Optimization of Resistance Spot Welding Process Parameters for Tensile Strength of Dissimilar Welded Joint

Jeevan A. Karande[1], Dr. K. H. Inamdar[2]

[1]P.G. Student, Department of Mechanical Engineering, Walchand College of Engineering, Sangli, Maharashtra, India

[2]Professor, Department of Mechanical Engineering, Walchand College of Engineering, Sangli, Maharashtra, India

Abstract: ***In vehicle and aviation enterprises resistance welding process is most ordinarily utilized for joining sheet metal. Around 6000-8000 spot welds are required in any automobile, which demonstrates the extent significance of the protection spot welding. It is a muddled procedure, as it includes cooperation of the mechanical, heat, electrical and metallurgical discipline. This paper presents an experimental investigation for the Tensile Shear (T-S) strength of resistance spot weld by using Taguchi method. An experimental study is conducted under various levels of process parameters. Spot welds are carried out on Stainless Steel (304L) and Aluminium 6061-T6 material. Dissimilar joining of aluminium and steel, particularly utilizing resistance spot welding is a critical Process. Welding current, Electrode force, Squeeze Time and Weld time are process parameters with four levels of each. Taguchi quality design concept of L16 orthogonal array has been used to determine S/N Ratio, Analysis of Variance (ANOVA). The level of significance of welding parameters for T-S strength is located out by ANOVA in Minitab 17 software.***

Keywords: Resistance Spot Welding (RSW), Stainless Steel (304L), Aluminium 6061, Taguchi method, ANOVA.

1. Introduction

Resistance welding is one of the most established of the welding forms being used by industry today. Resistance welding is a welding process in which work pieces are welded due to a combination of a pressure applied to them and a localized heat generated by a high electric current flowing through the contact area of the weld. There are different parameters such as welding current, electrode pressure etc. which directly and indirectly controls the quality of the weld. In order to gets better quality welds, proper combination of values required to be chosen while welding.

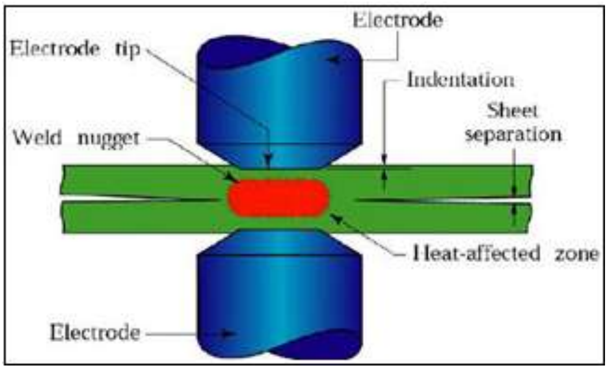

Figure 1: Resistance spot welding principle

1.1 Resistance Welding Process

Resistance spot welding is a process in which coalescences produced at two faying surfaces by heat generated at the joint to form lap joint. Spot welding produces single spot like welds, which are called nuggets. By applying pressure on the electrode materials to be joined are brought together. High electric current passes through the electrode and workpieces hold between the electrodes. Electrodes are located on both sides of the workpiece in which one is movable and other is fixed. The heat is generated by resistance to flow of current though the workpiece. Due to contact resistance and Joule heating localized heat generated a molten weld nugget is formed in the workpieces. Current, time and resistance between the workpiece control the amount of heat produced. It is desirable to have the maximum temperature at the interface of the parts to be joined. Therefore, the resistance of the workpieces and the contact resistance between the electrodes and work should be kept as low as possible with respect to the resistance between the faying surfaces. [3] The principle of operation is as shown in Fig. 1.

As the name indicates, it uses the resistance of the materials to the flow of current that causes localized heating between the parts to be joined. Excessive heat in the electrodes reduces the electrode cap life and deteriorates the weld quality. Hence, the electrodes are cooled via water circulation through channels opened inside them. The resistance obtained during resistance spot welding operation is as shown in Fig. 2. R_{ew}, R_w, R_c, R_e are the resistance at the Electrode tip and plate surface, Resistance of joining plates, Resistance at the interface of two plates and resistance of electrodes respectively.

