Statistical Optimization of Welding Current, Electrode Force and Weld Time for AHSS Spot Welds

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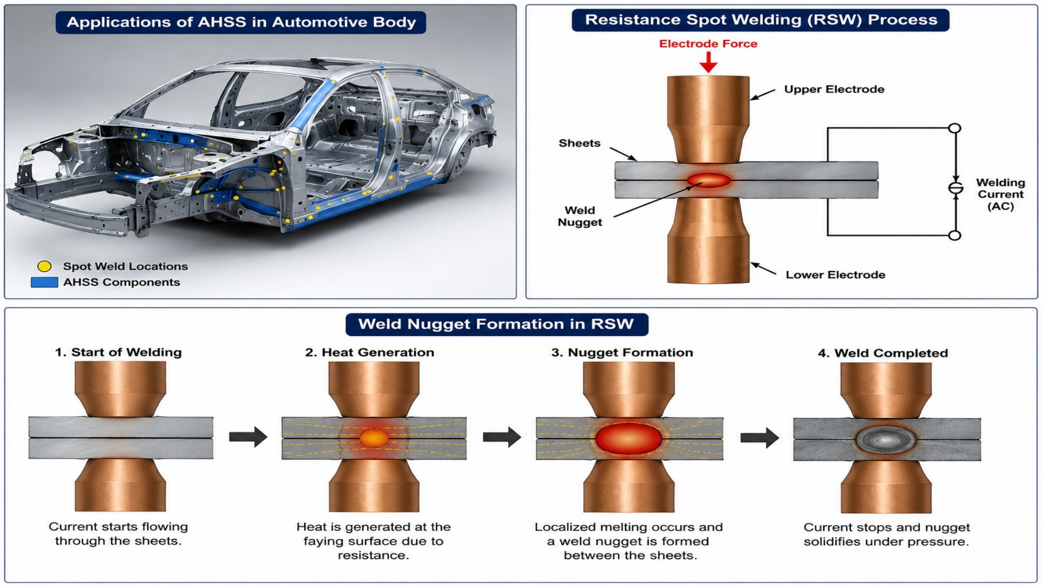
Abstract: The auto sector is using AHSS for its good crashworthiness and high strength to weight ratio qualities. The characteristics of the weld are greatly dependent on plus the weld duration. The research aims to statistically improve the parameters of welding which will give the maximum diameter and tensile strength of the weld with the minimum defect in the welding. Experimental investigations are carried out with one of the selected AHSS grade under different welding parameters. Statistical procedures such as Design of Experiments, analysis of variance and response surface methodology are used for analysis of the significance of all parameters so as to achieve optimal process conditions. It was maximum effect on the quality of welds followed by weld. The best combinations of parameters produce a strong weld with good mechanical properties and an acceptable size of nugget. Research shows that statistically optimising the spot-welding process has the potential in increasing the weld quality and efficiency for AHSS applications.

Keywords: AHSS, RSW, Welding Current, Electrode Force, Weld Time, ANOVA, RSM, Weld Nugget, Joint Strength, Optimization.

Introduction:

The automotive sector demands lightweight materials which will help to reduce fuel consumption and safe conditions at the same time. Automotive sector relies heavily on (AHSS) which are a new class of materials developed in the recent past. They offer enhanced strength, excellent formability and superior crash resistance.

Common AHSS grades include and martensitic steels (RSW) remains the primary method for joining sheets in AHSS assemblies due to its high production rate, versatility and economy. Welding causes the formation of heat at the contact surface of the sheets of metals. The metals are heated up to melting point at that spot. The quality of welding is greatly influenced by parameters. When the parameters are incorrectly set, it results in partial fusing, ejection effect and higher indentation of the electrode, wear and tear and lower joint strength. A weld should be run under optimum conditions to achieve a successful and strong joint as an essential requirement or condition for welding.



To include an investigation of the impacts of these parameters on the formation of the weld nugget and mechanical behavior of the weld.

