Experimental Investigation of Resistance Spot Welding of IF Steel Sheets

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Abstract- *The welding input parameters of any welding have a major role on the quality, productivity and expenses of the assembly formed. In this experimental study, the spot-welding parameters were optimized and by conducting the T-S strength test of the IF steel weld the parameter was validated. Also, the effects of parameters on the weld were studied. The experimental study is conducted by using the Taguchi design method by considering three different levels of process parameters. The RSW input parameters chosen were welding current, welding time and pressure with 3 different levels of each one of them. An L9 orthogonal array was designed for Taguchi analysis. The S/N ratio was determined after conducting the T-S strength test of the weld material. The importance level of each welding parameter for tensile test is done by the Analysis of Variance (ANOVA) technique. Hence, it can be concluded that Taguchi method helps in increasing the welding quality by optimizing the weld parameters in the RSW process. Finally, it can be validated that we can increase the tensile shear strength or in broader terms, the quality of the weld by using the optimum RSW parameters.*

Index terms- *Resistance Spot Welding (RSW), Tensile Shear Strength, Taguchi Method, S/N Ratio.*

1. Introduction

Resistance Spot Welding (RSW) is regularly used as a successful joining method for a variety of jobs in the automotive and manufacturing fields [1] [9]. In this paper, a trial has been done to optimize resistance spot welding parameters of IF Steel sheets. The spot-welding process parameters have a direct impact on the weld strength and quality [3]. The quality of weld is determined by its strength, geometry and other properties. If the welding parameters are optimized then the weld quality will also improve [5].

The major motto of the research is to determine the optimum input parameters of welding such as welding current, pressure, welding time etc. and to study their effect on weld quality. In this study, we have performed different tests on the weld such as tensile shear strength test, microstructural analysis and finally finding out the defects created during the welding process. We have applied the Taguchi Design Method in order to reduce the number of experiments without losing the statistical accuracy.

2. Resistance Spot Welding Process

Resistance welding is of various types, but one of the main types is Resistance Spot Welding which is basically used for coalescence of two metal sheets by the help of pressure and heat obtained by electric current on the weld zone. By the help of copper alloy electrode, electric current and pressure is applied on the steel sheets. Both the copper alloy electrodes are placed opposite to each other separated by the metal sheets. The heat which is dissipated melts the metal and the pressure which is applied from the electrodes squeezes molten metal to form the "nugget". This nugget or the weld created during the process is in the form of a small dot and that is why it is called as Spot Welding [2]. Resistance spot welding is basically used for coalescence of two electrically conductive metal sheets like low carbon steel, aluminium, etc. It is usually used to manufacture automobile components. [1]. A vehicle generally has over 1000 spot welds over its body panels.

