Experimental Study & Optimization of Input Parameters on Fibre Laser Micromachining of Inconel 718

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Abstract— Nickle alloy are super alloys and plays a very important role in engineering applications in the area of advanced structures and technologies for aerospace and power industry, medical science, nuclear and defense equipments, owing to its unique combination of physical, chemical and mechanical properties such as high strength and stiffness at elevated temperatures , high corrosion resistance, fatigue resistance, high strength to weight ratio and ability to withstand moderately high temperatures without creeping. The conventional cutting methods not only face difficulties for cutting these alloys due to their poor thermal conductivity, low elastic modulus and high chemical affinity at elevated temperatures but also undergo from higher cost associated with the machining of Inconel 718 caused by lower cutting speeds and shorter tool life. The present research work deals with fibre laser micromachining on Inconel 718 of 0.5 mm thickness in atmospheric condition with different parametric combinations such as power, frequency and marking speed.
Key words: Fibre laser, micromachining, Inconel 718

I. INTRODUCTION

Laser beam micro-machining is a well-established and mature technology for high-precision micro fabrication and is constantly being applied into new application areas. It is a noncontact type of machining process with several unique advantages such high output power, high quality products, compact size, lower cost of ownership, minimal part replacement, greater, material utilization and green manufacturing [1]. Inconel 718 is highly used for liquid fueled rockets, cryogenic tank,casings, rings and various formed sheet metals for land-based gas turbine and aerospace engines because of its unique properties like high strength and stiffness at elevated temperatures , high corrosion resistance, fatigue resistance, etc. [2]. Cutting of metallic cardiovas- cular stent with fibre laser was performed by the auther. In comparison with traditional laser, there are so many advantages for fiber laser [3]. Laser micromachining has proven to be an optimal tool in delivering high precision, consistent results, faster throughput, higher yields and lower manufacturing cost[4].

II. EXPERIMENTAL PLANNING

Laser micro-machining is based on the interaction of laser light with solid matter and it is very complex process. In the recent years, fibre lasers have emerged as the most promising alternatives to the conventional solid state lasers and the merger between the most innovative and advanced technologies in the laser world–active optical fibres and semiconductor diodes. The diode pointer assures the work piece is on the focal plane. The experimental setup of fibre laser is shown in the figure 1. The fibre laser system has a wavelength of 1064 nm and pulse duration of 120 ns. The mode of operation in which all the experimental works are carried out is pulsed mode. The material used for this experimentation is Inconel 718 sheet of 0.5 mm thickness. In the present study the aim was to investigate the influence of various process parameters on various responses such as surface roughness, depth and material removal rate. The range of parameters was chosen from the previous research works. Total 20 of micro-cutting operations were performed. In the present research, all the experiments were carried out on multi-diodes pumped Ytterbium doped fibre laser machining system of 20W, made by EtchON Marks Control Company. The experimental setup of fibre laser is shown in the figure. The fibre laser system has a wavelength of 1064 nm.

Fig. 1: Fibre laser machine

Model	FLE P20
Laser type	Fibre laser
Power output	20W
Standard marking area	110mm x 110mm
Marking area	7000mm/s
Wavelength	1064nm
Frequency of pulse	20-80 kHz
Marking depth	≤0.1mm (depends on material
Minimum line width	0.01mm
Power supply	AC220V±50Hz
Cooling	Air cooling
Laser generator life	50000-100000 hours
Software	EZCAD
System compatible form	Windows XP or JPG, JPEG, TIF, etc.

Table 1: Specifications of Fibre Laser Machine Used in the Experiment

A. Input and Output parameters with results:

Sl. No.	Power (W)	Frequency (Khz)	Marking Speed (mm/sec)	Surface roughness (µm)	Depth (µm)	MRR (cumm/sec)

1.	13	35	12	3.978	0.0753	$4.11x10^{-}$
2.	18	35	12	5.909	0.051	$2.78x10^{-}$
3.	13	67	12	1.802	0.0556	$3.03x10^{-}$
4.	18	67	12	1.063	0.0665	$3.63x10^{-}$
5.	13	35	40	3.965	0.0167	$9.12x10^{-}$
6.	18	35	40	5.994	0.0105	$2.15x10^{-}$
7.	13	67.0000	40.0000	566	0.0197	$4.03x10^{-}$
8.	18	67.0000	40.0000	1.01	0.0546	$1.11x10^{-}$
9.	11.2	51.0000	26.0000	2.74	0.0383	$5.03x10^{-}$
10	19.7	51.0000	26.0000	4.275	0.0249	$3.27x10^{-}$
11	15.5	24.0913	26.0000	1.253	0.0513	$6.75x10^{-}$
12	15.5	51.0000	2.4549	1.165	0.0769	$8.43x10^{-}$
13	15.5	77.9087	26.0000	7.057	0.0108	$1.42x10^{-}$
14	15.5	51.0000	49.5451	1.17	0.0258	$6.65x10^{-}$
15	15.5	51	26	3.364	0.031	$4.07x10^{-}$
16	15.5	51	26	3.575	0.031	$4.07x10^{-}$
17	15.5	51	26.0000	3.575	0.031	$4.07x10^{-}$
18	15.5	51	26.0000	3.575	0.031	$4.07x10^{-}$
19	15.5	51	26.0000	3.398	0.031	$4.07x10^{-}$
20	15.5	51	26.0000	3.398	0.031	$4.07x10^{-}$

Table 2: Results

III. INFLUENCE OF LASER PROCESS PARAMETERS ON MICROMACHINING CRITERIA:

Due to complexity of relationship between laser cutting parameters and the cutting quality, three parameters i.e. power, frequency and marking speed were considered so as to find out the influence of fibre laser micromachining process parameters on various responses such as surface roughness, depth and marking speed. The parametric analyses of the laser micromachining characteristics to study the influences of parameters have been performed.

