Experimental Investigation and Performance Analysis of Resistance Spot Weld Parameters For AISI 304 Using Taguchi Based Grey Relation Analysis

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Abstract- *Resistance Spot Welding is the process of joining sheet metal parts which forms the automobile body structure. Two to four light gauge overlapping metal sheets of thickness up to 3 mm can be joined using resistance spot welding method. In this study, Taguchi based Grey Relation Analysis is used for determining the optimum process parameters of Resistance Spot Weld for AISI 304 Steel grade. Electrode force, welding current, and weld time are the process parameters selected for this analysis. Tensile strength and nugget diameter are the performance measures investigated and optimized using Taguchi's DOE. On the basis of Taguchi method, orthogonal array L9 is designed for the process parameters. To find out the optimal value, grey relation grade have been determined.*

Keywords- ANNOVA, Grey Relation Analysis (GRA), Orthogonal Array (OA), Resistance Spot welding (RSW), Taguchi method, Tensile strength (T-S), Weld nugget

I. INTRODUCTION

THE spot welding is widely used joining technique for sheet metals of automotive body construction. There are many parameters involved in spot welding process. Optimizing these parameters to get a good weld strength and proper weld nugget is a tough task. These are the output obtained from spot welding process and should be optimum. The tendency of alloying with electrode which results in increased tool wear and subsequent deterioration of weld quality is the problem associated with Resistance spot welding method. RSW is the dominant process in sheet metal joining. The remotest possibility of producing even one or two defective welds in a critical component needs to be eliminated in order to ensure and maintain the structural integrity of automotive body structure under service condition such as a crash situation. Hence, for the reliability of the vehicle and for improving the economics of vehicle production, evaluation of spot weld quality is a vital issue. In the present work, tensile shear strength and weld nugget indicates the strength of the spot weld are determined by welding current, weld time and electrode force. Variations in tensile strength, weld nugget diameter as well as weld indentation is due to variation in these parameters will cause. Suitable combination of these parameters, called as the welding schedule is required to achieve the spot weld with the desired weld characteristics (tensile shear strength, weld nugget diameter).

A. Heat generation in Spot Welding

The spot welding parameters (Weld current, electrode force and weld time) should be controlled properly so as to obtain good quality weld. The amount of heat generated in resistance spot welding process is governed by the formula,

$$Q = I^2 RT \qquad (1)$$

Where

Q = heat generated, Joules
I = Current, Amperes
R = Resistance of work piece, Ohms
T = Time, Second

Shaik Shafee, et.al [1] used Taguchi method for improving the resistance spot weld quality characteristics. The significance of RSW parameters on the quality characteristics can be determined by ANNOVA. Optimization of RSW process parameters along with its effect on shear tensile strength and direct tensile strength can be studied by GRA. A. G. Thakur et.al, [2] [3] presented the Application of Taguchi Method for RSW of Galvanized steel. Combination of optimum parameters for maximum tensile shear strength can be obtained using analysis of S/N ratio. Also a systematic approach was done using Taguchi method to determine the effect of process parameters on tensile strength of weld joint of austenitic stainless steel AISI 301. A. K. Pandey [4] investigated the effect of welding parameters on tensile strength and weld nugget of spot welds. Norasiah Muhammad, et.al [5] presented an alternative method to improve and optimize process parameters of RSW. Ramkrishna Parihar [6] used Grey relational analysis to optimize the welding parameters for dissimilar sheets of material in RSW. Mayank Sao [7] optimized the resistance spot welding parameters for dissimilar material thickness using GRA. K. N. Wakchaure et.al [8] aimed to optimize the friction stir welding process parameters using Taguchi based Grey Relational Analysis. S. R. Thorat, et.al [9] focuses on use of Taguchi based GRA method for optimizing the burnishing parameters for aluminum alloy. Arunkumar Sivaraman, et.al [10] optimized the process parameters of MIG welding for SS2219-T87 by Taguchi method. The laser welding process has been optimized using Taguchi based Grey relational analysis by Shanmugarajan B, et.al [11]. In this study, Taguchi technique is used with combination of GRA to ascertain RSW parameters with optimum tensile strength and weld nugget to obtain good weld quality for the spot weld.