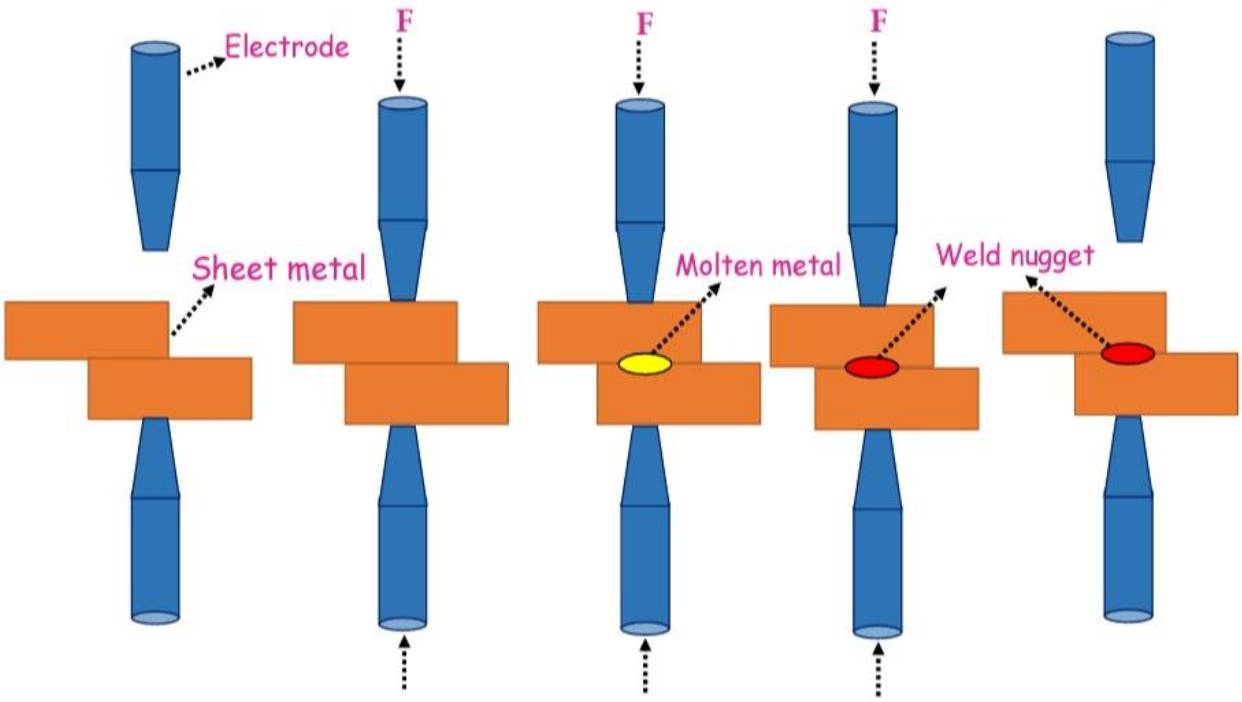

Figure - 1: Spot Welding Stages

3. Literature Review

Sushree Sefali Mishra [1] sheds light on the RSW of different dissimilar metal sheets and their analysis. It discusses the various factors that determine corrosion fatigue strength. The metal sheets analysed were Aluminium-Zinc coated low carbon steel and Stainless-Steel Galvanized steel. It was concluded that corrosion fatigue strength remains unaffected when different strength levels of the materials were applied. It was also found out that with the increase in sheet thickness the overall fatigue strength of the welded structure gets increased.

Shravan Singh Rao et al. [2] in their study mainly deal with the estimation of critical nugget diameter and variation in different process parameters of high strength interstitial free steel. The mechanical properties were determined through tensile testing on Universal Testing Machine. A thickness of 1.6 mm was considered. At the end of the experimental analysis, it was found out that as the contact resistance increases the nugget diameter is found to decrease. As more heat is generated, tensile shear strength also gets increased.

Sachin K Jadav et al. [3] , in their research mainly studied the impact of various RSW process parameters on the quality of the joint formed by welding. The study was performed by changing the values of weld time, weld current, holding time and squeeze time. T-S strength of the weld is the measure of the weld quality which was determined using the GRA Method. The optimum welding parameters of the spot-welding process was obtained by the help of grey relational analysis.

Manoj Raut et al. [4] estimate the maximum tensile strength of the spot weld after optimizing the welding parameters. The parameters required for the welding were found out using the Taguchi method. The various in process parameters were studied using the S/N ratio analysis. The results obtained validated and upheld the Taguchi method. The welding parameter directly affects the quality of the weld and its strength in particular. It may cause the strength of the weld to rise or fall based on the parameters chosen.

P P Choughule et al. [5], in their research carry out the resistance spot welding of two non-similar metals namely mild steel and stainless steel plates and study the effect of parameters like welding current, pressure, welding time on tensile strength and further analysed by analysis of variance, the dimension of specimens is 150*25*1 mm, different parameters is used to determine good result of nugget diameter and high tensile strength and other mechanical properties, it's observed that increase in welding current in spot welding of dissimilar metal increases nugget diameter.

Vijay Kamble [6] performs resistance spot welding on low carbon steel and experiment and tests the effect of various input parameters such as weld force, weld current, weld time and the diameter of the electrode on the T-S strength of specimens. To find setting of the process parameters Taguchi's experimental design method is used and by using S/N ratio, and ANOVA optimum parameter combination was determined. In the experiment 1 mm and 2 mm sheet is used with different parameters. If the welding current and welding time is increased to a higher level, then it will deteriorate the weld quality and the electrode will get overheated. This will also negatively affect the weld strength.

Shaik Safee et al. [7] , in their study, carry out many experiments with different parameters such as welding force, welding current and welding time to find out best outcome and their influence on the RSW process. Taguchi design method, S/N ratio and ANOVA are used for checking the effect of different parameters on spot welding. 2 types of specimens of thickness 0.8mm and 1 mm are used with different process parameter levels and S/N ratio, direct tensile strength is measured. For 0.8 mm, welding current and welding time are are the major parameters and for 1 mm specimen, welding current and welding force are the major parameters.

Pampa Ghosh et al. [8] selected two types of IFHS material for their study which are batch annealed IFHS and continuous annealed IFHS. Different compositions (C, N, P, S, Al, Mn, Ti and Nb) of both types of material are used to study the effect of composition on IFHS. Scanning electron microscopy (SEM) is used to investigate microscopy and transmission electron microscopy is used for studying precipitation behaviour. Both thin foil method and carbon extraction method is used. In this paper different precipitation relation with texture and formability and it also effect, strength, and removal of C from IF steel is observed.

