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OPTIMIZATION OF PROCESS PARAMETERS OF FIBRE LASER ON THE CUTTING QUALITY OF STAINLESS STEEL-304 BY USING FULL FACTORIAL DESIGN OF EXPERIMENT APPROACH

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Abstract: Fibre laser technique is a latest technology in laser cutting. This technique is also available at different power levels and very narrow spot size. Stainless Steel is widely used in various industries throughout the world for producing a number of machinery parts. It requires higher power due to the refractivity & hardness. Therefore, fibre lasers are used for cutting Stainless Steel specially. The aim of this work is to study the influence of process parameters like: cutting power, laser power, assist gas pressure on cutting quality like depth of cut and surface roughness. Full factorial Design of Experiment approach will be applied to find the number of experiments runs to perform on the fibre laser machines. A regression analysis was to find the connection between process parameters and response. Also the interaction between process parameters and its effect on response was done by using ANOVA analysis.
Keywords: Cutting Speed, Laser Power, Laser Cutting, Stand-off Distance (SOD), Surface Roughness, Assist Gas Pressure, Design of Experiment (DOE).

I. INTRODUCTION

Laser cutting operation is a thermal based non-contact process that is capable of cutting complex contour on material with high degree of precision and accuracy. It involves process of heating, melting and evaporation of material in a small well defined area and capable of cutting almost all materials. The laser cutting process has developed significantly over the last few decades & has become daily routine in sheet metal fabrication process as a result of attractive cutting velocities, processing flexibility, excellent cutting quality and wide spread application.[1] The first working laser was invented in May 1960 at the Hughes Research Laboratories by T. H. Maiman when he successfully applied an optical pumping technique to an active material (ruby crystal) resulting in the attainment of stimulated optical emission.[2] In Laser cutting process, heating, melting & evaporation is done. Laser can also be defined as Light Amplification by Simulated Emission of Radiation. In industries laser is used as unconventional process for cutting, melting, & welding purposes. Laser has a broad range of applications in various manufacturing and other industries. Laser is used to cut various materials like rubber, ceramic, wood, stainless steel, & many more materials. [3]

II. LASER CUTTING TECHNIQUE

There are a number of LASER techniques are available. The techniques are classified as:
1) CO_2 Laser
2) Nd:YAG Laser
3) Fibre Laser

2.1 CO_2 Laser:

Because of their ability to produce very high power with relative efficiency, carbon dioxide (CO_2) lasers are used essentially for materials-processing applications. The standard output of these lasers is at 10.6 mm, and output power can range from less than 1.5W to 10 kW. Unlike atomic lasers, CO_2 lasers work with molecular passage which lie at low enough energy levels that they can be populated thermally, and an increase in the gas temperature, caused by the ejection, will cause a decrease in the inversion level, reducing output power. There are many types of CO_2 lasers are available. High-power pulsed lasers typically use a transverse gas flow with fans which move the gas through a laminar-flow discharge territory, into a cooling territory, and back again. Low-power lasers most often use waveguide structures, coupled with radio-frequency excitation, to produce small & compact systems. It uses a wavelength of infrared light produced is 10.6 µm. Furthermore, whereas the long CO_2 wavelength removes material thermally through boiling of material, the CO_2 lasers with wavelengths near 200 nm remove material through ablation without any thermal damage to the surrounding material.

2.2 Nd:YAG Laser:

The neodumium (nd) & neodymium yttrium aluminium gamet (Nd:YAG) lasers are identical in style & differ in application. Nd:YAG laser is differ in that the wave length of infrared light produced is 1.06 µm. It uses crystalline material for lasing operation. The Nd:YAG lasers are commercially available in power up to 5 kw.

2.3 Fibre Laser:

Fibre laser is seen as an efficient reliable & compact solution for micro machining which heat affected zone, kerf width & dross could be diminished to a minimum. This because its important advantages as the mixture of high beam power with high beam quality, higher efficiency, small spot sizes & less maintenance. Industrial users of laser technology have demanded laser systems with higher powers. A fibre laser is a type of solid state laser that's been rapidly growing within the metal cutting industries. Unlike CO_2, Fibre technology utilizes a solid gain medium, as opposed to a gas or liquid. The fibre laser produce laser beam and amplified within glass fibre. With a wavelength of only 1.064 micrometers fibre lasers produce an extremely small spot size (approximately up to 100 times smaller compared to the CO_2) making it ideal for cutting reflective metal material. This is one of the main advantages of fibre compared to CO_2.

