Strength optimization and thermo-mechanical modeling of dissimilar weld joint

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***Abstract*--Laser welding is one of the important welding processes in industries for joining similar or different metals. Demand of dissimilar metal welding has increased now a days from high performance, cost saving and efficiency point of view. Various parameters like speed, beam power, spot diameter affect the quality, strength and cost of welding process. In this paper the influence of speed, beam power and spot diameter over strength of welded specimen is studied using Taguchi's method. Two dissimilar metals such as Inconel (625) and Mild steel (1020) is welded using laser beam. The experiments are carried out as per Taguchi orthogonal array design matrix to predict optimum process parameters Analysis of variance (ANOVA) is carried out to determine significantly affecting parameter and the mathematical model to estimate ultimate tensile strength has been developed using Regression method. The simulation of welding process to predict temperature distribution and residual stresses is predicted.**

I. INTRODUCTION

Laser welding is a welding process used to join two metals by the use of a laser source. The laser source provides a concentrated and high density heat source. The process is mostly used in high rate production industries, such as in the automotive industry. The implementation of dissimilar metal combination provides flexibility of design so that both metal can be used in efficient way. Laser welding is most efficient way of fusing dissimilar metals. Among all the conventional method laser welding has its own advantages over quality and durability of welded joint.

Inconel has high strength and has high oxidation and corrosion resistance. It has wide application in high temperature and pressure zone like gas turbines. Inconel also has application in automotive exhaust, nuclear plant and high pressure vessels.

Process optimization is important technique for saving manufacturing time, cost of process and obtaining high strength welded parts. Thus Taguchi method is one of important process optimization technique which can be implemented for laser parameters. The greatest advantages are saving experimental efforts, time, and cost and finding significant factors very quickly.

Temperature and residual stresses are important parameters which affects the strength and quality of welding. It is also used to study thermo-mechanical behavior of welded joints.

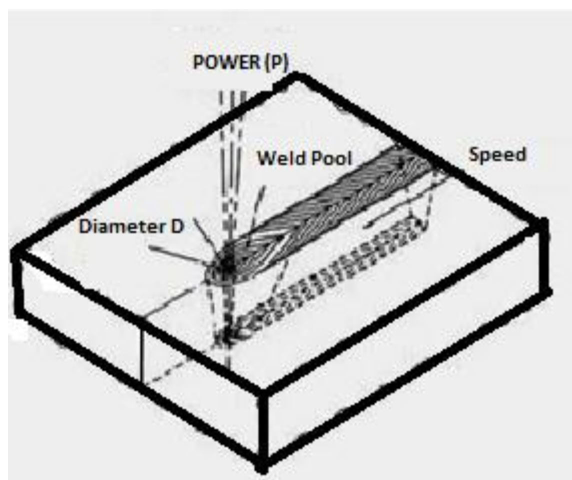

Figure 1: Laser welding with different process parameters

II. OBJECTIVE

1) Selection of process parameters and their effect on dissimilar metal joints.
2) To optimize laser welding process parameters to obtain maximum weld strength.
3) Development of mathematical model to predict weld strength using regression analysis.
4) Comparison experimental results of strength results with mathematical model develop.
5) Thermo-mechanical modeling of laser welding process to predict temperature distribution and residual stresses.

III. MATERIAL SPECIFICATION

Mild steel 1020 and Inconel 625 are joined together with CO_2 laser welding process. Inconel is Nickel chromium based metal generally referred as Nickel alloy. It has 20-23% of chromium, 50-62% Nickel, 8-10% molybdenum and remaining is carbon, sulfur and iron. Mild steel is carbon steel containing 0.17-0.23% carbon and Iron as major constitute.

IV. EXPERIMENTAL SETUP

Table 1: Process parameters and their levels

Factors	Level 1	Level 2	Level 3
Welding Speed (mm/s)	2	4	6
Beam Power(W)	900	1200	1500
Spot Diameter (mm)	0.4	0.6	0.8

Mild steel and Inconel plates are prepared with dimensions of 150X60X0.78 (l X w X t) mm. Both the plates are welded in width direction using laser beam. The gap between two plates is 0.01mm. Nine plates are welded with different process parameters using Taguchi orthogonal array table 2.

Table 2: Orthogonal array table for L9 Taguchi

Sr no	Welding Speed (mm/s)	Beam Power (W)	Spot Diameter (mm)
1	1	1	1
2	2	2	1
3	3	3	1
4	1	2	2
5	2	3	2
6	3	1	2
7	1	3	3
8	2	1	3
9	3	2	3

Out of welded plates, specimens are cut by laser for tensile test. The dimensions of tensile test specimen are shown in figure. Same procedure is conducted for nine welded plates. The ultimate tensile strength along with process parameters are shown in table 3.