Min Jou [9] observed that it is impossible to examine the weld nugget size by thermal model, a method to identify the nugget size is to measure the electrode displacement caused by the combined thermal expansion and solid-to-liquid volume change in the workpieces, in this paper it is discussed how factors like different part fit-up conditions, surface condition, base material can affect displacement curve and experiment done in this research paper discuss the phenomenon of how changes of % heat input affect the electrode displacement curve.

4. Experimental Procedure

4.1 Material and its properties

The material used in the experiment is Interstitial Free (IF) Steel. IF steel is a type of steel with no interstitial solute atoms to strain the solid iron lattice which results in a soft steel. IF steels have interstitial free Body Centred Cubic (BCC) ferrite matrix. Since alloying elements like Mn and Si are present in the IF Steel, it has very good mechanical properties [2]. Since the fraction of precipitate in IF steel is very low hence, it is also called as Clean Steel. Vacuum degassing is used to eliminate carbon monoxide and other such gases and hence IF steel has less percentage of carbon. There are very minimal changes in the mechanical properties of IF steel with the passage of time since the carbon atoms in the interstitial sites are replaced by Titanium which forms Titanium Carbide. IF steels have high formability and strain rate whereas its yield strength is very low [8]

Table 1- Chemical Composition of IF Steel Sheets (Weight %)

C	Si	Mn	P	S	N	Al	Nb	TI
0.002	0.01	0.15	0.01	0.01	0.0025	0.04	0.016	0.025

4.2 RSW Process Parameters

The welding input parameters in any welding are very important. If anyone parameter is changed then it will affect all the other parameters and the overall quality of the weld will also be affected. The optimized spot-welding parameter will result in high strength joints and improved weld quality. Welding input parameters which are considered during the experiments were:

Welding time: Welding time refers to the time interval during which the weld current is passed through the metal sheets to be welded. As the heat generation increases, welding time also increases. After passing the weld current the heat passes through the weld area and in the metal sheet and also the heat gets dissipated from the open surface to the nearby surroundings, which results in the formation of weld if proper weld time is given. If the weld time is stretched then expulsion can occur and even the electrode may get distorted. [4]

Welding Current: Welding current is defined as the electricity/current flowing through the electrode to the metal sheet being welded. With the rise in weld current, the dimensions of the weld nugget increase. But if the current is very large then expulsions may occur and can cause damage to the electrode. [4]

Electrode Force or Pressure per square inch: The electrode force helps in squeezing the metal sheets to be joined together. The force should be high enough otherwise the quality of the weld will get compromised. But the electrode force should not be very large because if force is very large then the area of contact will get increased and it may lead in low density of current and less contact resistance. This, in turn, will decrease the heat being generated and will reduce the diameter of weld nugget. [4]

The process parameters range was determined by the Design of Experiment (DOE) approach. Apparently, many welding tests were found, but after the trial tests, the feasible working range was determined. Different combinations of welding parameters were used in the test and the nugget was checked to decide whether the testing value is correct. The given table represents the selected welding process parameters range as rest parameters resulted in welding defects and incomplete penetration.

Table - 2: Process parameters with their values at three different levels in DOE

Levels	Welding time cycle (ms) (A)	Welding current ka) (B)	Pressure per sq. inch (C)
1	5.00	15	50.00
2	12.50	45	67.50
3	20.00	75	85.00

Figure - 2: IF Steel Sheets post Welding

4.3 Tensile Shear Strength Test

The Tensile shear strength test is a measure to determine the weld quality [7]. In this experimental study, the tests were conducted on the specimen whose length was 100 mm, width 25 mm and thickness 1.2 mm, as shown in the figure 2.

4.4 Taguchi Design Method

In order to get high quality without compromising the cost, the Taguchi Design Method optimizes the input parameters. It is so because the optimized input parameters obtained from the Taguchi analysis does not change with changes in surroundings or any other changes. In this study, Taguchi method was used wherein experiments were done by applying L9 Orthogonal Array with 3 parameters (pressure, welding time and welding current) with 3 distinguished levels. If there are more input parameters then number of experiments to be done also becomes more due to which the complexity also increases. So, to solve this problem, Taguchi Design method is used wherein a special orthogonal matrix is developed which decreases the number of experiments after optimizing the entire input parameters. This orthogonal array helps the designer to study the impact of multiple controllable factors and their variations in a rapid way and also decreases the cost. Hence, all the workpieces used in the experiment are welded by the help of design of experiment mentioned in the below table, in which we have considered 3 Welding Parameters and 3 different levels of every parameter. Hence, a nine Level Array (L9) for studying the levels of all the 3 parameters three times has been constructed. The L9 orthogonal array is more effective as compared to L6 array if time is available and cost is not an issue as in L9, there are 3 levels and all of them are tested by all the parameters. And this cost will be obviously less than the complete analysis, as the number needed for entire factorial analysis will be N=LP = 33 = 27 ; where N= number of experiments, L= number of Levels and P= number of Parameters. [4]

