MICROMACHINING OF POLY (METHYL METHACRYLATE) POLYMER USING KRF EXCIMER LASER

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ABSTRACT

In the present work micromachining of PMMA was carried out using KrF excimer laser. Excimer laser pulse with a wavelength of 248 nm was generated with a coherent COMPexPro 110 excimer laser system. A micro-hole of Ø150 μm was machined on PMMA substrate during the experimentation. The PMMA substrate was mounted on the translation stage. The PMMA substrates were ex-posed to different number of pulses (1, 2, 5, 10, 20, 50 and 100) at repetition rate of 2, 5 and 10 Hz respectively by keeping the pulse energy unchanged at 200 mJ. In the present experimentation, the effect of pulse repetition rate and number of pulses on ablation depth has been investigated. The experimental results for micromachining demonstrate ablation process as a photo-chemical mechanism. The results of the experimentation have revealed that, ablation depth is directly proportional to pulse number & pulse repetition rate has no significant effects on the ablation depth.

KEYWORDS

Micromachining, Excimer laser, PMMA, Ablation depth, Pulse repetition rate, Number of pulses

1. INTRODUCTION

All laser micromachining techniques use the process of laser ablation, where the interaction of the laser energy with the sample leads to material removal[1]. Polymethyl Methacrylate (PMMA) polymer exhibits very good optical properties. Typical PMMA grades allow 93% of light to pass through it, which is more than glass or other plastics. This outstanding clarity enables the use of PMMA in many different optical and related applications like in lenses and magnifying glasses[2]. Combined with its good degree of compatibility with human tissue, it can be used for replacement intraocular lenses or for contact lenses[3]. PMMA, due to its scratch resistance and favourable physical properties, finds a number of applications in protective coatings and as a prototype material for structural components in micro devices[4]. UV light transmission of PMMA is almost negligible for wavelength less than 300 nm[5]. Its absorption coefficient is 0.0063 μm at wavelength of 248 nm and thermal diffusivity is of the order of 10^{-3} cm^2 /sec[6].

Excimer lasers possess ultraviolet (UV) wavelength with comparatively short pulse duration to ensure high peak densities (fluences) and high pulse energies, which allow the radiation to be efficiently absorbed by the surfaces of most materials[7]. Excimer lasers remove materials from the substrates through the ablation mechanism, by either vaporization (photothermal) or decomposition (photochemical) or by a combination of these two[8]. The excimer laser has been one of the most capable and popular tools for machining microstructures with feature sizes on the order of 1–100 mm for all kinds of materials, including polymers, metals, and ceramics [9].

Excimer laser micromachining has gained an important role in research and development efforts due to rapid demand in processing the new generations of semi-conductors, polymers and ceramics[10]. UV laser beam with short wavelength and high photon energy directly break chemical bonds and reduces the laser material interaction time, thus a smaller heat affected zone (HAZ) is formed[11]. Ablation mode, thermal or non-thermal, for polymers may result from many coupled phenomenon, such as energy absorption, fragmentation, ejection of debris, shock waves, vaporization, plasma shielding and heat affected zone (HAZ). The capacity of a laser for micromachining a surface depends upon its wavelength, energy density, and shape of the laser beam [12]. However, investigations about micromachining of polymers like PMMA are very limited [4]. With lower laser fluence thresholds for materials, such as PET, PU, PMMA and polyimide polymers, the photochemical mechanism dominates the ablation process. For materials with higher laser fluence thresholds such as ceramics, metals, the photothermal mechanism dominates the ablation process [13].

2. EXPERIMENTATION

2.1 EXPERIMENTAL SETUP

Fig. 1 shows schematic representation of an excimer laser micromachining system. This setup has a KrF laser having wavelength 248 nm, pulse duration 20 ns, pulse repetition frequency 50 Hz and maximum pulse energy up to 400 mJ. Beam delivery system consists of attenuator, homogenizer, field lens, mask and doublet.

