Study And Analysis Of Welding Process Parameters On Failure Load Of Spot Welds Of Stainless Steel 304L Grade

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Abstract: ***Resistance Spot Welding (RSW) is a high speed process, wherein the actual time of welding is a small fraction of second and it is one of the cleanest and most efficient welding process that has been widely used in sheet metal fabrication.Spot welding is a basic manufacturing process for making components or assemblies which are widely used in automobile, refrigeration, food processing industry and chemical industry. High corrosion resistance, good weldability and aesthetic looks are the most beneficial features which make the use of 304L grade stainless steel superior to carbon steel and other grades of stainless steel. In the present work, the effect of spot welding parameters (welding current, weld time, electrode force) on failure load of resistance spot welds of austenitic stainless steel (304L grade) sheets (0.5 mm to 2.0 mm thick) were analyzed.***

Keywords – Failure load, RSM, Resistance spot welding.

1. INTRODUCTION

Resistance Spot Welding (RSW) is a high speed process, wherein the actual time of welding is a small fraction of second and it is one of the cleanest and most efficient welding process that has been widely used in sheet metal fabrication. The process is used extensively for joining low and mild carbon steel sheet metal components for automobiles, cabinets, furniture and similar products. Stainless steel, aluminum and copper alloys are also spot welded commercially.[4]

To produce an acceptable weld, it is usually matter of specifying a proper combination of current and welding time to obtain adequate heat generation.[2] The resistance is affected by a wide range of factors, including temperature and pressure. The control function of the welding machine defines the welding cycle. The particular steps controlled are squeeze time, welding time, hold time and off time.[1]

Since accurate method for selection of welding variables (welding current, welding time and electrode force) are lacking, a trial and error approach is adopted whenever a new-type of metal is used. Field experience has shown that in resistance spot welding the basic welding variables are practically linear functions of metal thickness.[7]These greatly simplify the choice of welding variables. In most of the cases, RSW joints are used under tensile-shear loading.[3]

In general, the statistical method of design of experiment is based on a more sound logic than any other approach and helps in minimizing the time and the cost of experimentation and at the same time increases the authenticity of the results. Many latest techniques are available for experimental design which can be effectively used in scientific investigations of welding processes. One such important technique is Response Surface Methodology for evaluating the effect of the parameters and their interactions on the response. Hence in the present work, this approach was selected for conducting the experiments and generating the data for predicting the effect of spot welding process parameters on the failure load of the weld joint of 304L grade.

2. PLAN OF INVESTIGATION

The research work was carried out in the following steps:

- Identifying the important process control variables.
- Finding the upper and lower limits of the control variables.
- Developing the design matrix.
- Conducting the experiments as per the design matrix.
- Recording the responses.
- Developing the mathematical models and calculating the coefficients of the polynomials.
- Evaluation of the adequacy of the models developed.
- Presenting the direct effects of different process parameters on failure load graphically.

2.1 Identification of the process variables and finding their limits

Visualizing the influence of various welding parameters on the failure load (tensile shear) of weld, four main parameters are selected to carry out the investigations. These are:

1. Weld current, I (A/KA)
2. Electrode force, F (N/KN)
3. Weld time, T (cycles/ms)
4. Thickness, θ (mm)

Trial runs were carried out by varying one of the process parameters whilst keeping the rest of them at constant values. The working range was decided upon by inspecting the weld quality (failure load) and the absence of any visible defects. The parameters/variables and their levels are given in Table 1.

2.2 Developing the design matrix

Central Rotatable Composite design can be represented in the form of design matrix where column and row correspond to levels of the factors and the different experimental runs respectively. The present design matrix is shown in Table 2.