II. DESIGN OF EXPERIMENT

A. *Taguchi Method*.

To study many factors simultaneously and most economically, a statistical technique known as Taguchi's Design of Experiment is used. The technique helps to seek out the best design amongst many alternatives [1]. Using this technique, best factor combination can be determined by studying the effect of individual factor on the result. Taguchi technique was developed by Genichi Taguchi based on Orthogonal Array (OA) of the experiments [7]. Signal to Noise (S/N) ratio is the statistical measure of performance used in Taguchi Methods to evaluate the process parameters. The ratio of mean (signal) to the standard deviation (noise) is known as S/N ratio. Nominal the Best (NB), Higher the Best (HB), and Larger the Best (LB) are the generally used S/N ratios. A larger S/N ratio corresponds to the better quality characteristics. However, using traditional Taguchi method, multi objective optimization problem cannot be solved. Hence, Taguchi method is combined with Grey Relation Analysis (GRA) to overcome this problem. OA are used to determine characteristics with minimum number of experiments which are transferred into signal-to-noise ratio [10].

B. *Selection Of Orthogonal Array (OA)*

Various types of orthogonal arrays experimental designs are used for investigating the various parameters effect on the performance characteristics in the process [3] [7]. In this study, the spot welding parameters considered are welding current, electrode force and welding time. In Taguchi method, for 3 parameters with 3 levels, L9 orthogonal array was selected.

C. *Grey Relation Analysis (GRA)*

This method which is used to study the uncertainties in a system model, analyze the relation between the systems and forecast & make decisions; was developed by Deng in 1989. The normalization of experimental data between the range 0 to 1 is the first step in grey relation generation. Followed by this step grey relation coefficient is calculated to set up the correlation between desired and actual experimental data. By normalizing the different characteristics single grey grade is given to every parameter. So the multi response problem can be converted into a single response process optimization problem with overall grey relation grade as objective function. A multi-criteria optimization problem is thus converted to a single objective optimization problem using a combined approach of Taguchi design and GRA. Higher value of GRG leads to the optimum or close to the optimum combination of input parameters [10].

III. EXPERIMENTATION

A. *Material*

Steel sheets of AISI304 grade was selected for investigation purpose in this study. The chemical composition (wt%) of AISI 304 is 0.0297 C, 0.402 Si, 20.20 Cr, 7.73 Ni, 0.0010 Mo, 1.51 Mn, 0.0005 S, 0.0308 P, 69.8 Fe. To determine the weld quality, a batch of sheet samples in dimension 100mm X 27mm X 1mm were used in spot welding process.

TABLE I
PROCESS PARAMETERS WITH THEIR VALUES AT THREE LEVELS

Parameter	Symbol	Level 1	Level 2	Level 3
Welding Current (Amp)	A	6500	7000	8500
Electrode Force (Kgf)	B	400	450	500
Weld time (cycles/sec)	C	8	10	12

Table I shows the input parameters at three different levels.

B. *Method of Experiment*

1) *Taguchi method*

In this study, three welding parameters such as welding current, electrode force and weld time are selected with three levels of each parameter. Using Taguchi method L9 orthogonal array was used for experimental process as shown in Table III.

TABLE II
L9 ORTHOGONAL ARRAY

Run No.	Process parameters		
	A	B	C
1	6500	400	8
2	6500	450	10
3	6500	500	12
4	7000	400	10
5	7000	450	12
6	7000	500	8

TABLE III
EXPERIMENTAL RESULTS AND S/N RATIO

Run no.	Process Parameters			Response	
	A	B	C	T-S (Kgf)	W/H
1	6500	400	8	38.31	5.1047
2	6500	450	10	34.46	4.4579
3	6500	500	12	32.10	6.1744
4	7000	400	10	35.21	4.0238
5	7000	450	12	36.11	4.4576
6	7000	500	8	36.14	4.2758

Tensile strength was obtained by conducting a tensile test on Universal Testing Machine. To obtain the weld nugget dimensions, the welded samples were cut in transverse direction using simple cutting machine. Using metallurgical polishing methods, samples were prepared and etched with nital solution. The weld zone was captured in image analyzer using a metallurgical microscopes interface as shown in Fig. 1.