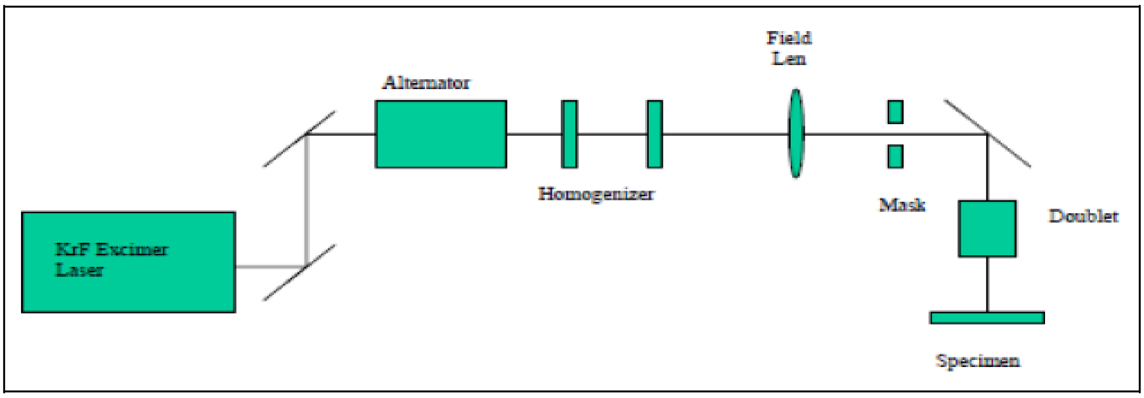
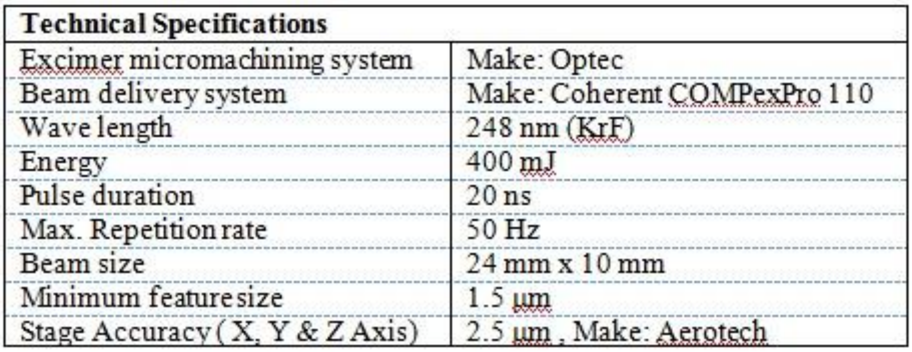


Figure 1. Schematic of experimental setup for excimer laser micromachining of PMMA



Technical Specifications	
Excimer micromachining system	Make: Optec
Beam delivery system	Make: Coherent COMPexPro 110
Wave length	248 nm (KrF)
Energy	400 mJ
Pulse duration	20 ns
Max. Repetition rate	50 Hz
Beam size	24 mm x 10 mm
Minimum feature size	1.5 µm
Stage Accuracy (X, Y & Z Axis)	2.5 µm , Make: Aerotech

Table 1. Excimer laser system technical specifications.

Figure 2. Excimer Laser Micromachining System at CMTI, Bangalore

2.2 EXPERIMENTAL PROCEDURE

The experiments were carried out on a sample (50 mm × 20 mm, 2 mm thickness) of Polymethyl Methacrylate (PMMA) polymer. Before and after laser ablation, the sample is cleaned ultrasonically and with distilled water. The laser beam from a KrF excimer laser (Model: Coherent COMPex*Pro* 110) with wavelength 248 nm is focused on the sample by optical arrangement and workpiece movement is achieved by XYZ translational stage (Aerotech Co.,). Micromachining is carried out at different operating conditions, i.e. number of pulses (1, 2, 5, 10, 20, 50 and 100) and pulse repetition rates (2, 5 and 10 Hz) by keeping pulse energy constant at 200 mJ. The objective was to find out the variation of ablation depth with number of pulses and pulse repetition rate. The surface micrographs as shown in Fig.5 and depth of ablation are taken by confocal microscope at 20 x (Make: OLYMPUS, Model: OLS4000). Optical micrographs as shown in Fig. 3 are taken by stereo microscope (Make: Carl Zeiss, Model: Discovery V20). The measured values of ablation depth are tabulated in Table 2.

