Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 11, No.4, November : 2024

# RESISTANCE SPOT WELDING OF AUTOMOTIVE STEEL SHEETS

**DR G. Janardhan,** Senior Assistant Professor, Dept.Of Mechanical, GMR Institute of Technology College, Rajam
**G. Prasanth,** Student, Dept. Of Mechanical, GMR Institute of Technology College, Rajam
**P, Srinivasrao,** Student, Dept. Of Mechanical, GMR Institute of Technology College, Rajam
**K. Tharun kumar,** Student, Dept. Of Mechanical, GMR Institute of Technology College, Rajam
**A. Lokesh,** Student, Dept. Of Mechanical, GMR Institute of Technology College, Rajam
**J. Alekhya** Student, Dept. Of Mechanical, GMR Institute of Technology College, Rajam

## ABSTRACT
Resistance spot welding (RSW) of aluminum/steel is a key process in automotive manufacturing in response to the industry's need for lightweight, high-strength structures. However, there are metallurgical and physical incompatibilities inherent between aluminum and steel, including oxide film formation, brittle intermetallic compounds (IMCs), and inconsistent heat distribution. This review collects progress to date on electrode design and its influence on weld quality. The study specifically looks into generalized electrode shapes, categorized as planar (P-type) and spherical (S type), and how they affect heat generation, IMC formation, and mechanical performance. FEM simulations and experimental validations highlight the superiority of an asymmetric S-P combination of the electrode. This geometry reduces sheet deformation and optimizes nugget size and strength over traditional symmetric setups that pose inherent drawbacks.
In heat energy dynamics and IMC growth kinetics, it is stressed that the factors of interest depend heavily on the geometry and size of electrodes. Optimizing the 9 mm and 60 mm diameters of S-P type electrodes at P and S types respectively, resulted in the best balance of mechanical strength and minimal deformation. These results clearly make way for practical recommendations on welds strong and economical, promoting the wider application of hybrid aluminum-steel structures in modern industry. The present review is considered a detailed guide to enhance RSW techniques, a bridge between theoretical models and practical applications.

**Keywords**:
Advanced High-Strength Steels (AHSS), Spot-Welding Behavior, Tensile Shear Strength, Microstructure and Phase Transformation, Quenching and Partitioning (Q&P) Steels

## I. Introduction
Resistance spot welding (RSW) is one of the most widely utilized joining processes in the automotive industry. It has gained immense attention due to its easy handling for assembling steel sheets within vehicle body structures. Recently, high-strength steel grades have gained importance among automotive manufacturers as vehicle safety, fuel efficiency, and environmental standards are being carried on. These advanced high-strength steels (AHSS) provide an ideal balance between strength and ductility, making it possible to produce lighter but stiffer vehicle components that comply with the demanding specifications of modern automotive requirements.
Regardless, the efficiency of the resistance spot welding process will be dependent upon several factors, namely, the material properties of the steel sheets, welding parameters, and the microstructural changes resulting from the process. The overall performance of the spot-welded joints is evaluated based on parameters such as tensile shear strength, weld nugget size, modes of failure, and hardness distribution across the weld region. This will be very vital for the structural integrity and safety of the vehicle.
The high strength and variability of microstructures among AHSS varieties - such as dual-phase (DP) and transformation-induced plasticity (TRIP) steels - make them more difficult to produce with the spot welding process. Q&P steels are another complicating factor, as the heat treatment processes

optimized for these steels affect the transformations they undergo, which in turn affects weld quality. It is therefore necessary to understand the effects of initial microstructure, phase transformations during cooling, and critical welding parameters to achieve reliable welds without defects such as expulsion or cracking.
This paper aims to provide a comprehensive analysis of resistance spot welding techniques for automotive steel sheets, focusing on the metallurgical phenomena, mechanical performance, and optimization of welding parameters. By exploring advanced characterization methods and experimental approaches, this study seeks to establish criteria for high-quality, industrially viable welds, contributing to the broader goals of enhancing vehicle safety and manufacturing efficiency. This introduction outlines the relevance and challenges of resistance spot welding in the automotive industry, emphasizing the importance of understanding material behavior and process optimization

