EXPERIMENTAL INVESTIGATION ON AISI 316L MATERIAL USING LASER BEAM WELDING PARAMETERS

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ABSTRACT

The SS316L is widely used *in under water, marine, oil* and *gas industries, boilers, evaporators, pressure vessels etc,.* It have *high corrosion resistance* and *offers suitable performance in the hot de-aerated seawater.* These are used in oil and gas tansistion pipeline due to its high corrosion resistance to low temperature, embrittlemenet and corrosion resistance.*The purpose of the study is to develop an optimal welding method for austenitic stainless steel by deducting and controlling the parameters of Nd:YAG pulsed laser beam for use at low temperatures. Characterizations were conducted by optical microscope, to understand the micro structural changes developed during welding. Micro hardness test and tensile tests are carried out at the welded joints to ensure its weldment strength and hardness.* To find the best welding parameters by using *Taguchi's L9 Orthogonal Method. The test results show that ANOVA models are significant to prove the weld efficiency of ASI316L austenitic stainless steel to meet the requirements of* oil and gas industries.

Keyword:- SS316l, Pulsed Nd:YAG Laser, Pipelines, oil and gas industries

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1. INTRODUCTION

316stainless steel is selected because of its distinct properties, cheaper cost and its availability in the market. The SS 316L is a chromium-nickel-molybdenum austenitic stainless steel developed to provide improved corrosion resistance.316L is more resistant than 304 in range of atmospheric environments and many corrosive media due to the increased chromium and molybdenum content. The addition of molybdenum improves general corrosion and chloride pitting resistance. This grade has high corrosion resistance and can be operated at elevated temperature. They find application on exhaust manifolds, furnace parts, heat exchangers, jet engine parts, pharmaceutical and valve and pump trim, chemical equipment, digesters, tanks, evaporators, pulp, paper and textile processing equipment.

Weld quality mainly depends on features of bead geometry, mechanical-metallurgical characteristics of the weld as well as on various aspects of weld chemistry and these features are expected to be greatly influenced by various input parameters like current, voltage, electrode stick-out, gas flow rate, edge preparation, position of welding, welding speed and many more in Nd:YAG laser welding[9,7]. Moreover, the cumulative effect of the mentioned quality indices determines the extent of joint strength that should meet the functional aspects of the weld in practical field of application. Therefore, preparation of a satisfactory good quality weld seems to be a challenging job. The welding investigators have always been in search for better quality of weldment. Welding of austenitic stainless steel in general, and laser welding of such steel in particular, can well be considered as one of the areas where more extensive research may contribute, in a significant way, to the precise control of welding procedure for better and acceptable quality of weldment[11,7]. These are used in heat exchangers, boilers, food industry, and in the areas such as pollution control, oil and gas retrieval, chemical processing, acid production, pickling process reprocessing radioactive wastes. They are best suited for marine environment because it has high immune against the corrosion by sea water.

LNG pipeline are required to maintain sufficient rigidity, ductility and corrosive resistant at low temperature. TIG and MIG welding are recognized as the choices for welding small components. But it requires skill and has some disadvantages. To overcome this, advance high energy laser beam welding is found to be beneficial for welding 316L SS. Pulse width is the most significant factor affecting the tensile strength of 316SS and it is followed by laser power and scanning speed [4,5]. The author Zhongmei Gao et al.,[3] reported hybrid fibre laser weld on SS316L and give relationship between process parameters with an bead geometry. The bead geometry was more differed by laser power compare than other parameters of hybrid fibre laser welding. The author Vicente Afonso Ventrella et al.,[4] reported Nd:YAG pulsed laser weld on hastelloy C276 and give effect of pulse energy to a bead geometry. The bead was fussed completely and the pulse energy increases than the depth of weld and tensile strength of alloy C217 also increased. Then pulse energy is acting major role of bead geometry.

The high laser power and less focal position gives maximum strength of weld. The bead was fused completely on heat affected zone and the hardness value on the weld, base, HAZ was high [Celalettin Yuce et al.,2017]. A. Ruggiero et al.,[11] reported the laser power of 1.1 kW was a optimum input to obtain excellent welded joints produced from austenitic stainless steel AISI316 and low carbon steel dissimilar weld. Then this study the laser power was affected bead geometry and it's a primary factor to produce a quality weld. The author P.Sathiya et al.,[13] reported laser beam welding on AISI 904 super austenitic stainless steel. In this study the maximum tensile strength obtained by laser power and welding speed.

