

Influence of focal length on depth of engraved PMMA surface

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Abstract. The paper focuses on laser cutting of polymer material PMMA. Specifically, the influence of optics on the engraved surface is investigated with use focal length lenses of 1.5"; 2.5"; 4". Commercial CO₂ laser ILS 3NM by Laser Tools & Technics Corp. Taiwan, was used for experimental machining.

1. Introduction

The selection of optimal technological conditions is dependent on the chosen material. Polymers are one of the youngest groups of construction materials. Chemical substances are those, which have very different properties, and their huge molecules contain mostly the atom of carbon, oxygen, nitrogen and hydrogen. As a final product, polymeric materials are solid, but during processing at high temperature and pressure, they are liquid to assume the future shape of the product. It is possible to modify the properties using various modification and additives. Generally, the plastics are light weighted; they have thermal and electrical insulation properties and no corrosion [1-2].

A polymer is a macromolecular substance formed by the chains of the macromolecules (Figure 1). These are formed by linking the building units by primary covalent bonds and contain a large number of the atoms. Low-molecular substances, so-called mers, which repeated in the chain, are the basic building part. The basic part of the chain forms a carbon atom, which is able to bind to each other to form long chains [1-2].

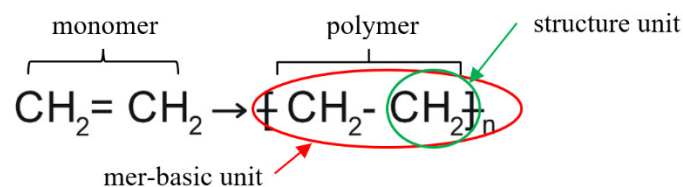


Figure 1. Polymer structure.

The plastics are polymers, which are the in at normal conditions mostly hard. With increasing temperature they become moldable and plastic (hence the name plastics). The plastics are divided into thermoplastics and thermosets. The thermoplastic is able to be repeatable heated and convert to the state of melt or to the viscous flow. By cooling below the melting temperature, which characterizes the semi-crystalline polymers, or below the flow point, which characterizes the crystalline polymers, the thermoplastics can be allow to solidify at temperatures that characterize the given type of

thermoplastic. Thanks to this ability, thermoplastics are recyclable because there is no structural change [2].

They consist of linear long chain macromolecules. These chains are connected by intermolecular interactions (van der Waals forces, hydrogen bonds). When the thermoplastic heats up, the intermolecular interactions decrease and the polymer softens. Thermoplastics are process able materials and can be easily cast or moulded [2].

Laser beam machining (LBM) is one of the most widely used thermal energy based non-contact type advance machining process, which can be, applied for almost whole range of materials. Laser beam, is focussed for melting and vaporizing the unwanted material from the parent material. It is suitable for geometrically complex profile cutting and making miniature holes. Among various type of lasers used for machining in industries, CO₂ laser are most established. In recent years, researchers have explored a number of ways to improve the LBM process performance by analysing the different factors that affect the quality characteristics. The experimental and theoretical studies show that process performance can be, improved considerably by proper selection of laser parameters, material parameters and operating parameters [3-9].

2. Sample preparation

Samples were made using device ILS 3NM, CO₂ laser, having a wavelength $\lambda = 10.6 \mu\text{m}$ and with a maximum power $P = 100 \text{ W}$, maximum feed rate $v_f = 1524 \text{ mm.s}^{-1}$. For the depth cut measurement, the PMMA samples with the thickness of 5 mm were created at constant power $P = 100 \text{ W}$ and variable cutting speed v_f , which changed from 10 – 100 % (Table 1, Figure 2) using lenses with the different focal distance $f = 1.5''$, $2.5''$ and $4''$.

Table 1. Feed rate.

Sample	1	2	3	4	5	6	7	8	9	10
v_f %	10	20	30	40	50	60	70	80	90	100
v_f mm.s ⁻¹	152.4	304.8	457.2	609.6	762	914.4	1066.8	1219.2	1371.6	1524

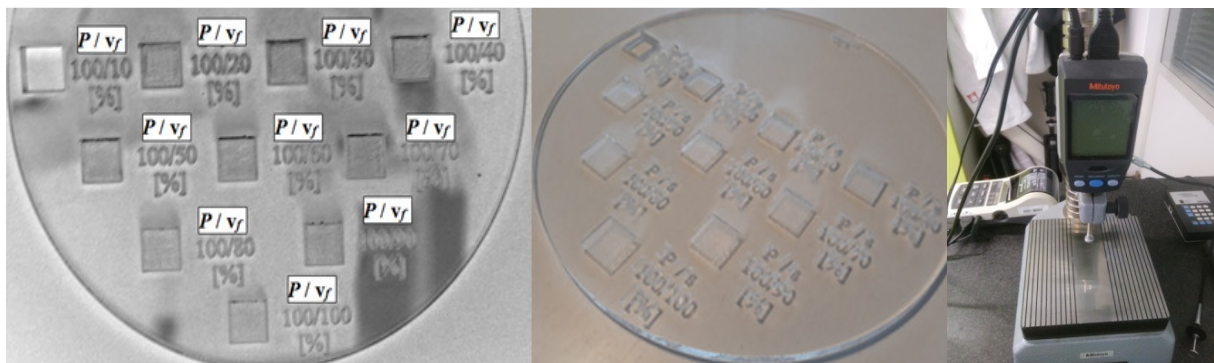


Figure 2. Samples for experiment and measurement device.

