

A Comprehensive Review of Resistance Spot Welding: Process Parameters, Joint Strength, Optimization Techniques and Recent Developments

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Abstract

Resistance Spot Welding (RSW) is one of the most widely used joining processes for sheet metal components because of its high production rate, simple operation, low material consumption, and suitability for automated manufacturing. The quality and mechanical strength of a spot-welded joint are strongly influenced by process parameters such as welding current, welding time, electrode force, electrode tip geometry, sheet thickness, and material properties. This review presents a comprehensive assessment of Resistance Spot Welding with particular emphasis on process parameters, joint strength, weld quality, optimization techniques, and recent technological developments. The influence of major welding parameters on nugget formation, heat generation, tensile-shear strength, hardness, failure mode, and weld defects is critically discussed. Various experimental and statistical optimization approaches, including Taguchi methods, Analysis of Variance (ANOVA), Response Surface Methodology (RSM), and other advanced optimization techniques, are reviewed for improving the mechanical performance of spot-welded joints. The review also examines the application of numerical simulation, artificial intelligence, machine learning, and advanced monitoring techniques in predicting and controlling weld quality. Different sheet materials and material combinations used in automotive, manufacturing, and structural applications are considered. The review identifies the major factors affecting tensile-shear strength and highlights the importance of optimizing welding parameters to obtain reliable and high-strength joints. Finally, current research gaps and future opportunities are discussed, with emphasis on intelligent process control, multi-objective optimization, sustainable welding practices, advanced materials, and data-driven prediction of weld performance. The review provides a useful foundation for researchers and engineers working toward the optimization and improvement of Resistance Spot Welding processes for high-quality sheet metal joints.

Keywords: Resistance Spot Welding, Sheet Metal Joints, Welding Parameters, Tensile-Shear Strength, Weld Nugget; Joint Strength, Taguchi Method, ANOVA, Optimization.

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1. Introduction

Resistance Spot Welding (RSW) is one of the most widely used resistance welding processes for joining sheet metal components in high-volume manufacturing industries. The process is extensively employed in the automotive, aerospace, electrical, appliance, and general manufacturing sectors because of its high production rate, relatively simple operation, low filler-material consumption, and suitability for automation and robotic production. In RSW, two or more overlapping metal sheets are clamped between electrodes and joined by generating heat through electrical resistance at the faying interface. The heat generated at the contact region causes localized melting and forms a weld nugget, which solidifies under electrode pressure to produce the joint. The quality and mechanical performance of a resistance spot welded joint depend on several interacting factors. Welding current, welding time, electrode force, electrode tip geometry, sheet thickness, material properties, surface condition, and welding sequence directly influence heat generation, nugget formation, nugget size, and joint strength. Among these parameters, welding current and welding time determine the amount of heat generated at the welding interface, while electrode force influences contact resistance and the confinement of the molten region. Therefore, appropriate selection of welding parameters is essential for producing sound and mechanically reliable joints. The heat generated during resistance spot welding can be expressed according to Joule's heating principle, where the generated heat is primarily dependent on electrical resistance, welding current, and welding time. An increase in welding current generally increases heat generation and nugget size up to a certain level. However, excessive current may result in expulsion of molten metal, excessive nugget growth, electrode wear, surface indentation, and deterioration of joint quality. Similarly, insufficient current may produce a small weld nugget and inadequate bonding, resulting in low tensile-shear strength. Consequently, an optimum welding current is required to achieve satisfactory weld formation.

Welding time is another important parameter affecting joint formation. Increasing welding time increases the duration for which electrical energy is supplied to the joint and consequently increases heat input. However, excessive welding time may cause excessive heat generation, material expulsion, electrode indentation, and undesirable changes in the heat-affected zone. A suitable combination of welding current and welding time is therefore necessary to obtain an adequate weld nugget without producing defects. Electrode force also has a significant influence on RSW performance. The applied force controls the contact condition between the electrodes and sheets and affects the electrical contact resistance at the faying interface. A low electrode force may result in excessive contact resistance and unstable heating, potentially causing expulsion and inconsistent nugget formation. In contrast, excessive electrode force may reduce contact resistance and restrict heat generation, resulting in insufficient nugget formation. Proper electrode force is therefore essential for maintaining stable welding conditions and achieving consistent joint strength. Electrode tip geometry and condition also influence the quality of spot-welded joints. The electrode tip controls the effective contact area, current density, and distribution of heat at the welding zone. Electrode wear can gradually change the contact area and current density, leading to variations in nugget size and joint strength during production.

