

Experimental Investigation and Parametric Optimization of Resistance Spot Welding For Enhanced Tensile-Shear Strength of Sheet Metal Joints

Kamlesh Kumar Jangid¹; Gajendra Das Kori²

¹PG Scholar; ²Asst. Professor

SAGE University, Indore (M.P.) India

Email: erkamlesh1983@gmail.com

Abstract

Resistance Spot Welding (RSW) is widely used for joining sheet metal components because of its high production rate, simple operation, and suitability for automated manufacturing. The tensile-shear strength and overall quality of RSW joints are strongly influenced by welding process parameters. A comprehensive literature review was conducted to examine the influence of different process parameters on the mechanical performance of resistance spot welded joints. Based on the findings of the literature review, the present research focuses on the experimental investigation and parametric optimization of resistance spot welding for enhancing the tensile-shear strength of sheet metal joints. Three important process parameters, namely electrode force, welding current, and welding time, were selected for the experimental investigation. The experiments were designed using the Taguchi Design of Experiments with an L18 orthogonal array to systematically study the influence of the selected parameters on tensile-shear strength. The Signal-to-Noise (S/N) ratio was used to determine the optimum combination of process parameters, while Analysis of Variance (ANOVA) was considered to evaluate the relative contribution and significance of the selected parameters. A confirmation experiment was subsequently conducted using the optimum parameter combination obtained from the Taguchi analysis. The experimental results demonstrated that appropriate selection of electrode force, welding current, and welding time can significantly improve the tensile-shear strength of the welded joints. The confirmation experiment further validated the reliability of the optimized parameter combination. The study confirms that the Taguchi method provides a systematic, efficient, and economical approach for optimizing resistance spot welding parameters and improving the mechanical performance and reliability of sheet metal joints.

Keywords: Resistance Spot Welding, Sheet Metal Joints, Tensile-Shear Strength, Electrode Force, Welding Current, Welding Time, Taguchi Method, L18 Orthogonal Array.

1. Introduction

Resistance Spot Welding (RSW) is one of the most widely used fusion joining processes for manufacturing sheet metal components. It is extensively applied in the automotive, electrical, appliance, aerospace, and general manufacturing industries because of its high production rate, low operating cost, ease of automation, and suitability for joining overlapping metal sheets. In

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this process, two or more sheets are placed between copper electrodes and subjected to mechanical pressure while an electric current is passed through the sheets. The electrical resistance at the contact region generates heat, which locally melts the material and forms a weld nugget. After the current is stopped, the molten region solidifies under electrode pressure and produces a permanent joint.

The quality and mechanical performance of a resistance spot welded joint depend significantly on the selection of appropriate welding parameters. The major process parameters include welding current, welding time, electrode force, electrode tip geometry, sheet thickness, material properties, and surface condition. Among these parameters, welding current, welding time, and electrode force have a direct influence on heat generation, weld nugget formation, nugget diameter, and joint strength. Therefore, proper control of these parameters is essential for producing strong, consistent, and defect-free welded joints. The heat generated during resistance spot welding is primarily governed by Joule's heating principle and can be represented by the relationship between welding current, electrical resistance, and welding time. An increase in welding current generally increases the heat generated at the welding interface and consequently increases the weld nugget size. However, excessive current may cause molten metal expulsion, excessive indentation, electrode damage, and deterioration of weld quality. On the other hand, insufficient welding current may result in inadequate nugget formation and poor bonding between the sheets. Hence, an optimum welding current is necessary to obtain satisfactory joint strength. Welding time is another important parameter that controls the amount of heat supplied to the welding zone. Increasing welding time generally increases heat input and can improve nugget growth up to an optimum level. Excessive welding time, however, may lead to excessive heat generation, material expulsion, increased heat-affected zone, and electrode wear. Therefore, an appropriate combination of welding current and welding time is required to achieve adequate nugget formation without producing undesirable defects.

