OPTIMIZATION OF RESISTANCE SPOT WELDING PROCESS PARAMETERS USING MOORA APPROACH

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ABSTRACT

Efforts Optimization of resistance spot welding (RSW) process parameters was carried out to obtain optimal parametric combination to yield favorable weld nugget diameter, heat affected zone (HAZ) and breaking load in AISI 316 L austenitic stainless steel plates. Taguchi's L16 orthogonal array (OA) design and signal- to- noise ratio (S/N ratio) have been used in this study. Weld nugget diameter, heat affected zone (HAZ) and breaking load are selected as objective functions. In this case the multi objective optimization on the basis of ratio analysis (MOORA) is applied to solve this multi objective, problem. MOORA in combination with standard deviation (SDV) was used for optimization process. Standard deviation (SDV) was used to determine the weights that were used for normalizing the responses obtained from the experimental results. It was found that welding current of 14 kA, welding time 14 cycle, electrode force 200Kgf and holding time 10 cycle produced the weldment with the best mechanical properties. This method can be used successfully in other welding applications.

KEYWORDS: *RSW; SDV; Orthogonal array; MOORA; HAZ*

1.0 INTRODUCTION

Resistance spot welding (RSW) is a multi factor, multi objective metal joining process, in which several process control parameters interact in a complicated manner and influence quality of weld. In most resistance spot welding (RSW) the weld quality is judged by nugget size, heat affected zone (HAZ) and joint strength. So it is important to select the welding process parameters to get the desired quality of the weld. Usually, the selection of the desired process parameters is selected by trial and error. This is time consuming costly and may not be accurate. This does not ensure optimum weld nugget and other properties to ensure a proper weld.

In order to overcome this problem various optimization techniques are used so that a perfect relationship between input and output variables can be developed using mathematical relationship so that desired output can be predicted. There are many research work done in modelling and process optimization in RSW and other welding process like gas metal arc welding (GMAW) flux cored arc welding (FCAW) and Tungsten inert gas welding (TIG). Thakur and Nandedkar presented a systematic approach to determine effect of process parameters on tensile shear strength of

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resistance weld joining of austenitic stainless steel AISI 304 using Taguchi method (Thakur & Nandedkar, 2010). Joseph, William and Odinikuku (2015) optimized gas metal arc welding parameters using MOORA approach. Norasiah, Yupiter, Manurung and Hafidzi (2012) optimized resistance spot welding parameters towards development of weld nugget zone and heat affected zone (HAZ) using multi objective Taguchi method (MTM).
In this study Taguchi method coupled with SDV-MOORA method was used to optimize the welding process parameters used for resistance spot welding on AISI 316 L austenitic steel plates. SDV was standard deviation method used for determining the weight attached to each mechanical property. The traditional Taguchi method cannot solve multi-objective optimization problems. In order to overcome this difficulty, the Taguchi method coupled with MOORA analysis used to solve the optimization problem in this study.

2.0 MOORA METHOD

Since standard deviation is applied to this study for unbiased allocation of weights. The importance of weights in solving multi criteria decision making (MCDM) cannot be over emphasized .to determine the standard deviation the range standardization wad done using Equation (1) to transform different scales and units among various criteria in to common measurable units in order to compute weights.

$$X_{ij}^{i} = \frac{X_{ij-min}X_{ij}}{maxX_{ij} - minX_{ij}} \qquad (1)$$

Where max X_{ij} , min X_{ij} are the maximum and minimum values of criterion (j) respectively. The standard deviation is calculated for every criterion using equation (2).

$$SDV_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(X_{ij} - \overline{X_j^i}\right)^2} \qquad (2)$$

Where $\overline{X_{ij}^{i}}$ is the mean of j[th] criterion after normalization and *j=1, 2 ...n* .After calculating for SDV for all criteria the next step is to determine the weights W_j of criteria considered using equation (3).

