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REVIEW AND ANALYSIS ON RESISTANCE SPOT WELDED JOINTS OF STAINLESS-STEEL ALLOY USING MULTI-OBJECTIVE OPTIMIZATION

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ABSTRACT

In industries such as automobile and railway manufacturing, the resistance spot welding (RSW) process is used extensively. An electric current is used in conjunction with mechanical pressure in the creation of RSW joints. Ferritic stainless steels are extensively utilized in the construction of buses and trains because of their excellent strength and corrosion resistance. Stainless steel austenitic is regarded to be a more expensive alternative. RSW welding of these steels is frequently required in the rail coach manufacturing industry, whether it is with the same material or with materials that are dissimilar. RSW has been the subject of a massive amount of research. Materials like low carbon steel, advanced high-strength steel, and austenitic stainless steel are frequently discussed in RSW literature. Ferritic stainless steel spot-welded joints have a dearth of data on their mechanical and microstructural properties. For ferritic stainless steel welds, optimization of the RSW method is absent in the literature. Size of the nuggets utilised in the welding process has a direct impact on the mechanical qualities of ferritic stainless steel weld joints, such as load bearing and energy absorption capacity. In the weld fusion zone, microhardness values exceeded those of base metal. The weld's high-temperature heat-affected zone was found to have grain growth. Columnar ferrite was found to be the dominant microstructure in the fusion zone. The relationship between welding current and failure mode was examined. Investigations were made into the correlations between input parameters and output quality characteristics. Multi-response optimization based on Taguchi's quality loss function approach was used to optimize the RSW process of AISI steel to achieve maximum weld strength with minimum electrode indentation. The obtained results were validated with a confirmation test. Furthermore, a linear first-order surface response model was developed using response surface methodology (RSM) and MINITAB software, for correlating both peak load and indentation, with the input parameters from the experimental data.

1. INTRODUCTION:

Elihu Thomson, who discovered the principle of melting metals together through resistance heating in the 1880s, is credited with inventing RSW. The RSW processes currently in use are based on the same fundamental principle. RSW is most commonly used in the automotive industry today. Other products like appliances, furniture, and small-scale circuit components are joined using RSW in the aerospace industry.

Automobiles and railroads both use welding technologies like resistance spot welding (RSW). It is less expensive, faster, and easier to automate than other welding methods. At the point where two or more metal sheets meet, fusion is used to fuse them together. When creating joints, RSW employs both electrical and mechanical forces. Heat is generated at the metal-to-metal interface because of a resistance to current flow. Nuggets are formed when the melting point of a metal is achieved, and they begin to develop when the metal cools. Welds are solidified by cutting off electrical power to them while the electrode force is still in place. The weld nugget's size and shape are affected by a variety of factors. Around 2000 to 5000 spot welds are commonly found on a modern car today. There is no need for filler metal or fluxes when compared to conventional welding procedures. The welding current and force are transferred to the workpiece by using copper alloy electrodes.

When it comes to securing components in transportation and automobiles, resistance spot welding (RSW) has been the go-to approach for decades. When it comes to producing automobiles, this joining process is a great alternative due to its low cost and outstanding robot automation capabilities. While other joining methods like laser welding, arc welding, or mechanical fastening are used on a much smaller scale, a typical modern automobile has between 3000 and 5000 resistance spot welds in it.

Product properties such as safety, crashworthiness, and fuel efficiency are critical to the success of RSW because of the method's widespread use in manufacturing. Variations in process results should be minimised to ensure robustness in RSW applications. There must be an accurate understanding and prediction of the process variations in order to minimise the risk. Process planning is a critical step in gaining a better understanding of and predicting process variations.

Welding is a production or sculptural process in which materials are fused together. There are a number of common methods of welding, including gas, arc, resistance, and solid state. One of the oldest methods of joining metals is the reduction weld.

1.1 Resistance welding:

Metals can be joined together by resistance welding, which involves heating the metals to a fusion point and using mechanical pressure to fuse them together. Resistance welding processes include spot, seam, and projection welding in commercial applications. Resistance Spot Welding is the most common type of welding in this group (RSW).

