Utilization of Q-switched Nd: YAG Laser in Cutting Acrylic Sheets

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Abstract

In this work, a Q – switched Nd:YAG laser is used to cut different thicknesses of acrylic sheets with different cutting speeds and laser repetition rates. The obtained results for the transparent sheets show clearly that it is difficult to cut these sheets completely, this is due to the fact that most of the laser power will be transmitted through them, while some will be absorbed causing the heat affected zone (HAZ), which is inversely proportional to the cutting speed.

On the other hand, cutting of the black sheets, using the same laser parameters showed that the depth of cut is inversely proportional to the cutting speed and the cutting process is easy.

The results showed, also, a linear relation between laser repetition rate and cutting depth. Higher laser repetition rates resulted in an increase in the depth of cut and vice versa.

ملخص

في هذا العمل، تم استخدام ليزر ND-YAG المضبوط نوعيا لقطع اسماك مختلفة من صفائح مادة اكريليك ولقيم مختلفة من سرعات القطع ومعدل تكرار نبضة الليزر. النتائج التي تم الحصول عليها تبين بوضوح مدى صعوبة القطع التام للالواح الشفافة، ويرجع ذلك إلى حقيقة أن معظم طاقة الليزر المرسلة سوف تنفذ من خلالها، بينما سيتم امتصاص بعض منها مسببة منطقة متأثرة حراريا (HAZ)، والتي تتناسب عكسيا مع سرعة القطع. ومن ناحية أخرى، ان قطع صفائح سوداء اللون باستخدام نفس معلمات الليزر السابقة بينت ان عمق القطع يتناسب عكسيا مع سرعة القطع وعملية القطع تكون اكثر سهولة. كذلك فقد بينت النتائج وجود علاقة خطية بين معدل تكرار نبضات الليزر وسمك القطع حيث ان معدلات تكرار النبضة العالية ينتج عنه زيادة عمق القطع والعكس صحيح

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1. Introduction

Lasers have been a byword for efficiency and quality in materials processing since their advent in the sixties. They offered an entirely new form of energy, which in turn lent itself to uses in manufacturing, medicine and communications. Able to heat, melt and even vaporise materials. Lasers are seen as the ideal medium for combining intense but controllable energy. Laser cutting is largely a thermal process in which a focused laser beam is used to melt material in a localized area. A co-axial gas jet is used to eject the molten material from the cut and leave a clean edge.

Moving the laser beam or work piece under CNC control produces a continuous cut. The process also lends itself to automation with offline CAD/CAM systems controlling either 3-axis flat bed systems or 6-axis robots for three dimensional laser cutting. The improvements in accuracy, edge squareness and heat input control means that laser is replacing other profiling techniques such as plasma cutting and oxy-fuel cutting. Lasers may be used to cut or shape a wide variety of materials. By cutting, we mean vaporization of material along a line, so as to separate the work piece into separate parts. [1,2]

Lasers have been widely used for cutting of plastics. The resulting edge quality may vary greatly depending on the exact composition of the material and the parameters of the cutting operation. A number of plastics can be cut well, but others often yield discolored or charred edges thermosetting plastics are practically difficult to cut well. For cutting of plastics, one should use a beam with high irradiance, a well-defined edge, and a high quality beam. [2]

Laser Cutting Advantages: include: Economical, Accuracy, Flexibility and Quality. [3]

Acrylic:

Acrylic plastics are hard, water-white thermoplastics based generally on methyl methacrylate monomers, although ethyl and butyl methacrylate polymers also are commercial. In addition a number of copolymers are produced.

The first major use of acrylics was during World War II as aircraft canopies and windshields. In these applications, acrylic offered aircrew's excellent visibility and a degree of protection from shrapnel and shell fragments. Since that time, acrylics have increased in sophistication and

importance and today are among the most widely used of the specialty plastics. [4]

Acrylics have a good balance of properties that suits them for a wide variety of applications. Most important are optical quality and weatherability. Acrylics also are noted for their moderate strength, good chemical resistance, thermal properties, electrical properties, and ease of fabrication and handling. [4]

Among the most important markets for acrylic sheet are formed parts for internally illuminated outdoor signs. Acrylics are finding increasing use in the building field in large-area enclosures for swimming pools, shopping centers, restaurants, and botanical gardens. Use of extruded or formed acrylic sheets as spandrel panels or other facings also is popular. Another building application is transparent window glazing, particularly in industrial plants and city school buildings where breakage can be a costly problem.

Polymethyl methacrylate, PMMA, is, commercially, the most important member of a range of acrylic polymers which may be considered structurally as derivatives of acrylic acid. [4]

Cutting of Acrylic Plates:

Many types of tools are used for this purpose, like:

- *Cutting with a knife or scriber.
- *Cutting with power saws.
- *Table and circular saws.
- *Saber saws.
- *Hand saws.
- *Routers and shapers. [5]

2. Experimental Work

Pulsed Nd: YAG, from the YAG-50 series laser scribing machine, was used to cut different samples of the 2mm thickness, 100 x 100 mm, commercial Perspex sheets. Nine samples of black and transparent commercial Perspex were prepared by cutting 300 x 300mm sheet of 2mm thick, using a scribing knife. The experimental set up is shown in Fig. (1).

