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Experimental Analysis of Laser Cutting Machine

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***Abstract*: -LASER(Light Amplification by Stimulated Emission of Radiation) cutting is one of the best technology developed for the cutting, drilling, micro machining, welding, sintering and heat treatment. It is one of the thermal energy based unconventional process used for cutting of complex profile materials with high degree of precision and accuracy. All cutting parameters have significant influence on quality work. The aim of this study is to relate the CO_2 laser cutting parameters such as laser power and cutting power. The laser beam is typically 0.2mm in diameter with a power of 1-10 kW. Depending on the application selection of different gases are used in conjunction with cutting. Increasing the frequency and the cutting speed, decrease the kerf width and the roughness of cut surface, while increasing the power and gas pressure increases the kerf width and roughness. The relation between the input parameters and the response were investigated. The performance of laser cutting process mainly depends on laser parameter. Laser has been an important tool in the modern industries. Due to its unique properties such as high power density , monochromaticity, coherency and directionality laser has a wide variety of application. It application involves in material processing, medicine, research and development, communications and measurements to name a few. The attractive features of laser machining includes: -Narrow Kerf width and material saving -narrow heat affected zone and low thermal distortiom -non contact process and no tool wear -soft tooling and simple fixturing -easy automation**

Keywords:-Laser cutting, Surface roughness, Process parameter, kerf width, CO_2, Heat affected zone.

1. INTRODUCTION

Laser beam cutting is well-established and effective method of cutting a wide eange of material.In recent time technological advancement can be seen in every area. Laser cutting works by concentrating a high power pulsed laser at a specific location on the material to cut. The energy beam is absorbed into the surface of the material and the energy of the laser is converted into the heat, which melt or vaporize the material. Industrial laser application in manufacturing are primarily in the areas of machining and welding , which accounyts for more than 70% of total laser use catogery in U.S. .It is a non-contact operative method hence a good precise cutting of complex shapes can be achieved. It can cut process material like ferrous metal, non-ferrous metal, stone, plastic, rubber and ceramic. There are many advantage of laser cutting over mechanical cutting, since the cut is performed by the laser beam, there is no physical contact with the material therefore contaminates or impurities cannot enter or get stuck into the material. The advantages of laser cutting include high productivity thanks to the high cutting speeds, narrow kerf width which leads to minimum material lost, straight cut edges, low roughness of cut surfaces, low metallurgical distortions, and easy integration. The two main laser sources which are widely used in laser cutting are CO_2 and Nd:YAG lasers. Nd:YAG laser is an optically pumped solid state laser, working at a wave-length of 1.06 um. CO_2 laser is an electrically pumped gas laser that radiates at wavelength of 10.6 µm. The main operating parameters associated with laser used machining are: laser power, spot diameter of the laser beam, cutting speed, feed rate and depth of cut. The cut quality traits like Edge Surface Roughness (Ra) and Surface Hardness are considered as output parameters. The cut edge is cooled by the gas flow thus restricting the width of the Heat Affected Zone (HAZ). Maximization of the productivity and the cut quality along with Minimization of costs are goals of manufacturers with a limited theoretical and practical background to assist in systematical selection, laser process parameters are usually chosen on the basis of handbook values, other manufactures recommendations and by previous experience. Improper selection of cutting parameters cause high manufacturing costs, low product quality and high waste. The performance of laser cutting process mostly depends on laser parameters. By proper control of the cutting parameters, good quality cuts are possible at high cutting rates. Therefore, it is important to investigate the impact of cutting parameters on quality of cut.

1.1 Working Principle

Laser cutting is a thermal, non-contact and highly automated process well suited for various manufacturing industries to

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produce components in large numbers with high accuracy and surface finish. The highly flammable oxidized gas from the gas cylinder comes in the nozzle where it gets ignited with the amplified light and produces the high intensed flame which imparts on the material and due to that the cutting action on the material takes place. This high intensed flame may be of different gases mainly the gases used are CO_2, O_2, N_2 , etc. depending on the cutting parameters different gases with pressure are adjusted to produce the flame. The main objectives of this flames are Sublimating, Melting, and Burning. The cutting process is executed by moving focused laser beam along the surface of work piece at a constant distance, thereby generating a narrow cut kerf. This kerf fully penetrates the material along the desired cut contour.

