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Mechanical Characterization of dissimilar metal welding of SS 202 & SS 409 by ND-YAG laser welding

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ABSTRACT

Laser welding being the non-conventional method for joining metals, and its main advantageous are high heating/cooling rates, high spot diameter densitywhich results in a minimum heat affected zone (HAZ). The study aimed at exploring the mechanical properties of different grades of stainless steel SS202 and SS409. A solid-state,9.9 kWALPHA LASER AL200 Nd: YAG laser was used. The experiments were carried out in austenite (SS 202) and martensite (SS 409) stainless steel sheets. These metals were welded and studied the properties at various parameters like laser power, pulse width and frequency, and keeping the focal beam diameter as constant to achieve the optimum combination parameter.By using of Minitab-19software analysis of variance (ANOVA) was carried out on the experimental data to govern which process parameters were statistically significant. Taguchi design is used to optimize the parameter. The mechanical characterization of the welded joints was carried out by hardness test, bend test and tensile test. The effects of various operating parameters of pulsed Nd: YAG laser welding of the dissimilar metals have been investigated. The results yielded the definition of the best position for the incident laser beam with respect to the position of welding, for welding the metals together.

1. Introduction

In the prevailing world, a foremost inclination in material research is to manufacture products more powerful, reliable and have better functionality. Laser welding is one of the solutions yielding maximum output in the industries for joining of dissimilar metals [1]. Mainly in industries such as automobile and aerospace, whose main aim is to reduce weight to achieve

enhanced performance, save energy and many more advantages [2,3]. Laser welding could be used to join numerous combinations of metals such as; similar metals, dissimilar metals, alloys, and non-metals. In the present-day,demand of joining of dissimilar materials continuously increases due to the possibility of achieving results with extreme advantages of high tensile strength, better and lighter weldments, high precision, low residual stress and high efficiency, which would provide appropriate mechanical properties and good cost reduction [4]. Laser welding being the non-conventional method for joining metals, with its main advantages being high spot diameter density, high heating and cooling rates which results in a minimum heat affected zone (HAZ) and low distortion [5]. Laser welding is characterized by parallel-sided fusion zone, narrow bead and high penetration [6]. With no requirement of the filler metals and comparatively high cooling rate results in the formation of a fine microstructure so that can enhance material strength without undergoing any finishing operations.
The materials used are the martensitic and austenitic grades of stainless steels which provides higher strength, better corrosion resistance due to the presence of high amounts of Chromium and nitrogen [7].
The optimization of process parameters viz. pulse width, frequency, power, welding speed, i.e. altering the values of each in different conditions characterizes the weld geometry [8,9], and can enhance the product quality and minimize the cost of performing numerous experiments and also reduces the wastage of the resources. In this study, the dissimilar SS sheets are butt welded, 9.9 kW LASER AL 200 Nd: YAG laser welding machine was used. At different operating parameters, variation in the mechanical properties of the welded joints is reported.

2. Materials and Methods

2.1 Material Properties:
Grade SS202 is an austenitic stainless steel with enhanced corrosion resistance properties than compared with the other grades due to the balanced chemical composition and due to high amount of chromium percentage. (Cr: 17-19%). With the presence of Nitrogen, it provides the 200 series of Stainless steel higher mechanical strength than the 300 series.It also possesses high toughness, high harness, and strength.

Material	Mn%	C%	Si%	Cr%	S%	P%	N%	Ni%
SS202	7.50-10	0.15	1	17-19	0.030	0.060	0.25	4-6

Table 1: Chemical composition of SS202

Applications of SS202:
1. Automotive trim
2. Railway cars
3. Trailers
4. Restaurant equipment
5. Architectural applications
6. Utensils

GradeSS409 is a martensitic stainless steel that has good mechanical properties and high-temperature corrosion resistance which is highly useful in the automotive and non-automotive exhaust applications. The class of martensitic stainless steels has limited and constrained weldability due to its hardenability.

Material	Mn%	C%	Si%	Cr%	S%	P%	Ni%
SS409	1	0.08	1	10.5-11.75	0.030	0.045	0.5

Table 2: Chemical composition of SS409

Applications of SS409:

1. Automotive and truck exhaust systems
2. Automotive manifolds and mufflers
3. Agricultural machining
4. Heat exchangers
5. Fuel filters

2.2 Experimental Work and Design:

SS 409 and SS 202 were brought in sheets of 100x100x2 mm to be welded using Nd: YAG laser. The Nd: YAG laser welding on the specimens was performed by keeping the focal diameter constant at 1.8 mmand varying the three other main parameters of laser welding, i.e. laser power, pulse width and frequency. Parameters were selected through design of experiments. [10,11] Taguchi method was used, as it utilizes a unique procedure of orthogonal exhibits to consider the whole parameter space with few examinations to overcome the issue of expensive number of investigations when the quantity of process parameters rises in value.

