Parametric Optimization of Surface Roughness and Kerf Width of Super Duplex Stainless Steel and Titanium Alloy Grade II by using Fiber Laser Cutting .

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ABSTRACT

laser is uniquely versatile tool for processing a remarkable range of metals, alloys, ceramics, glasses, polymers and composites In manufacturing industries. Fiber laser cutting, because of the narrow beam, small spot size, high intensity, depth of focus and easily absorbed by metal surfaces, present research work focuses on “fiber laser cutting process” out of all commercialized techniques for sheet metal cutting. The current research is based on experiments on cutting covering cutting of 2 mm thick super duplex stainless steel and 1.6 mm thick Titanium alloy using the 1000 watt high power fiber laser machine. The cut qualities were analyzed by measuring the surface roughness and kerf width by varying parameters like laser power, cutting speed and gas pressure. Oxygen assist gas was used for cutting of stainless steel.

Keyword:- laser cutting , laser power , cutting speed , gas pressure , surface roughness , kerf width

1.1 INTRODUCTION

Laser is an acronym of Light Amplification by the Stimulated Emission of Radiation. It is electrical-optical devices that produce coherent radiation. The concept use in developing laser is the concept of stimulated emission which was first suggested by Albert Einstein in 1916. [1]

Laser cutting is a thermal cutting process where the beam generates with laser power source, passes through focusing optic and focused beam then passes throughout the material thickness. Based on interaction of the laser beam with the work piece and the role of assist gas in the material removal process, lasers can be used in several ways in the material removal processes during cutting. The three main approaches to cut the material using laser are evaporative laser cutting, fusion cutting and reactive fusion cutting technique. The selection of optimum technique and operation condition depends on the thermo-physical properties of the material, the thickness of the work piece, and the type of laser employed. The incident focused laser melts through the material and the gas jet acting with the laser, removes the melt from the cut zone (e.g. argon for titanium or nitrogen for stainless steel)

2.1 LITRATURE REVIEW

[1]. Mohd yusrizal. Carbon dioxide laser cut quality using different feed rate and constant power level, Faculty of mechanical engineering, University Malaysia Pahang, November 2008

The objectives of this study are:
i. To analyze the effect of different feed rate values with a constant power value to the width of heat-affected zone (HAZ).
ii. To analyze the effect of different feed rate values with a constant power value to the striation frequency.
This research is carried out to verify the laser cut quality by follows the according scopes:
i. Analyze two laser cut quality parameters.

- Striation frequency
- The width of heat affected zone (HAZ)

ii. Run the experiment using ten values of feed rate (1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, and 1900) with a constant power value (25.5 W).
iii. Using Carbon Dioxide (CO2) laser cutter machine and acrylic (Polymethyl Methacrylate, PMMA) as the material to be cut.
iv. Analyzing the data by using manual calculation.

[2] Dr J. Powell, Dr A. Kaplan. Laser cutting: from first principles to the state of the art, Proceedings of the 1st Pacific international conference on application of lasers and optics 2004

This paper presents an overview of the subject of laser cutting. Subjects covered include; Laser-materials interactions, different laser types, the technical and commercial growth of laser cutting and the state of the art.
A Comparison of CO2 and Nd:YAG Laser Cutting.CO2 and Nd:YAG lasers both generate high intensity beams of infrared light which can be focused and used for cutting. Far fewer Nd:YAG lasers are sold as cutting machines compared with CO2 lasers. This is because for general cutting applications, CO2 lasers are most effective. Nd:YAG lasers are only preferred:
A. If very fine detailed work is required in thin section material.
B. If highly reflective materials such as copper or silver alloys are to be cut on a regular basis,
C. If an optical fibre is to be used to transport the laser beam to the work piece. Although both CO2 and Nd:YAG lasers generate infrared light, the wavelength of the CO2 laser light is ten times that of the Nd:YAG machines (10.6 microns and 1.06 microns respectively).