Electrode force also plays an important role in determining the quality of a spot-welded joint. It controls the contact condition between the electrodes and workpieces and influences the electrical contact resistance at the faying interface. Low electrode force may result in excessive contact resistance, unstable heat generation, and expulsion of molten material. In contrast, excessively high electrode force may reduce contact resistance and restrict heat generation, resulting in insufficient nugget formation. Proper selection of electrode force is therefore necessary to maintain stable welding conditions and obtain consistent joint strength. Therefore, determining the process conditions that maximize tensile-shear strength is an important requirement in resistance spot welding applications. Conventional trial-and-error methods for selecting welding parameters require a large number of experiments and may not effectively identify the interaction between different process parameters. To overcome this limitation, Design of Experiments (DOE) and statistical optimization techniques can be used. The Taguchi method is an effective experimental design technique that uses orthogonal arrays to investigate multiple parameters with a reduced number of experiments. It also uses Signal-to-Noise (S/N) ratio analysis to identify robust parameter combinations that provide improved performance with

reduced variation. In the present research, the Taguchi method with an L18 orthogonal array is used to systematically investigate the effects of electrode force, welding current, and welding time on the tensile-shear strength of resistance spot welded sheet metal joints. The selected parameters are varied at different levels, and tensile-shear tests are performed to evaluate the mechanical strength of the welded joints. The experimental results are analyzed using S/N ratio analysis to determine the optimum parameter combination. Analysis of Variance (ANOVA) is also used to identify the relative significance and contribution of the selected process parameters. Finally, a confirmation experiment is conducted using the optimum welding parameters obtained from the Taguchi analysis. The experimental and optimized results are compared to verify the improvement in tensile-shear strength. The present study aims to provide a systematic and efficient approach for selecting optimum resistance spot welding parameters and achieving enhanced tensile-shear strength and reliable performance of sheet metal joints

2. Problem Identification

Resistance Spot Welding (RSW) is widely used for joining sheet metal components in automotive and manufacturing industries. However, achieving consistent and high tensile-shear strength of spot-welded joints remains a significant challenge. The quality and strength of the welded joint are strongly affected by process parameters such as electrode force, welding current, and welding time. Welding current directly influences the heat generated at the welding interface. Low welding current may result in insufficient heat generation and inadequate weld nugget formation, whereas excessive current can cause material expulsion, excessive indentation, and other welding defects. Similarly, improper welding time can lead to insufficient bonding or excessive heat input, thereby affecting the strength and quality of the joint. Electrode force also has a significant effect on the welding process. Low electrode force may produce unstable contact and excessive heating, while excessive electrode force can reduce contact resistance and restrict heat generation. The combined effect of electrode force, welding current, and welding time makes it difficult to determine the optimum welding condition through conventional trial-and-error methods. The tensile-shear strength of the welded joint is an important indicator of weld quality and depends on proper weld nugget formation, heat input, and material interaction. Although several studies have investigated individual welding parameters, a systematic evaluation of their combined effects on tensile-shear strength is required to obtain reliable and optimized welding conditions. Therefore, the present research focuses on the experimental investigation and parametric optimization of electrode force, welding current, and welding time using the Taguchi L18 orthogonal array. The study aims to identify the optimum combination of process parameters for enhancing the tensile-shear strength and improving the overall quality and reliability of resistance spot welded sheet metal joints.

3. Research Objectives

Based on the problem identification, literature review, and proposed experimental investigation, the objectives of the present research are:

1. To experimentally investigate the effect of resistance spot welding parameters on the tensile-shear strength of sheet metal joints.