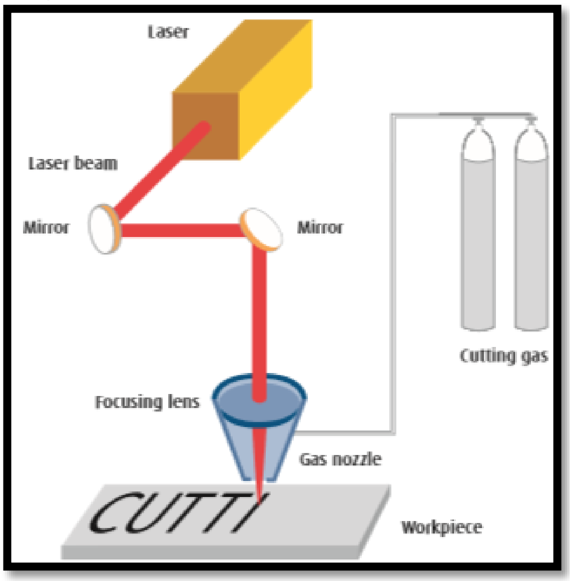


Figure 1: Principle of Laser cutting system[4]

III. LITERATURE REVIEW

V. Shenthilkumar et al[4], the objective of this paper is to investigate the effects of parameters related with CO2 laser cutting of Aluminium plate having thickness of 6 mm. The experiment was carried out on the basis of standard L9 Taguchi orthogonal array in which four laser cutting parameters i.e. laser power, cutting speed, assist gas pressure and stand-off distance were arranged at three levels. From the present research it can be concluded that laser cutting is capable of cutting multiplex profile in most of the material with accuracy & precision. The parameters like cutting speed, laser power, stand-off distance have major effect on surface roughness and kerf width. Whereas the effect of gas pressure over surface roughness and kerf width is less significant.

Mirosla Radovanovic and Milos Madic[5] this paper aim is to improving the cutting quality laser cutting. Laser cutting is widely used as non-contact type machining process. The experimental investigation on laser cutting of various material and identify most common parameters examine cut quality. The review shows that cutting speed, laser power, assist gas and pressure are most affected parameter on cutting quality. The cut quality includes kerf width, surface roughness. The experimental data are optimized using design of engineering and find optimum combination of process parameters. He mansions that cut quality is a very important characteristic on cutting of contour shape. This paper gives results of the experimental research referring to the determination of surface indicators acquired by laser cutting. In experiment observation carried out on 2 zones upper and lower one. The surface finish is good whose mutual distance is 0.1 mm to 0.2 mm while the latter has rougher surface due to the deposits of molten metal and slag. Rz increase with sheet thickness & it will decrease with increment in power of laser. By cutting with laser of 800W quality roughness Rz is 10µm for 1 mm thickness, 20 µm for 3 mm and 25 µm for 6 mm.

Riveiro[6], "The role of the assist gas nature in laser cutting of aluminium alloys" have been studied that the process depends on the removal of the melted material with the aid of a pressurized assist gas. Among the principal variables controlling the process, the assist gas type is an essential factor. This gas is normally chosen taking into account the material to be processed and the required cutting quality. While the effect of the utilization of other assist gas is perfectly studied in cutting steels, the influence of the assist gas type during laser cutting of aluminium alloys is not well studied. This work presents a study on the influence of different assist gases (argon, nitrogen, oxygen and air) on the edge quality and its surface chemistry during laser cutting of a typical Al-Cu alloy. After investigation the Results indicate a clear influence of the assist gas nature on the finishing characteristics. Formation of oxides and nitrides were observed to modify the cut quality and cutting speed. Oxygen, nitrogen and compressed air react to a greater or lesser extent with the molten material generating a large amount of oxides and/or nitrides. This widely affects the cutting speed and cutting quality of the obtained cuts. On the other hand, argon was arisen as the more efficient assist gas to obtain standard quality results and with the higher efficiency. Argon is the best choice for processing Al-Cu alloys from the point of view of quality & efficiency.

