THE EFFECT OF CO_2 LASER POWER ON THE THERMAL INSULATION OF ACRYLICS

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ABSTRACT

In this work, the effect of the power of CO_2 laser on the thermal insulation of acrylic sheets was studied. Five different colors of PMMA sheets with 100 x 100 x 2mm were irradiated by CO_2 laser to engrave micro-channels resemble blackbody cavities; namely red, green, blue, black and white sheets (RGBKW). The laser power was 30, 25, 20 and 15 Watts. The micromachining was done in the x-y platform controlled electro-pneumatically. Experimental results showed a temperature reduction between micro-machined and standard samples (without irradiation) of PMMA, using different laser powers. The thermal insulation was changed with increasing the laser power, which fulfilled the state of increased thermal insulation of acrylic sheets when laser micro-machined, and consequently fulfill the purpose of this work.

Keywords: Laser Micromachining; PMMA; Thermal Insulation; x-y; Laser in material processing.

INTRODUCTION

Traditional machine tools are normally designed for a particular purpose. They all perform to the most exacting standards. But they only perform a particular task. The industrial laser is different. It is a flexible machine tool that produces a beam of light with unique properties. Its light can be controlled accurately [1]. During the last years, processing of polymers has become an important field of applied and fundamental research. One of the most important fields is laser ablation involving various techniques and applications [2].

Short pulse lasers have been effectively used for the fabrication of optical waveguides in glasses such as silica, quartz and polymer like Polymethylmethacryle (PMMA). Polymers are widely used in industry because of their low cost, ease of availability and a well characterized and documented laser fabrication. Another advantage of using polymers for optical applications is their high transmission in the visible region. Because of these favorable properties, lasers have been used for the writing of waveguides and optical couplers in PMMA. Most of the written waveguides and optical couplers are planar thus restricted into two dimensions which limit their use and possible applications. Research groups have demonstrated successful laser written three dimensional waveguides in variously optically transparent materials [3].

Machining with the CO_2 laser involves removing material by thermal process. The infrared radiation excites the vibrational and rotational levels in the irradiated sample, which heats up and evaporates or burns. The exact nature of the process depends on the absorption characteristics of the sample material. Thus, it is crucial to select a material which responds in a useful manner to CO_2 laser irradiation. Otherwise the resulting structures will show

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effects due to the thermal nature of the material removal process, such as scorching or boiling up, on a length scale comparable to the structures themselves [4].

One of these applications is to increase the thermal insulation for such materials. We can improve the emissivity of objects by making so-called blackbody cavities, as shown in Figure 1.The principle is that any radiation entering the cavity is absorbed; then, since there are no reflections, the emissivity of the cavity must be 1.0. The ideal black body cavity is a perfect emitter and absorber of radiation [5].

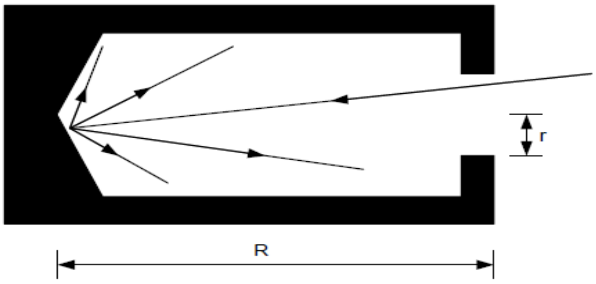

Figure 1: A simple representation of a blackbody cavity .The greater the ratio of the cavity size, R, to the aperture, r, the greater the emissivity of the cavity.

Figure 2 shows a cross sectional view of an object with a conical opening. If the infrared radiation is allowed to enter the opening, several internal reflections will occur before it reflects to the outside of the opening; we could imagine what will happen to that radiation.

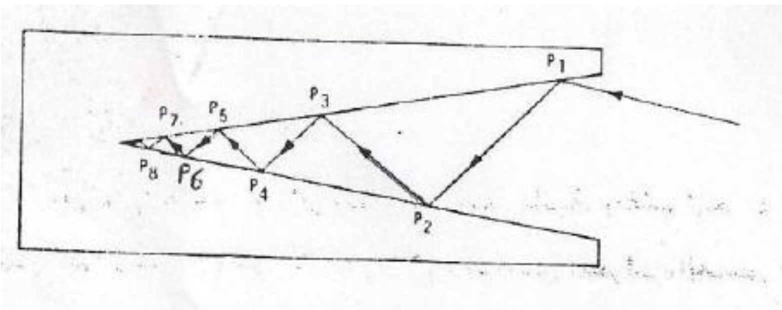

Figure 2: Reflection of incident rays in cross sectional view of a cone

For figure 2, let us assume that the material of the cavity is opaque having an emissivity of 0.5. Also we can assume that the angle of the conical opening allows the entering radiation to reflect internally ten times. Another assumption to make is that power entering is 100 Watts, then when it strikes point P_1, 50 Watt will be absorbed and 50 will be reflected. In point P_2 50% (25 Watt) will be absorbed and 25 will be reflected. At P_{10}, 99.9 Watt will be absorbed and only 0.0976 Watt will reflected outside.