## II. Literature

RSW is widely used in the automotive, shipbuilding, and light steel industries because of the reliability of joining thin metal sheets. It carries out operations through the application of heat along with pressure through copper electrodes. Research has extensively looked into the influence of welding parameters, including welding current, electrode pressure, squeeze time, and welding duration, on the mechanical performance and corrosion resistance of materials such as stainless steel (AISI 316L) and interstitial-free steel (IF steel).
Optimization techniques such as the DOE and Taguchi methods have been employed in studies related to AISI 316L stainless steel in order to determine the ideal welding conditions. Observations suggest that controlled parameters play a crucial role in achieving maximum tensile-shear strength while minimizing corrosion rates. For instance, increases in electrode pressure and welding currents boosted pitting and corrosion effects due to thermal stress and degradation of the Cr coating. Scanning Electron Microscopy (SEM) corrosion tests revealed localized corrosion phenomena at nugget interfaces.
Investigations of the corrosion behavior of welds of zinc-coated IF steel were directed to corrosion studies in different solutions, such as NaCl with either added NaOH or $H_2SO_4$ using polarization techniques. In these studies, it was pointed out that welds showed higher corrosion susceptibility than base metal due to non-uniform coatings and microstructural changes that include martensite. Microstructure and resistance were also significantly influenced by welding heat input. Lower heat inputs favored more uniform passive films, while higher inputs lowered the corrosion resistance since Zn coatings resulted in neither uniform nor even coating and residual stress built up.
These studies highlight the complex interplay of thermal, mechanical, and electrochemical factors in RSW. Although techniques improve, such as finite element simulations, to determine welding behavior, further research is warranted to close those gaps that appear related to the long-term effects of weld-induced microstructures and environmental conditions on weld integrity.
Resistance spot welding is a field that has evolved over time, particularly in joining dissimilar metal combinations such as aluminum to steel. This type of welding process is of significant importance for certain industry players, such as automotive, since its efficiency is challenged by the diversity of the physical and metallurgical properties of metals. Significant improvements can be seen in welding parameters optimization, including current, pressure, and electrode design, in order to solve problems like intermetallic compound formation, mechanical strength, and corrosion resistance.
Recent research shows the significance of electrode design towards weld quality. In particular, using spherical (S) and planar (P) electrodes based on FEM analysis, it showed that the S–P configuration can provide better mechanical properties, less deformation, and heat diffusion compared to the traditional use of P–P or S–S electrodes. Optimizing the sizes of electrodes to 9 mm for P-type and 60 mm for S-type further improved lap-shear strength and reduced the thickness of the IMC layer, thus improving the durability of the joints.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 11, No.4, November : 2024

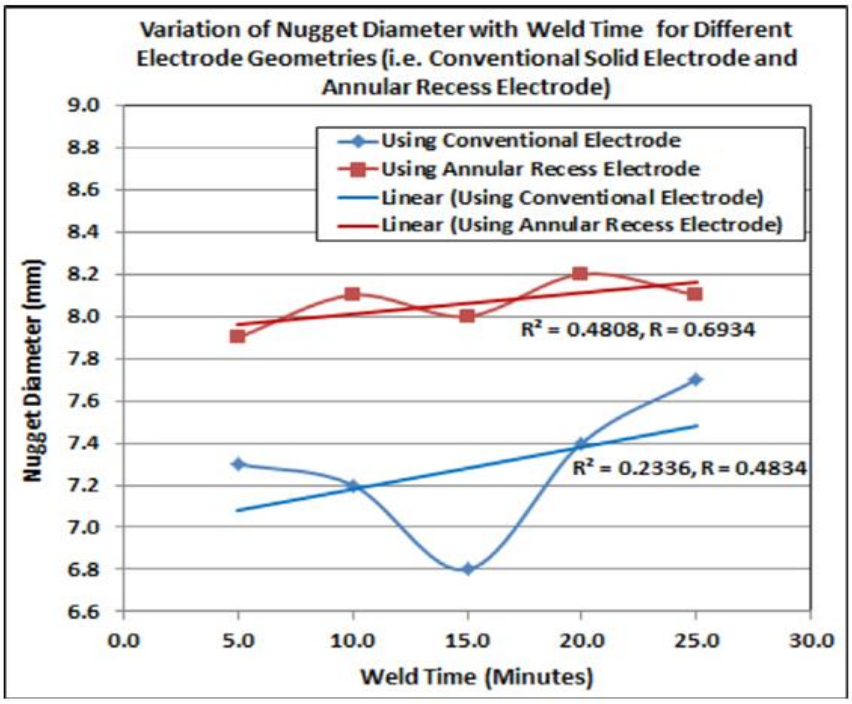


Fig.1 [7]

Corrosion resistance is another important parameter, especially for dissimilar metal welds exposed to aggressive environments. Investigations using electrochemical methods and scanning electron microscopy showed that localized corrosion predominates at nugget interfaces. Proper optimization of parameters can reduce this by ensuring uniform passivation, thus reducing residual stress.