These results are then transformed into a signal-to-noise ratio, using Taguchi-Analysis using Minitab 19, to measure the quality characteristics deviating from the desired value.The Minitab 19 software was used to optimise the drilling parameters through the Taguchi design. The process parameters have been mentioned below, in design of experiment.

Also, analysis of variance (ANOVA) of a general linear model using adjusted SS is conducted to achieve percentage of contribution and error percentage of each parameter in the respective test. This combined with the S/N analysis, the optimal parameters are easy to predict.

2.3 Design of Experiment (DOE)

The Parameters for the study have been mentioned below in Table 1.0. DOE is anefficient method to determine the relationship between factors affecting a process and the output of that process. [12,13]

Levels	**Process Parameters**		
	Power (W)	**Pulsewidth (μs)**	**Frequency (Hz)**
1	180	4	10
2	185	4.5	11
3	190	5	12

Table3: Parameters

These Parameters havebeen optimised using Minitab 19 (Taguchi design) and formed into an L9 orthogonal array to further test the specimens and to find the desired result.

S. No.	**Power (W)**	**Pulsewidth (μs)**	**Frequency (Hz)**
1	180	4	10
2	180	4.5	11
3	180	5	12
4	185	4	11
5	185	4.5	12
6	185	5	10
7	190	4	12
8	190	4.5	10
9	190	5	11

Table 4: Process Parameters L9 Array

3. Results and Discussion

All the samples resulted from the Taguchi design were butt-welded using ND-YAG laser and the following tests were performed to evaluate the mechanical properties of the same.

1. Rockwell Hardness test
2. Bend Test
3. Tensile Strength Test

From investigating the mechanical properties of the butt-welded specimens of SS 202 and SS 409, results of Rockwell hardness test, bend test and tensile strength test were summarized.

3.1 Rockwell Hardness Test:

The test was conducted on the 9 samples with process parameters taken from the L9 orthogonal array. Each sample (the butt-welded joints of SS202 and SS409) was undergone the test using “B” scale.

Testing conditions for B-scale;

1. Use a diamond indenter (1/16” diameter)
2. Max. load = 100Kg, min load 10Kg

The hardness of the material is dependent on the depth of indentation on the surface of the material. The material is considered to be less hard when the depth is high and is considered to be hard when the depth is low.

The results of the hardness test are given below:

S. No.	Power (W)	Pulse width (µs)	Frequency (Hz)	Hardness (HRB)
1	180	4	10	75
2	180	4.5	11	71
3	180	5	12	83
4	185	4	11	83
5	185	4.5	12	81
6	185	5	10	70
7	190	4	12	82
8	190	4.5	10	74
9	190	5	11	87

Table 5: Rockwell Hardness results

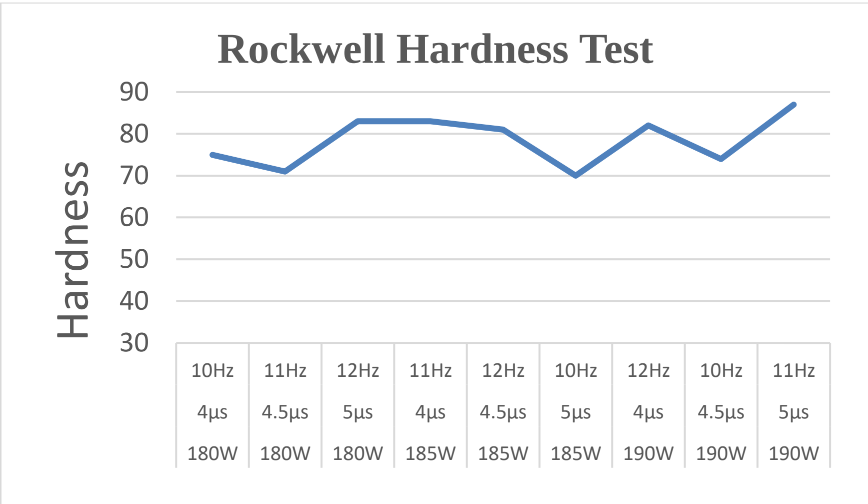

Fig. 1: Rockwell Hardness results

From the results of the hardness test, we have performed Taguchi Analysis, to achieve S/N ratio and also their response tables to better understand the importance of each parameter.

