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Resistance Spot Welding Technique of Advanced High-Strength Steels: Review

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A B S T R A C T

Resistance spot welding (RSW) is one of the most widely used welding techniques in modern industries due to its efficiency and speed in production, especially in the automotive industry. With the continuous development of engineering materials, advanced high-strength steels (AHSS) such as DP600, DP800, TRIP, and TWIP have emerged, which combine high strength, excellent ductility, toughness, and malleability, making them ideal for structural applications, load and impact resistance, and weight reduction. This makes them play a significant role in improving weld quality, and they are used in cars and aeroplanes due to their superior mechanical performance. In this study, the effect of welding parameters on tensile strength, micro-hardness, and changes in the mechanical properties of spot-welded joints from these advanced high-strength steels (AHSS) is examined. Three parameters were used: current, welding time, and weld thickness. Generally, the quality of the weld depends on the welding standards. In this review paper, the most important studies presented in this field are referenced, all of which indicate that the main welding parameters affecting these materials in the welding process are welding current, welding time, and thickness, and their impact on tensile strength, hardness, and mechanical properties. Studies show that the quality of welding heavily depends on welding parameters.

1. INTRODUCTION

Resistance spot welding (RSW) is being used more and more in the automotive industry to improve structural safety and fuel efficiency. Including the mechanical characteristics, microstructure development and chemical composition design during thermo-mechanical processing. For lightweight construction, materials including mild steel, titanium, aluminium and magnesium are recommended, as are IF, HSLA and AHSS .Weight reduction, safety, corrosion resistance and crash resistance are all enhanced by the use of advanced high-strength steel [1-3]. Ferritic-Bainitic (FB), Dual Phase (DP), Twinning

Induced Plasticity (TWIP) and Transformation Induced Plasticity (TRIP) steels are common varieties of Advanced High Strength Steel AHSS, A brief classification of AHSSs steels can be summarized in Figure 1, and they were compared to HSLA steel. Every steel produced FZ hardness values greater than 350 HV, with the exception of HSLA, which had values near 300 HV [4]. Mechanical deformation also has an effect that makes similar joints stronger in shear and dissimilar joints weaker in the electrical conductivity of the resistance spot weld [5]. The main factors affecting that clearly effect the peak load and energy absorption in spot welding are clearly the size of the weld mass, the beginning distance of the electrode, the failure type, and strength / ductility [6]. The effect of welding time on tensile and shear strength in RSW was observed, where the welding current periods were 5-10 KA and 12 KA with a fixed electrode pressure of 6 KN. The maximum tensile strength was achieved at a current of 10 kA for welding times of 12 and 15 [7]. The thickness, weld diameter, and distance between the welding locations are other variables that impact the spot weld's strength. The primary variables affecting the joint's strength are the weld's thickness and diameter. The spot weld's diameter has a major impact on the thin-walled beams' strength and fracture pattern [8]. In RSW, the formation of electrode files, the quick corrosion of electrode surfaces, and the reduction in thermal conductivity cause less heat to be transferred away from the material. This in turn causes more heat to build up inside the material, which melts and forms a weld at lower welding currents [9, 10] Additionally, the resistance spot welding machine is depicted in this figure 2 [11].

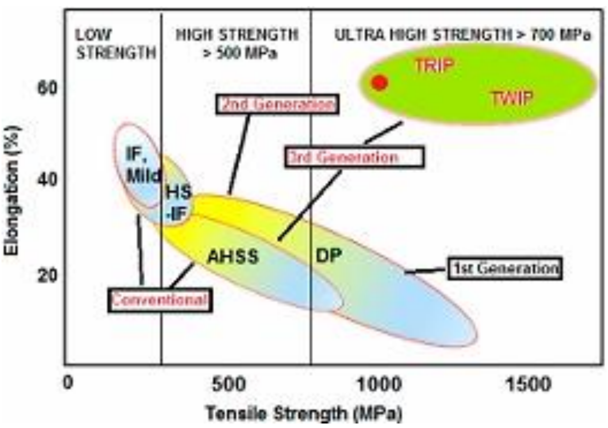


Fig. 1. An overview of important advanced high strength steels (AHSS) [10].

Fig. 2. The image of the RSW machine [11].

2. RSW OF SIMILAR MATERIALS

An explanatory table of the materials used from AHSS steel (DP600, DP800, TRIP, and TWIP) in the spot welding process indicates that DP is relatively easier to weld, TRIP is more sensitive to heat than DP—which results in a reduction in mechanical properties in that area—and TWIP, unlike DP, is more difficult to weld and requires precise settings for current, pressure, and welding time.

Table 1. The chemical composition of DP (600,800), TRIP800 and TWIP steel (wt. %) [12-15].

Material	DP600	DP800	TRIP800	TWIP
C	0.11	0.104	0.179	1.015
Si	0.40	0.017	1.719	0.488
Mn	1.43	1.779	1.691	18.14
P	0.01	0.017	0.011	0.015
S	<0.01	0.006	0.007	0.002
Al	0.02	-	0.027	2.436
Mo	0.05	-	0.025	-
Nb	<0.01	-	0.053	-
Co	-	-	0.072	-
Ti	0.02	-	0.014	-
Sn	-	-	0.01	-
Cr	0.21	0.026	0.065	-
Ni	0.03	0.011	0.074	-
Cu	0.01	0.025	0.1	-
Fe	-	-	95.902	Balance
V	0.01	-	0.013	-
Mg	-	-	0.001	-
W	-	-	0.04	-

3. EFFECT OF RSW PROCESS PARAMETERS ON THE AHSS CHARACTERISTICS

In spot welding, the most significant factors influencing the shear-tensile strength are the welding current, electrode strength, holding time after welding and current density and welding time [16], Neystani et al. [17] found that the size of the fusion zone and the failure mode, which are regulated by welding parameters including current, electrode strength and welding time, had the greatest effects on the vitality of weld quality. The size of the weld bead is significantly influenced by the strength of the electrode, with the weld point achieving the highest value in DP600 steel, according to studies. In addition to sheet thickness and welding time, the most important factors influencing the expansion of the molten region and the heat-affected zone are the intensity of the current, Similarly, a welding period of 10 cycles and a welding current of 4 kA can yield the greatest shear tensile strength value for the weld joints in DP600 1mm-1mm, Static shear testing showed that the samples' maximum load ranged from 8.1 to 8.3 kilo-amperes [18-21].

