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Optimization of Process parameters for Laser Fiber micromachining of micro – channels on Stainless Steel

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Abstract: Today Laser beam machining plays a very important role in the field of micro system technology. This work aims to show how the process parameters of laser Fiber Fusion engraving machine influence the final features of work- piece and also optimized the results through ANOVA software. Arrays of micro-channels were manufactured using various set of scanning speeds, pulse intensities and pulse frequencies. The results suggested that PF, PI and SS are the significant parameters in terms of depth and width of the channel which are the important for manufacturing in industry.

Keywords: Scanning Speed (SS), Pulse Frequency (PF), Pulse Intensity (PI), Micro-channels or Pin Fin.

1 Introduction

Laser beam machining is widely used in the field of micro system technology sectors, automotive manufacturing, diagnostic, medical applications, biomedicines, display units, printing technology etc. Developments in Fiber laser techniques (pulsed laser) and system has enhanced the applicability of laser in the complex component productions without expensive tooling. Machining of laser have wide range of materials such as metals and nonmetals, soft and difficult to machine. Pulsed lasers have more intensities than continuous wave lasers and are suited best solution for the fabrication of micro-channels or pin-fins structures. The Material removal during the laser machining process depends upon characteristics of the laser and the properties of the work-piece, Factors such that pulse frequency (PF), pulse intensity (PI), scanning speed (SS) and overlapping are influenced on laser and work-piece interaction. Many of these factors can be optimized in order to obtain the desire quality.

Various authors have investigated how laser parameters affect the resultant machined features. Teixidor et al 2013-[1] studied the capabilities of laser micro-machining by performing experiments on hardened steel with a pulsed Nd:YAG laser. Arrays of micro-channels were manufactured using various scanning speed, pulse intensities and pulse frequencies. The results are presented in terms of the main industrial requirements for nay manufactured good: dimensional accuracy (width and depth), surface roughness and material removal rate. E. V. Bordatchev et al 2003-[2] investigated experimentally the effect of laser pulse energy on the geometric quality of the machined parts in terms of accuracy, precision, and surface quality. They have experimentally formed the craters on thin copper foil with variation in laser pulse energy, the geometry and the surface topology. The geometrical parameters were measured and statistically analyzed with respect to incident pulse energy. Statistical analysis including pattern recognition was used to analyze the experimental data systematically and to serve proper selection of the process parameters to achieve the desired geometric quality of the machined parts. They have discussed the plausible trends in the crater geometry with respect to the laser pulse energy. Basem. F. Yousefa et al 2001-[3] described how an artificial neural network can be used to create a nonlinear model of the laser material-removal process in order to automate micro-machining tasks. The multilayered neural network was used to predict the pulse energy needed to create a crater of specific depth and average diameter. Laser pulses of different energy levels were impinged on the surface of the test material in order to investigate the effect of pulse energy on the resulting crater geometry and volume of material removed. They test the network's performance using experimentally acquired data from several sample materials. The experimentally acquired data demonstrates that the proposed network can simulate the behavior of the physical process to a high degree of accuracy. Kant Rishi et al 2014-[4], optimized the process parameter of laser micromachining technique which produce smooth machined surfaces. In addition, the impact of process parameters like raster speed, laser power, print resolution etc. were optimized using two target functions of dimensional precision and surface roughness. They analyzed the PMMA samples using 3D- profilometry and Field emission scanning electron microscope (FESEM) for surface quality and dimensional precision. Semaltianos et al 2010-[5] studied the effects of fluence and pulse frequency on surface roughness and MRR in nickel-based alloys with a Nd:YVO4 picosecond laser. They also analyzed the surface morophology of these alloys with AFM and SEM techniques.

Cadot et al 2016-[6] studied about the generation of controlled 3D micro-features by pulsed laser ablation in various materials. The key enabler of pulsed laser ablation for micro-machining was the prediction of the removal rate of the target material, thus allowing real-life machining to be simulated mathematically. Usually, the modeling of micro-machining by pulsed laser ablation is done using a pulse-by-pulse evaluation of the surface modification, which could lead to in accuracies when pulses overlap. To address these issues, a novel continuous evaluation of the surface modification that use trenches as a basic feature was presented in their work. The author investigated the accuracy of this innovative continuous modelling framework for micro-machining tasks on several materials.

