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INFLUENCE OF RESOLUTION ON SURFACE ROUGHNESS DURING CO_2 LASER BEAM MACHINING

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ABSTRACT

CO_2 laser being a localized non-contact type machining process depends on the thermal and mechanical properties of a material to a great extent. The present work deals with the study of the variation of process parameters during circular pocket machining on polymethylmethacrylate (PMMA) by CO_2 laser (0-100W). The parameters selected are beam power, scanning speed and resolution. Experimental results are obtained at 10 mm thick plate by varying process parameters. An attempt is made to analyse the variation of surface roughness as a function of process parameters such as power, speed and resolution (dpi).

KEYWORDS: CO_2 Laser, Power, Speed, Resolution, Surface Roughness

1. INTRODUCTION

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Laser beam machining is a non-traditional thermal process based on the conversion of electrical energy into light energy and then thermal energy [16]. Lasersare widely used in manufacturing industry such as cutting, drilling, welding, cladding, soldering (brazing), hardening, ablating, surface treatment, marking, engraving, micromachining, pulsed laser deposition, lithography, alignment etc.In each and every application, the major requirement is the excellent quality characteristics in terms of topography and surface roughness. Surface roughness or waviness is the random and repetitive deviation from the normal surface. The various parameters used for the evaluation of surface roughness are shown in Fig. 1. Lamikiz et al [1] studied a method for the surface finish for the parts made using SLS method where 80.1% surface reduction was achieved. Metallurgical analyses show that the heat affected zones do not present cracks or porosity. It was concluded that laser affected areas present a more homogeneous composition than the initial ones.Pfefferkorn et al. [3] studied a two-pass process where the first pass thermocapillary flow is made use to reduce the surface roughness whereas in the second pass the unconsumed process features are discarded.

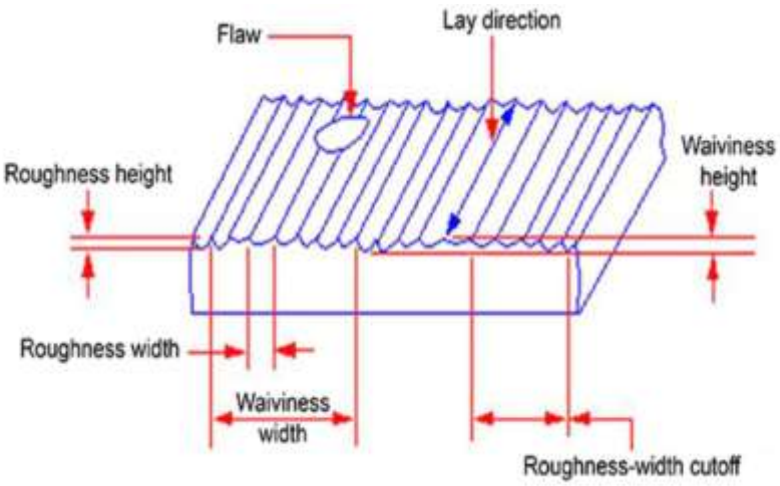

Figure 1 Term used Roughness measurement [16]