[3] **Jasim Hassan Rasheed The Role of Nozzle and it's Stand off distance in metal–cutting with "CO2 laser – gas jet", Department of physics, , science college Diyala Journal for pure science**

The aim of the present research is to study the role of nozzle and the effect of the stand –off distance which are the most important parameters for cutting mild steel by "CO2 laser – gas jet .
Relationship between the laser power and stand-off distance of nozzle at different cutting speed and thicknesses were achieved. It was found that the power increases with cutting speed for particular stand-off distance. In addition , the laser power proportional with stand-off distance for low cutting speed but out the proportionality at high cutting speed . However, the results of this study are necessary in order to move another step towards understanding and to clarify their benefits for cutting process by laser.

[4] Rajaram N., Sheik-Ahmad J. and Cheraghi S. H. CO2 laser cut quality of 4130 steel, International Journal of Machine Tools & Manufacture Volume 43 (2003) pp. 351-358

Samples of 4130 steel were cut on a CO2 laser cutting system and the combined effects of power and feed rate on kerf width, surface roughness, striation frequency and the size of heat affected zone (HAZ) have been studied. For the range of operation conditions tested, it was observed that power had a major effect on kerf width and size of HAZ, while feed rate affects were secondary. On the other hand, surface roughness and striation frequency were affected most by feed rate. At low power levels, the smallest kerf width and HAZ are obtained and the effect of feed rate is moderate. Low feed rates gave good surface roughness and low striation frequency. For optimum cut quality, kerf width, HAZ and surface roughness are kept at a minimum. However, operating conditions that satisfy these requirements while maintaining high productivity could not be identified.

Conclusion for this project is Power had a major effect on the kerf width, while feed rate played a minor role. Decreasing power and increasing feed rate generally led to a decrease in kerf width and HAZ. At low power levels, increasing feed rate led to a slight decrease in kerf width and a slight decrease in HAZ. At high power levels, increasing feed rate led to a greater decrease in kerf width and a slight increase in HAZ.

[5] Kai Chen and Y. Lawrence Yao. Striation formation and melt removal in laser cutting process, Dept. of mechanical engineering, Columbia university, New York-1999

Kai Chen and Y. Lawrence Yao discussed the mechanism of melt ejection and striation formation. Striation formation is depended on the oscillatory characteristics of thin melt film on the cutting front during melt ejection. Cutting speed determine that liquid film will rapture or generate waves on cutting front. They molded a theoretical model based on instability theory of thin liquid film in a high velocity gas jet and the diffusion controlled oxidation theory. From that they conclude that striation is due to the unstable characteristics of the melt ejection combined with the oxidation oscillation. A cyclic pattern is formed on the cut edge by film rapture results in a sudden increase of the melt removal and thus higher oxidation and melting.

***[6]* Kai Chen,Y. Lawrence Yao, and Vijay Modi. Gas dynamic effects on laser cut quality, Dept. of mechanical engineering, Columbia university, New York-2001**

Paper is about study of Gas jet has a dynamic effect on the laser cutting quality. Laser cutting efficiency and cut quality are strongly affected by gas pressure and nozzle standoff jet impinging on a work piece. The two improvement forces exerted by the gas jet for melt ejection namely shear force and pressure gradient show the same trend as that of mass flow rate with varying gas pressure and standoff distance. Laser cutting of mild steel under the corresponding condition was performed and the cut quality characterized and recast layer thickness was analyzed by them. They found that removal capability of gas jet in terms of shear stress and pressure gradient is affected by the shock structure of the impinging jet interacting with the work piece. Their expe riment produced of cut quality characteristics such as roughness, dross attachment, and recast layer thickness confirms their association with the shock structure and gas removal capability predicted

Assist gas plays an important role in laser cutting in order to eject melt from the cutting front. The cutting efficiency and cut quality are strongly dependent on the effective organization of the gas jet. In industrial practice, convergent nozzles are commonly employed to direct a gas jet to the cut region of the work piece. The operating pressure and the distance of the nozzle from the work piece (standoff) are normally determined empirically in industrial practice. Pressure levels and large standoffs that deviate significantly can lead to poor and unrepeatable cut quality. For a convergent nozzle, the flow downstream of the nozzle exit becomes supersonic if the upstream total reservoir.Pressure is greater than 1.89 bar for air. This is typically the case in most laser cutting operations. The complex nature of the shock structure associated with the supersonic gas jet impinging on a work piece can lead to unreliable behavior and poor cutting quality.

