

Analysis of Influence of Process Parameters of Laser Cutting on Al 6061

Prof. S. V. Tawade¹, Ms. Samrudhi Mane², Mr. Ayan Athar³, Mr. Kunal Main⁴

¹ Department of Mechanical Engineering, Navsahyadri Group of Institutes, Faculty of Engineering, Pune, India

^{2,3,4} Department of Mechanical Engineering, Navsahyadri Group of Institutes, Faculty of Engineering, Pune,
(Savitribai Phule Pune University)

Abstract – The research work aims to investigate the impact of process parameters on the quality and efficiency of laser cutting for aluminium alloy (Al6061) and optimize these parameters for improved cutting outcomes. 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 of the research. The final would be the use of modern and advanced tools to study the results of experiments in virtual environment. The experiments will be carried out considering various parameters necessary in the field of Laser Beam Machining. Two key types of LBM processes which are used in more extent 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 tool to analyze the results from the experiments and compare them.

Key Words: Laser, Cutting, Aluminium, Parameters

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 nonconventional 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, electrochemical machining, chemical machining processes, ultrasonic 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.

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. 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 depending on the type of energy source used for excitation. CO₂ 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 (PW). 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

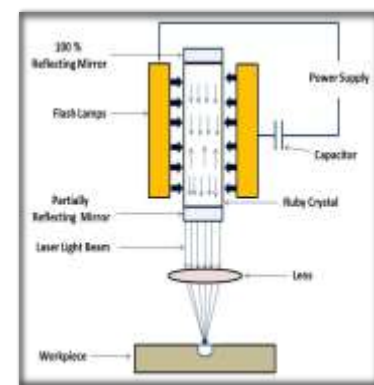


Fig -1: Laser Beam Machine

Laser Beam Machining is a modern machining process in which thermal energy from lasers is used to remove material and it can be performed on wide range of materials. The high frequency of monochromatic light will fall on the surface then heating, melting and vaporizing of the material take place due to impact of photons. Laser Beam Machining is best suited for brittle materials with low conductivity, but can be used on most materials. The above diagram explains the detailed working of fiber Beam Machining. The lasers used in LBM are of various types including gas, solid states lasers, and excimers. Some Of the most commonly used gases consist of He-Ne, Ar, and Carbon Dioxide laser. The use of LBM ranges for various machining processes like welding, cladding,

marking, surface treatment, drilling, and cutting along with other applications.

3.LITERATURE REVIEW

[1] Irene Buj Corral, The most influential terms on roughness are frequency, followed by frequency and by the interaction between pulse width and speed. At low speed, the influence of pulse width on dimensional error is not so important as at high speed. The most influential terms on burr thickness are frequently followed by pulse width and by the interaction between frequency and speed. At low speed, the influence of pulse width o dimensional error is not so important as at high speed. [2] S. D. Jadhav, The material properties include thermal conductivity, melting point and reflectivity governs the selection of laser system for machining. The various stages are involved in the mechanism of metal removal by lasers include melting vaporizing and degrading. The energy transfer by irradiation without any cutting force investigation was found in Al6061 by employing laser it is most sought form an industrial perspective. [3] P. P. Kharche, Higher levels of laser power create higher temperature and melting volume at a lower processing time, which can increase the temperature gradient during laser cutting significantly. The effect of increasing laser power on temperature rise during laser cutting of different materials has been investigated [22,42]. Every material, according to the thermophysical properties and surface condition, has a special threshold level for laser power. [4] Michael Rose, The regression coefficients are provided to meet the law of dimensional consistency [30]. This law of dimensional consistency of regression model has been investigated for kerf width [14,15,27], heat-affected zone (HAZ) [15,27,31], kerf taper angle [14,15,27], and surface roughness [32,33] of laser cutting process in previous studies. Despite previous study [13], all energy-based processing parameters, including laser power (p), scanning velocity (v), and focal position (f.) and gas-based processing parameters including workpiece distance (d), the diameter of the nozzle (n), and gas amplitude (g) are considered to construct regression model. [5] A.M. Kangal [9] The laser optics and CNC (Computer Numerical Control) are used to direct and then to move the laser beam generated onto the material, resulting with a continuous cut. Cut quality depends upon the proper selection of process parameters, since all cutting parameters have a significant influence on the resulting surface quality [3,4]. In general, cutting parameters are adjusted and tuned based on trial-and-error experiments or more rarely on empirical and physical models to provide the desired quality of the cut and maximized productivity. [6] D. Sai Chaitanya Kishore [8] Laser cutting of 6061 T6 Aluminium alloy sheet through the employment of a 150 W multimode pulsed lase is investigated. Two experiment test

