gas (nitrogen) did not have any discernable effect, indicating that the superalloy, as well as the zirconia top coat, do not have any chemical interaction with the oxygen assist gas. The lack of reaction between zirconia and oxygen was expected since zirconia was already an oxide. There exists a wide range of materials that has been laser machined including several types of rocks [9].

Berrie et al. [10] experimented on the effect of lens, position and focal plane, speed of cut and power on the cutting and drilling rates of perspex. They found that the drilling rate was faster for longer focal lengths in the time range investigated and an increase in power increased the rate of drilling. Another point noted was that holes drilled with different lenses differed only superficially with the short focal lengths producing shorter, wider holes, whereas with the longer focal lengths, tapering was more pronounced. At low speeds or large depths there was little or no dependency of depth of cut on the focal length of the lens.

II. EXPERIMENTAL SET-UP

The laser generation tube was set up as shown in Figure 1. After the laser beam generation, the beam was manipulated through the beam delivery system as shown in Figure 2. The arrows indicate the beam manipulation. When machining each material, the scanning speed, laser and focusing optics were held constant to investigating properties such as the kerf width while machining time and the number of scans were varied and their effects on cut parameters investigated.

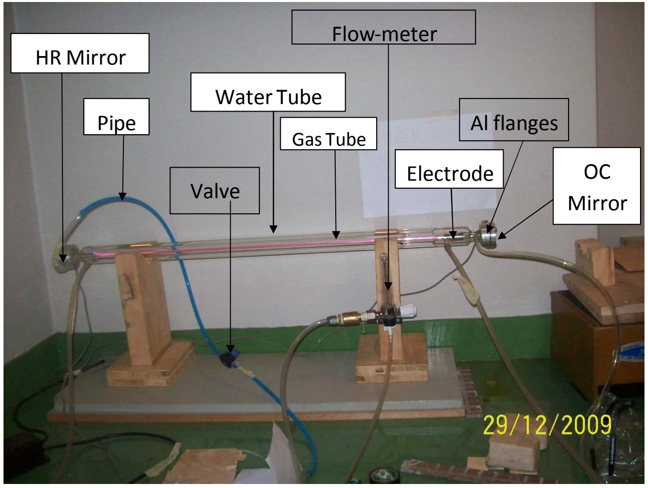

Fig. 1. Laser generation tube

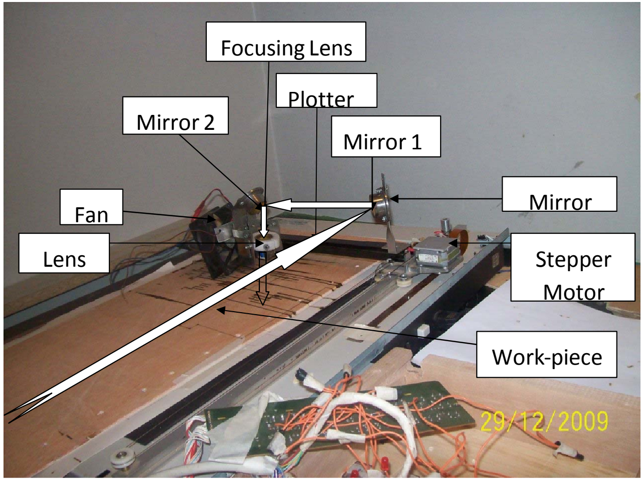

Fig. 2. Laser beam delivery system

During the experiments, the aim was to focus the beam on the workpiece so as to concentrate the beam to the minimum spot possible and thus achieve maximum power density which would consequently increase the material removal rate (MRR) and reduce the HAZ. The workpiece was placed with the surface on the focal plane. With the focal length of the lens as 38 mm, Equation 1 was used where H and h are in mm.

$$H = h + 38 \quad (1)$$

For glass, each specimen was placed under the focused beam and the time it took to crack measured. The hole diameter, crack length and thickness were measured using the profile projector.

