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Design and Optimization of Lap Joint Resistance Spot Welding Parameters Using Taguchi Techniques

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Abstract: Resistance spot welding (RSW) is a major sheet metal joining in many industries like domestic, air craft, domestic applications, automobile, space craft fabrication are done by Resistance spot welding method (RSW). This method is very efficient for sheet metal joining. The three welding process seam, spot and projection produces metal coalescence at the surface faying by producing enough heat at that spot of contact by the flow of current resistance. Arcing of the surfaces faying is avoided by applying force before the current given also in other cases forging is done after heating. Here the optimization of the various parameters used in the resistance spot welding is shown. The experimental readings has been performed by varying welding time, pressure and welding current. In this study, the main characteristic i.e. tensile strength has been measured using Taguchi optimization method. The experimental analysis have been performed by changing the hold times, weld for joining two sheets and the welding currents. The significance of the variables of welding on the tensile shear strength is resolute by the software ANOVA. By using ANOVA software, we have found out the extremely effective parameters as time and current of welding by tensile shear strength, and also a less effective factors were electrode diameter and electrode force. The output data established the rationality of used Taguchi method for improving welding procedure as well as enhancing the welding parameter in the process of resistance arc process of welding. The validation experiment showed that this it is feasible to rise tensile shear strength considerably.

Keywords: Spot Welding, LAP joint, S/N ratio, Tensile Strength, ANOVA.

I. INTRODUCTION

Resistance spot welding (RSW) is a significant sheet metal joining technique used in a variety of industries, including household, aircraft, automotive, and spacecraft construction [1-3]. When connecting sheet metal, this technique is highly effective. By generating sufficient heat at the point of contact by the flow of current resistance, the three welding processes— seam, spot, and projection—create metal coalescence at the surface faying. Applying force prior to the current is one way to prevent surface arcing; in other situations, forging is carried out after heating [4-5]. Then the method is done inside a particular cycle time period. Usually, melting happens on the surface of faying at the process of welding. Also it is getting major significance in manufacturing automobile industries like bus, car, and locomotive industries like railway bodies etc. due to fast and automatic development [6-7]. One of the major problem of RSW is that alloy leaning occurs with the electrode which causes the wearing tool and ultimately results in poor weld quality. Overheating and discharge of electrodes occurs due to more time and current which further damages the quality of the welding along with unexpected strength of the weld. These problems of the method is to be analyzed for optimizing the parameters for improving the quality of the weld. The heat created in this procedure is calculated by using the formula:

$$Q = I^2 R\,T \qquad (1)$$

Where Q = generated heat, Joules I = Applied current, Amperes R = work piece resistance, Ohms T = current flow time. Taguchi optimizing process commends a three steps process to complete a desired product class by parameter designing, tolerance designing and system designing. In which the parameter designing should define the parameter levels which gives the best output of the products and system designing helps to identify the levels of working of design parameters [8-9]. The best state is choices such that the effect of the factors which cannot be controlled or factors of the noise makes least difference to performance of the system. ANOVA, Orthogonal arrays, F-test and S/N ratio analysis are the important apparatuses for designing of the parameters.

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Always the current of preheating is used before the current of welding to splitting the coating. The importance factors like time, current, electrode force, electrode material properties, contact resistance and surface condition, material of sheet etc. which are effecting this process [10-11]. The superiority is evaluated by Heat affected zone (HAZ), joint strength of the joint and also nugget size. A mathematical model was developed [12-14] for calculating the tensile shear strength and nugget steel galvanized of diameter where the parameters of input are current of welding, current of the preheating, pressure of welding and time of welding. The RSW process optimization parameters [15-18]] for SAE1010 steel were studied by using Taguchi method it was achieved by Taguchi process of optimization. The strength of fatigue of RSW welded steel galvanized AISI 304 was reported, where they showed that the fatigue limit of the combined galvanised steel sheet is highest. It has been discussed how a variation in governable parameter like heat input percentage which can marks a calculable signal output revealing of the strength as well as the electrode displacement for different steel sheets applied in automobile sector[1922].

The lap joint is one of the several joint types used in resistance spot welding, but it is the most commonly used joint type. As described in the lap joint, two metal sheets are stacked over each other and then welded together using heat and pressure through the use of copper electrodes. Heat is produced as a result of the high currents passing through the metal sheets for a particular duration of time to form resistance in the area where the sheets overlap. Resistance spot welding of a lap joint results in the formation of a weld nugget which cools down to form a firm joint between the sheets [23-25]. Lap joint resistance spot welding finds wide application in the manufacturing of automobile bodies, rail cars, aircraft structures, household appliances, batteries, and structural sheet metals. In the modern manufacturing system, there have been changes in demands on manufacturing processes. Lightweight materials and higher production rates and better structural properties have raised the importance of proper optimization of resistance spot welding process parameters to improve the performance and increase weld quality. There are several factors that have an impact on the performance of lap joint resistance spot welds. Among them, welding current is regarded as one of the most significant due to its effect on the heat energy generated during the process. This heat energy depends on the electric current, resistance, and time as per the Joule’s law. If the welding current is higher, the heat energy generated becomes more, resulting in the formation of bigger weld nuggets [27-29].