Moreover, the advancement of numerical modeling, such as making use of FEM, has thrown more light into heat generation, nugget formation, and IMC growth during welding. These models validated experimental results by allowing careful control of thermal and mechanical fields in the weld to greatly improve weld quality.

In conclusion, while RSW remains a cost-effective and widely used joining method, ongoing innovations in electrode design, parameter optimization, and numerical modeling are crucial for meeting the demands of modern manufacturing, especially in the context of lightweight and sustainable materials.

The studies mainly explore the microstructure and mechanical properties of resistance spot-welded joints in advanced high-strength steels (AHSS), such as DP600 and DP780, and their combinations with softer or ultra-low carbon steel counterparts, such as DC54D. In these researches, there was an emphasis on the complexity of welding dissimilar thickness and material joints due to their variations in composition and mechanical properties, which may affect the microstructure, hardness, and failure mechanisms.

Microstructural Analysis

Welded joints have three discernible regions: base metal (BM), heat-affected zone (HAZ), and fusion zone (FZ). The FZ will have high martensite content, which is due to rapid cooling, whereas the HAZ has coarse-grained, fine-grained, and intercritical zones. There is a gradual increase in grain size and martensite volume fraction from BM to FZ. Martensite formation, essential for the joint's strength, is alloyed with elements and peak temperature during welding.

Mechanical Properties

The hardness distribution is highly varied across the weld, with FZ hardness often greater than BM hardness due to the presence of martensite. Dilution effects can cause a reduction in hardness, especially in dissimilar material joints. Tensile-shear testing shows two failure modes: interfacial failure and pullout failure. IF to PF transition is weld nugget size dependent, having a critical nugget diameter as the key determining factor.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 11, No.4, November : 2024

Process Optimization

Optimal welding parameters—such as current, time, and electrode force—are pivotal to achieving desirable nugget characteristics and mechanical performance. Excessive heat input can cause expulsion, reducing joint quality. Adjusting these parameters transitions failure modes from brittle IF to more ductile PF, enhancing energy absorption and structural integrity.

Dissimilar Welds

This type of combination, for example, DP600/DC54D, generates special problems due to property dissimilarity. While the DP600 side contributes high strength through martensite, the DC54D side, ferrite dominated, shows localized weakening at HAZ/BM interfaces, often because of grain growth anomalies and stress concentration there.

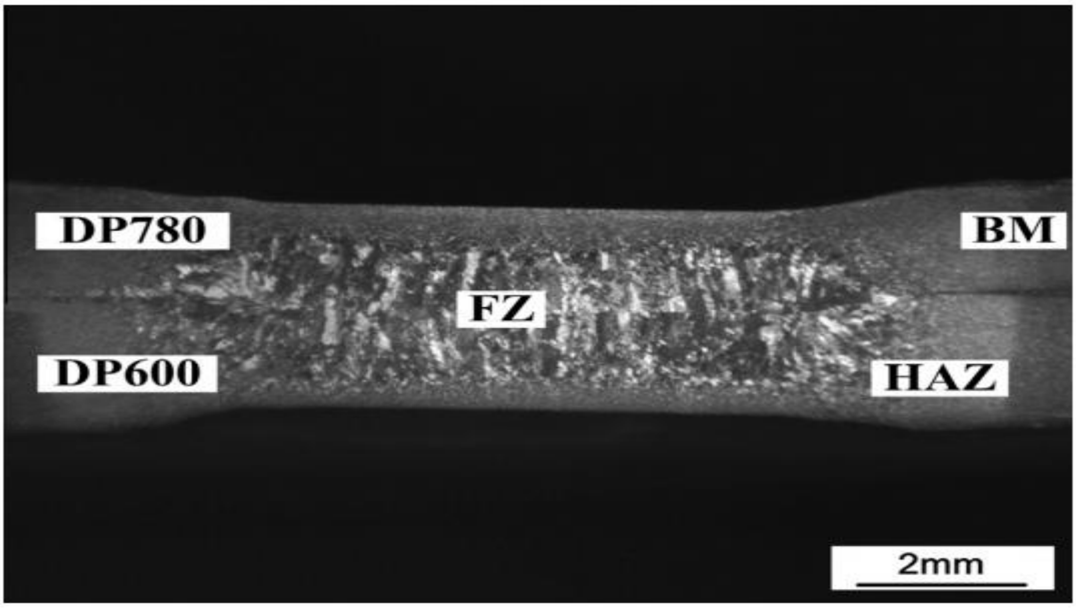


Fig.2 Typical macrostructure of weld joint [11]

