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An Experimental Investigation and Evaluation of SS430 Using Nd- YAG Laser Welding Process

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Abstract – Stainless steel as a welded joint has very important applications in industry. In this project, laser welding of stainless steel was studied at different values of laser power, pulse width and frequency, and keeping beam diameter as constant. A 9.9 kW ALPHA LASER AL200 Nd:YAG laser was used. The experiments were carried out in two sets on an SS430 ferritic stainless steel plate (100 x 100 x2.5 mm). Metallurgical and mechanical characterizations were carried to evaluate the weld beads. Macro and micro structural analysis is carried done to evaluate the bead profile and microstructures. Mechanical properties of the welded seam were evaluated by hardness and tensile strength testing. Durable joining was achieved only when the laser power is 2.2KW, Pulse width is 3.6 µs and Frequency is 14Hz. The Percentage of contribution found in ANOVA for each Process parameters were result of maximum tensile strength is based on the pulse width-41 percent and result of minimum hardness is based on the Power- 80 percent. The results of the various tests and examinations enabled definition of the best position for the incident laser beam with respect to the joint, for welding together the stainless steels. Microstructure revels that, it contains coarser ferrite grains with randomly distributed carbides. Due to laser beam welding and fast solidification. It forms dendritic grain structure in the outer portion of the weld, and equiaxed axial grains in the central regions of the weld.

Index Terms – Stainless Steel, Laser, Nd-YAG, ANOVA.

1. INTRODUCTION

1.1. Background and Motivation

Laser welding is one of the nonconventional and non-traditional methods to join materials. Laser beam welding has high power density, high heating and cooling rates which result in small heat affected zones (HAZ)]. Industrial lasers are used for welding, cutting, drilling and surface treatment of a wide range of engineering materials. A wide range of materials may be joined by laser- similar metals, dissimilar metals, alloys, and non-metals. In the present scenario demand of the joining of dissimilar materials continuously increases due to their advantages, which can produce very narrow heat affected zone (HAZ), low residual stress, and small welding defects. There is no requirement of the filler metals and high cooling rate favours the formation of a fine microstructure so that can enhanced material strength without undergoing any finishing operations. In this study Nd: YAG laser used which is a solid state laser. AISI 304L stainless steel with pure cupper can be joined by using Nd:YAG laser machine without using filler materials. The effect of the laser process parameters viz. power, velocity, pulse duration and focusing position on the weld joint tensile strength has been investigated. Laser is widely used as a thermal source for industrial applications; this is because of the local treatment, precise operation, and short processing time. One of the important industrial applications of laser processing is the laser welding, which offers considerable advantages over the conventional welding methods. High intensity laser beam melts and partially evaporates the welded material during the process. The laser also has the ability of pulse shaping at pulse repetition rates of up to several kilohertz and with a duration varying from 0.5 to 20 ms .This flexibility gives control of the thermal input with a precision not previously available. The demand for producing joints of dissimilar materials is continuously increasing due to their advantages, which can provide appropriate mechanical properties and good cost reduction . Laser welding is characterized by parallel-sided fusion zone, narrow bead and high penetration. That advantage comes from its high power density, which make the laser welding one of the keyhole welding processes.

M.J.Torkamany[1],et al were investigated Laser welding of low carbon steel to 5754 aluminum alloy was studied in keyhole welding mode in steelon-aluminum overlap configuration. In order to decrease formation of intermetallic components duringlaser welding, effect of laser power, pulse duration and overlapping factor was investigated. Tensile testwas performed to identify the effect of each parameter on the weld. The phase composition was characterizedby energy dispersive spectrometry and Vickers microhardness test and microstructure by opticaland scanning electronic microscopes. Results obtained show that increasing peak power (in constantpulse energy), pulse duration (in constant peak power) and overlapping factor (in constant pulse energyand peak power) will increase percentage of intermetallic components (PIC). On the other hand, decreasingthe mentioned parameters will cause destructive effects such as inadequate penetration depth, spatteringand cavity formation. Improvement in the tensile strength was attributed to low values ofintermetallic components in weld metal. Finally, an optimized peak power, pulse duration and overlappingfactor were reported.

