International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 4, October 2014

Research Paper

OPTIMIZATION OF SPOT WELDING PROCESS PARAMETERS FOR MAXIMUM TENSILE STRENGTH

Manoj Raut[1]* and Vishal Achwal[1]

*Corresponding Author: Manoj Raut, ✉ rautmanoj007@gmail.com

This experimental study is based on an investigation of the effect and optimization of welding parameters on the tensile shear strength in the Resistance Spot Welding (RSW) process. The experimental studies were conducted under varying electrode forces, welding currents, and welding times. The settings of welding parameters were determined by using the Taguchi experimental design of L18 Orthogonal array method. The combination of the optimum welding parameters have determined by using the analysis of Signal-to-Noise (S/N) ratio. The confirmation test performed clearly shows that it is possible to increase the tensile shear strength of the joint by the combination of the suitable welding parameters. Hence, the experimental results confirmed the validity of the used Taguchi method for enhancing the welding performance and optimizing the welding parameters in resistance spot welding operations.

Keywords: Resistance Spot Welding (RSW), Tensile shear strength, Taguchi method, S/N ratio, Optimization

INTRODUCTION

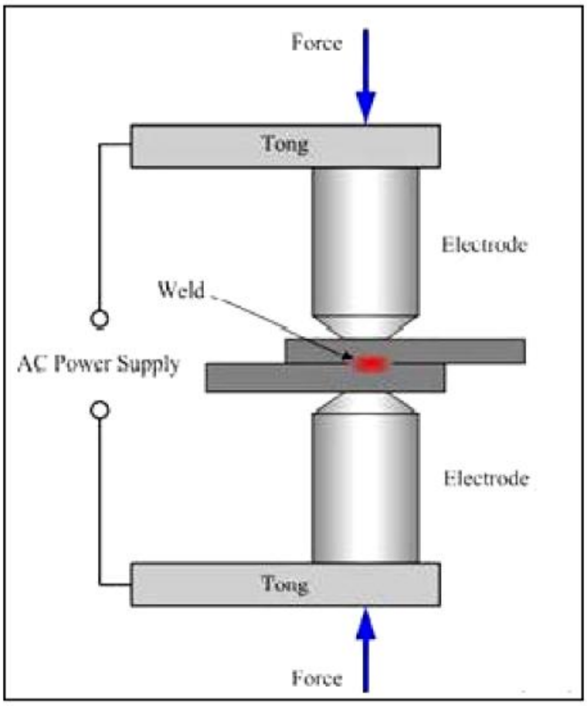
Resistance spot welding is getting significant importance in car, bus and railway bodies etc due to automatic and fast process. The major factors controlling this process are current, time, electrode force, contact resistance, property of electrode material, sheet materials, surface condition etc. the quality is best judged by nugget size and joint strength. This study presents a systematic approach to determine effect of process parameters (electrode force, weld time and current) on tensile shear strength of resistance weld joint of mild steel using Taguchi method.

A general introduction for principle, working and parameters of spot welding is given below.

Resistance Spot Welding (RSW) is among the oldest of the electric welding method that used in the industry and it is useful and accepted method in joining metal.

[1] Truba College of Engineering and Technology, Indore, Madhya Pradesh, India.

Figure 1: Resistance Spot Welding



Spot welding is widely used in welding carbon steel because they have higher electrical resistance and lower thermal conductivity than the electrode that made from copper. The Spot welding is commonly being used in automobile industry, where it is used to weld the sheet metal forming a car.

Spot welders can also be completely automated, and many of the industrial robots found on assembly lines are spot welders. Spot welding also being used in the repair industries.

Principle of Operation for Resistance Spot Welding

Resistance Spot Welding (RSW) is included in the group of resistance welding processes that heat is used in joining the work parts of metal. Heat is generated from electrical resistance across the two work parts In Resistance Spot Welding two work part of metal are joined together by applying electric current and pressure in the zone to be weld and resistance welding is different From arc welding because it's not required filler metal or fluxes added to the weld area during the welding process.

Spot welding operates based on four factors that are:

1. Amount of current that passes through the work piece.
2. Pressure that the electrodes applied on the work piece.
3. The time the current flow through the work piece.
4. The area of the electrode tip contact with the work piece.

During the welding process the amount of electric current is flow from the electrodes to the work pieces. The weld force is applied by leg pedal.