These studies underscore the importance of tailored welding parameters to balance strength, ductility, and failure resistance in resistance spot-welded AHSS and dissimilar joints. The results obtained are critical for automotive and structural applications where both lightweight and crashworthiness are emphasized.

Third-generation AHSSs, like QP, for example, quenching and partitioning steels, are proven efficient in balancing strength and ductility for automotive applications. These studies emphasize the significance of process parameters, such as current, time, and pressure of the electrode, while also determining weld quality, nugget size, and mechanical outcomes like peak load and failure energy. Microstructural analysis shows that the FZ is predominantly composed of martensite, while the HAZ can soften considerably, especially in dissimilar welds involving softer steels like SPFC780Y.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 11, No.4, November : 2024

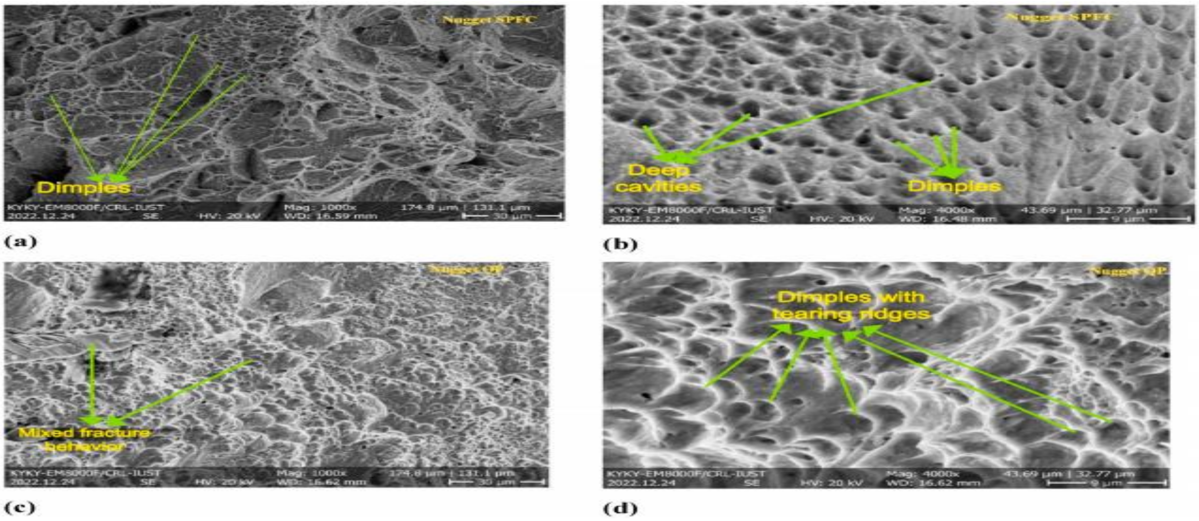


Fig.3 (a) the pulled nugget from the SPFC side, (b) higher magnification for the nugget on the SPFC side, (c) fracture surface on the QP side, and (d) higher magnification of QP side fracture surface.

Hardness profiles and fractography analyses reveal dilution effects in FZ as a function of chemical composition and its influence on mechanical performance. This work focuses on the pullout failure mode as the preferable outcome in energy absorption and structural integrity by optimizing the parameter setting. Innovative methods for predicting weld behavior as well as effects of asymmetric material properties further contribute towards the advancements of RSW for dissimilar AHSS combinations

## III. Conclusion

The interaction of welding parameters, microstructure, and mechanical overall performance in resistance spot welding of advanced high-energy steels- crucial insights into automotive applications. advanced excessive-energy metal grades, such as twin-section, transformation-prompted plasticity, and quenching and partitioning steels, are these days commercially hired because of their properties inclusive of electricity and ductility. but the complex nature of the microstructures of these grades of AHSS complicates the weldability; as a result, cautious optimization of technique parameters is needed.

