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Research Article

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Optimization of the Process Parameters of Resistance Spot Welding of AISI 316l Sheets Using Taguchi Method

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Abstract: Resistance spot welding (RSW) is a fabrication process that is being used in the automobile and aerospace industry since many years for joining low carbon or "mild" steel. Quality and strength of the welds depend upon the process parameters of RSW. The most effective parameters in this process are: current intensity, welding time, sheet thickness and material, geometry of electrodes, electrode force, and current shunting. This paper presents the experimental investigations for the optimization of tensile shear stress of RSW for stainless steel grade 316L sheets by using Taguchi method. The experiments were conducted using Taguchi's L27 orthogonal array under varying process parameters, namely electrode diameter, welding current, and heating time. The experimental data were analyzed using signal-to-noise ratio (S/N ratio) to find the optimal process parameters. Analysis of variance (ANOVA) and F test were used to find the most significant parameters affecting the spot weld quality characteristics. Confirmation tests with optimal process parameters were conducted to validate the test results. From the results, it was found that it is possible to increase tensile shear stress significantly.

Keywords: Resistance spot welding, stainless steel, Taguchi method, tensile shear stress, S/N ratio, ANOVA

1 Introduction

Resistance spot welding is a resistance welding process in which coalescence of metal is produced at the faying surface by the heat generated at the joint because of contact resistance to the flow of electric current. Force is always applied before, during, and after the application of current to prevent arcing at the faying surfaces and to forge the weld metal during post heating. The process is used extensively for joining low and mild carbon steel sheet metal components for automobiles, cabinets, furniture, and similar products. Stainless steel, aluminum, and copper alloys are also spot welded commercially [1]. It is a high-speed process, in which the actual welding time is but a fraction of a second. The speeds of the process, the ease of operation, and its adaptability to automation are its major advantages. Major factors controlling this process are current, time, electrode force, electrode diameter, contact resistance and property of electrode material, sheet materials, surface conditions, and so on. Quality of the weld is determined by the size of the weld nugget and joint strength. The size of the weld nugget and joint strength depends upon the selection of the welding process parameters. Normally, the welding process parameters are selected based on experience or from handbooks. However, it does not ensure that the selected welding process parameters can produce an optimal strength of the weld.

2 Literature Survey

In order to increase the strength of products, many researchers have studied RSW process by experimental and numerical techniques. Eisazadeh *et al.* [2] developed an incremental finite element model for the parametric study of nugget size in resistance spot welding process. They used the published experimental data to verify their model, and investigated the effects of contact resistance and electrode force on nugget size and shape. They found that with increasing electrode force, nugget size reduces due to decreasing contact resistance. Thakur *et al.* [3] presented a systematic approach to determine the effect of process parameters on tensile shear strength of RSW of austenitic stainless steel AISI 304 using the Taguchi method. Luo *et al.* [4] developed a mathematical model by using nonlinear multiple regression analysis and artificial neural network (ANN) approach for predicting the nugget diameter and tensile shear strength of galvanized steel. According

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Table 1: Chemical composition of 316L stainless steel

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
316L	Min	-	-	-	-	-	16.0	2.00	10.0	-
	Max	0.03	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10

to the prediction model, the predicted systems of welding process parameters were formulated in order to obtain the desired welding quality.

Esme [5] used the Taguchi method to investigate the optimization and effect of welding parameters on the tensile shear strength of spot welded SAE 1010 steel sheet. Correlations between the microstructure and the hardness in weld joints, and the relationship between hardness and strength have been established for engineering materials. The hardness of the material is dependent on its microstructure, as presented by Ming-Liang Zhu *et al.* [6] Shamsul *et al.* [7] studied the influence of welding current on nugget size and hardness distribution in the plates of austenitic stainless steel (AISI 304), which was placed as a lap joint and spot welded under varied welding current. The results have shown that increasing welding current increased the nugget size. The nugget size does not influence the hardness distribution. Also, increasing welding current does not increase the hardness distribution.

Feulvarch *et al.* [8, 9] presented a finite element formulation to measure the interface contact properties. It was shown that the calculated nugget appears earlier. It was also noticed that the nugget grows faster across the thickness. Hou *et al.* [10] developed a 2D axisymmetric thermo-elastic–plastic FEM model using ANSYS software package. The objective of this study was to investigate the behavior of the mechanical features during the RSW process. They studied the distribution and change history of the contact pressure at both the faying surface and the electrode-workpiece during welding. The deformation of the weldment and the electrode displacement due to the thermal expansion and contraction were also calculated. They observed that the electrode displacement has a direct correlation with the nugget formation and suggested utilizing this parameter for quality monitoring and process control in RSW.