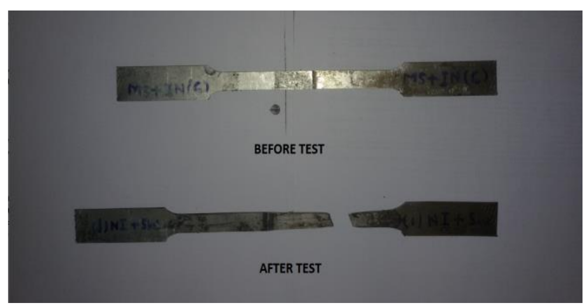

Figure 2: Specimens before and after tensile test

Table 3: Parameters and response of tensile test

Sr no	Speed (mm/s)	Beam Power (W)	Spot Dia (mm)	Tensile Strength (Mpa)	S/N ratio	Mean
1	2	900	0.4	351.05	50.90	351.05
2	4	1200	0.4	342.9	50.70	342.9
3	6	1500	0.4	420.15	52.46	420.15
4	2	1200	0.6	415.08	52.36	415.08
5	4	1500	0.6	421.45	52.49	421.45
6	6	900	0.6	310.86	49.85	310.86
7	2	1500	0.8	459.45	53.24	459.45
8	4	900	0.8	335.22	50.56	335.22
9	6	1200	0.8	325.35	50.24	325.35

V. TAGUCHI METHOD

A. Analysis of signal to noise ratio (S/N)

Taguchi S/N ratio is logarithmic function of output as its objective function of optimization. S/N takes both mean and the variables into account. There are three quality characteristics for Taguchi method

a) Nominal is best: $\frac{S}{N} = 10\ Log\ \frac{y}{s^2}$

b) Lower is best : $\frac{S}{N} = -10\ Log\ \frac{1}{n}(\sum y^2)$

c) Larger is best: $\frac{S}{N} = \ -10\ Log\ \frac{1}{n}(\sum \frac{1}{y^2})$

For our process parametric optimization we use lager is best.

Table 4: Analysis of signal to noise ratio

Level	Speed (mm/s)	Power (W)	Spot Diameter (mm)
1	52.17	50.42	51.36
2	51.23	51.1	51.57
3	50.86	52.75	51.33
Delta	1.32	2.31	0.24
Rank	2	1	3

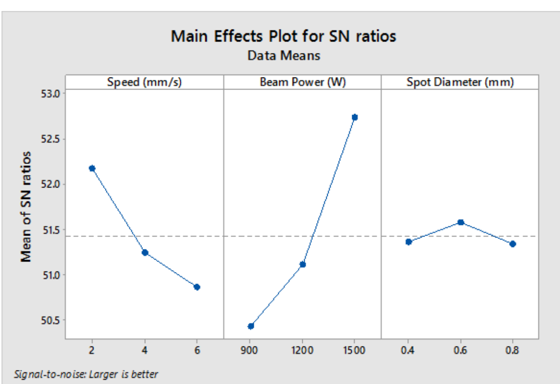

Figure 3: S/N ratio of different parameters

Based upon S/N ratio, welding process parameter with greater tensile strength is obtained at welding speed at Level 1, Beam power at Level 3 and spot diameter at level 2. Table 5 shows optimum process parameters for greater strength

Table 5: Optimum process parameters

Speed (mm/s)	Beam Power(W)	Spot diameter(mm)
2	1500	0.6

B. Regression analysis

Weld speed, power and spot diameter are considered for development of mathematical model. Correlation between these parameters is obtained by multiple regression method. In this method, coefficient of regression R^2 should be greater than 90% for fit experiment.

Using Minitab the regression equation obtain is

Tensile Strength (MPa) = 226.6 – [14.10 X Speed (mm/s)] + [0.1688 X Beam Power (W)] + [4.9 X Spot Diameter (mm)]

Coefficient of regression is 89.9 %

Tensile strength value by equation: 454.54 MPa

Experimental tensile test value: 449.84 MPa

C. Analysis of variance (ANOVA)

Analysis of variance is used to obtain maximum contribution of process parameter for maximum tensile strength

Table 6: Percentage contribution of parameters using ANOVA

Source	DF	Sum of square	Mean Square	F-ratio	P-ratio	%
Speed	2	4772.6	2386.3	9.46	0.028	21.02
Beam Power	2	15394.6	7697.3	30.52	0.003	67.83
Spot diameter	2	5.8	2.9	0.01	0.918	0.025
Residual Error	2	2522.2	1261.1			11.11
Total	8	22695.1				100

From the above table, the percentage contribution of beam power is more (67%) than other process parameters for obtaining maximum tensile strength.