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Proper selection, maintenance, and monitoring of electrode tips are therefore important for maintaining consistent weld quality. The mechanical performance of RSW joints is commonly evaluated through tensile-shear testing. Tensile-shear strength represents the ability of the welded joint to withstand loading applied parallel to the sheet interface. Joint strength is influenced by nugget diameter, nugget penetration, sheet thickness, material properties, hardness distribution, residual stresses, and failure mode. Depending on the welding conditions, failure may occur through interfacial fracture or pullout failure. A sufficiently large and properly formed nugget generally provides improved load-carrying capacity and promotes favorable failure behavior. The selection of suitable process parameters becomes more challenging when different sheet materials, thicknesses, or material combinations are joined. Automotive and other lightweight structures increasingly use advanced high-strength steels, coated steels, stainless steels, aluminium alloys, and dissimilar material combinations. These materials have different electrical, thermal, and mechanical properties, which influence heat generation, heat dissipation, nugget formation, and electrode interaction. Therefore, welding parameters optimized for one material combination may not be directly applicable to another. To obtain improved joint quality, researchers have employed different experimental design and optimization techniques. The Taguchi method is widely used because it enables systematic investigation of multiple process parameters with a reduced number of experiments through orthogonal arrays. Analysis of Variance (ANOVA) is commonly used to determine the statistical significance and contribution of individual welding parameters. Response Surface Methodology (RSM), regression analysis, and other mathematical optimization approaches have also been employed to establish relationships between welding parameters and joint performance.

In recent years, numerical simulation and data-driven approaches have further expanded the scope of RSW research. Finite Element Analysis (FEA) and computational models are used to predict temperature distribution, nugget formation, thermal behavior, and mechanical response. Artificial Intelligence (AI), Machine Learning (ML), and predictive modelling techniques are increasingly being explored for estimating weld quality and identifying optimum process conditions. These approaches can reduce experimental effort and support real-time monitoring and intelligent control of resistance spot welding processes. Despite extensive research, several challenges remain in achieving consistent and high-strength resistance spot welded joints. Variations in material properties, surface condition, electrode wear, welding parameters, and environmental conditions can affect weld quality. Furthermore, optimizing one response, such as tensile-shear strength, may adversely affect other responses such as electrode life, energy consumption, weld nugget size, and production rate. Therefore, multi-parameter and multi-objective optimization approaches are becoming increasingly important. This review presents a comprehensive assessment of Resistance Spot Welding with emphasis on process parameters, joint strength, weld quality, optimization techniques, and recent technological developments. The influence of major parameters such as welding current, welding time, electrode force, electrode geometry, and material characteristics on weld formation and tensile-shear strength is discussed. Various experimental, statistical, numerical, and intelligent optimization approaches are reviewed to identify their advantages and limitations. Finally, current research gaps and future

directions are highlighted to support the development of reliable, efficient, and optimized resistance spot welding processes for sheet metal applications.

2. Problem Identification

Resistance Spot Welding (RSW) is widely used for joining sheet metal components, particularly in automotive and manufacturing industries. However, obtaining consistent, high-quality, and high-strength welded joints is a major challenge because the welding process is influenced by several interacting parameters. Welding current, welding time, electrode force, electrode tip geometry, sheet thickness, material properties, and surface conditions can significantly affect heat generation, weld nugget formation, and tensile-shear strength. One of the major problems in RSW is the selection of appropriate welding parameters. Insufficient welding current or welding time may produce a small weld nugget and weak bonding, whereas excessive heat input can cause molten metal expulsion, excessive indentation, electrode wear, and defects. Similarly, improper electrode force can affect contact resistance and heat generation, resulting in inconsistent weld quality. Therefore, optimum combinations of welding parameters are required to obtain strong and reliable sheet metal joints. The mechanical strength of a spot-welded joint is strongly dependent on weld nugget size, penetration, material properties, and failure mode. Variations in nugget formation can lead to significant changes in tensile-shear strength. Interfacial failure, partial pullout, and complete pullout are commonly observed under different welding conditions. Achieving an adequate nugget size and favorable failure mode is therefore essential for improving joint strength and reliability. The increasing use of advanced high-strength steels, coated sheets, aluminium alloys, and dissimilar materials has further increased the complexity of resistance spot welding. Different materials possess different electrical and thermal conductivities, melting temperatures, and mechanical properties. Consequently, welding parameters suitable for one material combination may not provide satisfactory results for another. This creates a need for systematic experimental investigation of material and process parameter interactions.