To investigate the effect of an assist gas in glass cutting, one set of experiments was done without any assist gas while the other was done with compressed air as the assist gas. The interaction time between the beam and the workpiece was varied from 5-25 seconds and the effect on hole diameter measured. Three different experiments were performed on the specimens as follows:

1) experiments without any assist gas
2) experiments with assist gas at 10 mm above the workpiece surface, at 45 degrees inclination
3) experiments with assist gas at 3 mm above the workpiece surface, at 45 degrees.

III. RESULTS AND DISCUSSION

A. Wood drilling with CO_2 laser

For the holes or slots made using the CO_2 laser, HAZ was evident and defined as a darkened area around the holes or slots where the beam intensity was not sufficient for a clean cut. The holes were also tapered as illustrated in Figure 3. This was due to the Gaussian power distribution of the beam. An increase in machining time resulted in an increase in kerf widths, hole diameters and depth. The increase in these dimensions with an increase in machining time or number of passes is due to the fact that more laser energy is absorbed by the material as time progresses resulting in more material being ablated. However, due to the limited laser beam diameter and DOF, these measured dimensions seem to reach some saturation for this stationary beam and thus do not increase infinitely with an increase in machining time or number of passes.

Figure 4 shows that an increase in machining time results in an increase in hole diameter, depth and HAZ. when drilling wood. This is an increase in machining time means an increase in the interaction time between the material and the laser beam. This means more energy is absorbed by the workpiece and thus removes more materials. In Figure 5, the charred region refers to the darkened area along the cutting path. This increases with an increase in machining time due to the heat wasted around the machining path. Figure 6 shows that the depth machinable can be predicted using a simple equation. This is important so that one does not machine for so long as this does not increase the depth past some saturation. This would only increase manufacturing cost and HAZ.