The author Abdel-Monem El-Batahgy et al.,[9] reported the transformation of ferrite to austenite in a fusion zone is strongly influenced by cooling rate which is depended on laser power and/or welding speed. The satisfactory mechanical properties obtained by the parameters such laser power, focal position, frequency. The author F. 0.Olsen[10] give a over review of difference between Co2 laser and Nd;YAG laser . The good result of weld was obtained by Nd;YAG compare than Co2 laser. The penetration of beam was depended high frequencies also. The author Nihkil Kumar et al.,[5] reported the pulse width was most significant factor to produce high tensile strength and also depended on laser power and scanning speed. And mechanical properties are obtained by this welding process is satisfactory. The authorJ. Kellet al.,[2] reported the stress analysis of laser beam welded plate 316L and the stress founded maximum on the weld region. Then the welding should be proper without any diffractions.

As per the literature, suitable welding parameters are found to be beneficial when empolyed on SS316L austentic stainless steel. Then here choose primary parameters which are affecting weld. Hence, in this work an effort is made to join SS316L using Nd:YAG pulsed laser beam welding and also weld and fusion zone microstructural changes that occurred during the welding process and their corresponding effect on the mechanical properties is correlated.

2. EXPERIMENTAL PROCEDURE

2.1 MATERIAL SELECTION

In this work we choosen SS316l austentic stainless steel.Its primary alloying elements of chromium(16-18%),nickel(10-12%),molybdenum(2-3%) and primary element of iron.The chemical compostion shown below in the table(1).

Table No.1 Composition of Material

Element/ Material	C	Si	Cu	Mn	P	S	Ni	Cr	Mo	Fe
SS 316L	0.02	0.46	0.31	1.67	0.02	0.003	10.0	16.6	2.11	68.9

2.2 SPECIMEN PREPERATION

In this study, the base material used is stainless steel 316 with a dimension of 100mm × 150mm × 3mm thick. The samples are prepared using wire electrical discharge machine (WEDM) followed by eliminating oxide layer[6] which is formed during the wire cutting by sand paper and clean it with acetone.

Figure(1). The welded plates

2.3 SELECTION OF MACHINING PARAMETERS

The frequency, laser diameter and power are the parameters that are controlled to get an effective result. And the laser beam welding machine shown in figure (2). The process parameters selected for welding are shown in table (2). The process parameters employed for welding plate shown in table (3).

Table No.2 Process parameters of pulsed laser beam welding

Max mean power	100 W
Pulse frequency	0.5-20 Hz
Focus diameter	0.2-2.5mm

The various process parameters employed on welding plates are shown in the figure (1).The three levels and three factors forms L9 orthogonal array of 9 various experiments.

Table No.3 Process parameters employed for welding on plate

SpecimenNo.	LaserDia.	Power	Frequency
1	0.3	44	8
2	0.3	45	9
3	0.3	46	10
4	0.4	44	9
5	0.4	45	10
6	0.4	46	8
7	0.5	44	10
8	0.5	45	8
9	0.5	44	9

Figure (2). The laser beam welding machine

3. METALLURGICAL CHARACTERISATION

Cross-sectional microstructure is observed for the sample of 100 mm × 75 mm × 3 mm dimensions is cut for weld. As per ASTM-E3 procedure, sample is polished up to 2000 grit with emery sheet and finish it with alumina slurry. Etching is done using 7.5 mL HNO3 + 5 mL HCL + 5 mL acetic acid mixture by gently swabbing the polished surface. The microstructure of the weld cross-section is observed using Carl Zeiss inverted-type microscope with the Motic Image software.The images of the welded region, left and right zone shown in figure(3(a)-3(e)).

4. MECHANICAL CHARACTERISATION

Vickers micro hardness test is carried out as per ASTM E-384-16 is performed using a Matsuzawa tester.Most reliable and good resolutions are obtained at higher loads and hence a 500 g load is employed and the duration of indentation is 10 s. The tensile sample preparation is as per ASTM E8. The tensile test has been carried out using a Tinius Olsen universal testing machine. The cross-sectional moment of the UTM head is 1 mm min−1. The maximum load applied on the specimen is 20 kN.

The tensile specimen before and after conducting the tensile test are shown in figure(3).The yield strength, ultimate tensile strength, elongation and ultimate tensile load of given samples are shown in table (5). Three samples have been tested for repeatability.They are based on best results obatined from tensile testing. The hardness testing conducted for the three specimens which gives best result from tensile. The hardness conducting for in specimen in the place of weld, base, heating affected zone. The values of hardness shown in table (6).

