Application of Taguchi Method for Resistance Spot Welding of Stainless Steel-304 Grade

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Abstract: ***This paper presents an experimental investigation for the Tensile Shear (T-S) strength and Nugget diameter of resistance spot weld by using Taguchi method. An experimental study is conducted under various levels of process parameters. Spot welds are carried out on Stainless Steel (304) material. Welding current, Electrode force and Weld time are process parameters with three levels of each. Taguchi quality design concept of L27 orthogonal array has been used to determine S/N Ratio, Analysis of Variance (ANOVA). The level of importance of welding parameters for T-S strength and Nugget Diameter are determined by ANOVA in Minitab 16 software.***

Keywords: Resistance Spot Welding (RSW), Taguchi method, Stainless Steel (304) material, ANOVA, Tensile Shear Strength and Nugget Diameter.

1. Introduction

Resistance spot welding (RSW) process in which coalescence of metal is produced at the faying surface by the heat generated at the joint by the contact resistance to the flow of electric current. The materials to be joined are brought together under pressure by a pair of electrodes. A high electric current passes through the work pieces hold between the electrodes. Due to contact resistance and joule heating, a molten weld nugget is formed in the work pieces. The amount of heat produced is a function of current, time, and resistance between the work pieces. It is desirable to have the maximum temperature at the interface of the parts to be joined. Therefore, the resistance of the work pieces and the contact resistance between the electrodes and work should be kept as low as possible with respect to the resistance between the faying surfaces. The principle of operation is as shown in Fig. 1.

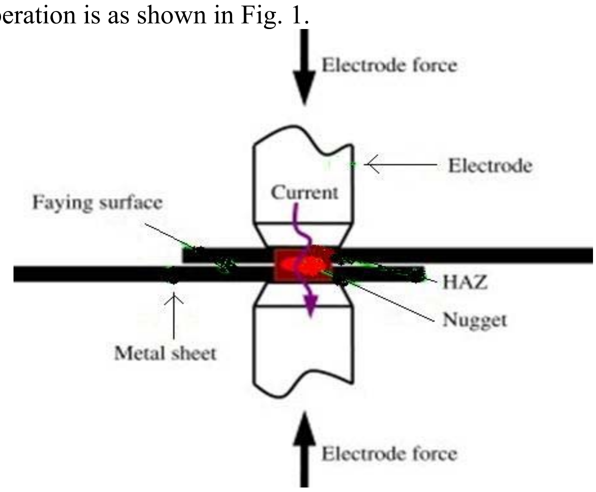

Figure 1: Resistance spot welding principle

RSW has excellent techno-economic benefits such as low cost, high production rate and adaptability for automaton which make it an attractive choice for auto-body assemblies, truck cabins, rail vehicles and home appliances. As the name implies, it uses the resistance of the materials to the flow of current that causes localized heating between the parts to be joined. Excessive heat in the electrodes reduces the electrode cap life and deteriorates the weld quality. Hence, the electrodes are cooled via water circulation through channels opened inside them. The temperature and resistance obtained during resistance spot welding operation is as shown in Fig. 2. Where R1, R2, R3 are the resistances at the Electrode tip and plate surface, Resistance of joining plates, Resistance at the interface of two plates respectively.

The weld strength is measured by a number of standardized destructive tests, which subject the weld to different types of loading. Some of these are tension-shear, tension, torsion, impact, fatigue, and hardness. The stiffness and the operating strength of sheet metal parts are strongly influenced by the welding parameters and location of the spot welding. It is very important to select the welding process parameters for obtaining optimal weld strength. The desired welding process parameters are determined based on experience or from a handbook. However, this does not ensure that the selected welding process parameters can produce the optimal or near optimal weld strength for that particular welding machine and environment. Various aspects of modeling, simulation, and process optimization techniques are used in the resistance spot welding process. Detailed analysis has been made to establish relationships between welding parameters weld strength, weld quality, and productivity to select welding parameters leading to an optimal process [1-2].

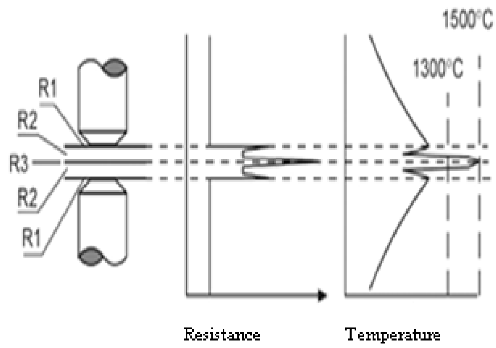

Figure 2: Resistance and temperature distribution curve

The three main parameters in spot welding are current, contact resistance and weld time. In order to produce good quality weld the above parameters must be controlled properly. The amount of heat generated in this process is governed by the formula,

$$Q = I^2RT \tag{1}$$

Where,

Q - Heat generated (J);
I - Welding current (A);
R - Resistance of the work piece (Ω);
T - Time of current flow (Sec or cycle).