Aslanlar *et al.* [11] have investigated the effects of welding time on the tensile-peel strength and tensile-shear strength of welding joints in electrical resistance spot welding. Danial Kianersi *et al.* [12] have presented an investigation on the optimizing welding parameters namely welding current and time in resistance spot welding (RSW) of the austenitic stainless steel sheets grade AISI 316L. Afterward, the effect of optimum welding parameters on the resistance spot welding properties and microstructure of AISI 316L austenitic stainless steel sheets has been investigated. Effect of welding current at constant welding time was considered on the weld properties such as weld nugget size, tensile-shear load bearing capacity of welded materials, failure modes, failure energy, ductility, and microstructure of weld nuggets.

Kachhoriya *et al.* [13] have used regression modeling to get the highest ultimate strength in the range in case of RSW of low carbon mild steel. Response surface methodology has been used for predicting the weld zone development for the resistance spot welding of low carbon steel of 1 mm thickness [14]. Hefin Rowlands *et al.* [15] presented the use of Taguchi’s loss function analysis and RSM to a spot welding process in order to discover the key process parameters, which influence the tensile strength of welded joints. Zhou *et al.* [16] have done a computer simulation by using design of experiments (DOE) concept and quantitative relationships were established to link a weld’s geometric and mechanical attributes to its strength under tensile-shear loading.

In this work, an attempt has been made to optimize the process parameters, namely welding current, electrode diameter, and heating time to find out the ultimate tensile stress of stainless steel 316L using the Taguchi method. On the selected parameters, experiments have been conducted using L27 orthogonal array (OA) and optimum process parameters experiments were found out.

3 Experimental Procedure

3.1 Test Specimens

In this work, stainless steel 316L sheets of 1.6 mm thickness have been selected for the experimental work. The chemical composition and mechanical properties of 316L stainless steel material are given in Tables 1 and 2.

The specimens were cut by means of wire cut EDM, parallel to the rolling action of the sheets. The dimensions are 300 mm length and 25 mm width, the overlap being equal to the width of the specimen and are shown in Figure 1.

Table 2: Mechanical properties of 316L stainless steel

Grade	Tensile Stress (MPa) min	Yield Stress 0.2% Proof (MPa) min	Elongation (% in 50 mm) min	Hardness	
				Rockwell (HRC) max	Brinell (HB) max
316L	485	170	40	95	217

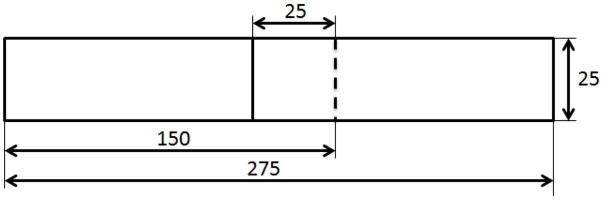

Figure 1: Dimensions of the welded specimen

3.2 Process Parameters

In this work, the three process parameters, viz., electrode diameter, welding current, and heating time, were selected. Their values at different levels are given in Table 3. The output parameter predicting strength of weld joint is tensile shear stress.

Table 3: Process parameters and their values at different levels

S. No.	Process parameters	Unit	Level 1	Level 2	Level 3
1	Electrode diameter (A)	mm	6	7	8
2	Welding current (B)	KA	7	8	9
3	Heating time (C)	ms	7	8	9

3.3 Selection of Orthogonal Array

According to the Taguchi method, a system with 3 parameters and 3 levels can be performed with 27 experiments [17]. In this work, L27 orthogonal array was employed for the experimentation.

3.4 Experimentation

Figure 2: Photograph of spot welded tensile specimen

The photograph of spot welded specimen for tensile test is shown in Figure 2. The experimental data are given in Table 4. Based on the randomized OA, total 27 runs of experiments were conducted on the universal testing machine in the order from trial 1 to trial 27. Three responses were taken for each setting, and at the end of each trial, the average of the tensile-shear stress was calculated.