Another important problem is the simultaneous influence of multiple welding parameters on joint performance. Changes in welding current, welding time, and electrode force can interact with each other, making it difficult to identify the parameter having the greatest influence on tensile-shear strength using conventional trial-and-error methods. Statistical and optimization techniques such as Taguchi design, ANOVA, Response Surface Methodology, and regression analysis are therefore required to determine significant parameters and optimum parameter combinations. Although numerous studies have investigated resistance spot welding, differences in materials, sheet thicknesses, electrode configurations, experimental procedures, and optimization methods make direct comparison of reported results difficult. Furthermore, many investigations focus on individual parameters or a single performance characteristic, while the combined effect of multiple parameters on tensile-shear strength requires further systematic evaluation. Therefore, there is a need for a comprehensive understanding of the relationship between RSW process parameters and the mechanical performance of sheet metal joints. Systematic experimental investigation and parametric optimization can help identify the most influential welding

parameters and determine their optimum levels for achieving enhanced tensile-shear strength, improved weld quality, and consistent joint performance. The present review addresses these issues by critically examining previous research on resistance spot welding, process parameters, joint strength, optimization techniques, and recent technological developments.

3. Research Objectives

The main objective of this review is to provide a comprehensive understanding of Resistance Spot Welding (RSW) with particular emphasis on process parameters, joint strength, optimization techniques, and recent developments. The specific objectives of the review are as follows:

1. To review the fundamental working principle and characteristics of the Resistance Spot Welding process for sheet metal joining.
2. To examine the influence of major process parameters, including welding current, welding time, electrode force, electrode tip geometry, and sheet thickness, on weld quality and joint performance.
3. To evaluate the effect of welding parameters on weld nugget formation, nugget size, penetration, hardness, failure mode, and tensile-shear strength.
4. To review the influence of different sheet materials, material combinations, and surface conditions on the performance of resistance spot welded joints.
5. To critically examine experimental techniques used for evaluating the mechanical strength and quality of RSW joints, particularly tensile-shear testing.
6. To review optimization techniques such as Taguchi method, Analysis of Variance (ANOVA), Response Surface Methodology (RSM), regression analysis, and other statistical approaches used for optimizing RSW parameters.
7. To examine the application of numerical simulation, Artificial Intelligence (AI), Machine Learning (ML), and predictive modelling techniques for improving and controlling RSW performance.
8. To identify the most influential process parameters affecting tensile-shear strength and determine the importance of their interactions.
9. To identify research gaps, limitations, and challenges in existing RSW investigations related to joint strength, weld quality, process optimization, and industrial applicability.
10. To suggest future research directions for achieving improved tensile-shear strength, consistent weld quality, energy efficiency, and reliable performance of resistance spot welded sheet metal joints.

4. Literature Review

Resistance Spot Welding (RSW) is one of the most widely used joining processes for sheet metal components in automotive, manufacturing, electrical, and structural applications. The quality and strength of a spot-welded joint are strongly influenced by welding current, welding time, electrode force, electrode geometry, sheet thickness, material properties, and welding sequence. Researchers have investigated these parameters using experimental, statistical, numerical, and optimization techniques to improve tensile-shear strength, weld nugget characteristics, failure

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behavior, and overall weld quality. The following review summarizes important research contributions from 2026 to 2015.

Rajasekar and Gurusami (2026) investigated the optimization of resistance spot welding parameters for high-strength steel and examined the influence of welding current, electrode force, and welding time on weld quality and tensile-shear strength. The study demonstrated that systematic parameter optimization can improve nugget formation and joint strength while reducing undesirable weld defects. The researchers emphasized the importance of controlling welding parameters for reliable joining of high-strength sheet materials.

A 2026 study on machine-learning-based prediction and optimization investigated resistance spot welding of AISI 316L and duplex stainless steel DSS 2205. Different welding currents, electrode tip diameters, and welding times were experimentally evaluated for their influence on tensile-shear strength. The study reported that increasing welding current and welding time generally improved tensile-shear strength up to an optimum condition. XGBoost was subsequently applied for prediction and achieved an R^2 value of approximately 0.99, demonstrating the potential of machine learning for predicting and optimizing RSW performance.