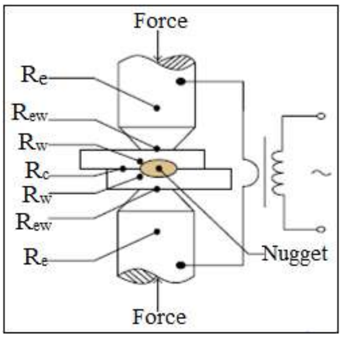

Figure 2: Resistance Distributions in Spot Welding [2]

The advantages of spot welding include cost efficiency, good dimensional accuracy and reliable production. Without large deformation, it can be used for joining of several metallic materials and sheets of different thicknesses together.

1.2 Heat Generation

Heating phenomenon plays important role in heat generation in resistance welding. The heat generated depends upon the current, the time the current is passed and the resistance at the interface. The resistance is a function of the resistivity and surface condition of the parent material, the size, shape, and material of the electrodes and the pressure applied by the electrodes.

$$Q = I^2 Rt \quad (1)$$

Where, I is the current passing through the metal combination, R is the resistance of the base metals and the contact interfaces, and t is the duration/time of the current flow.

The amount of resistance at the interface of the workpiece depends on the heat transfer capabilities of the material, the material's electrical resistance, and the combined thickness of the materials at the weld joint.

1.3 Resistance spot welding parameters

The spot welding process parameters have their own importance. These parameters will determine the quality of the welds. The appropriate combination of the spot welding parameter will produce strong joining and good quality of welding. Spot welding parameters include welding current, welding time, electrode force, electrode diameter and geometry. Various parameters which directly and indirectly control the weld quality are shown in Fig. 3

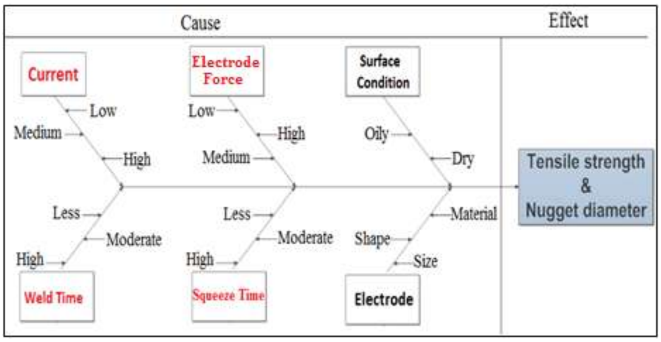

Figure 3: Cause and Effect diagram

2. Literature Review

A literature survey has been done for analyzing the process parameters and their effect on the response variables of the resistance welding.

Rawal and Inamdar [1] examined different optimization techniques and the utilization of the Taguchi method to decide the ideal procedure parameters. This is on the grounds that the Taguchi method is an orderly use of plan and investigation of examinations to design and enhancing item quality at the design stage. Welding parameters settings were dictated by utilizing the Taguchi test plan technique. The level of significance of the welding parameters on the tensile shear strength is determined by using analysis of variance (ANOVA).

Yuan et al. [4] Studied welding current, welding time, and electrode force effect on the DP 600 of 1.6 mm thickness and DC540 of 1 mm thickness. When welding current, welding time and electrode force increased, the tensile-shear strength of the welded spot experienced two levels of a remarkable increase and after further increase in parameter leads to decrease.

Kang et al. [5] studied the spot welding of dissimilar aluminum alloy of 2mm thick AA575 wrought sheet and 3mm thick Aural2 die casting sheet. They investigated load-controlled fatigue behavior of dissimilar aluminum alloy spot welds made with and without the addition of adhesive. Main fatigue crack initiates at the edge of the nugget diameter and it penetrates in the Aural2 die casting sheet in the thickness direction. With the use of adhesive nugget diameter of aluminum spot weld is increased, while Tensile-Shear strength is same for with and without use of adhesive.