There are various parameters with different levels of operation which directly or indirectly controls the quality of spot weld joint. Whereas, welding current, electrode force and welding time are the main process parameters which controls the quality of spot weld. So that these process parameters are selected for experiment with three levels of each.

2. Literature Review

Ugur Esme [1] investigated on the optimization and the effect of welding parameters on the tensile shear strength of spot welded SAE 1010 steel sheets. The level of importance of the welding parameters on the tensile shear strength is determined by using ANOVA. Based on the ANOVA method, the highly effective parameters on tensile shear strength were found as welding current and electrode force, where as electrode diameter and welding time were less effective factors. The results showed that welding current was about two times more important than the second ranking factor (electrode force) for controlling the tensile shear strength.

A.K. Pandey, M.I. Khan. K.M. Moeed [2] investigation indicate the welding current to be the most significant parameter controlling the weld tensile strength as well as the nugget diameter for AISI-1008 steel sheets .Also they effectively use taguchi method for optimization of spot welding parameters.

D.S. Sahota, Ramandeep Singh, Rajesh Sharma, Harpreet Singh [3] has studied the effect of parameters on resistance spot weld of ASS316 material. In order to his study the significance of the process parameters i.e. current, electrode force and weld cycles, towards the percentage improvement in material hardness. From his results it is clear that parameters significantly affect both the mean and the variation in the percentage improvement in Hardness values of the ASS316 material.

Niranjan Kumar Singh and Dr. Y. Vijayakumar [4] has presented an investigation on the optimization and effect of welding parameters on indentation of spot welded AISI 301L stainless steel. The level of importance of the welding parameters on indentation is determined by ANOVA (main effect plots). Based on ANOVA method, the highly effective parameters on indentation are found as weld cycle, interaction between weld current & weld cycle and interaction between weld current, weld cycle & hold time whereas weld current, hold time and cool time were less effective factors.

A. G. Thakur et al. [5] An experimental investigation for effect of process parameters on tensile shear strength of resistance weld joint of austenitic stainless steel AISI 304 using taguchi method. Interaction effect of welding current, Pressure and weld time are also discussed.

Feramuz Karc et al. [10] this paper deals with the characterization and understanding the effect of weld time and the influence of different weld atmospheres in the resistance spot weld ability of AISI304 grade stainless steel deformed in tension by 5%, 10%, or 20%. Therefore, the microstructure of the weldment was evaluated and the hardness and tensile shear load bearing capacity of weldment were also determined. It was found that the final mechanical properties of weldment are directly related to the parameters of the process used, knowing the weld time and rate of deformation prior to welding.

Nachimani Charde et al. [11] this research paper analyses the spot weld growth on 304 austenitic stainless steels with 2mm sample sheets. The growth of a spot weld is primarily determined by its parameters such as current, weld time, electrode tip and force. This paper is intended to analyze only the effects of nuggets growth due to the current and weld time increment with constant force and unchanged electrode tips. The welded samples were undergone tensile test, hardness test and metallurgical test to characterize the formation of weld nuggets.

Danial Kianersi et al. [15] has 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, 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.

Mehdi Mansouri Hasan Abadi et al. [17] has Studied Structure-properties relationships in dissimilar resistance spot welding of AISI 304 austenitic stainless steel (SS) and AISI 1008 low carbon steel (CS). Fusion zone microstructure was ranged from Ferrite-Austenite-Martensite to full martensite depending on the melting/dilution ratio of base metals.

3. Experimental Details

The specimens were cut from a sheet metal of 4ft × 4ft. The Specimens were cut parallel to the rolling action of the sheets. The dimensions are 100 mm length (L) and 30 mm width (W), the overlap being equal to the width of the specimen. This overlap was chosen as per American

Welding Society (AWS) recommendation as shown in Fig. 3 [6]. The material used in the present work is Stainless Steel (304 grade) sheet of 1 mm thickness.