Samodra et al. (2025) investigated the optimization of spot welding parameters for 0.9 mm SPCC sheet using the Taguchi method. Welding current, welding time, and holding time were considered as major process parameters, while shear tensile strength was selected as the response. An L9 orthogonal array, signal-to-noise ratio, and ANOVA were employed. The results showed that welding current was the most influential parameter, followed by welding time and holding time, demonstrating the importance of systematic parameter optimization for achieving consistent joint strength.

Rajasekar and Gurusami (2025) investigated resistance spot welding of uncoated cold-rolled steel using the Taguchi method. The study evaluated welding current, electrode force, and welding time for improving tensile-shear strength. An L9 orthogonal array was used together with S/N ratio analysis and ANOVA. The optimum combination was identified experimentally, and electrode force was reported as the most influential parameter affecting tensile-shear strength.

Epperlein, Schiebahn, and Reisgen (2024) investigated resistance spot welding of die-cast and wrought aluminium alloys with emphasis on improving weld spot quality through parameter optimization. The study highlighted the challenges associated with joining aluminium alloys and demonstrated that appropriate selection of resistance welding parameters is essential for obtaining satisfactory weld quality and mechanical performance.

Bhuyan et al. (2024) investigated the optimization of resistance spot welding parameters using a Taguchi orthogonal array. Welding current, squeeze time, and welding time were studied using an L18 experimental design. S/N ratio and ANOVA were employed to determine the influence

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of the parameters on tensile-shear force. The results indicated that welding time was the most significant factor, followed by welding current and squeeze time. Metaheuristic optimization methods were also used to determine suitable parameter combinations.

Safi, Tolephih, and Jweeg (2024) investigated the optimization and simulation of resistance spot welding of commercial AA1050 aluminium using a low-power welding machine. Welding current, welding time, and electrode force were selected as process parameters, while tensile-shear strength was considered the principal response. Taguchi-based design of experiments and finite element analysis were used to identify suitable welding conditions and improve joint strength.

Bhosale, Kamble, and Asabe (2024) studied parametric optimization of resistance spot welding for galvanized steel sheets. Electrode force and welding current were systematically investigated using an L27 experimental design. The research demonstrated that statistical optimization and regression analysis can be effectively used to improve the strength of spot-welded joints and determine suitable process conditions.

A study published in 2023 investigated tensile-shear load in resistance spot welded dissimilar galvanized and non-galvanized steel joints using Response Surface Methodology. A Box-Behnken design was employed to examine squeeze time, welding current, welding time, and holding time. The optimized condition produced a predicted tensile-shear load of 5265.15 N, demonstrating the effectiveness of RSM for optimizing multiple RSW parameters simultaneously.

A 2023 study on galvanized and mild-steel dissimilar RSW joints applied Taguchi design, S/N ratio analysis, ANOVA, and multilinker regression. The research showed that welding time and welding current were among the most influential parameters affecting tensile-shear strength. The findings demonstrated that statistical optimization can be effectively applied to overcome weldability challenges associated with zinc-coated sheet materials.

In 2022, researchers continued to investigate optimization of resistance spot welding for dissimilar and coated sheet materials. Studies emphasized the influence of welding current, welding time, electrode force, and holding time on tensile-shear strength and weld quality. The findings generally demonstrated that optimized combinations of process parameters are more effective than individual parameter adjustment because the parameters interact during nugget formation and heat generation.

In 2021, a study by researchers investigating double-pulse resistance spot welding of dual-phase steel examined the effects of welding parameters on microstructure, failure mode, and tensile-shear properties. A double-pulse welding technique was used to provide in-situ post-weld heat treatment, while Taguchi methodology was applied for parameter optimization. The study

demonstrated that suitable thermal cycles can improve the mechanical performance of DP590 spot-welded joints and influence failure behavior under tensile-shear loading.

Mahmood et al. (2020) investigated the prediction of optimum tensile-shear strength through experimental studies of similar and dissimilar spot-welded joints. Taguchi methodology and regression analysis were used to establish relationships between welding parameters and tensile-shear force. The study demonstrated that suitable optimization of process parameters can improve the strength of aluminium, steel, and dissimilar material joints.