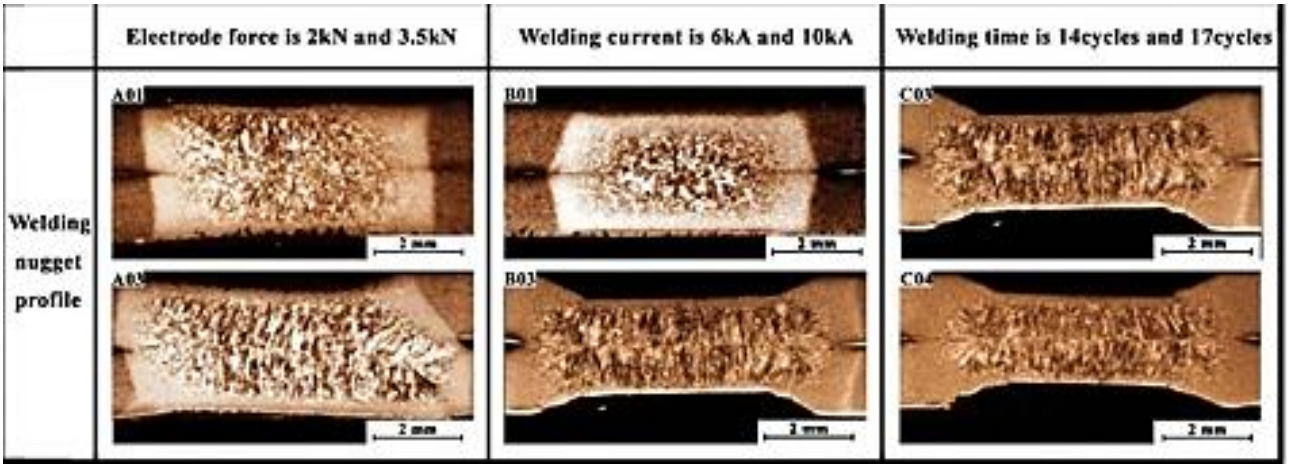


Fig. 3. Welding nugget profiles under different welding parameters DP600 [22].

The macro-structural and mechanical characteristics of DP800 steel were found to be significantly influenced by the electrode strength a high electrode strength also postpones the creation and growth of the melting zone [22].

TRIP samples were subjected to thermal treatments at 300, 400, 500, and 650 degrees Celsius to assess the effects of annealing on mechanical properties. Up to 500 degrees Celsius, the yield strength increases, By influencing the joint's size, shape and the quantity of zinc coating that evaporates during the welding process, welding parameters can have an impact on spot welds' ability to withstand corrosion. In addition to damaging the TRIP coating, improper welding settings can result in metal expulsion and the development of metal spots at the seams. Large nuggets produced by a high current and extended period might have a high shear strength [23-24], the primary characteristics of TRIP steel are its exceptional hardenability and application in automobile pillars. Additionally, the shear strength in welded joints clearly rises with increasing core size. In resistance welding, Tensile strength, separation and welding duration were all found to be correlated and three types of fracture failure modes were obtained: coalescence, separation and tearing. The tensile-tearing strength increases with the increase in welding time, however, 20 cycles with a welding current of 13.5 kA recorded the maximum tensile and shear load values. At welding times of 10 and 15 periods, the tensile shear loads rose to 15 KA, As shown in the figure, the effect of welding time on shear tensile strength is illustrated figure 4 [25-27]. According to Yu et al. [28] the three main welding parameters used are electrode strength, welding current, and welding time in TWIP. Zeytin et al. [29] found that the tensile strength of TWIP welded samples increases with the welding parameters, reaching a maximum at 7 kA of welding current and 25 seconds of welding time. However, the welding strength decreases due to excessive heat input. As the welding current rose in tandem with the rise in heat input, shrinkage voids developed throughout the welding process. Grain size in the HAZ rose, melting took place, dendritic structures developed in the fusion zone, and hardness values decreased [30]. Tutar et al. [31] explained that because of the increased heat input, a macro eject cavity forms in the welding area during RSW when the welding current is significantly increased to 12 KA (owing to the phenomenon of wide ejection). Verma et al. [32] found that adding more heat causes the welding duration to rise, which in turn causes the weld bead's size to increase. Nevertheless, longer welding periods result in a decrease in core diameter.

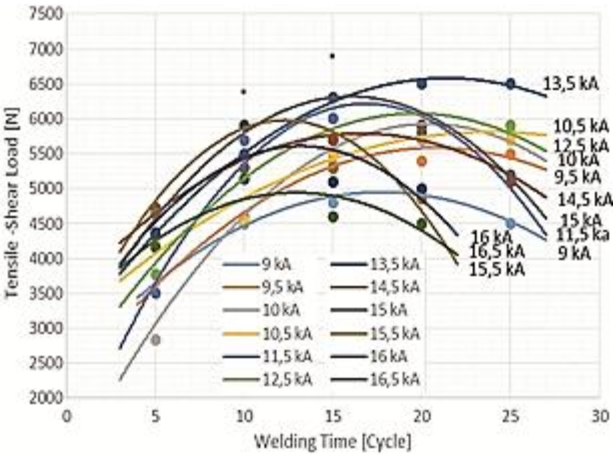


Fig. 4. Effect of welding time on tensile-shear load of weld joints [27].