Venkatakrishnan et al. 2002-[7] studied the laser micromachining on 1000 nm thick gold film using femstosecond laser. They found that during micromachining two ablation regimes exist. In the first regime no molten material is present and cutting is very shallow whereas in second regime the pulse energy is higher than ablation threshold and redeposition of molten material takes place. They suggested controlling the pulse energy in first ablation regime to get clean and precise microstructure. Similarly Venkatakrishnan et al.2002-[8] investigated the feasibility of sub-micron machining of metallic film with fs pulse. They found that sub-spot size feature can be obtained by the precise control of the peak fluence just above the threshold fluence. When the peak fluence is 2% higher than threshold value we can get a feature size of one-tenth the size of laser spot. Authors fabricated holes of diameter less than 200 nm with focused laser spot of 1.7 mm in 100 mm thick metallic thin film. Dausinger 2003-[9] found that fs lasers have certain disadvantages like deformation of laser beam near the focus and deflection of s-polarized radiation at hole wall. No significant change in thermal behavior is observed when the pulse duration is below 10 ps whereas the scattering effect increases when pulse width is less than 5 ps, therefore pulse duration of 5–10 ps is more suitable for micromachining of metals. Rizvi 2003-[10] reviewed the applicability of fs laser for micromachining of different types of materials. It was found that the waveguide writing is the only unique application where no other laser except fs can be applied. It was observed that ns laser pulses could also produce similar results for certain materials. Kamlage et al. 2003-[11] have demonstrated that the fs laser is suitable to fabricate microholes with special geometries, superior quality and high reproducibility. Tong et al. 2004-[12] have explored the prospect of fabricating embedded microheater patterns in thermal sprayed nichrome alloy coatings on alumina substrates. . Heater patterns have been designed to produce a uniform heat flux, a linear distributed heat flux and a non-uniform heat flux for uniform temperature distribution.

2. Experimental set up

The experiments, set up to study the influence of the process parameters, were carried out through 30 watt Fiber Laser (air cooled, digitally controlled, co2 laser tubes are fully modular and permanently aligned and field replaceable) with pulsed 20-80 kHZ and resolution user controlled choice of 75, 150, 200, 300, 400, 600 or 1200 dpi. The sample of material was stainless steel, selected because it is a widely used material in various industries. Dimensional measurements were performed with digital microscope (Dinolite 2) and 3D optical profilometer Contour GT (Bruker).

Several micro-channels were machined in each case changing one single parameter while the other remained fixed. By this, we could see the effect of single control variable, in order to determine the control parameter range. Variable factors and factor levels presented in Table 1, which is used to study effect of the input. Micro-channels array (20 x 20) has been fabricated in a 10 mm x 10 mm x 1.3 mm rectangular stainless steel plates. In the experiments influence of process parameters such as scanning speed (SS), pulse intensity (PI) and pulse frequency (PF) were carried out with Epilog Laser Fiber Mark Fusion Machine model -13000.

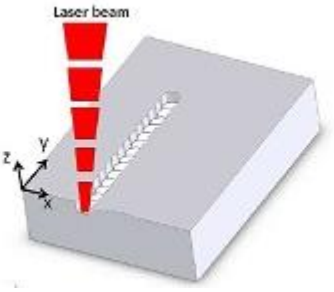


Fig 1: A schematic illustration of the Fiber Laser machining.

Table 1. Variable factors and factor levels.

