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INFLUENCE OF PROCESS PARAMETERS ON WELDED JOINT BY LASER BEAM WELDING

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Abstract - *This paper proposes an integrated method for process parameters optimization and objective analysis in the laser welding based on Taguchi and Gray relational method. The Taguchi and gray relational method is established and applied for the objective of increasing the ratio of signal-to-noise (S/N) in the welded joints. Numerical analyses are incorporated into identifying the desired responses and the process parameters effects on the objective without consuming time, materials, and labor effort. The three process parameters, laser power (LP), welding speed (WS), and diameter of laser beam (D) have been taken into consideration during the optimization process. The optimized results are confirmed, and trend of the objective variation near the optimal process parameters is analyzed. For gray relational grade in Laser welding operation, minimum % elongation and maximum tensile strength and weld hardness are the indication of the better performance. The results demonstrate that the proposed method is reliable and effective for improving the quality of welded joints in the practical production level.*

Key Words: Laser Welding, Tensile Strength, Weld Hardness, Gray Relational Analysis.

1. INTRODUCTION

Laser Beam Welding (LBW) is a welding technique used to join pieces of metal or thermoplastics through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications using automation, such as in the automotive industry. It is based on keyhole or penetration mode welding. The acronym “LASER” stands for Light Amplification by Simulated Emission of Radiation is a coherent and amplified beam of electromagnetic radiation. The key element in making a practical laser is the light amplification achieved by stimulated emission due to the incident photons of high energy [1].
Laser comprises of three components namely lasing medium, lasing energy source and optical delivery or feedback system.

The laser medium may be a solid, liquid or gas. Laser light differs from ordinary light because it has photons of same frequency, wavelength and phase, laser beams are highly directional, have high power density and better focusing characteristics. Among different types of lasers Nd:YAG and CO_2 are most widely used now a days. In this process material is joined by focusing highly intense laser beam on the work piece.

Welding is a process of joining the surfaces of two work pieces (usually metals) through localized coalescence. It is a precise, reliable, cost-effective and high-tech method for joining materials. No other technique is widely used by manufacturer to join melts and alloy efficiently and to add value to their products.

Most of the familiar objects in modern society, from buildings and bridges, to vehicles, computers and medical devices could not be produced without the use of welding. Welding goes well beyond the bound of its simple description [2]. This technique is applied to a wide variety of materials and products, using advanced technologies, such as lasers and plasma arcs. The future of welding holds even greater promise as methods are devised for joining dissimilar and non-metallic materials, and for creating products of innovative shapes and designs. Lots of research are investigation to deal with the estimation of weld bead geometry, Heat affected zone, hardness and microstructure.

2. LITERATURE REVIEW

Balasubramanian (2006) has worked on Mathematical and ANN Modeling of Nd: YAG laser welding of thin SS Sheets. The effect of laser power (0.6-1.4 kW), welding speed (0.8-2 m/min) and shielding gas flow rate (5 - 15 l/min) on the weld-bead geometry i.e. depth of penetration (DOP), weld bead width (BW) was investigated. Modeling was done using artificial neural network and multiple regression analysis. Comparison of neural network model and multiple linear regression models was made [1]. Alexandra (2003) has worked on laser beam welding hard metals to steel. They have examined Laser beam weld ability of hard metal to steel with high power CO_2 laser [2].

Padmanaban (2010) has worked on an optimization of laser beam welding process parameters to attain maximum tensile strength in AZ31B magnesium alloy. An empirical relationship was developed to predict tensile strength of the laser beam welded AZ31B magnesium alloy by incorporating process parameters such as laser power, welding speed and focal position. The experiments were conducted based on a three factor, three level, central composite face centered design matrix with full replications technique. The empirical relationship can be used to predict the tensile strength of laser beam welded AZ31B magnesium alloy joints at 95% confidence level. The results indicate that the welding speed has the greatest influence on tensile strength, followed by laser power and focal position [3].

Ribolla (2005) has investigated the use of CO_2 weld for large scale volume assembly of automotive body in white. They have suggested some advantages in laser welding as a variety of benefits over other types of welding. Deep penetration of precise narrow welds, small heat affected zone, low heat input, fast weld times, minimum part distortion, no secondary processing and high repeatability can be mentioned as great advantages [4].

