

Parametric Optimization of Resistance Spot Welding to Improve the Weld Strength

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Abstract

This research offers important insights in to enhance spot welded joint strength with practical applications across a wide range of industries. Galvanized steel sheets, prized for their corrosion resistance and extensive use in various applications, serve as the base material. L27 is used to study design and process parameters (electrode force and welding current) systematically. The tensile shear and tensile loading conditions are rigorously tested on universal testing machines using specially designed fixtures. The regression modelling technique is used in the study to determine the mathematical relationship between welding characteristics and joint strength. The Taguchi method and an ANOVA are used to determine the critical parameters and the signal to noise ratio helps to identify the best welding parameter combinations. The correlation between the experimental results and the regression analysis confirms the robustness of the models produced. In order to achieve significant gains in tensile shear and tensile strength, the research closes by showing the best combinations for lap shear and cross tension specimens.

Keywords: Welding current, Spot spacing, Tensile and Shear strength, Taguchi method, Regression analysis, Optimization method.

1. Introduction

Electric resistance spot welding (ERSW) emerges as a versatile and widely utilized technique in the intricate world of metal joining. This research explores ERWS comprehensively, focusing keenly on galvanized steel sheets known for their corrosion resistance—a pivotal attribute, especially in automotive and household applications. At the heart of this research lies a dual challenge: understanding the Parameters of resistance spot welding and their dynamic effect sand optimizing the process to enhance tensile and shear strength. [1] A systematic parametric study unfolds, examining welding current, welding time, electrode force, and processing time through a series of meticulously designed experiments. The theoretical foundations of resistance spot welding, coupled with regression modelling, contribute to the development of mathematical equations. These equations capture

weld strength as a function. The application of the Taguchi method adds another layer of sophistication, guiding the exploration of design and process parameters toward optimized outcomes. RSW is increasing, especially in the automobile sector. Joining the metal sheets that make up the car's body structure, also known as the body-in-white, requires RSW (BIW). [2-6] The reliability, speed, adaptability, and low cost of RSW have made it a popular choice in the automotive sector. Between four thousand and six thousand spot welds take the brunt of a car's static load, impact load, and fatigue load over its lifetime. Three fundamental RSW factors—welding current, welding time, and electrode force Weld nugget diameter and tensile shear strength rise as the welding current is raised to the point of expulsion. Weld nugget development and tensile shear strength up until ejection have been

increased with longer welding times and lower electrode forces. To produce a spot weld with the specified properties, it is necessary to find an appropriate combination of these parameters, known as the welding schedule.

1.1. Methodology

Embarking on a structured and comprehensive investigation, the methodology for this project is designed to unravel the nuances of resistance spot welding, focusing on both single-spot and multiple-spot welds. The journey begins with an in-depth theoretical study aimed at unravelling the intricacies of the welding mechanism, providing a foundational understanding for subsequent phases. Next, a work piece arrangement is chosen for the theoretical investigation's findings. This lays the groundwork for the trial phase when parameters and loading conditions for the welding process will be meticulously selected. The parameters have been fine-tuned to function with the theoretical framework for an in-depth look into the dynamics. RSW, single and multi-spot welds, is used on the work piece configuration chosen for the experiment. Weld consistency and reliability strength testing process is ensured using custom-designed and -manufactured fixtures. The next step is an in-depth examination using a plethora of experimental data. The goal is to determine how different process factors affect resistance spot welds' tensile and shear strength, especially when subjected to varying loads. This analytical phase connects field data and a finished regression model. [7-10] The regression model, incorporating process variables and work piece properties, emerges as a predictive tool for evaluating weld strength. This model lays the groundwork for the optimization phase, where the Taguchi technique is applied. Leveraging the insights from the regression model, the Taguchi technique facilitates identifying and implementing optimal process parameters for single-spot and multiple-spot welds. This methodology blends theoretical insights, experimental precision, analytical rigor, and optimization strategies, presenting a holistic approach to unravelling the complexities of resistance spot welding for enhanced weld strength in single and multiple spot configurations.

1.2. Flow Structure

The project follows a structured flow to explore and optimize resistance spot welding processes comprehensively. The flow structure is outlined as followed in figure 1.