This process is successful only if the melt zone completely penetrates the workpiece. Laser metal cutting is therefor generally restricted to thin section. While cutting has been reported through 100 mm sections of steel, the process is more typically used on metal sheets 6 mm or less in thickness.

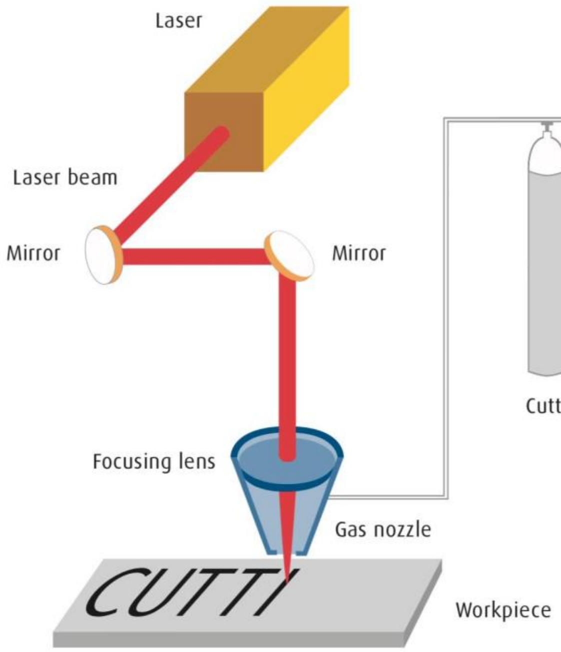

Fig 1.1 Schematic Diagram

2. PROCESS PARAMETERS

The laser cutting has been a major are of research for the cutting of the metals. The various parameter affecting the cutting quality like cutting speed, focal point, laser power, gas pressure, etc. The various parameters are listed which affects the cutting process.

2.1 Surface roughness :- It is the effective parameter representing quality of a machined surface. K.A Ghany & M. Newishy [5] predicted that with the increase in cutting speed and frequency and decreasing laser power and gas pressure roughness reduces. The laser cut surface revels a specific for of unevenness.

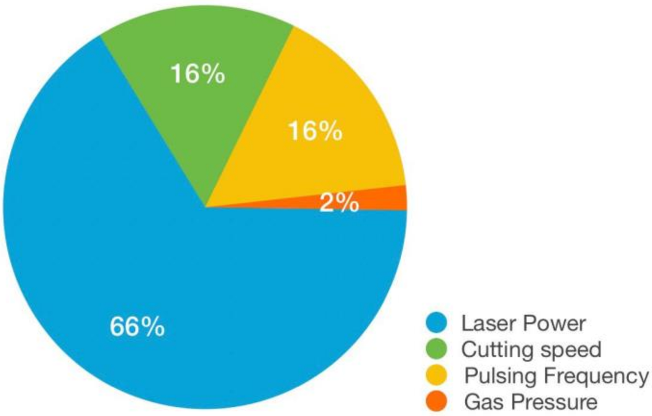

Fig 2.1

2.2 Kerf width:- The major of portion cutaway by laser is known as kerf . The portion of cut is known as kerf width. The kerf width refers to the width of slot that is formed during through-thickness cutting and is normally narrower at bottom surface of workpiece than at the top surface. The kerf width shows the size of the cut and the amount of material wasted, therefore small diameter of laser is required for the less wastage of material. The width of the cut kerf corresponds to circular beam waist size which is determined mainly by the laser beam quality and focus
optics.

