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Modeling Spot Welding Process by Using Box Behnken Design for Zinc Coated Steel Sheet

Amit K Girase[1], L Boriwal[2]

[1],*PG Student, Department of Mechanical Engineering, Sagar Institute of Research &Technology Indore, India*
[2]*Associate Professor, Department of Mechanical Engineering, Sagar Institute of Research &Technology Indore, India*

A B S T R A C T

Resistance Spot Welding (RSW) is used to joint sheet metal sheets up to 3.2 mm thickness, when the design permits the use of lap joints and leak tight seams will not be required. Occasionally the process is used to join steel plates 6.35 mm thick or thicker; however, loading of such joints is limited and the joint overlap adds weight and cost to the assembly when compared to the cost of an arc welded butt joint. Most of the automobile industries use RSW process as it is easily automated and consumes no filler material. Moreover, the process requires very less operator's skill. In this work, the Zinc coated steel sheet statistical analysis has been done by using the Box Behnken Design. The interaction effect of process parameter have been analysed by Analysis of variance. The final results shown better adequacy of the developed mathematical model. Also validation has been done

Keywords:RSW, Zinc coated steel sheet, ANOVA,

1 Introduction

Resistance Spot Welding (RSW) is used to joint sheet metal sheets up to 3.2 mm thickness, when the design permits the use of lap joints and leak tight seams will not be required. Occasionally the process is used to join steel plates 6.35 mm thick or thicker; however, loading of such joints is limited and the joint overlap adds weight and cost to the assembly when compared to the cost of an arc welded butt joint. Most of the automobile industries use RSW process as it is easily automated and consumes no filler material. Moreover, the process requires very less operator's skill. In RSW, the weld nugget is produced at the faying surface of metal sheets by the heat generated due to the electrical resistance offered by the metal sheets. The heat generated in the process is adequate to melt and fuse the faying surfaces. The total heat generation in the process increases with the increase in the welding current. The process is used in preference to mechanical fastening, such as riveting or screwing, when disassembly for maintenance is not required. It is much faster and more economical because separate fasteners are not needed for assembly.

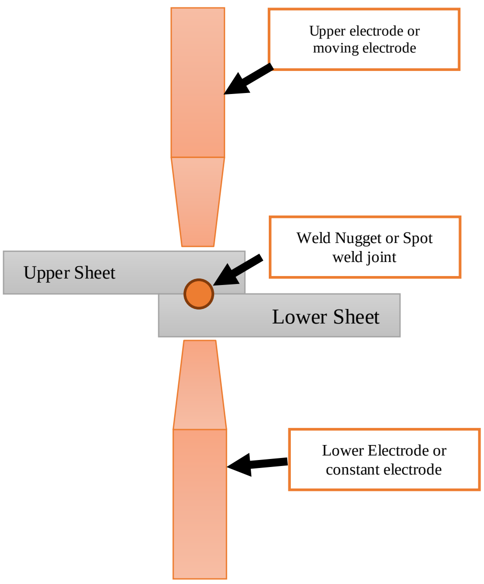

Figure 1: Schematic diagram of RSW

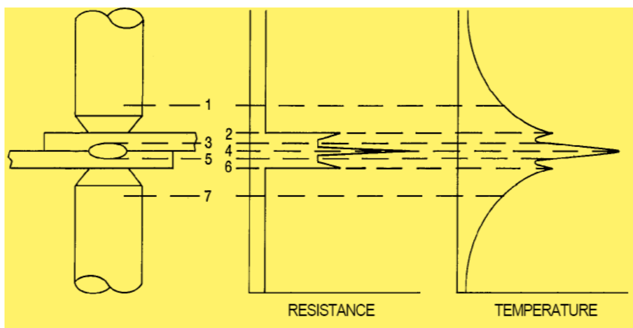

Figure 2: Temperature profile during the RSW Process [2]

Factorial designs are most capable to find out the effect of process parameters on the responses. By a factorial design, each complete trial or replicate of the experiment all possible combinations of the levels of the factors are investigated. For example, if there are a levels of factor A and b levels of factor B, each replicate contains all AB treatment combinations. When factors are arranged in a factorial design, they are often said to be crossed.

Boriwal L et al [1]. They investigated the optimized process parameters of the zinc coated steel sheet by using the full factorial design. They performed the pilot experiments to identify the range and levels of input process parameters. Welding current, weld time, and electrode pressure has been taken as a input process parameters and nugget size as response of it. Based on 3 level and 3 factor, total 27 combination of process parameters has been developed say design of experiments by using the Minitab 14 software.Mohammed B et al. [4] they combined the box bhenken design technique with the response surface methodology to optimization of the photo catalytic mıneralızatıon of C.I. basıc red 46 dye from aqueous solutıonXiaobing C et. al [5] they applied the response surface methodology and genetic algorithm to analyzed and optimized the resistance spot welded 5052 aluminum to Al-Si coated boron steel.