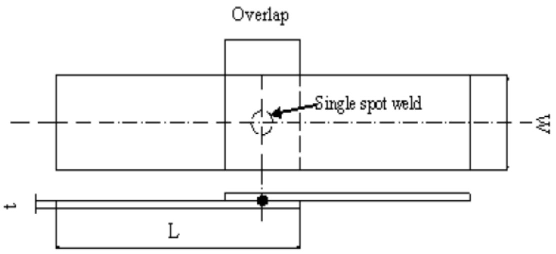

Figure 3: Spot weld specimen dimension by AWS.

3.1 Chemical composition of Stainless Steel material

The chemical composition for each element of the above material is listed below in table 1:

Table 1: Chemical composition of Stainless Steel

Content	*Value (%)*
C	0.103
Si	0.302
Mn	1.90
P	0.0040
S	0.0082
Cr	19.05
Mo	0.079
Ni	8.08
Fe	70.3

3.2 Selection of Process Parameters and Levels

In the present study of resistance spot welding, three main parameters namely Welding Current, Electrode Force and Weld Time are selected with three levels of each as shown in table 2. The output parameter predicting strength of weld joint is tensile shear strength.

Table 2: Process Parameters and Levels

Sr. No	*Process Parameters*	*Parameter*	*Level 1*	*Level 2*	*Level 3*
1	Welding Current (kA)	A	4.8	5.9	7
2	Electrode Force (kN)	B	0.490	0.539	0.588
3	Welding Time (cycle)	C	45	50	55

3.3 Selection of Orthogonal Array (OA)

Depending upon number of levels in a factor, a 2 or a 3 level OA can be selected. If some factors are two-level and some three-level, then whichever is predominant should indicate which kind of OA is selected. Once the decision is made about the right OA, then the number of trials for that array must provide an adequate total DoF, When required DoF fall between the two DoF provided by two OAs, the next larger OA must be chosen [3,8].

Here for experimentation L27 Taguchi orthogonal array is selected for three process parameters and three levels of each parameter. Fig. 4 (a) and (b) shows photograph of tensile test on UTM machine and nugget diameter test on video profile projector respectively.

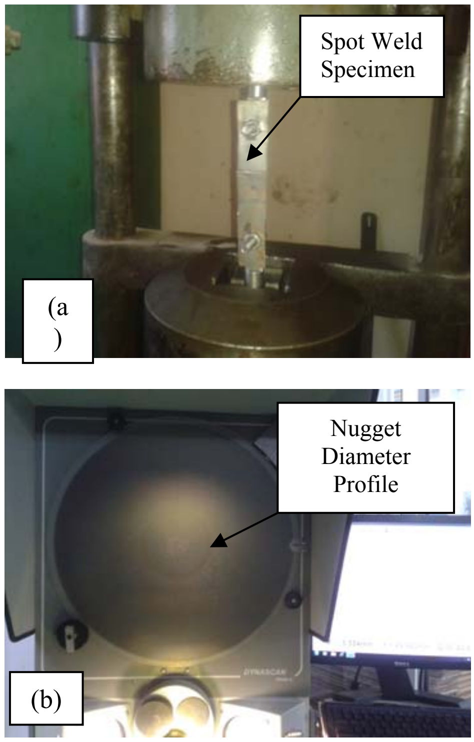

Figure 4: Photograph of (a) Tensile Testing on UTM machine (b) Nugget Diameter checking on video profile projector.

3.4 Overall Loss Function and S/N Ratio

Taguchi recommends analyzing data using the S/N ratio that will offer two advantages; it provides guidance for selection the optimum level based on least variation around on the average value, which closest to target, and also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target. The experimental results are analyzed to investigate the main effects.

According to quality engineering the characteristics are classified as Higher the best (HB), lower the best (LB) and Nominal the best. HB includes Tensile Shear strength (T-S) and Nugget Diameter (N-D) which desires higher values. Similarly LB includes Heat Affected Zone (HAZ) for which lower value is preferred.

The loss function of the larger-the-better quality characteristics can be expressed as,

$$L_j = \frac{1}{N}\sum_{i=1}^{n}\frac{1}{Y^2} \qquad (2)$$

$$\eta_j - 10 \log L_j \qquad (3)$$

Where, n is the number of tests, and yi the experimental value of the ith quality characteristic, Lj overall loss function and ηj is the S/N ratio [1, 3-8]. By applying Equations (2)–

(3), the η corresponding to the overall loss function for each experiment of L27 were calculated and given in Table 3.