2. RELATED WORK

Xiu-Bo Liu,[2]et.alwere carried out cast Ni-based superalloy K418 turbo disk and alloy steel 42CrMo shaft were conducted. Microstructureof the welded seam was characterized by optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD), energydispersivespectrometer (EDS). Mechanical properties of the welded seam were evaluated by microhardness and tensile strength testing. Thecorresponding mechanisms were discussed in detail. Results showed that the laser-welded seam had non-equilibrium solidified microstructuresconsisting of FeCr0.29Ni0.16C0.06 austenite solid solution dendrites as the dominant and some fine and dispersed Ni3Al __ phase and Laves particlesas well as little amount of MC short stick or particle-like carbides distributed in the interdendritic regions. The average microhardness of the weldedseam was relatively uniform and lower than that of the base metal due to partial dissolution and suppression of the strengthening phase __ to someextent. About 88.5% tensile strength of the base metal was achieved in the welded joint because of a non-full penetration welding and the fracturemechanism was a mixture of ductility and brittleness. The existence of some Laves particles in the welded seam also facilitated the initiation andpropagation of the microcracks and microvoids and hence, the detrimental effects of the tensile strength of the welded joint. The present resultsstimulate further investigation on this field.

S.A.A. AkbariMousavi,[3]et alIn this paper, pulsed Nd:YAG laser welding of 321 austenitic stainless steel and 630 (17-4PH) precipitationhardening stainless steel is being studied. The joints had a circular geometry and butt welded. Studieswere focused on the effects of laser power, beam diameter and pulse duration on the depth and widthof the welds. Microstructures of the welded joints were investigated by optical and scanning electronmicroscopy. The results show that both weld depth and weld width increase with voltage. In addition,the pulse duration have bilateral effects on the weld bead depth and width. Very fine cellular and dendriticstructures were achieved in the weld zone. The martensitic microstructure was achieved in theweld metal adjacent to the AISI 630 side and austenitic–ferritic microstructure was obtained near the AISI321 side. The microhardness tests showed that the maximum hardness was produced for the 630 stainlesssteel side and the minimum hardness was occurred for the 321 stainless steel side.

A. Arun Mani,[4]et. alwere studied, microstructural characteristic of dissimilar welded components (AISI 430 ferritic-AISI 304 austenitic stainless steels) by CO2 laser beam welding (LBW) was investigated. Laser beam welding experiments were carried out under argon and helium atmospheres at 1500W heat inputs and 50-100-150 cm/min, welding speeds. The microstructures of the welded joints and the heat affected zones (HAZ) were examined by optical microscopy, SEM analysis. The tensile strengths of the welded joints were measured. The result of this study indicated that; the width of welding zone and HAZ became much thinner depending on the increased welding speed, on the other hand, this width become wider depending on the increased heat input. Tensile strength values also confirmed this result. The best properties were observed at the specimens welded under helium atmosphere, at 1500 W heat input and at 100 cm/min welding speed.

Han Guo Ming,[5]et.alwere experimentally analyzed distribution of the temperature field in laser welding based on stainless steel 304 sheet was dynamically simulated by the FEA software – ANSYS in this paper. In view of the characters of laser welding, a travel heat source combined with the body loads was designed by analyzing both the temperature relativity of the thermal physical parameters of material and latent heat of fusion and the effect of convection radiation on temperature field. Considering the high nonlinear of the laser welding process, the transition element modeling was adopted. During load history, a residue control method was taken to ensure the precision of node selection. Through the calculation, it was shown that the simulation results of weld shape were in accordance with the experimental results.

3. EXPERIMENTAL WORK

3.1. Nd:YAG Laser:

The Nd:YAG laser is commonly used type of solid-state laser in many fields at present because of its good thermal properties and easy repairing. The generation of short pulse duration in laseris one of the researcher areas. Nd:YAG is chosen for most materials processing applications because of the high pulse repetition rates available [19]. The power supply of pulsed Nd:YAGlaser is designed to produce a maximum average power. The beam quality and output power aredepending on length of resonator [19]. The beam quality is important to the laser designer because the quality of a given beam profile depends on the application for which the beam is intended. The beam quality can be improved by inserting an aperture inside the resonator in order to reduce the effective radius of the gain medium [19]. Nd:YAG laser can be used for direct energy conduction welding of metals and alloys; the absorptive of metals increases as wavelength decreases. Since conduction welding is normally used with relatively smallcomponents, the beam is delivered to the work piece via a small number of optics. Simply beam defocusing to a projected diameter that corresponding to the size of weld to be made [19].