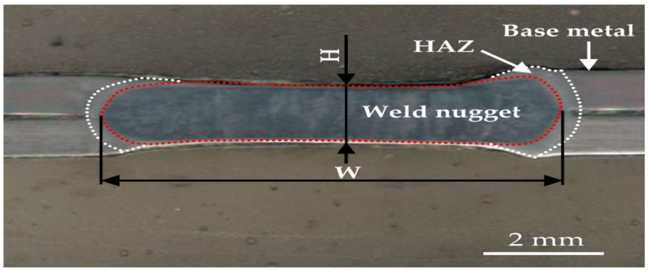

Fig. 1.Micro image of weld zone

A weld nugget is shown in Fig. 1 which includes its width (W) and height (H). Width and height of weld nugget are measured for each sample and their ratio is considered. S/N ratios for tensile strength and weld nugget were found out using Minitab 17. Microstructure found austenitic polygonal grain of AISI 304 stainless steel base metal with a low delta ferrite content. Grain size is ASTM 7.

The values of the observed data for Tensile Strength (T-S) and weld nugget (W/H) are shown in Table III.

2) Grey Relational Analysis

For optimizing the performance involving multiple responses, Grey relational analysis is used. Steps involved in Grey Relational Analysis are –

Normalization-Based on the responses obtained, data normalization is done Following equations are used for normalization. In this study, normalization using higher the better equation is used. Following are the types of normalization equations.

Higher-the-better (HB)

$$X_i(k) = \frac{Y_i - \min Y_i(k)}{\max Y_i(k) - \min Y_i(k)} \quad (2)$$

Lower-the- better (LB)

$$X_i(k) = \frac{\max Y_i - Y_i(k)}{\max Y_i(k) - \min Y_i(k)} \quad (3)$$

Nominal-the-best (NB)

$$X_i(k) = \frac{Y_i(k) - Y_i(k)}{\max Y_i(k) - Y_i(k)} \quad (4)$$

i = 1,2,3,…m; k = 1,2,3,…n

Where X_i (k) is value of grey relation, max Y_i *(k)* and min Y_i *(k)* are the maximum and minimum value of Y_i *(k)* for the k^{th} response [9].

The relationship between comparability sequence $X_i(k)$ and reference sequence $Xo(k)$ are explained using Grey relational coefficient.

$$\Delta_{0i} = |Xo(k) - Xi(k)| \quad (5)$$

Where, Δ_{0i} is the deviation sequence.
Using the deviation sequence calculated, grey Relational Coefficient is calculated using formula below

$$\left|\xi i = \frac{\Delta \min + \theta \Delta \max}{\Delta_{0i} + \theta \Delta \max}\right|$$

Where
ξi is the grey relational coefficient, θ is the distinguish coefficient and is taken as 0.5 and 0.5 for tensile strength and weld nugget depending upon the importance of the characteristics and its value ranges between 0 to 1. The value of grey relational coefficient is obtained as 1 when two sequences agree at all points.

Δmin and Δmax are the minimum and maximum values amongst the deviation sequences.

Averaging the grey relational coefficient, grey relational grade is determined as

$$\gamma_i = \frac{1}{n}\sum_{K=1}^{n} \xi i \quad (6)$$

Where γ_i = Grey relational grade, and n = total no of responses.

Higher the grey relational grade, closer is the combination to its optimum value.

IV. ANALYSIS OF EXPERIMENTAL RESULTS

A. Taguchi Analysis

Table IV includes the S/N ratios for two different responses. It is expressed in decibles (db). Larger the S/N ratio, better are the corresponding characteristics.