3. EXPERIMENT WORK AND MEASUREMENT

Laser beam welding is a non-contact process that requires access to the weld zone from one side of the parts being welded. The weld is formed as the intense laser light rapidly heats the material typically calculated in milliseconds. Laser welding is a joining process where laser are used as a heating source for joining the two metal parts. Many advantages of laser welding technology such as high speed and noncontact welding make the use of the technology more attractive in the automotive industry. Lot of researchers work has been studied on laser welding used 2 kW laser for welding of stainless steel to determine the tensile strength weld hardness and % elongation. They observed that the tensile strength of the laser beam can't neglect in certain welding conditions and tensile studied on the welding of stainless steel by using the 1KW laser. The output parameters were laser power of different values, welding speed and diameters shielding gas Helium and Argon.

A stainless steel plate of dimension 240mm x 40mm x 3mm was used. The plate was cut in to pieces of equal dimension of 180mm x 25mm x 3mm. One of the smaller sheets of equal dimension was taken and the sheet was cut in to small strips of width 25mm and length 90 mm. The surface of the sheets to be welded should be very smooth. The surfaces are finished in grinding machine. To remove the burrs filing was done. In finishing operation the stainless steel sheet is grinded slowly and steadily.

4. EXPERIMENTAL PROCEDURE

Welding has been done on the two S304 stainless steel plates of 90 x 25 x 3mm size; plates are placed close to each other to ensure that the joint must in ZERO-gap. First the operator holds the two specimens using specimen holder and then passes a low powered Laser beam applied up on the joint to check the position and direction. Spot the three high power beams on the joint to ensure the line of direction. Repeat the procedure for all 9 experiments as per given level of parameters shown in Table 2. Figure 1 shows laser welded joint specimens.

Table- 1:- Level of Process Parameters

S.NO.	PROCESS PARAMETERS	NOTATIONS	UNITS	LEVEL 1	LEVEL 2	LEVEL 3
1	POWER	A	volts	250	300	350
2	DIAMETER	B	mm	0.20	0.35	0.40
3	WELD SPEED	C	mm/sec	0.5	1.0	1.5

Table -2: Experimental Table

Exp. No.	Power (Watt)	Diameter (mm)	Weld Speed (mm/sec)	Tensile Strength (N/mm^2)	Weld Hardness (HV)	% Elongation
1	250	0.35	0.5	185.86	410.3	1.9
2	250	0.20	1.0	198.05	395.6	1.86
3	250	0.40	1.5	285.6	411.2	2.38
4	300	0.20	1.0	187.14	388.2	1.91
5	300	0.35	1.5	104.03	395.6	1.89
6	300	0.40	0.5	201.49	380.1	1.84
7	350	0.40	1.5	188.82	417.6	3.16
8	350	0.35	0.5	271.04	402.1	2.46
9	350	0.20	1.0	178.27	396.8	1.65

From the table 2, it is identified that the minimum tensile strength value 104.03 N/mm² is obtained at the value of 300 watt power, 1.5 mm/sec welding speed and 0.35mm diameter. The maximum tensile strength value 271.04 N/mm² is obtained at the value of 350 volts power, 0.5 mm/sec welding speed and 0.35 mm diameter. The minimum weld hardness 380.1 HV is obtained at the value of 300 watt power, 0.5 mm/sec welding speed and 0.4 mm diameter. The maximum weld hardness value 417.6 HV is obtained at the value of 350 watt power, 1.5 mm/sec welding speed and 0.40 mm diameter. The minimum percentage of elongation 1.65 is obtained at the value of 350 watt power, 1 mm/sec welding speed and 0.2 mm diameter. The maximum percentage of elongation value 3.16 is obtained at the value of 350 watt power, 1.5 mm/sec welding speed and 0.40 mm diameter.

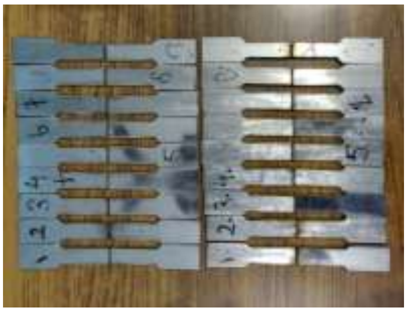

Fig.1 Laser Beam welded specimens

Tensile strength was determined using universal testing machine and the percentage elongation of the each specimen was found out. The weld hardness values also found out using Vickers hardness testing machine. The tensile test specimens are shown in figure 2.