Squeezing the electrode to the work pieces, the right amount of pressure that applied on the work pieces is very important in order to obtain the good quality of welds. During the welding process, the electric current is flow

Figure 2: Resistance Welding Machine Circuits

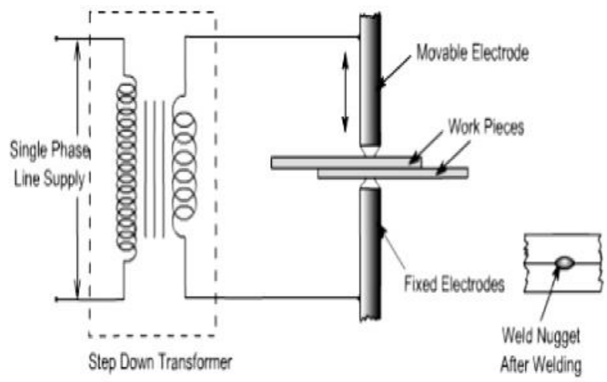
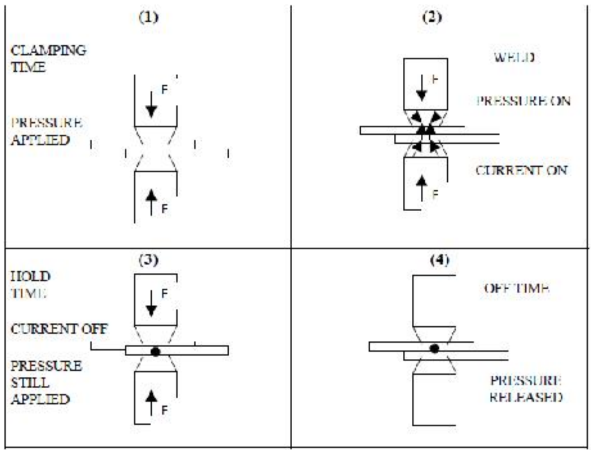


Figure 3: Time Sequence of the Resistance Spot Welding Cycle: (1) Clamping Time, (2) Weld Time, (3) Hold Time, (4) Off Time



through electrode tips to the separate work pieces of metal to be joined.

The resistance of the base metal to electrical current flow causes heat, the heat is limited to the area which the tip of the electrode and weld area contacts. While the welding force is maintained, the heat is generating. In the holding stage (where the pressure is still maintained), the current is switched off and the nugget is cooled under the pressure. The heat that generated in spot welding is basically depend on the electric current and the time being used and on the electrical resistance of material between electrodes.

The amount of heat generated is a function of current, time and resistance between the electrode the heat that generates in resistance spot welding according to Joule's law is expressed by the Equation.

$$H = I^2Rt$$

where

H = Heat is generated in joules

I = Current (in amperes)

R = Resistance (in ohms)

t = Time to current flow (in seconds)

Resistance Spot Welding Parameters

The spot welding process parameters have their own importance. A small change of one parameter will affect all the other parameters. 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.

1. Electrode force
2. Diameter of the electrode contact surface
3. Squeeze time
4. Weld time
5. Hold time
6. Weld current

Electrode Force

The purpose of the electrode force is to squeeze the parts to be weld and the primary purpose is to hold the parts to ensure the parts in intimate contact at the joining interface. When the electrode force is increased the heat energy will decrease, a high pressure that exerted on the weld joint will decrease the resistance at the point of contact between the electrode tips and the parts surface. This means that the higher electrode force requires a higher weld current. Weld spatter can be happen because the pressure on the tips is too light or when weld current becomes too high. Too heavy pressure will cause small spot weld. In other words when the pressure increases, the electrical current and subsequent heat are transfer to a wider area, the penetration and area of the weld will reduce.

Diameter of the Electrode Contact Surface

One general criterion of resistance spot-welding is that the weld shall have a nugget diameter of $5 \times t^{1/2}$, "t" being the thickness of the steel sheet. Thus, a spot weld made in two sheets, each 1 mm in thickness, would generate a nugget 5 mm in diameter according to the $5 \times t^{½}$-rules. Diameter of the electrode contact surface should be slightly larger than the nugget diameter.