The findings emphasize the effects of welding present day, time, and electrode stress at the weld pleasant and performance. certainly, those elements decide the FZ size, HAZ properties, and nugget formation. The microstructural analyses screen that the FZ is basically martensitic, giving excessive hardness and electricity, while HAZ softening often limits weld joint performance, regularly in dissimilar welds.

other examples contain DP600 with DC54D or Q&P980 with SPFC780Y, wherein belongings mismatch outcomes in unique issues. The electricity of the AHSS element is fine, but the softer counterpart can be weakened domestically, with common strain awareness and reduced resistance to failure. Optimization of the welding technique allows a transition from interfacial failure to the extra ductile pullout failure mode, improving power absorption and structural durability.

superior techniques, including fractography and hardness profiling, reveal that the chemical composition and dilution effects play an important role within the FZ. Predictive modeling and experimental strategies allowed best adjustment of welding parameters to obtain balanced mechanical residences. those studies collectively increase the knowledge had to make green RSW within the manufacturing of car manufacturing with lightweight designs without compromising the crashworthiness of these automobile designs.

typical, the incorporation of AHSS in automobile systems is modern; however, their successful welding depends upon an in-intensity understanding of metallurgical conduct and process optimization. these findings provide a strong foundation for designing excessive-performance, safe, and gas-efficient motors with the aid of accounting for the interaction of microstructural changes and mechanical necessities.

**References**

[1]Temiz, R. Ö., Onan, M., Cebi, H., Aslanlar, S., & Talaş, Ş. (2024). Effect of Electrode Type and Weld Current on Service Life of Resistance Spot Weld Electrode. International Journal of Automotive Science And Technology, 8(1), 52-64.

[2]Panza, L., De Maddis, M., & Spena, P. R. (2022). Use of electrode displacement signals for electrode degradation assessment in resistance spot welding. Journal of Manufacturing Processes, 76, 93-105

[3]Watmon, T. B., Wandera, C., & Apora, J. (2020). Characteristics of resistance spot welding using annular recess electrodes. Journal of Advanced Joining Processes, 2, 100035.

[4]Zheng, Z., Tao, J., Fang, X., & Xue, H. (2023). Life and failure of oriented carbon nanotubes composite electrode for resistance spot welding. Matéria (Rio de Janeiro), 28(1), e20230005.

[5] Zhou, L., Li, T., Zheng, W., Zhang, Z., Lei, Z., Wu, L., ... & Wang, W. (2022). Online monitoring of resistance spot welding electrode wear state based on dynamic resistance. Journal of Intelligent Manufacturing, 33, 91-101

[6]Zhou, K., Ren, B., & Yu, W. (2023). Optimized designing of generalized electrodes for aluminum/steel resistance spot welding process based on numerical calculation. *Journal of Manufacturing Processes*, *99*, 563-580.

[7]Watmon, T. B., Wandera, C., & Apora, J. (2020). Characteristics of resistance spot welding using annular recess electrodes. *Journal of Advanced Joining Processes*, *2*, 100035.

[8]Temiz, R. Ö., Onan, M., Cebi, H., Aslanlar, S., & Talaş, Ş. (2024). Effect of Electrode Type and Weld Current on Service Life of Resistance Spot Weld Electrode. *International Journal of Automotive Science And Technology*, *8*(1), 52-64.

[9]Hassan, L. I., & Lafta, H. D. (2023). The Effect of Electrode Geometry and Pre-heating Treatment on Resistance Spot Welding Strength. *Engineering and Technology Journal*, *41*(7), 954-962

[10] Haghshenas, N., & Moshayedi, H. (2020). Monitoring of resistance spot welding process. *Experimental Techniques*, *44*, 99-112.

[11] Perka, A. K., John, M., Kuruveri, U. B., & Menezes, P. L. (2022). Advanced high-strength steels for automotive applications: arc and laser welding process, properties, and challenges. Metals, 12(6), 1051.

[12] Hussein, K. M., Akbari, H., Noorossana, R., Yadegari, R., & Ashiri, R. (2024). Microhardness and microstructure correlations to the mechanical performance for dissimilar third generation AHSS resistance spot welding. Journal of Materials Research and Technology, 30, 7938-7945.