However, if the current is too high, it will result in poor quality of weld, since problems such as metal expulsion, sticking of electrodes, indentation, and burning may occur. Thus, finding a right level of welding current is vital for optimal welding performance. Weld time is another factor related to lap joint resistance spot welding process. Sufficient force minimizes contact resistance between the electrode and the workpieces' surfaces without minimizing interface resistance, which should remain relatively high in order to generate heat in the intended region. Insufficient force may cause instabilities in current flow and arcing resulting in spatter and poorly formed welds. Excessive force, on the other hand, may inhibit nugget formation due to reduction in interface resistance [30-31]. Consequently, electrode force must be optimized to obtain quality welds with no defects. The design and diameter of the electrode tip determine the current density, distribution of heat, and size of the nugget formed during welding. Small electrodes create a high current density and greater penetration, but large electrodes result in distribution of heat on a wider region with lower indentation.

The wearing out of the electrode through the constant production process will affect the quality and uniformity of the welds, hence the need for maintenance and re-shaping during continuous production in an industrial setting. Similarly, the nature and thickness of the sheets being joined are also very significant when it comes to establishing suitable welding parameters. There is a variety of material such as mild steel, stainless steel, aluminum alloys, galvanized steel, and advanced high-strength steels that have unique properties and characteristics [32-34]. For instance, aluminum alloys require increased welding current due to its high thermal conductivity and reduced electrical resistivity. On the other hand, galvanized steels pose a problem of coating vaporization and contamination of the electrode during welding process. Modern industries use computerized resistance spot welding machines that are equipped with advanced monitoring and controlling features. Simulation models allow engineers to optimize the parameters of welding without resorting to excessive experimental tests, saving both money and time spent on development [35-36]. Besides, more attention is paid to quality control by non-destructive testing means including ultrasonics, acoustic emission, and infrared thermography that are widely used for spot welding quality assessment in industry. Current scientific researches on lap joint resistance spot welding involve dissimilar metals, including steel-aluminum alloys, which are extremely important for construction of lightweight automotive bodies and batteries for electric vehicles. But dissimilar metals welding implies specific issues related to different thermal characteristics, intermetallic compounds formation, and uneven heating.

II. MATERIAL METHODS

For making a lap joint, a 120mm × 50mm × 2 mm sheet of AISI 304 material was considered. Tensile strength was measured for comparing weldability of individual groups of experiment. The experiment was repeated three times in same conditions. A set of optimum parameters was done by S/N ratio and predominant process parameters were analyzed by ANOVA (analysis of variance). Welding parameters such as electrode pressure (A), welding current (B), and time (C) are varied as per values for individual level (Table 1). In this case Squeeze and Hold times are considered to be constant. In this experiment L27 orthogonal array (OA) was considered. Welding parameters are required for analyzing the characteristics of each experiment effectively. Table 2 shows the mean value of tensile strength and S/N ratio. S/N ratio was calculated by:

$\eta = -10 \log [1/Ns\ 1/y\_i\^2]$ (2)

Where, i= 1,2,3…n ;

TABLE 1.1
WELDING PARAMETERS AND DIFFERENT LEVELS

Symbol	Welding Parameter	Unit	Level 1 (low)	Level 2 (medium)	Level 3 (high)
A	Pressure	Mpa	0.36	0.48	0.56
B	Current	kA	7.6	8.3	9.7
C	Welding time	Cycle	5	9	12

TABLE 1.2
EXPERIMENTAL DATA FOR TENSILE STRENGTH AND S/N RATIO FOR BREAKING STRENGTH

Experiment number	Pressure (A)	Current (B)	Welding time (C)	Tensile strength (N) mean	Breaking strength (db)
1	1	1	1	2265.27	66.94
2	1	1	2	3201.14	71.00
3	1	1	3	5723.23	74.96
4	1	2	1	7122.07	77.00
5	1	2	2	8441.01	78.53
6	1	2	3	8034.18	77.97
7	1	3	1	8195.17	78.29
8	1	3	2	8335.28	78.34
9	1	3	3	8681.57	78.66
10	2	1	1	3796.25	72.07
11	2	1	2	4187.19	72.35
12	2	1	3	7265.01	76.94
13	2	2	1	6312.16	76.00
14	2	2	2	7271.08	77.35
15	2	2	3	8675.97	78.49
16	2	3	1	8216.87	78.21
17	2	3	2	8616.92	78.67
18	2	3	3	8878.00	78.98
19	3	1	1	6514.96	77.00
20	3	1	2	7298.00	77.36
21	3	1	3	7919.07	77.96
22	3	2	1	2618.08	68.36
23	3	2	2	3298.11	71.00
24	3	2	3	5610.07	74.96
25	3	3	1	5876.98	75.15
26	3	3	2	7416.97	76.96
27	3	3	3	8918.39	78.97