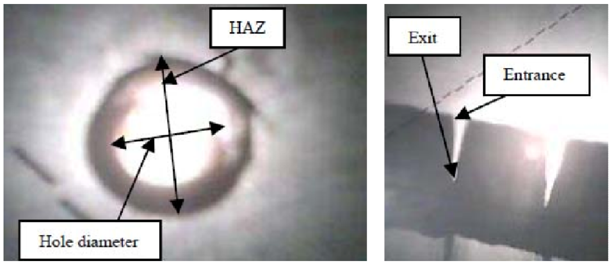

Fig. 3. Tapered holes

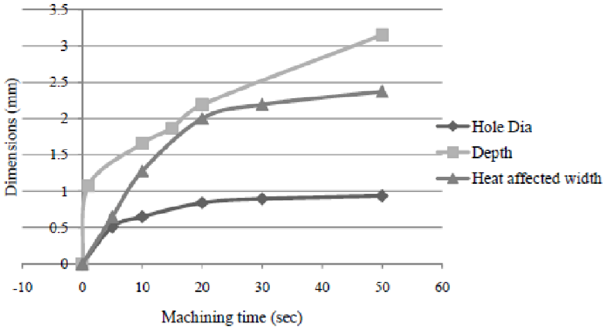

Fig. 4. Effect of machining time in wood drilling

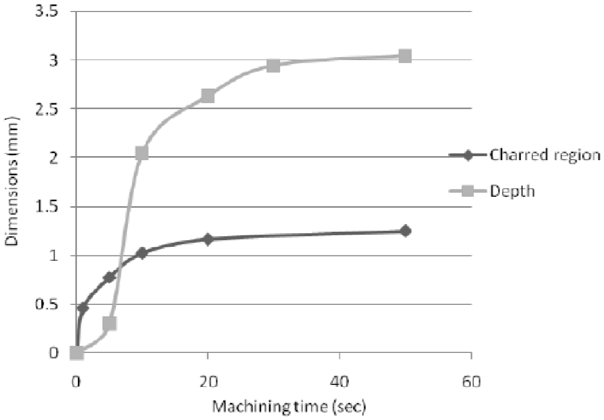

Fig. 5. Charred region and depth versus machining time in wood cutting

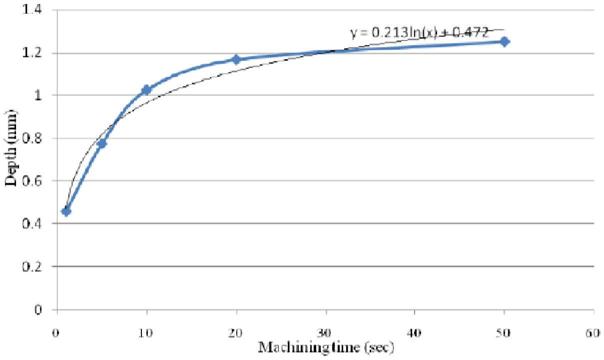

Fig. 6. Depth prediction in wood drilling

B. CO_2 laser cutting and drilling of perspex

An increase in the number of passes resulted in an increase in HAZ, kerf widths and depths as shown in Figure 7. Depth machined increased with the number of passes and interaction time but not infinitely since the maximum depth a stationary laser can machine depends on its depth of focus (DOF). It was found that depths attainable for perspex could be predicted as shown in Figure 8.

Figure 8 illustrates that the depth machinable can be predicted from the machining time. Figure 9 compares kerf widths of the three materials under test. It is evident that perspex is more machinable than glass due to its less energy requirement than the later. Figures 10, 11 and 12 compare the HAZ, depth and aspect ratio between wood and perspex. This implies that perspex is easier to machine than wood due to the same reason of energy requirements.