TABLE IV
CORRESPONDING S/N RATIOS FOR TENSILE STRENGTH AND WELD NUGGET

Run no.	Process Parameters			Response		S/N Ratio	
	A	B	C	T-S (Kgf)	W/H	T-S (db)	W/H (db)
1	6500	400	8	38.31	5.1047	31.66	14.16
2	6500	450	10	34.46	4.4579	30.74	12.95
3	6500	500	12	32.10	6.1744	30.13	14.38
4	7000	400	10	35.21	4.0238	30.93	12.09
5	7000	450	12	36.11	4.4576	31.15	12.98
6	7000	500	8	36.14	4.2758	31.16	12.62

Figure 2 and figure 3 shows the analysis of main plot for S/N ratios of responses obtained versus the controlling factors. From fig.2, the optimum values of controlling factors to achieve maximum tensile strength were obtained as; for parameter A at level 1, while B and C at level 2. Similarly, for weld nugget, the setting of parameters should be done as A at level 3, B at level 3.

B. Grey Relational Analysis (GRA)

As observed, for multi response, every time there’s a conflict between parameter values at different level for different quality characteristics. Hence, combination of GRA with Taguchi method is used to overcome this problem.

1) Normalization

The measure values of tensile test and weld nugget are normalized from zero to one. Here, for both the responses, higher the better equation is used for normalization. Using equation 1, normalized values are calculated which are shown in Table V below. Deviation sequence (Δ_{0i})is determined using normalize values. Here, the reference sequence ($Xo(k)$) is 1.

TABLE IV
NORMALIZED VALUES AND DEVIATION SEQUENCE

Run No.	Normalized Responses		Deviation Sequence (Δ_{0i})	
	T-S	W/H	T-S	W/H
1	1	0.5612	0	0.4388
2	0.3831	0.2948	0.6169	0.7052
3	0.00557	1	0.99443	0
4	0.5043	0.1155	0.4957	0.885
5	0.6473	0.2939	0.3527	0.7061
6	0.6522	0.2218	0.3478	0.7782

2) Grey Relational Coefficient and Grey Relational Grade

To represent the relationship between the actual and desired data, grey relational coefficient is determined. The grey relational grade is the average value of the grey relational coefficient of tensile strength and weld nugget. Both, grey relational coefficient and grey relational grade are summarized below in Table V.

TABLE V
GREY RELATIONAL COEFFICIENT AND GREY RELATIONAL GRADE

Run No.	Grey Relational Coefficient		Grey Relation grade	Rank
	A	B		
1	1	0.5235	0.3831	1
2	0.4476	0.4146	0.2155	7
3	0.3345	1	0.3336	2
4	0.5022	0.3611	0.2158	6
5	0.5863	0.4145	0.2502	3
6	0.5897	0.3903	0.2450	5

V. RESULTS AND DISCUSSION

A. Taguchi Analysis.

Using Taguchi technique, S/N ratio for both the responses are mention in the Table V. Larger the S/N ratio, better are the characteristics obtained that level. As observed, form maximum value of current, the S/N ratio is higher for both tensile strength and weld nugget.

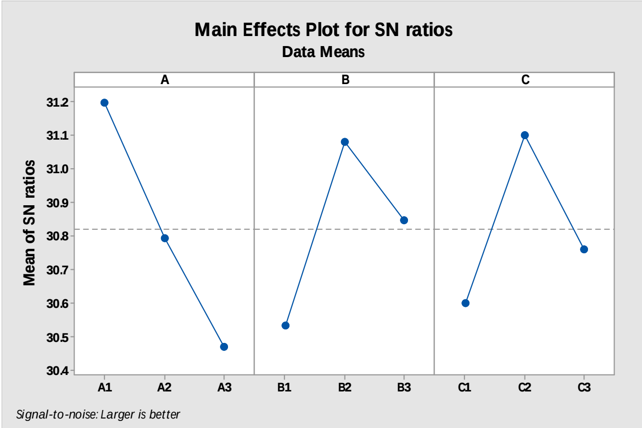

Fig. 2. Mean of S/N ratio of tensile strength v/s Welding current (A), Electrode force (B) and Weld time (C)

Figure 2 and figure 3 shows the analysis of main plot for S/N ratios of responses obtained versus the controlling factors. From fig.2, the optimum values of controlling factors to achieve maximum tensile strength were obtained as; for parameter A at level 1, while B and C at level 2. Similarly, for weld nugget, the setting of parameters should be done as A at level 3, B at level 1 and C at level 3.