Table 2. Depth of ablation in µm

Number of pulses (N)	2 Hz	5 Hz	10 Hz
1	0.0	0.0	0.0
2	2.06	1.44	2.15
5	13.85	11.20	11.70
10	29.56	28.45	26.88
20	58.75	59.95	59.32
50	159.84	161.52	163.35
100	243.43	337.10	329.08

Table 2 shows the depth of ablation measured in PMMA after 1, 2, 5, 10, 20, 50 and 100 laser pulses with repetition rates of 2, 5 and 10 Hz

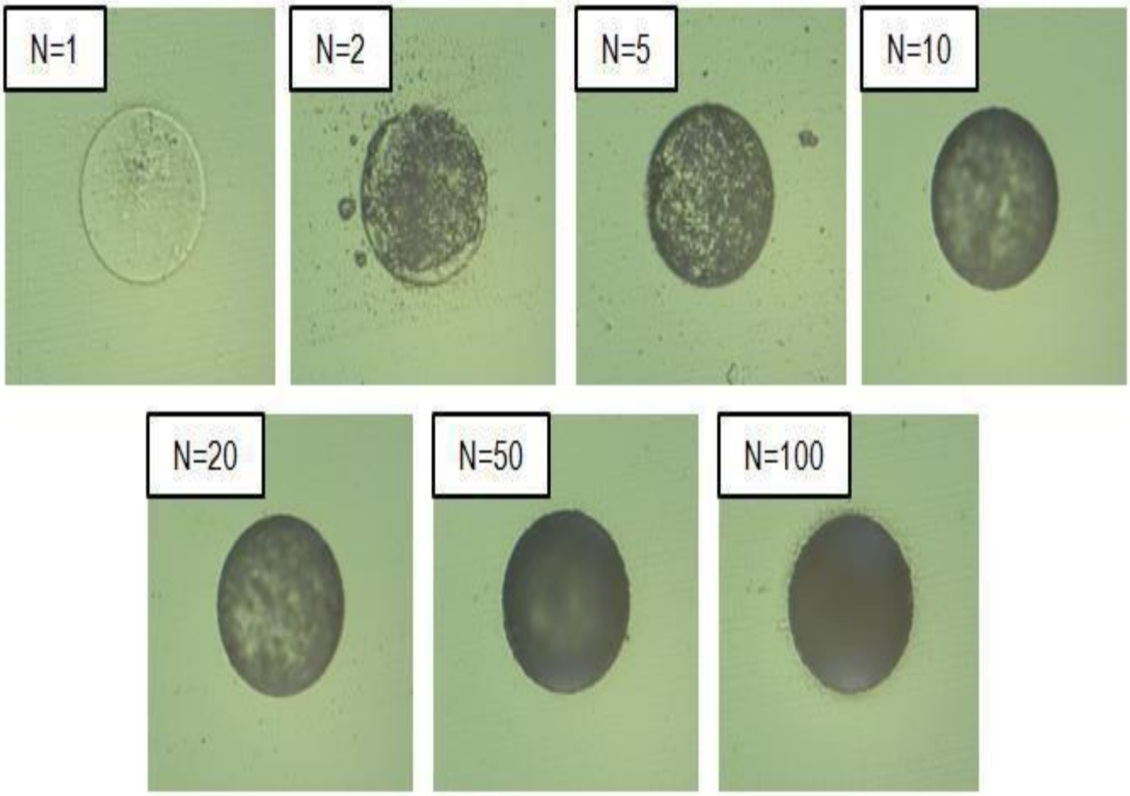


Figure 3. Optical micrographs of the top views of PMMA samples ablated at repetition rate of 2 Hz at variable number of pulses (1-100 Pulses)