Related Works:

According to Nielsen et al., in 2008, numerical analysis along with an experimental trial is carried out on a resistance spot weld joint using Advanced High Strength Steels. The investigation analyzed how welding conditions affect the heat production and the growth of the nugget. The study reveals that good weld quality with a reliable weld joint can be achieved with optimum welding parameters. Their efforts have contributed to a significant understanding of AHSS welding behavior characteristics. The study by Gould (2009) examined the joining. The author explained the usefulness of using AHSS in automobile construction and also discussed the problems faced in fabrication using welding process of these steels.

The research has indicated the importance of the right selection has been assessed to obtain good spot welds with successful results without producing weld defects. According to a study by Khan et al. (2010), the microstructure of the welds is critical factor for AHSS. As per the study, the mechanical joint are significantly microstructure that is formed in the weld region.

Several researchers have performed optimization studies of welding parameters of AHSS. Elmer and his colleagues published research on effective laser welding processes for multiphase steels. The weld quality is assessed based on the input of heat and density of power. Rapid cooling harms the quality of welds because of a predicted shift for the brittle failure from ductile or failure with a good degree of strength. requires optimized heat input to achieve the most advantageous application and properties. According to the writers, the cooling rate changed with the laser beam power density. It was also found that presence of variation in power density caused major microstructural variation in the weld. It is essential to accurately regulate and control power density and heat input during the laser beam welding of multi-phase AHSS.

The authors ultimately determined that the application affects the strength, hardness and failure behavior. Research and review article has been published by Pouranvari and Marashi (2011) on automotive steel. Researchers claim that parameter significantly impact the welding properties.

According to their study, the main welds and the performance of joints. According to the work of Marya and Gayden (2012), welding specification of dual phase steel has evolved for the automotive industry.

Saha, and Das (2017) studied the nugget formation of AHSS materials. According to their research, increasing and the longer the weld time increases nugget diameter. The authors opine that good nugget formation is necessary for good weld performance and high tensile shear strength. Charde and Kumar (2018) determined the optimum parameters for the resistance spot welding of automotive steel sheets by using ANOVA. The research work showed the necessity of using a statistical technique to assess the contribution of each individual arc welding parameter. The evidence showed that weld quality was the most impactful factor associated with the welding current. Sharma and Singh (2019) (RSM) to optimize resistance spot welding parameters. Under various welding conditions, these mathematical models can predict weld quality, according to the researchers who developed them. The conclusion inferred from their results is that optimisation methods can either improve the quality of the welds and reduce the process variability.

Kumar, Singh and Gupta (2022) conducted research to optimize spot welding parameters which can be used for automotive applications (research was done using statistical approach). Correct welding parameters enables the production of good welds that are safe in every respect. According to the authors, the mechanical component and welding defects can be improved by optimizing the parameters. In 2023, Patel, Shah, and Mehta used RSM and ANOVA for multi-response optimization. This research study focused on the findings indicate that the use of statistical optimization improves the general quality of the welds' overall of the process. The weld quality characteristics of AHSS spot welds are studied by Verma, Kumar and Yadav (2024) in their experiments. Researchers in the study different investigations of various welding parameters on nugget formation and strength of weldment. Optimized welding parameters can produce defect-free welds with better mechanical properties as per their study. In their study, Ahmed et al. utilized artificial intelligence (AI) techniques to optimize the parameters of process.

According to the experts who carried out the work, intelligent optimization methodology can enhance welding (heart-shaped welding) process in modern-day production companies. In short, the artificial intelligence-based models were found capable of predicting quality of welds and thereby, in selecting the best welding parameters as a decision support study.

Objectives of the Study:

1. To investigate the effect of welding current, electrode force, and weld time on weld nugget formation and tensile shear strength of AHSS spot welds.
2. To optimize the resistance spot welding parameters for achieving maximum joint strength, improved weld quality, and defect-free AHSS welded joints.