METHODOLOGY

The experimental setup used in this work was composed of the electro-pneumatically operated x-y work station for work-piece movement, beside the CO_2 laser system and other accessories. The laser was used to make parallel grooves in samples of colored acrylic sheets using the x-y work station The acrylic sheet samples, after micromachining, were used to reduce the temperature inside wooden boxes. The wooden boxes and the data loggers were used for measuring the temperature difference between outside and inside the wooden box.

Data loggers are electronic temperature measuring units capable of measuring temperature in the range of -40 to +70°C with accuracy of 0.001°C, loggers were used in this work to measure the ambient temperature, out of a wooden box, the temperature inside an open-top box, the temperature inside a box with its top closed by un-machined standard acrylic sheet and the temperature inside a box with its top closed with micro-machined sheets.

The Laser system used in this study was 30W CO_2 Laser Model IB-601B supplied from (Beijing InnobriTechnology,China), with 10.6 µm wavelength. The experimental setup was provided with a longitudinal pneumatic system capable of pulling or pushing the table with different velocities. The lateral system together with the longitudinal system, subjected to laser radiation are capable of apply micromachining process to the 100 x100 x2 mm acrylic sheets, see Figure 3.

Figure 3: The experimental setup used for laser micromachining of PMMA

The experimental procedure was done in the following steps:

1 - Acrylic sheets with colors of: red, green, blue, black and white were chosen to represent the RGB model of colors. Black was chosen to represent the addition of the subtractive coloration.

2 - Samples were cut to the dimensions of 100 x 100 x 2 mm, and coded according to color, laser power, and number of passes, e.g., code number R30W3P, means that the color is red, power is 30 Watt and passes are 3. Samples marked STD means standard samples without micromachining process, e.g. RSTD means standard red sample.

3 - Wooden boxes were designed and fabricated according to the size of acrylic samples. Inside the boxes the data loggers were put to record the solar temperature with four situations, namely the ambient temperature outside the box, the temperature inside an open-top box, inside a box closed with standard un-machined, standard sheet, and the temperature of the logger inside a box closed with micro-machined acrylic sheet.

4 - The parameters used for temperature comparison between the machined and standard samples were chosen to be color, laser power of 15, 20, 25 and 30 Watt, and one pass.

5 - Speed of the pneumatic cylinder was fixed.

6 - Micro-channels were engraved by moving the x-stage pneumatically to the out-stroke direction with the laser in operation to ablate the sheet and make the channel.

7 - When the laser is in the off-position, the stepper motor moved the workpiece in the y-direction a distance of 1 millimeter, to allow for engraving of the next channel. By

synchronization of the motion in the lateral and longitudinal directions, the entire width of the sheet was micro-machined.

RESULTS

Micromachining of Red samples using 15, 20, 25 and 30 Watts

A Comparison between temperature differences in degree C for red PMMA samples irradiated by 15, 20, 25, and 30 Watts are graphically represented in figure 4.

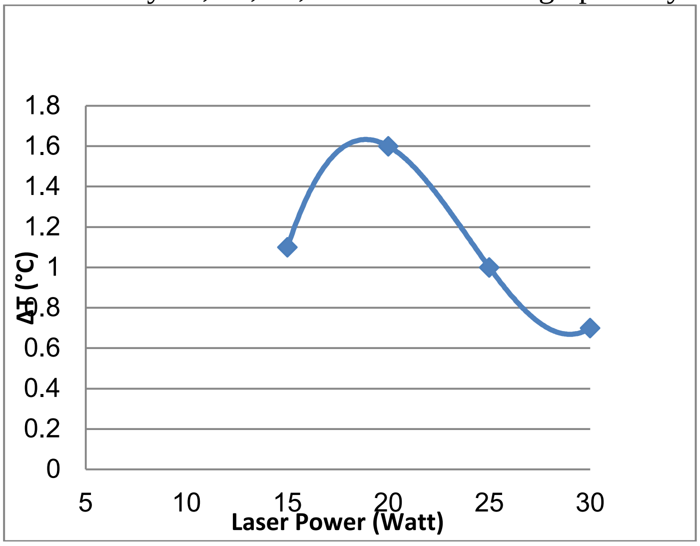

Figure 4: The Effect of Varying Laser Power on the Temperature Difference in Red Samples.

Micromachining of Green samples using 15, 20, 25 and 30 Watts

The comparison between temperature differences in degree C for green PMMA samples irradiated by 15, 20, 25, and 30 watts is graphically represented in figure 5.