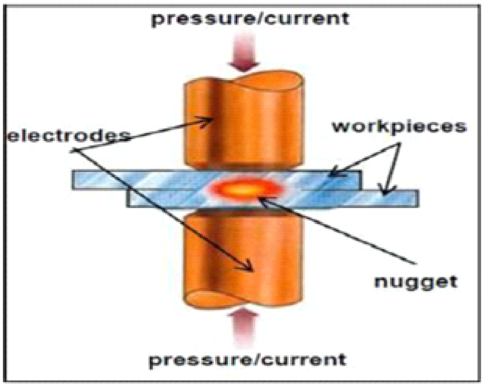

Fig 1: resistance spot welding process

1.2 Resistance spot welding:

Lap joints can be welded by flowing electricity through the electrode tips, which fuse the joint's false surface. The metal's resistance to electricity causes the joints to overheat. High amperage and low voltage A.C. current binds the components together (A.C.). Fusing occurs at the junction when the flow of current is impeded because of the high temperature of both components. Tongs and electrode tips are used to apply pressure to the parts during and following a welding current time cycle (through which current is flowing).

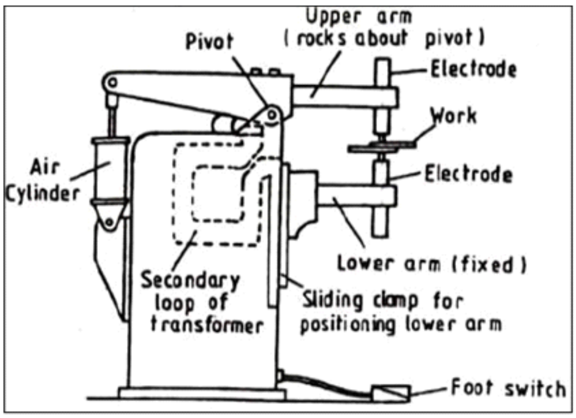

Fig 2: Spot welding

In a conductor, as heat goes through it, the conductor's electrical resistance works to obstruct the flow of electricity through it. This results in a discharge of heat. This is a way to say that heat generation can be explained.

$H = I^2R$

The following is an example of how heat is generated over time:

$H = I^2RTK$

Where, H = Heat, I2 = Weld Current squared,R = Resistance, T = Weld time, K = Heat losses

Unlike any other method, this one uses an internal weld nugget rather than one attached to the base metal's surface. Instead of an airtight assembly, spot welds are sufficient for welding sheet metal pieces with thicknesses of 3 mm or less. Sheetmetal and bars are used in the mass production of metal products such as automobiles, appliances, metal furniture, and more.

1.3 Need for the Study:

A vehicle's crashworthiness is defined as its ability to protect its occupants from serious injury or death in the case of an accident involving a collision. RSW technique is one of the primary welding procedures used in the production of vehicle structures and is heavily reliant on the integrity and mechanical performance of the spot welds. It has been determined that joint failure, such as resistance spot weld joint failure, is an important cause for vehicle accidents. It is possible that spot weld failure could have a negative impact on the vehicle's NVH and stiffness performance on a global scale. Resistance spot welds' quality, performance and failure characteristics are critical to the design of automobiles' longevity and safety. Weld characteristics, mechanical qualities, and failure mode are some of the criteria used to evaluate the quality of resistance spot welds. Understanding how resistance spot welding 3 procedures affect the weld joint's mechanical and metallurgical properties is essential for quality evaluation and subsequent improvement.

1.4 Problem Statement:

The use of ferritic stainless steel in railcar manufacturing is on the rise, particularly in the fabrication of railcar body panels. There are a lot of RSW welders around here. Resistance spot weld performance, quality, and failure characteristics are all important factors in vehicle safety design. Studying welding process factors and interrelationships between weld performance and spot weld quality are both necessary for the evaluation procedure. It is hard to estimate weld characteristics in RSW due to its heterogeneous nature. As a result, it is critical that the spot welds be thoroughly understood in order to ensure the vehicle's crashworthiness. Spot welding quality evaluation is also critical to improving vehicle production costs.