Table 3: Experimental data for T-S Strength, Nugget diameter and S/N ratio

A (kA)	*B (kN)*	*C (cycle)*	*T-S (kN)*	*N-D (mm)*	*S/N Ratio for*	
					T-S	*N-D*
4.8	0.490	45	3.973	3.315	11.9824	10.409
4.8	0.490	50	3.728	3.710	11.4295	11.387
4.8	0.490	55	4.022	4.485	12.0888	13.035
4.8	0.539	45	3.777	3.710	11.5429	11.387
4.8	0.539	50	4.267	3.900	12.6025	11.821
4.8	0.539	55	4.120	4.100	12.2979	12.255
4.8	0.588	45	3.973	4.100	11.9824	12.255
4.8	0.588	50	4.022	4.295	12.0888	12.659
4.8	0.588	55	4.169	4.100	12.4006	12.255
5.9	0.490	45	5.494	4.740	14.7978	13.515
5.9	0.490	50	5.150	4.790	14.2361	13.606
5.9	0.490	55	5.101	5.095	14.1531	14.142
5.9	0.539	45	4.806	4.875	13.6357	13.759
5.9	0.539	50	5.297	5.070	14.4806	14.100
5.9	0.539	55	5.444	5.110	14.7184	14.168
5.9	0.588	45	5.199	4.875	14.3184	13.759
5.9	0.588	50	5.297	4.935	14.4806	13.865
5.9	0.588	55	5.640	5.580	15.0256	14.932
7.0	0.490	45	6.327	5.550	16.0240	14.885
7.0	0.490	50	6.180	5.265	15.8198	14.428
7.0	0.490	55	6.376	6.435	16.0910	16.171
7.0	0.539	45	6.131	6.240	15.7506	15.903
7.0	0.539	50	6.229	5.265	15.8884	14.428
7.0	0.539	55	6.916	6.045	16.7971	15.627
7.0	0.588	45	6.180	5.850	15.8198	15.343
7.0	0.588	50	6.523	6.825	16.2889	16.682
7.0	0.588	55	6.572	6.380	16.3540	16.096

The mean S/N ratio for each level of the welding parameters is summarized and called the S/N response table for tensile shear strength and Nugget diameter are as shown in table 4 and Table 5 respectively.

Table 4: Response of S/N Ratios for T-S Strength (kN)

Level	*Welding Current (kA)*	*Electrode Force (kN)*	*Welding Time (cycle)*
1	12.05	14.07	13.98
2	14.43	14.19	14.15
3	16.09	14.31	14.44
Delta	4.05	0.24	0.45
Rank	1	3	2

Table 5: Response of S/N Ratios for Nugget Diameter (mm)

Level	*Welding Current (kA)*	*Electrode Force (kN)*	*Welding Time (cycle)*
1	11.94	13.51	13.47
2	13.98	13.72	13.66
3	15.51	14.21	14.30
Delta	3.57	0.70	0.83
Rank	1	3	2

The tabulated values shown in table 4 and 5 can be well understood by main effect plot for S/N ratio as shown in Fig. 6 and Fig.7. This shows which parameter level is significant for each parameter corresponding higher T-S strength and Nugget Diameter of spot welded specimen.