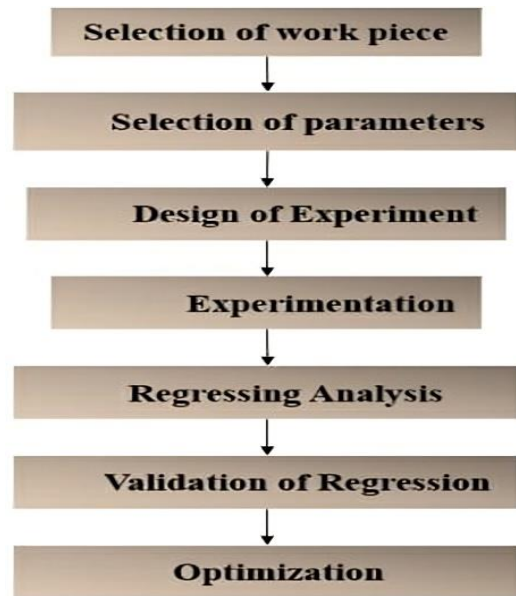


Figure 1 Flow Chart of the System

- **Selection of Work Piece Configuration:** The initial step involves choosing work piece configurations suitable for single-spot and multiple-spot welding experiments.
- **Selection of Welding Process Parameters and Loading Conditions:** Deliberate selection of critical electrode force, welding current, and heat input are all examples of welding process parameters spot spacing and loading conditions for the experimental design.
- **Design of Experiment (DOE):** Formulating a systematic experimental plan encompassing single-spot and multiple-spot welding scenarios to capture a broad range of process variations.
- **Experimentation:** Execution of the designed experiments involving resistance spot welding for single spot and multiple spot welds. This phase includes careful monitoring of welding variables and conditions.

- **Regression Analysis:** Thorough analysis of experimental data to discern the intricate relationships between process parameters and resistance spot weld tensile and shear strength. The goal is to develop a regression model that accurately represents these relationships.
- **Validation of Regression Model:** Rigorous validation of the developed regression model to ensure its robustness and reliability in predicting resistance spot weld strength under diverse conditions.
- **Optimization Using Taguchi Technique:** Application of the Taguchi technique for optimization purposes. This involves identifying optimal parameter settings to enhance resistance spot welds' tensile and shear strength. The Fig. 1 shows the entire process, with each step seamlessly leading to the next, forming a cohesive and systematic approach to understanding, analyzing and optimizing resistance spot welding for single-spot and multiple-spot configurations. This structured methodology ensures a comprehensive exploration of the welding mechanism, leading to practical insights and recommendations for enhancing the efficiency and reliability of spot-welding processes.

1.3. Resistance Spot Welding Process

RSW operates in pivotal resistance-welding techniques, prominently featuring in mass production across various industries. Notably, it extensively applies to manufacturing automobiles, appliances, and sheet metal products like furniture. Particularly prevalent in the automotive sector, where a typical car body boasts around 10,000 spot welds, RSW contributes significantly to the economic landscape, with global automotive production reaching tens of millions of units annually. In the RSW process, in a lap joint, fusing the mating surfaces is accomplished at a precise place by applying a voltage between two electrodes. This technique is primarily employed for joining sheet-metal parts, utilizing a series of spot welds. [11] It is especially suitable for applications where creating an airtight assembly is optional. The

electrode tip configuration determines the weld spots' shape and size. While the round shape is the most common, hexagonal, square, and other variations are also utilized. The resulting weld nugget has a 5-10 mm diameter, and the zone extends beyond the nugget into the base metals by a little margin. When done correctly, a spot weld has the same strength as the metal around it. Effect of Specimen Thickness: Tensile strength significantly increases with specimen thickness. Increased thickness enhances the cross-sectional area, contributing to higher tensile strength.