[7] Yogesh D Pawar, Dr. K. H. Inamdar ,Optimization of Quality Characteristics of Laser, JETIR (ISSN-2349-5162) June 2015, Volume 2, Issue 6

In this process the molten material removed with the help of laser beam which is a mixture of gases supplied through laser generators with aid of pressurized gas which referred as assist gas. In this paper different approaches such as Taguchi method, statistical and mathematical models, and response surface methodology are used to evaluate the quality characteristics of laser cut components, such as heat affected zone (HAZ), surface roughness, kerf width. The main aim of this paper is to evaluate above mentioned quality characteristics by varying different input parameters such as laser power, speed, feed, pulsing frequency, gas pressure, duty.

The quality characteristics which discussed in paper are most important related to final product and they are strongly depend on the type of assist gas used for cutting and input parameters such as laser power, speed ,feed etc. work piece material has not significant impact on this quality characteristics. Selection of assist gas for different materials is important in case of laser cutting because assist gas react chemically with the material due to which certain reactions like oxidation takes place which results in poor quality characteristics in the final product.

[8] Mayank N Madia, Prof. Dhawal M Patel, Effect of Focal Length on Surface Roughness of 1mm Thin Brass Sheet, Int. Journal of Engineering Research and Applications Vol. 3, Issue 5, Sep-Oct 2013, pp.349-352

The experiments were performed on as received 1 mm thin sheets of brass. Experiments were conducted using a continuous wave Bhramastra future x fiber laser cutting machine with the 2 kW maximum output power. They cut 25 mm × 25 mm piece from the brass sheet. Surface roughness was inspected using Mitutoyo surface roughness tester SJ-210.

The effects of focal length and Laser Power on quality characteristics of laser cut brass specimens have been studied in this work. As per ANOVA they found that the Factor–focal length is most significant factor for Surface Roughness of brass 1 mm thin sheet. Improper focal length affects the surface roughness and cutting speed. Results revealed that good quality cuts can be produced in brass sheets, at a window of laser cutting speed 7500 mm/min and at a power of 1500 Watts surface is 1.491 μm.

[9] A. SEN, B. DOLOI, B.BHATTACHARYYA, EXPERIMENTAL STUDIES ON FIBRE LASER MICRO-MACHINING OF Ti-6Al-4V. 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India.

Ti-6Al-4V is used extensively in hip and dental implants for its low cytotoxicity and biocompatibility, corrosion resistance, wear resistance and fatigue resistance . In case of aerospace industries, it is widely used in aircraft structural components, airframes etc

The challenge in machining titanium alloys is chiefly the high tool wear associated with the reactivity of titanium with tool materials and its low thermal conductivity. On the other hand laser cutting is a high-speed, repeatable, and reliable method for a wide variety of material types and thicknesses producing very narrow and clean-cut width.For air assisted laser cutting, the reaction of titanium with oxygen and nitrogen produces a thin layer of hard and brittle oxides and nitrides, and generates much thicker HAZ in comparison to that of nitrogen or argon.

In order to overcome these problems titanium alloys may be cut by using inert gases such as argon and helium. Rao etal. have used nitrogen (N2), argon (Ar) and helium (He) for the pulsed laser cutting of 1mm pure titanium Sheet

Nd: YAG laser cutting of Ti and Ti alloy sheets. They found that use of nitrogen assist gas increases surface hardness from 2 to 3 times due to the formation of TiN while a mixture of He and Ar gases reduces the irregular edges and also eliminates the nitride formation

[10] Pradip kumar S. Chaudhari1, Prof. Dhaval M. Patel, Parametric effect of fiber laser cutting on surface roughness in 5 mm thick mild steel sheet (IS-2062), International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 6, August – 2012

This paper investigates experimentally the quality of laser cutting for the mild Steel IS-2062 Grade-A, with the use of a pulsed fibar laser 915,930 and 965 Watt laser cutting system. The quality of the cut has been monitored by measuring the edge roughness (Surface Roughness). This work aims at evaluating processing parameters, such as the laser power, the cutting speed and the gas pressure, for the laser cutting of mild Steel. Result revealed that good quality cuts can be produced in mild steel sheets, at a window of laser cutting speed 1450 mm/min and at a heat input of 915 watts under an assisting O2 gas pressure of 0.8 bar.