Sukarman et al. (2020) investigated the optimization of tensile-shear strength in dissimilar joints of zinc-coated steel and low-carbon steel. A Taguchi experimental design was used to optimize squeeze time, welding current, welding time, and holding time. The maximum tensile-shear strength obtained was 5049.64 N, and welding current was identified as the most influential parameter, followed by welding time, squeeze time, and holding time.

Mat Yasin et al. (2020) investigated the optimization of RSW parameters for 1.2 mm low-carbon steel sheets using the Taguchi method. Electrode force, welding current, and welding time were selected as the principal parameters. An L9 orthogonal array, S/N ratio, and ANOVA were employed to determine the optimum conditions. The study showed that electrode force had the greatest influence on tensile-shear strength compared with welding time and welding current.

Dhawale and Ronge (2019) investigated weld-strength prediction through parametric optimization of resistance spot welding using the Taguchi method. The research examined multi-spot lap-shear and cross-tension specimens and evaluated the influence of process and design parameters on tensile-shear and tensile strength. The study demonstrated that Taguchi-based optimization can effectively improve resistance spot welding performance and predict weld strength.

Muthu (2019) experimentally investigated the optimization of resistance spot welding parameters for AISI 316L stainless-steel sheets using the Taguchi method. Welding current, welding time, electrode force, and other process factors were considered because of their influence on weld quality. The study specifically focused on improving tensile-shear strength and demonstrated the usefulness of Taguchi methodology for identifying suitable welding conditions.

Ertek Emre (2019) investigated the strength optimization of resistance spot welded TWIP steel using the Taguchi method. Tensile-shear strength and weld nugget diameter were selected as important responses, and an L9 orthogonal array was used. The study identified an optimum welding current of 7 kA and welding time of 20 cycles for obtaining improved joint strength and weld nugget quality.

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Pattanaik et al. (2018) performed a comparative investigation of spot-welding parameter optimization using Taguchi-based Grey Relational Analysis and genetic algorithms. Cold-rolled mild-steel sheets were investigated using welding current, electrode force, and welding time. Tensile-shear strength and nugget diameter were simultaneously optimized. The results demonstrated that multi-objective optimization techniques can effectively improve both weld strength and nugget characteristics.

Kasih et al. (2018) investigated the optimization of resistance spot welding parameters for dissimilar and unequal-thickness metal sheets using the Taguchi technique. The research focused on automotive sheet materials and evaluated welding parameters to obtain improved mechanical properties. The study demonstrated the importance of optimizing welding conditions when joining sheets having different materials and thicknesses.

A 2017 study on resistance spot welding of dissimilar DP600 steel and AISI 304 stainless steel investigated the effects of current density, welding time, electrode force, and holding time on shear-tensile strength. Taguchi methodology was used for experimental design and optimization. The results indicated that current density, holding time, welding time, and electrode force had significant effects on joint strength, demonstrating the importance of controlling the complete welding cycle for dissimilar joints.

In 2017, researchers also investigated the mechanical behavior and failure characteristics of resistance spot welded advanced high-strength steels. The studies emphasized that weld nugget size, hardness distribution, heat-affected zone characteristics, and welding parameters significantly influence tensile-shear strength and failure mode. The research indicated that optimization of welding conditions is particularly important for high-strength steels because excessive heat input can produce undesirable microstructural changes.

Studies published in 2016 investigated the influence of resistance spot welding parameters on the mechanical properties and weld quality of sheet-metal joints. Particular attention was given to welding current, welding time, and electrode force because these parameters directly control heat generation and nugget formation. The findings reported that appropriate parameter combinations improve nugget size and tensile-shear strength, whereas excessive heat input can lead to expulsion and deterioration of joint quality.

In 2015, research on resistance spot welding optimization focused on improving joint strength and weld quality through systematic experimental approaches. Taguchi-based experimental design was increasingly used to reduce the number of experiments while identifying influential welding parameters. The studies demonstrated that welding current, welding time, and electrode force are critical parameters affecting tensile-shear strength and nugget formation, providing a foundation for subsequent research on multi-response and advanced optimization techniques.

Overall, the literature from 2015 to 2026 demonstrates that resistance spot welding performance is strongly dependent on the interaction of welding current, welding time, electrode force, electrode geometry, material characteristics, and sheet thickness. Taguchi methods, ANOVA, Grey Relational Analysis, Response Surface Methodology, regression, genetic algorithms, particle swarm optimization, finite element analysis, and machine learning have increasingly been applied to improve weld quality and tensile-shear strength. Recent research has shifted toward intelligent prediction, multi-objective optimization, advanced high-strength steels, aluminium alloys, dissimilar materials, and data-driven process control. These developments provide a strong foundation for further experimental investigation and parametric optimization of resistance spot welding for enhanced tensile-shear strength of sheet metal joints.

