

Experimental Investigation and Analysis of Spot Welding on Different Grades of Steel

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ABSTRACT

Resistance Spot Welding (RSW) is a dominant joining technique used for sheet metal assemblies in industries such as automotive, railway, aerospace, and household appliances. The growing application of multiple steel grades—including mild steel, stainless steel, and advanced high-strength steels—has increased the need for a deeper understanding of their weldability under varying resistance spot welding conditions. This study presents an experimental investigation into spot welding of different steel grades by analyzing the effects of key process parameters such as welding current, welding time, and electrode force. Mechanical characteristics including tensile shear strength, weld nugget size, hardness variation, and failure behavior are examined to evaluate joint performance. Previous research confirms that nugget diameter plays a critical role in determining joint strength, where optimized welding conditions enhance mechanical properties while minimizing defects like metal expulsion and interfacial cracking. Mild steel generally exhibits a broad process window, whereas stainless steels and advanced high-strength steels pose challenges due to differences in electrical and thermal properties. Statistical optimization techniques such as Taguchi and ANOVA reveal that welding current and electrode force are the most influential parameters affecting weld quality. The findings of this study contribute toward establishing optimized welding guidelines for different steel grades, supporting improved joint reliability and performance in industrial applications. Advanced high-strength steels provide excellent strength-to-weight ratios and are widely used in modern vehicle structures, but they present challenges during spot welding due to their narrow welding parameter range and susceptibility to brittle failure. Various researchers have shown that weld nugget size directly affects tensile shear strength, with optimal welding conditions maximizing mechanical performance while minimizing defects such as expulsion and interfacial cracks.

Keyword: - Resistance Spot Welding (RSW) , Different Grades of Steel, Welding Parameters, Mechanical Properties of Weld Joints , Weld Nugget Formation and Microstructure

1. INTRODUCTION

Resistance Spot Welding (RSW) is one of the most widely adopted welding processes for joining thin metal sheets in modern manufacturing sectors. Its extensive use in automotive body structures, railway coaches, aerospace components, and domestic appliances is attributed to its high productivity, low cost, ease of automation, and consistent weld quality. As industries strive for lightweight and high-strength structures, resistance spot welding continues to play a crucial role in steel component assembly.

In the RSW process, overlapped metal sheets are pressed between water-cooled copper alloy electrodes. When a high electric current flows through the sheets for a short duration, heat is generated at the interface due to electrical resistance. This localized heating causes melting and formation of a weld nugget. Upon termination of current flow, the molten metal solidifies under applied pressure, creating a metallurgical bond. The quality of the weld is governed by precise control of parameters such as welding current, weld time, and electrode force.

Steel remains one of the most versatile engineering materials due to its strength, availability, and cost efficiency. Various grades of steel have been developed to meet specialized requirements. Mild steel is commonly used because of its ductility and excellent weldability. Stainless steel is preferred for applications demanding corrosion resistance, while advanced high-strength steels (AHSS) are increasingly utilized in the automotive industry to reduce vehicle weight without compromising safety.

1.1 Literature Survey

The generated heat causes localized melting, forming a weld nugget after solidification.

The growing demand for lightweight, strong, and cost-effective structures has increased the application of various grades of steel in engineering industries. Mild steel is commonly used due to its good weldability and

low cost. Stainless steel is preferred for corrosion resistance and durability, while advanced high-strength steels are used to reduce weight without compromising strength. However, welding these different grades of steel using the same parameters can lead to inconsistent weld quality.^[1]

Spot welding parameters play a crucial role in determining weld strength and quality. Improper selection of welding current, time, or electrode force can cause defects such as expulsion, cracks, insufficient nugget formation, or excessive electrode indentation. Therefore, experimental investigation and analysis are necessary to understand the behavior of different steel grades under spot welding conditions.

1.2 General Studies on Resistance Spot Welding

Extensive research has been carried out on resistance spot welding due to its industrial importance. Foundational studies explain that heat generation and nugget formation are primarily controlled by welding current, time, and electrode force. Among these, welding current is widely reported as the most influential parameter affecting nugget diameter and joint strength, while time and force act as supporting factors.

Low-carbon steels have been reported to possess excellent weldability with a wide processing range, making them suitable for experimental studies. Investigations show that tensile shear strength increases with welding current up to an optimal limit, beyond which expulsion occurs, reducing joint strength.^[2]

1.3. Influence of Welding Parameters on Mechanical Properties

Research focusing on the relationship between nugget size and joint strength indicates that larger nuggets typically result in pull-out failure, which is considered a desirable failure mode. Conversely, smaller nuggets often lead to interfacial failure. Studies also suggest that a critical nugget diameter is required to ensure acceptable weld performance, making failure mode analysis a reliable indicator of weld quality.