Table – 4*:* L9 Orthogonal Array

Experiment	Welding time (ms)	Welding current(ka)	Pressure per sq. inch
1	5	15	50
2	5	45	67.5
3	5	75	85
4	12.5	15	67.5
5	12.5	45	85
6	12.5	75	50
7	20	15	85
8	20	45	50
9	20	75	67.5

5. Results and Discussions

5.1 Tensile Shear Strength Test Results

The tensile shear strength test was performed using the Universal Testing Machine for the entire specimen mentioned in the L9 Orthogonal array and the results obtained are as follows:

Table – 5: T-S strength test results

Experiment	Welding time (ms)	Welding current (ka)	Pressure per sq. inch	T-s strength
1	5	15	50	10
2	5	45	67.5	6.95
3	5	75	85	10.67
4	12.5	15	67.5	11.05
5	12.5	45	85	9.73
6	12.5	75	50	10.80
7	20	15	85	10.25
8	20	45	50	10.45
9	20	75	67.5	10.40

Figure - 3: Universal Testing Machine

Figure – *4:* Weld after Tensile shear strength test

5.2 S/N Ratio Analysis

A loss function is defined to calculate the deviation between the experimental value and the desired value. This value is further transformed into a Signal to Noise(S/N) Ratio.

The loss function of the "larger the better" characteristic is given as:

$$\mu = -10*\log(1/N) * \sum_{i=1}^{n}\left(\frac{1}{y^2}\right)$$

The S/N ratio for each level of process parameters is computed by the help of "Minitab" software and is given below:

Table – 6: S/N ratio values

Experiment	Welding time(ms)	Welding current(ka)	Pressure/in²	T-s strength	S/n ratio
1	5	15	50	10	20.00
2	5	45	67.5	6.95	16.84
3	5	75	85	10.67	20.56
4	12.5	15	67.5	11.05	20.86
5	12.5	45	85	9.73	19.76
6	12.5	75	50	10.80	20.69
7	20	15	85	10.25	20.21
8	20	45	50	10.45	20.38
9	20	75	67.5	10.40	20.34