The experiments were performed on as received 5 mm thickness sheets of mild steel. Experiments were conducted using a continuous wave YLR – 1000, ytterbium single mode fiber laser with the following specification: 1 kW maximum output power, 1.07 µm wavelength, 14 µm output fiber core diameter. The laser beam was focused using a 125 mm focal length lens, which achieved a beam diameter of nominally 50 µm. Surface roughness was inspected using Mitutoyo SJ-201 surface roughness measuring instrument.

[11] Nukman Yusoff1, Noor Azuan Abu Osman2, Khairi Safwan Othman1, Harizam Mohd Zin1 A STUDY ON LASER CUTTING OF TEXTILES

For textile cutting process, the usage of laser as the cutting agent is still new. M. Jackson *et al*.
reported that conventionally, this process is done by using mechanical cutting agents such as discs, band blades and reciprocating knives. Laser beam is a zero force cutting system and has the potential to cut at higher velocities because the absence of cutting forces removes the bunching up phenomenon which usually experienced by the conventional cutting processes.

The experiments were performed on a low power CO2 laser with maximum output of 500W and maximum cutting speed is 7500 mm min-1. The control of the machine is performed using software provided with the system (C-Cut). Machining parameters: There are two experiments conducted in this study, Experiment A (using single layer of textile and Experiment B (using multiple layers of textiles).

[12] **Vikrant B. Mahajan, Vidya N. Nair, A Literature Review on Fiber Laser Cutting on Stainless Steel-304, IJSRD - International Journal for Scientific Research & Development| Vol. 1, Issue 9, 2013**

The recent up gradation of newer and high strength materials have made the machining task in fiber laser cutting is quite challenging. Thus for the optimum use of all the resources it is essential to make the required mechanical properties, accuracy and quality. This paper reviews the various notable works in field of Fiber Laser Cutting and magnifies on effect of machining parameters on strength, kerf width and surface roughness.

There are different operating parameters which affect different mechanical properties of the material to be cut and also quality of the cutting. These parameters are operating power, cutting speed, assist gas type, and assist gas pressure, focal point, stand-off distance and also material specific properties.

3.1 MATERIALS AND METHODS

Through this research work different materials like Super Duplex Stainless Steel 32750 and Titanium grade II identified which is being cut to check the different parameters of laser machine. Selected material for experimental work whose compositions were shown in table.

ELEMENT	CONTENT (%)
Chromium , Cr	24 – 26
Nickel , Ni	6 – 8
Molybdenum , Mo	3 – 5
Manganese , Mg	1.20
Silicon , Si	0.80
Copper , Cu	0.50
Nitrogen , N	0.24 – 0.32
Phosphorous , P	0.035
Carbon , C	0.030
Sulfur , S	0.020

Table 1 Chemical Composition of Super Duplex Stainless Steel

ELEMENT	CONTENT (%)
Nitrogen , N	0.03
Carbon , C	0.1
Hydrogen , H	0.015
Iron , Fe	0.3
Oxygen , O	0.25
Titanium , Ti	Balanced

Table No.3.2 Chemical Composition of Titanium Alloy Grade 2

4 .1 Company Profile

From the referred contents of chapter 1 and 2, required experimental work is designed and fabricated at R & D division of an esteem organization Shree Sai Industries B-58 Tejendra Opp C.M.C , Near soni ni Chawl, Odhav ,Ahmedabad-382415

Shree Sai Industries is a special purpose machine manufacturing group and is specialized in exclusive design, developing, manufacturing, marketing and CNC industrial machines. Shree Sai Industries , is a leading provider of Laser job work.