Variable Factors	Factor Levels			
Scanning Speed (SS) in %	30	50	70	90
Pulse Intensity (PI) in %	50	70	90	-
Pulse Frequency (PF) in %	30	50	70	90

3. Experimental results and discussion

48 samples were machined with the laser machining process by following the design of experiments as summarized in Table 1. Dimensional measurement for each micro-channel, take three different locations on same sample and evaluate average these measurements for depth and width of micro-channels. 48 micro-channels were machined and experimental results were obtained, these machined features for all the combinations of the variable factors are shown in Table 2. The micro-channels have variations in dimensions and shape. These variations in micro-channels are clearly shown in Figure 2, 3 and 4. Analysis of variance was performed for each response factor to understand the influence of the process parameters. It is evident from figure 2 that the width of the channel decreases and depth increases as PI increases. The images in figure 3 indicate that as SS increases the depth increases and width decreases.

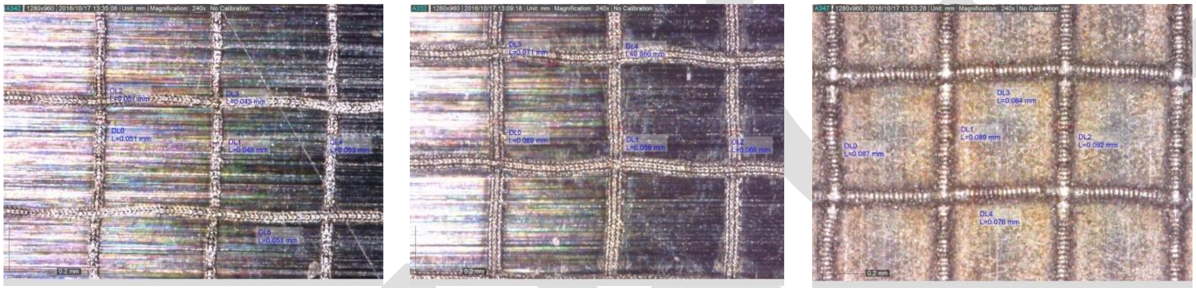
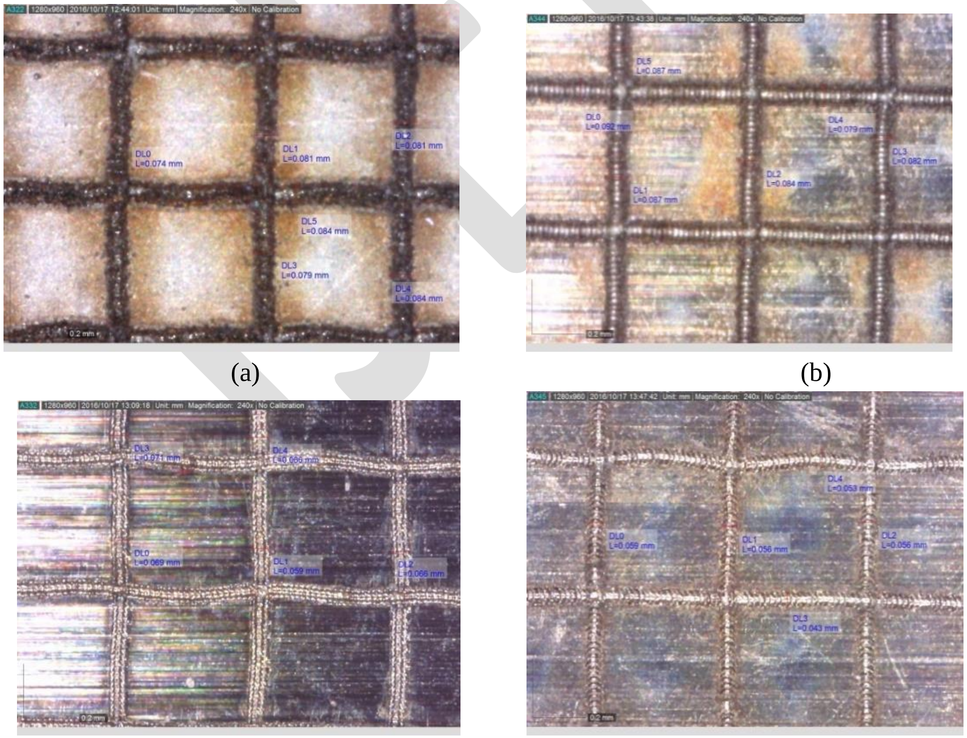