3.2. Processing parameters:

Processing is normally carried out at room temperature in a clean environment. Appropriate fixturing is needed to ensure that the parts do not move relatively to one another welding to prevent misalignment and the formation of gap. Molten weld metals are protected from environmental contamination by a quiescent blanket of inert shielding gas such as argon.

Figure 1 UW-600A

Specifications of "UW -600A given bellow

Wavelength	1064nm
Maximum Average Length	300W
Pulse Energy	150 MJ -80J
Peak Pulse Power	9.9 KW
Pulse Duration	0.5MS-20MS
Pulse Frequency pulse,20Hz -30Hz	Single
Focus Diameter	1100* 120 mm

3.3. Material properties:

Grade 430 is a ferritic, straight chromium, non-hardenable grade, combining good corrosion resistance and formability characteristics with useful mechanical properties. Its ability to resist nitric acid attack permits its use in specific chemical applications but automotive trim and appliance components represents its largest fields of application. Grade 430F is the free-machining version of this grade, available in bar form for use in automatic screw machines. Grade 434 is the molybdenum bearing version of Grade 430 and has the same useful combination of properties. Its molybdenum addition improves corrosion resistance.

Table.1 chemical composition of SS430

Material	C%	M%	Si%	Cr%	S%	P%	N%
SS430	0.12	1	1	16-18	0.03	0.04	0.5

These properties for 430 are specified for flat rolled product (plate, sheet and coil) in ASTM A240/A240M. Similar but not necessarily identical properties are specified for other products such as forgings and bar in their respective specifications. Properties of Grade 430F are specified for bar in ASTM A582.

Applications

Typical applications for 430 grade include:

- Linings for dish washers
- Refrigerator cabinet panels
- Automotive trim
- Lashing Wire
- Element Supports
- Stove trim rings
- Fasteners
- Chimney Liners

4. EXPERIMENTAL DESIGN

4.1 TAGUCHI DESIGN

Basically, experimental design methods were developed original fisher. However experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of the process parameters increases, to solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal – to – noise (S/N) ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristics in the analysis of the S/N ratio, i.e., the – lower – better, the – higher – better, and the – nominal – better. The S/N ratio for each level of process parameter is compared based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio Furthermore, a statistically significant with the S/N and ANOVA[3] analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems. The formulae for signal to noise ratio are designed so that an experimenter can always select the largest factor level setting to optimize the quality characteristic of an experiment. Therefore a method of calculating the Signal-To-Noise ratio we had gone for quality characteristic. They are

1. Smaller-The-Better,
2. Larger-The-Better,
3. Nominal is Best.

4.2 DESIGN OF EXPERIMENT

Process parameters and their levels responses for all noise factors for the given factor level combination on Table2

Levels	**Process parameters**		
	POWER KW	**PULSE TIME μs**	**FREQUENCY HZ**
1	2.2	3.2	10
2	2.4	3.6	12
3	2.6	4.0	14

Table 2

4.3 PROCESS PARAMETER

SL.NO	**POWER KW**	**PULSE TIME μs**	**FREQUENCY HZ**
1	2.2	3.2	10
2	2.2	3.6	12
3	2.2	4.0	14
4	2.4	3.2	12
5	2.4	3.6	14
6	2.4	4.0	10
7	2.6	3.2	14
8	2.6	3.6	10
9	2.6	4.0	12

Process Parameter - Table 3

5. EXPERIMENTAL ANALYSIS AND OPTIMIZATION

5.1 ROCKWELL HARDNESS TEST

1. Rockwell Hardness systems use a direct readout machine determining the hardness number based upon the depth of penetration of either a diamond point or a steel ball. Deep penetration indicated a material having a low Rockwell Hardness number.

2. However, a low penetration indicates a material having a high Rockwell Hardness number. The Rockwell Hardness number is based upon the difference in the depth to which a penetrator is driven by a definite light or “minor” load and a definite heavy or “Major” load.

3. The ball penetrators are chucks that are made to hold 1/16” or 1/8” diameter hardened steel balls. Also available are ¼” and ½” ball penetrators for the testing of softer materials.

4. There are two types of anvils that are used on the Rockwell hardness testers. The flat faceplate models are used for flat specimens. The “V” type anvils hold round specimens firmly.