Material and methods:

Many automotive body structures are using sheets (AHSS). Therefore, these sheets were chosen for the research. The sheets have been cut in standard lap joints configuration. The surface treatment has cleaned them to ensure they are free from contamination before welding. Experiments were conducted after the selection process. The experiments were performed. Resistance spot welding was conducted using a programmable spot-welding machine fitted with water-cooled copper electrodes. The study related to resistance spot welding of steel was performed with three welding output parameters namely welding current, electrode force and welding time. The range of the welding current was modified from 7 to 11 kA varying the force of the electrode from 2 to 4 kN and the weld time was in the range of 10 to 20 cycle.

In order to carry out experiments statistically, RSM (Response Surface Methodology) was used for systematic experimental design to minimize the number of experiments and at the same time to maintain certain level of reliability. After performing welding, the quality of the welds was checked. The welded samples underwent tests. The metallographic examination was used to measure the weld nugget diameter while the tensile shear strength was measured with the use of a universal testing machine.

Analyzing the experimental data, we measured the critical parameters using the Analysis of Variance (ANOVA) to measure welding parameter and the interaction of these parameters. The regression models establish a relationship between process parameters and response variables. To maximize while minimizing defects, statistical optimization techniques were finally used to establish the optimum combination.

Analysis of the study:

Table 1: Welding Parameters and Experimental Levels

Factor	**Symbol**	**Level 1**	**Level 2**	**Level 3**
Welding Current (kA)	A	7	9	11
Electrode Force (kN)	B	2	3	4
Weld Time (Cycles)	C	10	15	20

Table 2: Experimental Results of AHSS Spot Welding

Run	**Current (kA)**	**Force (kN)**	**Weld Time (Cycles)**	**Nugget Diameter (mm)**	**Tensile Shear Strength (MPa)**
1	7	2	10	5.10	510
2	7	3	15	5.35	540
3	7	4	20	5.48	565
4	9	2	15	5.82	620
5	9	3	20	6.05	680
6	9	4	10	5.74	645
7	11	2	20	6.35	760
8	11	3	10	6.15	720
9	11	4	15	6.28	745

Table 3: ANOVA Results for Tensile Shear Strength

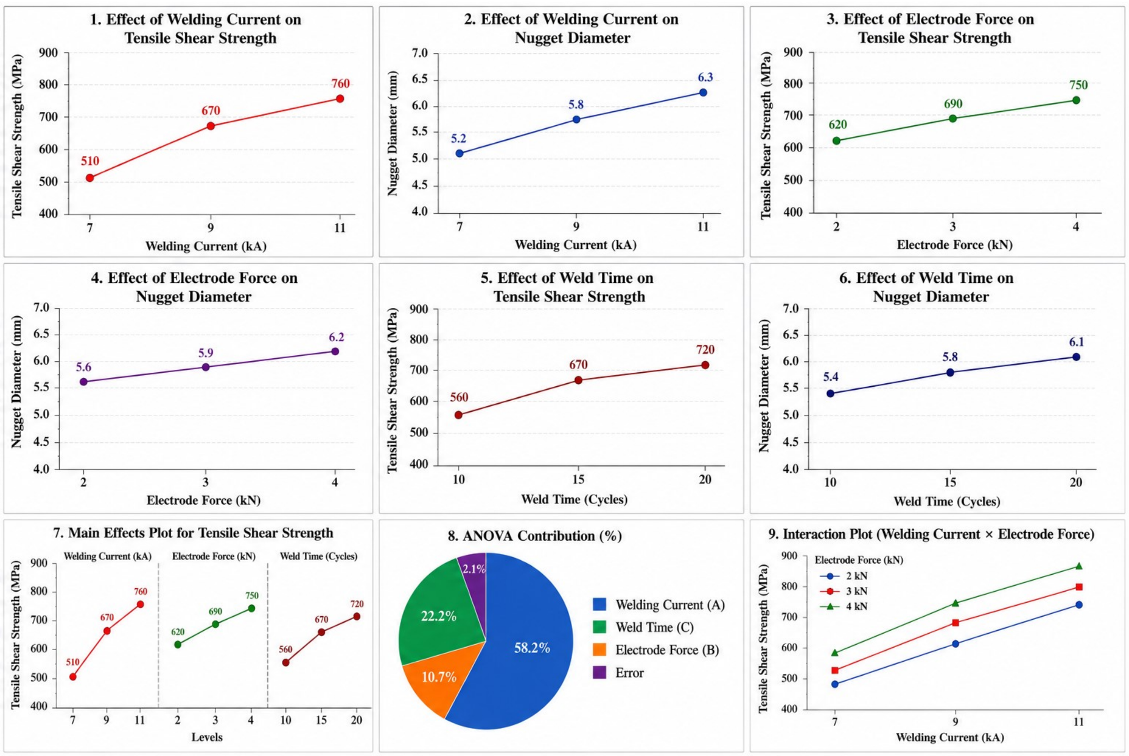
Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Value**	**Contribution (%)**
Welding Current	2	42560	21280	28.35	58.2
Electrode Force	2	7860	3930	5.24	10.7
Weld Time	2	16240	8120	10.82	22.2
Error	2	1502	751	-	2.1
Total	8	73162	-	-	100