Table 1: Experimental Values Of Cutting Parameters[4]

Experiment	**Laser Power**	**Cutting Speed**	**Gas Pressure**	**SOD**	**R_a**	**Kerf Width**
1	1	1	1	1	13.335	0.128
2	1	2	2	2	12.555	0.093
3	1	3	3	3	13.940	0.097
4	2	1	2	3	13.545	0.148
5	2	2	3	1	10.457	0.111
6	2	3	1	2	15.176	0.208
7	3	1	3	2	12.5	0.08

					62	8
8	3	2	1	3	13.9 06	0.07 4
9	3	3	2	1	16.2 31	0.16 8

Table 2: Input Parameters Level[4]

Parameters	**Level 1**	**Level 2**	**Level 3**
Laser Power(w)	3000	3100	4000
Cutting Speed (mm/s)	600	800	1000
Assist Gas Pressure	10	12	13
Stand-Off-Distance	0.7	0.8	0.9

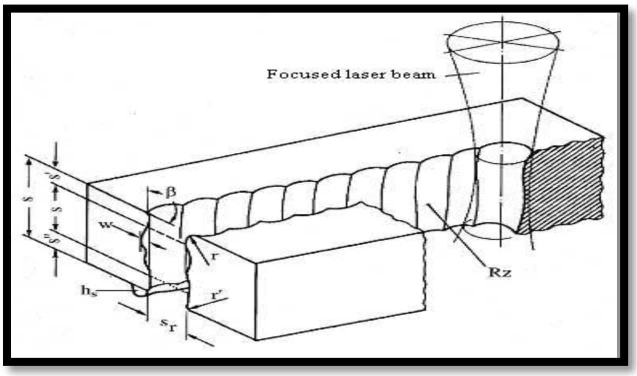


Figure 2: Laser Cut with process parameters[5]

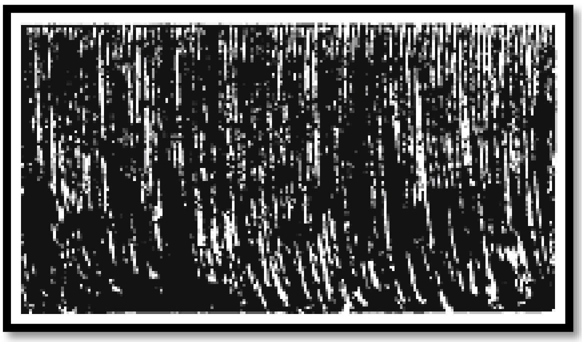


Figure 3: Picture of laser cut[5]

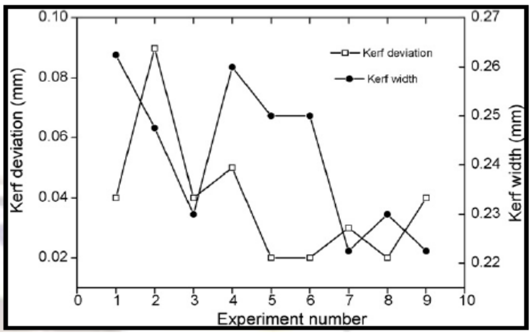
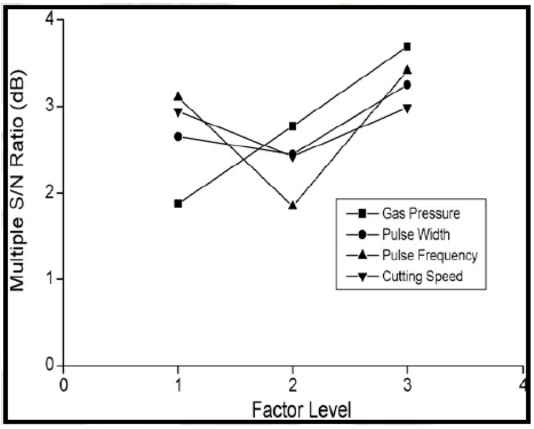


Figure 4: Variation of kerf deviation and kerf width with experiment number[7]



"Figure 5: Effect of factor levels on multiple S/N ratio (0.9mm Al-Alloy sheet)[7]"

P.S. Chaudhari *et al*[7], This paper reviews the research work carried out in the area of laser cutting process and artificial intelligence. In simulated intelligence use for prediction model for given input data of laser cutting operation, there are many other factors that effect on performance of cutting process. Our aim is to identify more effective factor which give the consequential effect on cutting quality of material. After examine the paper conclude that laser power and cutting speed plays a significant effect on laser cutting."Artificial Intelligence" one of the most active branch of computer science that is concerned with the automation of intelligent behavior. This generally demands borrowing characteristics from human intelligence, and applying them as algorithms in a computer friendly way. A more or less workable or efficient approach can be taken depending on the requirements established, which are use for prediction of outcome & also save the time and money of experiment work.