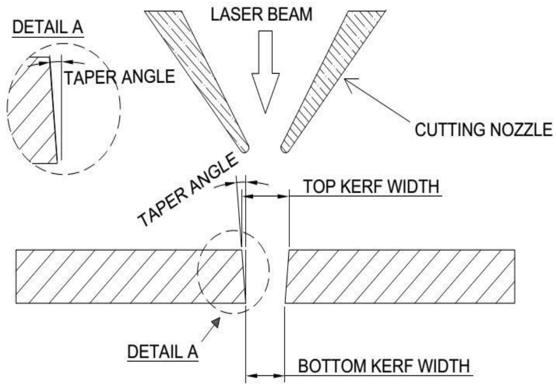

Fig 2.2 Kerf Width

2.3 *Heat Affected Zone(HAZ):-*The HAZ is something that occurs when metal is subjected to high temperature. It has negative impact on the design and structure of the metal. With the mechanical cutting, the shear strength of material surpassed. The majority of the energy converts into heat that influences both life span of the tools and metal to be cut. As increasing gas pressure and cutting speed results in a increase of HAZ width. As the gas pressure increases the power produced due to the exothermic reaction becomes higher and produces higher HAZ width. The increase in laser power and stand off distance results in decrease of HAZ width but their effect seems to be negligible than the effect of cutting speed and gas pressure.

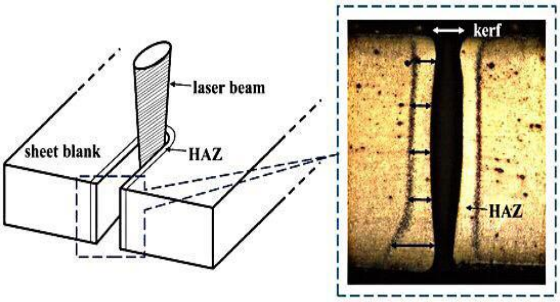

Fig 2.3 HAZ

2.4 *Cutting Speed:-* The cutting speed must be matched to the type and thickness of the workpiece . A speed which is too fast or too slow leads to increased roughness, burr formation and to large drag line. The energy balance for the laser cutting process is such that the energy supplied to the cutting zone is divided in two parts namely: energy used in generating cut and the energy losses from the cut zone. It is shown that the energy used in cutting is independent of the time taken to carry out the cut but the energy losses from the cut zone are proportion to the time taken. Therefore, the energy lost from the cut zone decreases with increasing cutting speed resulting into an increase in the efficiency of the cutting process. The cutting speed must be balanced with the gas flow rate and the power. When oxygen is applied in mild steel cutting, too low cutting speed results in excessive burning of the cut edge, which degrades the edge quality and increase the width of the Heat Affected Zone (HAZ). The speed must be decreased when cutting sharp corners with a corresponding reduction in beam power to avoid burning. The cutting speed for a material is inversely proportional to its thickness. As from the derived formula by[6] M.M Noor, K.Kadirgama and M.M rahman keeping power and tip distance constant and varying the speed of the nozzle the Ra value obtained are shown in fig.3.4.

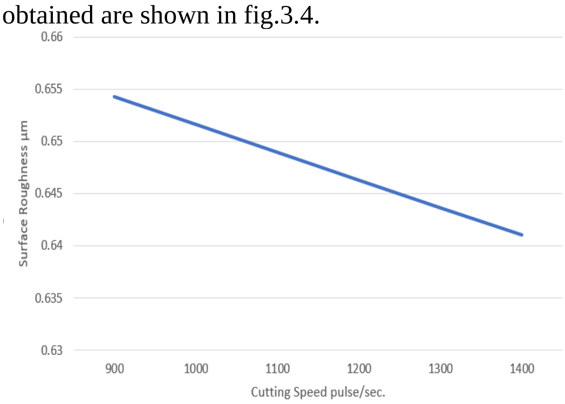

Fig 2.4 Cutting Speed vs Surface roughness

2.5 *Laser Power:-* The laser power must be adjusted to suit the type and thickness of the work-piece. A reduction in the laser power may be necessary to achieve high accuracy on complex shaped work-pieces or very small parts. Laser power is the total energy emitted in the form of laser light per second while the intensity of the laser beam is the power divided by the area over which the power is concentrated. High beam intensity, obtained by focusing the laser beam to a small spot, is desirable for cutting applications because it causes rapid heating of the kerf leaving little time for the heat to dissipate to the surrounding which results into high cutting speeds and excellent cut quality. Additionally, reflectivity of most metals is high at low beam intensities but much lower at high intensities and cutting of thicker materials requires higher intensities. The optimum incident power is established during procedure development because excessive power results in a wide kerf width, a thicker recast later and an increase in dross while insufficient power cannot initiate cutting. High power beams can be achieved both in pulsed and continuous modes; however, high power lasers do not automatically deliver high intensity beams. Therefore, the focus ability of the laser beam is an important factor to be considered.