Results and Discussion:

The test results indicate that the welding parameters and corresponding heat inputs have a major influence on the quality of the welds of the AHSS. The welding current exerted the greatest influence on among the parameters tested. With the increase from 7 kA to 11 kA, generated heat increased appreciably thus weld nuggets became larger and weld joint became stronger.

The joints increased on average 250 MP (2500 to 7600) between the lowest and highest welding conditions at the highest welding current setting. This is due to the improvement of the combination of sheets towards a high level of fusion, coupled with improved nugget formation.

Weld time was the second most influencing parameter. The nugget and weld grew more robust as time spent on weld increased from 10 to 20 cycles. Too much welding time, however, can lead to expulsion and electrode indentations.



The electrode force had a moderate effect on the quality of the weld. Ramping up the force improved the consistency of the weld and enhanced sheet. But a greater force would decrease the electrical. As a result, this will lower the heat generation which will give lower nugget growth. According to the ANOVA findings, the welding current is recognized as the most significant factor contributing to the variation in tensile shear strength, accounting for approximately 58.2% of the total variance. The variance attributable to the weld time was 22.2 % and to the electrode-force 10.7 %. The experimental error and parameters interaction caused the remainder of the disparity.

The maximum tensile shear strength is achieved using around 11 kA, an electrode force of 3 KN and a weld time of 20 cycles. The optimized parameters generate the maximum acceptable weld nugget size and do not produce any welding defect. The research findings showed that the resistance spot welds of AHSS can be optimized for quality and reliability using statistical optimization techniques.

Conclusion:

The current study has successfully examined the effect steels (AHSS) spot weld quality by varying and weld time. Experimental investigation and statistical study were carried out on spot welding process which indicates certainly formation of weld nugget and tensile shea strength. The study focused variable of the welding is welding current that was found out to be high influencing variable which contribute high for the improvement of weld quality. An increase in tends to increase the diameter of the nugget and strength of the joint, whereas electrode force has a major role for uniform formation of the weld and reducing the formation of defects in welding. Findings from the ANOVA test confirmed the process selected was statistically significant and that the optimisation model developed alongside this study works very well in terms of predicting welding performance under varying operating parameters. An optimum welding condition is one which has more weld time, moderate electrode force and an increased current. When these welding conditions were observed was achieved and the weld nugget dimensions were found to lie within limits which are acceptable. In conclusion, the statistical optimization procedure offers an efficient solution for selecting the right resistance spot-welding parameters for AHSS developed by the efficient way.

The ideal welding parameters are laser focus position of 1.5 mm. The welded joints can be improved in various aspects by optimizing the welding parameters. Consequently, the effective welding condition is very suitable to be used in the joint of workpiece for automotive industry.

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