Bhaduri et al [7] studied the experimental analysis of the oxidation on metal surface using X-ray photoelectron spectroscopy and glow discharge optical emission spectroscopy. A surface reduction rate of 94% is obtained using laser polishing. Fengzhou FANG [9] shows that the diffraction limit of the laser beam is one of the other major challenges indulged with laser polishing process. When the diffraction limit is less, the resolution of the beam hitting on the metal surface will be less. Thus, in order to polish metal surface more beams would be needed where in turn results in high power consumption rate. Ismail Bilicana [11] studied the PMMA ablation consisting of two steps of which the second one occurs at higher temperature. Since the laser beam cannot ablate the whole material at the mentioned speed and power settings, there leave some material at liquid state after laser passes which resolidify later. Hence the remaining surface becomes planer then before ablation. Benoit Rosa [12] adopted afive-pass strategy with 100W power and 3000 mm/min feed rate. As a result, the surface was smoothed after laser polishing process and no geometrical deviation was highlighted. The decrease of energy density enables to eliminate the geometrical deviation but increases final surface roughness. Shashi Prakash, SubrataKumar [20] developed and validated an energy balance based analytical model with experimental results for predicting microchannels profiles on PMMA substrate in multi-pass processing. Multi-Pass processing was found to be time and cost-effective method for producing smooth microchannels on PMMA. Cong Zhou et al. [23] shows that the surface quality obtained by picoseconds laser cleaning is much better than nanosecond laser cleaning. In addition, the welding experiment shows that the laser cleaning pre-treatment can effectively improve the welding quality. Andre Temler et al [28] observed that a laser-based process chain is a possible solution to increase precision and reduce production time in optics manufacturing of components with complex shaped surfaces. Tianhao Wu et al [38] observed that the multi-pass translational method not only produces a clean bottom like the static multi-pass method but can modify the cross-sectional topography to produce a clean trapezoidal micro-channel. Chao Tan et al [39] concluded that material's removal depth was proportional to the track pitch and spot moving speed. The periodic ripple structure on the surface processed by 10μs pulsed laser were formed by the superposition of materials' residual height during laser scanning.

Looking to the intense literature carried out in the direction of assessment of surface roughness during laser beam machining, a very few works has been observed for the influence of resolution (dpi) on the surface quality along-with power and speed as process parameters. Hence, the present work deals with an attempt to study the influence of process parameters such as power, speed and resolution on the surface roughness on PMMA. Also, a statistical model is developed to establish the relation between input parameters and surface roughness which will serve as a base for carrying out roughness estimation with the given parameters.

2. EXPERIMENTATION AND MEASUREMENTS

Polymethylmethacrylate (PMMA) or acrylic is used as a work piece material. Acrylic is a transparent thermoplastic material with outstanding strength, stiffness, optical clarity, melting and boiling properties. This material has good capacity of to absorb CO_2 laser radiation incident on it.Cylindrical cavities of 10 mm diameter were machined on the material with the help of 100 W CO_2 laser (Model: SIL) as shown in Fig. 2.

Figure2 Experimental setup

Honeycomb table shown in Fig. 2 is an ideal option designed for straightness and flatness for cutting or engraving thin and soft materials as it offers a very flat working area. It also redirects exhaust air flow below and above the material for better smoke removal and dissipates the heat. Auto Focus gauge adjusts the laser engraver to the precise focal point on the engraving area automatically. The Auto Focus is the most effective lens focusing tool that prevents human error when exact measurement of distance from the surface of the working material is needed. The process parameters selected for machining cylindrical blind cavities on PMMA were laser power, scanning speed and resolution as shown in Table 1.Using the concept of full factorial methodology, experiments were carried out on PMMA and the machined specimen appears as shown in Fig. 3.

Table 1 Range of parameters

Power in W	25	50	75
Speed in mm/s	100	200	300
Resolution in dpi	100	200	300

Figure 3 Machined specimen

The measurement of surface roughness was carried out on the machined cavities using stylus-tip type surface roughness tester. The working schematic as well as measurement process is shown in Fig. 4 and Fig. 5 respectively. With contact type roughness setup, a stylus tip makes direct contact with the surface of the cavities. The detector tip is equipped with a cone-shaped stylus tip, which traces the surface and electrically detects the vertical motion of the stylus. As the stylus tracks the surface peaks and valleys, its vertical motion is converted to a time varying electrical signal that represents surface profile.