3. RESULTS AND DISCUSSIONS

A preliminary test of ablation for PMMA samples is conducted at constant pulse energy of 200 mJ and repetition rate of 2 Hz with variable number of pulses . Ablation depths for different repetition rates are measured using confocal microscope and are tabulated in table 2. In Fig. 3 and Fig. 5, significant ablation depth is observed after 5 number of pulses of 13.85 μm with an average increase (etch rate) of 2.7 μm per pulse . Between 5 and 10 number of pulses, an average increase of 3.14 μm per pulse is observed. During 10–20 number of pulses, the ablation depth increased at an average of 2.91 μm per pulse. During 20–50 number of pulses, the ablation depth increased at an average of 3.36 μm per pulse and during 50-100 number of pulses 1.67 μm per pulse. Linear in-crease of ablation depth is observed over a range of repetition rates. Up to 50 number of pulses , the ablation depth increases linearly for all the three repetition rates (2, 5 and 10 Hz) which implies uniform material removal. Minor increase in diameter of the hole geometry is observed as the number of pulses are increased.

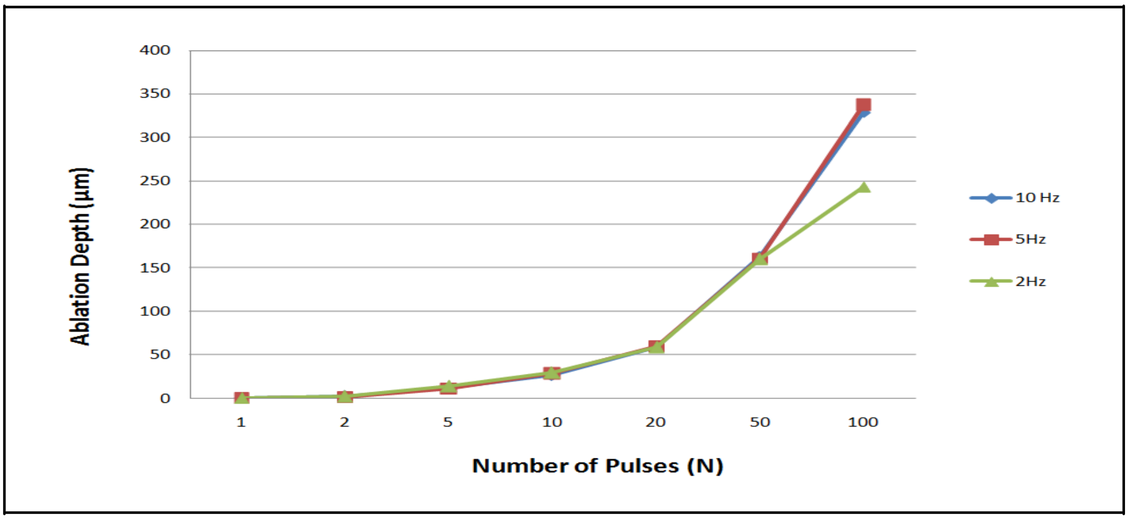


Figure 4. Variation of ablation depth with increase in number of pulses at pulse energy of 200 mJ

Fig.4 shows the variation in ablation depth with the increase in number of pulses (1–100 pulses at 2–10 Hz) at pulse energy of 200 mJ. After 50 number of pulses the ablation depth for 5 and 10 Hz increases rapidly but, for 2 Hz repetition rate, the depth of ablation decreases slightly as compared to 5 and 10 Hz. One of the reasons for lower ablation can be lower repetition rate leaving enough time for the exposed area to cool down before the next pulse arrives at the surface.