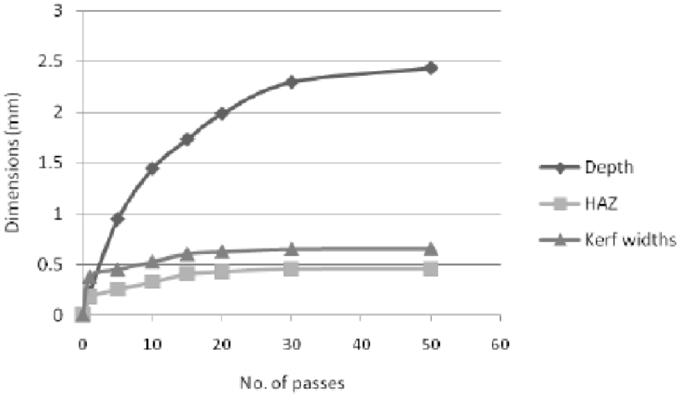

Fig. 7. Effect of the number of passes on dimensions in perspex cutting

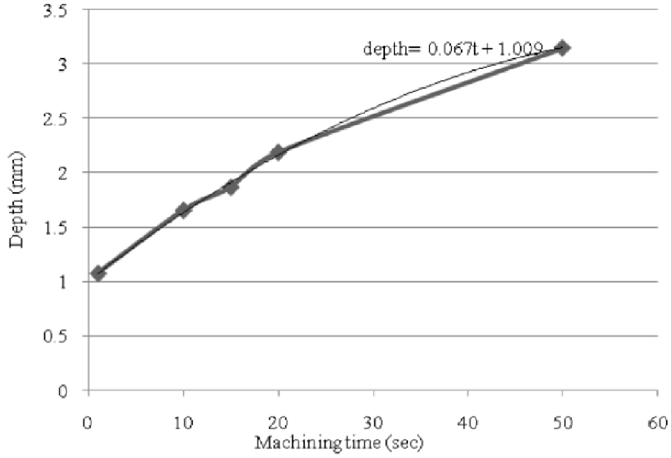

Fig. 8. Prediction of depth in perspex drilling

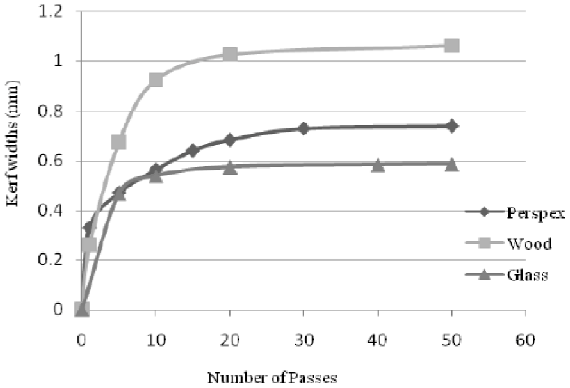

Fig. 9. Comparison of kerf widths in wood, glass and perspex

Aspect ratio, A_r was calculated from:

$$A_r = \frac{d}{D} \tag{2}$$

where *d* is depth machined and *D* is hole diameter. This A_r was observed to decrease with an increase in machining time but this decrease also reduced with the machining time as shown in Figure 12.

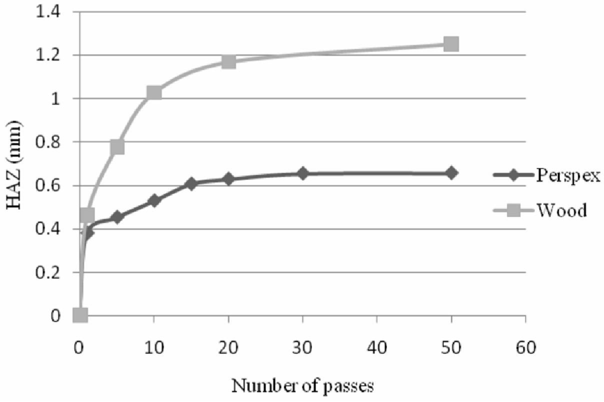

Fig. 10. Comparison of HAZ in wood and perspex

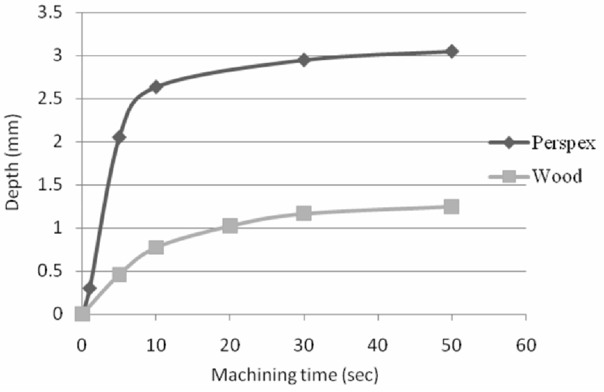

Fig. 11. Comparison of depth in wood and perspex

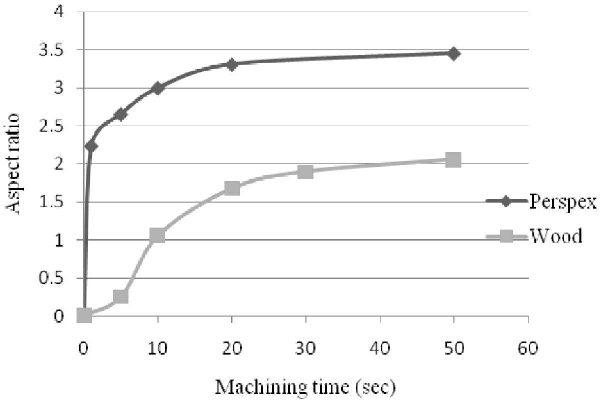

Fig. 12. Comparison of aspect ratio in wood and perspex

C. CO_2 laser machining of glass

For the first few passes, there was no sign of cracking. This can be associated with the presence of less heat available. Glass machining was possible but to a less extent than with wood and perspex. This can be associated with the higher melting point of glass as compared to perspex which meant more heat energy requirements. An increase in machining time resulted in increase in hole diameters and HAZ as shown in Figure 13. An increase in the number of passes resulted in an increase in kerf widths but this increase reduced with time as shown in Figure 14. It was not possible to obtain the depth and hence the aspect ratio for glass due to equipment limitations.

