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Application of Taguchi method to determine resistance spot welding conditions of austenitic stainless steel AISI 304

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This study presents a systematic approach to determine effect of process parameters (pressure, weld time and current) on tensile shear strength of resistance weld joint of austenitic stainless steel AISI 304 using Taguchi method. Optimum welding parameters determined by Taguchi method improved welding strength.

Keywords: ANOVA, F test, S/N ratio, Taguchi method

Introduction

Resistance spot welding (RSW) is getting significant importance in manufacturing car, bus and railway bodies etc. due to automatic and fast process. Major factors controlling this process are current, time, electrode force, contact resistance, property of electrode material, sheet materials, surface condition etc. The quality is best judged by nugget size and joint strength.

This study presents a systematic approach to determine effect of process parameters (pressure, weld time and current) on tensile shear strength of resistance weld joint of austenitic stainless steel AISI 304 using Taguchi method.

Experimental Section

An AISI 304 grade stainless steel (Fe, 72.18; C, 0.046; Cr, 18.14; Ni, 8.02; Mn, 1.26; Si, 0.34; S, 0.005; P, 0.012%) sheet (100 mm x 30 mm x 1 mm) was considered for welding of lap joint. For comparing weldability of each experimental group, tensile shear (T-S) strength was measured. Welding experiment was repeated three times under same conditions. Even though process was carried out identically, result of strength test was different due to a correlation of each parameter and environmental factor. Experimental data was used to compute performance characteristics of parametric combination for welding through calculation of signal to noise (S/N) ratio. Through S/N ratio, a set of optimum welding parameters was obtained. Using analysis of variance (ANOVA), predominant process parameters for spot welding were investigated.

Welding Parameter Selection

Level of each process parameter[1-6] (welding current, electrode pressure and weld time), identified to predict RSW characteristics of spot strength, was chosen in an available range for welding (Table 1). Squeeze (5 cycles) and hold (5 cycles) times were kept constant for all runs.

Orthogonal Array (OA)

Under Taguchi[7], system having 3 parameters with 3-level can be performed with 27 experiments. Therefore, in RSW, L27 orthogonal array[6,7] was selected. To analyze characteristic of each experiment effectively, interactions between welding parameters were also considered.

Experimentation and S/N Ratio

Parameters [pressure (A), current (B) and weld time (C)] were varied as per values for each level (Table 1). Three responses were taken for each setting. Mean value of T-S strength and S/N ratio were found out (Table 2). As strength should have larger value for better performance, S/N ratio [η (dB)] was calculated as $\eta = -10 \log [1/nS\ 1/y_i^2]$; i = 1, 2, 3, 4…n.

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Table—1 Process parameter with their values at three levels

Level	Pressure (A) Mpa	Current (B) kA	Weld time (C)
Low(1)	0.38	7.5	6
Medium(2)	0.46	8.5	8
High(3)	0.54	9.5	10

Table—2 Experimental data for tensile shear (T-S) strength and S/N ratio

Run No.	Pressure (A)	Current (B)	Weld time (C)	T-S strength (N) (mean)	S/N ratio for breaking strength, db
1	1	1	1	2266.67	67.02
2	1	1	2	3193.33	70.06
3	1	1	3	5666.67	75.03
4	1	2	1	7040.00	76.94
5	1	2	2	8440.00	78.53
6	1	2	3	8040.00	78.10
7	1	3	1	8200.00	78.27
8	1	3	2	8340.00	78.42
9	1	3	3	8676.67	78.76
10	2	1	1	3810.00	71.60
11	2	1	2	4280.00	72.60
12	2	1	3	7265.00	77.22
13	2	2	1	6296.67	75.96
14	2	2	2	7370.00	77.35
15	2	2	3	8693.33	78.78
16	2	3	1	8116.67	78.18
17	2	3	2	8626.67	78.71
18	2	3	3	8940.00	79.02
19	3	1	1	6450.00	76.19
20	3	1	2	7303.33	77.27
21	3	1	3	7986.67	78.05
22	3	2	1	2650.00	68.31
23	3	2	2	3383.33	70.58
24	3	2	3	5550.00	74.86
25	3	3	1	5960.00	75.50
26	3	3	2	7436.67	77.42
27	3	3	3	8963.33	79.05