eries were carried out . First, linear scans using the maximum average power 150W and different cutting directions and pulse duration were executed, On the basis of these tests, the maximum cutting speeds were determined. In the second experiment test series, cutting tests were performed by varying the beam travel direction, the duration and the cutting speed. [7] Bijoy Bhattacharyya, Biswanathdoloi They are highly reflective to electromagnetic radiation of 10.6 μm ; on the other hand, high thermal conductivity results in heating of the workpiece resulting in poor surface finish and large heat-affected zone which can decrease the mechanical components' fatigue life. Hence, surface quality plays a vital role in

customer satisfaction which is determined by the surface roughness and kerf dimensions of the product. Considerable research was carried out to analyze the laser cutting process, and it was found that many of the researchers focused on the quality characteristics. At high intensity laser beam, the materials refractive index changes thereby exhibiting the non-linear behavior on the material. Hence to achieve proper performance, the parameters have to be controlled precisely.

4.Al 6061 ALLOY OVERVIEW

Aluminium alloys are among the most widely used engineering materials in modern manufacturing industries due to their excellent combination of properties such as low density, good corrosion resistance, high strength-to-weight ratio, and ease of fabrication. Pure aluminum is relatively soft and has low mechanical strength; therefore, alloying elements such as magnesium, silicon, copper, manganese, and zinc are added to improve its mechanical performance and usability in engineering applications. Among all aluminum alloys, Aluminum Alloy 6061 (Al 6061) is one of the most important and widely used materials in engineering applications. It is considered a general-purpose structural alloy and is extensively used in aerospace, automotive, marine, construction, and general manufacturing industries. Aluminum Alloy 6061 belongs to the Al-Mg-Si (aluminum-magnesium-silicon) alloy system. It is a heat-treatable alloy that gains strength through precipitation hardening. The presence of magnesium and silicon forms magnesium silicide (Mg_2Si), which is responsible for the strengthening mechanism after heat treatment. Al 6061 was developed to provide a material with good mechanical strength, excellent corrosion resistance, and good workability. Over time, it has become one of the most commonly used aluminum alloys in engineering applications due to its versatility.

Table -1: Chemical Composition of Al 6061 Alloy

Element	Si	Fe	Cu	Mn	Mg
%	0.4–0.8	0.7	0.15–0.4	0.15	0.8–1.2
Element	Cr	Zn	Ti	Al	
%	0.04–0.35	0.25	0.15	Balance	

Table -2: Physical Properties of Al 6061 Alloy

Property	Value
Density	2.70 g/cm ³
Melting Range	582 – 652 °C
Thermal Conductivity	167 W/m·K
Electrical Conductivity	~40% IACS

Specific Heat Capacity	~0.896 J/g·°C
Coefficient of Thermal Expansion	$23.6 \times 10^{-6} / ^\circ\text{C}$

Table -3 Mechanical Properties of Al 6061 Alloy

Property	Value
Ultimate Tensile Strength	~310 MPa
Yield Strength	~276 MPa
Elastic Modulus	68.9 GPa
Hardness	~95 HB
Elongation	8–12%
Poisson's Ratio	0.33

5. METHADODOLOGY

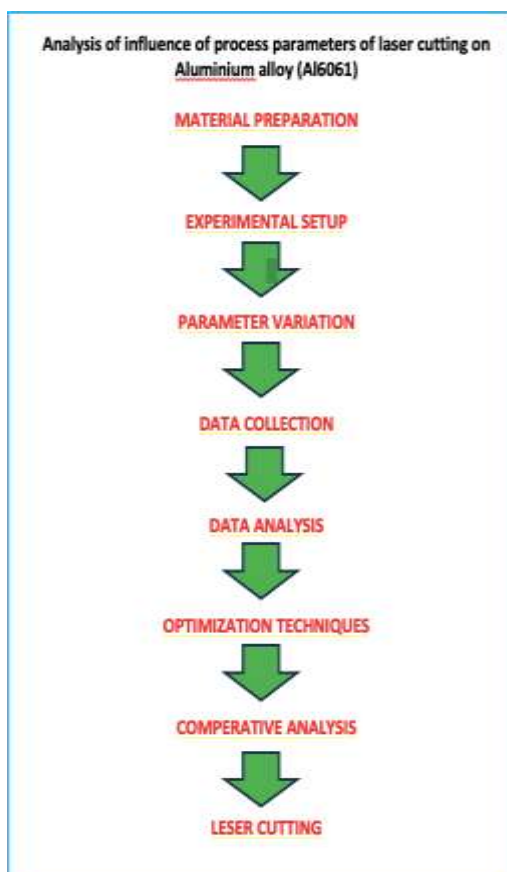


Fig -2 Methadology

6. EXPERIMENYTAL WORK AND RRSULTS

Selection of material : The material selected for this research is Aluminium Alloy (AL 6061). The reason to select Aluminium as the research material is because it has wide number of applications. It is extensively used in defence sectors like Army, Navy & Air Force and in other sectors for which we are conducting this research 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. 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. This is because it is corrosion resistant, very durable, temperature resistant and it has high tensile strength. For experimentations, a Aluminium plate of 250mm*250mm length and breadth respectively and 8mm thickness was selected.