The effect of cracks in the heat-affected zone (HAZ) on the fatigue resistance of spot-welded joints made from advanced high-strength steel was studied, where the production of samples containing cracks in the HAZ did not result in a decrease in fatigue resistance or failure cycles As shown in the figure 5.

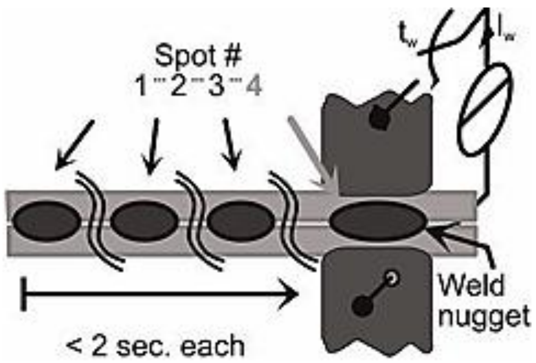


Fig. 5. Diagram of the weld sequence used to create overlap shear specimens' HAZ cracks [33].

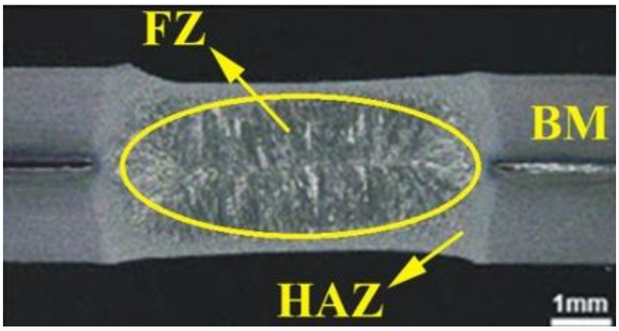
The nano-hardness test was used to evaluate the base metal and the heat-affected zone HAZ in resistance spot welding. There was softening in this area accompanied by a fracture in the appearance of sub-micro-meter particles in the tempered marten-site (TM) at a distance of 100 micro-meters from the Ac1 line, indicating carbide precipitation and partial recovery of the marten-site. The observations from the scanning electron microscope (SEM) were in good agreement with the nano-scale hardness of the TM phase along the heat-affected zone HAZ, Additionally, the fatigue test contributed to the spot weld cracks, and the dual-phase steel's fatigue strength was greater than that of the low-carbon steel models [33-35]. When dual-phase steel's weld- ability was poor, weld expulsion resulted, lowering quality and raising production costs. The impact of main gaps on welding expulsion for DP was examined. Increasing the gap distance also causes the temperature to rise more quickly and weld spatter to occur earlier.

3.1 RSW of Dis-similar materials

Spena et al. [36] investigated the mechanical performance and formability of welds in TRIP/TWIP plates composed of advanced high-strength steel. Similarly, Marwan and Kaçar [37] explained in their work that spot welding was used to unite two dissimilar steels, DP600 and TRIP800, by mixing different parameters. Aydin et al. [38]'s research found that the strongest hardness values occurred at a current intensity of 6 KA when DP600 and DP800 were spot-welded together. Wei et al. [39] investigated in their study the resistance spot welding between DP590 and TRIP Mn and the effect of single-pulse welding parameters and dual-pulse quenching current on the quality parameters and properties of these mechanical joints. However, there is a lack of studies related to the welding process of different metals in advanced high-strength steel (TWIP+TRIP, TWIP+DP, or TRIP+DP), in addition to the insufficient use of nan powders as enhancers for weld joints.

3.2 Effect microstructure of AHSS

The microstructure, which includes the heat-affected zone HAZ, the partially melted zone (PMZ), and the weld zone (FZ), is greatly impacted by the RSW spot welding process [40]. Multiple researchers have identified the failure mode that is dependent on the steel's strength, chemistry, and processing HASS, such as ferritic-bainitic FB, dual-phase DP, Twinning Induced Plasticity TWIP and transformation-induced plasticity TRIP. The cooling rate between the heat-affected zone and the welded metal can reach up to 1000 degrees Celsius, and the effect of current and welding time is directly proportional to these temperatures .When moving from medium speeds to impact speeds, Note a significant reduction in displacement and an increase in failure load in the microstructure of the base metal of the selected steel. Furthermore, failure loads decreased at all test speeds due to the martensitic structure and stress concentration at the interface, Employ a single-phase, 250 kVA resistance welding machine that runs at 60 Hz and has DC and pneumatic controls [41]. Da-Zhao et al. [42] have shown in their work that an increase in strain rate results in a tensile strength and a decrease in elongation in TWIP at low speeds, hence providing the steel with a high strain hardening capability. According to the study by Saha et al. [43] cracks appeared in the heat-affected zone HAZ when the weld diameter reached 4.5 mm or more, and the welding current also had a greater impact on the initiation of cracks figures 6.