Four samples, 100 x 100 x 2mm for each, were chosen to be cut by the YAG-50 Laser Scribing Machine, using different cutting speeds (5,10,15 and 20 mm/s) and pulse repetition rates(P.R.R.) of 8.67,9.6 and 10.5 kHz .

The experimental procedure was as follows:

- Holding each sample in the plat-form of the laser machine.
- Using the computer aided program, five cuts or lines were performed.
- Different cutting depths were obtained according to the different parameters used.
- The depth of cut from each black sample was measured and Heat Affected Zone for transparent ones.
- Different results were obtained for HAZ, cutting depth and quality.

Figure (1) the Experimental Setup

3. Results and Discussion

The obtained results are classified as follows:
Cutting Speed Effect on Transparent Sheets:

Actual cutting was not performed, but the effect of the laser was on the Heat Affected Zone of the transparent acrylic.
Graphical presentations are shown in figure (2)

Figure (2) Cutting Speed Effect on Opaque, black, sheets:

Cutting to a full depth, of two millimeters, of the acrylic sheets was successfully performed, using 5mm/s cutting speed at 10.5, 11.4 and 12.3 KHz. Different cutting depths were obtained when changing the P.R.R. and the cutting speed. The effect of the cutting speeds 5mm/s, 10mm/s, 15mm/s, and 20mm/s, on the black Perspex acrylic sheets were measured as the vertical depth of cut made by laser on those sheets. Results are shown graphically in figure (3).

**Figure (3) Cutting Speed Effect on Cutting Depth
Repetition Rate effect on Opaque, black, Sheets:**

The repetition rate is the number of pulses delivered by the modulated laser in one second. The effect of YAG-50 laser pulse repetition rate, which correspond to the operation current, on the depth of cut made by this laser in the Perspex sheets is shown in table (1).

Table (1): Rep. Rate Effect on Cutting Depth

Operation Current (Amperes)	Corresponding Rep. Rate(KHz)	Cutting depth (mm) at:			
		Cutting Speed 5mm/s	Cutting Speed 10mm/s	Cutting Speed 15mm/s	Cutting Speed 20mm/s
10	8.67	0.225	0.1	0.05	0.05
13	9.6	1	0.33125	0.15	0.125
16	10.5	2	1.0125	0.25	0.175
19	11.4	2 or more	1.0625	0.29375	0.1875
22	12.3	2 or more	1.16875	0.3625	0.25

Figure (4) P.R.R. Effect on Cutting Depth

The obtained results from laser cutting of the Perspex transparent sheets, using Q-switched laser, show clearly that it is difficult to cut these sheets completely, this is due to the fact that most of the power delivered by laser will be transmitted through them, while some will be absorbed causing the heat affected zone (HAZ), which is inversely proportional to the cutting speed.

On the other hand, cutting the black sheets using the same laser showed that the depth of cut is inversely proportional to the cutting speed and the cutting process is easy.

Five millimeters per seconds cutting speed shows complete cut at three pulse repetition rate values, namely 10.5, 11.4 and 12.3 KHz, which are related to the increase of the delivered pulse energy. Other P.R.R. values result in different depths of cut of inversely relationship to the cutting speed. This is attributed to the fact that low cutting speed provides more time for the absorption process for the laser energy, while higher speed caused less cutting depth due to the small time interval of the interaction between the laser and acrylic sheets which, then, reduced the penetration depth.

The results showed, also, a linear relation between laser repetition rate and cutting depth. Higher laser repetition rates resulted in an increase in the depth of cut and vice versa. This is attributed to the increase of the amount of energy delivered to the samples by increasing the pulse repetition rate.

In comparison between the quality of Q-switched Nd: YAG laser cutting and the manual cutting, it is clearly observed that the laser cut edges of the sheets are shiny compared to the dull edges of the manual cutting, this is due to the thermal effect of this infrared laser on the sheet, which perform cutting with simultaneous fire polishing, the process which can not be found in manual cutting.

The microscope photos show ,some how in some areas, similarity between the laser cutting using 5mm/s cutting speed ,and the manual cutting with respect to surface roughness ;However laser cutting is more rough in other areas due to precipitations of the molten material on the edges of the cut.

4-Conclusions:

From the previous results and practical work, one can conclude that:

- 1-It is possible to cut 2mm thick, or more, black Perspex sheets, completely or partially, using pulsed Nd: YAG laser.
- 2-The heat affected zone(HAZ) is inversely proportional to the cutting speed, provided that the operation current, consequently the energy and the spot size remain the same during the cutting operation.
- 3-The depth of cut is inversely proportional to the cutting speed, provided that the operation current, consequently the energy and the spot size remain the same during the cutting operation.
- 4-The depth of cut is directly proportional to the laser repetition rate, provided that the energy and the spot size remain the same during the cutting operation.

4. References

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