Optimization and Modeling of Process Parameters in Projection Welding Process using Multi-objective Taguchi method and RSM

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Abstract— Projection welding is a process that is being in industry for sheet and nut joining purpose especially in Automobile and Aerospace industries. This paper presents an alternative method to optimize process parameter of projection welding (PW) towards weld zone development. The optimization approach attempts to consider multiple quality characteristics, namely torque and heat affected zone (HAZ), using multi-objective Taguchi method (MTM). Also this paper presents and experimental investigation for optimization of torsional strength and HAZ of low carbon mild steel by using Taguchi method. The experimental study was conducted for plate thickness 1mm and M6 SQ nut under different electrode pressure, welding current and weld time. The optimum welding parameters were investigated using the Taguchi method with L9 orthogonal array. The optimum value was analyzed by means of multi-objective method, which involved the calculation of total quality normalized loss (TNQL) and multi single to noise ratio (MSNR). Significant level of the welding parameter was further obtained by using analysis of variance (ANOVA). Additionally, the first order model of predicting the weld quality zone development is derived by response surface methodology (RSM). The experimental results confirmed the validity of used Taguchi method for enhancing welding performance and optimizing the welding parameters in projection welding process. The confirmation test indicates that it is possible to increase torque and smaller HAZ significantly.

Key words: Multi-objective Taguchi method, Multi-signal to noise ratio, Projection welding, Response surface methodology

I. INTRODUCTION

The design of experiment (DOE) is widely used in technical as well nontechnical research fields to develop a mathematical relationship between the process input parameters and the output variables in order to optimize the input parameters that lead to the desired quality. Projection, spot and seam welding are three resistance welding process in which coalescence of metal and nut is produced at the faying surface by the heat generated at the joint by the contact resistance to the flow of electric current. Electrode pressure is always applied before, during and after the application of current to prevent arcing at the faying surfaces and in some applications to pressure the weld metal during post heating. Projection welding process is a joining of different fasteners and nuts with sheet. It is more economical and is a much faster process compared to both casting and riveting. Preheating current is always applied before welding current to break the coating. The major factors controlling this process are welding current, weld time, electrode pressure, contact resistance, properties of electrode material and sheet material, surface condition etc. the quality is tested by higher torque and heat affected zone(HAZ).

X. Sun[1] presented the projection welding is a variation of resistance welding in which current flow is concentrated at the point of contact with a local geometric extension of one or both of the parts being welded. These projections are used to concentrate heat generation at the point of contact. Therefore to generate a weld nugget faster and a lower current level compared to conventional spot welding. It investigates the effect of projection height on projection collapse and nugget formation. Three projection designs with different projection heights were selected for 0.059inch.

Valdir Furlanetto, et al. [6] represented the correlation study between destructive testing traditional methods against ultrasonic B-Scan analysis of resistance projection welded nuts, used in automotive applications. Usually auto industry applies several types of projection welding in its structure, such as bolt and nuts, to increase bodies' assembly projection welding in its structure, such a bolt and nuts, to increase body's assembly production.

Mr. Aditya Kaushik, et al. [14] represented projection welding is a variation on resistance welding. Basically, a protrusion is placed on one of the two materials to be welded. This projection is then brought into contact against the second material. The research work was carried out on experimental investigation of projection welding on material AISI 1080 by using processes of derusting and oiling directly on the rod specimen of this same material. In this paper they have presented the main parameters used in projection welding on AISI 1080 material and they are compared with derusted and oiled specimens.

Raj Kumar, et al. [15] represented the feasibility of incorporating projection on the Nickel tab and optimization of welding parameters for the projection welding of Nickel tab to the Mild steel coated with Nickel (18650 Li-ion cell case material) using Taguchi method. Resistance welding is a group of joining process in which coalescence a produced by the heat obtained from resistance of work piece to current in a circuit of which the work piece is part and by the application of pressure.