Squeeze Time

Squeeze Time is the time interval between the initial application of the electrode force on the work and the first application of current. Squeeze time is necessary to delay the weld current until the electrode force has attained the desired level.

Weld Time

Weld time is the time during which welding current is applied to the metal sheets. The weld time is measured and adjusted in cycles of line voltage as are all timing functions. One cycle is 1/50 of a second in a 50 Hz power system. As the weld time is, more or less, related to what is required for the weld spot, it is difficult to give an exact value of the optimum weld time.

Hold time (Cooling-Time)

Hold time is the time, after the welding, when the electrodes are still applied to the sheet to chill the weld. Considered from a welding technical point of view, the hold time is the most interesting welding parameter. Hold time is necessary to allow the weld nugget to solidify before releasing the welded parts, but it must not be to long as this may cause the heat in the weld spot to spread to the electrode and heat it. The electrode will then get more exposed to wear. Further, if the hold time is too long and the carbon content of the material is high (more than 0.1%), there is a risk the weld will become brittle. When welding galvanized carbon steel a longer hold time is recommended.

Weld Current

The amount of weld current is controlled by two things:

- The setting of the transformer tap switch determines the maximum amount of weld current available.
- The percent of current control determines the percent of the available current to be used for making the weld.

Normally low percent current settings are not recommended because it may harm the quality of the weld. The weld current should be kept as low as possible. When determining the current to be used, the current is steadily increased until weld spatter occurs between the metal sheets. This indicates that the correct weld current has been reached. The temperature rises rapidly at the joined portion of the metal where the resistance is greatest if the current becomes too great internal spatter will result.

LITERATURE REVIEW

Resistance Spot Welding (RSW) is getting significant importance in manufacturing car, bus and railway bodies, etc., due to automatic and fast process. As the automobile joints are subjected to higher loading condition hence to avoid the failure higher strength of spot welded joint is required (Thakur and Nandedkar, 2010). When the spot welded joint is subjected to pure opening condition then it fails in the direction of load applied and when it subjected to combined opening and shear loading conditions it fails inclined from the surface of weld nugget (Lin *et al.*, 2003). Therefore the spot welded joint should be strong in both in pure opening condition and in combined opening and shear loading conditions. Though the process parameters of the spot welding also affect the mechanical behavior of welded joint in the loading conditions so the parameters should also be suitable for the higher strength of joint (Chetan Patel, Dhaval Patel, 2012).

Types of Failure of the Welding Joint

There are two fracture modes of the spot welding joint have analyzed, they are

- Interfacial mode (or nugget fracture): fracture of the weld nugget through the plane of the weld. The dominant failure mode for small diameter spot welds.
- Nugget pullout mode (or sheet fracture): fracture of the sheet around the weld; the nugget remains intact. Dominant for large diameter spot welds.

Spot welds for automotive applications should have a sufficiently large diameter, so that nugget pullout mode is the dominant failure mode. Interfacial mode is unacceptable due to its low load carrying and energy absorption capability (Stijn Donders *et al.*, 2005).

Effect of Process Parameters on Strength

The spot welding process parameters play an important role for the strength of the welding joint. If one of the parameter changes, it may affect the strength of the joint so the combination of suitable parameters are very important to get a high strength welding joint. The process parameters affect as an increase in weld current, weld time and electrode force results in an increase in weld nugget diameter and width. An increase in weld current, weld time and electrode force results in an increase in electrode indentation. So the parameters used should provide the high strength (Sahota *et al.*, 2013).

In the optimization of welding parameters the level of importance of the welding parameters on the tensile shear strength is determined, the highly effective parameters

Method for the Optimization of Process Parameters

Optimization of process parameters is the key step in the Taguchi method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors (Ugur Esme, 2009).

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for

Table 1: Dimensions of Specimen

Thickness (t) in mm	Width (w) in mm	Length (L) in mm	Contact Overlap in mm
0.8	25	150	25
1	25	150	25

experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool (Thakur *et al.*, 2010). L27 Orthogonal Array can be used to optimize the process parameters; a loss function is then defined to calculate the deviation between the experimental value and the desired value. The value of the overall loss function is further transformed into a Signal-to-Noise (S/N) ratio. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio (Mohd Zaim Bin Din, 2008).