A signal-to-noise (S/N) ratio was calculated by using the average values of the measurements. The ultimate tensile shear stress of the welded structure is in the category of the larger-the-better quality features. The loss function of the larger-the-better quality feature is given by:

$$\eta_j = -10\log_{10}\left(\frac{1}{N}\sum_{i=1}^{r}\frac{1}{y_i^2}\right) \qquad i = 1, 2 \ldots r \qquad (1)$$

where “N” is the number of tests conducted and “y_i” is the experimental value of the i^{th} quality feature and η_j is the S/N ratio. Using Eq. (1), S/N ratio for each experiment of L27 was calculated, as shown in Table 4.

4 Analysis of Variance (ANOVA) and Discussion

The analysis of variance (ANOVA) of raw data and S/N data were performed to identify the significant parameters and

Table 4: Experimental data for tensile shear strength

S. No.	Electrode Diameter (mm) (A)	Welding Current (kA) (B)	Heating Time (ms) (C)	Tensile Shear Stress (MPa)	S/N ratio for Tensile Shear Stress
1	6	7	7	461	53.274
2	6	7	8	548	54.776
3	6	7	9	511	54.168
4	6	8	7	502	54.014
5	6	8	8	538	54.616
6	6	8	9	542	54.680
7	6	9	7	521	54.337
8	6	9	8	590	55.417
9	6	9	9	650	56.258
10	7	7	7	386	51.732
11	7	7	8	410	52.256
12	7	7	9	392	51.866
13	7	8	7	406	52.171
14	7	8	8	420	52.465
15	7	8	9	431	52.690
16	7	9	7	503	54.031
17	7	9	8	507	54.100
18	7	9	9	466	53.368
19	8	7	7	368	51.317
20	8	7	8	354	50.980
21	8	7	9	361	51.150
22	8	8	7	382	51.641
23	8	8	8	395	51.932
24	8	8	9	380	51.596
25	8	9	7	432	52.710
26	8	9	8	438	52.829
27	8	9	9	461	53.274

to quantify their effect on the response characteristics. In the analysis, the sum of squares and variance were calculated. F-test value at 95% confidence level was used to decide the significant factors affecting the process, and the percentage contribution was calculated. Larger F-value indicates that the variation of the process parameter makes a big change on the performance. The ANOVA analysis for T-S stress is shown in Table 5. The S/N ratio analysis of rank of various parameters is shown in Table 6.

Table 5 shows the percent contributions of welding parameters on the tensile stress. From Table 5, it is evident that the most effective parameters with respect to tensile shear strength are electrode diameter, welding current, and heating time. Percent contribution indicates the relative power of a factor to reduce variation.

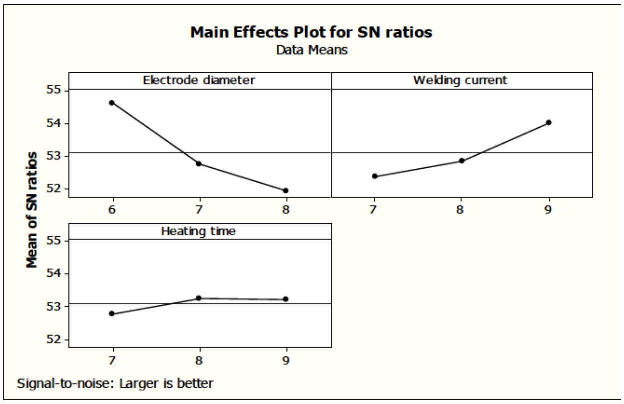

Figure 3: S/N ratio graph for tensile shear stress

Table 5: Results of ANOVA for signal-to-noise ratio

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	% C
Electrode diameter	2	34.0073	34.0073	17.0037	101.10	0.000	66.09
Welding current	2	12.8990	12.8990	6.4495	38.35	0.000	25.08
Heating time	2	1.1813	1.1813	0.5906	3.51	0.049	2.29
Residual error	20	3.3637	3.3637	0.1682			6.54
Total	26	51.4512					

S = 0.410102; R-Sq = 93.46%; R-Sq(adj) = 91.50%

Table 6: Response table for signal-to-noise ratio for tensile shear stress

Level	Electrode Diameter (A)	Welding Current (B)	Heating Time (C)
1	54.62	52.39	52.8
2	52.74	52.87	53.26
3	51.94	54.04	53.23
Delta	2.68	1.65	0.46
Rank	1	2	3

5 Conclusions

This paper presented the investigation of the optimization and effect of welding parameters on the tensile strength of resistance spot welded AISI 301L stainless steel.