Numerous studies have been conducted and published on RSW. Materials like austenitic stainless steel, which is the most prevalent austenitic stainless steel, have been the focus of RSW studies. The mechanical and microstructural characteristics of ferritic stainless steel spot-welded joints are unknown. When it comes to building railcars, ferritic stainless steel is a popular choice because of its high corrosion resistance. A common method for joining ferritic stainless steel to other stainless, low-carbon steel, and other materials is resistance spot welding.

The importance of studying the mechanical characteristics and microstructure of spot-welded joints of the same type in various metal configurations cannot be emphasized in this context.

2. LITERATURE REVIEW:

Nizamettin Kahraman et al [1] CP (commercially pure) titanium sheets were tested using a variety of welding parameters and welding conditions (ASTM Grade 2). The tensile shear strength of argon-filled joints increased as the current period and electrode force increased. The welding nugget was found to have the greatest hardness, while the heat-affected zone (HAZ) and the base metal had the lowest. It was determined that welding with argon gas had no influence on hardness levels. Microstructural study results showed that the welding zone was twinning rather than shearing. Twinning was also discovered to be a result of high pressure and long welding times.

S. Aslanlar et al [2] Sheets used in the automobile industry during electrical resistance spot welding have had their mechanical qualities examined for how nucleus size affects those properties. It's recommended to utilise a 7 or 8.5 kA welding current for 15 cycles if you need high tensile, shear or peel strength. Because of this, the maximum sheet thickness is at least 20% more than it should be. Color changes, substantial distortion, and overmelting can occur as a result of spot welding. Surface quality is more essential than structural strength when welding currents of 5, 4.5, and 6 kA are used for 15 cycles of welding time, 20 cycles of welding time, and 10 cycles of welding time, respectively. 6%, 10%, and 14% of the material is indented by the electrode at each of these depths. These results are clearly below the permissible 20% threshold.

M. Vural et.al. [3], The fatigue strength of various steel sheets resisting spot welding is being investigated in relation to the diameter of the weld nuggets. Fatigue tests were conducted on galvanised galvanised and austenitic stainless steel (AISI 304) sheets. Experiment factors included the materials used and the nugget's diameter. An S–N curve for each specimen was created following high cycle fatigue tests. The galvanised steel sheet combination proved to be the most beneficial in terms of fatigue. AISI 304 galvanised steel and galvanised galvanised steel sheets have the lowest fatigue limit. These measurements were made following the completion of fatigue tests on a stainless steel–galvanized sheet junction. The spot-welded galvanized–AISI 304 joining type has a lower crack propagation rate than base metals, at least initially.

L. Han et.al. [4], Spot welding in the aluminium alloy AA5754 was tested for mechanical strength and resistance. AA5754 aluminium alloy was utilised in this study to construct unique joint stack-ups with different process parameters and matching weld quality metrics. Quasi-static joint strength was evaluated using test geometries such as lap-shear, coach-peel, and cross-tension. More than a thousand samples were analysed, and the results show a wide range of fundamental connections. Lap-shear strength was shown to be strongly linked to the diameter of the weld nugget, while coach-peel test geometry yielded distinct strength levels depending on the controlling metal thickness of the parent sheet for each stack-up. With regard to crosstension strength, nugget diameter has a correlation; nonetheless, the statistics are subject to perimeter faults in the nugget itself. Because of these fundamental connections, the aluminium RSW design community now has a set of principles to follow when developing new products. There appears to be a correlation between the diameter of the plug and the breaking load in GMT's data for cross-tension test geometries. Spot welding in cross-tension can hold at least twice the weight of spot welding in coach-peel geometry, to put it another way.