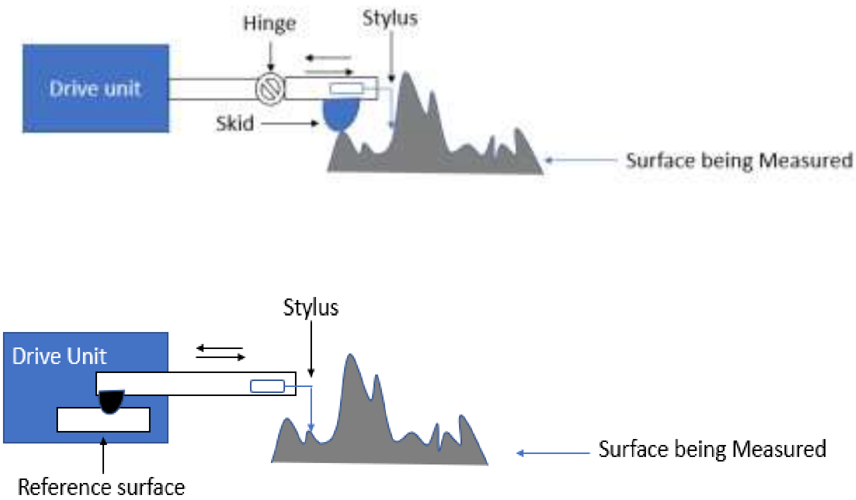

Figure 4 Schematic of surface roughness measurement


Figure 5 Surface roughness measurement process

3. RESULTS AND DISCUSSIONS

Since the laser is proportionally pulsed, the power selected in Table 1 represents how long the laser remains ON for each laser pulse fired. Basically, the power setting is directly related to how deep the engraving will be. Speed setting controls how fast the motion system moves when cutting or engraving straight lines as a percentage of the maximum speed per second of the system. The resolution as a process parameter indicates the number of dots per inch (dpi).Applying full factorial methodology on the design matrix as shown in Table 1, the number of runs required to carry out on laser machine turns out to be 27. For the machined specimen shown in Fig. 3, the measurement of surface roughness is carried out by stylus type roughness tester shown in Fig. 5. The observations collected from the measurement process are shown in Table 2.

Table 2 Roughness measurements data

Sr. No.	Power (W)	Speed (mm/s)	Resolution (dpi)	Roughness (micron)
1	25	100	100	12.3
2	25	100	200	10.9
3	25	100	300	8.5
4	25	200	100	11.6
5	25	200	200	10.5
6	25	200	300	9.7
7	25	300	100	29.5
8	25	300	200	21.7
9	25	300	300	14.1
10	50	100	100	14.8
11	50	100	200	12.1
12	50	100	300	10.7
13	50	200	100	32.4
14	50	200	200	12.1
15	50	200	300	8.3
16	50	300	100	16.4
17	50	300	200	15.5
18	50	300	300	14.4
19	75	100	100	17.8
20	75	100	200	14.9
21	75	100	300	12.5
22	75	200	100	15.1
23	75	200	200	9.9
24	75	200	300	6.6
25	75	300	100	31.1
26	75	300	200	15.4
27	75	300	300	13.6

