

# Analysis of Influence of Process Parameters of Laser Cutting on Aluminium Alloy Al6061

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**Abstract** - Laser Beam Machining is a type of modern machining process which includes the use of LASER (Light Amplification by Stimulated Emission of Radiation) to remove the material from the surface of a workpiece. The motive behind choosing this topic as a subject of study is to understand modern machining trend and use of some modern technologies for research regarding development in the field. First, various research papers of many known authors in the field are studied thoroughly. Then experiments are carried out after selection of material for the research. Finally modern and advanced tools utilized to explore results of experiments in the virtual environment. The experiments have been carried out considering various parameters necessary in the field of Laser Beam Machining. One of the key LBM processes which are extensively used in the industry i.e., Fiber Laser Machining are selected for the purpose of the study. Then the results of experiments will be fed to a DOE (Design of Experiments) tool to analyze the results from the experiments and compare them.

**Key Words:** Condition monitoring, Tool Wear, Surface Roughness, Vibrations, LBM, DOE, Reduction in bur formation.

## 1. INTRODUCTION

The use of traditional machining technologies is limited due to the emergence of innovative engineering materials, severe design requirements, intricate shape, and unusual size of workpiece. As a result, it was decided to design some advanced machining processes (AMPs), which are non-conventional machining procedures. Numerous advanced machining processes (AMPs) are used in today's industry, but each has its own set of constraints in terms of workpiece material, shape, and other factors. Advanced machining processes are beam machining processes, jet machining processes, electro discharge machining, ultrasonic machining. Laser Beam Machining (LBM) is a cutting technique that is used to shape a wide range of engineering materials. cutting, drilling, marking, welding, sintering and heat treatment are just a few of the applications for laser beams. Although the laser can be used for turning and

milling, its major application is in the cutting of metallic and non-metallic sheets.

## 1.1 Types of lasers

Solid State lasers and Gas Lasers are two types of lasers used in machining applications. Nd:YAG lasers, Fiber lasers, Diode lasers, and Ti: Sapphire lasers are the different types of solid state lasers. Solid state lasers are categorized as lamp pumped and diode pumped depend on the type of energy source used for excitation CO<sub>2</sub> Lasers, Excimer Lasers, and Copper Vapour Lasers are the three types of gas lasers used in machining. Lasers are categorized as Continuous Wave (CW) and Pulsed Wave (PW) based on their wave properties.

## 1.2 Principle of LBM

Melting, vaporization, and chemical degradation are all stages of the material removal mechanism during LBM. When a laser beam with a high energy density is focused on the work surface, the work volume is heated and transformed into a molten, vaporized, or chemically altered state as the thermal energy is absorbed, that can be easily removed with the help of a high-pressure assist gas jet.

## 1.3 LBM Variation

Drilling (1-D), cutting (2-D) and grooving, turning and milling (3-D), and micromachining of various workpiece materials are the most common LBM configurations. For drilling hundreds of closely spaced holes in structures, laser beam drilling has become the acknowledged and cost effective method. Trepan and percussion laser beam drilling are two forms of laser beam drilling. Trepan drilling entails cutting all the way around the hole's circumference, with no relative movement of the laser or workpiece, percussive drilling 'punches' directly through the workpiece material. The reduction in processing time is a natural benefit of the laser percussion drilling method.

## 2. Literature Review

The study of various parameters on cutting force, surface roughness and flank wear were experimentally conducted on In-situ Al6061-TiC. When cutting speed increased the cutting force and surface roughness decreased. Flank wear increased with increase in cutting speed

[1]. Laser cutting of 6061-T6 aluminium alloy carried out experimentally. The cutting speed increases with the longer pulse duration. The kerf width and taper angle were affected by beam travel direction.

[2]. Surface roughness was tested by varying various cutting parameters on tungsten alloy. The optimum values of cutting speed and laser power were determined for achieving uniform surface roughness.

[3]. The effect of paint removal on fatigue crack growth was investigated. The comparison of crack length on paint stripped and unstripped was done. It was observed that there is no change in conductivity.

[4]. The effect of cutting parameters on kerf width and surface roughness were tested. It was concluded that kerf width and surface roughness increase with increase in laser power.

[5]. The testing of thermography process was done in order to assure the quality. Quasi static tensile tests concluded that the open hole specimen are sensitive to expansion of Heat Affected Zone.