Li et.al [6] studied tensile shear properties of the weld joints of aluminium alloy 6061-T6 and commercial pure titanium. While joining titanium sheet remains solid so to change reaction between liquid aluminium and solid titanium to a reaction between liquid aluminium and liquid titanium there is a critical range of welding current. Tensile shear strength of Al-Ti weld joint is mostly influenced by welding current, while welding time has a small effect and there is no any considerable effect of electrode force.

Esme [12] conducted experiments under varying electrode forces, welding currents, electrode diameters, and welding times. The material used was SAE 1010 and welding parameters were set and determined by using the Taguchi experimental design method. It proved that current and electrode force are the most dominant process parameters in case of tensile strength of spot weld whereas electrode diameter and welding time were less effective factors. For controlling the tensile shear strength the results showed that welding current was about two times more important than the electrode force.

3. Experimental Details

The specimens were cut from a sheet metal of 2ft × 1ft. The Specimens were cut parallel to the rolling action of the sheets. The dimensions are 120 mm length (L) and 25 mm width (W), the overlap being equal to the width of the specimen. This overlap was chosen as per American Welding Society (AWS) recommendation as shown in fig. 4 [7]. The material used in the present work is stainless steel 304L and Aluminium 6061 of 1.5 mm thickness each.

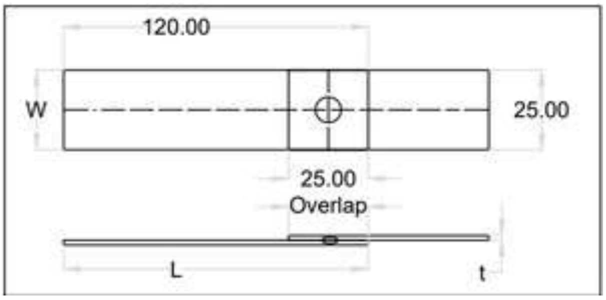

Figure 4: Standard Specimen Dimensions

3.1 Chemical Composition of materials:

The chemical composition for each element of the above material is listed below in table 1:

Table 1: Chemical composition of SS and Al

Weight %	*SS 304L*
Cr	18.57
Ni	8.28
Mn	1.36
C	0.26
Si	0.22
S	0.013
P	0.035
Fe	71.26

Weight %	*Al 6061-T6*
Mg	0.90
Si	0.53
Cu	0.26
Fe	0.228
Cr	0.087
Mn	0.014
Al	97.72

3.2 Selection of Process Parameters and Levels

In the present study of resistance spot welding, four main parameters namely Welding Current, Squeeze Time, Weld Time and Electrode Force are selected with four levels of each as shown in table 2. The output parameter predicting strength of weld joint is tensile shear strength.

Table 2: Process Parameters and Levels

Process Parameters	*Parameter*	*Levels*			
		I	*II*	*III*	*IV*
Weld Current (KA)	A	7	7.5	8	8.5
Squeeze Time (Cycles)	B	42	46	50	54
Weld time (Cycles)	C	33	36	39	42
Pressure (psi)	D	75	80	85	90

3.3 Selection of Orthogonal Array (OA):

The selected parameters and their levels are used for factorial design of experiments. Minitab 17 statistical software package is employed to see the Design of experiments. Taguchi's design of experiments is taken into account in the statistical software to choose the factorial design. The statistical tool derives L_{16} fractional orthogonal array as well as L_{256} full factorial design from the process parameters and their levels as fed in the statistical tool. Therefor L_{16} Orthogonal Array selected and experiments are carried out.

3.4 S/N ratio

Depending upon the character of quality characteristics the quality loss function can be of these types:
a) Smaller the better
b) Larger the better
c) Nominal the best

When response variable or parameter is needed to be kept at higher side to boost quality larger the better characteristics is employed, once it's needed to be kept at lower side to boost quality smaller the better characteristics is employed and once it's needed to keep in between maximum and minimum amount then nominal the better characteristics is employed. Maximum Tensile Shear Strength is desirable so Larger the better quality characteristics used for T-S Strength.