[13] Verma, R., Arora, K. S., Sharma, L., & Chhibber, R. (2021). Experimental investigation on resistance spot welding of dissimilar weld joints. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 235(2), 505-513

[14] Liu, F., Hou, Q., Hu, H., Ma, Y., Ning, S., & Wu, Y. (2020). Study on microstructure and properties of resistance spot welding of Mg/Ti dissimilar materials. Science and Technology of Welding and Joining, 25(7), 581-588.

[15] Mishra, D., Rajanikanth, K., Shunmugasundaram, M., Kumar, A. P., & Maneiah, D. (2021). Dissimilar resistance spot welding of mild steel and stainless steel metal sheets for optimum weld nugget size. Materials Today: Proceedings, 46, 919-924. Feng, M., Wang, Z., Ao, S., Ren, L., & Wang, P. (2024). Ultrasonic spot welding of open-cell Cu foam and Al plate: A study on the quality of joints. Journal of Materials Research and Technology, 29, 196-212.

[16] Zhou, L., Zheng, W., Li, T., Zhang, T., Zhang, Z., Zhang, Y., ... & Zhu, S. (2020). A material stack-up combination identification method for resistance spot welding based on dynamic resistance. Journal of Manufacturing Processes, 56, 796-805.

[17] Reza Kashyzadeh, K., Farrahi, G. H., Minaei, M., Masajedi, R., Gholamnia, M., & Shademani, M. (2022). Numerical study of shunting effect in three-steel sheets resistance spot welding. International Journal of Engineering, 35(2), 406-416.
[18] Xia, Y. J., Li, Z., Wang, W., Yang, T., Pi, G., & Li, Y. (2024). Influence Mechanism of Initial Gap Disturbance on the Resistance Spot Welding Process. Automotive Innovation, 7(2), 360-372.
[19] Shi, L., Xue, J., Kang, J., Haselhuhn, A. S., Ghassemi-Armaki, H., & Carlson, B. E. (2023). Fatigue behavior of three-sheet aluminum-steel dissimilar resistance spot welds for automotive applications. Procedia Structural Integrity, 51, 102-108
[20] Feng, M., Wang, Z., Ao, S., Ren, L., & Wang, P. (2024). Ultrasonic spot welding of open-cell Cu foam and Al plate: A study on the quality of joints. Journal of Materials Research and Technology, 29, 196-212.
[21] Zhou, L., Zheng, W., Li, T., Zhang, T., Zhang, Z., Zhang, Y., ... & Zhu, S. (2020). A material stack-up combination identification method for resistance spot welding based on dynamic resistance. Journal of Manufacturing Processes, 56, 796-805.
[22] Reza Kashyzadeh, K., Farrahi, G. H., Minaei, M., Masajedi, R., Gholamnia, M., & Shademani, M. (2022). Numerical study of shunting effect in three-steel sheets resistance spot welding. International Journal of Engineering, 35(2), 406-416.
[23] Xia, Y. J., Li, Z., Wang, W., Yang, T., Pi, G., & Li, Y. (2024). Influence Mechanism of Initial Gap Disturbance on the Resistance Spot Welding Process. Automotive Innovation, 7(2), 360-372.
[24] Shi, L., Xue, J., Kang, J., Haselhuhn, A. S., Ghassemi-Armaki, H., & Carlson, B. E. (2023). Fatigue behavior of three-sheet aluminum-steel dissimilar resistance spot welds for automotive applications. Procedia Structural Integrity, 51, 102-108
[25] Hussein, K. M., Akbari, H., Noorossana, R., Yadegari, R., & Ashiri, R. (2024). Microhardness and microstructure correlations to the mechanical performance for dissimilar third generation AHSS resistance spot welding. Journal of Materials Research and Technology, 30, 7938-7945.
[26] Hussein, K. M., Akbari, H., Noorossana, R., Yadegari, R., & Ashiri, R. (2023). Mechanical behavior investigation for quenching and partitioning steel dissimilar resistance spot welds. Journal of Materials Research and Technology, 27, 4064-4073.
[27] Fu, B., Shen, J., Suhuddin, U. F., Pereira, A. A., Maawad, E., dos Santos, J. F., ... & Rethmeier, M. (2021). Revealing joining mechanism in refill friction stir spot welding of AZ31 magnesium alloy to galvanized DP600 steel. Materials & Design, 209, 109997.
[28] Pandya, K. S., Grolleau, V., Roth, C. C., & Mohr, D. (2020). Fracture response of resistance spot welded dual phase steel sheets: Experiments and modeling. International Journal of Mechanical Sciences, 187, 105869.
[29] Huang, C. H., Hou, C. H., Hsieh, T. S., Tsai, L., & Chiang, C. C. (2022). Investigation of distinct welding parameters on mechanical and corrosion properties of dissimilar welded joints between stainless steel and low carbon steel. *Science Progress*, *105*(4), 00368504221126795.
[30] Haghshenas, N., & Moshayedi, H. (2020). Monitoring of resistance spot welding process. *Experimental Techniques*, *44*, 99-112.
[31] Hassan, L. I., & Lafta, H. D. (2023). The Effect of Electrode Geometry and Pre-heating Treatment on Resistance Spot Welding Strength. *Engineering and Technology Journal*, *41*(7), 954-962.
[32] Temiz, R. Ö., Onan, M., Cebi, H., Aslanlar, S., & Talaş, Ş. (2024). Effect of Electrode Type and Weld Current on Service Life of Resistance Spot Weld Electrode. *International Journal of Automotive Science And Technology*, *8*(1), 52-64.
[33] Watmon, T. B., Wandera, C., & Apora, J. (2020). Characteristics of resistance spot welding using annular recess electrodes. *Journal of Advanced Joining Processes*, *2*, 100035.
[34] Zhou, K., Ren, B., & Yu, W. (2023). Optimized designing of generalized electrodes for aluminum/steel resistance spot welding process based on numerical calculation. *Journal of Manufacturing Processes*, *99*, 563-580

