APPLICATION OF TAGUCHI METHOD FOR RESISTANCE SPOT WELDING OF GALVANIZED STEEL

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ABSTRACT

Resistance Spot Welding (RSW) is a process that is being used in industry for sheet joining purposes especially in the Automobile and Aerospace industry. The problems associated with RSW are tendency of alloying with the electrode resulting in increased tool wear, and subsequent deterioration of weld quality. More current and time lead to expulsion and over heating of the electrode affecting the weld quality and less value result in insufficient weld strength. The complicated behavior of this process must be analyzed to set the optimum parameters to get good quality weld. This paper presents an experimental investigation for optimization of Tensile Shear (T-S) strength of RSW for Galvanized steel by using Taguchi method. RSW of galvanized steel is always difficult due to tendency of zinc coating alloying with electrode. The experimental studies were conducted under varying welding current, welding time, electrode diameter and electrode force. Taguchi quality design concepts of L27 orthogonal array has been used to determine Strength to Noise(S/N ratio), Analysis of Variance (ANOVA) and F test value for determining most significant parameters affecting the spot weld performance. The experimental results confirmed the validity of used Taguchi method for enhancing welding performance and optimizing the welding parameter in RSW process. The confirmation test indicated that it is possible to increase tensile shear strength significantly.

Keywords: resistance spot welding, galvanized steel, taguchi method, sheet joining, S/N ratio, weld performance.

INTRODUCTION

Spot, seam and projection welding are three resistance welding processes 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. Force is always applied before, during and after the application of current to prevent arcing at the faying surfaces and in some applications to forge the weld metal during post heating. The process is completed within a specified cycle time. Generally, melting occurs at the faying surface during welding. The Resistance Spot Welding (RSW) is getting significant importance in manufacturing car, bus and railway bodies etc. due to automatic and fast process.

Preheating current is always applied before welding current to break the coating. Major factors controlling this process are current, time, electrode force, contact resistance, properties of electrode material and sheet material, surface condition etc.[1-2]. The quality is best judged by nugget size, Heat affected zone (HAZ) and joint strength.

Luo yi, *et al.* [3] have developed a mathematical model for predicting the nugget diameter and tensile shear strength of galvanized steel. The input parameters are preheating current, weld current, weld time and welding pressure. The non linear regression model shows the complexity of the welding of Galvanized sheet.

Ugur Esme [4] has studied optimization of RSW process parameters for SAE 1010 steel using Taguchi method. He investigated that increasing welding current and electrode force are prime factors controlling the weld strength. He concluded that Taguchi method can be effectively used for optimization of spot welding parameters.

M. Zhou *et al.* [5] 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.

G. Mukhopadhyaya *et al.* [6] have studied the effects of nugget diameter, mode of loading and alloy chemistry on the strength of spot welds in thin sheets of interstitial free steels. The results unambiguously infer that the strength values of spot welds remain same in a specific mode of loading, while the load-bearing capacity increases with increasing nugget size. The strength of the spot weld has been found higher than that of the base metal with an interesting observation that the former bears a constant ratio with the latter.

S. Aslanlar [7] in his study has done the characterization ,understanding the effect of welding current and welding time on tensile shear strength and tensile peel strength of RSW of chromided micro-alloyed steel sheets having 0.8 mm thickness and galvanized chromided micro-alloyed steel sheets having 1.0 mm thickness. The optimum parameters are suggested to get appropriate Tensile strength.

M. Vural *et al.* [8] have done study on the fatigue strength of resistance spot welded galvanized steel sheets and AISI 304 sheets. The results show that galvanized steel sheet combination has the highest fatigue limit. The sheet combination which has minimum fatigue limit is galvanized-AISI 304 sheet combination.

Min Jou [9] in his research explored how a change in controllable parameter (i.e., percentage heat input) affects a measurable output signal indicative of strength and weld quality (i.e., electrode displacement) for various steel sheets used in automotive industry.

Spot welding parameters and heat generation

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,

$$Q = I^2 R T \quad [1]$$

Where

Q = heat generated, Joules
I = current, Amperes
R = resistance of the work piece, Ohms
T = time of current flow, second

Introduction to Taguchi approach to quality

The quality engineering methods of Dr. Taguchi is one of the important statistical tools of total quality management for designing high quality systems at reduced cost. Taguchi recommends a three stage process to achieve desirable product quality by system design, parameter design and tolerance design. While system design helps to identify working levels of the design parameters, parameter design seeks to determine levels of parameter that provide the best performance of product or process under study. The optimum condition is selected so that the influence of uncontrollable factors (noise factors) causes minimum variation to system performance. Orthogonal arrays, ANOVA, S/N ratio analysis and F-test are the essential tools for parameter design. Tolerance design is a step to fine-tune the results of parameter design [10].