2. Statistical Modelling

The Design of Experiment is an experimental strategy in which process parameters are varied together, instead of one at one time. Three factor- three levels with Box Behnken design matrix was selected for a set of experiments. This design matrix produce the 15 set of combination of process parameters. The factor range and its level have been obtained from the Boriwal L published article. Minitab software is employed to generate the design matrix. Three factors and three levels with Box Behnken design were used for statistical analysis. The analysis of variance (ANOVA) and response regression coefficients of process parameters and their responses results were analyzed by using the Minitab software.

Generally, the relationship between the process parameters (x1, x2 …..xn) and response variable y may be known as In this study, nugget size is the function of input process parameters welding current (I), Weld time (WT) and electrode pressure (EP).

Nugget Size = f (I, WT, EP) (1)

As three process parameters, the selected polynomial could be expressed as:

Nugget Size = b0 + b1 (I) + b2 (WT) + b3 (EP) + b11 (I2) + b22 (WT2) + b33 (EP2) + b12 (I*WT) + b13 (I*EP) + b23 (WT*EP) (2)

In above equations nugget size is the surface response of the process contains linear, square and cross product terms of parameters. Where b0 and b'0 are the averages of responses. b1, b′1 and b11, b′11 are the coefficients that depend on the respective main and interaction effect of the process parameters. In this study, a factorial design which precisely fits the second order response surface was used.The final mathematical regression model to predict the nugget size of weld joint was developed by calculating regression coefficient is given as equations Where:

Welding current (I), weld time (WT), electrode pressure (EP), the quadratic effect on the welding current (I^2) and weld cycle (WT^2)

Nugget Size (mm) = 32.04 - 7.909 Welding Current (kA) - 0.665 Weld Cycle
- 3.898 Electrode Pressure (kg/cm^2)
+ 0.6718 Welding Current (kA)*Welding Current (kA)
+ 0.1966 Weld Cycle*Weld Cycle
+ 0.3681 Electrode Pressure (kg/cm2)*Electrode Pressure (kg/cm^2)
- 0.0776 Welding Current (kA)*Weld Cycle
+ 0.0866 Welding Current (kA)*Electrode Pressure (kg/cm^2)
+ 0.0830 Weld Cycle*Electrode Pressure (kg/cm^2)

The equation is valid under the following conditions:

$6 \leq I \leq 7.9$

$4 \leq WC \leq 6$

$2 \le EP \le 4$

Steel sheet thickness 0.9 mm

Table 1 Range and its level [1]

Levels	Welding current (kA)	Weld cycle (sec)	Electrode pressure (kg/cm2)
Low	6	4	2
Medium	7.11	5	3
High	7.9	6	4

3. Analysis of Variance

As seen in ANOVA Table 2, the quadratic model for nugget size was significant as its F –value was 1752.23 and its P-value was smaller than 0.5. The result reveal that the welding current (I), weld time (WT), electrode pressure (EP), the quadratic effect on the welding current (I2) and weld cycle (WT2) along with the interaction effect of welding current, weld time and electrode pressure are the significant factors affecting in the model that affecting the joints performance. The non-significant model terms are eliminated by the stepwise elimination process to simplify the quadratic model and improve the model adequacy. The coefficient of determination (R2) and adjusted R2 are generated by the developed response regression model. In this study, the difference between the predicted R2 and adjusted R2 is less than 0.01 for nugget size, which also verified that model is significant.

Table 3 Analysis of Variance for nugget formation (after elimination)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	25.8847	2.8761	1752.23	0.000
Linear	3	24.0069	8.0023	4875.34	0.000
Welding Current (kA)	1	12.2166	12.2166	7442.88	0.000
Weld Cycle	1	8.1709	8.1709	4978.06	0.000
Electrode Pressure (kg/cm2)	1	3.6194	3.6194	2205.09	0.000
Square	3	1.8014	0.6005	365.83	0.000
Welding Current (kA)*Welding Current (kA)	1	1.3574	1.3574	827.01	0.000
Weld Cycle*Weld Cycle	1	0.1427	0.1427	86.93	0.000
Electrode Pressure (kg/cm2)*Electrode Pressure (kg/cm2)	1	0.5003	0.5003	304.78	0.000
2-Way Interaction	3	0.0764	0.0255	15.51	0.006
Welding Current (kA)*Weld Cycle	1	0.0218	0.0218	13.25	0.015
Welding Current (kA)*Electrode Pressure (kg/cm2)	1	0.0271	0.0271	16.49	0.010
Weld Cycle*Electrode Pressure (kg/cm2)	1	0.0276	0.0276	16.79	0.009
Error	5	0.0082	0.0016		
Lack-of-Fit	3	0.0057	0.0019	1.55	0.415
Pure Error	2	0.0025	0.0012		
Total	14	25.8929			

4. Results and Discussion

4.1 Interaction effect of process parameters on nugget size.

It is essential to check the assumption of ANOVA before draw conclusions. There are three assumption in ANOVA analysis:

Normality

Constant variance

Independence.