S.M. Hamidinejad et.al. [5], Car body manufacture galvanised steel sheets were modelled and analysed for resistance spot welding. Galvanized interstitial-free (IF) and bake hardenable (BH) steel sheets are used in a resistance spot welding procedure to construct car bodywork, which are then heat treated. A backpropagation neural network model was used to analyse the RSW process and the interaction of parameters. It was found that by using Genetic Algorithms to optimise a set of process parameters, including joint strength, an ANN model was used to determine the fitness function for this study's second phase. It was found that the optimization results were very close to the experimental data. The RSW joints' tensile–shear strength is not linearly related to welding settings, according to regression analysis. According to the results of the ANN model, welding parameters and their interactions had a considerable impact on tensile–shear strength measurements. The RSW method for galvanised interstitial free (IF) and galvanise bake hardenable (BH) steel sheets can be utilised as a guide here. This research proposes an ANN/GA optimization technique to enhance the RSW process. According to the actual data, the GA-optimized results were verified to be correct.

Dawei Zhao et.al [6] Spot-welded titanium alloy failure energy was the subject of a process analysis and optimization. When building an RSM mathematical model, the Box–Behnken experimental design with three levels and three components was used. It was necessary to investigate each process parameter in order to determine how it influenced our ability to weld high-quality joints. An artificial fish swarm model was used to increase the failure energy of welded joints (AFSA). Electrode force and welding time were found to have less of an effect on failure energy than welding current in an ANOVA experiment. With the use of AFSA's mathematical model, weld failure energy can be maximised utilising a welding time of 9.54 milliseconds, an output current of 2.4 kA, and a force of 127 Newtons (N).

Norasiah Muhammad et al. [7] This study used the multi-objective Taguchi technique and RSM to optimise spot welding parameters while also accounting for numerous responses at the same time. Resistance spot welding (RSW) process parameters are optimised for weld zone development using an alternate method described in this study. Weld nugget and heat-affected zone (HAZ) quality parameters are optimised using the multi-objective Taguchi technique (MTM). A 1.5 mm thick plate was used to measure welding current, weld time, and hold time. The L9 orthogonal array developed by Taguchi was utilised to find the best welding parameters.. The best value was obtained by the application of MTM, TNQL, and the multi-signal to noise ratio (MSNR). An analysis of variance (ANOVA) was used to increase the significance of the welding parameters (ANOVA). Predicting the formation of weld zones using the response surface technique is also possible (RSM). Welding current (73.91 percent), weld time (16.72 percent), and hold time (6.72) comprise the majority of the control parameters (7.14 percent). HAZ width and radius weld nugget generation are both dependent on welding current.

Haiqiang Long et al. [8] There has been research done on the effect of holding time on weld joints between low carbon steel and advanced high strength steel to examine microstructure, hardness, and mechanical property changes. All three sections are clearly distinct microstructures in terms of their microstructures. In order to maintain manufacturing efficiency, a holding period of less than 15 cycles is recommended based on test results. This affects the welding efficiency. The tensile test is modelled using nonlinear finite element analysis. Because the fusion zone becomes tougher, weld nuggets with longer holding durations have a greater maximum shear resistance. As the holding period before failure switches from IF to PF, the weld joint's peak load increases. Increased holding time has no influence on the weld joint's peak load if button pull-out is the cause of the failure. The additional holding time has a negative impact on productivity. In order to ensure the efficiency of the thin sheet metal welding process, hardness and failure tests advise a holding duration of less than 15 cycles.

Min Jou et al [9] Resistance spot welding was used to check in real time the quality of the welds in sheet metal components. The quality of RSW welds varies substantially from weld to weld, according to him. Complexity and a wide range of circumstances that can lead to errors are just some of the aspects that contribute to this problem. It is the goal of this study to establish a link between a critical process input variable and a critical process output of a quality weld. The heat input percentage is the chosen input parameter since it has a direct impact on the final weld's size and strength. A weld nugget's growth and expansion may be properly predicted using the electrode displacement measurement. A variety of automotive-grade sheet steels will be studied to see how changing the heat input proportion affects the electrode displacement curve. It was determined that the electrode displacement curve was affected by variations in the percentage of heat input. These sources of variation and error can be compensated for in the process representation and development of a control technique.