Anil P. Varkey *et al*[8], titanium grade-5 material has high demand in industries but due to its chemical and mechanical properties they have difficulties in conventional cutting operation. The aim of the research is to develop kerf taper and surface roughness by remarkable control factors in CO_2 laser cutting of titanium grade-5 sheet. Titanium alloy sheet has been successfully cut using a CO_2 laser which is much difficult to cut by other conventional process. By the use of design of experiment optimize the responses kerf taper and surface roughness. The suggested optimal solution may be used for cutting titanium alloy for progressive purpose.

Table 3: Control Factors For Kerf Taper & Surface Roughness[8]

Symbol	**Parameters**	**Unit**	**Level 1**	**Level 2**	**Level 3**
A	Gas Pressure	bar	10	15	20
B	Cutting Speed	m/min	1.5	3	4.5
C	Laser Power	watts	1500	3000	4500

D	Focal Point Position	mm	-1	0	1

S. Spadlo *et al*[9], this paper presents the comparison of water jet cutting & laser cutting. Laser cut made with CO_2 laser True flow 5000 machine cutting abrasive jet held on the water-jet. The cutting was carried out on stainless steel EN 1.4016/AISI 430 of having different thickness. In the test, roughness of the surface was measured by using optical profilometer and kerf taper ratio of surface was measured by using high-resolution microscope. The cut surface roughness, waviness and kerf taper ratio are higher in the abrasive water jet machine rather than laser cutting. In this procedure laser cutting speed has to be faster than water jet cutting. The laser cutting technology has established to be better than water jet for cutting thin sheet of stainless steel EN 1.4016/AISI 430.

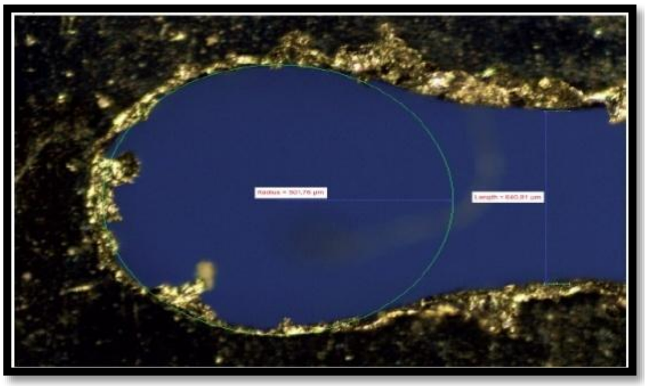


Figure 6: Water Jet Cutting[9]

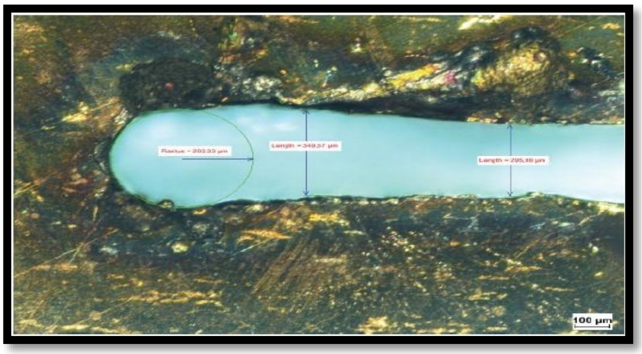


Figure 7: Laser Beam Cutting[9]

K.F.Kleine and K.G.Watkins[10], this paper presents micro cutting resolutions with pulsed fibre laser. The fibre laser concept is a new technology. Fibre laser are using pump laser diodes especially for telecommunication application and therefore it offers excellent controllability of the laser pulse frequency & pulse length. High power fibre lasers are now available at different power levels which are sufficient for micro cutting application. The fibre laser due to its excellent beam quality is able to achieve very small kerf width and is an excellent tool for micro-cutting too. The cut produce by the fibre laser shows very similar features to those which are produce with the help of Nd:YAG laser.

IV. CONCLUSION

The present papers indicate that the process parameters like cutting speed, laser power, assist gas pressure, stand of distance are major influence on cutting quality like kerf width, surface roughness, depth of cut and also vary with type of materials and thickness. After studies some research papers based on influence of process parameters on cutting quality, design of experiment (D.O.E) methods like ANOVA, TAGUCHI, ANN, RSM (Response Surface Method) are very effectiveness to optimized process parameters of laser cutting.

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