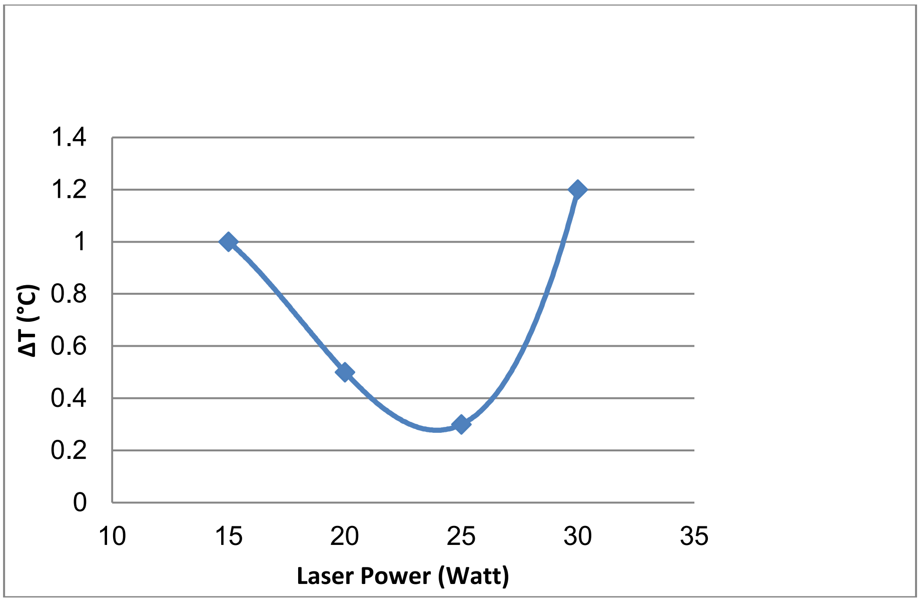

Figure 5: ΔT for Green PMMA Samples Irradiated by 30, 25, 20, 15 Watts

Micromachining blue samples using 15, 20 and 25, and 30 Watts

A comparison of temperature difference, ΔT, for blue PMMA samples irradiated by 15, 20, 25, and 30 Watts is shown in figure 6.

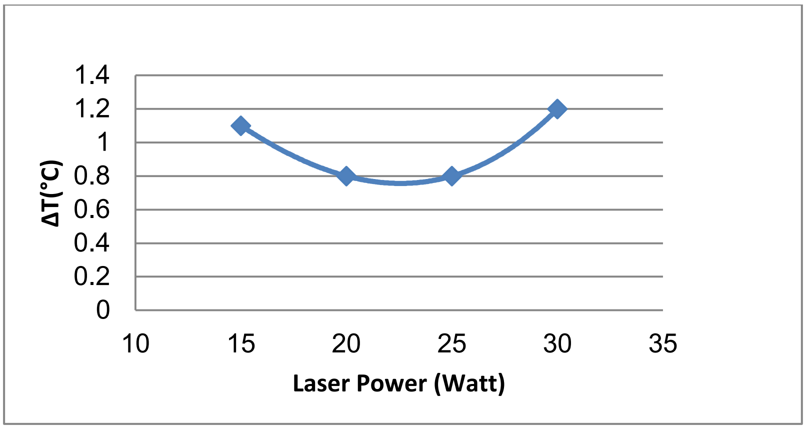

Figure 6: ΔT for Blue PMMA Samples Irradiated by 30, 25, 20, 15 Watts

ΔT for black PMMA samples

The temperature differences in °C for black PMMA samples irradiated by 15, 20, 25, and 30 Watts are graphically represented in figure 7.