Table 1 Coding of spot welding parameters

Parameter	Level coding	Levels				
		-2	-1	0	1	2
Current, I (A)	A	2500	4000	5500	7000	8500
Force, F (KN)	B	0.5	2.5	4.5	6.5	8.5
Time, T (ms)	C	80	160	240	320	400
Thickness, θ (mm)	D	0.5	1	1.5	2	2.5

Table 2 Design of Experiments

Experiment No.	Block 1				Experiment No.	Block 2				Experiment No.	Block 3			
	A	B	C	D		A	B	C	D		A	B	C	D
1	-1	1	-1	1	11	-1	-1	-1	1	21	0	0	2	0
2	0	0	0	0	12	-1	1	-1	-1	22	2	0	0	0
3	1	1	-1	-1	13	1	1	1	-1	23	-2	0	0	0
4	-1	1	1	-1	14	1	1	-1	1	24	0	0	-2	0
5	1	-1	1	-1	15	1	-1	-1	-1	25	0	0	0	-2
6	0	0	0	0	16	-1	-1	1	-1	26	0	2	0	0
7	-1	-1	1	1	17	-1	1	1	1	27	0	0	0	0
8	1	1	1	1	18	0	0	0	0	28	0	0	0	0
9	1	-1	-1	1	19	0	0	0	0	29	0	-2	0	0
10	-1	-1	-1	-1	20	1	-1	1	1	30	0	0	0	2

2.3 Conducting the experiments

The material used in the present work is austenitic stainless steel (Grade 304L) sheets having thickness ranging from (0.5 mm to 2.5 mm). The chemical composition of the steel sheet is given in the Table 3.

The specimens were cut from a sheet of 1m x 2.5m. The specimens were cut parallel to the rolling direction of the sheets. The geometry is illustrated in Fig. 1. Tensile-shear specimen was made by lapping two pieces one over the other. The dimensions were 100 mm length and 25 mm width, the overlap being equal to the width of the specimen. This overlap was chosen as per AWS recommendation.[9]

Table 3: Chemical composition of ASS (304L) specimen

Element	C	Si	Cr	Ni	Mo	Mn	Ph	S	Cu	Ti
Wt (%)	0.03	0.3733	18.48	8.663	0.4459	1.581	0.018	0.00503	0.081	0.0112

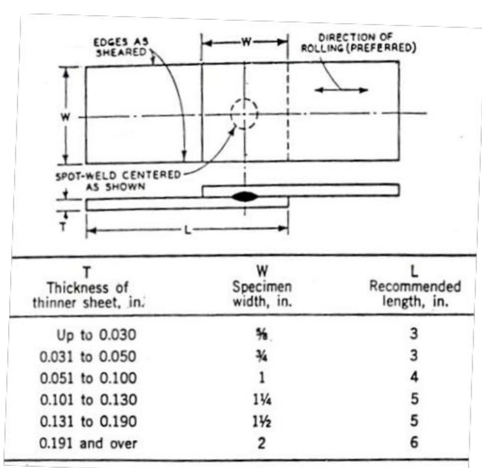

Fig.1: Tensile shear specimen

Surface cleaning of specimen was done by pickling [pickling solution – HCl (conc.) 36% (Vol.) + HNO_3(d 1.4) 5% (vol.) + HF (15%) 4% (vol.) + water 55% (vol.)] at room temperature for about 15-20 mins. followed by water rinsing (2 times) and then specimens were dried and were ready for welding.[8]

Since a number of set of tests has been performed, in which each set was designed to determine the effect of single variable for a specific geometry. Welding has been organized in such a way that a full set would be done on a single occasion. This has been done to minimize variation within any one set of samples that is not due to the factor being tested. Similarly, within each set all specimens with a single combination of variables have been welded before sequentially changing the test variables. Size of electrode diameter has been kept as per AWS recommendation.[5]

i.e. $d = 2\theta + 2.54$ mm
Where d = diameter of electrode
θ = plate thickness in mm

2.4 Recording the responses

The tensile shear test was carried out by uniaxially gripping of two ends of lap joint of standard specimen and by pulling in tension to destruction. Tensile shear tests have been performed on the specimens. These tests have been performed on Blue Star UT machine (Model UTN-20) having maximum capacity of 20 KN. Tensile load has been applied and value of failure load in KN has been recorded for number of specimens need at various combinations of parameters.For each specimen 3 readings were taken and the final reading was the average of the three.The observed and calculated values are given in Table 4.