S. No.	DESG.	Power (W)	Pulse width (µs)	Frequency (Hz)	Hardness (HRB)	SN. Ratio Value
1	$A_1B_1C_1$	180	4	10	75	-37.5012
2	$A_1B_2C_2$	180	4.5	11	71	-37.0252
3	$A_1B_3C_3$	180	5	12	83	-38.3816

4	$A_2B_1C_2$	185	4	11	83	-38.3816
5	$A_2B_2C_3$	185	4.5	12	81	-38.1697
6	$A_2B_3C_1$	185	5	10	70	-36.9020
7	$A_3B_1C_3$	190	4	12	82	-38.2763
8	$A_3B_2C_1$	190	4.5	10	74	-37.3846
9	$A_3B_3C_2$	190	5	11	87	-38.7904

Table 6: Hardness and Signal to Noise Ratio values of the welding process (Smaller is considered better)

Response Table for Signal to Noise Ratios

Level	**Power**	**Pulse width**	**Frequency**
1	-37.64	-38.05	-37.26
2	-37.82	-37.53	-38.07
3	-38.15	-38.02	-38.28
Delta	0.51	0.53	1.01
Rank	3	2	1

Table 7: Response table for S/N Ratios

Response Table for Means

Level	**Power**	**Pulse width**	**Frequency**
1	76.33	80.00	73.00
2	78.00	75.33	80.33
3	81.00	80.00	82.00
Delta	4.67	4.67	9.00
Rank	2.5	2.5	1

Table 8: Response table for Means

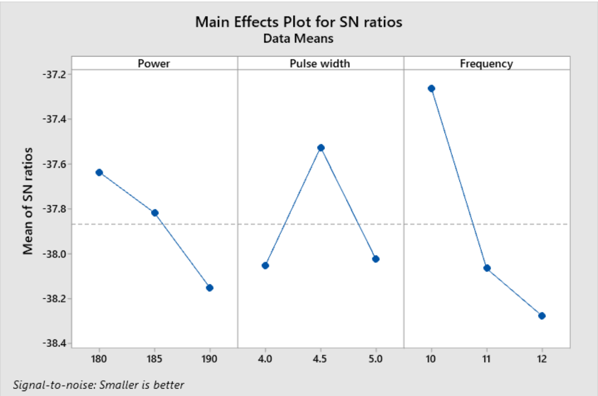

Fig. 2: Main effects plot for S/N ratios

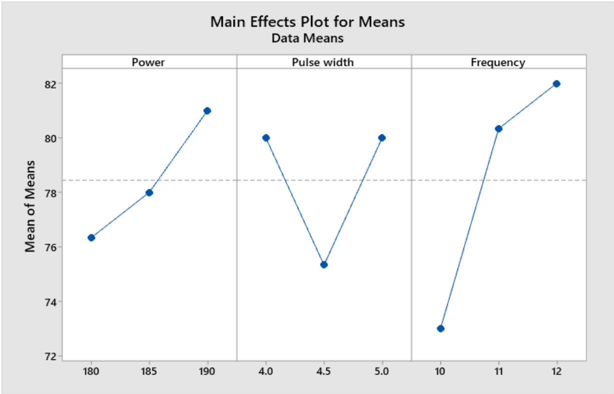

Fig. 3: Main effects plot for Means

General Linear Model: Hardness versus Power, Pulse Width, Frequency:

Method

Factor coding = (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Power	Fixed	3	180, 185, 190
Pulse width	Fixed	3	4.0, 4.5, 5.0
Frequency	Fixed	3	10, 11, 12

Table 9: Factor Information

Source	DF	Seq. SS	Adj. SS	Adj. MS	F-Value	P-Value	% of Contribution
Power	2	33.56	33.56	16.78	0.43	0.698	11.48%
Pulse width	2	43.56	43.56	21.78	0.56	0.640	14.90%
Frequency	2	137.56	137.56	68.78	1.77	0.361	47.07%
Error	2	77.56	77.56	38.78			26.54%
Total	8	292.22					100.00%

