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Parametric study of laser engraving process of AISI 304 Stainless Steel by utilizing fiber laser system

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Abstract. Laser engraving process is non-conventional machining process used for engraving of almost each material which cannot be mark by conventional machining processes. Laser engraving process is done by heat up mechanism which vaporize the material surface. With the use of laser engraving machine the engraving is possible by utilizing different input parameter as spot diameter, laser power, laser frequency, different wave length, engraving speed, number of passes etc. Output parameter is potentially material removal rate, surface finish and indentation. Parameters with multiple responses characteristic is optimized based on the Taguchi method analysis. Three input parameter (frequency, engraving speed and number of passes) were investigated its effect on surface roughness as it output parameter.

1. Introduction

Laser process is one of the most widespread technical inventions of the last century. Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. It is both subject of intense study from scientists and engineers to further expand the field of application and develop new and better laser system. The non-contact nature of the process allows wide variety of materials such as plastics, wood, metal and ceramics to be used as work piece that furthers the usefulness of the process. The principle of operation is based on ablation wherein the interaction between material and the laser beam, which comes from a laser system and passes through a focusing lens (convex lens), leads to the vaporization and melting of work material. It is also a good example of how a fundamental theoretical concept can rest for decades until it is rediscovered for a technical application. As a result, the material is removed from the work piece in layers via ablation mechanism.

Literature review provides the scope for the present study. Literature review plays important role to get information about the dissertation work It works as guide to run this analysis. Literature review includes different study on laser engraving processes for better surface finish with different laser by using parametric analysis, and effect of laser power, different wave length, pulse frequency, beam speed and other so many parameters also effect of surface finish, material removal rate and indentation of engraving.

Laakso et al. [1] reported that fiber laser allows independent tuning different laser parameters and the marking process can be optimized for producing colors with better quality and visual appearance. Has discussed Color marking of stainless steels as a process is known for some time but still it has not been used widely in the industry.

Cheng-Jung et al. [2] in their study mentioned that Moso bamboo lamina was engraved using various laser output power levels in conjunction with various feed speed ratios in order to understand the effects of feed speed ratio and laser output power on engraved depth and color difference. The results showed that the engraved depth became deeper for either higher laser power or a lower feed speed ratio. Moreover, the color difference values increased under a lower feed speed ratio and higher power, and resulted in a brownish color in the engraved zone. The average engraved depth and color difference values were 0.69–0.86 mm and 46.9–51.9 pixels by different engraving parameters, respectively. The effects of different feed speed ratios and laser output power levels on the engraved depth and color difference of Moso bamboo laminae were investigated, with the following results. 1. The laser engraved depth became deeper for either higher laser power or a lower feed speed ratio. 2. Color difference values increased under a lower feed speed ratio and higher power, and resulted in a brownish color in the engraved zone. 3. Effects of the feed speed ratio by laser power interaction regimens on the engraved depth and color difference were significant. Therefore, values of the engraved depth and color difference increased with an increase in laser output power; however, there was a decrease in the feed speed ratio. 4. The engraved depth and color difference values of Moso bamboo could be predicted and estimated by regression analyses. This prediction of two engraving performances can help laser engraving achieve varied requests and applied to the fields of decoration and gift industry.

Mingwei Li et al. [3] has presented that Laser micromachining of semiconductor materials such as silicon and sapphire has attracted more and more attention in recent years. In the study, two Q switched & one mode-locked diode-pumped solid-state 355 nm lasers have been used to scribe grooves on silicon and sapphire wafer substrates at different pulse widths (10ns, 32 ns, and 10 ps) and pulse repetition rates (30 kHz, 40 kHz, 50 kHz, and 80 MHz).Experimental results have been compared between different pulse widths, power levels, and pulse repetition rates. It has been found that at the same average power and same repetition rate, the grooves scribed by the longer pulse width laser are deeper, while the shorter pulse width laser produces better quality cuts.