MATERIALS AND METHODS

Materials

Galvanized steel sheet having chemical composition of (w_t %) 0.065 C, 0.095 Si, 0.017 Cr 0.032 Ni, 0.053 Cu, 0.404 M_n, 0.34 S_i, 0.017 S, 0.018 P, (balance) Fe was used. A batch of sheet samples in dimensions of 100mm × 30mm × 1mm were used for spot welding in order to determine weld quality. Electrode used was Cu Cr alloy having varying diameters.

Methods

Following input and output parameters are considered:

Input parameters selected are welding current, weld time, electrode diameter and welding force. Output parameter predicting strength of weld joint is Tensile-shear strength. The input parameters are shown in Table-1.

Table-1. Process parameters with their values at three levels.

Level	Welding current (kA)	Weld time (Cycle)	Electrode diameter (mm)	Welding force (kN)
	(A)	**(B)**	**(C)**	**(D)**
1	8	8	4	2
2	10	12	6	3.5
3	12	16	8	5

Selection of orthogonal array

Any nonlinear relationship among the process parameters, if it exists can only be revealed if more than two levels of parameters are considered [10]. Thus each parameter is selected at three levels. According to Taguchi method based on robust design, a L27 orthogonal array is employed for the experimentation.

Experimentation

Experimentation is the important step in the total analysis. Total 27 runs of experiments based on randomized OA were done. Current, weld time, electrode diameter and force are varied as per values for each level mentioned in Table-1. Three responses are taken for each setting. The experimental data is given in Table-2.

ANALYSIS OF EXPERIMENTAL RESULTS BASED ON TAGUCHI METHOD

Analysis of S/N ratio

According to Taguchi method, S/N ratio is the ratio of "Signal" representing desirable value, i.e. mean of output characteristics and the "noise" representing the undesirable value i.e., squared deviation of the output characteristics. It is denoted by η and the unit is dB. The S/N ratio is used to measure quality characteristic and it is also used to measure significant welding parameters [10].

According to quality engineering the characteristics are classified as Higher the best (HB) and lower the best (LB). HB includes T-S strength and Nugget diameter which desires higher values. Similarly LB includes Heat Affected Zone (HAZ) for which lower value is preferred [4, 10].

The summary statistics the S/N ratio η (dB) is given by

$$\eta = -10 \log \frac{1}{N} \sum_{i=1}^{n} \frac{1}{y^2}$$

Higher the best performance

$$\eta = -10 \log \frac{1}{N} \sum_{i=1}^{n} y^2$$

Lower the best performance

Mean and S/N ratio are shown in Table-2.

Table-2. Experimental data for tensile shear strength

Run No.	**Current** (kA)	**Weld time** (Cycle)	**Electrode diameter** (mm)	**Electrode force** (kN)	**T-S strength** (kN) (mean)	**S/N ratio for T-S strength in db**
	(A)	**(B)**	**(C)**	**(D)**		
1	1	1	1	1	3.83	11.66
2	1	1	2	2	4.6	13.25
3	1	1	3	3	3.6	11.12
4	1	2	1	2	5.43	14.69
5	1	2	2	3	4.86	13.74
6	1	2	3	1	4.47	12.99
7	1	3	1	3	5.23	14.37
8	1	3	2	1	5.43	14.69
9	1	3	3	2	5.67	15.06
10	2	1	1	1	5.63	15
11	2	1	2	2	6.57	16.34
12	2	1	3	3	5.64	15.01
13	2	2	1	2	6.94	16.81
14	2	2	2	3	6.43	16.16
15	2	2	3	1	6.17	15.8
16	2	3	1	3	6.93	16.81
17	2	3	2	1	7.03	16.94
18	2	3	3	2	7.53	17.54
19	3	1	1	1	6.27	15.94
20	3	1	2	2	6.9	16.78
21	3	1	3	3	6.03	15.61
22	3	2	1	2	7.56	17.57
23	3	2	2	3	6.93	16.82
24	3	2	3	1	6.6	16.38
25	3	3	1	3	7.03	16.94
26	3	3	2	1	7.06	16.98
27	3	3	3	2	7.56	17.57

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. The ANOVA analysis for T-S strength is shown in Table-3. The S/N ratio analysis of rank of various parameters is shown in Table-4.

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Table-3. ANOVA, F test value and % contribution (% C) for T-S strength.

CF	DOF	SS	V	F Ratio	% C
A	2	67.98	33.991	**1545.04***	**68.93**
B	2	18.41	9.209	**418.59***	**18.66**
C	2	1.12	0.560	**25.45***	01.14
D	2	8.45	4.229	**192.23***	**08.57**
A*B	4	1.12	0.281	**12.77***	01.14
Error	68	1.51	0.022		01.53
Total	80	98.62			100

R-Sq = 98.46 % R-Sq(adj) = 98.19% * Significant at 95 % confidence

Table-4. Response Table for S/N ratios for T-S strength.