MATERIAL SELECTION

Mild steel sheets of thickness 0.8 mm and 1 mm are used for the experiment. Mild steel comprises of largest percentage of material welded with the resistance spot welding process. The carbon present in the material may affect the properties of material after the welding; the joint may become hard and brittle.

As the thickness of material increases the welding current have to increase to produce the joint of sufficient strength.

Size and Dimensions of Specimen

The size of the specimens used for the experiment is 150 mm in length and 25 mm in width and the contact overlap is 25 mm as shown if below figure.

Figure 4: Configuration and Dimensions of Specimen (All Dimensions are in mm)

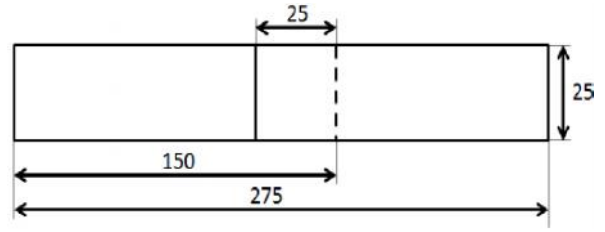


Figure 5: RSW Specimens

METHODOLOGY

Taguchi parametric design methodology was adopted. The experiments were conducted using L18 Orthogonal Array (OA) with three parameters (electrode force, weld current, weld time) with three levels (level 1, level 2 and level 3).

The process parameters, their symbols and their values at different levels are shown in the table.

Optimization of process parameters is the key step in the Taguchi method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors.

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification

Table 2: Process Parameters and Their Values at Different Levels

Thickness (mm)	Symbol	Process Parameter	Unit	Level 1	Level 2	Level 3
0.8 mm	A	Electrode Force	N	280.5	269.2	315
	B	Welding Current	KA	6.9	8.4	10.3
	C	Weld time	Cycle	5	10	15
1 mm	A	Electrode Force	N	315	334.5	345.3
	B	Welding Current	KA	8.4	10.3	11.8
	C	Weld time	Cycle	5	10	15

limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straight and forward and easy to apply to many engineering situations, making it a powerful yet simple tool.

The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value. Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables.

A large number of experiments have to be carried out when the number of the process parameters increases.

To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way.

So all the specimens are welded using the design of experiment shown in the Table 3.

Table 3: Experimental Layout Using L18 Orthogonal Array

Experiment	Electrode Force (N)	Welding Current (KA)	Weld Time (Cycle)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	1
5	2	2	2
6	2	3	3
7	3	1	2
8	3	2	3
9	3	3	1
10	1	1	3
11	1	2	1
12	1	3	2
13	2	1	2
14	2	2	3
15	2	3	1
16	3	1	3
17	3	2	1
18	3	3	2

RESULTS AND DISCUSSION

The initial process parameters $A_2B_1C_2$ has selected and their tensile shear strength for 0.8 mm and 1 mm specimens are found 2.3 KN and 2.8 KN respectively.

Table 4: Experimental Results for the Tensile Shear Strength

Experiment No.	Tensile Shear Strength (KN)	
	0.8 mm	**1 mm**
1	1.5	1.8
2	2.4	2.7
3	2.7	3.1
4	1.9	2.3
5	3.4	3.8
6	2.8	3.3
7	1.8	1.9
8	2.3	2.5
9	1.9	2.3
10	1.2	1.4
11	2.4	2.8
12	1.9	2.3
13	1.5	1.7
14	2.8	3.1
15	2.1	2.5
16	1.4	1.6
17	1.8	2.2
18	1.5	1.6

As we have seen before that all the specimens are welded using the taguchi method and now tensile shear testing of all the specimens has performed using a Universal testing machine. The tensile shear results of all the specimens are shown in the Table 4.

A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a Signal-to-Noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, i.e., the lower-the-better, the larger-the-better, and the more-nominal-the-better. The S/N ratio for each level of Process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. The loss function of the larger the better quality characteristics can be expressed as:

$$L_j = \left(\frac{1}{n} \sum_{k=1}^{n} \frac{1}{y_i^2} \right)$$

$$\eta_j = -10 \log L_j$$

where,

L_j = Overall loss function

n = Number of tests

y_i = Experimental value of the ith quanlity characteristic

η_j = S/N Ratio

By using the above equations η_j corresponding to overall loss function for each experiment was calculated and given in Table 5.