Preparations for Experimentations: After the selection of material, the actual experimentation work began. Firstly, was the task to select the material to carry out experiments. So, for the experiments AL 6061 was selected. Then the task was to find Laser cutting machines to cut the material. 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. For Fiber Laser Machining experimentations, a machine at Anand Lasers, Narhe was selected For Fiber Laser cutting, Bystronic AMADA Fiber machine at Anand Lasers was selected. The input power capacity of this machine is 9KW.

Actual Industrial Work: 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. 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. 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. 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 below: The controller is operated by a trained operator who changes the parameters according to the requirements of the customer. For actual cutting operation, 30mm * 30mm square specimens for every run were cut with the help of Laser Beam Machine. After the cutting operations were performed, the specimens came out to be as followed: After cutting, the quality of specimens differs for different runs. Depending on variance of input parameters, the output parameters i.e., These steps concluded the machining operations for the Laser Beam Machining processes. After this, there was work of measuring the outputs from the experimentations. For the purpose of analysis in this project, we considered 4 main output parameters i.e., Surface roughness, Kerf Taper Angle, Kerf Width & Striation. Further for the taking the readings of the outputs, various methods and machines were used. These measuring tools & machines were available in college laboratories. The output readings of these experimentations were taken with precaution & under supervision of professors. For calculating Surface Roughness, Mitutoyo Surface Roughness Tester machine was used. The probe of the tester oscillates on the surface for which the roughness is to be measured. Then it produces a graph & indicates the Ra value (Average Roughness) of the surface in microns. The tester machine used for calculating surface roughness of every specimen is as presented below:

kerf Width = Kerf Top – Kerf Bottom or Kerf Bottom – Kerf Top

To calculate the four parameter i.e. Striation, a Vernier Caliper was used. Vernier caliper is placed on the workpiece and measure the part on which the marks where produce on

fracture surface that show the incremental growth as shown below.

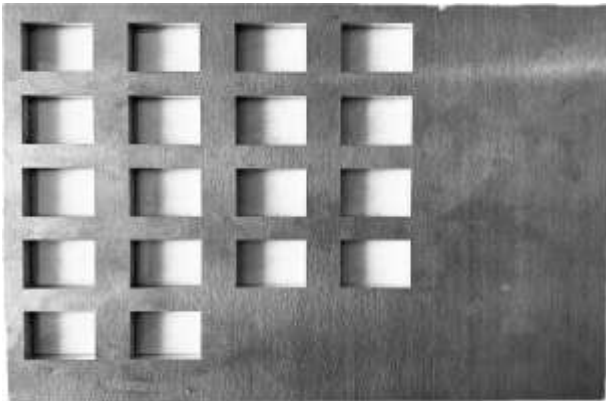


Fig -3 Machined Plates

Machibed specimens



Fig -3 Machined Specimens

Table -4 Experimentation parameters

Std	Run	Laser power (watts)	Cutting Speed (RPM)	Gas Pressure (bar)
1	15	8000	3800	9
2	2	9000	3800	9
3	9	8000	6000	9
4	7	9000	6000	9
5	8	8000	3800	10
6	11	9000	3800	10

7	17	8000	6000	10
8	3	9000	6000	10
9	6	7659.1	4900	9.5
10	14	9340.9	4900	9.5
11	16	8500	3050.03	9.5
12	12	8500	6749.97	9.5
13	5	8500	4900	8.6591
14	4	8500	4900	10.3409
15	1	8500	4900	9.5
16	10	8500	4900	9.5
17	13	8500	4900	9.5

7. CONCLUSIONS

We Selected material of Aluminum 6061 Alloy .We Selected Fiber as a Laser to cut the material. We Consider process parameter like cutting speed, laser power, gas pressure(bar). We 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 we generated a table. By using the DOE table we cut the aluminum material into 17 pieces.Now we have to measure the performance parameters.Then we have to develop the model to predict the performance parameters and analysis of model. Then we have to optimize the process parameters to improve performance parameters. The study investigated the effect of cutting speed, laser power, and gas pressure on the laser cutting of Aluminium 6061 A total of 17 experiments were conducted using the Design of Experiments (DOE) method. The process parameters were optimized using the Linear Regression method. Surface roughness increased with higher laser power and gas pressure, while it remained nearly constant with cutting speed. Kerf width and kerf taper increased with laser power but decreased with higher cutting speed and gas pressure. Striation decreased with an increase in laser power, cutting speed, and gas pressure, improving cut quality. The predicted results closely matched the experimental results, confirming the accuracy and reliability of the developed model. The optimized laser cutting parameters can be used to achieve better cutting quality for Aluminium 6061 alloy.

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