$$W_j = \frac{SDV_j}{\sum_{j=1}^{n} SDV_j} \qquad (3)$$

Where *i=1...m; j=1 ...n.*

The multi objective optimization on the basis of MOORA method starts with a decision matrix as shown in equation (4):

$$D = \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ \vdots \\ A_n \end{matrix} \begin{pmatrix} c_1 & c_2 & c_3 & \cdots & c_n \\ x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{pmatrix} \quad (4)$$

Step 1: Compute the normalized decision matrix by vector method defined by equation (5)

$$X_{ij}^{i} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \quad (5)$$

Where $i=1.....m; j=1...m$

Step 2; calculate the composite score as expressed in equation (6)

$$Z_i = \sum_{j=1}^{b} X_{ij}^{i} - \sum_{j=b+1}^{n} X_{ij}^{i} \text{ ; where } i=1 \ldots m \quad (6)$$

Where $\sum_{j=1}^{b} X_{ij}^{i}$ and $\sum_{j=b+1}^{n} X_{ij}^{i}$ are the benefit and non benefit criteria respectively .If there are some attributes more important than others, the composite score becomes as expressed in equation (7).

$$Z_i = \sum_{j=1}^{b} w_j X_{ij}^{i} - \sum_{j=b+1}^{n} w_j X_{n}^{i} \quad i=1 \ldots m \quad (7)$$

Where, W_j is the weight of the Jth criterion.

Step 3: Rank the alternatives in descending order.

3.0 EXPERIMENTATION

The sheets were cut parallel to the rolling direction. The dimension of austenitic stainless steel plate of grade AISI 316 L sheet are 140 mm length (L), 40 mm width (w) and 1 mm thick (t) shown in Figure 1. Overlap is equal to width of the sheet as per AWS standard. Sheet surfaces were chemically cleaned by acetone before resistance spot welding to eliminate surface contamination. The properties of base metal are shown in Table 1. Figure 1 shows Kirperker RSW welding machine and Fig. 2 shows sample specimen.

Figure 1. Kirperker RSW welding machine

Table 1 Chemical Composition of Base Metal

Elements, Weight %									
Material	C	SI	Mn	P	S	Al	Cr	Mo	Ni
316 L	0.030	0.75	2	0.045	0.03	-	-	-	0.1

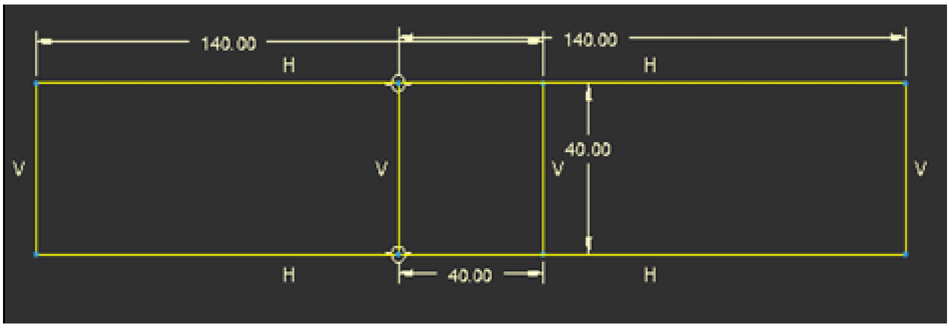

Figure 2. Dimension of specimen

4.0 PLAN OF INVESTIGATION

The research work is carried out in the following steps (Tarng & Yang, 1998).

1. Identifying the quality characteristics and process parameters to be evaluated.
2. Determine the number of levels for the process parameters and possible interactions between process parameters.
3. Select appropriate orthogonal array and assign process parameters to the orthogonal array.
4. Conduct experiment as per arrangement of orthogonal array.

5. Define problem.
6. Selection of alternatives.
7. Selection of the criteria describing alternatives.
8. Determination of criteria values.
9. Normalization of Matrix.
10. Determination of complex rationality.
11. Ranking alternatives.