S/N Ratio Analysis

In order to quantify influence of each level of parameters, mean of S/N ratio for A were computed by averaging S/N ratio for experiment Number 1, 2, 3, 10, 11, 12 for level 1, 4, 5, 6, 13, 14, 15 for level 2 and 7, 8, 9, 16, 17, 18 for level 3. Mean of S/N ratio for each level of other welding parameters were calculated in a similar way. Parameters with large difference indicate high influence to weld ability 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.

Table 5: Overall Loss Function and its S/N Ratio

Experiment Number	S/N Ratio (dB)	
	0.8 mm	1 mm
1	3.52	5.11
2	7.60	8.62
3	8.62	9.83
4	5.57	7.23
5	10.62	11.5
6	8.94	10.37
7	5.10	5.57
8	7.23	7.95
9	5.57	7.23
10	1.58	2.92
11	7.60	8.94
12	5.57	7.23
13	3.52	4.61
14	8.94	9.83
15	6.44	7.95
16	2.92	4.08
17	5.10	6.84
18	3.52	4.08

Based on S/N ratio, new operation parameters were obtained through maximum level of each parameter.

Variation in S/N Ratio with Process Parameters

The graphs drawn below shows the variation in S/N ratio with the process parameters. The graphs shows the effect of the parameters.

Graphs for 0.8 mm Sheet

Figure 6: Electrode Force (A) vs S/N Ratio

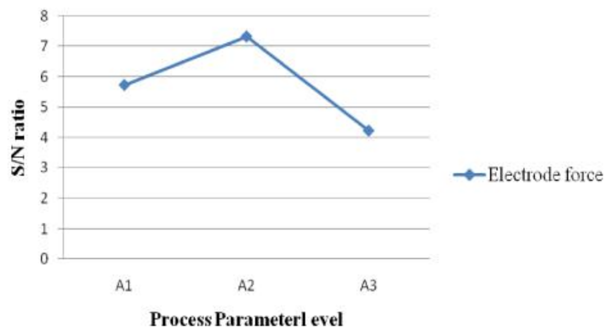


Figure 7: Welding Current (B) vs S/N Ratio

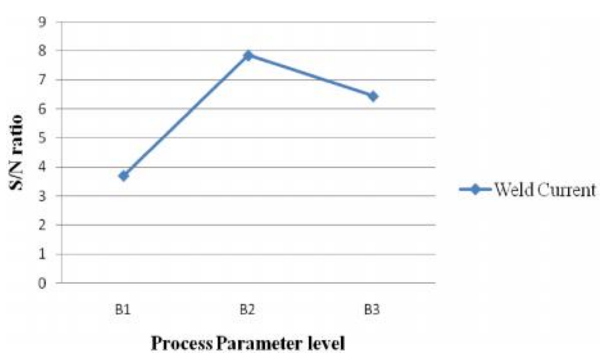
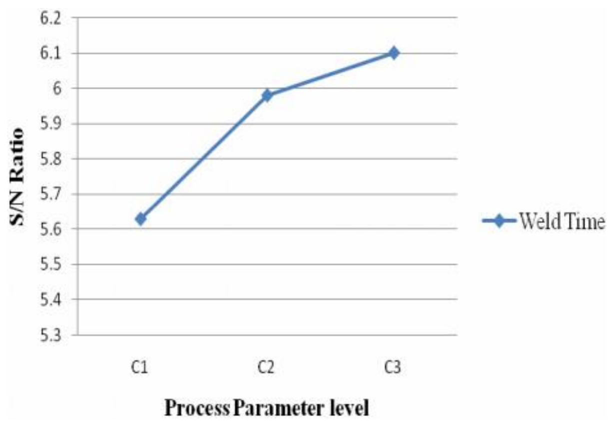


Table 6: S/N Responses for the Tensile Shear Strength

Thickness	Symbol	Process Parameter	S/N Ratio (dB)			Total Mean	Maximum-Minimum
			Level 1	Level 2	Level 3		
0.8 mm	A	Electrode Force	5.74	7.33*	4.24	5.89	3.09
	B	Welding Current	3.70	7.85*	6.44		4.15
	C	Time	5.63	5.98	6.10*		0.47
1 mm	A	Electrode Force	7.10	8.58*	5.96	7.21	1.48
	B	Welding Current	4.91	8.94*	7.78		1.16
	C	Time	7.22	6.94	7.49*		0.27

