International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

Analysis of Different Parameters of Crater Evolution at Acrylonitrile Butadiene Styrene (ABS) Polymer Surface using Nd:YAG Laser

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***Abstract*—The aim of this paper is to investigate the effect of Nd: YAG laser shots on geometry of crater by comparing different parameters. Acrylonitrile butadiene styrene (ABS) is irradiated with Nd:YAG laser (1.1 MW, 1064nm, 10ns and 10mJ) in ambient air for 25, 50, 75, 100, 125 and 150 laser shots respectively. Surface morphology is investigated by optical microscope (STM6-LM, OLYMPUS Corporation) with 0.1µm readout. Comparison of parameters exhibits that higher number of laser shots have greater area of heat affected zone (HAZ) and crater depth. Correlations have been developed for laser shots, area of HAZ, crater depth, crater area, crater volume and ablated mass. By increasing laser shots; area of HAZ crater depth, area and volume indicate different trends.**

Keywords — Surface morphology, Crater evolution, Heat affected zone

I. Introduction

A couple of proposed mechanisms are available to discuss the formation of microstructures on various surfaces. Nd:YAG laser create a very high temperature on polymer surfaces because of high linear absorption coefficient at 1064 nm. During temperature rise of polymer surface, carbon atoms from polymer chains are released due to polymer disintegration and they can move freely on the surface to establish carbon clusters with nanometer size. The agglomerates of carbon particles act as nucleation sites for different type of microstructures. Based on this understanding Nd:YAG laser induce a large molten layer underneath the ablation layer. At low solidification rate molten layer can induce the motion of carbon particles inside the layer. For the first ablation shot the carbon particles of micrometer size are free to move randomly on the ablated surface and therefore to agglomerate surface clusters. The formation of crater then follows to aggregate small microstructures in the molten layer upon repeated laser shots. It indicates that the crater density increases significantly at higher doses. This crater formation is strongly dependent on laser properties such as pulse energy, laser wavelength and energy dose of used laser [1]. Crater formation has also been discussed on different materials and by different parameters with their applications in various fields of life [2-19].

A vigorous model exists to explain the formation of various microstructure formations on the silicon surface in detail [20] which may be employed for polymer too. When Nd:YAG laser induced molten layer of irradiated target as an incompressible fluid undergoes a disturbance on its surface, some mechanical surface wave are created propagating on the fluid surface. This model may be applied to describe crater formation on ABS polymer. The dynamics is based on the successive events leading to the microstructures formation. The Nd:YAG laser irradiation covers a circular region where the molten layer appears. The layer thickness depends on the fluence, wavelength and pulse duration as well as material absorbance coefficient and corresponding heat transfer properties. Moreover, the incident laser beam on the surface generates a sharp mechanical displacement which causes the surface mechanical wave. The waves propagate to the surface boundaries travelling back and forth to produce standing waves subsequently. Afterwards, the molten layer is solidified in a definite time to form an initial resonance pattern. This process continues with the subsequent laser shot to re-melt previous one and increases the height of pattern in resonance condition after resolidification, enhancing the standing waves amplitude. The multiple pulses reshape the pattern. The crater formation on ABS polymer is fluence as well as material properties dependent process. The shot by shot evolution of crater is predicted by the present model steadily [21-22].

In our work, crater depth, area, volume and area of heat affected zone have been discussed with increasing number of laser shots.

II. Experimentation

ABS ($1\times1\times0.3$ cm^3) is exposed to Nd:YAG laser (1.1 MW, 1064nm, 10ns and 10mJ) which has Gaussian intensity profile, in ambient air using 25, 50, 75, 100, 125 and 150 laser shots respectively. Laser beam is tightly focused on the targets with IR transmission lens of focal length 8 cm. Laser beam makes an angle 0° with the normal to the target surface. Laser fluence used is 3.184 J/cm^2 with a laser Spot size of 100 µm on the surface to be examined. Optical microscope (STM6-LM, OLYMPUS Corporation) with 0.1µm readout is employed to check surface morphology.