A. Effect of power, frequency and marking speed on surface roughness:

During pulsed fibre laser micromachining operation of nickle alloys, minimization of surface roughness, as well as increase in material removal rate of the micromachine criterion are most important aspect for various fields of engineering applications. Therefore influences of the fibre laser micromachining parameters such as power, pulse frequency and marking speed on surface roughness, depth, and material removal rate phenomena during laser micro-grooving on Inconel 718 have been analyzed.

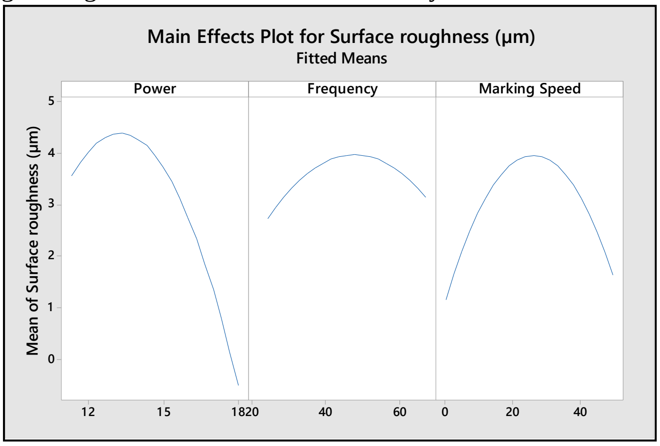


Fig. 2: Main effect plot for surface roughness

Surface roughness is an effective parameter representing the quality of machined surface. Figure shows the influence of power, frequency and marking speed on surface roughness on fibre laser ablated micromachined surface. Also as the average power is increasing, so it will lead to good surface quality after a certain value. As all the experiments were carried out without any assist gas some amount of molten material will be resolidified on the wall of the micromachined area. As the frequency is increased surface roughness initially increases which is undesirable and after a certain value decreases. Increase in marking speed leads more material is melted per unit time during micromachining operation and higher mass flow rate is achieved at higher marking speed. Low marking speed produces high level of spot over lapping and continuous power density per unit length which gives complete micro-cutting with uniform smooth surface. But when the marking speed is increased at higher value of pulse frequencies, it produces low spot over lapping, discontinuous power density, and less time for melting the materials which should result in rough cutting. But it has been found that surface roughness increases with the increase in marking speed and decreases after a certain value of marking speed which shows that there is a scope of optimization in parameters.

B. Effect of power, frequency and marking speed on depth:

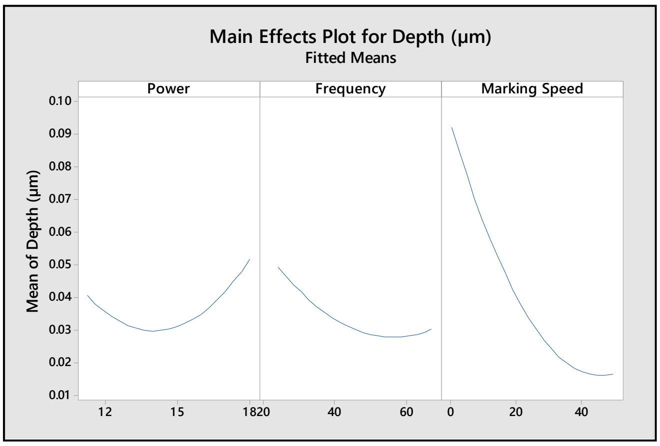


Fig. 3: Main effect plot for depth

Laser power determines the direct energy input to the microcutting process. Both cutting quality and the cutting performance depend on the laser power. Increase in laser power increases the depth due to increase in more power density, power input per unit area. After certain value of power, depth increases as power increases. Lower value of pulse frequency causes excessive removal of material from upto a certain value. After that there will be considerable amount of increase of depth. An increase in pulse frequency makes the laser closer to a continuous wave which impacts more power to the substrate. The laser power and marking speed have an important influence on depth. Also marking speed plays a significant role in depth of cut as marking speed increases depth of decreases