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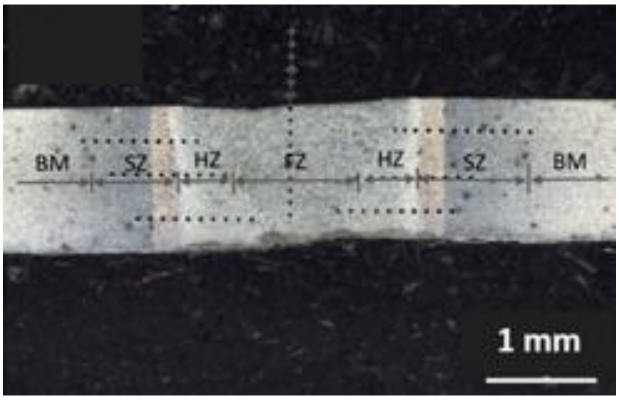

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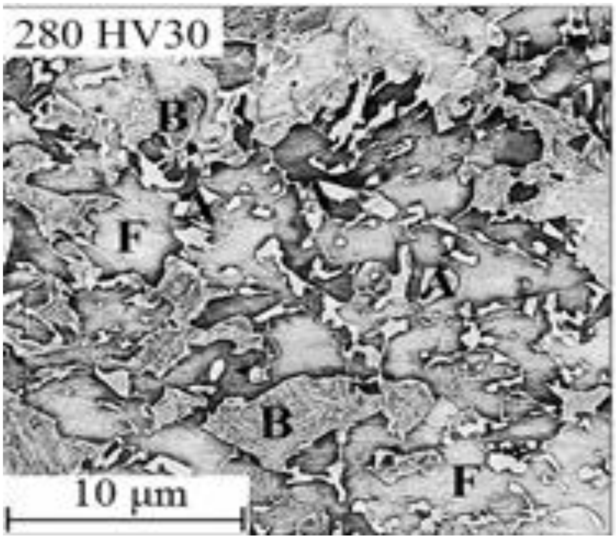

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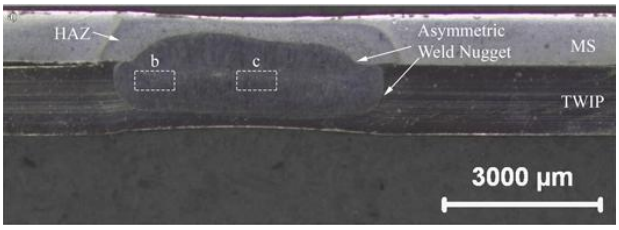

(d)

Fig. 6. Microstructure of: a. DP600, b. DP800, c. TRIP, d. TWIP of RSW [44-46].

3.3 Mechanical Properties

Bouaziz et al. [47] clarified the connections between microstructure and mechanical characteristics in this work, concentrating on the mechanisms of hardening and plasticity brought on by fatigue, fracture, yield stress, and deformation. In the study by Abid et al. [48] tensile, microstructure, and Vickers hardness tests were used to evaluate the welded joints. It was found that the tensile strength decreases with an increase in welding current or welding time, and the nugget diameter also increases with longer welding times. Madivala and Bleck [49] 's investigation made it clear that TWIP steel has higher energy absorption than TRIP and DP1000 steel at all speeds and that the ductility of TWIP, TRIP, and DP600 T steels is at its lowest. Sivaraj et al. [50] 's investigation shows that the interfacial region of the heat-affected zone is where most tensile failure occurs, with a maximum shear tensile stress of 18 KN at a welding current of 50 KA. Some researchers found no effect of hydrogen on the properties of TWIP steel, while others found a significant loss in ductility and strength. The measures to counteract hydrogen embrittlement include tempering for DP and TRIP steels, as well as using aluminium alloys for TWIP steel [51].

Shear tensile strength at the weld spot was directly related to the increase in heat input, according to studies on the effect of hardness. The heat-affected zone HAZ contains soft phases (ferrite), as demonstrated by microscopic analysis, which lessen the hardness of the material as a result of heat input [52], Micro-hardness files of the weld are examined to check for defects and also to provide an understanding of the tensile properties of the weld. Micro-hardness files are determined by measuring the hardness at intervals of 0.4 mm along an inclined diameter in the cross-section of the weld [53]. The hardness distribution of AHSS spot welds was found to be different from that of base metal (BM), with uniform hardness in the weld zone FZ and reduced hardness in the heat-affected zone HAZ [54]. Razmpoosh et al. [55] explained that exact hardness measurements revealed a minor decline throughout the TWIP heat-affected zone.

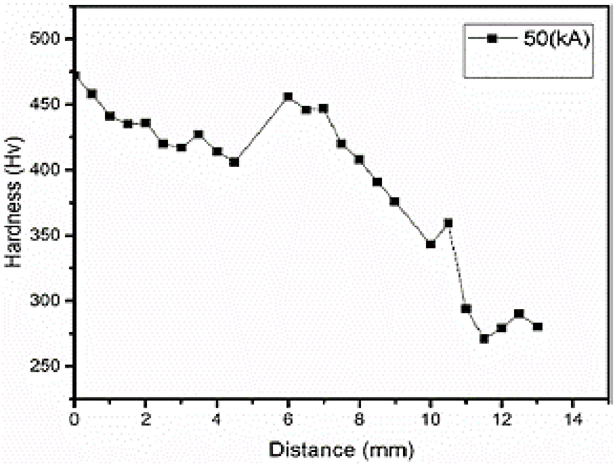

Fig. 7. Peak resistance spot weld load during a tensile shear test for different steel thicknesses and grades. Interfacial failure mode was used to fail all spot welds [56].

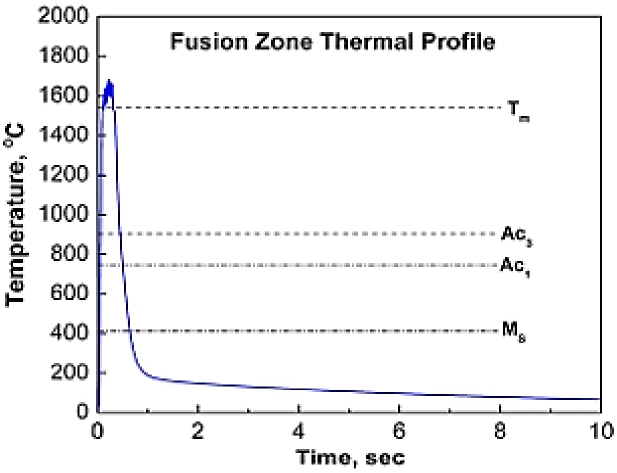

Fig. 8. The thermal profile of the fusion zone in the RSW of TRIP steels examined in this study was extracted from the authors' previous research [57].