Fig. 2 Tensile test specimens

5. RESULT AND DISCUSSION

Taguchi analysis for maximum tensile strength and weld hardness carrying capacity using the response of means and response table of S/N Ratios. The tensile strength is a good indicator for evaluating the engineering material; therefore, the tensile strength of the weld is considered as the quality factor in Taguchi method and then the typical signal analysis procedure was performed. It was considered that it should be the optimum condition if the tensile strength of the weldment is closed to that of the base metal. Hence, the "higher is better" criterion is applied for the analysis for tensile strength and weld hardness. It was considered that it should be the optimum condition if the % elongation of the weldment is closed to that of the base metal. Hence, the "lower is better" criterion is applied for the analysis for % elongation. Recalculate the response again, for the weld hardness and the optimum combination of the process parameter are shown in the table. Recalculate the response again for the % elongation and the optimum combination of the process parameter are shown in the table. After all the computation for tensile strength, weld hardness and % elongation an average response table for tensile strength, weld hardness and % elongation are shown in tables 4, 6 and 8.

5.1 INDIVIDUAL PERFORMANCE

In Taguchi designs, a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, you manipulate noise factors to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors.

Taguchi experiments often use a 2-step optimization process. In step 1 use the signal-to-noise ratio to identify those control factors that reduce variability. In step 2, identify control factors that move the mean to target and have a small or no effect on the signal-to-noise ratio.

Table- 3: S/N ratio for tensile strength

EXPERIMENT NO.	PROCESS PARAMETERS			TENSILE STRENGTH (N/mm^2)	S/N RATIO dB
	A	B	C		
1	1	2	1	185.86	45.3837
2	1	1	2	190.05	45.9354
3	1	3	3	285.60	49.1151
4	2	1	2	187.14	45.4418
5	2	2	3	104.03	40.3431
6	2	3	1	201.49	46.0850
7	3	3	3	188.82	45.5209
8	3	2	1	271.04	48.6606
9	3	1	2	178.27	45.0215

The maximum value of the tensile strength is obtained at the process parameters level of $A_1B_3C_3$.Hence, the experiment 3 has the maximum value of tensile strength.

Table- 4: Average effect for tensile strength

LEVELS	A	B	C
1	46.8114	45.4662	46.7097
2	43.9566	44.7958	45.4662
3	46.4010	46.9070	44.9930
Max-Min	2.8548	2.1112	1.7167
Rank	1	2	3

From the average effect of response of tensile strength in table 4, indicates that power has more influence on tensile strength. Next to process parameter power, diameter of laser beam has more influence on tensile strength. Weld speed has the least influence on the tensile strength.

Table- 5: S/N Ratio for weld hardness

EXPERIMENT NO.	PROCESS PARAMETERS			WELD HARDNESS (HV)	S/N RATIO dB
	A	**B**	**C**		
1	1	2	1	410.3	52.2620
2	1	1	2	395.60	51.9451
3	1	3	3	411.20	52.2810
4	2	1	2	388.20	51.7811
5	2	2	3	395.60	51.9451
6	2	3	1	380.10	51.5979
7	3	3	3	417.60	52.4152
8	3	2	1	402.10	52.0866
9	3	1	2	396.80	51.9714

Table- 6: Average effect for weld hardness

LEVELS	A	B	C
1	52.1627	51.8992	51.9821
2	51.7747	52.0979	51.8992
3	52.1577	52.0980	52.2137
Max-Min	0.3880	0.1988	0.3145
Rank	1	3	2

The process parameter level of $A_3B_3C_3$ has the maximum value of the weld hardness. Hence, the experiment 7 has the maximum value of weld hardness.

Power has more influence on weld hardness. Next to power, weld speed has the influence on weld hardness. Diameter of the laser beam has the least influence on the weld hardness.

Table- 7: S/N ratio for percentage elongation

EXPERIMENT NO.	PROCESS PARAMETERS			% ELONGATION	S/N RATIO dB
	A	B	C		
1	1	2	1	1.9	-5.5750
2	1	1	2	1.86	-5.3902
3	1	3	3	2.38	-7.5315
4	2	1	2	1.91	-5.6206
5	2	2	3	1.89	-5.5292
6	2	3	1	1.84	-5.2963
7	3	3	3	3.16	-9.9328
8	3	2	1	2.46	-7.8187
9	3	1	2	1.65	-4.3496

Table- 8: Average effect for % elongation

LEVELS	A	B	C
1	-6.1655	-5.1201	-6.2300
2	-5.4820	-6.3076	-5.1201
3	-7.3670	-7.5868	-7.6645
Max-Min	1.8850	2.4667	2.5444
Rank	3	2	1

The process parameter level of $A_3B_1C_2$ has the minimum value of the % elongation. The experiment 9 has the minimum value of % elongation.

Weld Speed has more influence on % elongation. Next to weld speed, the diameter of laser beam has the influence on % elongation. Power has the least influence on the % elongation.