[35] Pishva, P., Beni, S. S., Atapour, M., Salmani, M. R., & Ashiri, R. (2021). Study of corrosion behavior in resistance spot welds of thin sheets of zinc-coated interstitial-free steel. *Journal of Materials Engineering and Performance*, *30*, 1723-1736.
[36] Hassoni, S. M., Barrak, O. S., Ismail, M. I., & Hussein, S. K. (2022). Effect of Welding Parameters of Resistance Spot Welding on Mechanical Properties and Corrosion Resistance of 316L. *Materials Research*, *25*, e20210117.
[37] Pan, B., Sun, H., Shang, S. L., Wen, W., Banu, M., Simmer, J. C., ... & Li, J. (2021). Corrosion behavior in aluminum/galvanized steel resistance spot welds and self-piercing riveting joints in salt spray environment. *Journal of Manufacturing Processes*, *70*, 608-620.
[38] Garcia, M. P., Sarango de Souza, J., Glover, C., Ansell, P., Williams, G., Mantovani, G. L., ... & Antunes, R. A. (2021). Global and local corrosion of welded joints of high-strength low-alloy automotive steel. *Corrosion*, *77*(5), 564-576.
[39] Hussein, K. M., Akbari, H., Noorossana, R., Yadegari, R., & Ashiri, R. (2023). Mechanical behavior investigation for quenching and partitioning steel dissimilar resistance spot welds. Journal of Materials Research and Technology, 27, 4064-4073.
[40] Temiz, R. Ö., Onan, M., Cebi, H., Aslanlar, S., & Talaş, Ş. (2021). Effect of Electrode Type and Weld Current on Service Life of Resistance Spot Weld Electrode. International Journal of Automotive Science And Technology, 8(1), 52-64.
[41] Panza, L., De Maddis, M., & Spena, P. R. (2020). Use of electrode displacement signals for electrode degradation assessment in resistance spot welding. Journal of Manufacturing Processes, 76, 93-105.
[42] Watmon, T. B., Wandera, C., & Apora, J. (2024). Characteristics of resistance spot welding using annular recess electrodes. Journal of Advanced Joining Processes, 2, 100035.
[43] Zheng, Z., Tao, J., Fang, X., & Xue, H. (2020). Life and failure of oriented carbon nanotubes composite electrode for resistance spot welding. Matéria (Rio de Janeiro), 28(1), e20230005.
[44] Zhou, L., Li, T., Zheng, W., Zhang, Z., Lei, Z., Wu, L., ... & Wang, W. (2023). Online monitoring of resistance spot welding electrode wear state based on dynamic resistance. Journal of Intelligent Manufacturing, 33, 91-101.
12, no. 1, pp. 23–28, 2017.