2.6 *Gas Pressure:-*The material workpiece thickness must be matched to the gas pressure. When torch cutting, thin metal material is cut with higher gas pressure than thicker material . The pressure of gas must be regulated carefully, because the quality of cut is affected by even slight changes in the pressure of gas. If the pressure is too low, the fluid slag remains adhered to the base material, forming a permanent burr or closing the kerf again. If the pressure is too high, the lower edges of the cut are burnt out and often make the cut unusable. In contrast very high pressure cutting thicker workpieces are work at higher gas pressure.

2.7 *Nozzle diameter and standoff distance :-* The nozzle delivers the cutting gas to the cutting front ensuring that the gas is coaxial with the laser beam and stabilizes the pressure on the workpiece. The nozzle orifice determines the shape of the cutting gas jet and quality of cut. Mainly the diameter of nozzle ranges from 0.8mm – 3mm. Due to the smaller size of beam the cut kerf is often smaller then the diameter of nozzle. This distance influences the flow patterns in the gas, which have a direct bearing on the cutting performance and cut quality. Large variations in pressure can occur if the stand-off distance is greater than about 1mm. A stand-off distance smaller than the nozzle diameter is recommended because larger stand-off distances result in turbulence and large pressure changes in the gap between the nozzle and work piece, with a short standoff distance, the kerf acts as a nozzle and the nozzle geometry is not so critical.

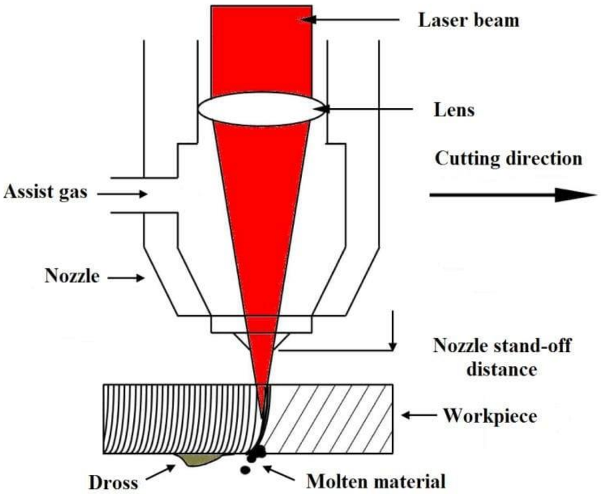

Fig 2.7

3.TYPES OF LASER CUTTING MACHINE

There are three main type of lasers used for cutting – Gas lasers -Crystal lasers -Fiber Laser

3.1 Gas Lasers :- Gas Laser cutting most often known as CO2 laser cutting is completed using a carbon mixed laser . It is made a viable by electrically stimulating carbon dioxide mixture.

3.2 Crystal Laser :- Crystal laser cutting is a process that uses laser made from Nd:YAG and Nd:YVO .These crystals are part of the solid state group, and the crystals allow for extremely high powered cutting . It can be used with both metals and non metals.

3.3 Fiber Laser :- The process for the cutting are continuous wave laser and pulsed fiber laser . It has several similarities to the crystal process, in fact that optical fiber also belongs to the solid state group , and has a wavelength of 1.064 micrometers.