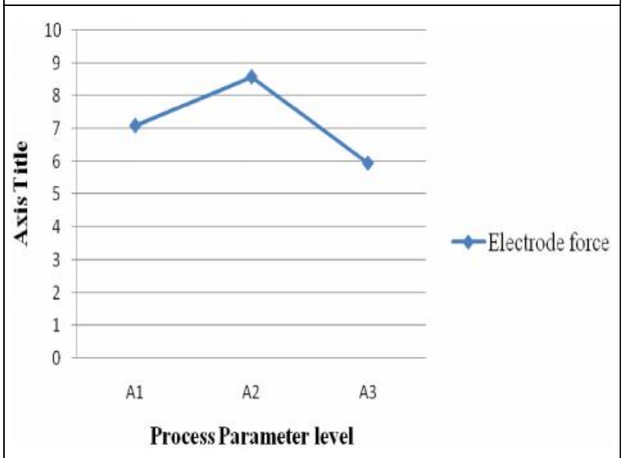
Note: The * marked in the above table shows the optimum level of S/N Ratio.

Figure 8: Weld Time (C) vs S/N Ratio



Graphs for 1 mm Sheet

Figure 9: Electrode Force (A) vs S/N Ratio



The response of the S/N ratio for the tensile shear strength is shown in Table 6. After the S/N ratio analysis it is found that the optimal

Figure 10: Welding Current (B) vs S/N Ratio

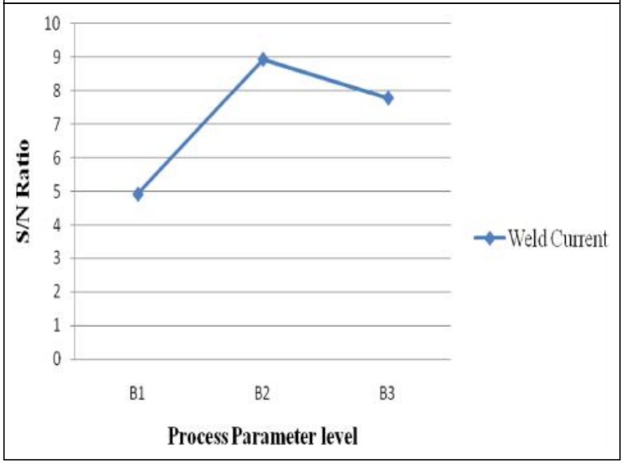
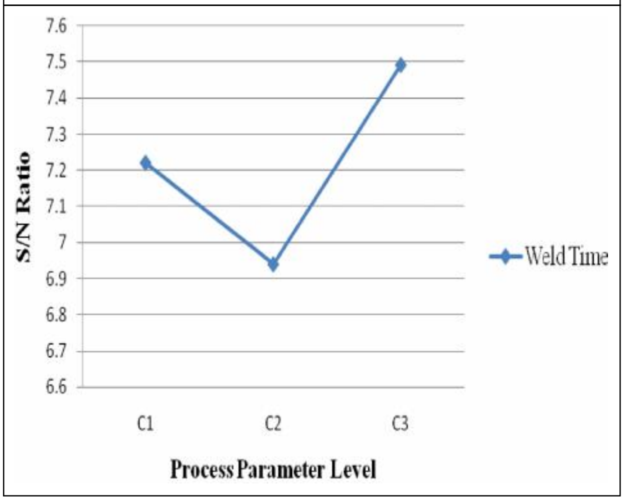


Figure 11: Weld Current (C) vs S/N Ratio



parameters for the experiment are $A_2B_2C_3$ for both the sheets of 0.8 mm and 1 mm.

