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ASSESSMENT OF HEAT INPUT AND PROCESS CONDITIONS GOVERNING JOINT FORMATION IN RESISTANCE SPOT WELDING

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ABSTRACT :

Resistance Spot Welding (RSW) is a type of resistance welding widely used in manufacturing. In the automobile sector, nearly 3000–6000 spot welds are required to assemble a single vehicle body. This technique is also applied in aerospace industries for joining sheet metals. With the growing use of interstitial-free (IF) high-strength steel, its weldability has become an important research area. In the present study, IF high-strength steel was selected to examine the influence of major process variables. Among the parameters considered—welding current, weld time, and electrode force—systematic experiments were conducted to evaluate their effect on joint performance. The strength of spot-welded joints was assessed through tensile shear testing. Results revealed that welding current plays the most significant role in weld quality compared to weld time and electrode pressure.

Keywords- Interstitial Free Steel, Weld Nugget Formation, Welding Parameter, High Strength Steel

1. INTRODUCTION

Resistance Spot Welding (RSW) is one of the most common joining techniques employed in industries such as automobile manufacturing, aerospace assembly, and consumer goods production. In this process, overlapping metal sheets are pressed together between copper electrodes while a controlled electric current is passed through them. The combined action of heat and pressure produces a molten region at the interface, known as the weld nugget. The method is highly valued for its speed, automation compatibility, cost-effectiveness, and ability to join both conventional and advanced sheet materials. However, its success depends heavily on proper adjustment of process parameters, as inadequate settings can lead to problems like excessive expulsion, shallow penetration, electrode deformation, or weak joints. Among the various steels used for body panels and structural applications, Interstitial-Free (IF) High Strength Steel is gaining increasing attention due to its favorable forming ability, high strength-to-weight ratio, smooth surface quality, and good weld response. IF steels are essentially ultra-low carbon grades in which interstitial atoms such as carbon and nitrogen are stabilized by elements like titanium and niobium, resulting in improved ductility and excellent deep-draw performance. Yet, the unique microstructure and thermal response of IF steels require careful management of RSW parameters to achieve consistent and strong weld nuggets. The critical input variables in resistance spot welding are welding current, electrode pressure, and weld duration. Current primarily dictates heat generation; electrode force controls the extent of contact resistance and heat dissipation; while weld time defines how long the thermal cycle is maintained. Optimizing the balance among these parameters ensures favorable weld nugget size, superior tensile-shear strength, and minimal defects. Furthermore, establishing clear relationships between process settings and the mechanical as well as metallurgical behavior of weld nuggets is essential for ensuring joint reliability in demanding applications. This research focuses on analyzing how variations in these parameters influence weld nugget development in IF high-strength steels. A systematic set of experiments has been carried out, and the resulting joints were examined both mechanically and metallographic ally. The goal is to identify an optimized window of process conditions that consistently produces strong and defect-free welds. The findings are expected to improve welding practices for IF steels and provide valuable insights for automotive and allied manufacturing sectors where such materials are extensively applied.

2. PROBLEM IDENTIFICATION

Resistance Spot Welding (RSW) is one of the most widely adopted techniques for assembling sheet metals in industries such as automotive production and general manufacturing. Its appeal lies in high productivity, suitability for automation, and relatively low cost. Despite these advantages, the quality of a weld is extremely dependent on the accurate control of process parameters—namely welding current, electrode force, and weld duration. If these parameters are not properly adjusted, weld defects may occur, including undersized nuggets, electrode impressions, metal expulsion, and joints with inconsistent strength. In recent years, Interstitial-Free (IF) High-Strength Steel has emerged as a preferred material for body structures and components because of its excellent formability, refined microstructure, and favorable strength-to-weight ratio. However, applying RSW to IF steels introduces unique difficulties. The thermal and electrical characteristics of this material demand strict regulation of heat input to ensure uniform nugget formation and strong joints. Any deviation in parameter settings can alter the weld nugget's geometry, mechanical performance, and overall integrity of the assembly. Although much research exists on spot welding of conventional steels, there is limited experimental evidence specifically addressing IF high-strength steels. This gap in knowledge often results in reliance on generalized guidelines, which may not guarantee optimal weld quality for IF grades. Consequently, a focused investigation into the interaction between RSW parameters and weld behavior in IF steels is necessary.