4.EXPERIMENTAL CONCEPTS

Laser cutting is used in industrial manufacturing of cars, aircraft, ships, robots and much more. It can also be used in other, diverse areas – in art and sculpture, architectural model making, cutting fabric in the world of fashion, engraving glass, for film and therater props and making the foam inserts for specialized packaging. It is an essential part of industrial fabrication and there are a wide variety of materials that can be cut or engraved using lasers depending on the type of machine used, from the most delicate paper, through styrene and acrylic to metals of all kinds. Different types of laser are used to cut different materials but the basic principle is the same, energy is converted into a high density, highly focused beam of laser light. Everything in the path of this beam of light is either, melted, burned or vaporized, depending on the application. It enables extreme precision, allowing inexpensive manufacturing of even very tiny objects. It produces a high quality cut surface that rarely needs any additional finishing. It enables the commercial manufacture of objects to a tolerance that would be incredibly expensive and time consuming to achieve by any other method, making it possible for small businesses to become competitive with larger rivals. Equations[26] for determining surface roughness parameters: the standard roughness R_z and the mean arithmetic profile deviation R_a are obtained , based to experimental results, in the form:

$$R_z = 12.528 \cdot \frac{s^{0.542}}{P_L^{0.528} \cdot v^{0.322}}$$

$$R_a = 2.018 \cdot \frac{s^{0.670}}{P_L^{0.451} \cdot v^{0.330}}$$

where: PL(kW) – the laser power, s(mm) – the sheet thickness, v(m/min) – the cutting speed.

4.1 Experimental Procedure: The laser cutting process leads itself to automation with offline CAD/CAM system controlling either three-axis flatbed system or six-axis robots for three-dimensional laser cutting.

4.2 Experimental observations:

Experiment No	Laser Power(P_L) KW	Cutting Speed(v) m/min	Material Thickness mm	Gas Pressure bar	R_a mm	R_z µm
1	1.2	1	12	13	9.8	74.68
2	1.4	1.4	12	13	8.21	61.78
3	1.8	2	12	13	6.51	48.23
4	2.4	3	12	13	5	36.36
5	2.6	4	12	13	4.38	31.78
6	2	4.4	12	13	4.78	35.39

5.RESULT AND DISCUSSION

This experiment have been performed on the CO_2 laser cutting machine with the CNC control. The technical characteristics of the CO_2 Laser are radiation wavelength 10.6 µm.The optimal laser power is 1200 to 2600 W.The focusing system lens is of 28 mm in diameter and of focal distance is 125 mm.The nozzle con opening is 1.6 mm.The material used for experiment is Mild Steel. The work process is carried out by the oxygen process of 98% in purity. Working conditions are the assisting gas is O_2 with pressure of 13 bar, laser power(P_L) is 1.2 to 2.6 KW, Laser spot is on top of the plate surface. In figure it is shown that the surface roughness changes with cutting speed and laser power. 1.2 KW to 2.6 KW of Laser power by cutting with CO_2 laser cutting machine.

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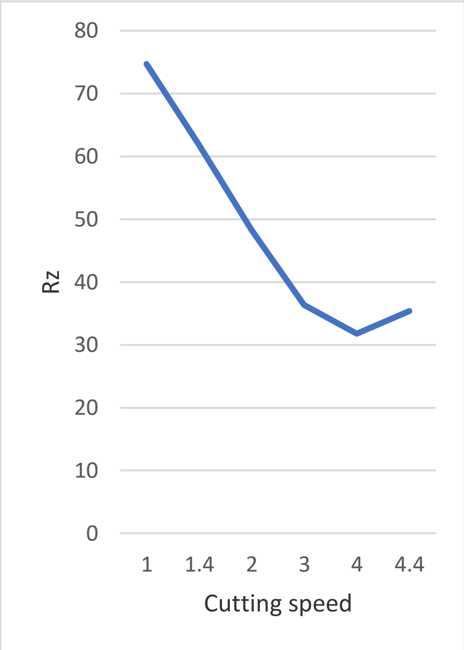
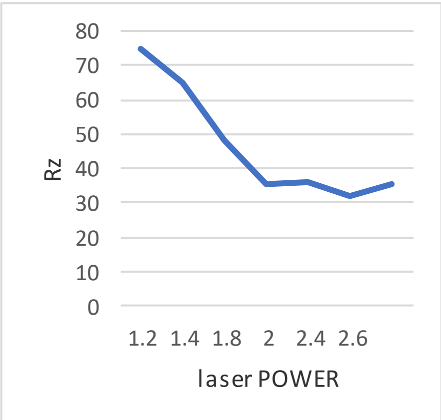
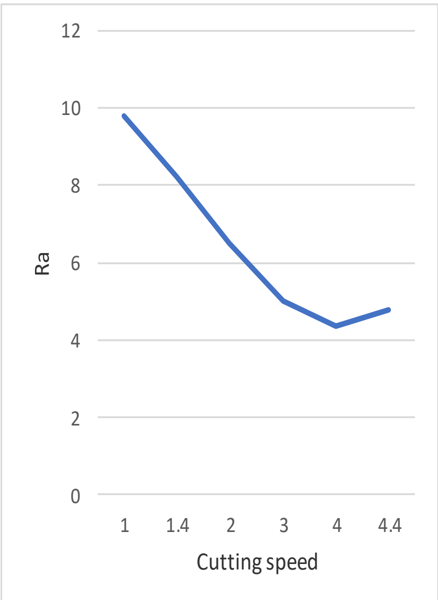