Table 7: Results of the Confirmation Experiment

Thickness		Initial Process Parameter	Optimal Process Parameter		Improvement in S/N Ratio
			Prediction	Experiment	
0.8 mm	Level	$A_2B_1C_2$	$A_2B_2C_3$	$A_2B_2C_3$	1.87
	Tensile shear strength (KN)	2.3	2.91	2.85	
	S/N (dB)	7.23	9.3	9.1	
1 mm	Level	$A_2B_1C_2$	$A_2B_2C_3$	$A_2B_2C_3$	1.74
	Tensile shear strength (KN)	2.8	3.38	3.42	
	S/N (dB)	8.94	10.59	10.68	

Then the prediction of S/N ratio and tensile shear strength is calculated by using the following relationship

$$\eta^* = \eta_m + \sum_{i=1}^{n} (a - m)$$

where,

η^* = Predicted S/N ratio

η_m = Total mean of S/N ratio

a = Mean of S/N ratio at the optimal level

n = The number of main welding parameters,

That significantly affects the performance

The results of experimental confirmation are shown in the Table 7. Using optimal welding parameters and comparison of the predicted tensile shear strength with the actual tensile shear strength using the optimal welding parameters are shown in Table. The improvement in S/N ratio from the starting welding parameters to the level of optimal welding parameters is 1.87 dB and 1.74 dB for 0.8 mm and 1 mm sheets respectively. The tensile shear strength is increased by 0.63 and 0.82 times for 0.8 mm and 1 mm sheets respectively. Therefore, the tensile shear strength is greatly improved by using the Taguchi method.

From the experiment it is found that the parameters of the spot welding are very important factors for the tensile shear strength of the welding joint. In this experiment it is found that the welding current is the main parameter, which may affect more to the strength of a welding joint.

The change in process parameters from the initial parameters results an increase in the strength of the welding joint.

CONCLUSION

This experiment was based on the optimization of spot welding process parameters to find out the maximum tensile shear strength of the spot welded joint. The mild steel sheets of 0.8 mm and 1 mm of dimensions 25 mm × 150 mm have used as the work piece. The Taguchi Method of L18 orthogonal array has used to perform the experiment. All the specimens are spot welded using the taguchi design of experiment. Then the tensile shear strength of work pieces is found out using a tensile testing machine. An optimum parameter combination for the maximum tensile shear strength was obtained by using the analysis of Signal-to-Noise (S/N) ratio. The confirmation tests indicated that it is possible to increase tensile shear strength significantly by using the suitable parameters. The experimental results confirmed the validity of the used Taguchi method for enhancing the welding performance and optimizing the welding parameters in resistance spot welding operations.

The experimental results show that the welding parameters are the important factors for the strength of the welded joint. which may increase or decrease the strength of the welding joint so we can say that the combination of the suitable parameters is necessary for the maximum strength of the spot welded joint.

REFERENCES

1. Chetan R Patel and Dhaval A Patel (2012), "Effect of Process Parameters on the Strength of Aluminium Alloy A5052 Sheets Joint Welded by Resistance Spot Welding with Cover Plates", August.

2. Khanna O P (2008), *A Text Book of Welding Technology*, pp. 184-198, Dhanpat Rai Publication.

3. Khanna O P and Lal M (2011), *A Text Book of Production Technology*, Dhanpat Rai Publication, pp. 2.28, 11.78-11.82.

4. Lin S-H, Pan J, Tyan T and Prasad P (2003), "A General Failure Criterion for Spot Welds Under Combined Loading Conditions", June.

5. Lin S H, Pan J, Wu S R, Tyan T and Wung P (2001), "Failure Loads of Spot Welds Under Combined Opening and Shear Static Loading Conditions", *International Journal of Solids and Structures*, July, pp. 19-39.

6. Mohd Zaim Bin Din (2008), "Experimental Study on Strength of Spot Welded Joint", November.

7. Nachimani Charde (2012), "Characterization of Spot Weld Growth on Dissimilar Joints with Different Thicknesses", June.

8. Sahota D S, Ramandeep Singh, Rajesh Sharma and Harpreet Singh (2013), "Study of Effect of Parameters on Resistance Spot Weld of ASS316 Material", March.

9. Stijn Donders, Marc Brughmans, Luc Hermans and Nick Tzannetakis (2005), "The Effect of Spot Weld Failure on Dynamic Vehicle Performance".

10. Thakur A G and Nandedkar V M (2010), "Application of Taguchi Method to Determine Resistance Spot Welding Condition of Austenitic Stainless Steel AISI 304", September.

11. Thakur A G, Rao T E, Mukhedkar M S and Nandedkar V M (2010), "Application of Taguchi Method for Resistance Spot Welding of Galvanized Steel", November, *ARPN Journal of Engineering and Applied Sciences*.

12. Ugur Esme (2009), "Application of Taguchi Method for the Optimization of Resistance Spot Welding Process", October.