Results and Discussion

S/N Ratio Analysis

In order to quantify influence of each level of parameters, mean of S/N ratio for A at levels 1, 2 and 3 were computed by averaging S/N ratio for experiments 1-9, 10-18 and 19-27, respectively (Table 3). Mean of S/N ratio for each level of other welding parameters were calculated in a similar way. Parameter with large

Table—3 Response table for S/N ratio for T-S strength

Level	Pressure (A)	Current (B)	Weld time (C)
1	75.68	73.89	74.22
2	76.60	75.49	75.66
3	75.25	78.15	77.65
Delta	1.35	4.26	3.43
Rank	3	1	2

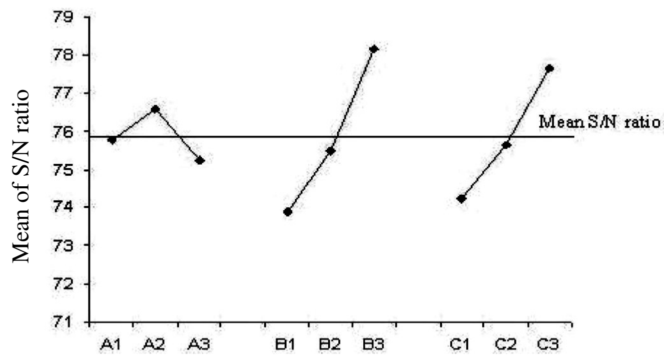

Fig. 1—Mean of S/N ratio vs A, B, C

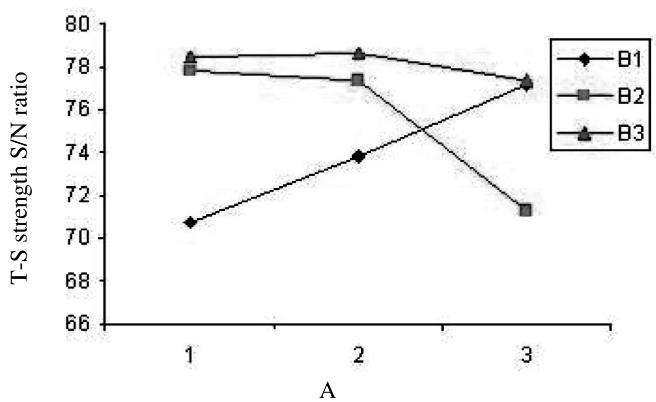

Fig.—2-Interaction plot for A*B

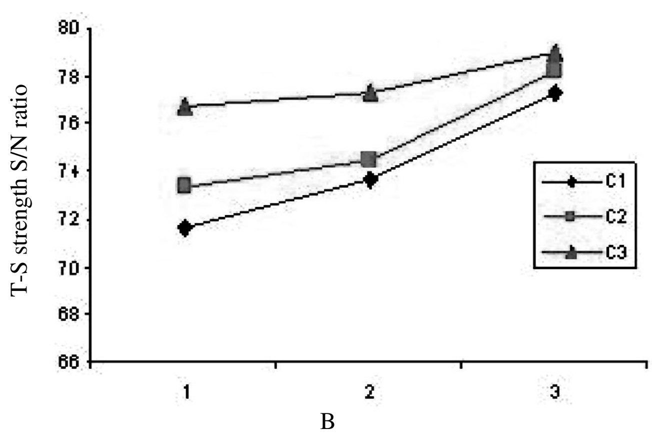

Fig. 3—Interaction plot for B*C

Table—4 ANOVA, F test and % contribution (% C) for T-S strength (all main factors and two way interaction)

CF	DOF	SS	V	F Ratio	% C
A	2	9943317	4971658	18.74*	2.89
B	2	106873469	53436734	201.39*	31.18
C	2	60926713	30463356	114.82*	17.77
A*B	4	140282981	35070745	132.17*	40.93
A*C (Pooled)	4	2306237	576559	2.17	00.67
B*C	4	5893530	1473382	5.55*	01.71
Error	62	16451009	265339		04.80
Total	80	342677256			100

S, 515.111; R^2, 95.20%; R^2(adj), 93.81%; SS, sum of squares; DOF, degree of freedom; V, variance; %C, percentage contribution; Tabulated F ratio at 95% confidence level, $F_{0.05, 2, 62}$, 3.15; $F_{0.05, 4, 62}$, 2.53; CF, control factor; *Significant at 95% confidence level