5. ANALYSIS OF VARIANCE (ANOVA)

Its a hypothesis – testing procedure used to evaluate mean differences between two or more treatments. In the statistical analysis, even when more then one units are used to a treatment per replication remains simpler. The researcher improves their chances of finding what changes as a result of the experimental treatment. Here we can find best optimal welding parametersto produce best weld.

Table No.4 The input and output parameters for ANOVA analysis

Specimen No.	Laser Dia. mm	Power W	Frequency Hz	Tensile Strength MPa
1	0.3	45	8	212
2	0.3	44	9	230
3	0.3	46	10	251
4	0.4	44	9	203
5	0.4	45	10	218
6	0.4	46	8	245
7	0.5	44	10	212
8	0.5	45	8	234
9	0.5	46	9	256

6. RESULT AND DISCUSSION

After visual examination of the laser beam welded SS316L plates let out that a defect free,fulll penetration butt weld joint could be executed.

In thsi research work, autoenous full penetration butt joint for a 3mm thickness SS316L was obtained by various welding parameters. Here mechanical and microstructural investigations of SS316L plates are completely disscussed.

6.1 MECHANICAL INVESTIGATIONS

Average base metal hardness is found to be 170 HV. Hardness values are found to be higher in the fusion weld zone compared to the interface and the base material. The hardness at the weld interface is found to be 195, 198 and 197 HV in the centre of the mid, cap and root, respectively. The base material zone is found to be softer compared to all the other zones and hence the tensile failure could occur in the weaker portion of base material.From the tensile test conducted on the 9 specimens from that best of 3 specimens are chosen for the hardness test and microstructure which was concluded from the results of ANOVA table used for choosing the best 3 specimens , among 3 specimens 9th specimen has the more yield strength and the elongation is about 15.5 % and fracture was occurred at the parent metal due to inclusion and the 6th specimen has low yield strength due to laser power was less compared to the 9th specimen. The tensile test results shown below table (5).

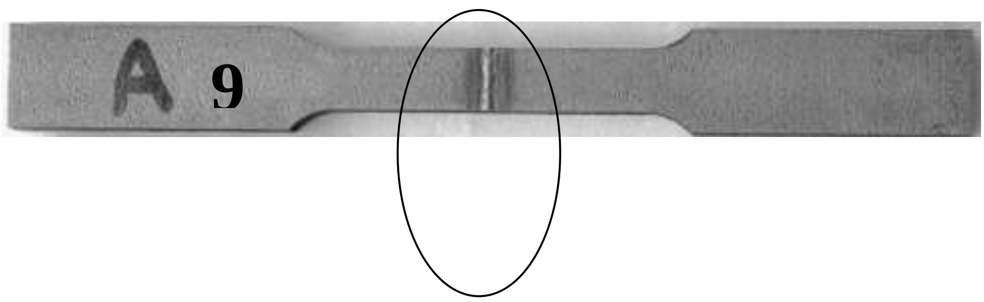

Figure-(3) Tensile specimen before and after conducting test

Table No.5 Tensile properties of laser beam welded SS 316L weldments

Tensile parameters/ sample No.	S1	S2	S3	S4	S5	S6	S7	S8	S9
Ultimate tensile strength (Mpa)	212	230	251	203	218	245	212	234	356
Yield strength(Mpa)	103	115	165	102	105	142	103	112	178
Elongation %	1.8	2.5	5.5	1.8	2.2	8	2.2	4.3	15.5
Ultimate tesnsile load(kN)	8.5	12.38	14.44	8.65	10.4	17.25	12.21	12.3	19.5

And also the hardness test conducted on the Vickers hardness testing machine at 3 areas of base metal, HAZ and weld. Maximum hardness found in the 9th specimen due to high intensity of laser and hardness value is higher in the HAZ due it was cooled from very high temperature also that hardness value found very high in the weld bead about 391 HV.

Table No.6 Hardness properties of weldments

Sample No. /Location	Base(max)	Haz(max)	Weld(max)
2	172	274	391
6	175	276	410
9	180	280	421

From the mechanical investigation the fracture was occurred in the base metal there is no crack found at the weld bead so that it can withstand more load at the welds so breakage is base metal can be reduced by adding more base metal.