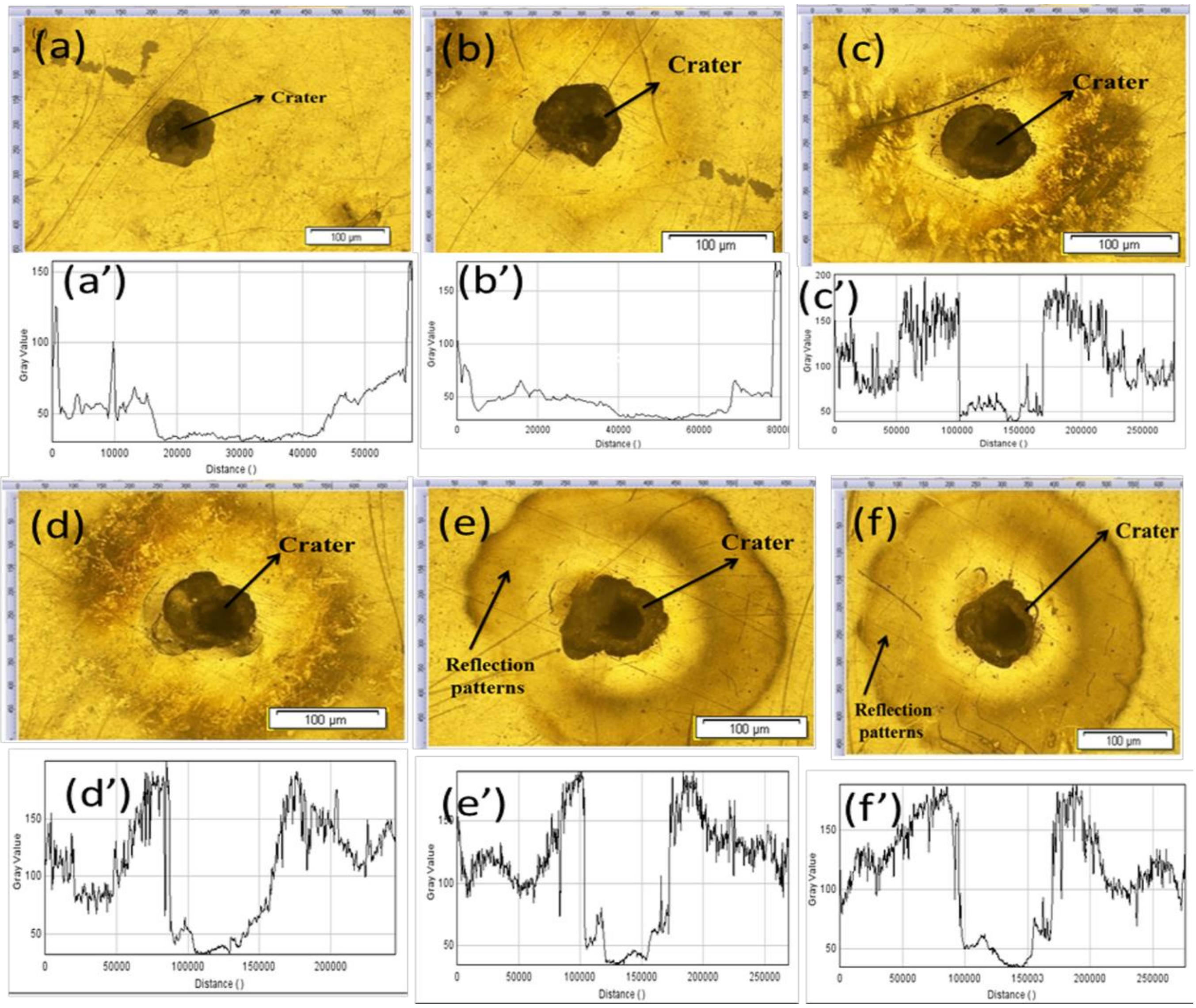

Fig. 1: Optical micrographs and intensity profiles of ABS polymer at 25 (*a, a'*), 50 (*b, b'*), 75 (*c, c'*), 100 (*d, d'*), 125 (*e, e'*) and 150 (*f, f'*) laser shots

III. Results and Discussion

Area of HAZ and crater area are found to be increase by increasing number of laser shots. Optical micrographs of irradiated ABS polymer at 25, 50, 75, 100, 125 and 150 laser shots are shown in figure 1. Intensity profile is also shown with respective laser shots images. Optical micrographs show that because of lowest melting point polymer ablated and crater formation takes place at very less number of laser shots. Crater depth is also calculated by optical microscope. Micrographs are also showing that during laser irradiation because of non-uniform heat conduction shape of crater is not symmetric.

By increasing number of laser shots from 25 to 50 there is an increase in crater depth as well as in heat affected zone as shown in figure 1 (*a*, *b*). Intensity profile is also showing that there is an increase in surface roughness at higher number of laser shots. Crater area, crater volume and ablated mass are also calculated. By increasing the laser shots there is an increasing trend in area, volume and ablated mass.

Optical micrographs in figure 1 (*c, d, e, f*) are showing at 75, 100, 125 and 150 laser shots with intensity profiles (*c', d', e', f'*). There is clearly an increase in surface roughness. Intensity profiles exhibit an increase in surface roughness and increase in crater depth with increasing laser shots. Crater depth, area, volume and ablated mass are increasing by increasing laser shots. All values are given in table 1. Prominent feature at these laser shots is the formation of reflection pattern around the crater because of heat accumulation. This pattern is formed around the crater and increases by increasing the laser shots. At 75 laser shots it is rough in spreading of heat but after these shots it is smoother and symmetric in shape.