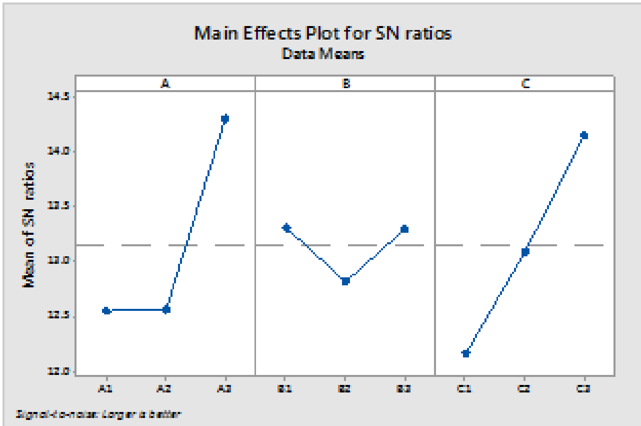

Fig. 3. Mean of S/N ratio of Weld nugget (W/H) v/s Welding current (A), Electrode force (B) and weld time (C)

B. Grey Relational Analysis.

Different optimum levels are obtained for two different responses, hence Grey Relational Analysis is used to convert multi-objective problem into single objective problem. The grey relational grade value for each input parameters is stated in Table V along with its rank. Response values for grey relation grade are derived by averaging the grade values for each parameter for every level as shown in Table VI.

The main effect of the parameters on the Grey Relational Grade shows that welding current has the maximum effect on the RSW process. The optimum level obtained for the welding process is A1B1C3.

TABLE VI
THE MAIN EFFECT OF THE PARAMETERS ON THE GREY RELATIONAL GRADE

Parameter	Grey Relational Grade			Main Effect	Rank
	Low	Medium	High		
A	0.31078	0.2370	0.2031	0.1076	1
B	0.2828	0.2197	0.2484	0.0631	3
C	0.1993	0.2738	0.2778	0.0785	2

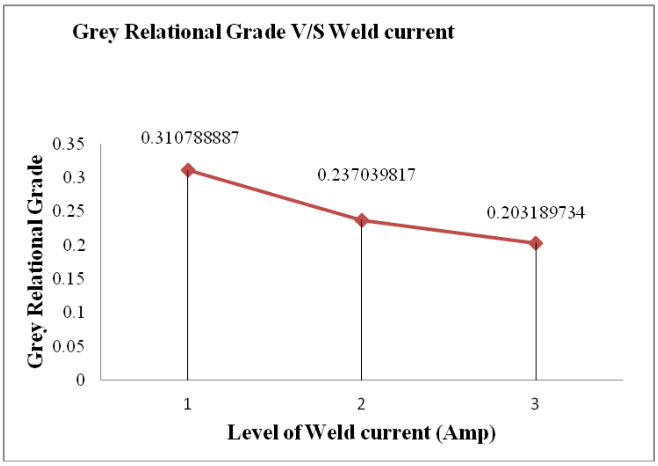

Fig. 4. Effect of Grey relational grade on Welding current

Larger the value of grey relational grade, better are the multiple performance characteristic obtained. From Fig. 4. Grey Relational Grade for welding current was found to be maximum for level 1, and its value is 0.310788887 (i.e. A1).