6.2THE RESULT OF METALLURGICAL INVESTIGATIONS

The cross-sectional macro-structural investigation shows that the joint is free from sub surface porosity and has good side wall fusion. The microstructures reveals the absence of heat affected zone and grain growth in the base material this is due to the lower amount of heat input supplied of 120 J mm−1 and higher welding speed of 1.5 m min−1.

From the cross section of the weLd joint its clearly noticible inthe detail region there is no detectable defects exists onthe weld surface of the weld bead or adjecencies this is due to the specimen welded in energy 2.5J and also weld bead are showing the weld chracteristics of pulsed lazer beam welding no weld cracks between the two materials this may due to stainless steel 316L has naturally resistant to cracks and also due to the optimal welding parameters. There is no discontinuities observed in the weld metal. its demonstrates the efficiency of the sheilding gas in preventing oxidation, large porosity and gas and gas inclusions. All are laser-welded in the conduction mode (direct heating and energy transmission). The mechanism of direct heating involved absorption of beam energy by material surface. some of the minute surface hole is found due to high lazer intensity. The micro structure of 9th specimen weld zone, heat affected zone, fusion zone shown in figure (3(a)-3(e)).

Figure-(3(a)) left base

Figure-(3(b)) Left fusion

Figure-(3(c)) weld area

Figure-(3(d)) Right fusion

Figure-(3(e)) Right base

The cross sectional macro structures of lap welds as a function of pulse energy no penetration were found at the bottom of the plate and no deporession at the top surface of the bead this might be due to no sufficient energy there couples.

The macrostructure shows that melting of metal stsrted at the surface radiaded by the lazer beam and the molten areab grew continiously to radial and axial axis. as reported in literature [7] if there is more eprecence of wide gaps likely to more deeply concave undefills this due to low energy pulse 1.8J on incresing the energy of pulsed lazer results in excess of molten metal at the root but no underfills. The both specimens posses good close contact between the plates. On going further more high energy pulsethere found depression at the top so this results more bending at the joint when served in the heat zones.

6.3 ANOVA ANALYSIS

From the experimentation value the L9 orthogonal array was made using the design expert software 7.0 and the ANOVA Table was shown below.

Table No.7 Analysis Of Variance Table

Analysis of variance table [Partial sum of squares - Type III]					
Source	Sum of Squares	Df	Mean Square	F Value	p-value Source Prob>F
Model	1957.5	3	652.5	10.84888	0.0125
A-Focal Dia	66.66667	1	66.66667	1.108443	0.3406
B-Power	1802.667	1	1802.667	29.97229	0.0028
C-frequency	88.16667	1	88.16667	1.465915	0.2801
Residual	300.7222	5	60.14444		
Cor Total	2258.222	8			

The Model F-value of 10.85 implies the model is significant. Values of "Prob> F" less than 0.0500 indicate model terms are significant.

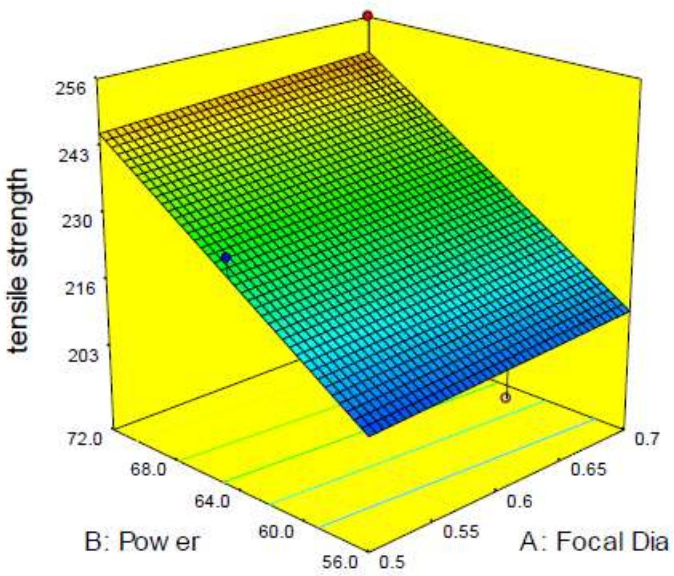

Figure (4) Focal diameter vs laser power on tensile strength

From the above figure (4) it is evident that the power plays the major role for tensile strength if the Focal Diameter of Laser Beam Increases there is gradual increase of Tensile Strength. At the same instance the Power increases from 56W to 72 W there is drastic increase in Tensile Strength from 203 MPa to 256 MPa.