[6]. Effect of different process parameters like pulse frequency, pulse width and speed on dimensional accuracy, surface roughness and burr thickness were investigated. It was observed that frequency affects the surface roughness and burr thickness. Dimensional accuracy can be controlled by changing pulse width.

[7]. Optimum values of the parameters kerf width and kerf deviation found while performing experiment on cutting aluminium alloy by laser beam cutting. Small change in kerf width after increasing laser power and gas pressure was observed.

## 3. EXPERIMENTATION

### 3.1 INTRODUCTION TO DESIGN OF EXPERIMENTS (DOE):-

Design Of Experiments (DOE) is a method used in almost every field of Engineering. It is used for effective solving of problems as well as for improvisation and optimization of Product Designs or Manufacturing Processes. Some common applications Of DOE in the field of Engineering include identification of proper design dimensions and tolerances, achieving robust designs, generating predictive math models that describe physical system behavior, and determining ideal manufacturing settings. In Design of Experiments in the field of Engineering, the main purpose of an experiment is to

predict the outcome by introducing a change of the preconditions, which is represented by one or more independent variables, also known as "input variables".

In DOE, the change in any one or more independent variables is generally hypothesized to result in a change in one or more dependable variables, also known as "output variables". In experimental design, the main concerns include the establishment of validity and reliability. These concerns can be solved by carefully choosing the independent variable, reducing the risk of measurement error, and ensuring that the documentation of the method is sufficiently detailed. Design of Experiments is done with the help of DOE Software. These DOE software have evolved from time to time in accordance with the advancements in the Engineering field. Some of the leading software used for Design of Experiments are JMP, Minitab, Cornerstone & Design-Expert. For our project work, we have selected Design-Expert Version 13 for designing experiments.

In this project, we have used Box-Behnken Response Surface Method for the analysis of outputs of our actual experimentations of Laser Beam Machining (Laser Cutting) on Aluminum 6061 Alloy material. The use of Design-Expert Software helped us to accurately analyze and determine the accuracy of the outcomes of the types of Laser Cutting Operation (Fiber Laser).

### 3.2 Design Of Experiments:-

As mentioned earlier, the Box-Behnken Response Surface Method is used for DOE in this project. The following steps are followed in the designing of experiments in this project

1. Firstly, the experimental data for Fiber laser Cutting is collected.

In the Box-Behnken Response Surface tab of Design-Expert Software, all the experimental data of both cutting operations (Input Parameters or Factors) is fed in the columns given in the first window.

3. Then in the next step, the number of columns for responses (Output Parameter or responses) and their details (Name of the response & its unit) are mentioned.

4. Then the Design-Expert Software presents with a table similar to that presented below

**Table 3.1 :- DOE Input Parameters**

Std	Run	Factor 1 A:Laser Power (watt)	Factor 2 B:Cutting Speed (mm/min)	Factor 3 C:Gas Pressure (MPa)	Response 1 Surface Rough... microns	Response 2 Kerf Width mm	Response 3 Kerf Taper (degree)	Response 4 Striation mm
10	9	8500	1000	1.8				
5	10	8000	2000	1.8				
12	8	8500	3000	0.06				
1	5	9000	2000	1.8				
4	17	8000	1000	0.93				
7	14	8000	3000	0.93				
3	15	8500	2000	0.93				
14	13	9000	2000	0.06				
13	1	9000	1000	0.93				
9	3	8500	2000	0.93				
11	4	8500	2000	0.93				
2	7	8500	2000	0.93				
15	16	8000	2000	0.06				
17	11	8500	3000	1.8				
6	12	8500	2000	0.93				
16	2	8500	1000	0.06				
8	6	9000	3000	0.93				

**Table 3.2 :- Actual Input Parameters**

Run	Factor 1 A: Laser power(Watt)	Factor 2 B: cutting speed(mm/min)	Factor 3 C: Gas Presser (bar)
1	9000	1000	0.93
2	8500	1000	0.6
3	8500	2000	0.93
4	8500	2000	0.93
5	9000	2000	1.8
6	9000	3000	0.93
7	8500	2000	0.93
8	8500	3000	0.3
9	8500	1000	1.8
10	8000	2000	1.8
11	8500	3000	1.8
12	8500	2000	0.93
13	9000	2000	0.6
14	8000	3000	0.93
15	8500	2000	0.93
16	8000	2000	0.6
17	8500	1000	0.93

As mentioned earlier, the Box-Behnken Response Surface Method is used for DOE in this project. The following steps are followed in the designing of experiments in this project.