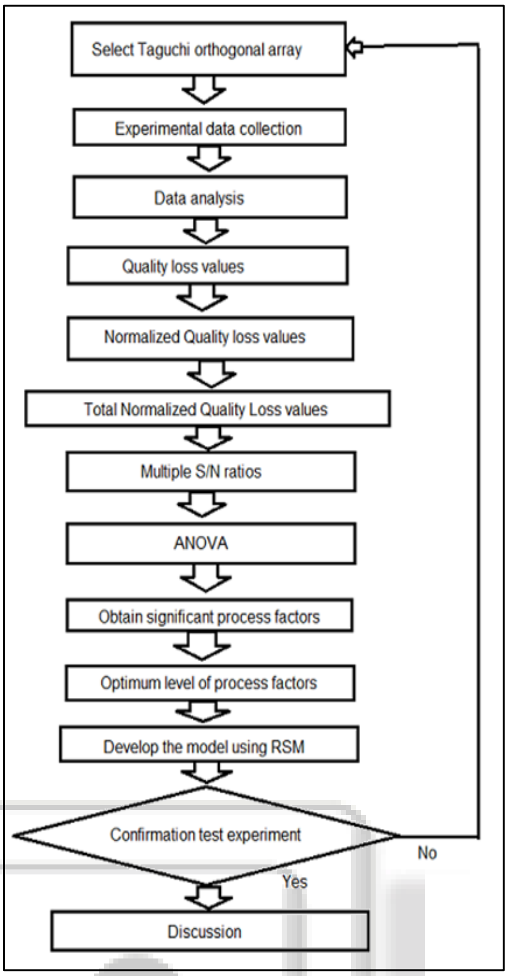

Fig. 1: Flow chart of research methodology

Projection must be designed pressure to support the electrode pressure to obtain a high contact resistance at the faying surface. Current flow through the faying surface between the two workpiece creates a rapid temperature increase. Electrode pressure then cause the collapse of the heated projection and the work pieces can be fastened together.

Taguchi methods have proved to be successful over the last fifteen years for the improvement of product quality and process performance. Based on the review of past researches, most of the investigations focused on modeling and optimizing single quality characteristic which may deteriorate other characteristics. As the main objective of the manufacturing process is always to improve the overall quality of a product, it is necessary to optimize multiple quality of a product, it is necessary to optimize multiple quality characteristics simultaneously.

In the present paper, multi-objective Taghuchi was applied to optimize the welding parameters under simultaneous consideration of multiple weld quality characteristic (larger torque and smaller HAZ size). The optimization approach starts with the calculation of total normalized quality loss (TNQL) under simultaneous consideration of response weighing factor and followed by the observation of multi signal to noise ratio (MSNR). The significant level of the welding parameters was further obtained by using analysis of variance (ANOVA). Furthermore, the first order response model, one can predict the development of higher torque and HAZ size. Experimental confirmation test was also conducted to validate the predicted model. The step applied in this research is shown in Fig. 1.

II. TAGUCHI & MULTI-OBJECTIVE TAGUCHI METHOD

Taguchi's method robust design is simple, systematic and more efficient technique for optimizing the process parameters. In this method, main parameters which are assumed to have influence on process results are located at different rows in a designed orthogonal array (OA). With such arrangement, completely randomized experiments can be conducted. An advantage of the Taguchi method is that it emphasizes a mean performance characteristics value close to the target value rather than a value within certain specification limits, thus improving the product quality. It can be used to quickly narrow the scope of a research project or to identify problems in a manufacturing process from data already in existence.

In this present work, optimization of projection welding operations using Taguchi's robust design methodology with multiple performance characteristics is proposed. In order to optimize the multiple performance characteristics, Taguchi parametric design approach was not applied directly. In this method, main process parameters or control factors which influence process results are taken as input parameters and the experiments is performed as per specifically designed OA. The selection of appropriate OA is based on total degree of freedom (dof) which is computed.

$$dof = \{(\text{number of levels} - 1)\text{for each factor}\} + \{(\text{number of levels} - 1) \times (\text{number of levels} - 1)\text{ for each inter action}\}. \qquad (1.1)$$

In general signal to noise (S/N) ratio (η, dB) represents quality characteristics for the observed data in the Taguchi design of experiments (DOE) and mathematically can be computed.

$$\eta = -10\log_{10}[\mathrm{MSD}] \qquad (1.2)$$

Where, MSD is mean square deviation from the desired value and commonly known as quality loss function.

Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio: smaller-is better, higher-is-better and nominal-is-best. In this research for the strength of torque (torsional strength) and width of HAZ the higher-is-best and smaller-is-better was chosen, respectively, with following equation.

Higher-is-better,

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \qquad (1.3)$$

Smaller-is-better,

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \qquad (1.4)$$

Where, y_i(mean) denote the observed data at ith trial and n is the number of trials. From the S/N ratio, the effective parameters having influence on process results can be obtained and the optimal sets of process parameters can be determined.

The Taguchi method also provides a better feel for the relative effect of the different parameters/factors that can be analyses by the analysis of variance (ANOVA). It is a statistical method to estimate quantitatively the relative significance factors on quality characteristics.