Level	A	B	C	D
1	13.51	14.52	15.53	15.15
2	16.27	15.66	15.74	16.18
3	16.73	16.32	15.23	15.17
Delta	3.22	1.80	0.51	1.02
Rank	1	2	4	3

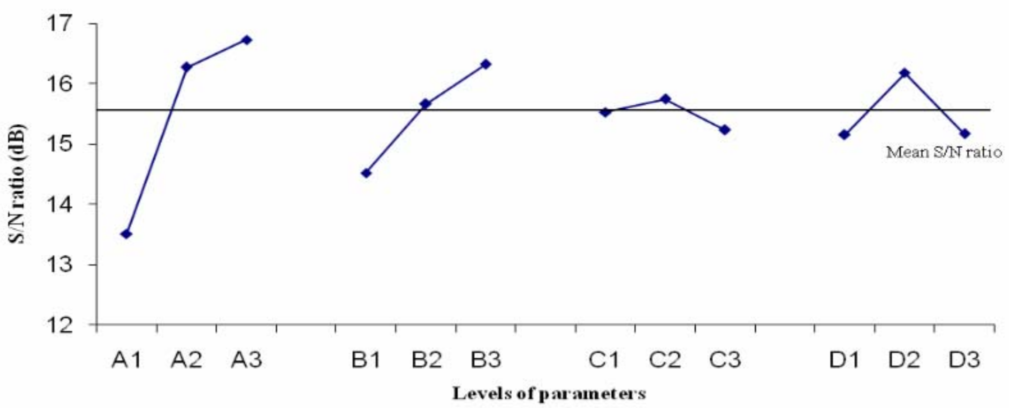

Fig.1 S/N Graph for tensile shear strength

Table-5. Results of confirmation experiment.

	Initial process parameter	Optimal process parameters		Improvement in S/N ratio(%)
		Predicted	Experimental	
Level	$A_2B_2C_2D_2$	$A_3B_3C_2D_2$	$A_3B_3C_2D_2$	13.43
T-S strength (kN)	7.07	7.91	8.02	
S/N (dB)	16.96	18.46	18.59	

RESULTS AND DISCUSSIONS

Figure-1 shows the S/N ratio graph where the horizontal line is the value of the total mean of the S/N ratio. Basically, the larger the S/N ratio, the better is the quality characteristic for the tensile shear strength. As per the S/N ratio analysis from graph the levels of parameters to be set for getting optimum value of T-S strength are $A_3B_3C_2D_2$.

According to ANOVA analysis as shown in Table-3, the most effective parameters with respect to tensile shear strength is welding current, welding time, electrode force and electrode diameter. Percent contribution indicates the relative power of a factor to reduce variation. For a factor with a higher percent contribution, a small variation will have a great influence on the performance. The percent contributions of the welding parameters on the tensile shear strength are shown in Table-3 According to this, welding current was found to be the major factor affecting the tensile strength (68.93%), whereas welding time was found to be the second factor (18.66 %). The percent contributions of electrode force and electrode diameter are much lower, being 8.57 % and 1.14 %, respectively. Welding current and welding time interaction is also having influence of 1.14% on T-S strength.

CONFIRMATION EXPERIMENT

The confirmation experiment is the final step in the first iteration of the design of the experiment process. The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. The confirmation experiment is performed by conducting a test with a specific combination of the factors and levels previously evaluated. In this study, after determining the optimum conditions and predicting the response under these conditions, a new experiment was designed and conducted with the optimum levels of the welding parameters.

The final step is to predict and verify the improvement of the performance characteristic. The predicted S/N ratio η using the optimal levels of the welding parameters can be calculated as

$$\eta_{opt} = \eta_m + \sum_{j=1}^{k} (\eta_j - \eta_m) ; j = 1,2 \ldots\ldots k$$

Where η_m is total mean of S/N ratio, η_j is the mean of S/N ratio at the optimal level, and *n* is the number of main welding parameters that significantly affect the performance. The results of experimental confirmation using optimal welding parameters and comparison of the predicted tensile shear strength with the actual tensile shear strength using the optimal welding parameters are shown in Table-5. The improvement in S/N ratio from the starting welding parameters to the level of optimal welding parameters is 1.63 dB. The tensile shear strength is increased by 11.84%. Therefore the tensile shear strength is greatly improved by using Taguchi method.

CONCLUSIONS

This paper has presented an investigation on the optimization and the effect of welding parameters on the tensile shear strength of spot welded galvanized 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 welding time, whereas electrode force and electrode diameter were less effective factors. The results showed that welding current was about two times more important than the second factor weld time for controlling the tensile shear strength. An optimum parameter combination for the maximum tensile shear strength was obtained by using the analysis of S/N ratio. The confirmation tests indicated that it is possible to increase tensile shear strength significantly (13.43 %) by using the proposed statistical technique. The experimental results confirmed the validity of Taguchi method for enhancing the welding performance and optimizing the welding parameters in resistance spot welding operations.

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