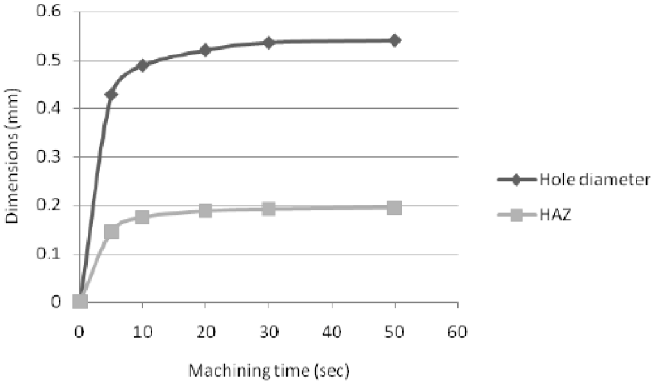

Fig. 13. Effect of machining time on hole dimensions in drilling of glass

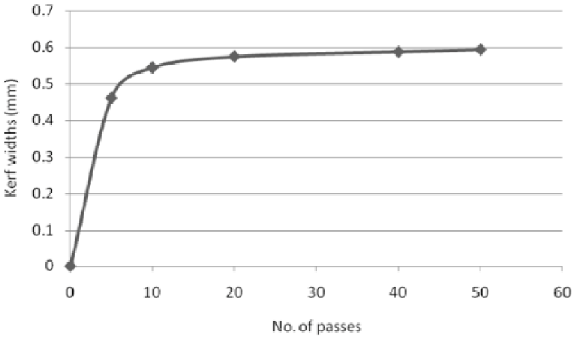

Fig. 14. Effect of machining time on kerf widths in cutting of glass

From the experiments on cracking of glass, these were the observations:

1) Although machining conditions (laser beam, focal positioning) were constant and the material was from the same sample of glass, all the pieces cracked or gave the cracking sound and some even separated over a wide range of time (from 6-60 seconds).
2) Some of the pieces gave the sound but with no visible cracks seen using the profile projector (PJ 311).
3) Other pieces even separated and were thrown far away from the machining area.
4) Other pieces separated along the full width of about 45 mm.
5) Crack thickness was not constant but varied. 6) Hole diameters also varied.

For the experiments without an assist gas, the earliest breaking of glass was noticed at less than one minute while another similar piece did not break even after two and half minutes. With no assist gas during machining and with the beam focused at 10 mm from the edge, breaking occurred after close to two minutes. Separation of the glass piece also occurred. With compressed air as the assist gas, cracking was counteracted since the gas also acted as a coolant and thus reduced thermal stresses. There was therefore no crack or separation even after about 20 minutes.

Another observation is that holes drilled with the assist gas had more circular profiles while those without had irregular profiles as shown in Figure 15. This is as a result of the compressed air being able to remove debris by blowing them away preventing solidification around the holes. Another reason is associated with the fact that compressed air also acted as a coolant and thus reduced thermal stresses. This subsequently prevented formation of microcracks around the holes and thus the regular and smooth surface. This has therefore shown the importance and advantage of using assist gas in laser machining to achieve precision. Components produced with microcracks are prone to early failure thus expensive to maintain since frequent replacement becomes an occasional necessity. This has shown that the use of compressed air as an assisting gas improves on profile accuracy in laser machining.

a) without compressed air b) with compressed air

Fig. 15. Effect of compressed air on hole profile

IV. CONCLUSION

From this study, the following conclusions can be drawn:

- There is a threshold exposure time (1 second) below which no material can be ablated from either wood or perspex.
- From the depth prediction graphs, one can concentrate on optimum machining time or number of passes and thus reduce on manufacturing costs. (IR) energy from CO_2 laser.
- Assist gas improves geometrical accuracy.
- Use of assist gas reduces the chances of glass cracking.

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