2. To study the effects of welding current, electrode force, and welding time as the major process parameters.
3. To prepare resistance spot welded specimens under different combinations of selected welding parameters and evaluate their tensile-shear strength.
4. To design the experiments using the Taguchi L18 orthogonal array for systematic investigation of the selected process parameters.
5. To analyze the experimental results using Signal-to-Noise (S/N) ratio analysis and determine the optimum level of each welding parameter.
6. To evaluate the relative influence and contribution of welding current, electrode force, and welding time on tensile-shear strength.
7. To determine the optimum combination of welding parameters for achieving maximum tensile-shear strength.
8. To conduct confirmation experiments using the optimum parameter combination obtained from the Taguchi analysis.
9. To compare the initial and optimized experimental results and evaluate the improvement in tensile-shear strength.
10. To validate the effectiveness of the Taguchi method for optimizing resistance spot welding parameters and improving the mechanical performance of sheet metal joints.

4. Research Methodology

The present research methodology involves a systematic experimental investigation and parametric optimization of Resistance Spot Welding (RSW) parameters to improve the tensile-shear strength of sheet metal joints. The study focuses on three major welding parameters, namely welding current, electrode force, and welding time. The experimental work is planned using the Taguchi Design of Experiments to identify the optimum combination of welding parameters. The research begins with the selection of suitable sheet metal material and preparation of the required specimens according to the standard dimensions for tensile-shear testing. The surfaces of the sheets are properly cleaned to remove oil, dirt, rust, and other contaminants that may affect electrical contact and weld quality. The specimens are then arranged in the required lap configuration for resistance spot welding. The resistance spot welding machine is used to join the prepared sheet specimens. The selected process parameters, namely welding current, electrode force, and welding time, are varied at different levels. An L18 orthogonal array is employed to design the experimental trials, thereby reducing the number of experiments while allowing systematic investigation of the selected parameters and their effects on tensile-shear strength. For each experimental trial, the required welding parameters are set on the RSW machine and the specimens are welded under controlled conditions. The welded specimens are then subjected to tensile-shear testing using a suitable Universal Testing Machine (UTM). The maximum load required to separate the welded joint is recorded and used to evaluate the tensile-shear strength of each specimen. The experimental results are analyzed using Signal-to-Noise (S/N) ratio analysis based on the “larger-the-better” quality characteristic because the objective is to maximize tensile-shear strength. The response values are compared at different parameter levels to determine the optimum level of welding current, electrode force,

and welding time. Analysis of Variance (ANOVA) is subsequently performed to determine the statistical significance and relative contribution of the selected welding parameters. The analysis helps identify which process parameter has the greatest influence on tensile-shear strength and provides a statistical basis for selecting the optimum welding condition. After determining the optimum parameter combination, confirmation experiments are conducted using the optimized welding conditions. The tensile-shear strength obtained from the confirmation experiment is compared with the initial experimental results and the predicted optimum response. The percentage improvement in tensile-shear strength is then determined to evaluate the effectiveness of the optimization process.

The specifications of the resistance spot welding machine used in the present investigation are given below:

Primary voltage: 440 V, 3-phase, 3-wire, 50 Hz AC supply

Maximum welding current: 12 kA

- Electrode force: 80 to 420 kgf
- Cooling system: Water cooling
- Electrode material: Industrial copper
- Electrode tip shape: Circular
- Electrode tip diameter: 4 mm
- Electrode gap: 30 mm
- Electrode type: Straight
- Welding time range: 5 to 495 cycles
- Step-down transformer rating: 20 kW
- Force application mechanism: Foot pedal

Figure 4.1 presents the details of different specifications.



Figure 4.1: Specimens
Table 4.1: Dimensions of specimen (all in mm)

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Thickness (t)	Width (w)	Length (L)	Contact overlap
0.8	25	150	25
1	25	150	25

5. RSW Parameters and their Levels

The Taguchi parametric design methodology is adopted to investigate the effect of resistance spot welding parameters on the tensile shear strength of the welded joints. Three major process parameters, namely electrode force, welding current and welding time, are selected for the experimental investigation. Each process parameter is investigated at three different levels, namely Level 1, Level 2, and Level 3. These parameters are selected because they have a significant influence on heat generation, weld nugget formation, joint quality, and ultimately the tensile strength of the resistance spot welded joint. The selected resistance spot welding parameters, their symbols, units, and corresponding levels are presented in Table 5.1.