4.2 Machine Specification:-

With kind permission at shree sai industries ltd, this research could able to work on identified machine model "brahmastra LD 3015" which is ytterbium fiber laser cutting machine shown in figure

Fif 1 Brahmastra LD 3015

Parameter	Specification
Laser type	Ytterbium fiber
Nominal output power	1000 watt
Drive Feed	Linear
Mode of operation	CW

Nozzle	1.5 mm
Laser cooling water temperature	18-26 C^{o}
Working table	3000 * 1500 mm
Z axis travel	200 / 150 mm
Work piece weight maximum	450 kg
Control method	X, y , and z axis
Travel method	Stationary table And X,Y,and Z axis movement for cutting head
Positioning speed	X axis – 150 m/min y axis – 150 m/min z axis – 15 m/min
Positioning accuracy	$\pm$ 0.1mm
CNC controller	Siemens sinumetric 840D
CNC control method	Fully closed loop method
Assist gas selector	Automatic
Electrical requirement	400 V , 3 phase , 60 Hz
Operating mode	Auto/Manual
Display	10.4* colour TFT

Table 3 specification of Brahmastra LD 3015

4.3 Parameters considered for experiment

Input Parameters

1) Laser Power

2) Cutting Speed

3) Gas Pressure

Output Parameter

1)Surface Roughness

2)Kerf Width

NO	Factor	Levels	Factors level value For SDSS	Factors level value For TiGrade II
1	Laser Power	3	800,900, 1000	900,950, 1000
2	Cutting Speed	3	4000,5000,	4000,5000

			6000	6000
3	Gas Pressure	3	10,12,15	10,12,15

Table 4 Input Parameter of Experiment

Experimental Table:-

NO	LP	CS	GP	Surface Roughness in µ	Kerf Width in mm
1	1000	6000	10	2.58	0.3931
2			12	1.77	0.3724
3			15	1.76	0.4275
4		5000	10	1.98	0.4206
5			12	1.93	0.4068
6			15	1.77	0.4344
7		4000	10	2.003	0.3448
8			12	1.87	0.3586
9			15	1.64	0.4137
10	900	6000	10	1.89	0.3862
11			12	1.63	0.5034
12			15	1.88	0.4758
13		5000	10	1.65	0.4689
14			12	2.03	0.4275
15			15	1.74	0.4896
16		4000	10	1.50	0.3586
17			12	1.17	0.3636
18			15	1.84	0.4206
19	800	6000	10	1.23	0.2689
20			12	1.10	0.2841
21			15	1.30	0.4896
22		5000	10	1.28	0.4137
23			12	1.61	0.3551
24			15	1.20	0.4137
25		4000	10	1.71	0.3517
26			12	1.62	0.3448
27			15	1.23	0.4827

Table 5 Data obtained by measurement of super duplex stainless steel

NO	LP	CS	GP	Surface Roughness in µ	Kerf Width in mm
1	1000	6000	10	2.12	0.5243
2			12	2.77	0.4965

3			15	2.76	0.5175
4		5000	10	2.82	0.5606
5			12	2.64	0.5368
6			15	2.42	0.5744
7		4000	10	2.90	0.4748
8			12	2.77	0.4686
9			15	2.22	0.4937
10	950	6000	10	2.32	0.4462
11			12	2.54	0.5834
12			15	2.67	0.5458
13		5000	10	2.89	0.5089
14			12	2.29	0.4875
15			15	2.02	0.4996
16		4000	10	1.80	0.4486
17			12	1.95	0.4336
18			15	2.05	0.4506
19	900	6000	10	2.10	0.4589
20			12	2.06	0.4672
21			15	2.21	0.4822
22		5000	10	2.25	0.4987
23			12	2.50	0.4878
24			15	2.34	0.4937
25		4000	10	2.41	0.4617
26				2.32	0.4946
27				2.52	0.5429