4.1 Identification of factors and responses

The weld nugget size, HAZ and breaking load has a significant effect on quality of resistance spot welding. The properties of the welding is the significantly influenced by diameter of weld nugget obtained. Hence control of nugget diameter is important in resistance spot welding where a low diameter is highly desirable. The chosen factors have been selected on the basis to get minimal weld nugget diameter, low HAZ and higher breaking load. These are current, hold time; weld time and electrode force. The responses chosen were weld nugget diameter, HAZ and breaking load. The responses were chosen based on the impact of parameters on final composite model (Gunaraj & Murugan, 1999).

4.2 Finding the limits of process variables

Working ranges of all selected factors are fixed by conducting trial run. This was carried out by varying one of factors while keeping the rest of them as constant values. Working range of each process parameters was decided upon by inspecting the smooth appearance without any visible defects. The chosen level of the parameters with their units and notation are given in Table 2.

Table 2. Welding Parameters and their Levels

Parameters	Factor Levels					
	Unit	Notation	1	2	3	4
Welding Current	KA	I	8	10	12	14
Welding Time	cycle	T	10	12	14	16
Electrode Force	Kgf	F	180	200	220	240
Holding Time	cycle	C	10	20	30	40

4.3 Development of orthogonal array

Design matrix chosen to conduct the experiments was Taguchi's orthogonal design. The design matrix comprises of L_{16} orthogonal array. Sixteen experimental trails were conducted that make the estimation of nugget diameter, HAZ and breaking load (Vermal et al., 2014).

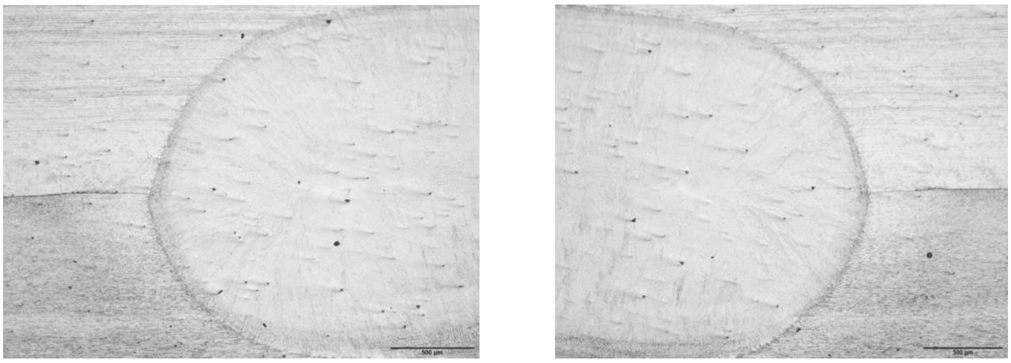

Figure 3. Scanned specimens

Table 3. Design Matrix

Trial Number	Design Matrix			
	I	T	F	C
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

I - Welding current; T - Welding time; F – Electrode force; C – Hold time

4.4 Conducting experiments as per orthogonal array

In this work sixteen experimental run were allowed as per orthogonal array correspond to each treatment combination of parameters on weld nugget diameter, HAZ and breaking load as shown Table 3 at random. At each run settings for all parameters were disturbed and reset for next deposit. This is very essential to introduce variability caused by errors in experimental set up.