(a) (b) (c)

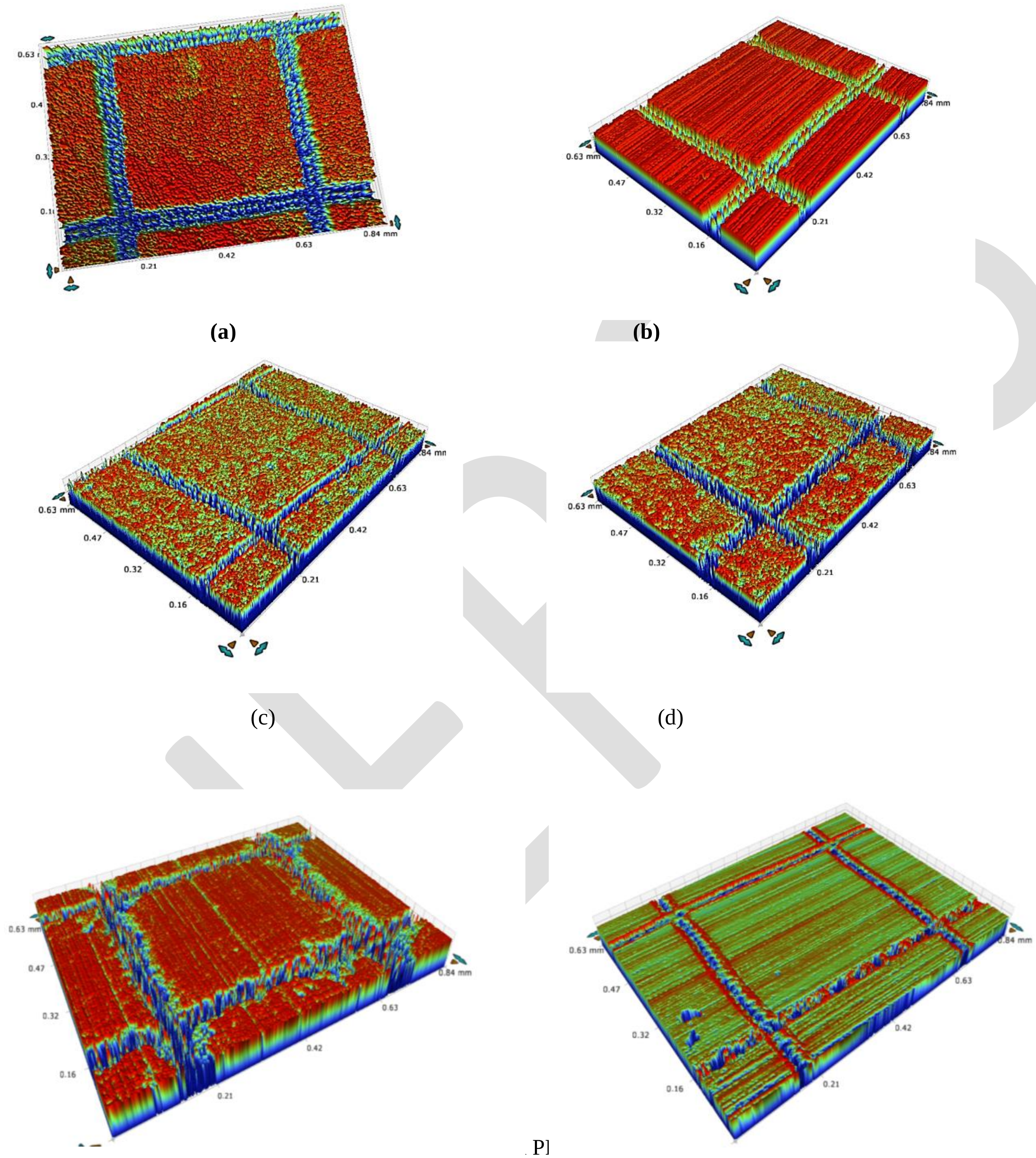
Fig 2: Images of micro-channels for Pulse Intensity (a) 50% (b) 70% and (c) 90%, for constant Scanning Speed 70%, and Pulse Frequency 30% taken from Digital Microscope.