Table 6 Data obtained by measurement of super duplex stainless steel

5.1 Analysis of Results and Discussions

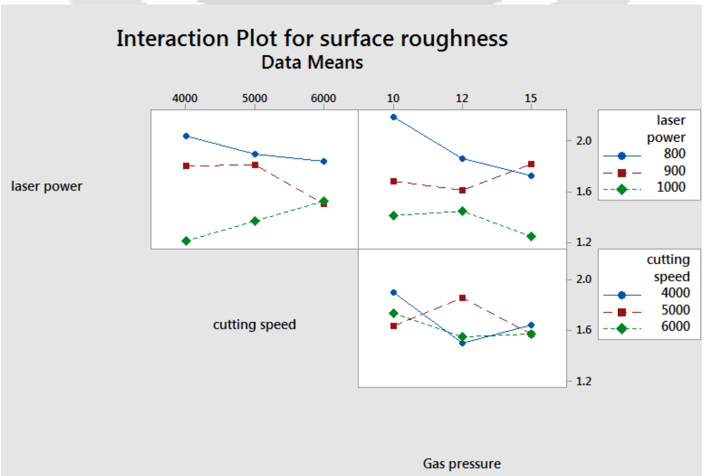

Fig 2 Cutting Speed, Gas pressure and Laser power versus Surface Roughness for SDSS.

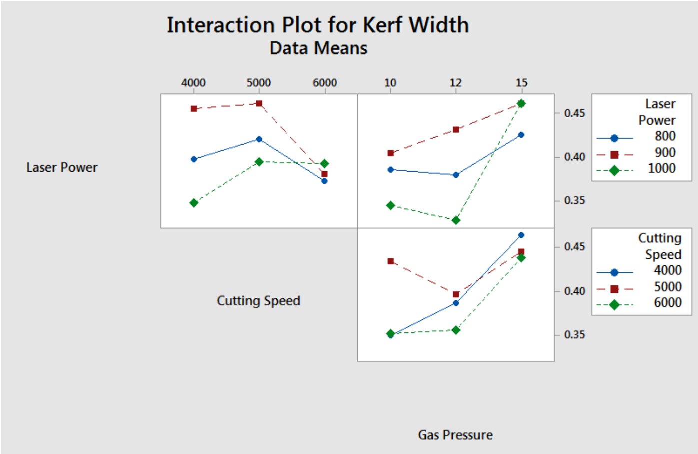

Fig 3 Cutting Speed, Gas pressure and Laser power versus Kerf Width for SDSS.

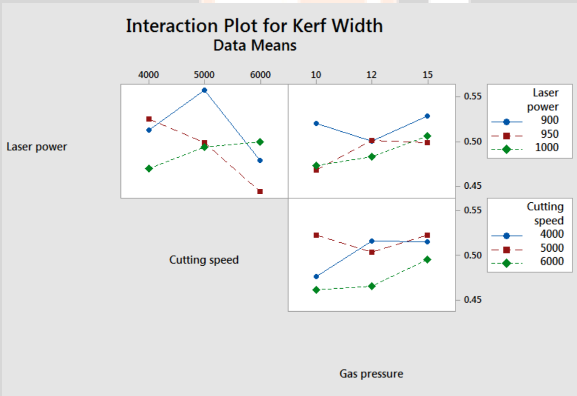

Fig 4 Cutting Speed, Gas pressure and Laser power versus Cutting Speed, versus kerf width. for Ti grade II

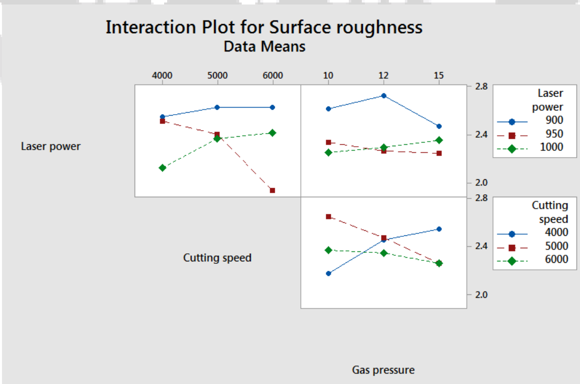

Fig 5 Cutting Speed, Gas pressure and Laser power versus for Surface Roughness Ti grade II.