In the figure, it shows the micro-hardness values with tensile properties when selecting a welding current of 50KA, which has a higher hardness value of 450 compared to another welding current. The difference is primarily due to the presence of a martensitic structure in the fully deformed area [58].

4. OPTIMIZATION OF RSW PROCESS PARAMETERS FOR AHSS

Gurav and Ambekar [59] study concentrated on enhancing the welding parameters in RSW by utilizing various techniques involving heat, pressure, and force. Additionally, studies show that welding parameters need to be managed to guarantee adequate heat generation, prevent molten metal from being ejected from the welding area, and minimize porosity in the finished weld [60].

1. Dual Phase Steel (600-800)

Dual-phase steel (DP600) was made more weld-able with a servo gun by modifying the electrode force while welding. Because of the low pressure force, there is less contact area between the welding sheets, which leads to a reduced melting current. The first stage's average electrode force was 4.5 KN, whereas the second stage's was 5 KN. The nugget size grew from 1.48 kA to 2.78 kA due to the modified welding power, which greatly improved dual-phase steel's weld-ability. In the stabilization phase, the electrode force - which influences the size of the nugget - is the most crucial element [61], The double pulse showed improvements in the maximum load and failure energy of 17% and 86%, respectively. According to a study on the impact of the second pulse in RSW for DP steel, it considerably increased the steel's CTS; yet, the TSS is nearly the same as that of the steel treated using the single pulse approach. At 11.94 kilo-new-tons, the critical tensile strength of the double pulse technique samples is 47% higher than that of the single pulse technique samples [62-63]. The Taguchi method was applied to DP600 sheets to achieve maximum shear tensile strength with dimensions of 250x250x1 mm at a welding current and pressure of 4 kA and 3.5 bar, respectively. The weld metal structure consists of the marten-site phase, with remnants possibly being 2-9% , except for the discovery of austenite. It was confirmed that welding current, welding time, and holding time are the main parameters affecting tensile strength, and the most important factor affecting TLBC is the welding current [64]. Dual-phase steel (DP800) parameters were optimized using the design of experiments (DOE) method, welding joints were created using the DOE approach, and the micro-hardness fluctuations in the weld area were recorded using the Vickers micro-hardness test, and it was discovered that the heat-affected zone HAZ and the welding current both increase the size of the melting zone, The fusion zone's FZ hardness is higher than the base metal's (BM) hardness, according to the study [65].

2. Transformation-Induced Plasticity (TRIP)

The study focuses on improving the RSW spot welding process. The different weld joints of TRIP steel affect how strong the joints are based on the welding settings, and Taguchi's Design of Experiments (DOE) shows that the best results occur when the current is 4.75 kA and the welding time is 500 milliseconds [66]. Nikoo et al. [67] explained in their study that better mechanical qualities result from rem-elting and expanding the weld core with a pulsed current. Weld size and quality are impacted by abnormal situations, including misalignment, improper assembly, edge welding and electrode degradation, as well as by enhancing welding process standards in metal sheet assembly and paying attention to welding current and time [68].

3. Twinning-Induced Plasticity (TWIP)

Optimal levels for welding variables such welding force, welding current, and welding time have been reached; the goal of this study is to optimise the spot welding parameters for TWIP steel [69]. Tutar et al. [70] found that while an increase in welding current and electrode force increases the ultimate tensile stress in RSW, the opposite is true for an increase in welding time. According to Aydin et al. [71] , the hardness of RSW welded steel plates is lower in the HAZ and FZ welding zones than in the BM, and it rises with longer welding periods . The impact of alloying elements in TWIP steel can improve its exceptional mechanical and microstructural qualities. Because of its high strength and capacity to absorb energy, it has become widely used in the automotive industry as a result of improvements in corrosion and stress corrosion behaviour [72].

5. CONCLUSIONS

The purpose of spot welding in advanced high-strength steel is explained in this study, along with the welding parameters of electrode force, welding current, and welding duration. Current density, welding current, and electrode force were shown to have the greatest effects on shear tensile strength. Welding current and time are exactly related to the influence of temperature, according to an analysis of the mechanical and structural characteristics.

REFERENCES

[1] S. M. Manladan, I. Abdullahi, and M. F. Hamza, "A review on the application of resistance spot welding of automotive sheets," *J. Eng. Technol.*, vol. 10, no. 20–37, p. 22, 2015.

[2] R. Kuziak, R. Kawalla, and S. Waengler, "Advanced high strength steels for automotive industry," *Archives of Civil and Mechanical Engineering*, vol. 8, no. 2, pp. 103–117, 2008.

[3] T. Tanmoy, "Resistance spot welding: principles and its applications," in *Engineering Principles – Welding and Residual Stresses*, 2022.

[4] K. Mi, K. Ml, E. Biro, and Y. Zhou, "Microstructure and mechanical properties of resistance spot welded advanced high strength steels," *Materials Transactions*, vol. 49, no. 7, pp. 1629–1637, 2008.

[5] M. S. Fakhri, A. Al-Mukhtar, and I. A. Mahmood, "Effect of mechanical deformation on the electrical conductivity of resistance spot welding joints," *Journal of Applied Science and Engineering*, vol. 27, no. 9, pp. 3095–3103, 2023.

[6] M. Pouranvari and S. P. H. Marashi, "Factors affecting mechanical properties of resistance spot welds," *Materials Science and Technology*, vol. 26, no. 9, pp. 1137–1144, 2010.