Table 10: Analysis of Variance for Hardness using adjusted SS for Tests

3.2 Bend Test:

Bend test was performed on the selected samples, selected on the basis of the observatory evaluation of their hardness from the hardness test results, which concludes that at higher hardness value, the material is more likely to break than the ones with lower value of hardness undergoing the bend testing. Hence, only 3 specimens were tested for bend test and the results of the test are tabularized below:

S. No.	Power (W)	Pulse width (μs)	Frequency (Hz)	Observation	Remark
1	180	5	12	No open discontinuity in the weld and HAZ	Satisfactory
2	185	5	10	No open discontinuity in the weld and HAZ	Satisfactory
3	190	5	11	Visually crack in weld metal	Unsatisfactory

Table 11: Bend Test Results

Post bend test, the evaluation of the specimens concluded that specimens with highest hardness parameters resulted in visual crack in the weld metal. Hence an unsatisfactory remark. Whereas, the specimens with low hardness parameters resulted in no discontinuity in the weld or the heat affected zone (HAZ). Hence, a satisfactory remark.

3.3 Tensile test results:

The joints were assessed for their mechanical characteristics using the tensile strength test. It was conducted on all the specimens using UTM (Universal Testing Machine) machine. A malleable test helps deciding the tensile properties, for example, modulus of elasticity,yield strength, percentage of reduction in area, tensile strength and percentage of elongation. UTM machine used for this test was UTM 40T, where "40T" indicates the load, 40 tones.

S. No.	Power (W)	Pulse width (μs)	Frequency (Hz)	T. LOAD (KN)	Tensile Strength (N/mm^2)
1	180	4	10	9.15	244.00
2	180	4.5	11	8.65	230.67
3	180	5	12	9.56	254.93
4	185	4	11	8.67	231.20
5	185	4.5	12	7.58	202.13
6	185	5	10	9.56	254.93
7	190	4	12	9.05	241.33
8	190	4.5	10	8.82	235.20
9	190	5	11	7.68	204.80

Table 12: Tensile Strength Results

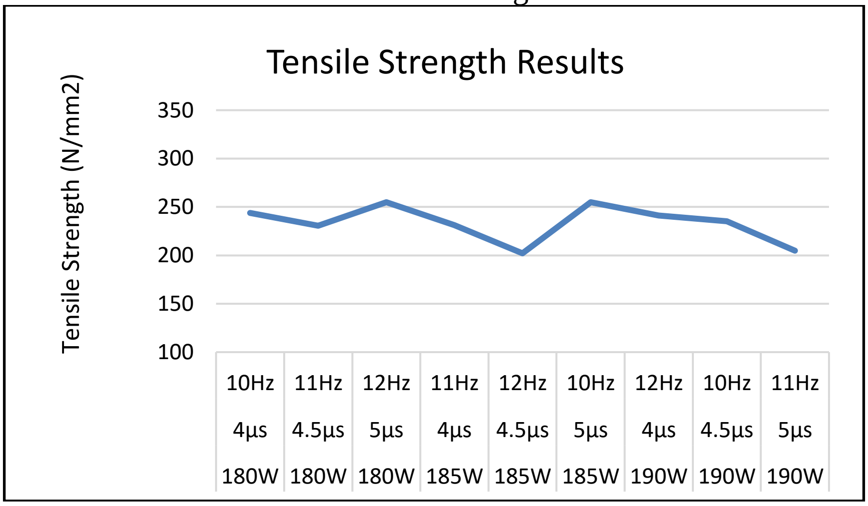

Fig. 4: Tensile Strength results

From the results of the Tensile test, we have performed Taguchi Analysis, to achieve S/N ratio and also their response tables to better understand the importance of each parameter.

S. No.	DESG.	Power (W)	Pulse width (µs)	Frequency (Hz)	Tensile Strength (N/mm^2)	SN. Ratio Value
1	$A_1B_1C_1$	180	4	10	244.00	47.7478
2	$A_1B_2C_2$	180	4.5	11	230.67	47.2598
3	$A_1B_3C_3$	180	5	12	254.93	48.1284
4	$A_2B_1C_2$	185	4	11	231.20	47.2798
5	$A_2B_2C_3$	185	4.5	12	202.13	46.1126
6	$A_2B_3C_1$	185	5	10	254.93	48.1284
7	$A_3B_1C_3$	190	4	12	241.33	47.6522
8	$A_3B_2C_1$	190	4.5	10	235.20	47.4287
9	$A_3B_3C_2$	190	5	11	204.80	46.2266

Table 13: Tensile Strength and Signal to Noise Ratio values of the welding process (Larger is considered better)