Leone C et al. [4] show that laser deep engraving is one of the most promising technologies to be used in wood carver operations in this work, the features and the performances given by a 5W of nominal power Q-switched diode-pumped frequency-doubled Nd: YAG green laser in the engraving of different kind of woods are discussed. The main conclusions are the surface carbonization depends on an incorrect selection of the process parameters and, for the adopted laser, it happens at beam speeds of up to 10mm/s. For speed more than 40mm/s, the engraved depth is very low and multiple laser scanning are required to obtain deep engraving. The engraved depth is strongly affected by the mean power, the pulse frequency, the beam speed and the number of repetitions. Increasing the speed is possible to obtaining engraving with a reduced frequency range around the value where the maximum output power is achieved. The maximum speed necessary to obtain engraving linearly depends on the mean power.

Peligrad et al. [5] describe two dynamic models relating processing parameters and melt pool width during laser marking/engraving of clay tiles using a high-power diode laser. The models were determined by process identification techniques and were validated with a PI algorithm. The input quantities investigated were laser power and traverse speed. Reasonable agreements between the measured data and the model outputs were achieved. Errors less than 1.3μm of the melt pool width for the operating points were found. On the basis of these models a simple PI-controller was designed and tuned to guarantee zero steady-state error in case of an absorptivity disturbance. Two parametric models relating laser power or traverse speed to melt track width were identified and simulated using a PI controller. There was a very good agreement between the established models and the experimental values. In addition, the process dynamics of laser marking of clay tiles was analyzed as follows. A smooth, well-defined mark was obtained at a beam velocity of around 6–10 mm/s and a laser power of around 60 W. Both models were simulated with a PI controller and the results show that there were improvements of the system performances in case of controlling the width of mark with varying absorptivity. The deviation of the melt pool width in the case of laser power or traverse speed as actuators was reduced.

These are covers the different laser engraving process of input parameter such as Laser power, Frequency, Pulse duration, Spot diameter, Number of passes, Air/Gas pressure, engraving speed are taken for different work piece materials i.e. aluminums alloy, semiconductor etc. and wooden also. It is obtained that the input parameters; frequency, no of pass and speed influenced the output parameters which are surface finish, material removal rate and indentation.

2. Material and Experiment Setup

2.1 Fiber laser machine

Laser engraving process can be divided into three main parts which are a laser, controller, and part surface (Figure 1). The laser is the beam that discharged and allows the controller to create patterns onto the surface. The common laser parameters are the controller direction, intensity, speed of movement, and spread of the laser beam aimed at the surface. The surface is picked to match what the laser can act on. The fibre laser engraving machine has technical specification which includes nominal average power, maximum peak power, pulse repetition rate, wavelength, pulse duration, power stability etc. These are shown in Table 1.

Figure 1. Fiber laser machine

Table 1. Specification of Laser Engraving Machine

PARAMETER	RANGE
Laser	Multi diode pump fibre laser
Nominal average power	20w (optional 10 w)
Max. Peak Power	>7.5 KW
Pulse Repetition Rate	20-80 KHz
Wavelength	1060 +/- 10nm
Pulse duration @20 KHz	<120 ns
Power Stability	>95 %

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2.2 Surface Roughness Measuring Equipment

The surface roughness for all trial runs is measured with surface roughness tester meter and their technical features are as under Figure 2 shows the measurement of surface roughness of cut piece of stainless steel plate of 1.5 mm thick.

Figure 2. Surface Roughness Tester

The Surface tester can be operated easily using the buttons on the front of the unit and under the sliding cover. Up to 10 measurement conditions and one measured profile can be stored in the internal memory. An optional memory card can be used as an extended memory to store large quantities of measured profiles and conditions.

2.3 Material Selection

The material selected for this dissertation work is Stainless Steel (AISI Type-304). Chemical composition of this material is shown in Table 2.

Table 2 Chemical Composition of Stainless Steel Plate

ELEMENTS	% CONTRIBUTION
Silicon	0.460 +/- 0.02
Nickel	8.090 +/- 0.04
Chromium	18.580 +/- 0.03
Manganese	1.050 +/- 0.05
Sulphur	0.012 +/- 0.03
Phosphorus	0.028 +/- 0.02
Carbon	0.058 +/- 0.01