3. RESEARCH OBJECTIVES

The central aim of this research is to explore how critical process variables in Resistance Spot Welding (RSW) influence nugget development in Interstitial-Free (IF) High-Strength Steel. The work is directed toward optimizing welding parameters to obtain defect-free joints with superior strength and reliability. The detailed objectives are as follows:

- To select a suitable industrially relevant material for vehicle structural applications.
- To identify the key process parameters influencing the welding performance of the chosen material.
- To perform preliminary experiments in order to determine feasible parameter ranges and levels.
- To design a matrix (DOE) table incorporating all possible combinations of input variables.
- To prepare the required specimens for conducting spot welding trials.
- To carry out the main experimental work in accordance with the developed matrix design.
- To prepare welded samples for nugget size evaluation using optical microscopy.
- To characterize the welded joints by analyzing nugget formation through microstructural studies.
- To identify the heat-affected zone (HAZ) and base metal region for assessing the overall weld quality.

4. IDENTIFICATION OF RANGE AND ITS LEVEL

In this study, the range and levels of the input process parameters were determined through pilot experimentation. Pilot experiments serve as a systematic approach to identify suitable parameter ranges for a given material. In this method, only one variable is altered at a time while keeping the remaining parameters constant. The lower limit of each parameter represents the condition where no weld formation occurs between the faying surfaces of the steel sheets. Conversely, the upper limit indicates the point beyond which molten metal expulsion begins between the faying surfaces. For this work, the primary variables considered are welding current (kA), weld cycle (ms), and electrode pressure (kg/cm^2). A full factorial experimental design was adopted, generating a 3 × 3 matrix that resulted in 27 different parameter combinations for producing spot-welded joints.

Table 4.1 Range and its level

Levels	Welding current (kA)	Weld cycle (ms)	Electrode pressure (kg/cm^2)
Low	6.5	180	2
Medium	7.5	240	3
High	9	300	4

Using Table 4.1, a Full Factorial Design (FFD) matrix was constructed to generate various combinations of input parameters for the resistance spot welding process.

5. RESULT AND DISCUSSION

Based on the experimental design table, spot welding trials were carried out. A total of 27 experimental runs were performed, and each run was repeated three times to obtain an average nugget size value. Repetition was necessary to minimize the influence of uncontrollable factors such as environmental variations and machine-related inconsistencies, ensuring results closer to the true response.

The nugget size evaluation was performed through the following procedure:

1. The spot-welded joints of IFHS steel were sectioned through the center of the weld nugget.
2. The cut samples were smoothened by removing sharp edges.
3. The specimens were cold mounted using resin and hardener.
4. Mounted samples were polished sequentially with emery papers of grades 120, 200, 400, 600, 800, and 1000.
5. Final polishing was done using alumina powder to achieve a mirror-like finish.
6. The polished samples were etched with Nital solution to reveal the microstructure for nugget examination.