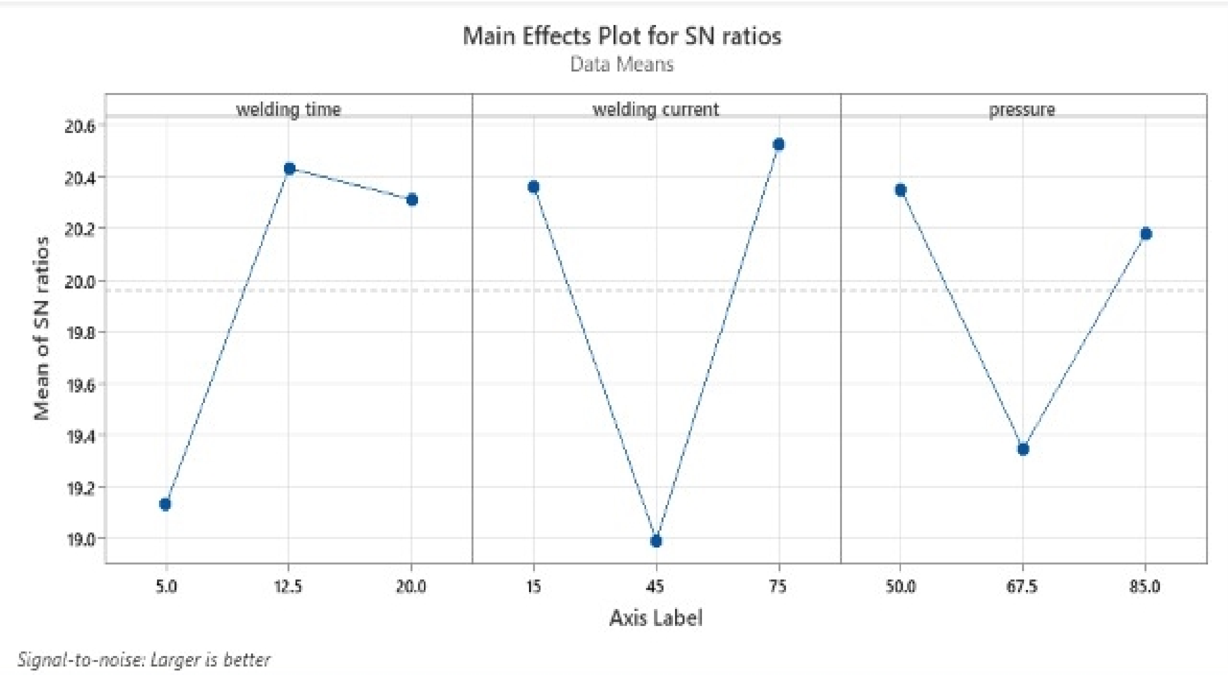

Figure – 5: Variation in S/N Ratio with the Process Parameters

The figure 5 shows the S/N ratio graph where the horizontal line is the value of the total mean of the S/N ratio. Basically, the larger the S/N ratio, the better is the quality characteristic for the tensile shear strength.

5.3 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. [6]

The tables 7.1 and 7.2 shows the results obtained from the ANOVA

Table - 7.1: Analysis of Variance for SN ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%C
Welding time	2	3.7939	1.2860	0.64299	1.13	0.553	27.97
Welding current	2	9.0392	6.6889	3.34446	5.90	0.280	66.64
Pressure	2	0.1624	0.1624	0.08120	0.14	0.14	1.19
Residual error	1	0.5673	0.5673	0.56727			
Total	7	13.5673					

According to ANOVA analysis as shown in the above table, the most effective parameters with respect to tensile shear strength is welding current (66.64%) followed by welding time (27.97%) and then finally pressure (1.19%).

Table 7.2: Response table for SN ratios

Level	Welding time	Welding current	Pressure
1	19.13	20.36	20.35
2	20.43	18.99	19.35
3	20.31	20.52	20.18
Delta	1.30	1.53	1.00
Rank	2	1	3

As per the S/N ratio analysis from the above table, the levels of parameters to be set for getting optimum value of T-S strength are A2B3C1.

6. Conclusion

This experiment was performed to optimize the spot welding process parameters to find out the maximum tensile shear strength of the spot welded joint of IF steel sheet. Based on the ANOVA method, the highly effective parameters on tensile shear strength were found as welding current and welding time, whereas pressure was least effective factor. For a factor with a higher percent contribution, a small variation will have a great influence on the performance. An optimum parameter combination (A2B3C1) for the maximum tensile shear strength was obtained by using the analysis of S/N ratio. The experimental results confirmed the validity of Taguchi method for enhancing the welding performance and optimizing the welding parameters in resistance spot welding operations.

References

1) Mishra, Sushree Sefali. "Research on Resistance Spot Welding of Dissimilar Metal Sheets: An Overview." *"Technological Advancement in Manufacturing & Processing of New Materials"(TAMPNM-2016) 9 th–10th April 2016*: 35. Technological Advancement in Manufacturing & Processing of New Materials. 319327732.

2) Rao, S. S., Chhibber, R., Arora, K. S., & Shome, M. (2017). Resistance spot welding of galvannealed high strength interstitial free steel. *Journal of Materials Processing Technology*, *246*, 252-261.

3) Sachin K Jadhav, Jaivesh Gandhi. "Experimental Investigation of Resistance Spot Welding: A Literature Review." " International Journal of Engineering Research and Technology" March,2014

4) Raut, Manoj, and Vishal Achwal. "Optimization of spot welding process parameters for maximum tensile strength." *International Journal of Mechanical Engineering and Robotics Research* 3, no. 4 (2014): 507-517.

5) Choughule PP, Biradar AK, Modi AK. Resistance Spot Weldability of Dissimilar Materials in 1 Mm Thick Sheet. J. Mech. Eng. Tech. 2016;4:15-21.

6) Ananda, Kamble Vijay. "Analysis of effect of process parameters on resistance spot welding shear strength"." *International Journal of Scientific Research* 2, no. 11 (2013): 224-227.

7) Shafee, Shaik, B. Balu Naik, and K. Sammaiah. "Resistance spot weld quality characteristics improvement by Taguchi method." *Materials Today: Proceedings* 2, no. 4-5 (2015): 2595-2604.

8) Ghosh, P., & Ghosh, C. (2009). Precipitation in interstitial free high strength steels. ISIJ international, 49(7), 1080-1086.

9) Jou, Min. "Experimental investigation of resistance spot welding for sheet metals used in automotive industry." JSME International Journal Series C Mechanical Systems, Machine Elements and Manufacturing 44.2 (2001): 544-552.