3.1 Effect of Power on Surface Roughness:

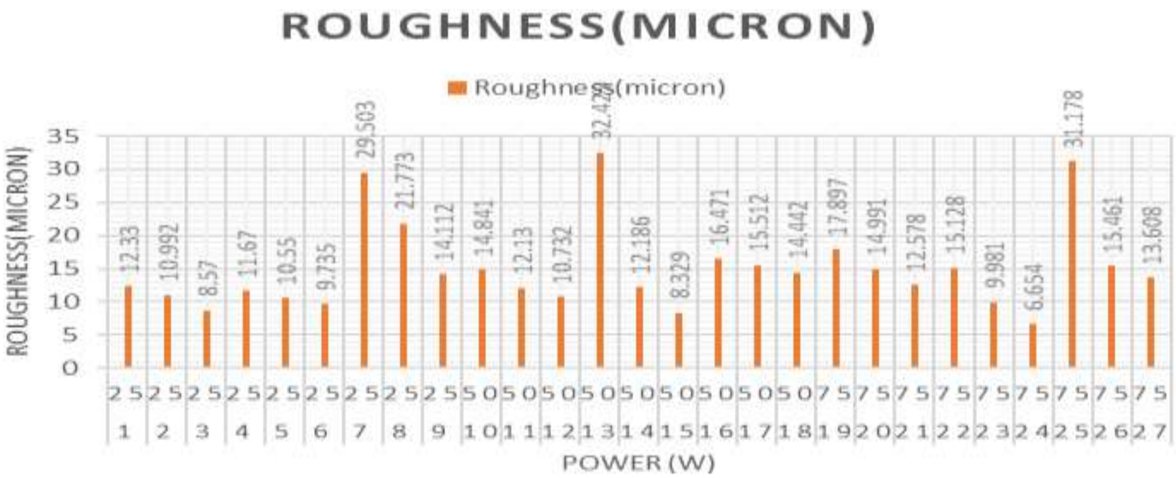

Figure 6 Variation of surface roughness with power

Roughness mainly depends upon the power level. Here Experiment was carried out with three power levels 25W, 50W, and 75W. As per Table 2, roughness measured at power level 25W was in the range of 8.57 to 29.503microns. which is the highest amount of roughness measured in the experiment. With power level 50W, the roughness was in the range of 8.329 to 32.429 microns. It had given lower surface roughness than 25W. With power level 75W, Surface roughness was in the range of 6.654 to 31.178microns. This power level showed the least amount of surface roughness. Although roughness depends upon a combination of all input parameters, it is observed that with a higher power level, material can achieve minimum surface roughness.

3.2 Effect of Speed on Surface Roughness:

Speed controls how fast the laser will pass from one point to another. So, laser will have more time machining with lower speeds. Therefore, it gives better surface roughness. In experiment we achieved similar kind of results. For experiment, speeds taken were 100 mm/s, 200 mm/s and 300 mm/s. with 100 mm/s roughness measured to be in range 8.57 to 17.897 microns. Surprisingly for 200 mm/s, roughness range was between 6.654 to 15.128.for 300 mm/s, Surface roughness observed to be in range of 13.608 to 31.178 microns. Roughness observed to be increasing with increase in speed. Least amount of speed observed with 200 mm/s with 75W power and 300 dpi.