Design of Experiments (DOE) approaches confirm that welding current has the highest statistical significance, while electrode force influences surface indentation and expulsion control.^[3]

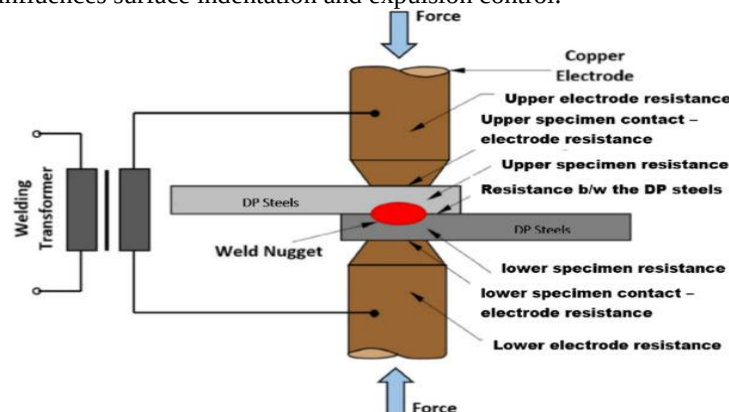


Fig -1 Resistance spot welding

2. LITERATURE SURVEY

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2.3 Spot Welding of Stainless Steel

Studies on austenitic stainless steels highlight the need for careful parameter optimization due to their high electrical resistance and low thermal conductivity. Improper control may result in excessive heat input, leading

to distortion or cracking. Optimization techniques such as Taguchi and Grey Relational Analysis have been effectively applied to improve weld strength and nugget consistency in stainless steels.

2.4 Spot Welding of Advanced High-Strength Steels

The increasing use of AHSS grades such as DP600 and DP780 has led to focused research on their spot welding characteristics. Findings indicate that current density significantly affects nugget formation and microstructure. Due to rapid cooling, martensitic structures often form in the weld nugget, resulting in high hardness but reduced ductility. Excessive heat input has been linked to brittle fracture behavior.

2.5 Microstructure, Hardness, and Failure Behavior

A typical spot weld consists of the fusion zone, heat-affected zone (HAZ), and base metal. Mild steels commonly exhibit ferrite-pearlite structures, while high-strength steels show martensitic or bainitic microstructures in the fusion zone. Hardness measurements reveal that the HAZ often has lower hardness, making it susceptible to crack initiation. Failure modes such as interfacial failure and pull-out failure are widely studied, with pull-out failure being preferable. Dynamic and fatigue performance under real service conditions remains a relatively underexplored area, especially for high-strength steels subjected to crash or impact loading.

Research Gap

Despite extensive studies, several limitations remain:

- Limited research on dynamic and fatigue behavior of spot-welded joints
- Insufficient understanding of dissimilar steel combinations
- Lack of integrated models linking microstructure evolution with mechanical response

3. METHODOLOGY

3.1. Material Selection

Mild steel, stainless steel (AISI 304/316), and advanced high-strength steel (DP600) will be selected.

3.2. Welding Experiments

Resistance spot welding trials will be conducted by varying welding current, time, and electrode force based on DOE principles.

3.3 Mechanical and Metallurgical Testing

- i. Tensile shear testing to determine joint strength and failure mode
- ii. Metallographic analysis to measure nugget diameter and microstructure
- iii. Vickers hardness testing across weld zones

3.4. Statistical Optimization

Taguchi and ANOVA methods will be used to identify significant parameters and optimal conditions.

Expected Outcomes

- i. Optimized welding parameter guidelines for different steel grades
- ii. Improved correlation between process parameters and mechanical properties
- iii. Enhanced understanding of failure mechanisms
- iv. Practical recommendations for industrial spot welding applications

4. CONCLUSION

Resistance spot welding performance is strongly influenced by both material properties and process parameters. Mild steel exhibits excellent weldability, while stainless steels and advanced high-strength steels require precise parameter control to avoid defects. Experimental investigation combined with statistical optimization provides an effective approach to improving joint quality. Future research should focus on dynamic loading, dissimilar materials, and advanced modeling techniques to meet the evolving demands of modern manufacturing industries.

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