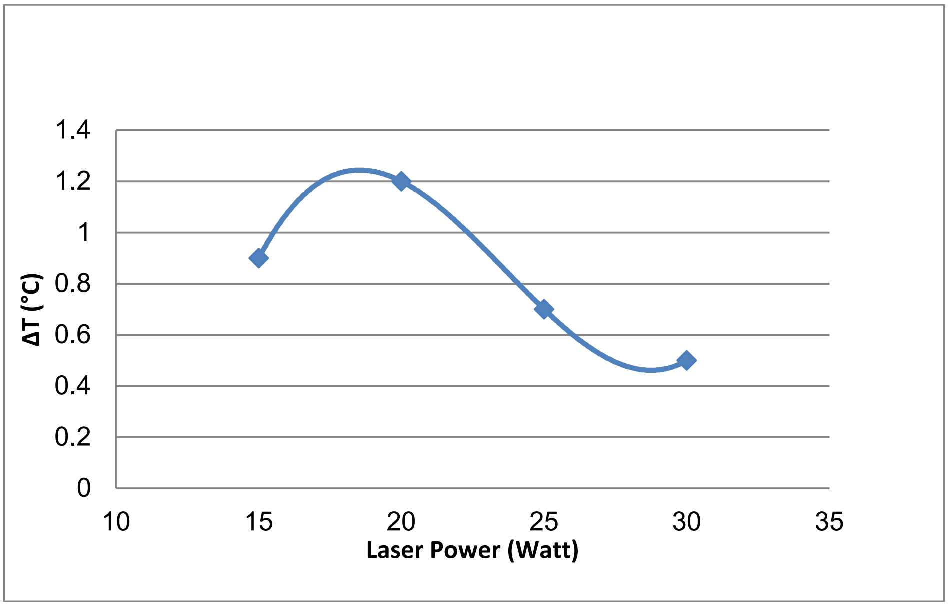

Figure 7: ΔT for Black PMMA Samples Irradiated by 30, 25, 20, 15 Watts

ΔT for white PMMA samples

The graph in figure 8 shows the effect of different laser powers on the temperature difference of the white PMMA samples.

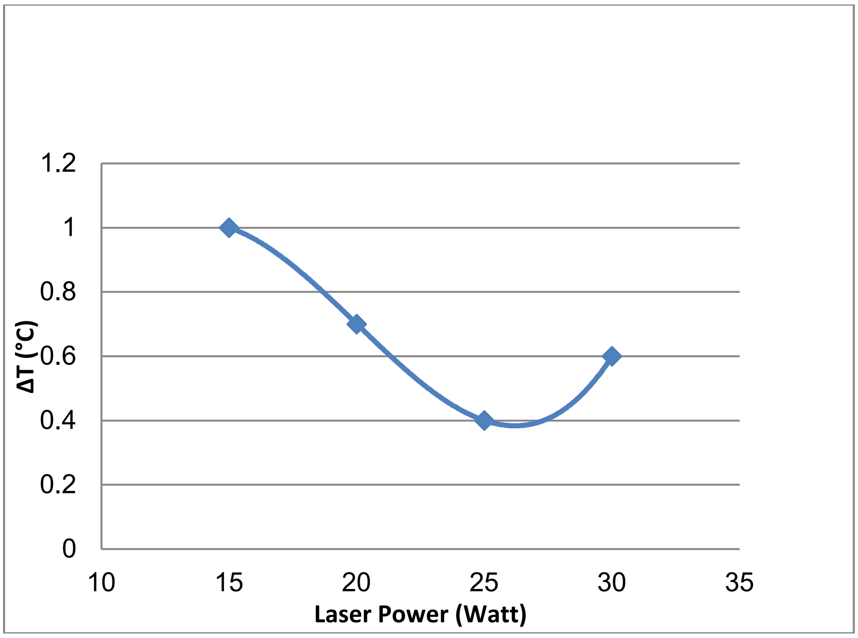

Figure 8: ΔT for White PMMA Samples Irradiated by 30, 25, 20, 15 Watts

DISCUSSION

It is clear from the experimental results that the PMMA samples of different colors (red, green, blue, black and white) were well micro-machined by CO_2 laser and that supports the results obtained by Martin F. [4], of getting good machinability of PMMA using CO_2 laser.
All the mentioned micro-machined samples showed increased thermal insulation to solar heat compared to the standard samples. The reduction in temperature was clearly indicated after laser micromachining which is positively backup the theory of increasing thermal insulation of PMMA by laser micromachining.

When comparing the thermal insulation for PMMA of different colors, the green and blue samples micro-machined by 30 Watt, showed the highest value of 1.2°C followed by red, black and finally white. Some of the reasons for that can be explained as a red color filter absorbs all colors and transmits only red light. Green sheets absorb red and blue light and transmit the green component of the incident white light. The fractional transmittance of a commercial blue glass color filter indicates that the filter absorbs red light strongly and transmits violet and blue-green light [6].

The highest average value of the temperature difference was 1.6 °C. In this respect, the results go in the same direction of what Wilhelm Pfleging et. al. were mentioned for the ablation of polymers which can be described by the ablation depth (d) as a function of laser power (P) and feed rate (*v*) of the laser beam. The ablation depth d is directly proportional to the laser power, and inversely proportional to the feed rate. Depending on the laser power and the feed rate, the energy input and therefore the ablation depth varies (Wilhelm Pfleging, 2009) [7].

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CONCLUSIONS

From the obtained results, the followings can be concluded:

1- PMMA with colors red, green, blue, black and white can be well micro-machined using CO_2 laser with 15 to 30 Watts output power.

2- Increasing the laser power lead to fluctuation in the thermal insulation of the micro-machined PMMA sheets.

3- A blend of green and blue colors for PMMA sheets, or using greenish-blue color of PMMA, may give better results in thermal insulation than that of other RGBKW colors.

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