R.S Florea et al. [10] It was found that the microstructure and fatigue life of 6061T6 aluminium alloy can be affected by welding conditions. The fatigue behaviour of an aluminium 6061-T6 alloy (AlMg1SiCu according to the nomenclature of the International Standard Office) was examined experimentally during resistance spot welding (RSW). Single weld lap-shear joint coupons were explored by conducting load control cycling testing. Iterations and "witness samples" were used to find the best current, force, and welding duration. The sensitivity of the process was examined and summarised. The "nominal" and "high" welding conditions specified in MIL-W-6858D were met or exceeded. To a large extent, welding current influenced the dimensions of the welding nuggets and the mechanical behaviour of the lap joints. The fatigue life was reduced by an order of magnitude on the "low" welding condition, which has a dramatic effect on mechanical properties under cycling loading. From 6000 to 2,000,000 cycles, the number of times the machine failed before it failed.

3. MULTI-OBJECTIVE OPTIMIZATION OF THE RESISTANCE SPOT-WELDING PROCESS:

Table 1: A review of the optimization of the RSW process for different steels and parameters

Authors	Materials	Optimizations methods	Variable input parameters	Output	Results of optimizations
S. H. M. Anijdan at al.8 (2018) [11]	DP600 / AISI 304 STEEL	Taguchi	Current density Welding time Electrodes force Holding time af- ter welding	Shear-tensile stress (N/mm^2)	Optimal parameter: 16 kA 16 cycle 5 kgf 35 cycle
H.A. Shende et al.9 (2017) [12]	AISI 304L / AISI 1020 STEEL	Grey- Taguchi /ANOVA	Current Pressure Weld time Hold time	Tensile strength (N/mm^2) Nugget diam- eter (mm)	The best combination of parameters for maximum tensile strength and minimum nugget diameter was found using an optimization technique: current 10 kA, pressure 4 bars, welding cycle time 10 cycles, and hold cycle time 25 cycles. I 91.6 percent, W T 7.16 percent, P 1.19 percent, and H T 0.017 percent are the most influential parameters in this study's response.
F. Reyes-Calderón et al.10 (2018) [13]	DP290/DP 290 STEEL	Taguchi	Force, Time and Current Intensity	Force (N)	Optimal conditions are: 0.75 MPa of pressure, 3.5 kA of current and 1,800 ms of welding time. Force (F) -33,82%, Time (T)- 19,5% and Current Intensity (I) - 46,67%
A. Arumugam et al11 (2015) [14]	SPHC / SPRC35 STEEL	Grey- Taguchi /ANOVA	Force, Time and Current Intensity	Tensile shear strength and weld diame- ter	The optimum welding schedule obtained from this paper is a combination of 3 kN of electrode force, time of 15 cycles and 9 kA welding current. Force (F) -21.5 %, Time (T)- 11.9 % and Current Intensity (I) - 58.7 %

Aleksija Djuric, et.al, [15], Resistance spot welding (RSW) continues to be the most prevalent method of welding steel in the automotive industry. Choosing the correct welding parameter for dual-phase steel, a cutting-edge automotive material, is essential. Because of this, this article focuses on the optimization of the RSW welding process of DP 500 steel. Due to the importance of spot welding quality, this study takes into account all three of these variables: failure load, weld nugget diameter, and weld nugget diameter. The results suggest that the welding current is the most important parameter in terms of mechanical qualities. The amount of time spent welding has the least effect on the final weld. For welding DP 500 steel, the best parameters are weld current 8 kA, electrode force 4.91 kN, and weld time 400 ms.

Ehab M. Shaheen,et.al, [16], Mathematical formulas for the tolerance of the GPS receiver to various interference signals, such as continuous wave, narrowband, partial band and broadband interference as well as match spectrum interference and pulse noise are the focus of this research project. For the purpose of determining the GPS receiver's response time to previously indicated interferences, this study calculates its mean time to loss lock. Extensive simulation experiments validate these derived analytical expressions.

S.H. Mousavi Anijdan, et.al, [17], The weld nugget's martensitic structure provided the weld nugget with relatively high strength and hardness, resulting in a PF-type fracture in a dissimilar joint of DP steel and ASS. There are also several issues with the conventional RSW dissimilar joint between DP steel and the Zn layer, which results in a deeper indentation than is desirable for the aesthetic appearance of the weld. The Zn layer on the DP steel must also be removed during the RSW process because it is more sensitive to contact pressure.