The signal-to-noise ratio is simply a quality indicator by which the effect of changing a particular process parameter on the performance of the process or product is evaluated. In general, a better signal is obtained when the noise is smaller, so that a larger S/N ratio yields better final results. That means, the divergence of the final results becomes smaller. Signal-to-noise ratios of each experimental run are calculated based on the following equation, and the values are listed below,

Higher is better: $L_i = 1/n \sum 1/y_i^2$ ………………….(1)

Lower is better: $L_i = 1/n \sum y_i^2$ ……......…………….(2)

Where, L_i is the loss function of the i*th* performance characteristics, n the number of data, y_i is the value of the i*th* performance characteristic. After the collection of raw data, average effect response values are calculated based on the following procedure. Typically, the average effect for level one of squeeze pressure is computed using the data from experiments. Similarly, the average effects for level 2 and 3 of squeeze pressure were computed using data from experiments.

Taguchi Analysis, for maximum tensile strength and weld hardness carrying capacity using the response of means and response table of S/N Ratios. The tensile strength is a good indicator for evaluating the engineering material; therefore, the tensile strength of the weld is considered as the quality factor in Taguchi method and then the typical signal analysis procedure was performed. It was considered that it should be the optimum condition if the tensile strength of the weldment is closed to that of the base metal. Hence, the “higher is better” criterion is applied for the analysis for tensile strength and weld hardness. It was considered that it should be the optimum condition if the % elongation of the weldment is close to that of the base metal. Hence, the “lower is better” criterion is applied for the analysis for % elongation. Recalculate the response again, for the weld hardness and the optimum combination of the process parameter are shown in the table 5. Recalculate the response again, for the % elongation and the optimum combination of the process parameter are shown in the table 6.

5.2 MULTIPERFORMANCE ANALYSIS- USING GRAY RELATIONAL ANALYSIS

In a complex multivariate system, the relationship among various factors is usually unclear. Such systems are often called as “gray” implying poor, incomplete and uncertain information. Gray relational analysis is an impacting measurement method in gray system theory that analyses uncertain relations between one main factor and all the other factors in a given system. When experiments are ambiguous or when the experimental method cannot be carried out exactly, gray analysis helps to compensate for shortcomings in statistical regression. Data preprocessing in gray relational analysis is normally required since the range and unit in one data sequence may differ from the others. In addition, it is a process of transferring the original sequence to a comparable sequence. For data preprocessing in the gray relational analysis process, “the lower the % elongation and higher the tensile strength and weld hardness” if the target value of original sequence is infinite. The original sequence can be normalized as following:

$$x_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)}$$

Where i=1,…,m; k=1,…,n m is the number of experimental data items and n is the number of parameters. $x_i(k)$denotes the sequence after the data processing, max $x_i(k)$ denotes the largest value of $x_i(k)$, min $x_i(k)$ denotes the smallest value of $x_i(k)$.

When the “lower is better” is a characteristic of the original sequence, the original sequence should ne normalized as following:

$$x_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)}$$

In gray relational analysis, the measure of the relevancy between two systems or two sequences is defined as the gray relational grade. When only one sequence is available as the reference sequence and all other sequence serve as comparison sequences, it is called a local gray relation measurement. After data preprocessing is carried out, the gray relation coefficient for the k*th* performance characteristics in the i*th* experiment can be expressed as following:

$$\xi_i(k) = \frac{\Delta \min + p\Delta \max}{\Delta x_i(k) + p\Delta \max}$$

Where delta is the deviation sequence of the reference sequence and the comparability sequence.

$$\Delta x_i(k) = \left| x_0(k) - x_i(k) \right|$$

$x_o(k)$ denotes the reference sequence and $x_i(k)$ denotes the comparability sequence. It is distinguishing or identification coefficient. A value is the smaller and the distinguished ability is the larger 0.5 is generally used. After the gray relational coefficient is derived, it is usual to take the average value of the gray relational coefficients as the gray relational grade.

Table- 9:-Gray relational coefficient and gray relational grade

Exp No	A	B	C	GRAY RELATIONAL COEFFICIENT			GRAY RELATION GRADE	ORDERS
				TENSILE STRENGTH	WELD HARDNESS	% ELONGATION		
1	1	2	1	0.4764	0.7197	1.0000	0.7320	2
2	1	1	2	0.5090	0.4601	0.8376	0.6022	6
3	1	3	3	1.0000	0.7454	0.5675	0.7709	1
4	2	1	2	0.4797	0.3894	0.9842	0.6177	4
5	2	2	3	0.3333	0.4601	0.7224	0.5052	8
6	2	3	1	0.5190	0.3333	0.5023	0.4515	9
7	3	3	3	0.4839	1.0000	0.3333	0.6057	5
8	3	2	1	0.8617	0.5474	0.5293	0.6461	3
9	3	1	2	0.4582	0.4740	0.7126	0.5482	7

$A_1B_3C_3$ has the highest gray relational grade for maximum tensile strength, maximum weld hardness and minimum % elongation.