Table 4 Experimental Results of the Response Characteristics

Std	Run	Block	Factor 1 Welding Current (A)	Factor 2 Welding Time (ms)	Factor 3 Electrode Force (KN)	Factor 4 Sheet thickness (mm)	Response Failure load (kN)
5	1	Block 1	4000.00	160.00	6.50	1.00	6.85
9	2	Block 1	5500.00	240.00	4.50	1.50	10.22
1	3	Block 1	4000.00	160.00	2.50	2.00	7.25
7	4	Block 1	4000.00	320.00	6.50	2.00	8.29
10	5	Block 1	5500.00	240.00	4.50	1.50	9.59
8	6	Block 1	7000.00	320.00	6.50	1.00	9.25
6	7	Block 1	7000.00	160.00	6.50	2.00	9.19
4	8	Block 1	7000.00	320.00	2.50	2.00	9.79
2	9	Block 1	7000.00	160.00	2.50	1.00	9.26
3	10	Block 1	4000.00	320.00	2.50	1.00	7.23
14	11	Block 2	7000.00	320.00	2.50	1.00	9.69
18	12	Block 2	7000.00	320.00	6.50	2.00	9.61
16	13	Block 2	7000.00	160.00	6.50	1.00	8.34
20	14	Block 2	5500.00	240.00	4.50	1.50	8.14
17	15	Block 2	4000.00	320.00	6.50	1.00	7.066
15	16	Block 2	4000.00	160.00	6.50	2.00	5.87
19	17	Block 2	5500.00	240.00	4.50	1.50	8.72
13	18	Block 2	4000.00	320.00	2.50	2.00	7.01
11	19	Block 2	4000.00	160.00	2.50	1.00	7.28
12	20	Block 2	7000.00	160.00	2.50	2.00	11.92
25	21	Block 3	5500.00	240.00	0.50	1.50	10.85
23	22	Block 3	5500.00	80.00	4.50	1.50	7.73
30	23	Block 3	5500.00	240.00	4.50	1.50	10.5
22	24	Block 3	8500.00	240.00	4.50	1.50	13.61
21	25	Block 3	2500.00	240.00	4.50	1.50	7.27
27	26	Block 3	5500.00	240.00	4.50	0.50	3.27
28	27	Block 3	5500.00	240.00	4.50	2.50	7.48
26	28	Block 3	5500.00	240.00	8.50	1.50	7.44
24	29	Block 3	5500.00	400.00	4.50	1.50	9.76
29	30	Block 3	5500.00	240.00	4.50	1.50	7.5

2.5 Development of mathematical models

The response function can be expressed as y = f (A,B,C,D). The relationship selected, being a second-degree response surface, is expressed as follows:

$$Y_1 = b_0 + b_1A + b_2B + b_3C + b_4D + b_{11}A^2 + b_{22}B^2 + b_{33}C^2 + b_{44}D^2 + b_{12}AB + b_{13}AC + b_{14}AD + b_{15}BC + b_{16}BD + b_{17}CD$$

The values of the coefficients were calculated by using Design Expert Software (Central Rotatable Composite Method).

2.6 Evaluation of the adequacy of the developed models

The adequacy of the models was then tested by the analysis-of-variance technique (ANOVA). The program calculates the effects for all model terms. It produces statistics such as F-values, and R-squared values for comparing the models.