Table 5.1: 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

The initial process parameters selected for 0.8 mm and 1 mm sheets are shown in the table 5.3 with their corresponding tensile strength.

Table 5.2: Initial Process Parameters

Thickness (mm)	Initial Process Parameters	Tensile Strength
0.8 mm	A ₂ B ₁ C ₂	2.3 KN
1 mm	A ₂ B ₁ C ₂	2.8 KN

6. Result and Discussion

The figure 6.1 to 6.3 drawn below for 0.8 mm sheet between the process parameters with their corresponding level and S/N ratio clearly show the variation of the S/N ratio with the variation in the spot welding parameter levels.

Variation in S/N ratio with process parameters For 0.8 mm sheet

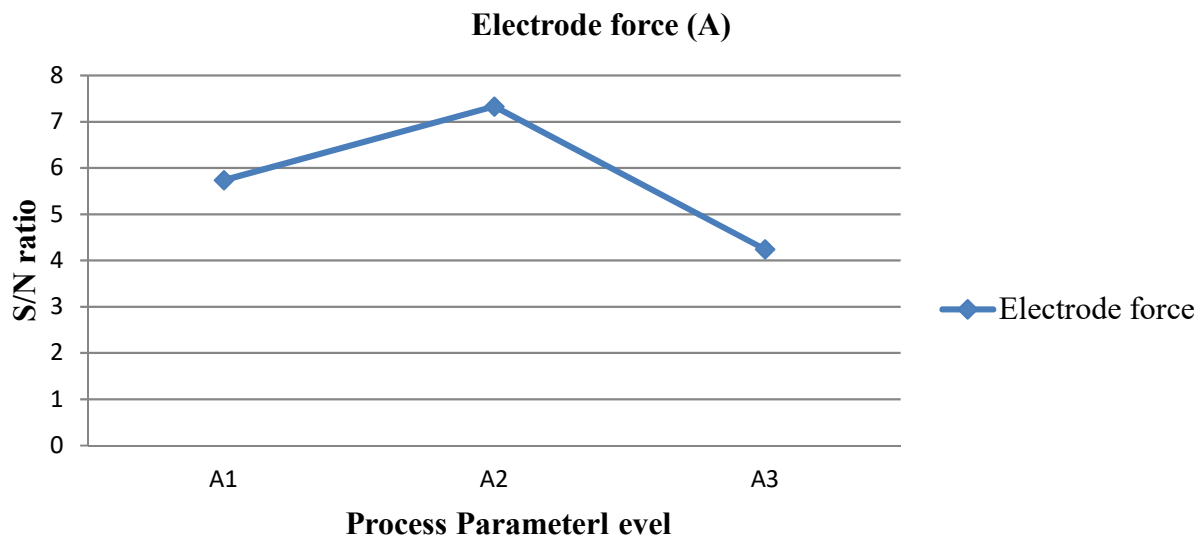


Figure 6.1: Electrode force (A) Vs S/N ratio

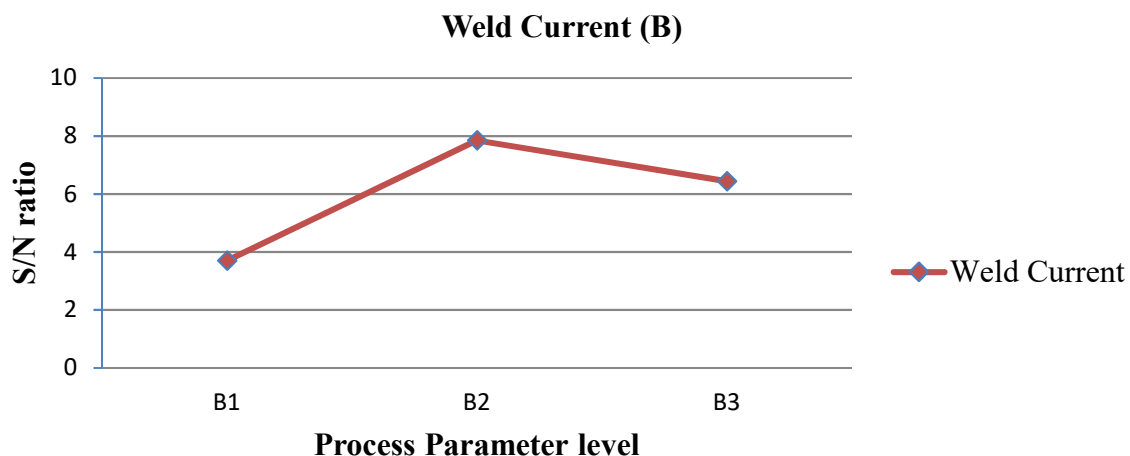


Figure 6.2: Welding current (B) Vs S/N Ratio

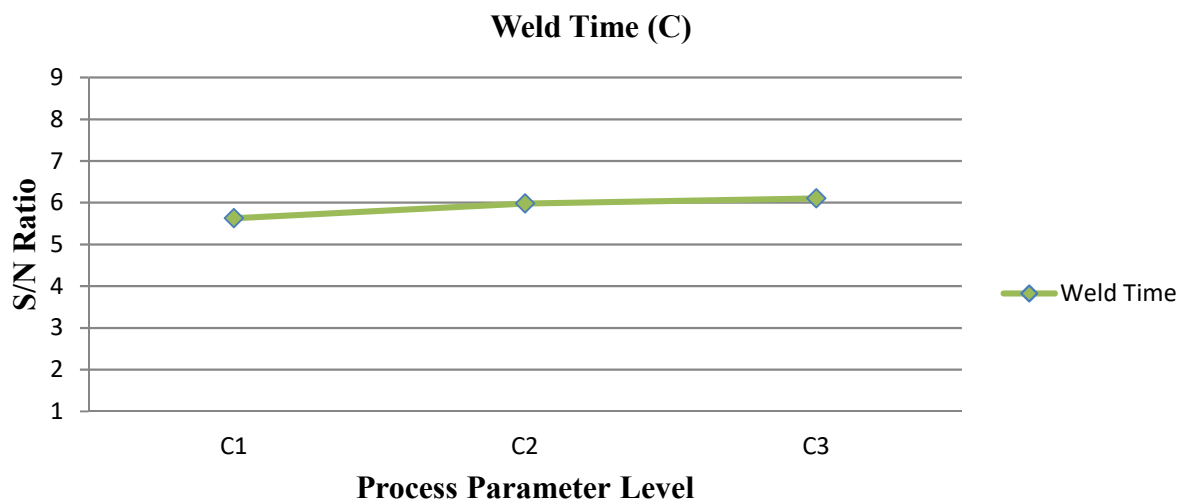


Figure 6.3: Weld time (C) Vs S/N ratio

After combining all the above figures 6.1, 6.2 and 6.3 the figure 6.4 shows clearly show the optimum level of parameters for 0.8 mm sheet they are $A_2B_2C_3$. The figure 6.4 clearly shows how the variation in parameters affects the tensile strength comparing by their S/N ratio.