VI. TEMPERATURE DISTRIBUTION

Using optimum process parameters, simulation is made in Simufact Welding software. The temperature distribution is shown in figure.

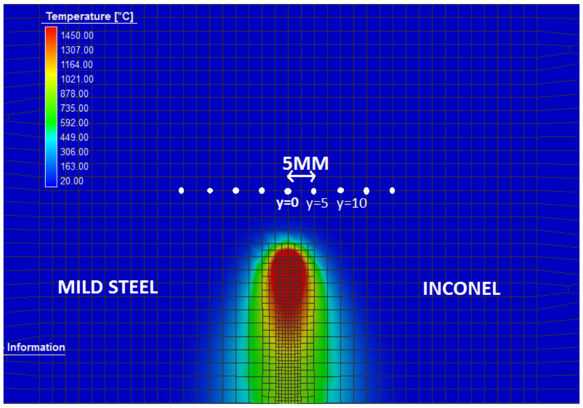

Figure 4: Temperature distribution at time 4 sec

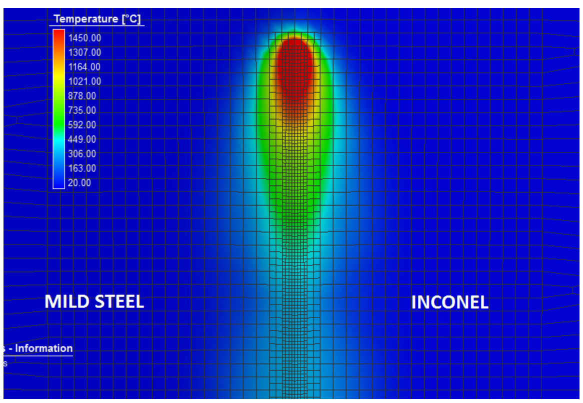

Figure 5: Temperature distribution at time 10 sec

Nine points are considered as shown in figure 4. The centerline or welding line is considered at y=0 mm. at interval of 5mm from center line remaining tracking points are considered along both sides.

Temperature vs time graph is shown in figure 6. Since y=0 is at heat source zone, the temperature reaches very high as shown in figure. At y=5mm and y=10mm the peak temperature goes on decreasing.

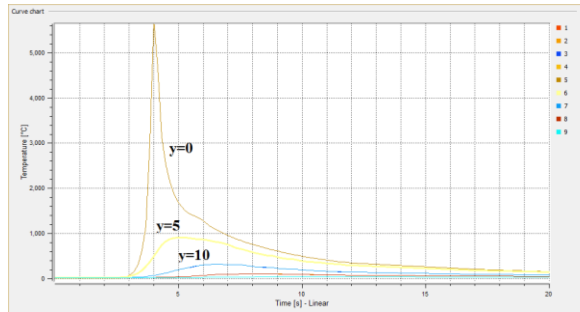

Figure 6: Temperature vs time graph along track points.

From figure 6 it can be observed that as distance increases from weld zone, the time required to reach peak temperature also increases.

VII. RESIDUAL STRESS

The residual stressed induced due to laser welding is show in figure. The maximum value of residual stress induced is 344.84 MPa.

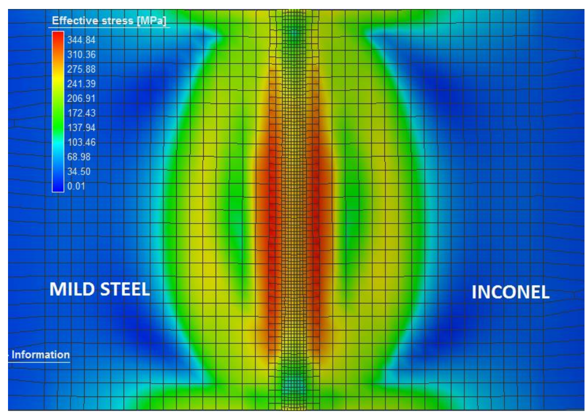

Figure 7: Residual stress induced in specimen

Future Scope

Experimental validation of temperature distribution can verified using either thermocouple or temperature gun. The residual stresses induced can be verified using X-ray diffraction machine.

VIII. CONCLUSION

Using Taguchi method the process parameters are optimized for maximum tensile strength of welded specimen.

S/N ratio shows the optimum process parameters are speed = 2 mm/s, Power = 1500 W and spot diameter = 0.6 mm

Regression equation is obtained and the maximum strength value is 454.54 MPa and is verified experimentally (449.84 MPa)

The temperature and stresses induced in specimen is predicted. The temperature contours and temperature cycle at different locations is predicted. Simulation shows maximum residual stress induced is 344.84 MPa.

VII. REFERENCES

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