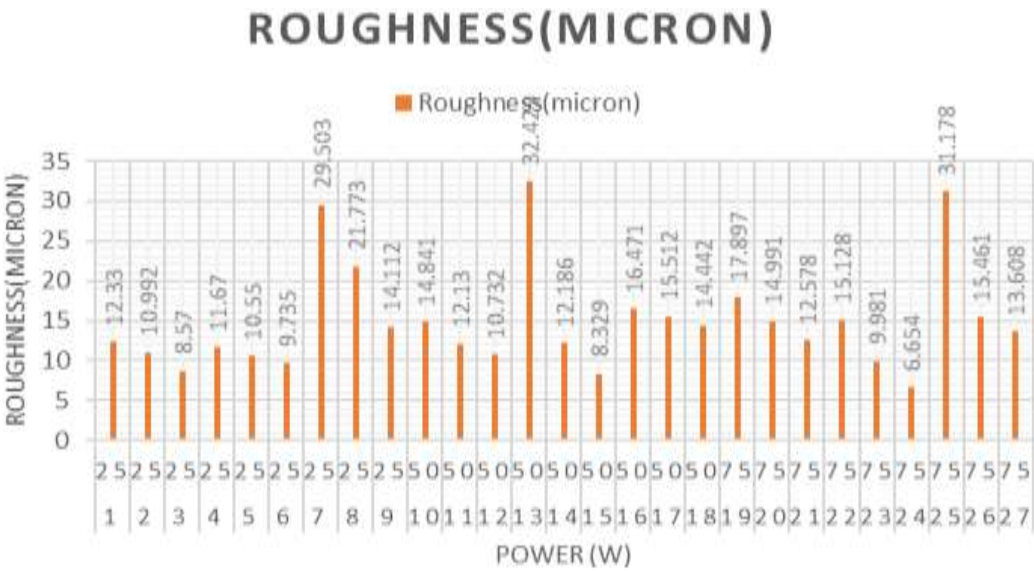

Figure7 Variation of surface roughness with speed

3.3 Effect of Resolution on Surface Roughness:

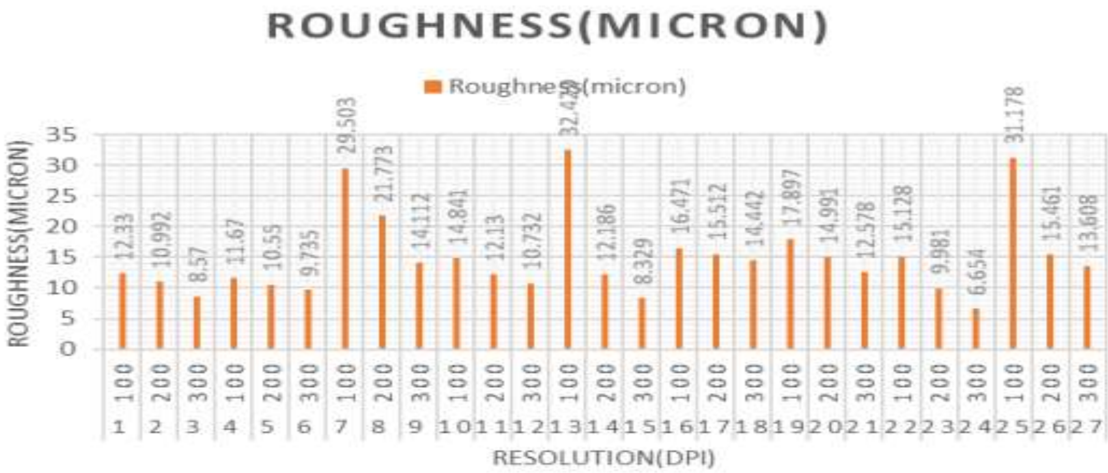

Figure8 Variation of surface roughness with resolution

Resolution is dots per inch, which will determine the amount of laser dots in a unit area. With the increase in resolution(dpi) surface roughness value tends to decrease. For this experiment resolution was set by 100, 200, and 300dpi. For 100dpi roughness range was observed between 11.67 to 32.429 microns. Roughness values were highest with the 100dpi. For 200dpi, the roughness range was observed to be between 10.992 to 21.773 microns. for 300dpi, the roughness was in the least amount and in the range of 6.654 to 14.442 microns. As the theory suggest, result achieved were same.

3.4 Analysis of Variance (ANOVA)

Analysis of variance is utilised to determine the LBM parameter levels in order to minimize the surface roughness of the cavity machined.Fig. 9 shows the response of optimum combination of parameters i.e. Power (W), Speed (mm/s) and resolution (dpi) for LBM which provides maximum value of suface roughness in ANOVA.