C. Effect of power, frequency and marking speed on material removal rate:

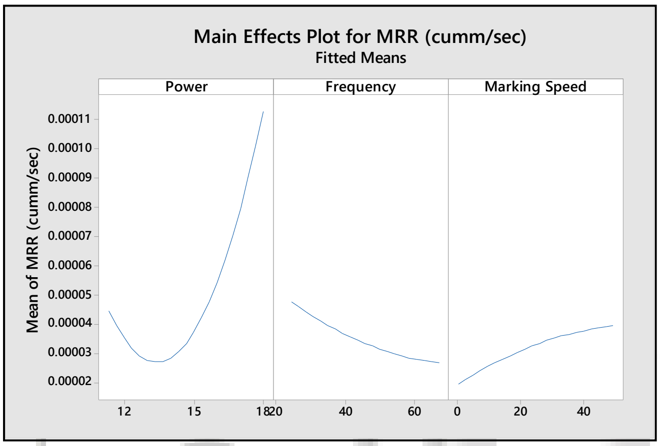
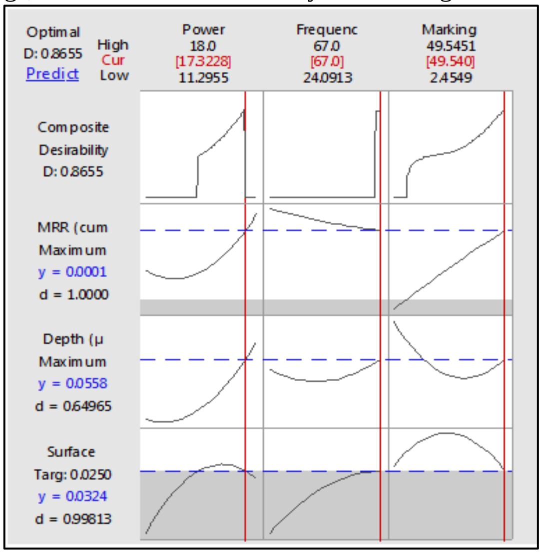


Fig. 4: Main effect plot for MRR

The efficiency of the laser cutting process depends on material removal rate. Power has significant effect on material removal rate. It was found that MRR first decreases and then increases after a critical value with increasing power density for. Marking speed and frequency doesn't have significant effect on material removal rate, however as frequency increases material removal rate decreases and as marking speed increases the material removal rate increases. When material is ablated by the laser, the influence of material properties and laser parameters such as the energy, pulse width, wavelength, and pulse frequency makes the removal mechanism somewhat complicated. At present, removal mechanisms such as regular melting, thermal vaporization, ultrafast melting, and photon mechanical damage have been proposed. However, during real ablation processing, the material is ablated by a combination of several mechanisms. These laws provide the theoretical basis and experimental support for the ablation mechanism of the laser and the improvement of the removal efficiency.

D. Optimization of power, frequency and marking speed during Micromachining:

The response optimization analysis has been performed for achieving the minimum surface roughness value (Ra) and maximum material removal rate. In order to minimize the responses, the weight value of upper bound of linear desirability function (D) is taken as 1. The MINITAB Software has been utilized for optimization of the responses during laser micromachining on Inconel 718. Each column of the graph corresponds to a factor. Each row of the graph corresponds to a response. Each cell of the graph shows how one of the response changes as a function of one of the factors. The numbers displayed at the top of a column show the current factor level settings and the high and low settings of factor in the experimental design. At the left of each row, goal for the response, targeted response, y at current factor settings, and individual desirability scores are given.



The current optimal parameter settings values are power 17.3228W, frequency 67 KHz and marking speed 49.540 mm/s. for achieving the minimum surface roughness and maximum material removal rate. The composite desirability, D is displayed in the upper left corner of the graph. The label above composite desirability refers to the current setting and changes for moving the factor settings interactively. The optimal response plot is generated using MINITAB software. The vertical lines inside the graph represent current optimal parametric settings. The horizontal dotted lines represent the current response values.

IV. Conclusion

The present research paper deals with the influence of three process parameters that are power of 10-20 W- frequency of 20-80 KHz, marking speed of 10-50 mm/sec; during the micromachining of Inconel 718 using 20W fibre laser. Different process parametric settings lead to different surface roughness, depth and material removal rate. From the results of present experimentation, the following conclusions can be drawn.

1) Frequency and power have significant roles on surface roughness. Also, as the power is increased, depth and material removal rate increases due to high amount of energy melts and evaporates more amount of material from the micromachined zone.
2) Surface roughness increases initially with an increase in marking speed and decreases after a certain value of marking speed is attained which shows that there is a scope of optimization in parameters
3) Also marking speed plays a significant role in depth of cut (as marking speed increases depth of cut decreases).
4) Surface quality has a tendency to gradually decrease owing to low spot over lapping, discontinuous power density.
5) Lower value of pulse frequency causes excessive removal of material from upto a certain value.

6) In the study it can be seen that power has greater effect and frequency has less effect on surface roughness.
7) Optimised values are power 17.3228W, frequency 67 KHz and marking speed 49.540 mm/s.
8) It is also observed that for multi-objective optimization, it is always preferable to assign equal importance to all the considered responses. The derived parametric combinations for fibre laser micromachining process would now help the process engineers to set the operating levels of various process parameters at their optimal values to have enhanced machining performance. This may also be helpful for parametric optimization of other machining processes.

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