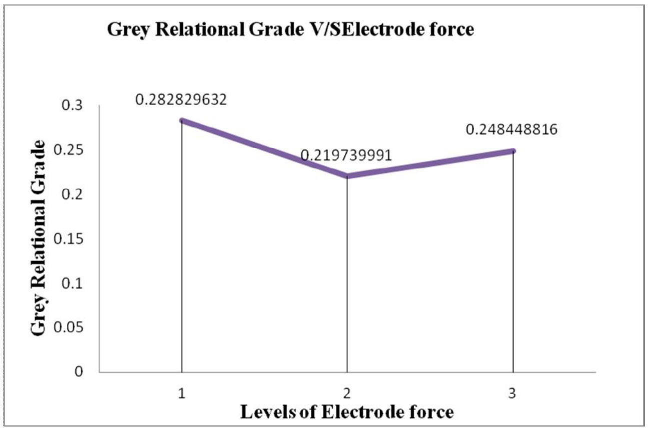

Fig. 5. Effect of Grey relational grade on Electrode force

From fig. 5. Maximum value of Grey relational Grade for electrode force is obtained at level 1 and its value is 0.282829632 (i.e. B1).

Fig. 6. Below shows that weld time has maximum value of 0.277794031 at level 3.

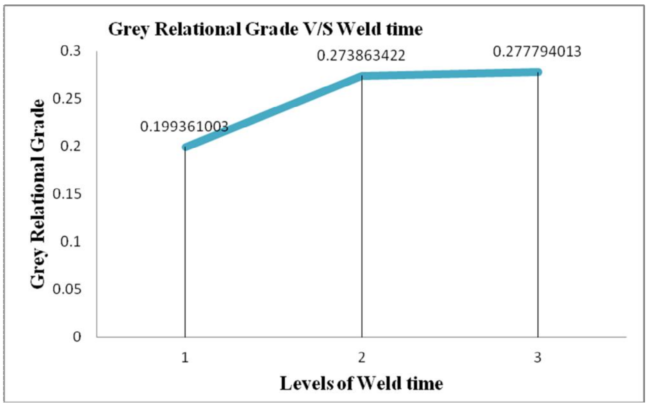

Fig. 6. Effect of Grey relational grade on Weld Time

Since, tensile strength and weld nugget are the important characteristics which govern the mechanical properties of the spot weld; it determines the overall joint area. For weld nugget, heat input rate controls the controls the fusion zone, which in turn; is governed by the welding parameters. The amount of heat generated is described in equation (1). Hence, welding current is the factor which affects the most in resistance spot welding process.

C. Analysis of Variance (ANNONA)

ANNOVA is an impartial decision making weapon to find out the unspecified differences in the medium performance of groups of items selected. It includes decision parameters that affect significantly output characteristics. Sum of squares (SS), mean square (MS) and F-test values are calculated in ANNOVA, for deciding significant factors which affect the process.

Also, contribution in terms of percentage for each process parameter is calculated. Generally, for higher F value, process parameter significantly influence the performance characteristics as shown in the Table VII

TABLE VII
ANNOVA RESULT FOR RSW PROCESS

CF	SS	DOF	MS	F RATIO	% C
A	0.0181	2	0.00908	0.4876	48.76
B	0.0059	2	0.00299	0.1607	16.07
C	0.0117	2	0.00585	0.3145	31.46
ERROR	0.0013	2	0.00071	0.0371	3.71

Table VII shows the detail analysis of variance with F ratio and percentage contribution. Welding current has major contribution in the welding process i.e. 49%. The weld time gives 31% of its contribution while electrode force has the lowest contribution i.e. 16%.

VI. CONCLUSION

This study presents the application of Taguchi based grey relational analysis method to obtain the optimized resistance spot welding parameters on AISI304 steel grade sheet. Following conclusions were drawn in the present study:

1. Percentage contribution of welding current was found to be maximum i.e. 49% while weld time contributed 31%. Electrode force had the minimum contribution of only 16% in the RSW process.
2. Taguchi analysis concluded different optimum values for individual response. For maximum tensile strength, optimum value for welding current is 6000 amperes, electrode force is 450 Kgf and weld time is 10 cycles/s. Similarly, for weld nugget, different optimum values are obtained- welding current 8500 amperes, electrode force 400 Kgf and weld time 12 cycles/s.
3. Grey Relation Analysis showed the combined optimum values of process parameters as welding current 6500 amperes, electrode force 400 Kgf and weld time as 8 cycles/s.

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