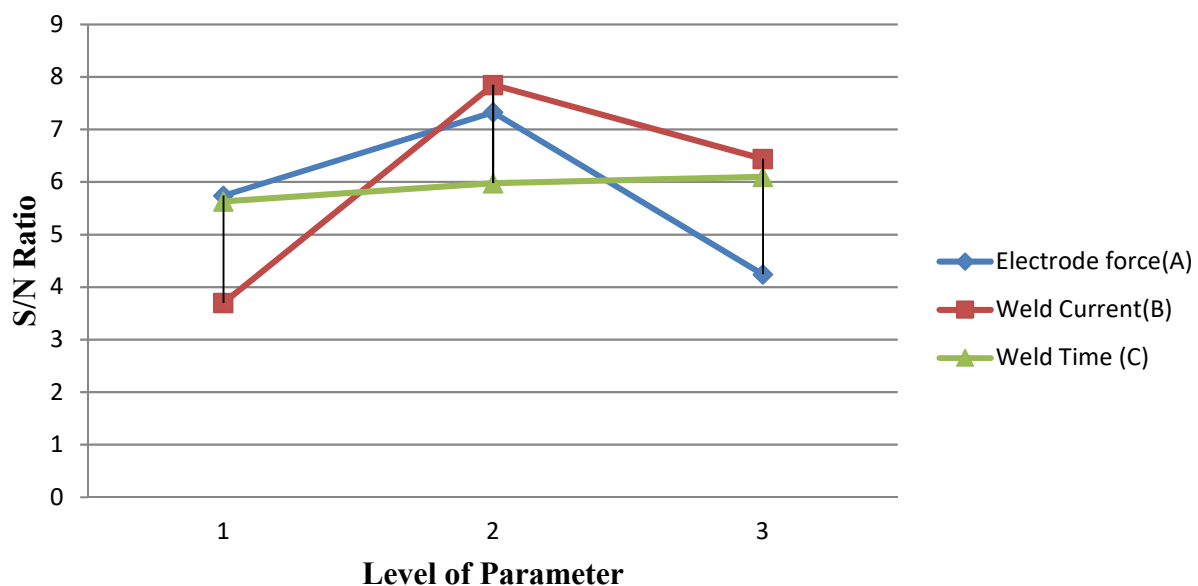


Figure 6.4: S/N curve for all Parameters

Similarly the S/N ratio for 1 mm sheet also varies with variation in the parameters. Figure 6.5 to 6.7 clearly show the variation in S/N ratio with the variation in the parameters for 1 mm sheet.