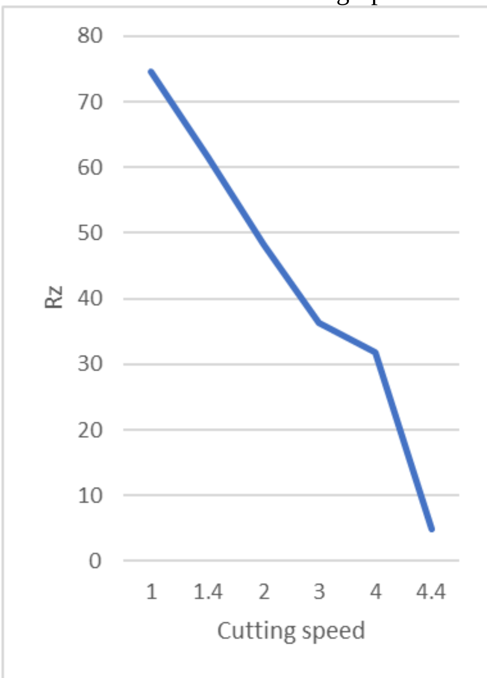
Ra Vs Laser Power



Rz Vs Laser Power



Ra Vs Cutting Speed



Rz Vs Cutting Speed

6. LITERATURE REVIEW

i. In 2008, Avanish Dubey In laser beam cutting (LBC) process, It has been found that the kerf width during LBC is not uniform along the length of cut and the unevenness is more in case of pulsed mode of LBC[8,14]. In this paper, two kerf qualities such as kerf deviation and kerf width have been optimized simultaneously using Taguchi quality loss function during pulsed Nd: YAG laser beam cutting of aluminium alloy sheet (0.9 mm-thick) which is very difficult to cut material by LBC process. A considerable improvement in kerf quality has been achieved.

ii. In March 2015, M Madic has been worked on an experimental analysis and optimization of CO2 laser cutting process on stainless steel plates. In this paper, multi-objective optimization of the cut quality characteristics such as surface roughness, width of HAZ and kerf width in CO2 laser cutting of stainless steel . The applied methodology integrates modelling of the relationships between the laser cutting factors (laser power, cutting speed, assist gas pressure and focus position) and cut quality characteristics using ANNs, formulation of the multi-objective optimization problem using weighting sum method and solving it by CSA (Comparative Sequence Analysis).Cuckoo search method is used for optimization purpose.