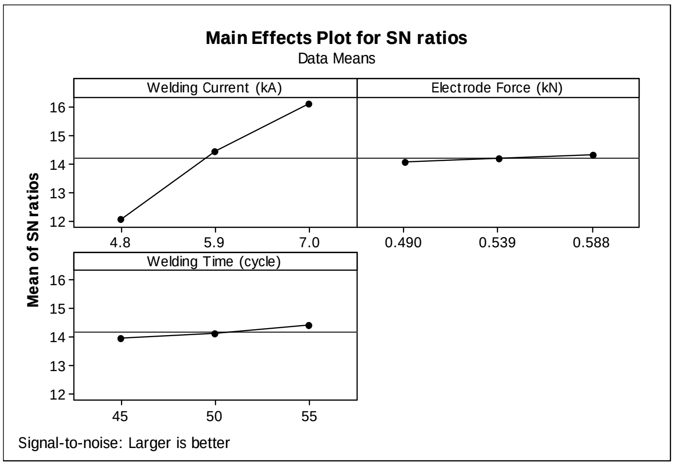

Figure 6: Main Effects Plot of S/N Ratios for T-S Strength

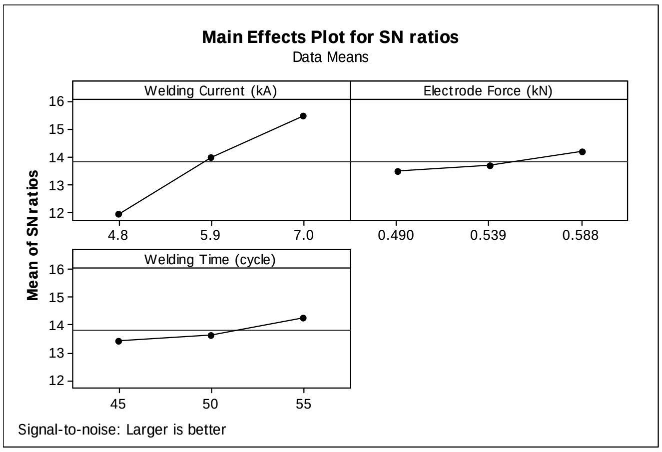

Figure 7: Main Effects Plot of S/N ratios for Nugget Dia.

3.5 Analysis of Variance (ANOVA)

A better feel for the relative effect of the different welding parameters on the tensile shear strength and nugget diameter were obtained by decomposition of variance, which is called analysis of variance (ANOVA).

The main aim of ANOVA is to investigate the design parameters and to indicate which parameters are significantly affecting the output parameters. In the analysis, the sum of squares and variance are calculated. F-test value at 95 % confidence level is used to decide the significant factors affecting the process and percentage contribution is calculated. Larger *F*-value indicates that the variation of the process parameter makes a big change on the performance. Table 6 and table 7 shows analysis of T-S strength and nugget diameter respectively.

According to this analysis, the most effective parameters with respect to tensile shear strength and nugget diameter are welding current, welding time and electrode force. Percent contribution indicates the relative power of a factor to reduce variation. For a factor with a high percent contribution, a small variation will have a great influence on the performance [1, 6, and 9].

Table 6: Results of ANOVA for T-S Strength

Source	DF	Seq SS	Adj MS	F	P	% C
A (kA)	2	25.4366	12.7183	321.5	0.000	95.55
B (kN)	2	0.0833	0.0416	1.05	0.368	0.03
C (cycle)	2	0.3601	0.1801	4.55	0.023	1.35
Error	20	0.7910	0.0396	-	-	2.97
Total	26	26.6710	-	-	-	100
S = 0.198877 R-Sq = 97.03% R-Sq(adj) = 96.14%						

Table 7: Results of ANOVA for Nugget Diameter

Source	DF	Seq SS	Adj MS	F	P	% C
A (kA)	2	18.2871	9.1436	87.69	0.000	82.51
B (kN)	2	0.7553	0.3777	3.62	0.045	3.41
C (cycle)	2	1.0360	0.5180	4.97	0.018	4.67
Error	20	2.0854	0.1043	-	-	9.41
Total	26	22.1638	-	-	-	100
S = 0.322909 R-Sq = 90.59% R-Sq(adj) = 87.77%						

4. Conclusions

The following conclusions could be drawn from the above investigation.

i. The response of S/N ratio for tensile shear strength indicates that, Welding current is the most significant parameter that controls the weld strength. Whereas electrode force and weld time are less significant.

ii. The optimum results are obtained by Taguchi method for tensile shear strength and nugget diameter are at Welding Current of 7 kA, Electrode force of 0.588 kN and weld time of 55 cycle.

iii. The relation graph is plotted for tensile strength and nugget diameter, from the nature of graph shown in Fig. 8 one can conclude that, Nugget diameter values increases at 2nd, 6th, 11th and 12th trial but the tensile strength of joint decreases as compared to compared to remaining trials.

iv. Whereas, At the 9th, 23th and 27th trial the tensile strength value goes on decreasing but value of nugget diameter decreases.

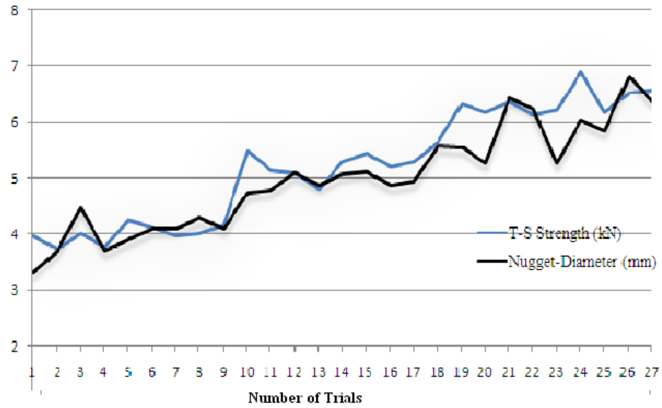

Figure 8: Comparison Plot of T-S strength and Nugget Diameter for L27 trials

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