(a) (b)

(c) (d)

Fig 3: Images of micro-channels for Scanning Speed (a) 30% (b) 50%, (c) 70%, and (d) 90% for constant Pulse Intensity 70%, and Pulse Frequency 30% taken from Digital Microscope.

The images taken from 3-D Profilometer as shown in fig 4 indicates that as the PF increases the visibility of microchannels are poor.



(a) **(b)**

(c) (d)

70%, PI 70% and PF 70% and (d) SS 90%, PI 90% and PF 90%, (e) SS 30,PI 30,PF 30 (f) SS30,PI 90,PF 90

Table 2 Experimental results with Input control variables

				Digital Micrometer	3D Optical Profilometer
SL No	SS %	PI %	PF %	Width (μm)	Depth (μm)
1	30	50	30	35	7.402
2	50	50	30	30	7.054
3	70	50	30	38	6.675
4	90	50	30	28	3.867
5	30	70	30	60	8.860
6	50	70	30	60	7.860
7	70	70	30	43	7.780
8	90	70	30	43	7.213
9	30	90	30	65	9.894
10	50	90	30	72	8.832
11	70	90	30	62	8.325
12	90	90	30	60	7.901
13	30	50	50	41	7.330
14	50	50	50	37	7.810
15	70	50	50	26	5.190
16	90	50	50	37	3.712
17	30	70	50	53	8.901
18	50	70	50	58	7.120
19	70	70	50	57	8.321
20	90	70	50	50	5.013
21	30	90	50	63	11.980
22	50	90	50	56	11.690
23	70	90	50	57	10.580
24	90	90	50	60	9.865
25	30	50	70	38	6.432
26	50	50	70	39	4.010
27	70	50	70	45	3.450
28	90	50	70	34	3.123
29	30	70	70	48	7.320
30	50	70	70	48	6.890
31	70	70	70	51	5.560
32	90	70	70	42	5.345
33	30	90	70	70	9.986
34	50	90	70	58	9.894
35	70	90	70	57	8.523
36	90	90	70	57	7.860
37	30	50	90	31	7.356
38	50	50	90	34	7.032
39	70	50	90	20	6.867
40	90	50	90	18	5.899

41	30	70	90	56	8.245
42	50	70	90	45	9.420
43	70	70	90	48	7.986
44	90	70	90	49	6.896
45	30	90	90	66	11.045
46	50	90	90	58	10.891
47	70	90	90	56	10.590
48	90	90	90	53	9.874

3.1 Micro-channel depth

With the help of Table 2's results obtained for micro-channel depths, the influence of the scanning speed and the pulse intensity on the depth dimensions is summarized in figure 5.