1. Firstly, the experimental data for Fiber Laser Cutting is collected.
2. In the Box-Behnken Response Surface tab of Design-Expert Software, all the experimental data of both cutting operations (Input Parameters or Factors) is fed in the columns given in the first window.

3. Then in the next step, the number of columns for responses (Output Parameter or responses) and their details (Name of the response & its unit) are mentioned.
4. Then the Design-Expert Software presents with a table like that presented below
5. Then in the next step, we enter the outputs of the experiments which we performed to analyze their reliability, reliability, and their validity. After filling the responses, we get a table like that presented below.
6. After entering the responses from actual experiments, we can begin the analysis of the responses to check for their validity. The option we get after is to configure the response we wish to analyze. The window similar to the following appears
7. After the 'Start Analysis' option, we get several analysis windows like Model Summary, Fit Summary, etc. The important of all and the one which we are concerned about is ANOVA (Analysis of Variance). ANOVA, with the help of suggested Fit model, determines and presents us with the significance of our model along with other factors of which Lack of Fit is important. Lack of Fit indicates the absence of correctness in our model. According to ANOVA of Design-Expert, the Model of our experiment must be significant and Lack of Fit must be insignificant.
8. After getting the ideal model of the experiment, it becomes multiple factors are available in Design-Expert software. The optimization of these is also possible in case of ideal model which still helps us to obtain desired outcomes from the available model of the experiment. easy for us to analyze the outcomes of our model with the help of different types of graphs. Various 2-Dimensional as well as 3-Dimensional graphs with single factor

### 3.4 Steps Involved in Experimentation selection of material

1. The material selected for this research is Aluminium Alloy ( AL 6061).
2. The reason to select Aluminium as the research material is because it has wide number of applications.
3. It is extensively used in defence sectors like Army, Navy & Air Force and in other sectors for which we are conducting this research.
4. Aluminium along with being a durable material, is very workable i.e., one can perform various operations on it without disturbing its original physical properties.

5. Machining operations like drilling, welding, etc. can be done easily on Aluminium without breaking it, which makes it a very reliable material that is trusted by the defence sector.
6. This is because it is corrosion resistant, very durable, temperature resistant and it has high tensile strength.
7. For experimentations, a Aluminium plate of 250mm\*250mm length and breadth respectively and 8mm thickness was selected.

### 3.5 Preparations For Experimentations:-

1. After the selection of material, the actual experimentation work began.
2. Firstly, was the task to select the material to carry out experiments. So, for the experiments AL 6061 was selected.
3. Then the task was to find Laser cutting machines to cut the material.
4. For the study of Laser Beam Machine, we carried out study at Anand Lasers, Narhe for a month. There overall working of Laser Beam Machine was studied.
5. For Fiber Laser Machining experimentations, a machine at Anand Lasers, Narhe was selected.
6. For Fiber Laser cutting, Bystronic AMADA Fiber machine at Anand Lasers was selected. The input power capacity of this machine is 9KW.



Fig 3.1: Controller Screen

### 3.6 Actual Industrial Work:

1. For Fiber Laser cutting, after the selection of Laser Cutting Machine at Anand Laser, laser cutting operations were performed according to the experiment design provided by Design-Expert Software.
2. After placing the Aluminium plate on machine bed for cutting, input parameters i.e., Power, Cutting Speed & Gas Pressure are varied according to the design suggested by Design-Expert Software.
3. Design-Expert Software provided 17 runs for Fiber Laser cutting design. For the types of machining processes, the input parameters were changed for every run according to the provided design with the help of controller setup screen available for changing parameters of the machine.
4. The controller is operated by a trained operator who changes the parameters according to the requirements of the customer. The controller screen is as presented in the Fig. 3.1
5. The controller is operated by a trained operator who changes the parameters according to the requirements of the customer.

### 4. SIMULATION WORK

#### Simulation using Desing-Expert Software

1. The analytical simulation for the Laser Beam Machining project is done. As mentioned earlier, various advanced and wide range of features and graph types of Design-Expert software are used in this project.
2. Also, as mentioned earlier, this project is carried out for one key types of Laser Beam Machining operations i.e., Fiber Laser Machining.
3. With the help of analytical tools in Design-Expert software, we have compared the output parameters of both Laser Machining operations.
4. The output parameters taken in consideration for this project are Surface Roughness, Kerf Taper Angle, & Kerf Width, Striation.
5. All the steps mentioned in Section 3 Design of proposed work were followed to carry out the analysis of the outputs obtained from the experimentations.
6. After conducting the experiments, the outputs were fed in Design-Expert Software & analysis of these outputs was conducted accordingly.
7. As required for the ideal experimental data to analysis it with more efficiency, the model of designed experiments for every output parameter



was obtained to be significant & Lack of Fit was obtained insignificant.