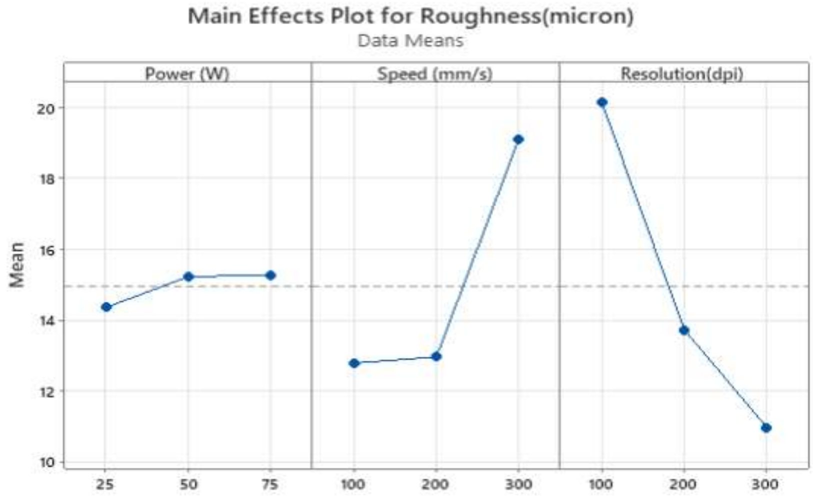

Figure 9 Mean Effective plots for surface roughness

Residual plots are used to evaluate the data problem is non-random variation, higher-order relationship, non-normality, non-constant variance, and outliers. It is shown in Fig.10 that residual plots for surface roughness are in an approximately straight line in a normal probability plot. These are approximately symmetric in nature of the histogram shown and the residual is normally distributed. The histogram identifies that the mean and median are closed, the data are fairly balanced or symmetric, too on each side. The residual process is a constant variance and is to be scattered randomly around the zero variance is plotted to mirror effect. The residual exhibit has no clear pattern and there is no error to the time or data collection order. If the P-values are less than 0.005 then particular parameter is considered to be highly statistically significant. Here resolution is considered to be most significant parameter.

3.5 Regression Analysis

Regression model are used for the response parameter prediction and is to be derived to using regression analysis. It is a mathematical measure to find an average relationship between two or more variables in their original unit of the data. It is a statistical tool to investigate relation of the variables. In regression analysis, two types of variables are predicted whose dependent variable and prediction values are independent.

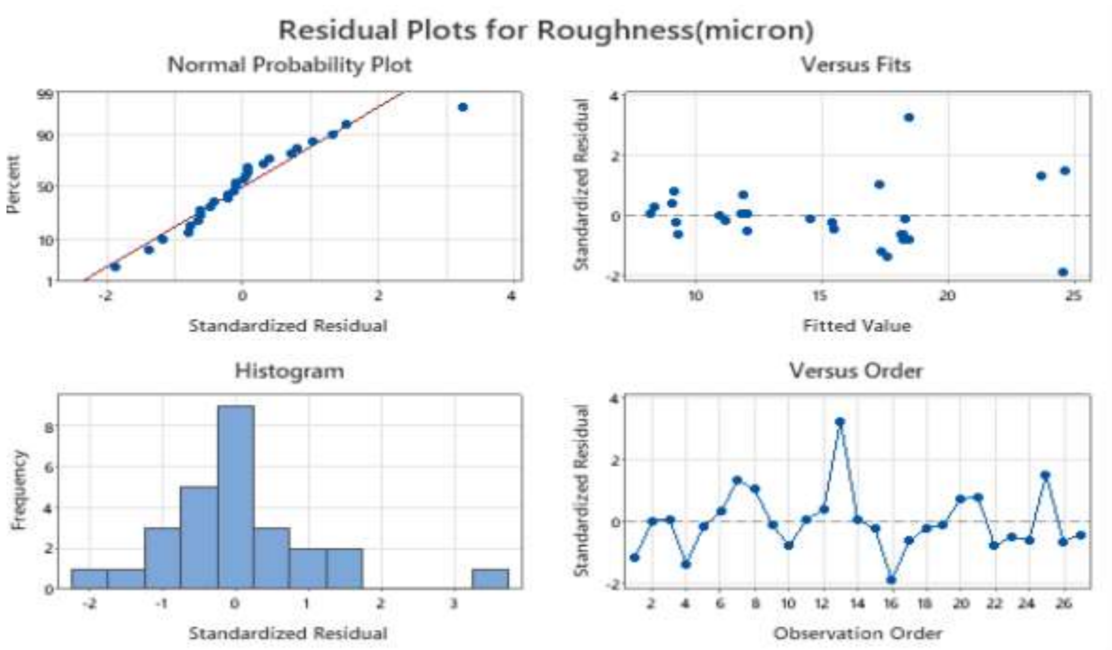

Figure 10 Residual plots for surface roughness

Table 3 ANOVA table for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Power (W)	2	4.80	2.398	0.10	0.909
Speed (mm/s)	2	234.09	117.044	4.69	0.021
Resolution (dpi)	2	400.08	200.038	8.01	0.003
Error	20	499.54	24.977		
Total	26	1138.50			

Residual plots are used to evaluate the data problem of non-random variation, higher order relationship, non-normality, non-constant variance and outliers. It is shown in Fig 11 that residual plots for Surface roughness in approximately straight line in normal probability plot and approximately symmetric nature of histogram and the residual is normally distributed.