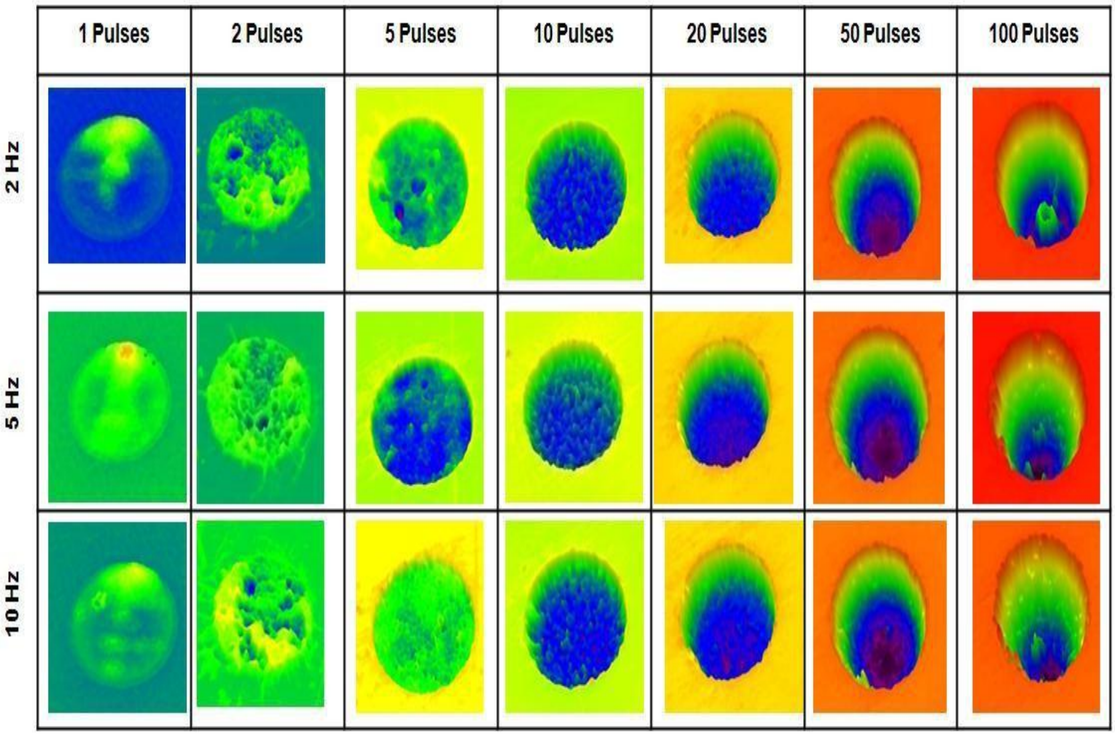


Figure 5. Surface mapping micrographs show ablation characteristics for machining PMMA at 200 mJ at variable repetition rates (2- 10 Hz) and number of pulses (1-100)

The images (Fig.5) show that depth of ablation increase with the number of pulses for all the repetition rates (2, 5 & 10 Hz) .The surface mapping micrographs at 1, 2 and 5 laser pulses for all the repetition rates (2 , 5 & 10 Hz) show irregular crater formation. For 10 and 20 consecutive laser pulses the resulting craters presented more uniform geometry. Irregular and porous ablated surface was also observed in PMMA [14]. According to the authors, these effects were related to thermal effects during the plasma formation and affected by the laser wavelength, laser pulse repetition rate and the number of laser pulses.

4. CONCLUSIONS

In the present work, micromachining of PMMA using KrF excimer laser has been investigated and arrived at the following conclusions

- The depth of ablation increases with number of pulses
- Pulse repetition rate has no significant effects on the ablation depth, but it has a noticeable impact on the morphology of the ablated surface
- The HAZ during an ablation process of PMMA specimen tends to in-crease as the repetition rate is increased

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