In multi-objective optimization, a single overall S/N ratio for all quality characteristics is computed in place of separate S/N ratios for each of the quality characteristics. This overall S/N ration is known as multiple S/N ratio (MSNR). Transform the total loss function into a multiple S/N ratio (MSNR) as follows:

$$\mathrm{MSNR} = -10\log_{10}(\mathrm{Y_j}) \quad (1.5)$$

$$\mathrm{Y_J} = \sum_{i=1}^{k} \mathrm{w_i y_{ij}} \quad (1.6)$$

$$\mathrm{y_{ij}} = \mathrm{L_{ij}}/\mathrm{L_i^*} \quad (1.7)$$

Where Y_J is total normalized quality loss in jth trial, w_i represented the weighting factor for the ith quality characteristics, k is the total number of quality characteristics and y_{ij} is the normalized quality loss associated with the ith quality characteristics at the jth trial condition and it varies from a minimum of zero to a maximum of 1. L_{ij} Is the quality loss or MSD for the ith quality characteristics at the jth trial, and L_i^* is the maximum quality loss for the ith quality characteristics among all the experimental runs.

III. EXPERIMENTAL SET-UP

In this project, experiment was conducted on IN “MAHINDRA CIE AUTOMOTIVE LTD”, on projection welding machine used to join sheet and nut workpiece of mild steel, plates size is 47mm length ×27mm width ×1mm thickness and nut size is M6 square(SQ). The chemical composition of the workpiece is listed in Table 1. Three welding parameters such as electrode pressure, welding current and weld time were selected for experimentation with tree levels of each factor. The value of the welding process parameter at the different levels is tabulated in Table 2. Experimental process was conducted using L_9 orthogonal array in Taguchi method which has nine rows corresponding to the number of experiments as shown in Table III. Experimental results for the torque and heat affected zone (HAZ) geometry using L_9 orthogonal array are shown in Table 3.

Percent Composition (%)	C 0.120	Mn 0.500	Si 0.181	P 0.040	S 0.450
Mechanical Properties	Yield strength (N/mm2) 190	Tensile strength (N/mm2) 270	% Elongation 37	% reduction in area 63	Hardness (HB) 78

Table 1: Chemical Composition and Mechanical Properties of Work piece

Symbol	Welding parameters	Level 1	Level 2	Level 3
A	Electrode pressure, Bar	4	5	6
B	Welding current, kA	10	12	14
C	Weld time, Cycles	4	6	8

Table 2: Welding Parameters With Different Level

Experiment number	Levels of factors		
	A	B	C
1.	1	1	1
2.	1	2	2
3.	1	3	3
4.	2	1	2
5.	2	2	3
6.	2	3	1
7.	3	1	3
8.	3	2	1
9.	3	3	2

Table 3: Experimental Layout Using L9 Orthogonal Array

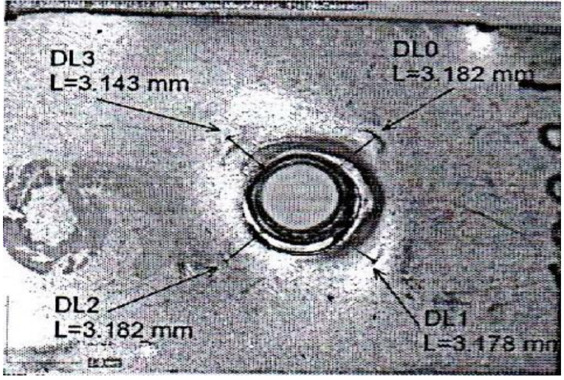

Fig. 2: Macrograph of HAZ

Fig. 3: Measurement of torque by torque meter

To measure the outputs which are the torsional strength torque range instrument. These specimens were prepared by the usual metallurgical polishing methods and etched with 3% nital solution, and the HAZ size captured using an inverted metallurgical microscope interfaced with an image analysis system as shown in Fig. 2 & Fig. 4.

Fig. 4: Inverted metallurgical microscope

IV. RESULTS AND DISCUSSION

The value of the observed data for the larger torque and HAZ size are shown in Table IV. Two or more experimental data are needed because the quality characteristic for torsional strength (torque) is larger-is-best and its S/N ratio on mean square deviation.