The normality can be checked with a normal plot of residuals. This graph plots between residuals (the difference between the observed and fitted response value) and individual cumulative frequency percent. The plot will resemble a straight line if the distribution of residuals is normal. Fig. 3 & Fig. 4 depicts the residuals plots for nugget size, which is indicated that all the residuals values are fall on a straight line. Linearity trend indicates that errors are distributed normally. This is also shown that the developed modelis good.

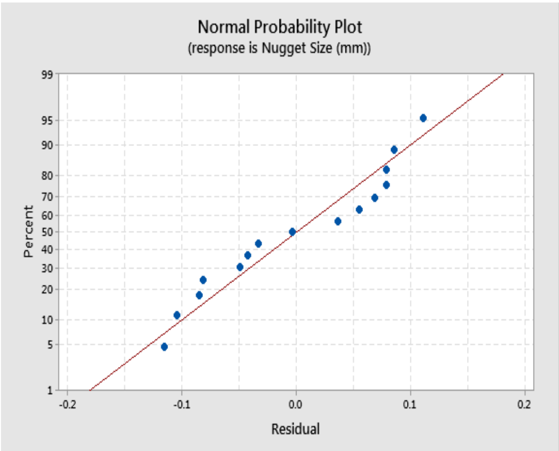

Figure 3: Radial stress generated by Eutectic alloy type ATC12CuMgNi

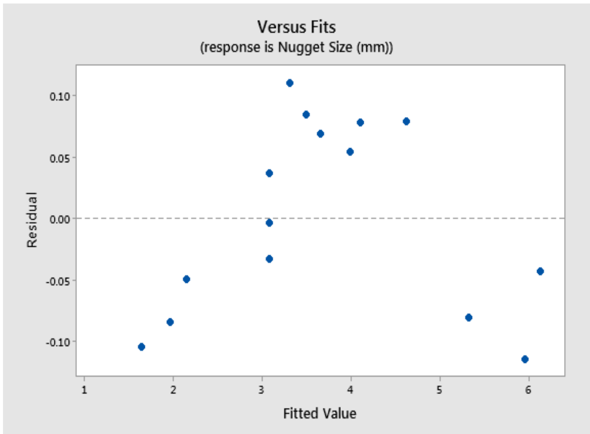

Figure 4: Radial stress generated by Eutectic alloy type ATC12CuMgNi

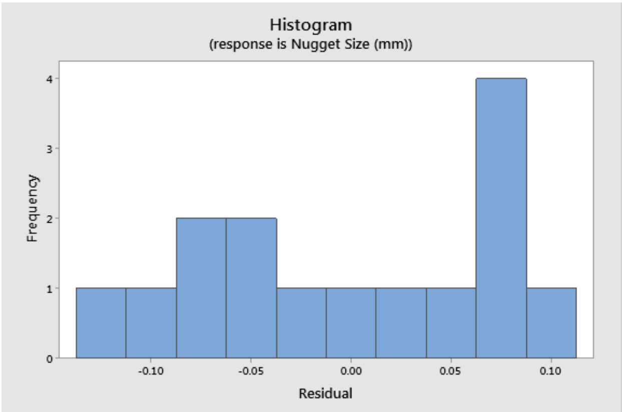

Figure 5 Histogram of residuals for nugget size of spot welds nugget size of spot welds

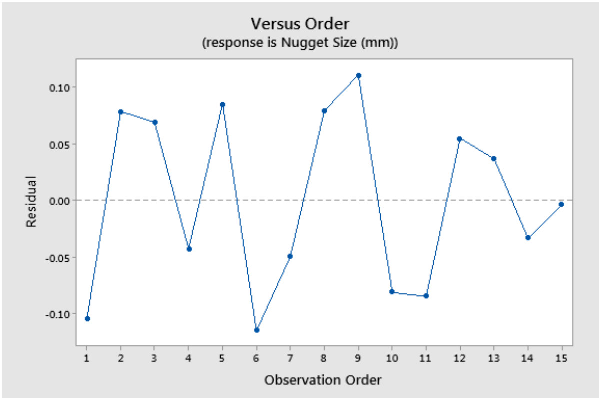

Figure 6 Residual and observation order plot of residuals

5. Conclusion

The following conclusions has been drawn for the current analysis:

- The non-significant model terms are eliminated by the stepwise elimination process to simplify the quadratic model and improve the model adequacy.
- The coefficient of determination (R^2) and adjusted R^2 are generated by the developed response regression model.

- In this study, the difference between the predicted R^2 and adjusted R^2 is less than 0.01 for nugget size, which also verified that model is significant.
- The residuals plots for nugget size, which is indicated that all the residuals values are fall on a straight line. Linearity trend indicates that errors are distributed normally. This is also shown that the developed model is good.

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