[7] S. Aslanlar, A. Ogur, U. Ozsarac, and E. Ilhan, "Welding time effect on mechanical properties of automotive sheets in electrical resistance spot welding," *Materials & Design*, vol. 29, no. 7, pp. 1427–1431, 2008.

[8] P. Rogeon, P. Carre, J. Costa, G. Sibilia, and G. Saindrenan, "Characterization of electrical contact conditions in spot welding assemblies," *Journal of Materials Processing Technology*, vol. 195, no. 1–3, pp. 117–124, 2008.

[9] N. J. den Uijl and R. D. T. Corus, "Thermal and electrical resistance in resistance spot welding," in *17th International Conference Computer Technology in Welding and Manufacturing*, 2008.

[10] W. S. Jeon, A. Sharma, and J. P. Jung, "Liquid metal embrittlement of galvanized TRIP steels in resistance spot welding," *Metals*, vol. 10, no. 6, art. 787, 2020.

[11] C. Rajarajan, T. Sonar, P. Sivaraj, S. Raja, and N. Mathiazhagan, "The effect of resistance spot welding parameters on microstructure and strength of DP800 steel joints using response surface methodology," *Advances in Materials Science*, vol. 22, no. 3, pp. 53–78, 2022.

[12] H. Yang, Y. Zhang, X. Lai, and G. Chen, "An experimental investigation on critical specimen sizes of high strength steels DP600 in resistance

spot welding," *Materials & Design*, vol. 29, no. 9, pp. 1679–1684, 2008.

[13] A. Kubit, H. A. Derazkola, K. Faes, and M. Korzeniowski, "Fatigue properties of spot joints of metal–plastic composites with DP800 steel prepared by ultrasound resistance spot welding," *Thin-Walled Structures*, vol. 201, art. 111992, 2024.

[14] V. Onar, S. Aslanlar, and N. Akkaş, "Effect of welding current on tensile-peel loading of welding joints in TRIP 800 and micro-alloyed steels in resistance spot welding," *Acta Physica Polonica A*, vol. 132, no. 3, pp. 822–824, 2017.

[15] V. Onar, "Mechanical and microstructural characterizations of resistance spot welded dissimilar TWIP/304L stainless steel," *Transactions of the Indian Institute of Metals*, vol. 75, no. 7, pp. 1731–1739, 2022.

[16] S. M. Anijdan, M. Sabzi, M. Ghobeiti-Hasab, and A. Roshan-Ghiyas, "Optimization of spot welding process parameters in dissimilar joint of dual phase steel DP600 and AISI 304 stainless steel to achieve the highest level of shear-tensile strength," *Materials Science and Engineering: A*, vol. 726, pp. 120–125, 2018.

[17] R. Neystani, B. Beidokhti, and M. Amelzadeh, "Fabrication of dissimilar Fe–Cu–C powder metallurgy compact/steel joint using the optimized resistance spot welding," *Journal of Manufacturing Processes*, vol. 43, pp. 200–206, 2019.

[18] D. W. Zhao, Y. X. Wang, L. Zhang, and P. Zhang, "Effects of electrode force on microstructure and mechanical behavior of the resistance spot welded DP600 joint," *Materials & Design*, vol. 50, pp. 72–77, 2013.

[19] M. Eshraghi, M. A. Tschopp, M. A. Zaeem, and S. D. Felicelli, "Effect of resistance spot welding parameters on weld pool properties in a DP600 dual-phase steel: A parametric study using thermomechanically-coupled finite element analysis," *Materials & Design*, vol. 56, pp. 387–397, 2014.

[20] S. Aktas, U. Ozsarac, and S. Aslanlar, "Effect of spot welding parameters on tensile properties of DP600 steel sheet joints," *Materials and Manufacturing Processes*, vol. 27, no. 7, pp. 756–764, 2012.

[21] C. Ma, D. L. Chen, S. D. Bhole, G. Boudreau, A. Lee, and E. Biro, "Microstructure and fracture characteristics of spot-welded DP600 steel," *Materials Science and Engineering: A*, vol. 485, no. 1–2, pp. 334–346, 2008.

[22] P. Zhang, J. Xie, Y. X. Wang, and J. Q. Chen, "Effects of welding parameters on mechanical properties and microstructure of resistance spot welded DP600 joints," *Science and Technology of Welding and Joining*, vol. 16, no. 7, pp. 567–574, 2011.

[23] C. Rajarajan, P. Sivaraj, M. Seeman, and V. Balasubramanian, "Influence of electrode force on metallurgical studies and mechanical properties of resistance spot welded dual phase (DP800) steel joints," *Materials Today: Proceedings*, vol. 22, pp. 614–618, 2020.

[24] M. Pouranvari and S. P. H. Marashi, "Key factors influencing mechanical performance of dual phase steel resistance spot welds," *Science and Technology of Welding and Joining*, vol. 15, no. 2, pp. 149–155, 2010.

[25] T. B. Hilditch, J. Y. Speer, and D. K. Matlock, "Effect of susceptibility to interfacial fracture on fatigue properties of spot-welded high strength sheet steel," *Materials & Design*, vol. 28, no. 10, pp. 2566–2576, 2007.

[26] P. Russo Spena, S. Rossi, and R. Wurzer, "Effects of welding parameters on strength and corrosion behavior of dissimilar galvanized Q&P and TRIP spot welds," *Metals*, vol. 7, no. 12, art. 534, 2017.

[27] U. Özsaraç, V. Onar, F. Özen, Y. S. Aslanlar, and N. Akkaş, "Effect of welding time on tensile-shear load in resistance spot welded TRIP 800 and micro-alloyed steels," *Indian Journal of Chemical Technology*, 2019.