Table 5 ANOVA for Response Surface Quadratic Model for failure load

Source		Sum of Squares	DF	Mean Square	F Value	Prob > F	
Block		0.54	2	0.27			
Model		93.84	14	6.70	5.43	0.0021	significant
	A	45.06	1	45.06	36.52	< 0.0001	
	B	1.52	1	1.52	1.23	0.2874	
	C	5.79	1	5.79	4.69	0.0495	
	D	6.39	1	6.39	5.18	0.0404	
	A^2	2.85	1	2.85	2.31	0.1524	
	B^2	0.28	1	0.28	0.23	0.6409	
	C^2	4.576E-005	1	4.576E-005	3.709E-005	0.9952	
	D^2	24.43	1	24.43	19.80	0.0007	
	AB	0.46	1	0.46	0.37	0.5515	
	AC	0.80	1	0.80	0.65	0.4354	
	AD	0.99	1	0.99	0.80	0.3871	
	BC	2.22	1	2.22	1.80	0.2030	
	BD	0.067	1	0.067	0.054	0.8193	
	CD	0.070	1	0.070	0.056	0.8158	
Residual		16.04	13	1.23			
Lack of Fit		11.17	10	1.12	0.69	0.7142	not significant
Pure Error		4.87	3	1.62			
Cor Total		110.41	29				

The Model is observed to be significant. There is only a 0.21% chance that a "Model F-Value" could occur large due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, C, D, D^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The "Lack of Fit F-value" of 0.69 implies the Lack of Fit is not significant relative to the pure error. There is a 71.42% chance that a "Lack of Fit F-value" could occur large due to noise.

2.7 Development of final mathematical models

The final mathematical models developed are given below. The process control variables are in their coded form.

Failure load = $+9.11 + 1.37A + 0.25B - 0.49C + 0.52D + 0.32A^2 - 0.10B^2 - 1.292E\text{-}003C^2 - 0.94D^2 - 0.17AB - 0.22AC + 0.25AD + 0.37BC - 0.065BD - 0.066CD$

In the present study A, C, D, D^2 are significant model terms. After droping out the insignificant terms the model can be expressed as:

Failure load = $+9.11 + 1.37A - 0.49C + 0.52D - 0.94D^2$

3. RESULTS AND DISCUSSIONS

The experiments were planned by using the parametric approach of the Central rotatable composite method of the surface response methodology. The main effects of process parameters for the data are plotted. The response curves (main effects) are used for examining the parametric effects on the response characteristics.

3.1 Effect of weld current on failure load

The effect of weld current on failure load has been shown in Figure 2. It has been observed that in case of 2mm thick specimen, when current increases from 5.6 KA to 7.4 KA, failure load increases from 7.85 KN to 13.51 KN. Expulsion was observed at current values of 8.0 KA, 8.6 KA and 9.2 KA and further increases in current results in excessive expulsion and more electrode indentation in the work piece.In case of 0.5 mm thick specimen, failure load increases with increasing welding current (keeping electrode force and weld time constant). When current increases from 2.5 KA to 5.0 KA, failure load increases from 1.39 KN to 3.5 KN. Expulsion was observed at current values of 4.5 KA, 5.0 KA and 5.5 KA and further increase in current results in excessive expulsion and more electrode indentation in the work piece. Keeping weld time (t) and electrode force constant, increase in weld current (I) results in large increase in total amount of heat generated (Q) as $Q = I^2Rt$. This large amount of heat generated at interface results in more fusion of metal at the interface. Hence the strength of joint increases. But as weld current increases, a stage is reached where excessive interfacial heating occurs at a rate much greater than the rate of heat dissipation, resulting in higher hydraulic pressure of the molten pool in comparison to the pressure zone provided by the electrode clamping action. This unbalanced pressure causes a sudden spillage with some of the molten pool spreading into the regions beyond the area between the electrodes. This is commonly referred as “expulsion”. Because of the expulsion, the current is no longer restricted to the hot region. This sudden change in the conduction mode is typified by a sudden drop in the resistance and it terminates further nugget growth and weaken the nugget due to loss of metal.