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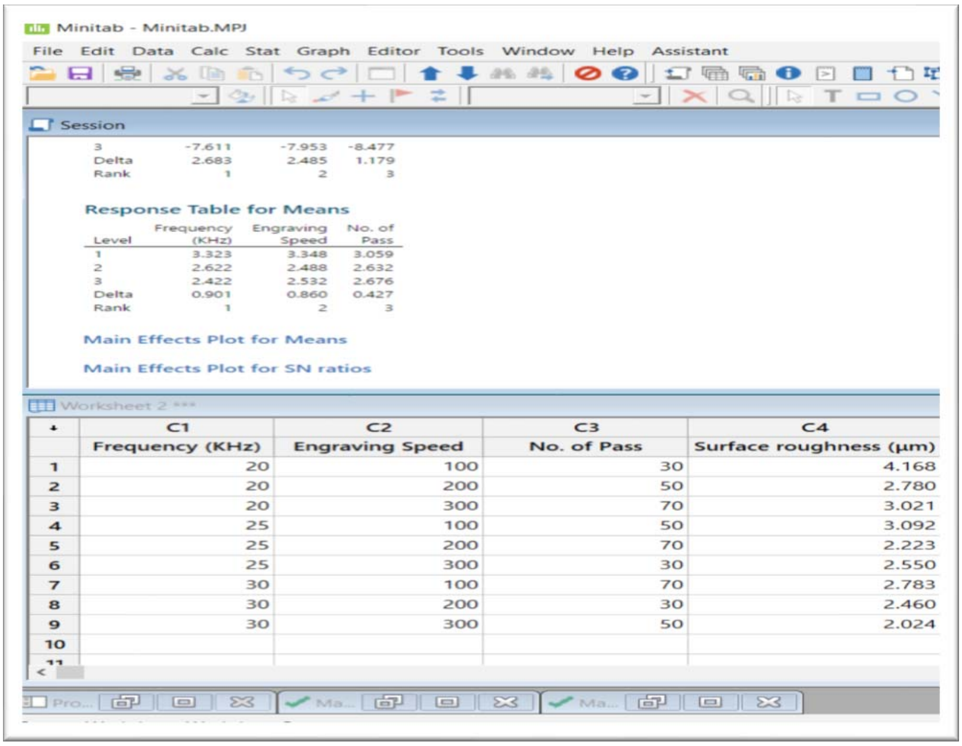
3. Experimental Procedure

Input parameter considered for laser engraving machine are frequency, engraving speed, and No. of passes and which reflected on output parameters such as Surface Roughness.



Level			
3	-7.611	-7.953	-8.477
Delta	2.683	2.485	1.179
Rank	1	2	3

Response Table for Means

Level	Frequency (KHz)	Engraving Speed	No. of Pass
1	3.323	3.348	3.059
2	2.622	2.488	2.632
3	2.422	2.532	2.676
Delta	0.901	0.860	0.427
Rank	1	2	3

	C1 Frequency (KHz)	C2 Engraving Speed	C3 No. of Pass	C4 Surface roughness (μm)
1	20	100	30	4.168
2	20	200	50	2.780
3	20	300	70	3.021
4	25	100	50	3.092
5	25	200	70	2.223
6	25	300	30	2.550
7	30	100	70	2.783
8	30	200	30	2.460
9	30	300	50	2.024
10				

Figure 3. Experimental design using Mini Tab-16 L9 array

The summary of experimental range is listed in Figure 3. The experimental results after laser engraving of Stainless Steel 304 material were evaluated in terms of the following measured machining performances: firstly, surface roughness (Ra). The surface roughness of laser engraved surfaces was measured using a surface roughness tester instrument. In order to achieve best engraving quality, full factorial experimental design was used. For this purpose a L9 orthogonal array was used for experiment. The experimental results are also summarized in Figure 4.

4. Result and Discussion on Surface Roughness Performance

Surface roughness Ra is commonly used to indicate the level of surface texture. It is measured by the aberrations in the normal direction of a part surface. If these aberrations are large, the surface is rough; if aberrations are small, the surface is smooth. In metrology, roughness measurement is typically considered to be the high-frequency but short-wavelength procedure. However, it is good to know the frequency and amplitude to ensure that a surface is appropriate for the applications.

Roughness apply important roles in determining how an object interact with the environment. Surface roughness wear more rapidly and have higher resistance than smooth surfaces. Roughness can predict the performance of a mechanical component, since irregularities on the surface. On the other side, roughness may promote gripping. In General, rather than scale specific descriptors, cross-scale descriptors such as surface factuality provide more significant predictions of mechanical relations at surfaces. In order to get good surface roughness and high accuracy in laser engraving process, it is needed to varies the laser engraving parameters.