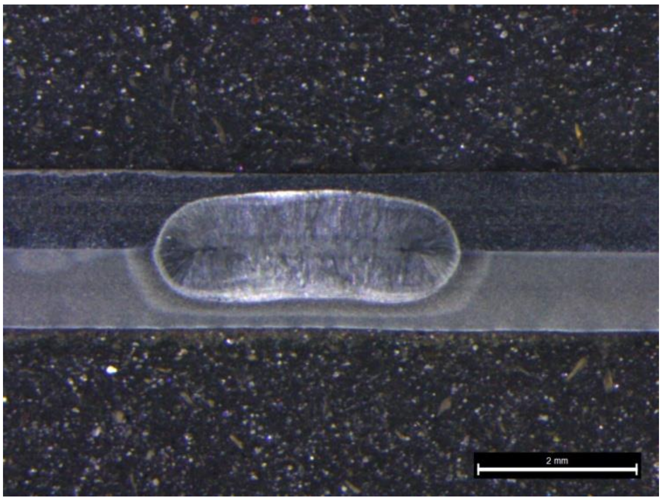

Figure 4. Welded specimen

4.5 Recording of Responses

For measuring the weld nugget diameter, Toolmakers microscope is used. For conducting tensile test specimens were prepared as per ASI 40 and specimen figure is shown in Fig 2. The tensile test is conducted in a UTM at Younus College of engineering technology, kollam, Kerala India. The observed values are shown in Table 4. The tensile-shear test is the most widely used test for evaluating the spot weld mechanical behaviours in static condition. Peak load, obtained from the tensile-shear load displacement curve, describes mechanical behaviour of spot welds. Figure 3 shows scanned specimen and Fig. 4 shows welded specimen.

Table 4. Design Matrix and Observed Values of Weld Nugget Diameter, HAZ and Max breaking load

Trial No.	Design Matrix				Bead Parameters		
	I	T	F	C	Weld Nugget Diameter(mm)	Max breaking load in KN	HAZ (mm)
1	1	1	1	1	7.306	18.81	1.072
2	1	2	2	2	8.243	19.54	0.8734
3	1	3	3	3	7.731	20.67	1.125
4	1	4	4	4	8.925	21.93	0.9238
5	2	1	2	3	8.792	18.44	0.8475
6	2	2	1	4	8.415	19.77	1.2581
7	2	3	4	1	6.777	19.18	0.8945
8	2	4	3	2	8.614	20.59	0.9765
9	3	1	3	4	8.908	21.53	1.1498
10	3	2	4	3	7.371	19.39	0.805
11	3	3	1	2	8.087	18.43	1.1689
12	3	4	2	1	8.112	20.52	0.986
13	4	1	4	2	9.125	19.42	1.0255
14	4	2	3	1	8.753	17.56	1.072
15	4	3	2	4	8.971	20.69	0.8734
16	4	4	1	3	8.807	19.24	1.125

Table 5. Weights assigned to criteria

Property	SDV_j	W_j
Weld Nugget Diameter(mm)	0.28739	0.199576
Max breaking load in KN	0.56175	0.390104
HAZ (mm)	0.59278	0.411653

Table 6. The square value of X_{ij}

	Bead Parameters		
	Weld Nugget Diameter(mm)	**Max breaking load in KN**	**HAZ(mm)**
1	53.37764	353.8161	1.787569
2	67.94705	381.8116	1.505529
3	59.76836	427.2489	0.880219
4	79.65563	480.9249	1.149184
5	77.29926	340.0336	0.762828
6	70.81223	390.8529	1.265625
7	45.92773	367.8724	0.853406
8	74.201	423.9481	0.718256
9	79.35246	463.5409	1.582816
10	54.33164	375.9721	0.80013
11	65.39957	339.6649	0.953552
12	65.80454	421.0704	1.32204
13	83.26563	377.1364	0.648025
14	76.61501	308.3536	1.366327
15	80.47884	428.0761	0.972196
16	77.56325	370.1776	1.05165
$\sum_{i=1}^{n} X_{ij}^2$	1111.8	9468.941	17.6193
$\sqrt{\sum_{i=1}^{n} X_{ij}^2}$	33.343	97.308	4.1975

Table 7. Normalized weld parameters

	Bead Parameters		
	Weld Nugget Diameter	**Max breaking load**	**HAZ**
1	0.219116	0.193304	0.318523
2	0.247218	0.200806	0.292317
3	0.231863	0.212418	0.223514
4	0.267672	0.225367	0.25539
5	0.263684	0.189501	0.208076
6	0.252377	0.203169	0.268017
7	0.203251	0.197106	0.220083
8	0.258345	0.211596	0.201906

9	0.267163	0.221256	0.299726
10	0.221066	0.199264	0.213103
11	0.24254	0.189399	0.232638
12	0.243289	0.210877	0.273925
13	0.273671	0.199572	0.191781
14	0.262514	0.180458	0.278475
15	0.269052	0.212624	0.234902
16	0.264133	0.197723	0.244312
Weights w_j	0.333844	0.66155	0.411653