If the P-values are less than 0.005 then particular parameter is considered to be highly statistically significant. Here resolution's P-value is 0.001 therefore it is considered to be most significant parameter. Final statistical models for the hardness, it can be used for prediction of the response and is to be given by following equation.

Regression Equation for Surface roughness

Roughness(micron) = 16.89 + 0.0183 Power (W) + 0.0317 Speed (mm/s) - 0.0459 Resolution(dpi)

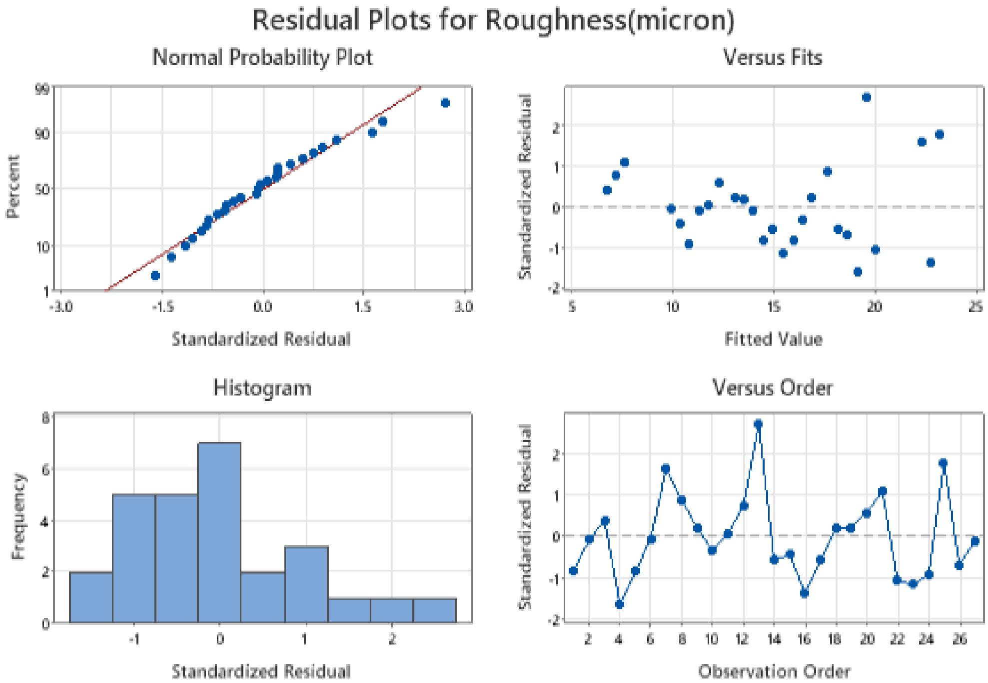

Figure 11 Residual plot of Regression Analysis for surface roughness

Table 4 Regression analysis of surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	564.11	188.036	7.53	0.001
Power (W)	1	3.77	3.773	0.15	0.701
Speed (mm/s)	1	180.49	180.494	7.23	0.013
Resolution (dpi)	1	379.84	379.841	15.21	0.001
Error	23	574.39	24.974		
Total	26	1138.50			

4. CONCLUSION

- CO_2 laser machining of PMMA might be a good method overcoming complexity and cost issues with respect to material selection.
- The experiments carried out during the reported work includes laser raster cutting of acrylic specimens by varying cutting parameters like Power (P), Speed (V) and resolution (dpi). The set of data obtained was useful in developing a statistical model of surface roughness for various combinations of speed, power and resolution.
- It was found that surface roughness decreases with increase in resolution (dpi).
- In this experiment for increase power 75 W, speed 200 mm/s and resolution 300 dpi using input parameter then it's effect of surface roughness is 6.654 micron (minimum value of surface roughness in this process). So, resolution increase then roughness is decrease.

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