The following conclusions were drawn from the present investigation.

1. The response of S/N ratio with respect to tensile strength indicates the electrode diameter to be the most significant parameter that controls the tensile shear stress, whereas the welding current and heating time are comparatively less significant in this regard.
2. The percentage contribution of electrode diameter is 66.09%, welding current is 25.08%, heating time is 2.29%, and the residual error is 6.54%.

References

[1] Aidun D. K., Bennett R. W.: Effect of resistance welding variables on the strength of spot welded 6061-T6, Weld. Jour., 64 (12), 1985, 15–25.

[2] Eisazadeh, H., Hamedi, M., Halvaee, A. : New parametric study of nugget size in resistance spot welding process using finite element method. Mater. Des. J. 31,2010, 149–157.

[3] Thakur, A. G., Nandedkar, V. M.: Application of Taguchi Method to Determine Resistance Spot Welding Conditions of Austenitic Stainless Steel AISI 304, J. Sci. & Ind. Res., 69, 2010, 680–683.

[4] Luo, Y., Li, C., Xu, H.: Modeling of resistance spot welding process using nonlinear regression analysis and neural network approach on galvanized steel sheet", Advanced Material Research, vol. 291–294, pp. 823–828, 2011.

[5] Esme, U.: Application of Taguchi method for the optimization of resistance spot welding process, The Arab. J. Sci. and Eng., 34, 2009, 519–528.

[6] Ming-Liang Zhu, Fu-Zhen Xuan: Correlation between microstructure, hardness and strength in HAZ of dissimilar welds of rotor steels. Mat. Sci. Eng. A., 527, 2010, 4035–42.

[7] Shamsul, J. B., Hisyam, M. M.: Study of spot welding of austenitic stainless steel type 304. J. Appl. Sci. Res. 3, 2007, 1494–1499.

[8] Feulvarch, E., Robin, V., Bergheau, J. M.: Resistance spot welding simulation: a general finite element formulation of electro thermal contact conditions. J. Mater. Process. Technol., 153, 2004, 436–441.

[9] Feulvarch, E., Robin, V., Bergheau, J. M.: Resistance spot welding process: experimental and numerical modeling of weld growth mechanisms with consideration of contact conditions. Numer. Heat Trans. Part A 49, 2006, 345–367.

[10] Hou, Z., Kim, I., Wang, Y., Li, C., Chen, C. J.: Finite element analysis for the mechanical features of resistance spot welding process. J. Mater. Process. Technol. 180, 2007, 160–165.

[11] Aslanlar S, Ogur A, Ozsarac U, Ilhan E.: Welding time effect on mechanical properties of automotive sheets in electrical resistance spot welding. Mater Des 29, 2008, 1427–31.

[12] Danial Kianersi, Amir Mostafaei, Ahmad Ali Amadeh: Resistance spot welding joints of AISI 316L austenitic stainless steel sheets: Phase transformations, mechanical properties and microstructure characterizations, Mat. and Des., 61, 2014, 251–263.

[13] Kachhoriya, A. K., Bangar, A., Sharma, R., Neetu: Optimization of Welding Parameters by Regression Modelling and Taguchi Parametric Optimization Technique, Int. J. Mech.l and Ind. Eng., 1, 2012, 1-5.

[14] Norasiah Muhammad, Yupiter, H. P. Manurung, Mohammad Hafidzi, Sunhaji Kiyai Abas, Ghalib Tham, M. Ridzwan Abd. Rahim.: A Quality Improvement Approach for Resistance Spot Welding using Multi-objective Taguchi Method and Response Surface Methodology, Int. J. Adv. Sci. Eng. Information Technology, 2(3),2012, 17–22.

[15] Hefin Rowlands and Jiju Antony: Application of Design of Experiments to a Spot Welding Process, Assembly Automation, .23, 2003, 273–279.

[16] Zhou, M., Zhang, H., Hu, S. J.: Relationships between Quality and Attributes of Spot Welds. Supplement to Welding Journal. 2003, 72–77.

[17] Ross. P. J.: Taguchi Techniques for Quality Engineering. Tata McGraw Hill, 2005.