Table—5 ANOVA, F test and % contribution (% C) for T-S strength after pooling non-significant factors

CF	DOF	SS	V	F Ratio	% C
A	2	9943317	4971658	17.49*	2.89
B	2	106873469	53436734	188.02*	31.18
C	2	60926713	30463356	107.19*	17.77
A*B	4	140282981	35070745	123.40*	40.93
B*C	4	5893530	1473382	5.18*	01.71
Error	66	18757246	284201		05.47
Total	80	342677256			100

S, 533.105; R^2, 94.53%; R^2 (adj), 93.37%; $F_{0.05, 2, 66,}$ 3.14; $F_{0.05, 4, 66}$, 2.51; *Significant at 95% confidence level

difference indicates high influence to weldability as its level is changed. In this study, parameter B had largest difference following its levels, whereas each level of parameter A showed less effect to output. Based on S/N ratio (Table 3, Fig.1), new welding operation parameters were obtained through maximum level of each parameter. Analysis of main plot (Fig. 1) and interaction plot (Figs 2 & 3) suggested that setting of parameters to be done as A at level 2, B and C at level 3 to get optimum strength of weld joint.

Analysis of Variance (ANOVA)

ANOVA[7-9] investigates design parameters significantly affecting output parameters. In this analysis, sum of squares and variance were calculated. F-test value at 95 % confidence level was calculated to decide significant factors affecting the process. ANOVA (Table 4) showed that main factors (A, B, C) and interaction (A*B and B*C) are statistically significant at 95% confidence level. Interaction A*C is insignificant and so it is pooled out of ANOVA (Table 5).

Estimation of Mean and Confidence Interval

In order to obtain estimation of mean value under interaction effect, trials which include specific treatment condition (here B_3C_3)[7-9] should be averaged. From Fig.3, it is clear that B_3 and C_3 combination is included in trials 09, 18 and 27. These trials are thus averaged to get B_3C_3 (8860 N); A_2 as average value of weld strength at 2nd level of pressure (7044 N); and T_{FF}, overall mean of weld strength (6628 N). Estimated mean of response characteristic can be computed as[7,8]

$$\mu_{FF} = \overline{B_3C_3} + \overline{A_2} - \overline{T_{FF}} = 7044 + 8860 - 6628$$
$$= 9276N \qquad \ldots(1)$$

Confidence interval (CI) for predicted mean on a confirmation run can be calculated as[7,8]

$$CI = \left(F_{\alpha;(1, f_e)} V_e \left[\frac{1}{n_{eff}} + \frac{1}{R} \right] \right)^{\frac{1}{2}} \qquad \ldots(2)$$

where, $F_{a; (1, fe)}$, F ratio required for a (risk), $\alpha = 0.05$; fe, error DOF (66); Ve, error variance (284201); n_{eff}, effective number of replications = N/(1+ Total DOF associated in the estimate of mean) = 81/ {1+ (2*2+2)} = 11.57; R, number of repetitions for confirmation experiment (3); $F_{0.05; (1, 66)}$, 3.99. Calculated CI is ± 687. Predicted mean of weld strength (μ_{FF}) is 9276 N. CI of predicted breaking strength is as follows: $[\mu_{FF} - CI] < \mu_{FF} < [\mu_{FF} + CI]$ i.e, $8589 < \mu_{FF}$ (N) < 9963.

Confirmation Experiment

Confirmation test is a crucial step recommended by Taguchi to verify experimental conclusions. Three tests were conducted to verify T-S strength at optimum level of A_2, B_3 and C_3 and values obtained were 8930 N, 9100 N and 8790 N respectively, with an average of 8940 N. This result was within 95% confidence interval of predicted optimal value of selected parameters. Optimal settings of process parameters, as predicted in analysis, were implemented.

Conclusions

Percentage contribution (%C) of current (31.18%) and weld time (17.77%) were significant as compared to pressure (2.89%) for T-S strength. Less (%C) of error indicated that other factors did not have much effect on T-S strength. Optimal setting of process parameters for optimal strength is as follows: pressure, 0.46 MPa; current, 9.5 kA; and weld time, 10 cycles. Confirmation experiment result revealed that T-S strength was within confidence intervals.

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