8. Thus, after obtaining optimal conditions for analyzing, 3D Surface Graphs for every output parameter of the types of Lasers Cutting Operations were compared.
9. The final readings for CO2 Laser Cutting are as mention in table.
10. With the help of these factors & responses (Input & Output parameters) of the actual experiments, the observation tables were prepared.
11. Based on this data, the analysis of every output parameter is performed. All the models of every response are obtained to significant & lacks of Fit are not significant. This means that all the models are ideal and all the outputs are valid & reliable.
12. The graphical analysis is also performed for these parameters.
13. To compare both types of Laser Beam Machining, #D Response Surface Graphs to analyze and find the range of optimal input parameters for every output parameter utilized.
14. The Graphical Analysis & Comparison for the output parameters of Laser Beam Operations are as follows.

Run	Factor 1 A: Laser power(Watt)	Factor 2 B: cutting speed(mm/min)	Factor 3 C: Gas Presser (bar)	Response 1: Kerf Taper (degree)	Response 2: Kerf width(mm)	Response 3: Surface roughness (microns)	Response 4: Striation (mm)
1	9000	1000	0.93	1.3	0.397	1.75	0.48
2	8500	1000	0.6	0.789	0.392	1.98	0.8
3	8500	2000	0.93	0.689	0.2	1.8	0.58
4	8500	2000	0.93	0.689	0.2	1.8	0.58
5	9000	2000	1.8	0.877	0.161	1.56	0.47
6	9000	3000	0.93	0.637	0.352	2.169	0.25
7	8500	2000	0.93	0.689	0.2	1.85	0.58
8	8500	3000	0.3	0.392	0.04	1.14	0.46
9	8500	1000	1.8	0.462	0.189	0.412	0.74
10	8000	2000	1.8	0.324	0.11	0.745	0.39
11	8500	3000	1.8	0.498	0.017	1.859	0.38
12	8500	2000	0.93	0.542	0.167	1.89	0.47
13	9000	2000	0.6	0.522	0.411	1.7	0.52
14	8000	3000	0.93	0.453	0.091	1.564	0.33
15	8500	2000	0.93	0.545	0.21	1.609	0.49
16	8000	2000	0.6	0.321	0.189	1.854	0.62
17	8500	1000	0.93	0.382	0.499	1.56	0.48

Table 4.1:- Response of Given Input

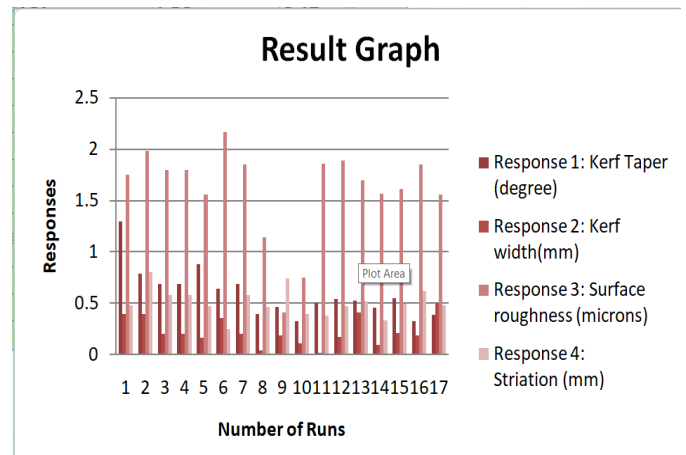


Table 4.2 :- Graphical Results

### 5. CONCLUSIONS

Selected material was Aluminum 6061 Alloy. Fiber as a Laser was chosen to cut the selected material. Considered process parameter like cutting speed, laser power, gas pressure(bar). Selected performance parameters like kerf width, kerf taper angle, surface roughness, HAZ(Heat affected zone), Striation. Using Design of Experimentation software V13 by using Box Behnken method generated a table. It was observed that minimum surface roughness was obtained when laser power was 8500 w, cutting speed was 1000 mm/min and gas pressure was 1.8 Mpa. The minimum value of kerf width was obtained for laser power was 8500 w, cutting speed was 3000 mm/min and gas pressure was 1.8 Mpa.

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