5. Test blocks or calibration blocks are flat steel or brass blocks, which have been tested and marked with the scale and Rockwell number. They should be used to check the accuracy and calibration of the tester frequently.

Using the “B” Scale;

a. Use a Diamond indenter

b. Major load: 100 Kg, Minor load: 10 Kg

c. Use for Case hardened steel titanium, tool steel.

d. Do not use on hardened steel

SL.NO	POWER KW	PULSE TIME µs	FREQUENCY HZ	HARDNESS HRB
1	2.2	3.2	10	62
2	2.2	3.6	12	58
3	2.2	4.0	14	62
4	2.4	3.2	12	64
5	2.4	3.6	14	62
6	2.4	4.0	10	64
7	2.6	3.2	14	68
8	2.6	3.6	10	66
9	2.6	4.0	12	68

Hardness value - Table 4

Table: 5 Hardness and s/n ratios values for the experiments of SS430 laser welding process

TRIAL NO.	DESG	POWER KW	PULSE TIME µs	FREQUENCY HZ	HARDNESS HRB	SNRATIO VALUE
1	$A_1B_1C_1$	2.2	3.2	10	62	-35.8478
2	$A_1B_2C_2$	2.2	3.6	12	58	-35.2686
3	$A_1B_3C_3$	2.2	4.0	14	62	-35.8478
4	$A_2B_1C_2$	2.4	3.2	12	64	-36.1236
5	$A_2B_2C_3$	2.4	3.6	14	62	-35.8478
6	$A_2B_3C_1$	2.4	4.0	10	64	-36.1236
7	$A_3B_1C_3$	2.6	3.2	14	68	-36.6502
8	$A_3B_2C_1$	2.6	3.6	10	66	-36.3909
9	$A_3B_3C_2$	2.6	4.0	12	68	-36.6502

Table:6 Response Table for Signal to Noise Ratios smaller is better

Level	**POWER KW**	**PULSE TIME μs**	**FREQUENCY HZ**
1	-35.65	-36.21	-36.12
2	-36.03	-35.84	-36.01
3	-36.56	-36.21	-36.12
Delta	0.91	0.37	0.11
Rank	1	2	3

Table: 7 Response Table for Means

Level	**POWER KW**	**PULSE TIME μs**	**FREQUENCY HZ**
1	60.67	64.67	64.00
2	63.33	62.00	63.00
3	67.33	64.67	64.00
Delta	6.67	2.67	0.67
Rank	1	2	3

Table: 8. Analysis of Variance for HARD, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% OF CONTRIBUTION
Power KW	2	67.556	67.556	33.778	76.00	0.013	80
Pulse width	2	14.222	14.222	7.111	16.00	0.059	18
Frequency Hz	2	0.889	0.889	0.444	1.00	0.500	1
Error	2	0.889	0.889	0.444			1
Total	8	83.556					100

5.2 TENSILE TEST REPORT

Friction processed joints are evaluated for their mechanical characteristics through tensile testing. A tensile test helps determining tensile properties such as tensile strength, yield strength, percentage of elongation, and percentage of reduction in area and modulus of elasticity. The welding parameters were randomly chosen within the range available in the machine. The joints were made with random parameters and evaluate tensile strength and burn off. Then the joints were made and evaluate the mechanical and metallurgical characteristics. The laser welded specimens were prepared as per the ASTM standards. The test was carried out in a universal testing machine (UTM) 40 tones FIE make.

SL.NO	**POWER KW**	**PULSE TIME μs**	**FREQUENCY HZ**	**T.LOAD KN**	**T.STRENGTH KN/mm^2**
1	2.2	3.2	10	16.4	0.215
2	2.2	3.6	12	15.3	0.202

3	2.2	4.0	14	16.8	0.220
4	2.4	3.2	12	14.4	0.189
5	2.4	3.6	14	16.8	0.217
6	2.4	4.0	10	14.4	0.280
7	2.6	3.2	14	13.7	0.180
8	2.6	3.6	10	12.0	0.155
9	2.6	4.0	12	16.4	0.212

Table:9 Tensile strength value

Table:10 Tensile strength S/N ratios values for the experiments of SS430 laser welding process