Response Table for Signal to Noise Ratios:

Level	Power	Pulse width	Frequency
1	47.71	47.56	47.77
2	47.17	46.93	46.92
3	47.10	47.49	47.30
Delta	0.61	0.63	0.85
Rank	3	2	1

Table 14: Response table (S/N Ratios)

Response Table for Means:

Level	Power	Pulse Width	Frequency
1	243.2	238.8	244.7
2	229.4	222.7	222.2
3	227.1	238.2	232.8
Delta	16.1	16.2	22.5
Rank	3	2	1

Table 15: Response table (Means

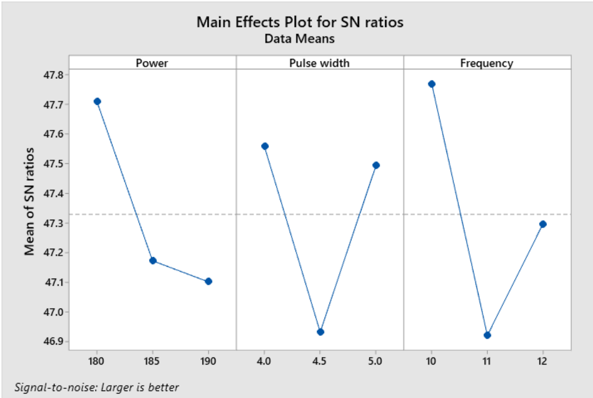

Fig. 5: Main effects plot (S/N Ratios)

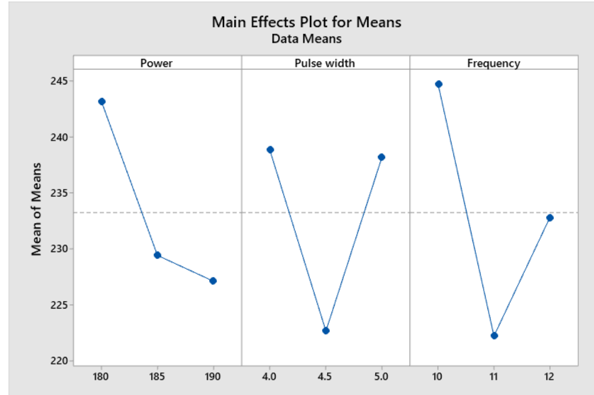

Fig. 6: Main effects plot (Means)

General Linear Model: Tensile Strength versus Power, Pulse Width, Frequency:

Method

actor coding = (-1, 0, +1)

Factor information:

Factor	Type	Levels	Values
Power	Fixed	3	180, 185, 190
Pulse width	Fixed	3	4.0, 4.5, 5.0
Frequency	Fixed	3	10, 11, 12

Table 16: Factor Information

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% of Contribution
Power	2	454.1	454.1	227.1	0.38	0.725	15.59%
Pulse width	2	504.0	504.0	252.0	0.42	0.704	17.30%
Frequency	2	759.4	759.4	379.7	0.63	0.612	26.06%
Error	2	1195.9	1195.9	598.0			41.05%
Total	8	2913.4					100.00%

Table 17: Analysis of Variance for Tensile Strength using adjusted SS for Tests

4. Conclusions

It is noted that the highest percentage of contribution in both, hardness test and tensile test, is frequency, hence it is an important factor for the welding of these specimens and this fact leads to the conclusion that slightest change in the frequency will cause major changes in the mechanical properties of the welded joint.
While doing the bend test for the welded samples it has been founded that the sample which was given power of 190 Watts has been founded that it was unsatisfactory , therefore the welded joints cannot withstand the power above 185 Watts and is proved to be inefficient.

Therefore, the study on the mechanical characterisation of 9.9KW LASER AL 200Nd: YAG pulsed laser welded dissimilar metals: SS202 and SS409, yields the following results:

- The welded joints cannot withstand the power above 185 Watts
- The projected results/conclusions from the software were similar to the experimental results/conclusion, which proved the correctness and feasibility of the method.

According to the Taguchi Analysis, hence from the main effect plots;

- Optimal control factor for maximum Tensile Strength:

Power-**180W**, Pulse width- **4μs**, Frequency- **10Hz**

- Optimal control factor for minimum Hardness:

Power-**180W**, Pulse width- **4.5μs**, Frequency- **10Hz**

Percentage of Contribution of the Process Parameters:

- Hardness: Frequency = 47.07%
- Tensile Strength: Frequency = 26.06%

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