Experimental number	Torque 1 (kNmm)	Torque 2 (kNmm)_	HAZ 1 (mm)	HAZ 2 (mm)
1.	40.2000	40.6000	0.7600	0.7500
2.	45.3900	45.4500	1.1350	1.3100
3	60.2500	60.3400	4.5350	4.5320
4.	38.6200	38.5800	0.8410	0.7910
5.	50.7800	50.8900	1.2200	1.7900
6.	56.5300	56.6600	1.7970	2.2710
7.	35.7600	35.6400	1.0500	0.8713
8.	50.8200	50.7900	0.9160	0.8860
9.	60.7500	60.6200	3.1625	3.1838

Table 4: Experimental Results

Experiment number	A	B	B	Quality loss value(dB)	
				Torque	HAZ
1.	4	10	4	0.0006127	0.5700
2.	4	12	6	0.0004847	1.4945
3.	4	14	8	0.0002751	20.5526
4.	5	10	6	0.0006712	0.6659
5.	5	12	8	0.0003870	2.2650
6.	5	14	4	0.0003122	4.1372
7.	6	10	8	0.0007846	0.9228
8.	6	12	4	0.0003874	0.8118
9.	6	14	6	0.0002715	10.0689

Table 5: Quality Loss Value For Torque And Haz

V. MULTI-OBJECTIVE OPTIMIZATION RESULTS

From Table IV. Quality loss value for different quality characteristics (larger-is-better for torsional strength (torque) and smaller-is-better for HAZ size) in each experimental run are calculated using Eqs. (1.3) and (1.4). These quality loss values are shown in Table V. The normalized quality loss values for both quality characteristics in each experimental run have been calculated using Eqs. (1.7) that is shown in Table IV. The total normalized quality loss value (TNQL) and MSNR for multiple quality characteristics for torsional strength (torque) and HAZ size have been calculated using Eqs. (1.6) and (1.5) respectively. These results are shown in Table VII.

In calculating total normalized quality loss values, two unequal weights, w_1=0.7 for torsional strength (torque) and w_2=0.3 for HAZ size were used. Higher weighting factor was assigned to the torque because it is more important compared HAZ in order to achieve good quality weld in projection welding process.

The effect of different control on MSNR is shown in Table VIII. The optimum levels of different control factors for larger torque and smaller HAZ obtained are weld current at level 2(12 kA), weld time at level 1(4 cycles) and electrode pressure at level 2(5 Bar).

Experimental number	A	B	C	Normalized quality loss values(dB)	
				Torque	HAZ
1.	4	10	4	0.7809	0.0277
2.	4	12	6	0.6178	0.0727
3.	4	14	8	0.3506	1.0000
4.	5	10	6	0.8554	0.0324
5.	5	12	8	0.4932	0.1102
6.	5	14	4	0.3979	0.2013
7.	6	10	8	1.0000	0.0449
8.	6	12	4	0.4938	0.0395
9.	6	14	6	0.3461	0.4899

Table 6: Normalized Quality Loss Values

Experimental number	A	B	C	TNQL	MSNR(dB)
1.	4	10	4	0.5549	2.5577
2.	4	12	6	0.4543	3.4269
3.	4	14	8	0.5454	2.6329
4.	5	10	6	0.6085	2.1575
5.	5	12	8	0.3783	4.2217
6.	5	14	4	0.3389	4.6990
7.	6	10	8	0.7135	1.4662
8.	6	12	4	0.3575	4.4674
9.	6	14	6	0.3892	4.0980

Table 7: Total Normalized Quality Loss Values (Tnql) and Multiple S/N Ratios (Msnr)

Symbol	Factors	Mean of multiple S/N ratio (dB)		
		Level 1	Level 2	Level 3
A	Electrode pressure(Bar)	2.873	3.693*	3.344
B	Welding current(kA)	2.063	4.039*	3.810
C	Weld time(cycles)	3.908*	3.227	2.774

Table 8: Multiple S/N Response (Average Factor Effect at Different Level)

ANOVA technique has been employed to detect significant factors in multi-objective optimization for torque and HAZ size. The result of ANOVA for the welding outputs is presented in Table IX. This analyzed shows that welding current was statistically, significant since its p-value is less 0.07. Furthermore, it also shows the percentage contribution which indicates the relative power of a factor to reduce variation. For a factor with a high percentage contribution, a small variation will have a great influence on the performance.

The percentage contribution of different control factors on multiple quality characteristics (torque and HAZ size) shows that welding current was the major factor (67.01%); it is followed by weld time (18.65%) and electrode pressure (9.69%).

Factors	Ele. pressure	Welding current	Weld time	Error	Total
DoF	2	2	2	2	8
Sum of square	1.0167	7.0263	1.9561	0.4874	10.4565
Mean of square	0.5083	3.5132	0.9781	0.2437	
F	2.09	14.42	4.01		
P	0.324	0.065	0.199		

Contribution %	9.69	67.01	18.65		95.35

Table 9: Anova Result

	Initial parameter setting	Optimal process parameters		Error (%)
		Prediction	Experiment	
Level	A2B2C3	A2B2C1	A2B2C1	
Torsional strength (kN-mm)	50.825	48.9767	51.65	5.45%
HAZ(mm)	1.5050	1.2152	1.16	4.75%
MSNR(dB)	4.2217	5.034	4.5094	
Improvement in multiple S/N ratio=0.2877dB				

Table 10: Result Of The Confirmation Experiment

VI. RESPONSE SURFACE MODELING

The first order response surface model for torsional strength and HAZ size was developed from the experimental response values obtained using OA experimental matrix. These equations were developed using RSM in MINITAB 14 software.