3.2 Effect of weld time on failure load

The effect of weld time on failure load has been shown in Figure 3. It has been observed that in case of 2mm thick specimen, as weld time increases from 6 cycles to 14 cycles, failure load increases from 7.83 KN to 13.66 KN. At weld time 14 cycles, metal expulsion was observed and further increase in weld time results in excessive expulsion and more electrode indentation in the workpiece. In case of 0.5 mm thick specimen, failure load increases with increasing weld time (keeping weld current and electrode force constant). By increasing weld time from 4 cycles to 12 cycles, failure load increases from 1.16 KN to 2.29 KN. At weld time 14 cycles, metal expulsion was observed and further increase in weld time results in excessive expulsion and more electrode indentation in the workpiece. Keeping weld current (I) and electrode force constant, increase in weld time (t) results in increase in total amount of heat generated (Q) as $Q = I^2Rt$. This large amount of heat generated at interface results in more fusion of metal at the interface. Hence strength of joint increases. But as weld time increases, a stage is reached where excessive interfacial heating occurs at a rate much greater than the rate of heat dissipation, resulting in expulsion of metal as in case of weld current. This expulsion causes a reduced strength of the joint. The higher weld time should not be used, because it causes unnecessary heat dissipation and an increased over all welding time.

3.3 Effect of electrode force on failure load

The effect of electrode forces on failure load has been shown in Figure 4. It has been observed that when electrode force increases from 7.2 KN to 8.4 KN, failure load increases from 8.83KN to 12.26KN. Further increase in electrode force results in slightly reduced strength of the joint e.g. Failure load is 10.83KN at the electrode force 9.6 KN. Further reduction in shear strength is observed at higher electrode force. Maximum shear strength of nugget is observed at the electrode force 8.4 KN. It is also observed that expulsion of metal occurred at low electrode force 7.2KN & 7.6 KN. In case of 0.5 mm thick specimen, when electrode force increases from 300 N to 500 KN, failure load increases from 0.97 KN to 1.54 KN. Further increase in electrode force results in slightly reduced strength of the joint e.g. Failure load is 1.363 KN at the electrode force 600 N. Keeping welding current and weld time constant, lower force causes higher interfacial resistance and hence in turn higher heat generation at the interface. But the pressure zone provided by the electrode is lower. This unbalanced pressure causes metal expulsion. An increase in electrode force results in higher forging action and lower interface resistance.[6] Initially increase in electrode force results in increase in failure load as well as shear strength. Because in this case, forging action is dominant over the resistance. A higher electrode force lowers this resistance substantially and thus reduces the effective heat, results in decrease in failure load. Therefore the balance between forging action and interface resistance is quite important.