Table 8. Clustered weld properties according to criteria

NUMBERS	**(Maximum)**	**(Minimum)**	**(Minimum)**
	Max breaking load in KN	**Weld Nugget Diameter(mm)**	**HAZ (mm)**
1	0.12788	0.073159	0.131121
2	0.132843	0.082542	0.120333
3	0.140525	0.077415	0.09201
4	0.149092	0.089371	0.105132
5	0.125364	0.08804	0.085655
6	0.134406	0.084265	0.11033
7	0.130395	0.067862	0.090598
8	0.139981	0.086257	0.083115
9	0.146372	0.089201	0.123383
10	0.131823	0.07381	0.087725
1	0.125297	0.08098	0.095766
12	0.139506	0.08123	0.112762
13	0.132027	0.091374	0.078947
14	0.119382	0.087649	0.114635
15	0.140661	0.089832	0.096698
16	0.130804	0.08819	0.100572

Table 9 Ranking step

	Bead Parameters			
No	$\sum max$	$\sum min$	$\sum max$ -$\sum min$	**Rank**
1	0.12788	0.20428	-0.0764	16
2	0.132843	0.202875	-0.07003	15
3	0.140525	0.169425	-0.0289	3
4	0.149092	0.194503	-0.04541	9
5	0.125364	0.173695	-0.04833	8
6	0.134406	0.194595	-0.06019	13
7	0.130395	0.15846	-0.02807	2
8	0.139981	0.169372	-0.02939	4
9	0.146372	0.212584	-0.06621	14
10	0.131823	0.161535	-0.02971	5
11	0.125297	0.176746	-0.05145	10
12	0.139506	0.193992	-0.05449	11
13	0.132027	0.170321	-0.03829	6
14	0.119382	0.202284	-0.0829	1
15	0.140661	0.18653	-0.04587	7
16	0.130804	0.188762	-0.05796	12

5.0 RESULT ANALYSIS

In this study the weight allocation for each output parameters, that is, the weld mechanical properties were determined. In determining the weights the range of standardized decision matrix is determined using equation (1). Table 5 shows allocated weight. By applying the equation (5) Table 6 and Table 7 created. Next step is to multiply the allocated weights to the values in Table 7.This leads to the creation of table 8.The last step is to sum the parameters comparing higher the better and smaller the better values and Table 9 is created and then parameters are ranked. Rank Number one determines the optimized condition.

The nugget diameter considered in this study range from 6.7 mm to 9.2 mm. Applying MOORA method the selected parameters produced a weld with nugget diameter 7.7 mm. Breaking load considered in this study is within the range of 17.5 KN to 22 KN .By applying The MOORA method penetration is found to be 20.6 KN. HAZ considered in this study range from 1.2 mm to 0.8 mm. Applying MOORA method the selected parameters produced a weld with HAZ 1.072 mm.

Figure 5. Weld structure of optimized model

For this study weld sample 14 produced optimum weld. From Table 3 It was found that welding current of 14 kA, welding time 14 cycle, electrode force 200Kgf and holding time 10 cycle produced the weld with the best mechanical properties. $I_4T_2F_3C_1$ is the optimum process parameters obtained from this study.Fig 5 represents the optimized condition.

6.0 CONCLUSIONS

In this study, a detailed methodology of MOORA technique has been presented for evaluating the nugget diameter, maximum breaking load and, HAZ and parametric combinations in resistance spot welding process. For achieving optimal parametric combination to get minimum nugget diameter, minimum HAZ and maximum breaking load of the weldment produced by resistance spot welding a multi objective optimization process is used. Taguchi method coupled with MOORA analysis is very popular and efficient method for optimization that can be performed with limited number of runs. However standard deviation was used to determine the weights allocated to each value of mechanical property utilized in the course of running MOORA process. It is here by concluded that MOORA method has successfully optimized the process parameters considered in this study and microstructure of the optimized weldment agree that optimization result produced confirm the quality of the weldment.

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