Torsional strength,

$$= -14.4708 + (0.179167 \times \text{A}) + (5.23958 \times \text{B}) - (0.0808333 \times \text{C}) \qquad (1.8)$$

Width of HAZ,

$$= -5.86673 - (0.246033 \times \text{A}) + (0.600758 \times \text{B}) + (0.275758 \times \text{C}) \qquad (1.9)$$

Where A, B, C are electrode pressure, welding current, weld time respectively.

To test whether the data are well fitted in the model or not, the values of S and R^2 are observed. In general, the more appropriate regression model is the higher the value of R^2(R is correlation coefficient) and the smaller the value of standard errors of samples).

Factors	Constant	Electrode Pressure	Welding current	Weld time
Coef	48.8150	0.1792	10.4792	-0.1617
SE coef	0.9512	1.1650	1.1650	1.1650
T	51.318	0.154	8.995	-0.139
P	0.000	0.884	0.000	0.895
S = 2.854 R-sq = 94.25% R-sq (adj) = 90.7%				

Table 11: Estimated Regression Coefficient For Torque

From the developed models, calculated S value of regression analysis on torque is 2.854 and HAZ size is 0.7136, which are smaller and R^2 value for both response (torque and HAZ size) are 94.25% and 81.0% respectively. These are moderately high; therefore the data for each response are well-fitted in the developed models.

Term	Constant	Electrode pressure	Welding current	Weld time
Coef	1.7668	-0.2460	1.2015	0.5515
SE coef	0.2379	0.2913	0.2913	0.2913
T	7.428	-0.845	4.124	1.893
P	0.001	0.437	0.009	0.117
S = 0.7136 R-sq = 81.0% R-sq (adj) = 69.6%				

Table 12: Estimated Regression Coefficient For Haz

VII. CONFIRMATION TESTS

The final step is verification experiments to validate that the optimum condition suggested by matrix experiment does indeed give the projected improvement. The confirmation experiment is performed by conducting the test with specific combination of the factors and levels previously evaluated. After determining the optimum conditions, a new experiment was conducted with the optimum levels of the welding parameters ($A_2B_2C_1$). Then the predicted value of MSNR (η_{opt}) at the optimum parameter levels was calculated by using the following equation,

$$\eta_{\text{opt}} = \bar{\eta} + \sum_{i=1}^{p}(\eta_{mi} - \bar{\eta}) \qquad (2.1)$$

Where η the mean MSNR of all experimental runs, p is the number of main welding parameters that significantly affect the performance and η_{mi} is the average of MSNR at the optimal level.

The predicted value o MSNR and that confirmation experiment as shown in Table X. The improvement in multiple S/N ratios is from initial parameter which is ($A_2B_2C_3$) is found to be 0.2877Db. The results show considerable improvement in both the quality characteristics (torsional strength and HAZ size) with the multi-response optimization used, as compared the initial value of radius torque and HAZ size.

Confirmation experimental results are also compared with Eqs. (8) and (9). Results of confirmation rest compared to predicted value for torque and HAZ size using the developed model and also the percentage error are also shown in Table X. The percentage error for torque and HAZ size is 5.45% and 4.75% respectively: the percentage errors are within the acceptable range. It shows that the model equation presents good agreement with experimental result.

VIII. CONCLUSION

A multi-objective Taguchi method has applied for simultaneous consideration of multiple responses (torsional strength (torque) and HAZ size) to optimize multiple quality characteristics is projection welding process it can be concluded that

1) Multiple characteristics such as torque and HAZ size can be simultaneously considered using multi-objective Taguchi method.
2) The contribution of different control factors is welding current (67.01%), weld time (18.65%) and electrode pressure (9.69%). The effective parameter For the development of torque and HAZ size is welding current.
3) The optimum parameters for larger torsional strength and smaller HAZ size are: welding current at level 2(12 kA), weld time (at level 1(4 cycles) and electrode pressure at level 2(5 Bar).
4) The developed linear response surface model for prediction of torsional strength and HAZ size has been found well fitted.
5) The confirmation test is validated the use of multi-objective Taguchi method for enhancing the welding performance and optimizing the welding parameters in projection welding (PW).

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