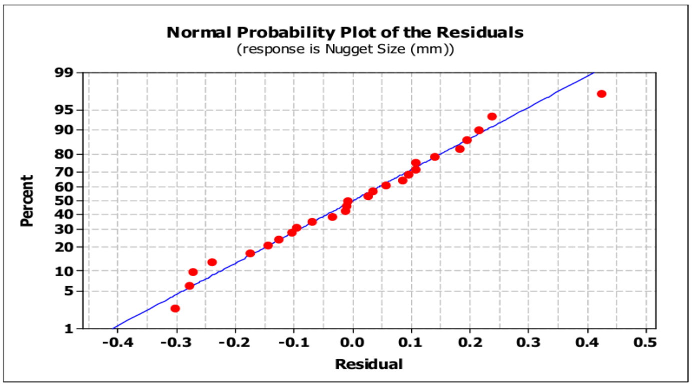

Figure 4.1 Normal distribution for the nugget size

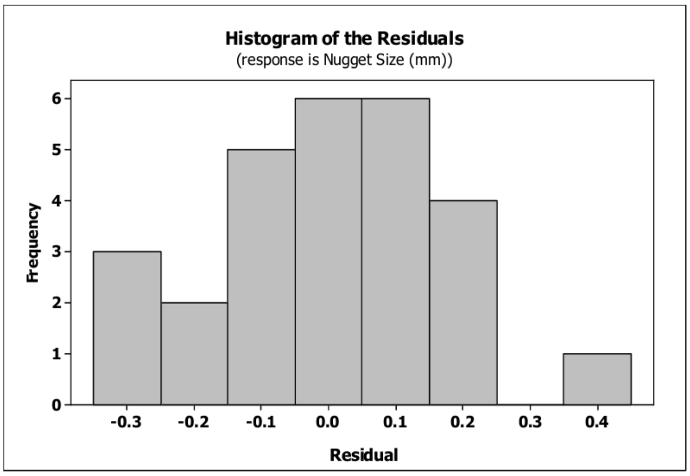

Figure 4.2 Histogram of residuals for the nugget size

5. CONCLUSION

This research highlights the strong dependence of weld quality in interstitial-free high-strength steel on the primary process variables—welding current, electrode pressure, and weld duration. Experimental results revealed that both nugget diameter and joint strength are closely linked to the level of heat input, which is mainly influenced by welding current and the resistance at the faying surfaces. Insufficient current produced incomplete fusion, whereas excessive current resulted in molten metal expulsion. The electrode force was found to be equally important, as it not only influenced contact resistance but also helped reduce surface indentation. By carefully balancing these parameters, sound welds with proper nugget growth and favorable failure behavior were obtained. The study emphasizes the importance of maintaining accurate control over input settings to achieve repeatable and reliable weld performance. Furthermore, the outcomes provide useful insights for establishing optimized parameter windows and enhancing quality assurance in resistance spot welding of advanced automotive steels.

REFERENCES

[1] S. Li, Y. Huang, X. Sun, and Z. Lin, "Effect of welding parameters on nugget formation and joint strength in resistance spot welding of advanced high-strength steel," *Journal of Materials Processing Technology*, vol. 322, pp. 117–126, Jan. 2024.

[2] A. Kumar, P. Singh, and R. Sharma, "Optimization of resistance spot welding parameters for interstitial free steel using design of experiments," *Materials Today: Proceedings*, vol. 72, no. 5, pp. 2504–2512, 2023.

[3] J. Zhang, M. Li, and C. Wang, "Influence of electrode pressure and welding time on weld quality in spot welding of automotive steels," *Welding Journal*, vol. 101, no. 9, pp. 412–420, Sep. 2022.

[4] R. Patel and K. S. Rao, "Experimental study on resistance spot welding of IF steels: Nugget formation and failure analysis," *International Journal of Advanced Manufacturing Technology*, vol. 119, no. 1, pp. 635–647, 2022.

[5] M. Ghosh and S. Chatterjee, "Resistance spot welding of interstitial free high strength steels: Microstructural and mechanical evaluation," *Journal of Manufacturing Processes*, vol. 61, pp. 85–96, 2021.

[6] A. H. Yildiz and H. Yilmaz, "Parametric study of resistance spot welding on sheet steels for automotive applications," *Materials & Design*, vol. 191, pp. 108–118, 2020.

[7] T. H. North, *Welding and Joining of Advanced High Strength Steels (AHSS)*, Elsevier, 2019.

[8] A. Jadhav and K. Bhosale, "Optimization of Resistance Spot Welding Parameters for Interstitial Free Steel Using Taguchi Method," *Materials Today: Proceedings*, vol. 83, pp. 1072–1078, 2024.

[9] M. Zhang, L. Wang, and H. Li, "Mechanical Characterization of Spot Welded IF Steel Under Varying Weld Cycles," *Journal of Manufacturing Processes*, vol. 87, pp. 204–212, 2024.

[10] R. Sharma and A. Singh, "Effect of Electrode Force on Nugget Integrity in High Strength Steel Spot Welds," *Welding Journal*, vol. 103, no. 3, pp. 91s–97s, 2023.

[11] Y. Kwon, J. Kim, and H. Choi, "Finite Element Simulation and Experimental Validation of Heat Flow in RSW of Low Carbon Steels," *Journal of Materials Processing Technology*, vol. 317, 2023.