For larger the better characteristics,

$$\frac{S}{N} = -10\log\frac{1}{N}\sum_{i=1}^{n}\frac{1}{Yi^2} \quad (2)$$

Where n is number of tests and *Yi* the experimental value of i'th experiment.

The η corresponding to the overall loss function for each experiment of L16 were calculated using above formulae (2) and given in Table 3.

Table 3: Experimental data for T-S Strength

Exp. No.	*A KA)*	*B (Cycles)*	*C (Cycles)*	*D (psi)*	*T-S (kN)*	*S/N ratio for T-S*
1	7	42	33	75	2.721	8.6946
2	7	46	36	80	3.344	10.4853
3	7	50	39	85	3.785	11.5613
4	7	54	42	90	2.142	6.6164
5	7.5	42	36	85	3.413	10.6627
6	7.5	46	33	90	3.213	10.1382
7	7.5	50	42	75	2.348	7.4140
8	7.5	54	39	80	3.353	10.5087
9	8	42	39	90	4.236	12.5391
10	8	46	42	85	4.085	12.2238
11	8	50	33	80	3.792	11.5774
12	8	54	36	75	4.142	12.3442
13	8.5	42	42	80	2.674	8.5432
14	8.5	46	39	75	3.458	10.7765
15	8.5	50	36	90	2.832	9.0419
16	8.5	54	33	85	3.183	10.0567

The mean S/N ratio for each level of the welding parameters is summarized and called the S/N response table for tensile shear strength are as shown in table 4 respectively.

Table 4: Response of S/N Ratios for T-S Strength (kN)

Level	*Welding Current (kA)*	*Squeeze Time (Cycles)*	*Weld Time (Cycles)*	*Pressure (psi)*
1	9.339	10.11	10.117	9.807
2	9.681	10.906	10.634	10.279
3	12.171	9.899	11.346	11.126
4	9.605	9.881	8.699	9.584
Delta	2.832	1.024	2.647	1.542
Rank	1	4	2	3

The tabulated values shown in table 4 can be well understood by main effect plot for S/N ratio as shown in Fig. 4. This shows which parameter level is significant for each parameter For higher T-S strength of spot welded specimen. Main effects plot for means also shown in fig 5.

It is observed that, there is a significant shift of response variable from first level to third level with the steepest line for welding current and therefore, current has the maximum influence on tensile-shear strength as compared to that of other process parameters. Weld time curve have more slope compare to remaining two process parameters. The line for squeeze time and pressure is least deviated from the mean value, which denotes its least influence on the strength. Although slope of lines for each process parameter is different, all the process parameters have the significant impact on tensile-shear strength.

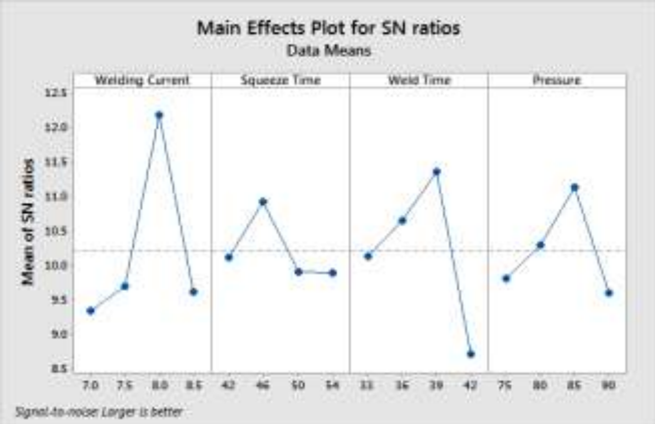

Figure 4: Main Effects Plot for means for T-S

Main effects plot for S/N ratios shown in fig. 4 gives the best settings for each factor to maximize strength of spot weld. S/N ratio values determined by using larger the better quality characteristic are plotted against the levels of process parameters to identify the optimum level of each process parameter. Mean value line for means is also shown in the fig. 5 to show the variability of response values from the mean value. The maximum values of S/N ratio are observed at 8 kA welding current, 46 cycles of squeeze time, 39 cycles of weld time and 85 psi pressure. Therefore, these are the optimum levels of process parameters to obtain maximize weld strength.