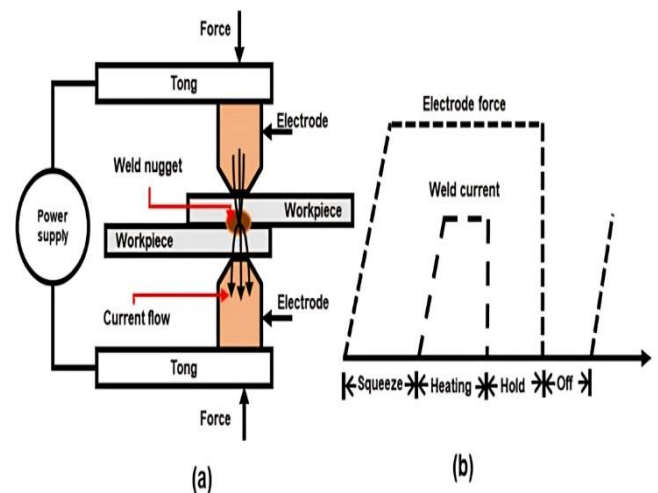


Figure 2 Resistance Spot Welding Process

The process involves a cycle, as illustrated in Figure 2. The key steps include inserting parts between open electrodes, closing the electrodes with applied force, initiating the weld with current, maintaining or increasing force after turning off the current (occasionally applying reduced current for stress relief), and finally, opening the electrodes to remove the welded assembly. Electrodes crucial to RSW are crafted from two primary material groups: copper-based alloys and refractory metal compositions, including combinations of copper and tungsten. The efficacy and reliability of RSW make it a cornerstone in modern production processes, particularly in high-volume manufacturing scenarios. [12]

2. Result and Discussion

The project results demonstrate the significant impact of Variables on Resistance Spot welded tensile strength. Results of the experimentations and

regression analysis are obtained. The effect of design and process parameters is analyzed by considering the average value of the welding parameter. [13] Effect of Welding Current: There is a noticeable increase in tensile strength with an increase in spot welding current. Lower welding currents result in a smaller fusion zone, coarser grain structure, and lower hardness, decreasing spot weld strength. Tensile strength reaches a maximum at a specific welding current and decreases afterwards. Effect of Number of Spots: Tensile strength significantly increases with the number of spots. The maximum tensile strength is achieved when spot welds are made with more spots up to a specific limit.