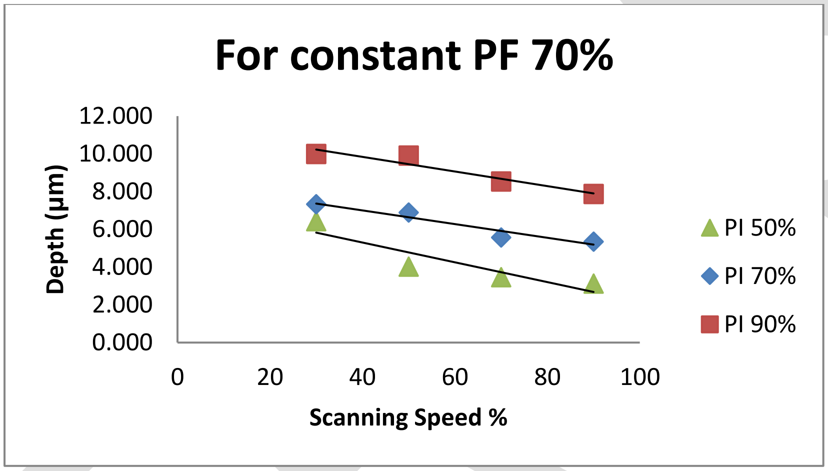


Fig 5: Influence of scanning speed and pulse intensity on depth dimension

The trend lines in figure 5 shows that higher scanning speeds produce smaller depths and higher pulse intensities produce in deeper micro-channels. Higher pulse intensities and lower scanning speeds result in deeper micro-channels because the surface is machined with high energy for longer time, which allows a large amount of energy to be absorbed by the work-piece. So figure 4 explains that for higher depths, higher pulse intensity values would be necessary.

Table summarizes the result of the ANOVA revealing that the significant factors for the average depth of micro- channels are pulse intensity and scanning speed.($p<0.05$). The F value indicates that the pulse intensity is the most significant factor, which is made clear by the contribution value.

Table 3: ANOVA Result for 3 D optical profilometer depth

	Sum of		Mean	F	P	
Source	**Squares**	**DOF**	**Square**	**Value**	**Value**	**Contribution (%)**
A-SS	*36.2*	*1*	*36.2*	*28.81*	*0.0001*	21.688335
B-PI	*130.09*	*1*	*130.09*	*103.55*	*0.0001*	77.9402073
C-PF	*0.62*	*1*	*0.62*	*0.49*	*0.4862*	0.37145767
Residual	55.28	44	1.26			
Cor Total	222.19	47				

3.2 Micro-channel width

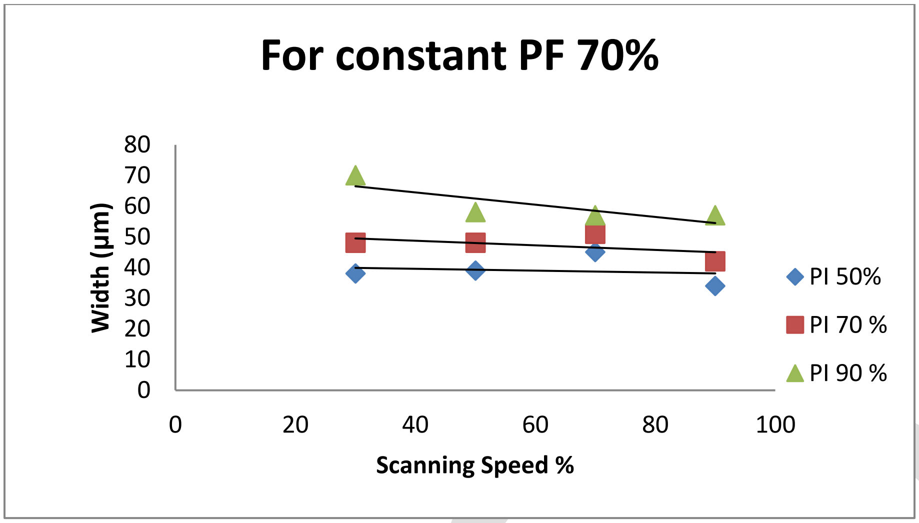


Fig6: Influence of scanning speed and pulse intensity on width dimension

The table 2 presents width dimension that range from 18 to 72 µm. Figure 6 shows how the scanning speed and the pulse intensity affect the width. The trend lines in figure 6 shows that higher scanning speeds produce smaller width. Thus, as the channel becomes deeper, the width becomes greater.

Source	Sum of Squares	DOF	Mean Square	F Value	P Value	Contribution (%)
A-SS	*426.67*	*1*	*426.67*	*13.8*	*0.0006*	6.45880576
B-PI	*6022.53*	*1*	*6022.53*	*194.75*	*0.0001*	91.1672989
C-PF	*156.82*	*1*	*156.82*	*5.07*	*0.0294*	2.37389533
Residual	1360.65	44	30.92			
Cor Total	7966.67	47				

Table 4: ANOVA Result for width

The table 4 summarizes the result of the ANOVA revealing that all the factor (Scanning speed, pulse intensity and pulse frequency) have significant influence on the width ($p<0.05$) in contrast to Teixidor, Grzenda et al [1]. The experimental results shows that the significant importance of pulse frequency. The F value indicates that the pulse intensity is the most significant factor followed by scanning speed and pulse frequency.