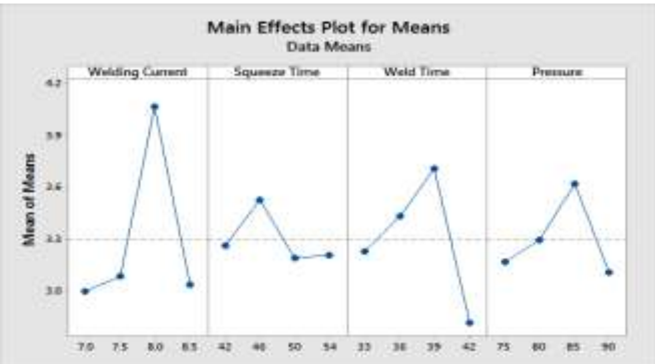

Figure 5: Main Effects Plot for S/N ratios for T-S

3.5 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. Larger *F*-value indicates that the variation of the process parameter makes a big change on the performance. Table 5 shows analysis of T-S strength. According to this analysis, the most effective parameters with respect to tensile shear strength is welding current, welding time, electrode force and squeeze time. Percent contribution indicates the relative power of a factor to reduce variation. For a factor with a high percent contribution, a small variation will have a great influence on the performance.

Table 5: Results of ANOVA for T-S Strength

Source	*DF*	*Adj SS*	*Adj MS*	*F*	*P*	*%C*
A	3	3.16	1.055	21.72	0.015	53.33
B	3	0.29	0.097	2.01	0.29	4.94
C	3	1.70	0.569	11.72	0.037	28.78
D	3	0.62	0.207	4.27	0.132	10.48
Error	3	0.14	0.048			2.45
Total	15	5.93				100

4. Conclusions

The following conclusions are drawn from the above investigation.

1) The response of S/N ratio for tensile shear strength indicates that, Welding current is the most significant parameter that controls the weld strength. Whereas weld time, electrode force and squeeze time are less significant.
2) The optimum results are obtained by Taguchi method for tensile shear strength at welding current of 8 kA, weld time of 39 cycles, Electrode pressure of 85psi and squeeze time of 46 cycle.
3) Welding current has the maximum contribution with 53.33% towards the T-S strength followed by weld time having contribution 28.78% whereas pressure (10.48%) and squeeze time (4.94%) has the least contribution on strength.

References

[1] M. R. Rawal and K. H. Inamdar, “Review on Various Optimization Techniques used for Process Parameters of Resistance Spot Welding”, international Journal of Current Engineering and Technology, pp. 160-164, 2014.

[2] T. Arunchai, K. Sonthipermpoon, P. Apichayakul and K. Tamee, “Resistance Spot Welding Optimization Based on Artificial Neural Network, International Journal of Manufacturing Engineering, Volume 2014, Article ID 154784, pp.1- 6 2014.

[3] M. Raut and V. Achwal, “optimization of spot welding process Parameters for maximum tensile Strength” International Journal of Mechanical Engg. & Robotics Research, vol.3, pp. 506 – 517, Oct. 2014.

[4] X. Yuana, C. Lia, J. Chena, X. Lia, X. Lianga and X. Pan, “Resistance spot welding of dissimilar DP600 and DC54D steels”, Journal of Materials Processing Technology, vol. 239, pp. 31-41, 2017.

[5] J. Kang, Y. Chen, D. Sigler, B. Carlson and D. S. Wilkinson, “Fatigue Behavior of Dissimilar Aluminum Alloy Spot Welds”, 1st International Conference on Structural Integrity, vol. 114, pp. 149-156, 2015.