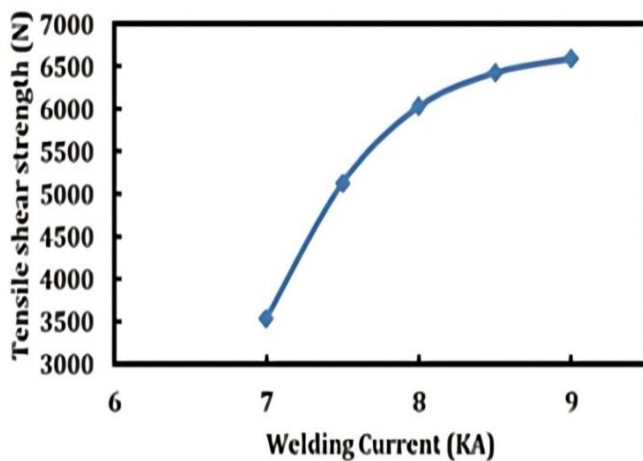


Figure 3 Welding Current and Tensile Shear Strength

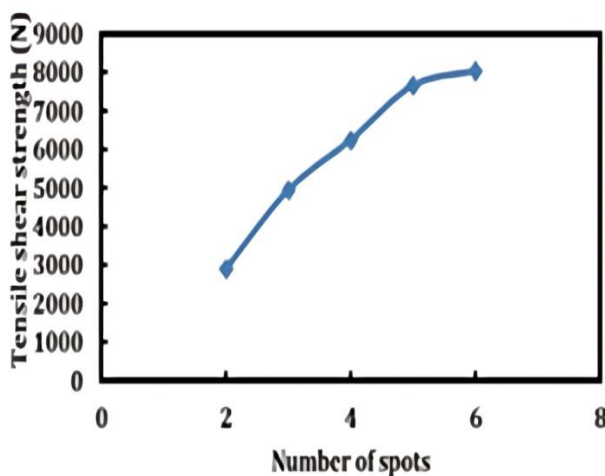


Figure 4 Number of Spots and Tensile Shear

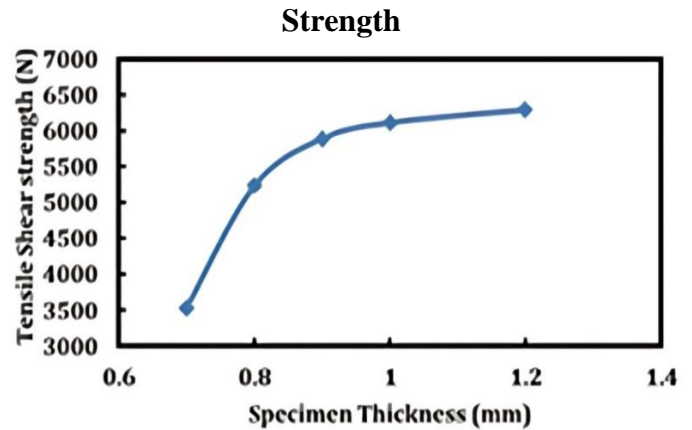


Figure 5 Specimen Thickness and Tensile Shear Strength

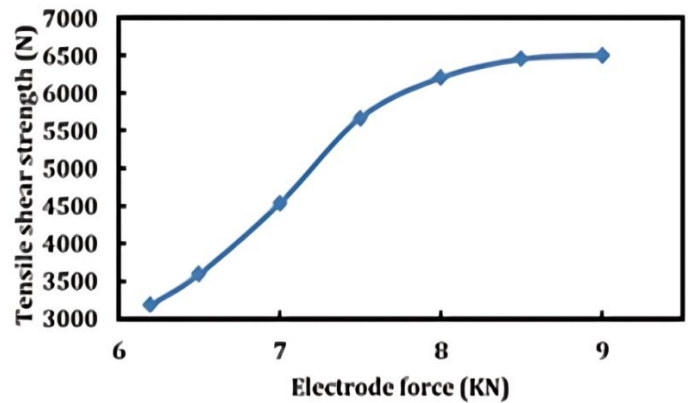


Figure 6 Electrode Force and Tensile Shear Strength

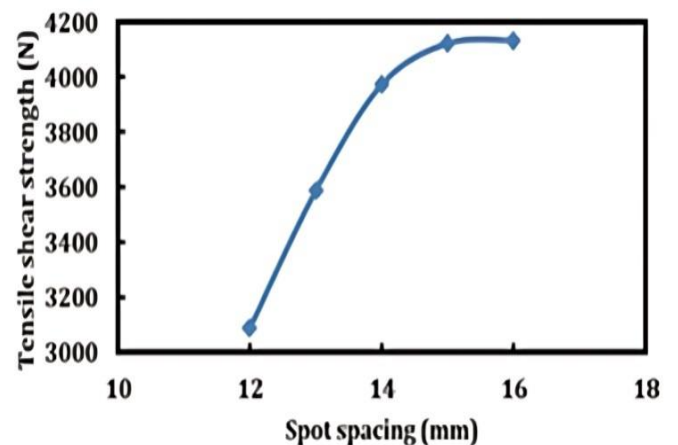


Figure 7 Spot Spacing and Tensile Shear Strength

Effect of Electrode Force: Tensile strength increases with higher electrode force. Figure [3-7] explains the Graphical representation of the results. [Low

electrode pressure reduces contact area and increases cooling rate, decreasing strength. Effect of Radial Spot Spacing decrease in tensile strength as the radial spot spacing from the specimen center increases. Specimens with more extensive radial spot spacing exhibit lower tensile strength. The project highlights the intricate interplay of a factor in the designs (number of spots, radial spot spacing, specimen thickness) and the method's parameters on spot weld tensile strength .It suggests that optimizing these parameters can improve tensile strength .Practical insights are discussed, such as compromising the number of spots for increased specimen thickness to enhance tensile strength .The visual representations (graphs) clearly understand the relationships between individual parameters and tensile strength. These findings offer valuable

insights for optimizing resistance spot welding processes, enhancing the understanding of the nuanced effects of each parameter, and providing a foundation for further research and process improvement. The Particle Swarm Optimization (PSO) method, a pivotal component of this study, is meticulously implemented with a designated configuration of 500 iterations and a population size of 25. An innovative addition to the PSO algorithm involves the incorporation of mutation. This strategic inclusion aims to mitigate premature convergence and suboptimal iteration effectiveness, ensuring a robust search field and augmenting the algorithm's capability to find optimal solutions. The infusion of mutation serves the dual purpose of preserving population diversity and bolstering the efficacy of the solution-seeking process. [14 -18]