TABLE 1.3
RESPONSE TABLE FOR S/N RATIO (TENSILE STRENGTH)

Symbol	Welding Parameter	Unit	Level 1 (low)	Level 2 (medium)	Level 3 (high)	Delta	Rank
A	Pressure	Mpa	75.59	76.65	75.37	1.38	3
B	Current	kA	73.91	75.51	77.91	4.32	1
C	Welding time	s	73.99	75.36	77.59	3.46	2

TABLE 1.4
% CONTRIBUTION AND F TEST FOR TENSILE STRENGTH

Control Factor	DOF	Sum of Square	Variance	F ratio at 95% confidence level	% Contribution
A	2	974328	4872759	17.98	3.08
B	2	110873169	53316714	200.93	30.96
C	2	59987693	32164017	115.07	18.10
A*B	4	150010781	31620856	131.98	39.97
B*C	4	5718538	1381978	6.07	01.71
Error	63	17511709	259687		04.18
Total	81	337891371			49.78

III. RESULTS AND DISCUSSIONS

To measure the control of every levels parameter, S/N ratio (mean) for A at levels 1, B at levels 2 and C at levels 3 were calculated by averaging the S/N ratio for experiments no 1-9, 10-18 and 19-27 (Table 1.3).

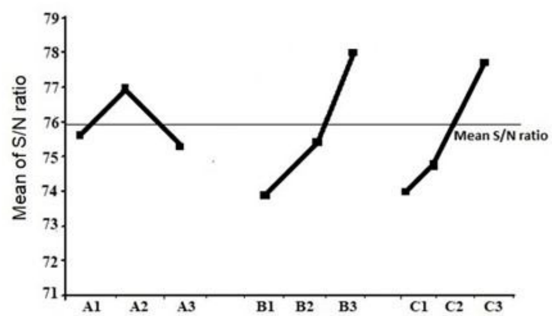

Fig. 1 Mean of S/N ratio

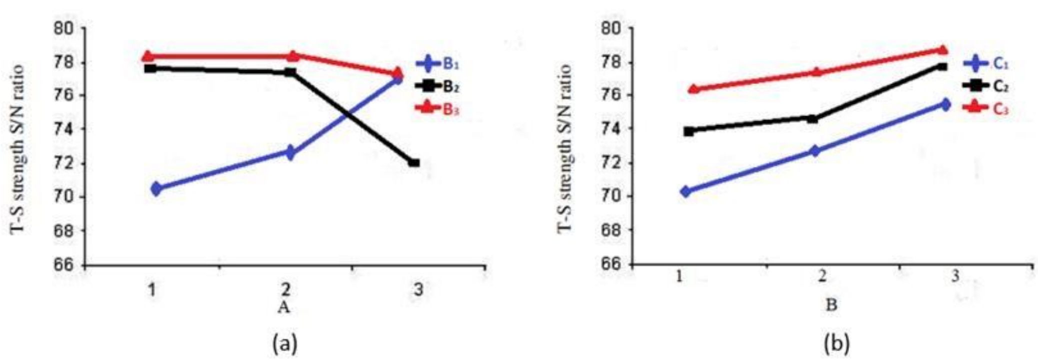

Fig. 2 (a) Interaction of A*B and (b) Interaction of B*C

Mean of S/N ratio for all level of other welding parameters were analyzed in a same way. In this experiment, “B” parameter has largest differences subsequent its level, but every level of “A” parameter has minimum effect to output. Table 1.3 and Figure 1 shows the welding parameters were achieved through highest level of individual parameter. Figure 1 shows that setting of parameters “A” at level 2, “B” at level 3 and “C” at level 3 get optimum strength of weld joint. In ANOVA analysis, the sum of square and variance were examined. Table 1.4 shows the factor A, B, C and also the interaction factor of A*B, B*C are statistically considerable at 95% confidence level (Figure 2). In Confirmation test, three test were done for verifying the tensile strength at A2, B3, C3, and the values are 8872N, 8930N and 8832N, the average 8878N. The result is within 95% confidence interval of expected optimal value of preferred parameters.

IV. CONCLUSIONS

In this experiment it is shown that the welding parameter plays an important role in the strength of welded joint, which lead to the increase or decrease in the strength of welding operation. Therefore the maximum strength of the spot welded joint is required for the combination of the suitable parameters. The best state is choices such that the effect of the factors which cannot be controlled or factors of the noise makes least difference to the performance of the system. Optimal setting of process parameters for optimal strength are pressure 0.48 Mpa, current 9.7 Ka, welding time 12 Cycles. Confirmation test result represented that tensile strength was in confidence periods.

V. ACKNOWLEDGMENT

The accompanying author can provide the data supporting the study's conclusions upon reasonable request. There are no conflicts of interest to report. For this effort, we thank the OmDayal Group of Institutions' Department of Mechanical Engineering.

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