Variation in S/N ratio with process parameters For 1 mm sheet

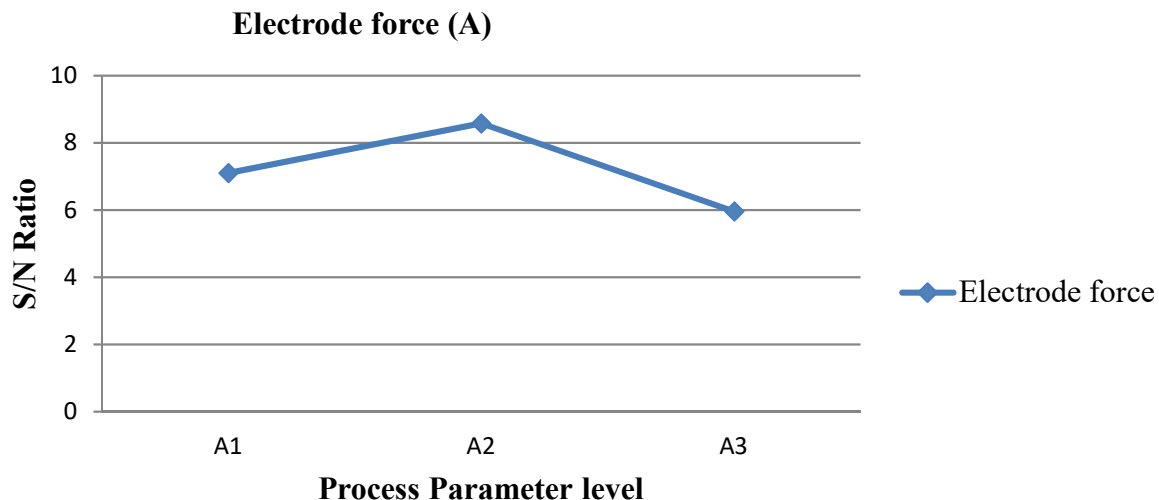


Figure 6.5: Electrode force (A) Vs S/N ratio

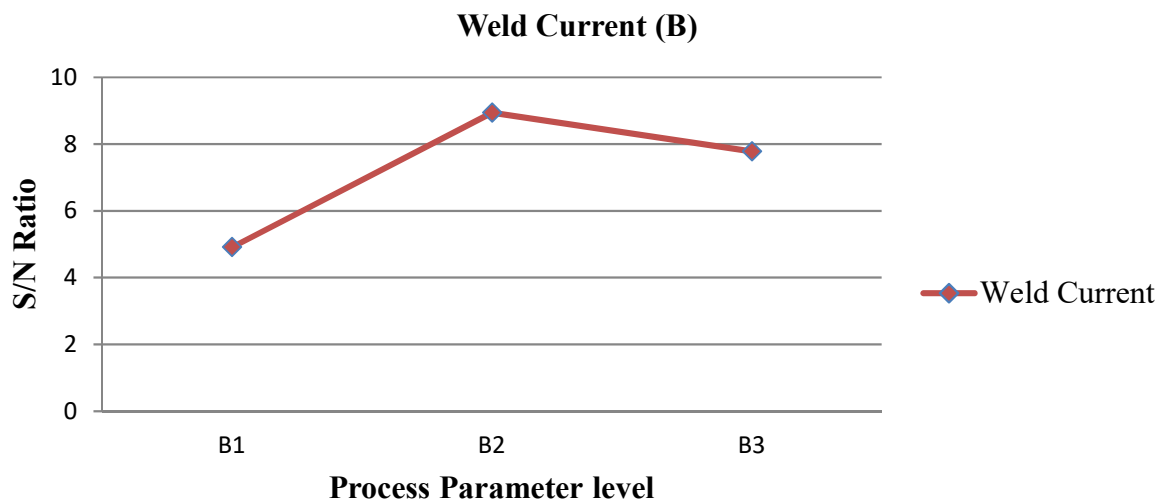


Figure 6.6: Welding current (B) Vs S/N ratio

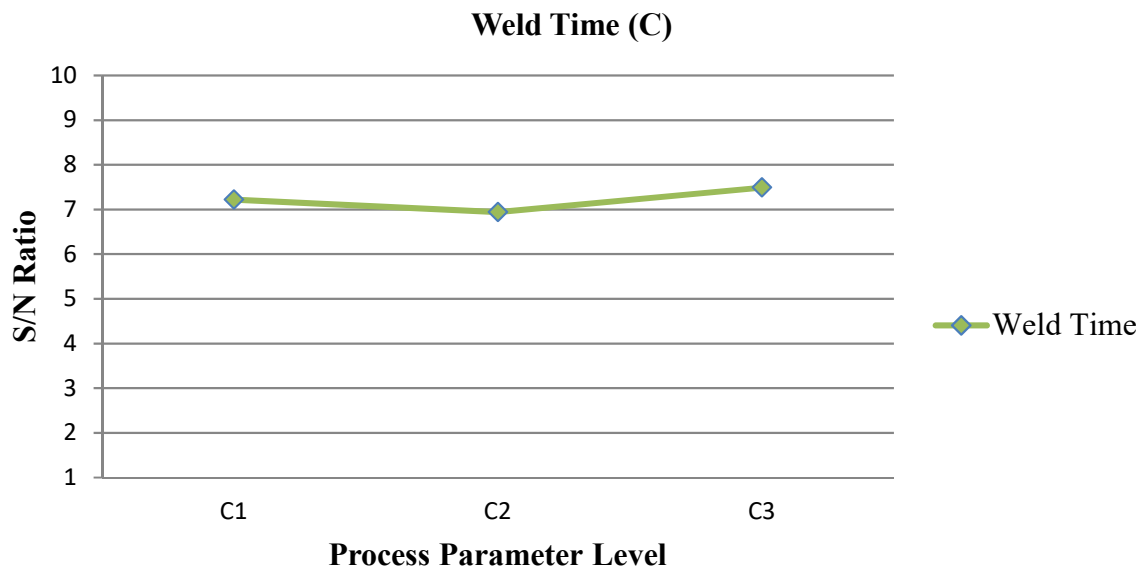


Figure 6.7: Weld current (C) Vs S/N ratio

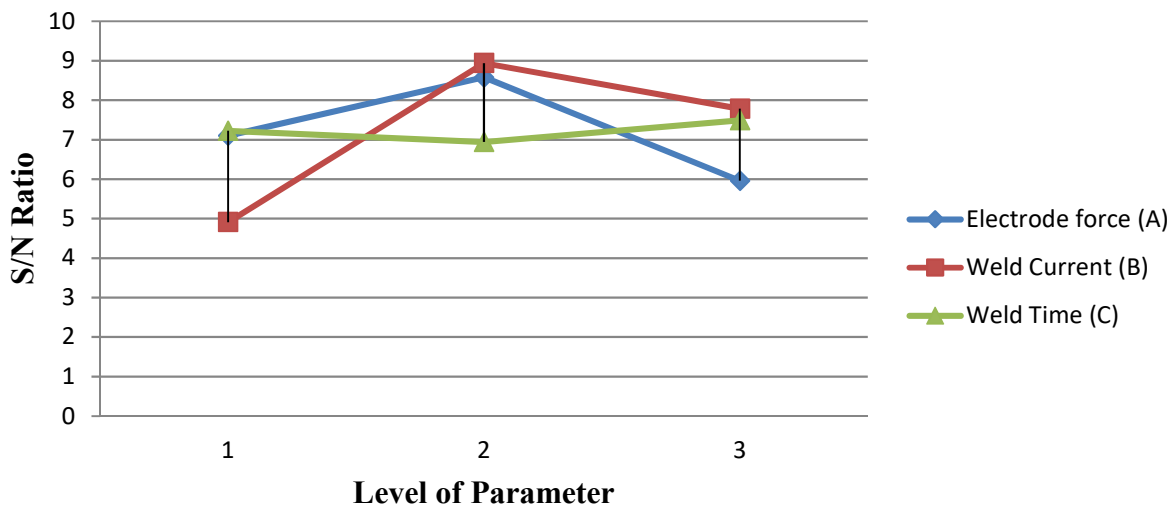


Figure 6.8: S/N curve for all Parameters

The figure 6.8 shows that the tensile strength of the joint varies with the variation in the parameter levels; hence from the graph we can conclude that the optimum parameters for 1 mm sheets are also $A_2B_2C_3$.

Table 6.4: Results of the confirmation Experiment

Thickness	Parameters	Initial Process Parameter	Optimal Process Parameter		Improvement in S/N Ratio
			Prediction	Experiment	
0.8 mm	Level	A ₂ B ₁ C ₂	A ₂ B ₂ C ₃	A ₂ B ₂ C ₃	1.87
	Tensile shear strength(KN)	2.3	2.91	2.93	
	S/N(dB)	7.23	9.3	9.1	
1 mm	Level	A ₂ B ₁ C ₂	A ₂ B ₂ C ₃	A ₂ B ₂ C ₃	1.74
	Tensile shear strength(KN)	2.8	3.38	3.62	
	S/N(dB)	8.94	10.59	10.68	

4. Conclusion

The resistance spot welding parameters were successfully optimized using the Taguchi L18 orthogonal array.

1. Welding current was found to be the most influential parameter affecting tensile-shear strength.
2. The optimum parameter combination for both sheet thicknesses was A₂B₂C₃.
3. For 0.8 mm sheet, tensile-shear strength increased from 2.30 kN to 2.93 kN.
4. For 1.0 mm sheet, tensile-shear strength increased from 2.80 kN to 3.62 kN.
5. The confirmation experiments validated the optimized results.
6. Overall, the Taguchi method effectively improved the tensile-shear strength of resistance spot welded joints.

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