TRIAL NO.	**DESG**	**POWER KW**	**PULSE TIME µs**	**FREQUENCY HZ**	**T.STRENGTH KN/mm^2**	SNRATIO VALUE
1	$A_1B_1C_1$	2.2	3.2	10	0.215	-13.3512
2	$A_1B_2C_2$	2.2	3.6	12	0.202	-13.8930
3	$A_1B_3C_3$	2.2	4.0	14	0.220	-13.1515
4	$A_2B_1C_2$	2.4	3.2	12	0.189	-14.4708
5	$A_2B_2C_3$	2.4	3.6	14	0.217	-13.2708
6	$A_2B_3C_1$	2.4	4.0	10	0.280	-11.0568
7	**$A_3B_1C_3$**	**2.6**	**3.2**	**14**	0.180	-14.8945
8	$A_3B_2C_1$	2.6	3.6	10	0.155	-16.1934
9	$A_3B_3C_2$	2.6	4.0	12	0.212	-13.4733

Taguchi Analysis: TS versus POWER, PULSE WIDTH, FREQUENCY

Table: 11 Response Table for Signal to Noise Ratios Larger is better

Level	**POWER KW**	**PULSE TIME µs**	**FREQUENCY HERTZ**
1	-13.47	-14.24	-13.53
2	-12.93	-14.45	-13.95
3	-14.85	-12.56	-13.77
Delta	1.92	1.86	0.41
Rank	1	2	3

Table: 12 Analysis of Variance for TS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% OF CONTRIBUTION
Power KW	2	0.0033136	0.0033136	0.0016568	1.83	0.354	35

Pulse width	2	0.0039476	0.0039476	0.0019738	2.18	0.315	41
Frequency Hz	2	0.0003882	0.0003882	0.0001941	0.21	0.824	5
Error	2	0.0018142	0.0018142	0.0009071			19
Total	8	0.0094636					100

S = 13.4205 R-Sq = 97.89% R-Sq(adj) = 91.56%

5.3 DEPTH OF PNETRATION

Inadequate weld bead dimensions such as shallow depth of penetration may contribute to failure of a welded structure since penetration determines the stress carrying capacity of a welded joint .To avoid such occurrences the input or welding process variables which influence the weld bead penetration must therefore be properly selected and optimized to obtain an acceptable weld bead penetration and hence a high quality joint. To predict the effect of welding process variables on weld bead geometry and hence quality researchers have employed different techniques.

5.3.1 BEAD WIDTH AND DEPTH OF PENETRATION VALUES

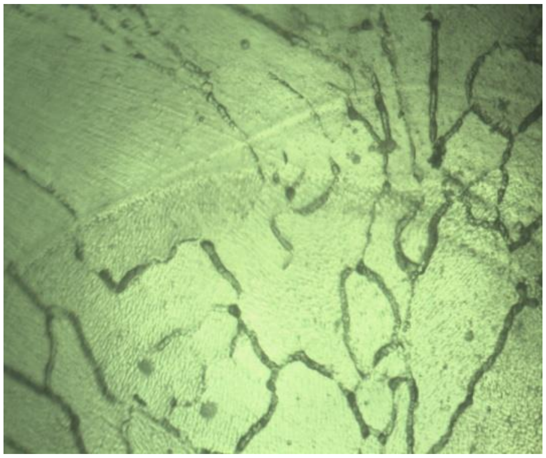
Sl.no	Area	Mean	Min	Max	Angle	Length
1	0.064	169.357	126	197.333	180	3.009
	0.04	160.976	100.701	200.667	91.975	1.858
2	**0.024**	**148.313**	**118.804**	**179.451**	**3.366**	**1.09**
	0.044	**110.364**	**64.083**	**164.5**	**88.21**	**2.05**
3	0.051	163.325	110.054	192.937	-178.452	2.37
	0.034	140.698	63	172	90	1.6
4	0.036	112.881	45.487	167.936	-2.203	1.666
	0.023	85.261	39.333	168	90	1.088
5	0.051	161.239	141.153	178.559	-3.094	2.372
	0.022	158.236	92.333	190.667	90	1.024
6	0.029	153.642	131.413	168.667	2.726	1.346
	0.021	131.56	61	164.733	93.814	0.962
7	0.041	143.841	104.667	169.333	0	1.921
	0.019	97.111	64.667	150.667	90	0.896
8	0.038	179.135	91.333	245.667	180	1.793
	0.025	190.43	98.444	233.204	86.82	1.154
9	0.039	183.204	151.667	221	-177.955	1.794
	0.022	201.771	118	228.667	90	1.024

Various Sizes Of Bead Widthand Depth Of Penetration Laser Welding Process Tabel 11

6. MICROSTRUCTURAL ANALYSIS

The microstructural examinations (microstrictural analysis, phase analysis) were carried out with the help of an image analyser (Model: Olympus DMI3000M).