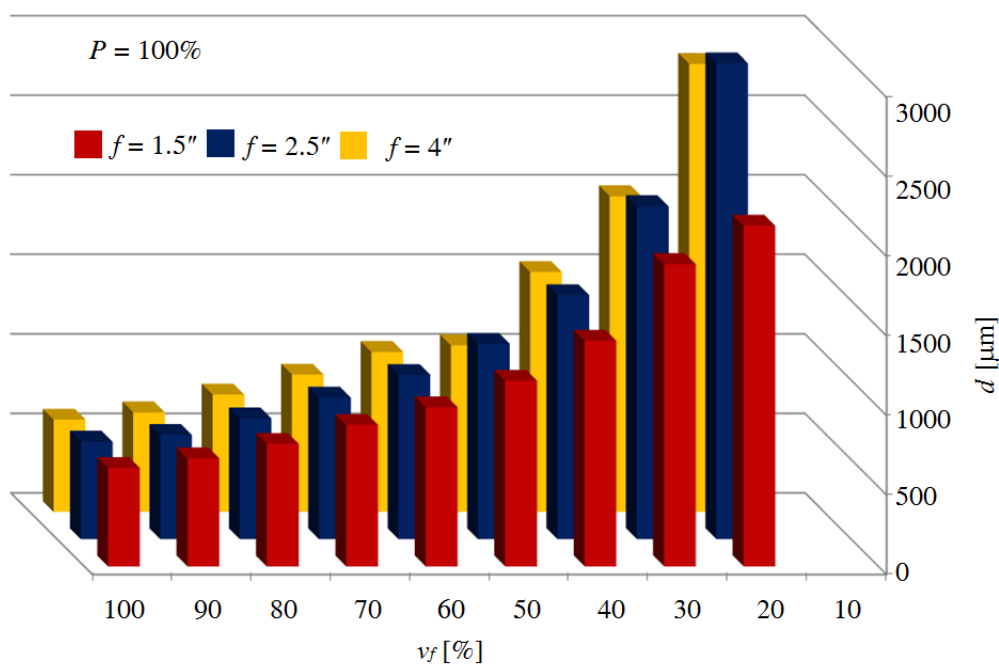
3. Depth measurement of cut

The digital gauge H0530 – Mitutoyo with the resolution 0.001 mm and the measurement range from 0 to 30 mm used for the depth cut measurement of the engraving.

In the Table 2, the measured values of depth d of the removed material by ablation are listed in the dependence on the processing conditions, power P and cutting speed for engraving v_f and various focal distance f . The measured values are compared in the followed Figure 3.

Table 2. Summary of results.

Sample	1	2	3	4	5	6	7	8	9	10
[%]	10	20	30	40	50	60	70	80	90	100
v_f [mm. s ⁻¹]	152.4	304.8	457.2	609.6	762	914.4	1066.8	1219.2	1371.6	1524
f ["]	d [μm]									
1.5	through	2817	1900	1490	1048	1000	889	769	679	619
2.5	through	2992	2094	1534	1228	1032	889	759	655	613
4	through	2142	1985	1509	1167	1006	863	738	626	580

**Figure 3.** Comparing the depth of cut for different focal lengths on feed rate.

4. Results

From measured results of the removed layer by laser ablation with the depth of d it is possible to see, that during static parameter of power P and variable feed rate v_f , the values changed with the change of focal distance f (Figure 4).

The cutting speed 10 % (15.24 mm.s⁻¹) caused the removal of whole thickness of the sample (5 mm) during the use of all three lenses.

Using the cutting speed from 20 % (304.8 mm.s⁻¹) caused the highest amount of the removed thickness during the use of the lens with the focal distance 2.5".

The lens with the focal distance 4" caused during the engraving from 20 to 60 % of feed rate the increase of the value d compared to the focal distance 1.5". In the range of speeds from 70 % (1066.8 mm.s⁻¹) to 100 % (1524 mm.s⁻¹), the removed material by ablation had the higher values d with the focal distance 1.5" in comparison to 4". At the speed of 1066.8 mm.s⁻¹ it was reached the same value of $d = 889 \mu\text{m}$ with 1.5" and 2.5" focal distance.

The greatest depth value $d = 2992 \mu\text{m}$ was reached using feed rate $v_f = 304.8 \text{ mm.s}^{-1}$ and the lens with the focal distance $f = 2.5''$. The smallest depth $d = 580 \mu\text{m}$ was reached using feed rate $v_f = 1524 \text{ mm. s}^{-1}$ and the lens with the focal distance $f = 4''$.