Graphical representation of data in figure 2 exhibits that area of heat affected zone, crater area, crater depth and crater volume increases by different trend by increasing number of

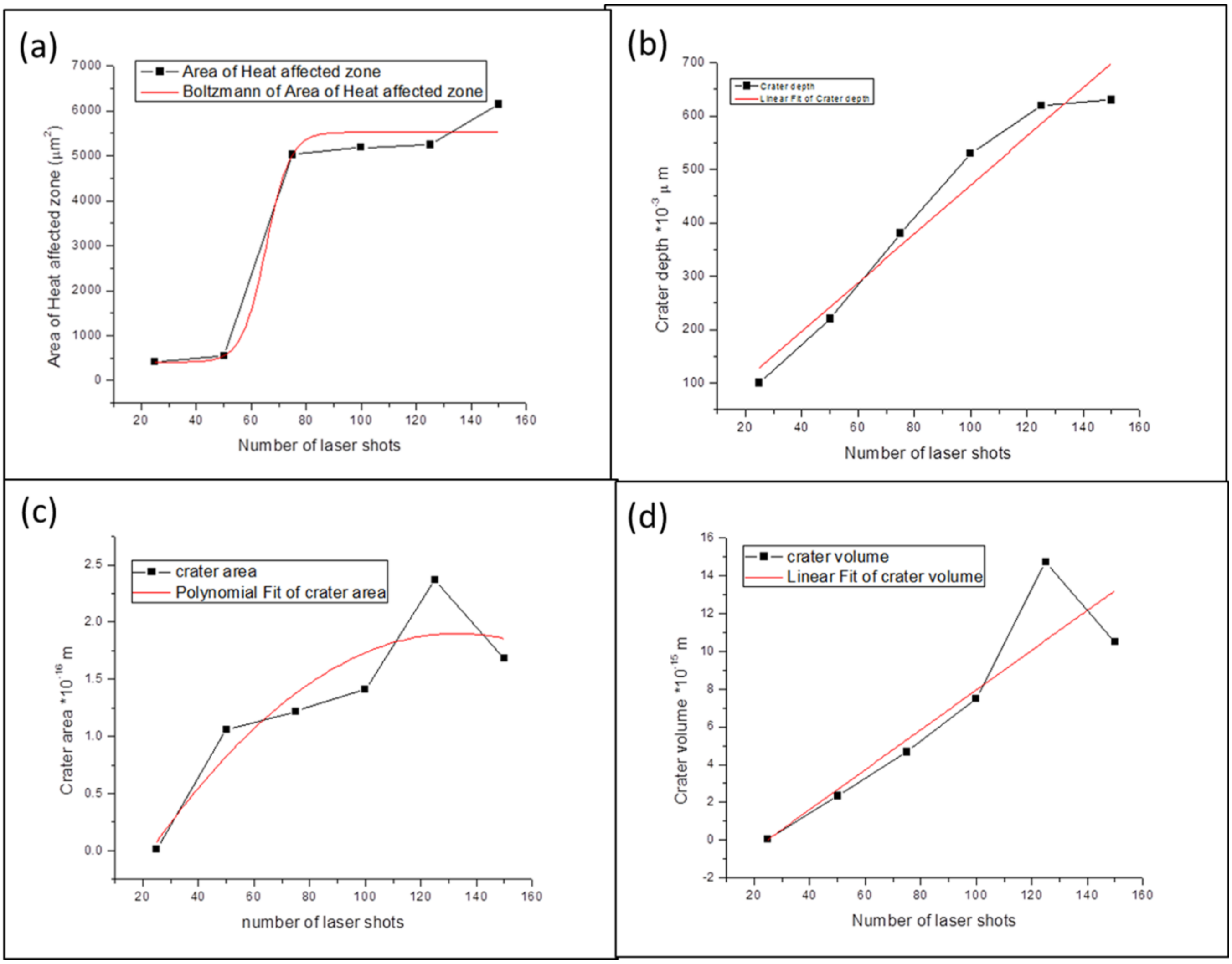

Fig. 2: Influence of number of laser shots on (*a*) Area of HAZ, (*b*) crater depth, (*c*) Crater area, (*d*) Crater volume

TABLE 1

Increasing number of laser shots with crater depth, area, volume, ablated mass and heat affected zone.

Laser Shots	Depth ($\times 10^{-3}$) μ m	Area (10^{-16} m^2)	Volume (10^{-15} m^3)	Ablated Mass (10^{-12} Kg)	Area of HAZ (μm^2)
25	100	0.0139	0.039	0.0150	415.265
50	220	1.06	2.34	2.53	551.2663
75	380	1.22	4.66	5.03	5024
100	530	1.41	7.50	8.10	5182.227
125	620	2.37	14.7	10.59	5246.204
150	630	1.68	10.5	11.4	6148.316

laser shots. Area of heat affected zone increases by Boltzmann trend, crater depth linearly, crater area by polynomial and crater volume by linear trend.

IV. CONCLUSIONS

ABS polymer is irradiated by Nd: YAG at 25, 50, 75, 100, 125 and 150 laser shots in air. It is noted that because of lowest melting point this polymer melts at very less number of shots and crater formation takes place. Intensity profiles show that surface becomes very rough and crater is deeper at higher number of laser shots. By increasing number of laser shots area of HAZ increases by Boltzmann trend, crater depth linearly, crater area by polynomial and crater volume by linear trend.

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