[6] Y. Li, Y. Zhang and Z. Luo, “Microstructure and mechanical properties of Al/Ti joints welded by

resistance spot welding", Science and Technology of Welding and Joining, vol. 20, No-5, pp. 385-394, 2015.
[7] D. S. Sahota, R. Singh, R. Sharma and H. Singh, "Study of effect of parameters on resistance spot weld of SS316 material", Mechanical Confab, vol. 2, No. 2, pp. 67-78, March 2013,.
[8] D. Kianersi, A. Mostafaei and A. A. Amadeh. "Resistance spot welding joints of AISI 316L austenitic stainless steel sheets: Phase transformations, mechanical properties and microstructure characterizations", Materials and Design vol.61, pp. 251–263, 2014.
[9] N. Ma and H. Murakawa, "Numerical and experimental study on nugget formation in resistance spot welding for three pieces of high strength steel sheets", Journal of Materials Processing Technology vol.210 pp. 2045–2052, 2010.
[10] S. J. Sung, J. Chen and J. Pan, "Stress Intensity Factor Solutions for Similar and Dissimilar Spot Welds in Lap-Shear Specimens under Clamped Loading Conditions", Journal of Engineering Fracture Mechanics, vol. 179, pp 328-347, 15 June 2017.
[11] Y. Kim, B. Jo, J. Kim, and I. Kim, "A Study on Dissimilar Welding of Aluminum Alloy and Advanced High Strength Steel by Spot Welding Process", International Journal Of Precision Engineering And Manufacturing, Vol. 18, No. 1, pp. 121-126, January 2017.
[12] U. Esme, "Application of Taguchi method for the optimization of resistance spot welding Process", The Arabian Journal for Science and Engineering, Volume 34, Number 2B, pp. 519-528, October 2009.
[13] A. G. Thakur, T. E. Rao, M. S. Mukhedkar and V. M. Nandedkar, "Application of Taguchi method for resistance spot welding of galvanized steel", ARPN Journal of Engineering and Applied Sciences, vol. 5, No. 11, pp. 22-26, November 2010.
[14] K. Vignesh, A. E. Perumal and P. Velmurugan, "Optimization of resistance spot welding process parameters and microstructural examination for dissimilar welding of AISI 316L austenitic stainless steel and 2205 duplex stainless steel", International Journal Advance Manufacturing Technology, vol.93, issue1-4, pp.455-465, Oct. 2017.
[15] N. Muhammad, Y. Manurung, M. Hafidzi, S. Abas, G. Tham and E. Haruman, "Optimization and modeling of spot welding parameters with simultaneous multiple response consideration using multi-objective Taguchi method and RSM", Journal of Mechanical Science and Technology, vol. 26, No. 8, pp.2365-2370, March 2012.
[16] D. Min, Z. Yong & L. Jie, "Dissimilar spot welding joints of AZ31-443 ferritic stainless steel with cover plate", International Journal of Advance Manufacturing Technology, vol. 85, issue 5-8, pp. 1539-1545, July 2016.
[17] A. K. Pandey, M. I. Khan, K. M. moeed, "Optimization of Resistance Spot Welding parameters using Taguchi method" International Journal of Engineering Science and Technology, vol. 5, pp. 234-241, Feb. 2013.
[18] M. Alizadeh-Sh and S.P.H. Marashi, "Resistance spot welding of dissimilar austenitic duplex stainless steels: Microstructural evolution and failure mode analysis", Journal of Manufacturing Processes, vol. 28, pp. 186-196, 2017.
[19] K. Zhou and L. Cai, "Study on effect of electrode force on resistance spot welding process", Journal of applied physics, vol. 116, pp. 1-7, (2014).

Author Profile

Jeevan A. Karande is M.Tech student in Mechanical-Production Engineer in Walchand College of Engineering, Sangli. He Completed his graduation in mechanical engineering in 2015 from Shivaji University, Kolhapur

Dr. K. H. Inamdar is Professor in Department of Mechanical Engineering, WCE, Sangli. He has published more than 80 Technical papers in various National /International conference as well as journals. His area of interest is Quality control and he acquired patent related to it