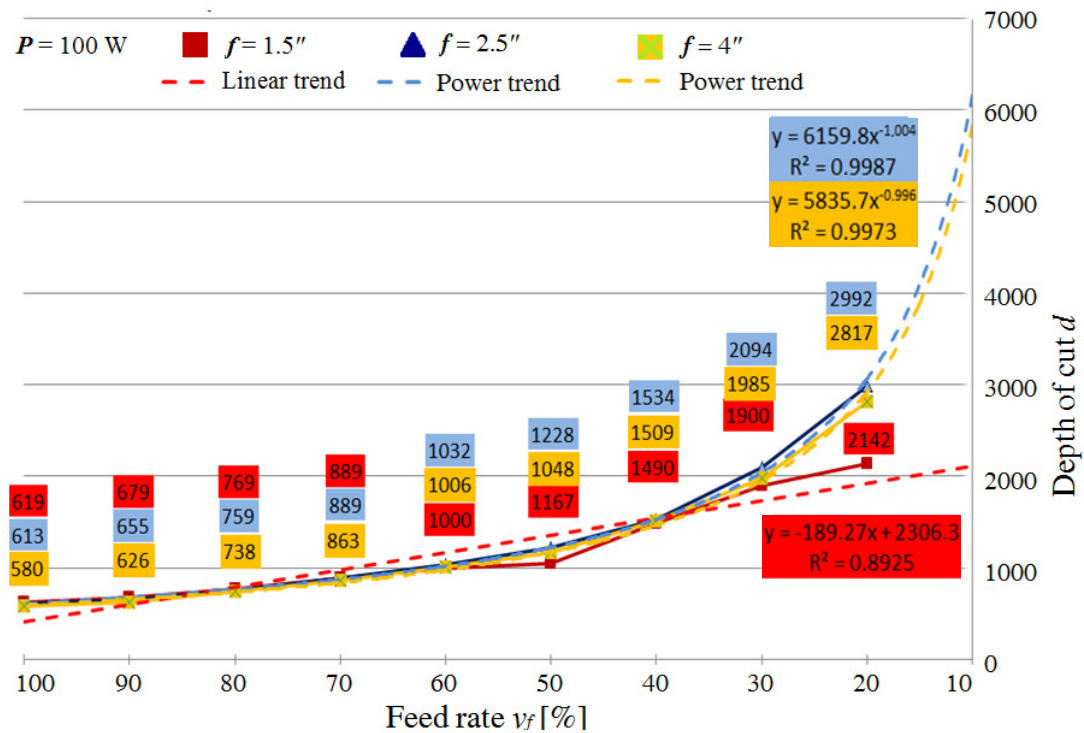
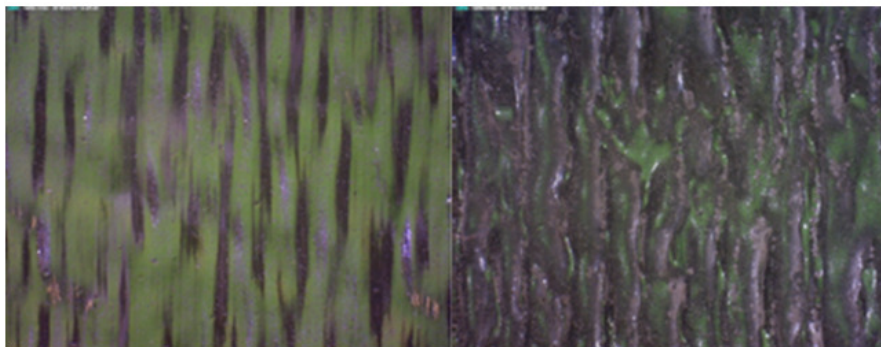


Figure 4. Dependency depth of cut from feet rate.

On the machined surface, at various setting of feed rates and the changing of focal distance, the changes of the sectionalisation surface occur. In Figure 5, the surface with the maximal depth $d = 2992 \mu\text{m}$ and minimal depth $d = 580 \mu\text{m}$ is displayed.

$f = 4''$; $v_f = 1524 \text{ mm}\cdot\text{s}^{-1}$; $P = 100 \text{ W}$



$f = 2.5''$; $v_f = 304.8 \text{ mm}\cdot\text{s}^{-1}$; $P = 100 \text{ W}$

Figure 5. Influence of process conditions on surface structure.

5. Conclusion

The aim of this study was to find out at which cutting condition it is possible to achieve the certain depth using various focal distances. With changed processing conditions, the depth after engraving and the appearance of the surface changed. It is necessary to take in consideration not only the depth in the dependence on the cutting conditions, power P and feed rate v_f , but also the influence of the focal distance f , which, as shown by, causes at PMMA the variable thickness of the removed material

in the dependence on the change of the feed rate. All those mentioned factors influence the proper choice of the processing conditions. Trends equations have been establish and in most cases have a power character.

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