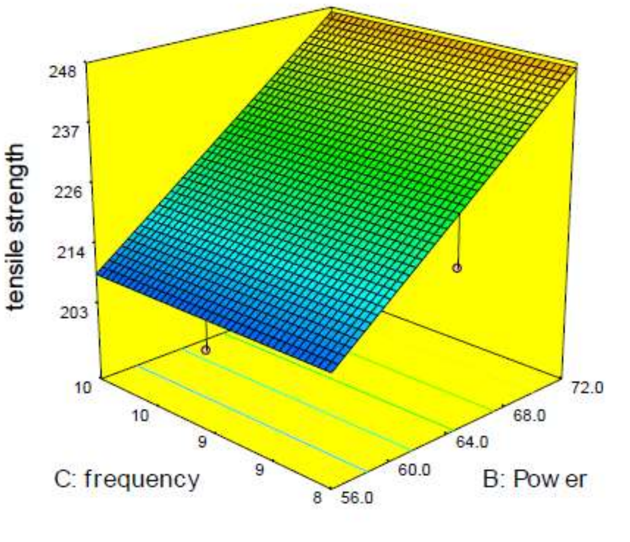

Figure (5) Frequency Vs Power significance on tensile strength

From the above figure (5), it is evident that the power plays the major role for tensile strength. If the power of Laser Beam Increases there is gradual increase of Tensile Strength. At the same instance the Power increases from 56W to 72 W there is drastic increase in Tensile Strength from 205 MPa to245 MPa.

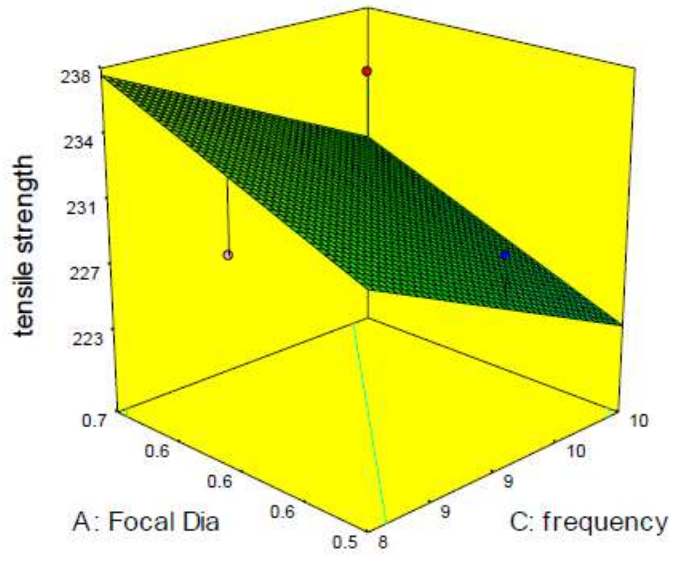

Figure (6) Focal Diameter Vs Frequency on tensile strength

From the above figure (6), it is evident that there is a slight change in tensile strength and Focal Diameter. But both the parameters have proportional increase in tensile strength as these values of theses parameters increases. From the above Observations it is inferred that the power plays the major role in increasing the tensile Strength of the welded samples. The Remaining two parameters have less influence comparatively.

Tensile strength - 1957.5 + 66.67 *focal distance +1802.66 *Power + 88.16 * Frequency is the mathematical model observed from ANOVA table.

CONCLUSION

From the experimental study it is concluded that major improvements were found.From the Taguchi's L9 Orthogonal Method of optimization the optimized parameters are 0.5mm beam diameter, 46 W power and 9Hz frequency which yields the maximum Tensile Strength to the welded samples of SS316 using Laser Beam Welding Process and its shows below asadvantages as well as limitations .

The developed second order derivative method can predict the values of the weld quality characteristics with significant accuracy. The developed model on the software has been tested by analysis-of-variance(ANOVA)with a confidence level of 92%.The fusion zone the austenite transformation into ferrite completely and quality was high at the weld zone. In the heat affected zone the material was fused completely and give fine strip structure.

Laser welding gives a good quality weld and provides greater strength and good depth of penetration and the laser power is a main factor affecting the bead geometry (like depth, penetration, width etc.,) and it is followed by pulse frequency and laser spot diameter. Failure occurs at the near welded joint on the parent metal because of the pores inclusions. The maximum tensile strength was obtained for high value of laser power. The hardness value is high at the heat affected zone to meet requirements. The samples namely S9,S6, S3 are given maximum tensile and hardness value.

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