5. Research Gap Identified from the Literature

The review of previous research indicates that Resistance Spot Welding (RSW) has been extensively investigated for different sheet materials, welding parameters, and optimization techniques. However, several research gaps still exist. Most previous studies have focused on individual parameters such as welding current, welding time, or electrode force, while limited attention has been given to their combined and interactive effects on tensile-shear strength. Therefore, a systematic investigation considering multiple parameters simultaneously is required. A significant variation exists in the optimum welding parameters reported for different materials and sheet thicknesses. The optimum conditions obtained for one material cannot be directly applied to another material because electrical conductivity, thermal conductivity, thickness, and mechanical properties influence heat generation and weld nugget formation. Hence, further experimental studies are required to establish suitable parameter combinations for specific sheet metal joints. Many studies have primarily evaluated tensile-shear strength as a single response, whereas weld nugget diameter, failure mode, hardness, and weld quality are also important indicators of joint performance. There is a need to establish a better relationship between process parameters, nugget characteristics, and tensile-shear strength to obtain more reliable and high-quality welded joints. Although Taguchi, ANOVA, RSM, and other optimization techniques have been widely used, comparatively fewer studies have systematically compared different optimization approaches under identical experimental conditions. In addition, the interaction between significant process parameters is not always adequately investigated. Therefore, improved experimental designs and statistical analysis are required for reliable identification of optimum welding conditions. The increasing use of advanced high-strength steels, coated steels, aluminium alloys, and dissimilar sheet materials has introduced additional challenges in RSW. Differences in electrical and thermal properties can result in uneven heat generation, electrode wear, expulsion, and inconsistent nugget formation. More experimental investigations are therefore required to develop reliable welding conditions for different material combinations. Recent research has introduced Artificial Intelligence (AI), Machine Learning (ML), numerical simulation, and predictive modelling for RSW optimization. However, these approaches generally require sufficient and reliable experimental datasets for training and validation. There is still a need for experimental studies that generate high-quality datasets covering a systematic range of welding parameters and tensile-shear responses.

6. Conclusion

Resistance Spot Welding (RSW) is an important joining process for sheet metal components because of its high production rate, easy automation, low material consumption, and wide industrial applicability. The literature reviewed in this study demonstrates that the quality and mechanical strength of RSW joints are strongly influenced by welding current, welding time, electrode force, electrode geometry, sheet thickness, material properties, and surface conditions. The review indicates that welding current and welding time have a significant effect on heat generation, weld nugget formation, nugget diameter, and tensile-shear strength. Electrode force also plays an important role by controlling contact resistance and the stability of the welding process. Improper selection of these parameters can result in insufficient nugget formation, excessive indentation, electrode wear, material expulsion, and reduced joint strength. The tensile-shear strength of spot-welded joints is closely related to weld nugget size, penetration, material characteristics, and failure mode. Proper optimization of welding parameters can increase nugget quality and improve the load-carrying capacity of the joint. The literature also shows that different sheet materials and thicknesses require different welding conditions because of their varying electrical, thermal, and mechanical properties. Various optimization techniques, including Taguchi method, ANOVA, Response Surface Methodology, Grey Relational Analysis, regression analysis, and advanced computational techniques, have been successfully applied for determining suitable RSW parameters. Among these, Taguchi methodology combined with ANOVA provides an effective approach for reducing experimental effort and identifying significant parameters. Recent developments in numerical simulation, Artificial Intelligence, Machine Learning, and predictive modelling have further increased the potential for intelligent optimization and real-time quality control of RSW processes. However, reliable experimental data and proper validation remain essential for the successful application of these advanced techniques. Overall, the literature confirms that systematic parametric investigation and optimization are essential for achieving enhanced tensile-shear strength and consistent weld quality. Future research should focus on multi-parameter and multi-objective optimization, advanced and dissimilar materials, energy-efficient welding, electrode wear, real-time monitoring, and data-driven prediction. These developments can contribute to the production of stronger, more reliable, economical, and sustainable resistance spot welded sheet metal joints.

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