6.1 MICROSTRUCTURE ANALYSIS IMAGES-SAMPLE NO-3



Parameter

Power-2.2 Kw

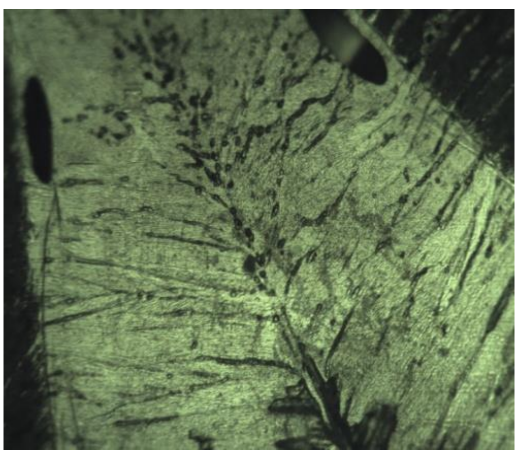
Pulse Time-4 µs

Frequency-14-HZ

ETCHANT:10% Oxalic acid etch

Location:Weld Zone

6.2 MICROSTRUCTURE ANALYSIS IMAGES-SAMPLE NO-6



Micro Examination:

Parameter

Power-2.4 Kw

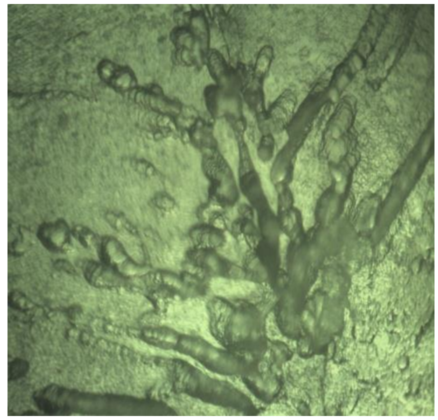
Pulse Time-4 µs

Frequency-10-HZ

ETCHANT:10% Oxalic acid etch

Location:Weld Zone

6.3. MICROSTRUCTURE ANALYSIS IMAGES-SAMPLE NO-6



Micro Examination:

Parameter

Power-2.6 Kw

Pulse Time-4 µs

Frequency-12-HZ

ETCHANT:10% Oxalic acid etch

Location: Weld Zone

7. RESULT

Microstructure revels that, it contains coarser ferrite grains with randomly distributed carbides. Due to laser beam welding and fast solidification. It forms dendritic grain structure in the outer portion of the weld, and equiaxed axial grains in the central regions of the weld.

8. CONCLUSION

From the investigation on and mechanica property of laser butt welding of SS430 steel, conclusions were summarized as following Nd: YAG laser welding of stainless steel was carried out by keeping the focal diameter constant (1.8 mm) and varying the other three main laser welding parameters, i.e. first speed was fixed and laser power,pulse timeasewellas frequency were varied. Parameter wereselected through design of experiments. Finally we concluded the suitable input parameter for SS 430 steel in LASER welding process

According to the Taguchi design optimized parameter for maximum tensile strength

OPTIMAL CONTROL FACTOR

1. Tensile strength-A1(Power -2.2KW)B2(Pulse width -3.6µs)C3(Frequency-14Hz)

According to the Taguchi design optimized parameter for mimimum Hardness

1. 2. Hardness- -A1(Power -2.2KW)B2 (Pulse time -3.6µs)C3(Frequency-14Hz)

PERCENTAGE OF CONTRIBUTION OF PROCESS PARAMETER

1.Tensile strength–powe72%-

2. Hardness - Power 80 % -

Microstructure revels that, it contains coarser ferrite grains with randomly distributed carbides. Due to laser beam welding and fast solidification. It forms dendritic grain structure in the outer portion of the weld, and equiaxed axial grains in the central regions of the weld.

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