iii. Yusof et al. (2008) have found that at all cutting speeds, the kerf width increases by increasing the laser powers while sideline length and percentage over length decreases by increasing laser power. Increasing the cutting speed in pulsed mode led to rough surface and incomplete cutting while in CW mode, increasing the cutting speed with equivalent increase in power, led to better quality and smoother cut surface upto 8 m/min cutting speed. The SR also increases by increasing the peak power, gas pressure, pulse frequency and duty cycle. The surface roughness of the cut specimen can also be changed by changing spot over lap and pulse width

iv. In 2006 Miroslav and Predrag has worked on surface roughness by laser cut. Quality is very important. Observation of the cut surface can reveal two zones: the upper one in the area of the laser beam entrance side and the lower one, in the area of the laser beam exit side. The former is a finely worked surface with proper grooves whose mutual distance is 0.1...0.2 mm while the latter has a rougher surface characterized by the deposits of both molten metal and slag. Standard roughness Rz increases along with the sheet thickness, but decreases with increase of laser power. By cutting with laser power of 800 W standard roughness R is 10 µm for sheet thickness of 1 mm, 20 µm for 3 mm, and 25 µm for 6 mm. Correlation which connected the standard roughness (ten point height of irregularities) and mean arithmetic profile deviation, the linear and exponential relationships can be used.

v. In 2012 Snežana Radonjić and Pavel Kovač has defined process parameter of laser machine Experimental research carried out during laser processing of AISI 314 resulted in an optimal cut . The optimal cut is obtained using the following processing parameters: feed rate 1250 mm/min, laser power 4400 W, focal point 16 mm, gas pressure 17 bars and nozzle distance 7 mm.

vi. In august 2011 B.S.Yilbas has researches on Laser hole cutting into Ti-6Al-4V alloy and thermal stress analysis.

vii. In April 2012 Martin Grepl1, Marek Pag´aˇc1, Jana Petr˚u1 researches on Laser Cutting of Materials of Various Thicknesses and found upon that suit- able parameters for cutting Haynes .To avoid any influence of the surrounding atmosphere on the cut, it is suitable to measure the re- cast layer using a microprobe, and then to perform a microchemical analysis. We recommend that in- creased attention be paid to a study of the recast layer and its increased dependence on cutting parameters. It would be suitable to perform the micro- hardness measurement at the melting boundary of the original material and more importantly, on the recast layer itself. Our paper has contributed a com- prehensive view on the influence of the process parameters on a narrow group of materials used in the aerospace industry.

7.CONCLUSION

Based on the literature review, it has been found that most of the experimental studies on laser cutting are based on the one parameter at a time approach (OPAT). Most of the researchers have investigated the effects of different process parameters on different quality characteristics in laser cutting. The parameters studied in this work are kerf width, surface roughness, nozzle alignment, nozzle diameter standoff distance, focal distance, gas pressure and cutting speed. Consequently, all the parameters are analyzed to get the best result in laser cutting process. Certain parameters are needed to be adjusted to receive a best result for the laser cut on the work piece and enhance the quality of the laser cut. Laser cutting process is capable of cutting complex profiles in most of the materials with a high degree of precision and accuracy and the performance of laser cutting process depends on the input process parameters like laser power, cutting speed, assist gas pressure and stand-off distance on the important performance characteristics like surface roughness and kerf width.The parameters such as laser power, cutting speed, stand-off distance have major impact on surface roughness and kerf width. Whereas, the effect of assist gas pressure over surface roughness and kerf width is less significant. Laser cutting process is capable of cutting complex profiles in most of the materials with a high degree of precision and accuracy.The performance of laser cutting process depends on the input process parameters like laser power, cutting speed, assist gas pressure etc and also on the important performance characteristics like surface roughness, HAZ and kerf width.This paper just presents an overview of the recent experimental investigations in laser cutting of various engineering materials concerned with cut quality like surface roughness, HAZ and kerf width and identifies the most common process parameters and cut quality characteristics.

By referring different review and research paper we can conclude that with the changes in the power the roughness of the material decreases, while the gas pressure also has great effect on the surface roughness but with the high speed the roughness increases any may leads to the increase wider kerf width. For different material different gases are used this parameter has a wider impact on the material roughness and surface finishing. Mainly the CO_2 , O_2 and N_2 are mainly used for the cutting process but with the use oxygen gas the surface may some times the material gets cracked and leads to failure of workpiece. Gas pressure has a major effect on all the quality parameters, i.e., HAZ width, kerf width and roughness.

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