$A_2B_3C_1$ has the least gray relational grade for maximum tensile strength, maximum weld hardness and minimum % elongation.

Table 10:- Response table for average gray relational Grade

PROCESS PARAMETERS	AVERAGE GRAY RELATIONAL GRADE BY FACTOR LEVEL			Max-Min
	LEVEL 1	LEVEL 2	LEVEL 3	
A	0.7017	0.5248	0.6000	0.1769
B	0.5893	0.6277	0.6093	0.0384
C	0.6098	0.5893	0.6272	0.0379

From table 10, power has more influence on the gray relational grade. Weld Speed has the least influence on gray relational grade.

After calculating all the values for gray relational grade, experiment 3 has highest gray relational grade through which orders have been decided. Higher the gray relational grade means the grade 1 and so on.

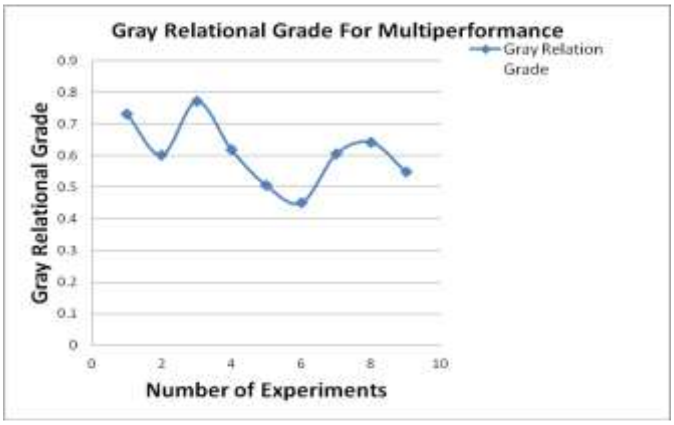

Fig. 3: Gray relational grade for multi-performance.

In Laser welding operation, minimum % elongation and maximum tensile strength and weld hardness are the indication of the better performance. For data preprocessing in the gray relational analysis process, % elongation and tensile strength, weld hardness were taken as the "lower is better" and the "higher is better" respectively. Let the result of 09 experiments be the comparability sequence. All the sequences after data preprocessing using by the above equations and it is denoted as $x_o(k)$ and $x_i(k)$ for reference sequence and comparability sequence, respectively. The distinguishing coefficient can be substituted into the equation to produce the gray relational coefficient. In addition, to the determination of optimum process parameters for % elongation, tensile strength and weld hardness, the response table of Taguchi Method was used to calculate the average gray relational grade for each level of process parameters. The procedures include the gray relational grades with factor level for each column in the orthogonal array and average of them. The gray relational grade values for each level of the process parameters were calculated using the same method. The greater the value of the gray relational grade means the comparability sequence has a stronger correlation to the reference sequence. In other words, regardless of category of the performance characteristics, a greater gray relational grade value corresponds to better performance. Therefore, the optimal level of the process parameters is the level with the greatest gray relational grade value. The optimal process parameters for the minimum % elongation and maximum the tensile strength and weld hardness was obtained.

6. CONCLUSIONS

Experiments were conducted on LBW to evaluate the strength characteristics of 304 stainless steel welded joints.

Laser power, welding speed and diameter of laser beam were considered as process parameters while tensile strength, weld hardness and percentage elongation were considered as output responses.

The method was applied in order to identify the optimized values of process parameters by taking maximum tensile strength and weld hardness. Based on the results for tensile strength and weld hardness, it was depicted that the process parameters: laser power, weld speed and diameter have more influence on the strength.

The laser power has the most influence on the tensile strength and weld hardness has the least performance on tensile strength.

The laser power has more influence on weld hardness and diameter of laser beam has the least influence on the weld hardness.

The weld speed has more influence on % elongation and power has the least influence on the % elongation.

The experimental run $A_1B_3C_3$ has the highest gray relational grade for maximum tensile strength, maximum weld hardness and minimum % elongation and $A_2B_3C_1$ has the least gray relational grade for maximum tensile strength, maximum weld hardness and minimum % elongation.

The laser power has more influence on the gray relational grade. Weld Speed has the least influence on gray relational grade.

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