The experimental condition used for cutting the 2mm thick SDSS and 1.5 mm Titanium grade II is above given **Table3**, summarizes (Table 4) the variation of surface roughness as a fuction of Laser Cutting Speed 4000, 5000,6000 mm/min, Laser Power 800, 900, 1000 Watt and Gas pressure 10, 12 and 15 bar, for Super Duplex Stainless Steel, Laser Cutting Speed 4000, 5000,6000 mm/min, Laser Power 900, 950, 1000 Watt and Gas pressure 10, 12 and 15 bar for Titanium Grade II.

(1) From **Fig. 3** As the Cutting Speed is 4000 to 6000 mm/min, Laser Power is 800 Watts the Gas Pressure is increases from 10 to 12 bar then the Surface Roughness is increases from 1.23 to 1.71 µm. Similarly for same Cutting Speed the Laser Power is taken 900 Watts the Gas Pressure increases 10 to 15 bar then Surface Roughness is increases from 1.17 to 2.03 µm and same Cutting Speed the Laser Power is taken 1000 Watts the Gas Pressure increases 10 to 15 bar then Surface Roughness is increases from 1.64 to 2.58 µm for Super Duplex Stainless Steel.

From **Fig. 5** As the Cutting Speed is 4000 to 6000 mm/min, Laser Power is 900 Watts the Gas Pressure is increases from 10 to 12 bar then the Surface Roughness is increases from 2.06 to 2.52 µm. Similarly for same Cutting Speed the Laser Power is taken 950 Watts the Gas Pressure increases 10 to 15 bar then Surface Roughness is increases from 1.80 to 2.89 µm and same Cutting Speed the Laser Power is taken 1000 Watts the Gas Pressure increases 10 to 15 bar then Surface Roughness is increases from 2.12 to 2.90 µm for Titanium Grade II.

5.2 Conclusions:

The effects of Cutting Speed, Gas pressure and Laser Power on quality characteristics of laser cut Super Duplex stainless steel and Titanium grade II specimens have been studied in this work. As per ANOVA Analysis we can found that the Factor A – LASER POWER is most signeficant factor for Surface Roughness of Super Duplex stainless steel and Titanium grade II

Results revealed that good quality cuts can be produced in mild steel sheets, at a window of laser cutting speed 4000 mm/min and at a heat input of 900 Watts under an assisting N2 gas pressure of 12 bar the surface roughness is 1.10 µm for Super Duplex Stainless Steel .and cuts can be produced in Titanium Grade II, at a window of laser cutting speed 4000 mm/min and at a heat input of 950 Watts under an assisting N2 gas pressure of 12 bar the surface roughness is 1.90 µm

Sources of Variation	**Degree of freedom f**	**Sum of squares S**	**Variance (Mean square)**	**Variance ration F**	**Percentage contribution P**
Factor A	2	1.51	0.755	23.675	52.61
Factor B	2	0.3861	0.1930	6.052	13.45
Factor C	2	0.3361	0.1680	5.2681	11.71
Error (e)	20	0.6378	0.3189	1	22.22
Total	26				100

Table 7 Total contribution of Process Parameter for Surface Roughness and Kerf Width

Sources of Variation	**Degree of freedom F**	**Sum of squares S**	**Variance (Mean square)**	**Variance ration F**	**Percentage contribution P**
Factor A	2	0.3233	0.1616	0.0985	7.94
Factor B	2	0.1264	0.0632	0.0385	3.10
Factor C	2	0.3383	0.1691	0.1031	8.31
Error (e)	20	3.28	1.64	1	80.62
Total	26				100

Table 8 Total contribution of Process Parameter for Surface Roughness and Kerf Width.

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[1] Dr J. Powell, Dr A. Kaplan. Laser cutting: from first principles to the state of the art, Proceedings of the 1st Pacific international conference on application of lasers and optics 2004.

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