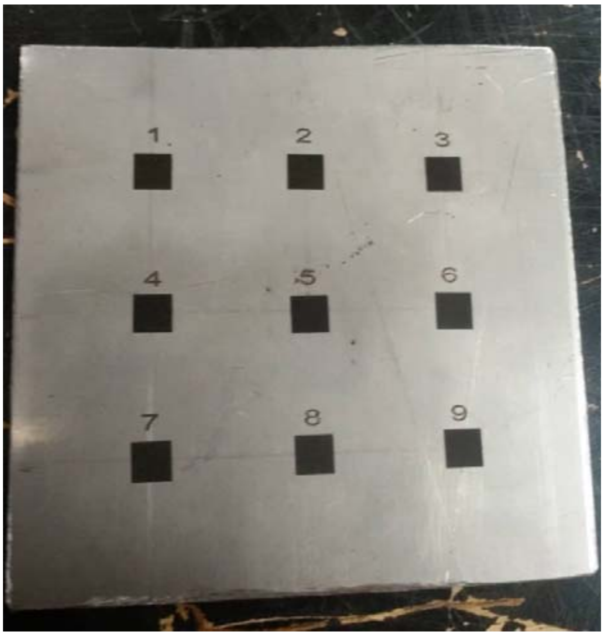


Figure 4 Surface roughness work pieces

Surface roughness data is taken by measuring Ra using profilometer. Readings are taken with a cut-off length of 7.5 mm and an evaluation length of 7.5 mm and the average is reported.

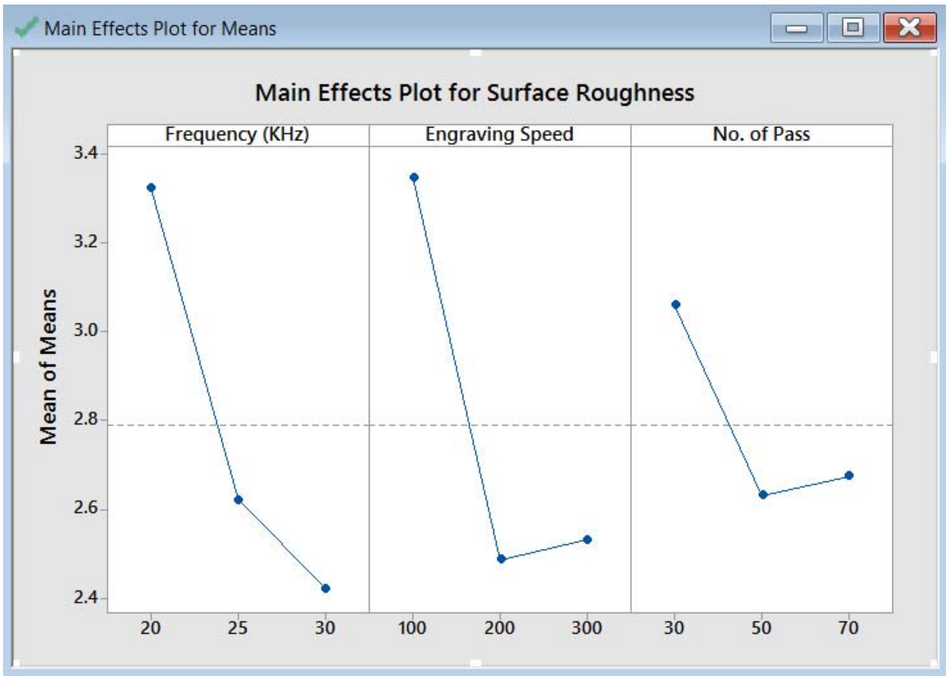


Figure 5 Main Effect Plot for Surface Roughness

5. Conclusion

In the graph, by using the lower the better pattern of surfaces roughness, it is clearly shown that as the frequency increase, then the surface roughness are better. For the engraving speed that applied at 200 mm/sec, it provides better surface roughness. Then 50 number of pass provide the best surface roughness among the test sampling.

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