[28] J. Yu, J. Shim, and S. Rhee, "Characteristics of resistance spot welding for 1 GPa grade twinning induced plasticity steel," *Materials Transactions*, vol. 53, no. 11, pp. 2011–2018, 2012.

[29] H. Kazdal Zeytin, H. Ertek Emre, and R. Kaçar, "Properties of resistance spot-welded TWIP steels," *Metals*, vol. 7, no. 1, art. 14, 2017.

[30] S. Şahin, F. Hayat, and O. C. Çölgeçen, "The effect of welding current on nugget geometry, microstructure and mechanical properties of TWIP steels in resistance spot welding," *Welding in the World*, vol. 65, pp. 921–935, 2021.

[31] T. S. Sheet, "Effect of weld current on the microstructure and mechanical properties of a resistance spot-welded TWIP steel sheet," *Metals*, vol. 7, no. 12, 2017.

[32] R. Verma, K. S. Arora, L. Sharma, and R. Chhibber, "Experimental investigation on resistance spot welding of dissimilar weld joints," *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, vol. 235, no. 2, pp. 505–513, 2021.

[33] H. Gaul, G. Weber, and M. Rethmeier, "Influence of HAZ cracks on fatigue resistance of resistance

spot welded joints made of advanced high strength steels," *Science and Technology of Welding and Joining*, vol. 16, no. 5, pp. 440–445, 2011.

[34] V. H. Baltazar Hernandez, S. K. Panda, Y. Okita, and N. Y. Zhou, "A study on heat affected zone softening in resistance spot welded dual phase steel by nanoindentation," *Journal of Materials Science*, vol. 45, pp. 1638–1647, 2010.

[35] J. Xu, Y. S. Zhang, L. Xinmin, and G. L. Chen, "Experimental investigation of fatigue performance of spot welded dual phase sheet steels," *Science and Technology of Welding and Joining*, vol. 13, no. 8, pp. 726–731, 2008.

[36] P. Russo Spena, L. Cortese, F. Nalli, and K. Májlinger, "Local formability and strength of TWIP–TRIP weldments for stamping tailor welded blanks (TWBs)," *The International Journal of Advanced Manufacturing Technology*, vol. 101, pp. 757–771, 2019.

[37] K. O. H. Marwan and R. Kaçar, "Optimization of welding parameters for DP600/TRIP800 dissimilar joints," *Materials Testing*, vol. 60, no. 1, pp. 40–48, 2018.

[38] K. Aydin, M. Hidiroglu, and N. Kahraman, "Characterization of the welding zone of automotive sheets of different thickness (DP600 and DP800) joined by resistance spot welding," *Transactions of the Indian Institute of Metals*, vol. 75, no. 5, pp. 1279–1291, 2022.

[39] F. Wei, Y. Zhu, Y. Tian, H. Liu, Y. Zhou, and Z. Zhu, "Resistance spot-welding of dissimilar metals, medium manganese TRIP steel and DP590," *Metals*, vol. 12, no. 10, art. 1596, 2022.

[40] J. Shen, Y. S. Zhang, and X. M. Lai, "Influence of initial gap on weld expulsion in resistance spot welding of dual phase steel," *Science and Technology of Welding and Joining*, vol. 15, no. 5, pp. 386–392, 2010.

[41] B. C. De Cooman, O. Kwon, and K. G. Chin, "State-of-the-knowledge on TWIP steel," *Materials Science and Technology*, vol. 28, no. 5, pp. 513–527, 2012.

[42] D. Z. Li, Y. H. Wei, C. Y. Liu, L. F. Hou, D. F. Liu, and X. Z. Jin, "Effects of high strain rate on properties and microstructure evolution of TWIP steel subjected to impact loading," *Journal of Iron and Steel Research International*, vol. 17, no. 6, pp. 67–73, 2010.

[43] D. C. Saha, I. Chang, and Y. D. Park, "Heat-affected zone liquation crack on resistance spot welded TWIP steels," *Materials Characterization*, vol. 93, pp. 40–51, 2014.

[44] H. He, F. Forouzan, J. Volpp, S. M. Robertson, and E. Vuorinen, "Microstructure and mechanical properties of laser-welded DP steels used in the automotive industry," *Materials*, vol. 14, no. 2, art. 456, 2021.

[45] P. Russo Spena, L. Cortese, M. De Maddis, and F. Lombardi, "Effects of process parameters on spot welding of TRIP and quenching and partitioning steels," *steel research international*, vol. 87, no. 12, pp. 1592–1600, 2016.

[46] A. Ramazani, K. Mukherjee, A. Abdurakhmanov, M. Abbasi, and U. Prahl, "Characterization of microstructure and mechanical properties of resistance spot welded DP600 steel," *Metals*, vol. 5, no. 3, pp. 1704–1716, 2015.

[47] O. Bouaziz, S. Allain, C. P. Scott, P. Cugy, and D. Barbier, "High manganese austenitic twinning induced plasticity steels: A review of the microstructure–properties relationships," *Current Opinion in Solid State and Materials Science*, vol. 15, no. 4, pp. 141–168, 2011.

[48] H. J. Abid, H. I. Khalaf, F. H. Alazawi, and A. A. Ugla, "Experimental investigation of the effect of spot-welding process parameters on the tensile strength of similar metal joints," *International Review of Mechanical Engineering*, vol. 15, no. 2, 2021.

[49] M. Madivala and W. Bleck, "Strain rate dependent mechanical properties of TWIP steel," *JOM*, vol. 71, no. 4, pp. 1291–1302, 2019.

[50] P. Sivaraj, M. Seeman, D. Kanagarajan, and R. Seetharaman, "Influence of welding parameter on mechanical properties and microstructural features of resistance spot welded dual phase steel sheets joint," *Materials Today: Proceedings*, vol. 22, pp. 558–562, 2020.