Table 1 Optimization Result for Tensile Shear Strength by PSO

Particle	10	25	50	75	100	150	200	300	500
A	741.65	700	700	700	700	700	700	700	700
B	5.5886	6	6	6	6	6	6	6	6
C	12	16	16	16	16	16	16	16	16
D	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
E	8.9	9	9	9	9	9	9	9	9
Tensile Shear Strength (N)	8852.80	9399.54	9399.54	9399.55	9399.55	9399.55	9399.55	9399.55	9399.55

Table 1 encapsulates the outcomes of the optimization process for tensile shear strength in cross-tension specimens using PSO. The optimized values reveal that a welding current of 9554A, specimen thickness of 0.3 mm, electrode force of 350N, radial spot spacing of 12mm, and six numbers of spots collectively yield a remarkable tensile shear strength of 2275.493 N. Notably, the optimization process demonstrates a gradual increase in tensile strength values as the number of particles varies from 10 to 500. A graphical representation of differences in tensile strength due to the number of particles employed in the PSO algorithm is illustrated in Figure 8. The graph distinctly depicts a consistent value of tensile shear strength within the range of 400 to 500 particles, indicating the attainment of a global minimum. This graphical depiction offers valuable insights into the convergence behavior of the PSO algorithm, substantiating its efficacy in reaching a

stable and optimized solution for the specified parameters. These findings, embedded within the broader context of the research, underscore the effectiveness of PSO in fine-tuning specimens in resistance spot welding applications. [19]

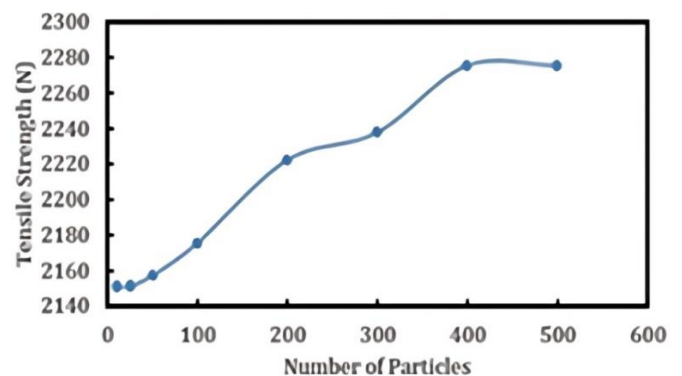


Figure 8 Variation of Tensile Strength Concerning the Number of Particles

Conclusion and Future Scope

In conclusion, optimizing the multi-spot RSW method has been systematically investigated, considering five parameters with three levels. The experimental phase utilized a Taguchi-based Orthogonal Array (OA) L27 for comprehensive testing, employing a Universal Testing Machine (UTM) alongside specially designed fixtures. Derived regression equations accurately determined the Weld strength for various design and process parameters. The Taguchi method facilitated the identification of optimum values for spot welding parameters to achieve maximum weld strength. [20] The study progressed to enhance the welding process's efficacy by incorporating the Particle Swarm Optimization (PSO) method. This iterative optimization approach allowed for further refinement of weld strength by exploring a broader solution space. The combined application of Taguchi and PSO methodologies underscores the commitment to achieving robust and optimized resistance spot welding processes. Optimized parameters provide valuable insights for practitioners in the field, contributing to the advancement of multi-spot welding techniques. This research enhances our understanding of the complex interplay between welding parameters and provides practical and implementable solutions for optimizing weld strength in multi-spot welding scenarios. The successful application of these optimization techniques holds great promise for improving the efficiency and reliability of resistance spot welding in diverse industrial applications. The research on optimizing resistance spot welding processes suggests several promising avenues for future exploration. This includes delving into advanced optimization algorithms like Genetic Algorithms and Machine Learning, exploring multi-objective optimization for a comprehensive understanding of trade-offs, extending applicability to various materials, integrating advanced sensing for real-time monitoring, incorporating robotics for automation, assessing environmental impacts, implementing digital twin technology, and fostering collaborative research for standardized guidelines and innovative solutions. These directions aim to enhance precision, sustainability, and adaptability in resistance spot

welding processes, contributing to advancements in manufacturing practices.

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