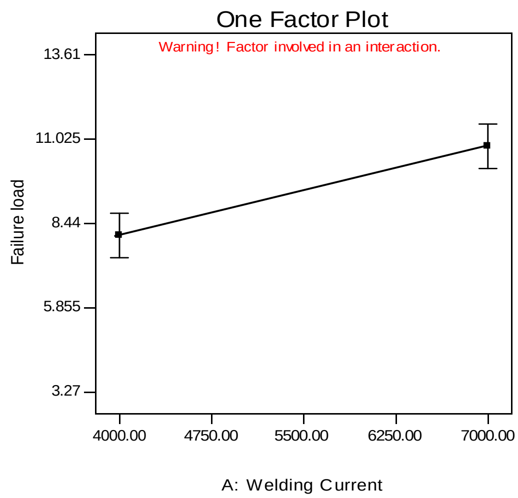

Fig. 2 Effect of welding current on failure load

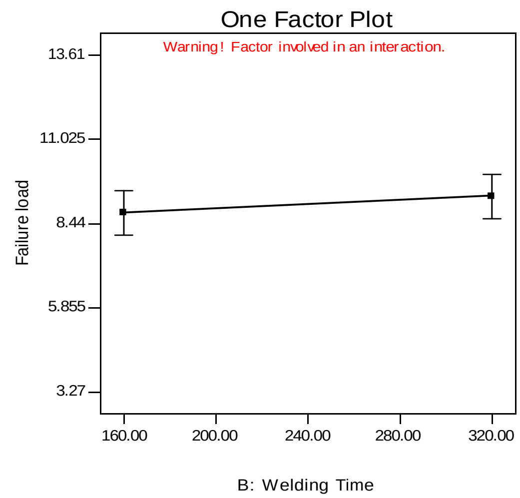

Fig. 3 Effect of welding time on failure load

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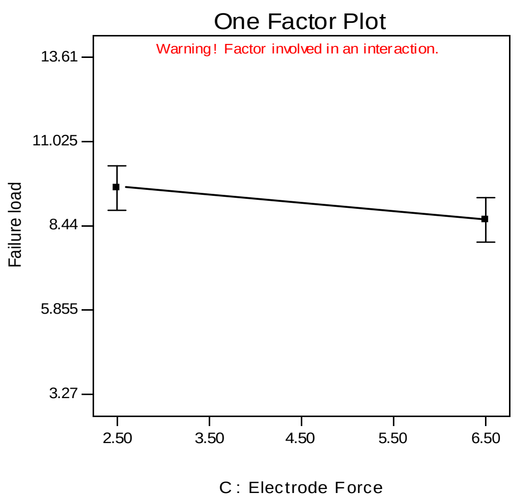

Fig. 4 Effect of electrode force on failure load

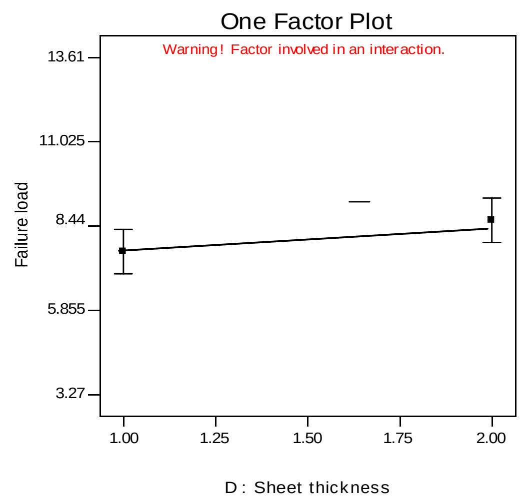

Fig. 5 Effect of sheet thickness on failure load

4. CONCLUSIONS

1. Response surface methodology can be employed for predicting relationship between welding parameters and strength within the design limit of parameters for the spot welding process which is a non linear process.
2. The weld current, electrode force and sheet thickness are found to affect the failure load significantly.
3. An increase in weld current results in increase in failure load of weld.
4. Failure load of weld increases with increase in weld time.
5. As electrode force increases, failure load of the weld increases.
6. Failure load increases with increase in sheet thickness.

5. REFERENCES

1. D.K. Aidun and R.W. Bennett, Effect of resistance welding on the strength of spot welded 6061-T6 aluminium alloy. Welding Journal, 64(12): 15-25, 1985.
2. H. Zhang and J. Senkara, Resistance welding – Fundamentals and applications. Taylor and Francis group, CRC Press, 2006.
3. B. Bouyousfi, T. Sahraoui, S. Guessasma and K.T. Chaouch, Effect of process parameters on the physical characteristics of spot welded joints. Materials and Design, 28: 414-419, 2007.
4. Welding Handbook, Resistance and solid state welding and other joining processes. American Welding Society, USA, 7th Ed., vol.3, 1980.
5. Welding Handbook, Metals and their weldability. American Welding Society, USA, Leaver Hume Press Ltd, 7th Ed., vol.4, 1984.
6. H. Tang, W. Hou and S.J. Hu, Force characteristics of resistance spot welding of steels. *Welding Research Supplement (Supplement to Welding Journal)*, 175s-183s, 2000.
7. P.L. Chuloshnikov. Resistance welding – A practical guide for thewelder. MIR Publishers, Moscow, 1978.
8. Recommended practices for resistance spot welding. American Welding Society, USA. 1990.
9. Welding Handbook. Welding science and technology, American Welding Society, USA, 9th Ed., 1: 158-179, 240-259.