[51] Q. Liu, Q. Zhou, J. Venezuela, M. Zhang, J. Wang, and A. Atrens, "A review of the influence of hydrogen on the mechanical properties of DP, TRIP, and TWIP advanced high-strength steels for auto construction," *Corrosion Reviews*, vol. 34, no. 3, pp. 127–152, 2016.

[52] V. H. Lopez-Cortez and F. A. Reyes-Valdes, "Understanding resistance spot welding of advanced high-strength steels," *Welding Journal*, vol. 87, no. 12, pp. 36–40, 2008.

[53] M. Tumuluru, "Resistance spot welding techniques for advanced high-strength steels (AHSS)," in *Welding and Joining of Advanced High Strength Steels (AHSS)*, Woodhead Publishing, 2015, pp. 55–70.

[54] M. Tamizi, M. Pouranvari, and M. Movahedi, "Welding metallurgy of martensitic advanced high strength steels during resistance spot

welding," *Science and Technology of Welding and Joining*, vol. 22, no. 4, pp. 327–335, 2017.

[55] M. H. Razmpoosh, M. Shamanian, and M. Esmailzadeh, "The microstructural evolution and mechanical properties of resistance spot welded Fe–31Mn–3Al–3Si TWIP steel," *Materials & Design*, vol. 67, pp. 571–576, 2015.

[56] P. Sivaraj, M. Seeman, D. Kanagarajan, and R. Seetharaman, "Influence of welding parameter on mechanical properties and microstructural features of resistance spot welded dual phase steel sheets joint," *Materials Today: Proceedings*, vol. 22, pp. 558–562, 2020.

[57] S. S. Nayak, V. H. Hernandez, Y. Okita, and Y. Zhou, "Microstructure–hardness relationship in the fusion zone of TRIP steel welds," *Materials Science and Engineering: A*, vol. 551, pp. 73–81, 2012.

[58] H. Li, S. Gao, Y. Tian, D. Terada, A. Shibata, and N. Tsuji, "Influence of tempering on mechanical properties of ferrite and martensite dual phase steel," *Materials Today: Proceedings*, vol. 2, suppl., pp. S667–S671, 2015.

[59] B. D. Gurav and S. D. Ambekar, "Optimization of the welding parameters in resistance spot welding," *International Journal of Mechanical Engineering and Technology*, vol. 4, no. 5, 2013.

[60] Z. Nasir and M. I. Khan, "Resistance spot welding and optimization techniques used to optimize its process parameters," *International Research Journal of Engineering and Technology (IRJET)*, vol. 3, no. 5, pp. 887–893, 2016.

[61] X. Zhang, G. Chen, Y. Zhang, and X. Lai, "Improvement of resistance spot weldability for dual-phase (DP600) steels using servo gun," *Journal of Materials Processing Technology*, vol. 209, no. 5, pp. 2671–2675, 2009.

[62] N. Zhong, X. Liao, M. Wang, Y. Wu, and Y. Rong, "Improvement of microstructures and mechanical properties of resistance spot welded DP600 steel by double pulse technology," *Materials Transactions*, vol. 52, no. 12, pp. 2143–2150, 2011.

[63] I. A. Soomro, S. R. Pedapati, and M. Awang, "Double pulse resistance spot welding of dual phase steel: Parametric study on microstructure, failure mode and low dynamic tensile shear properties," *Materials*, vol. 14, no. 4, art. 802, 2021.

[64] A. Alzahougi, B. Demir, and M. Elitas, "An optimization study on resistance spot welding of DP600 sheet steel via experiment and statistical analysis," *Engineering, Technology & Applied Science Research*, vol. 13, no. 4, pp. 11106–11111, 2023.

[65] C. Rajarajan, P. Sivaraj, and V. Balasubramanian, "An empirical relationship for estimating metallurgical and mechanical behavior of resistance spot welded DP800 steel joints," *Journal of Manufacturing Engineering*, vol. 14, no. 2, pp. 66–70, 2019.

[66] J. Valera, V. Miguel, A. Martínez, J. Naranjo, and M. Cañas, "Optimization of electrical parameters in resistance spot welding of dissimilar joints of micro-alloyed steels TRIP sheets," *Procedia Manufacturing*, vol. 13, pp. 291–298, 2017.

[67] S. Sajjadi-Nikoo, M. Pouranvari, A. Abedi, and A. A. Ghaderi, "In situ post-weld heat treatment of transformation induced plasticity steel resistance spot welds," *Science and Technology of Welding and Joining*, vol. 23, no. 1, pp. 71–78, 2018.

[68] M. Hamedi, M. Shariatpanahi, and A. Mansourzadeh, "Optimizing spot welding parameters in a sheet metal assembly by neural networks and genetic algorithm," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 221, no. 7, pp. 1175–1184, 2007.

[69] M. Tutar, H. Aydın, and A. Bayram, "Multi-objective Taguchi optimization approach for resistance spot welding of cold rolled TWIP steel sheets," *Journal of Physics: Conference Series*, vol. 885, no. 1, 012010, 2017.

[70] M. Tutar, H. Aydın, and A. Bayram, "The optimisation of welding parameters for electrical resistance spot-welded TWIP steels using a Taguchi method," 2018.

[71] H. Aydın, M. Tutar, and A. Bayram, "The influence of welding time on mechanical properties of resistance spot welded TWIP steel sheets," *Machines. Technologies. Materials.*, vol. 10, no. 11, pp. 19–22, 2016.

[72] T. O. Olugbade, "Stress corrosion cracking and precipitation strengthening mechanism in TWIP steels: Progress and prospects," *Corrosion Reviews*, vol. 38, no. 6, pp. 473–488, 2020.