Conclusion

The study reveals that Fibre-laser machining process is suitable for fabricating micro-channels. In this study, dimensional features and the productivity of micro-channels have been studied. Although the results obtained for the micro-channels present variations, they do suggest that laser machining is capable of producing micro-geometries. Several specific conclusions should be pointed out:

1. Low scanning speeds and high pulse intensities increase the depth and decrease the width of the micro-channels.
2. The surface quality of the channels improves with a rise in scanning speed, and surface quality improves with at lower Pulse Frequency.
3. Laser micromachining productivity increases with high pulse intensities and low scanning speeds.
4. ANOVA results show that PF is also statistically significant along with PI and SS for the responses under study of width of micro channel.
5. ANOVA results show that PF is statistically insignificant for the responses under study of depth of micro channel.

Future work will consider other AI techniques for validation of study, such as ensembles of classifiers or regressors. These ensembles are built by combining different basic classifiers that could improve final model accuracy. Non-linear models will also be tested, such as non-linear regressors, to ensure that any interaction effect is taken into account and evaluated.
Further, the rate of heat transfer can also be studies and modelled for better understanding the response of micro-channels under various parameters.

REFERENCES:

1. Teixidor, D., Grzenda M., Bustillo, A., Ciurana, J., “Modelling pulsed laser micro-machining of micro-geometries using machine-learning techniques”, Journal of Intelligence Manufacturing, june 2013.

2 .E. V. Bordatchev and S. K. Nikumb, “An Experimental Study and Statistical Analysis of the Effect of Laser Pulse Energy on the Geometric Quality During Laser Precision Machining”, MACHINING SCIENCE AND TECHNOLOGY Vol. 7, No. 1, pp. 83–104, 2003.

3. Basem. F. Yousefa, George K. Knopfa, Evgueni V. Bordatchevb, Suwas K.Nikumb, “Neural network modeling of the laser material-removal process”, Sensors and Controls for Intelligent Manufacturing II, Peter E. Orban, Editor, Proceedings of SPIE Vol. 4563 (2001).

4. Kant Rishi, Gupta Ankur, Bhattacharya S., “Studies on CO2 laser micromachining on PMMA to fabricate micro channel for microfluidic applications”, 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India.

5. Semaltianos NG, Perrie W, “Picosecond laser ablation of nickel-based superalloy C263”, Applied physics A; Materials Science and Processing Vol 98(2), pp.345-355 (2010).

6. Cadot G.B.J , Axinte D.A. ,.Billingham J, “Continuous trench, pulsed laser ablation for micro-machining applications” International Journal of Machine Tools & Manufacture 107, pp.8-20 (2016).

7. Venkatakrishnan K, Tan B, Ngoi BKA. Femtosecond pulsed laser ablation of thin gold film. Opt Laser Technol ;34 pp.199–202 (2002).

8. Venkatakrishnan K, Tan B, Sivakumar NR. Sub-micron ablation of metallic thin film by femtosecond pulse laser. Opt Laser Technol;34, pp575 (2002).

9. Dausinger F. Femtosecond technology for precision manufacturing: fundamental and technical aspects. RIKEN Rev;50: pp77–82, (2003).

10. Rizvi NH. Femtosecond laser micromachining: current status and applications. RIKEN Rev 50:pp77-82 (2003).

11. Kamlage G, Bauer T, Ostendorf A, Chichkov BN. Deep drilling of metals by femtosecond laser pulses. Appl Phys A;77 pp.307 , (2003).

12. Tong T, Li J, Chen Q, Longtin JP, Tankiewicz S, Sampath S. Ultrafast laser micromachining of thermal sprayed coatings for microheaters: design, fabrication and characterization. Sens Actuator A;pp.114:102 (2004).