Manladan et at [18]. Energy absorption and peak load are all influenced by RSW process factors. Peak load and energy absorption are reduced as a result of the larger nuggets. Failure mode transformation into substrate was blamed for this high nugget size. As a result, the higher current variable has a negative influence on strength. Increases in welding duration and electrode force increased the joint's strength. Metal fillers, particularly AHSS and ASS, have been overlooked in several studies on dissimilar metal joint procedures.

G. Park, et.al, [19], In thin sheet assembly, resistance spot welding (RSW) is a common method of joining materials together. Welds are created by combining heat, pressure, and time in a rapid sequence. Because of its speed and ability to be automated, this welding technique is popular in the automotive industry. In order to fulfil the emissions, strength, and sustainability requirements of the automotive industry, many components of this production process must be addressed. Problems to be solved include brittle failures caused by insufficient welding parameters and high production costs resulting from excessive energy consumption during welding. Welds that are both strong and ductile can be produced with less energy and time by optimising process parameters.

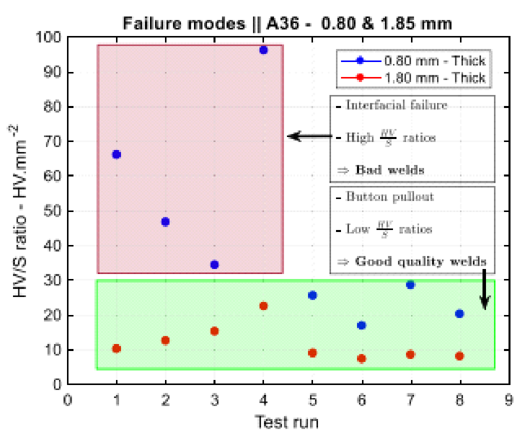

Fig. 3 HV/S ratios versus failure modes for A36 steel

Both interfacial and button pullout failures occurred in the welds in the red and green rectangles, respectively.

Pashazadeh et al. [20] performed a study on how to improve the weld nugget geometry by adjusting the machine parameters during RSW To begin, they constructed a factorial experiment with three independent variables, each with a two-level scale: current, pushing force, and welding time. In order to carry out the actual optimization, they combined the multi-objective genetic algorithm with an artificial neural network hybrid. Prediction errors of 1.28 percent for nugget diameter and 6.98 percent for nugget height were used to validate the optimised parameters.

T. Safuddeen, et.al, [21], ASTM A36 and ASTM A653 hot dipped galvanised steel were used in this project. Because of its exceptional malleability and weldability, ASTM A36 is one of the most commonly utilised hot-rolled steels in North America. For automotive interiors, it is a common choice of material For its part, corrosion-resistant galvanised steel is becoming increasingly popular in the automotive industry. Corrosion-resistant zinc coatings are responsible for achieving this level of corrosion resistance. As a result, galvanised steel is widely used for external automobile parts.

Boriwal L, et.al, [22], With resistance welding, one may join steel sheets without using any filler material and it is a low-cost, fully automated procedure. Resistance spot microwelding, also known as small-scale resistance spot welding (SSRSW), has grown in popularity in recent years as a method for attaching tiny sheets of metal 0.2–0.5 mm in thickness. Resistance spot welding (RSW) is one of the numerous forms of RSW, which is also known as "typical" RSW (LSRSW). For this procedure, sheets with a thickness more than 0.6–0.8 millimetres are frequently utilised (p. 121). The application of resistance microwelding in the production of electronic components and devices, such as batteries, cell phones, and the interconnections in printed circuit boards (PCBs), relays, sensors, and air-bag diffuser screens (DSSs) in medical equipment, has increased recently.

Amada Miyachi [23] A high welding power supply is required for small and micro-scale resistance welding to be successful. Welding costs, weld quality, system management, and the material and geometry of the piece all need to be taken into account when deciding on a power source. For most large-scale resistance welding systems, AC power is the primary source of power. Because of its short cycle periods and sensitivity to voltage changes, this sort of power supply is ineffective for microscopic and microscale resistance welding. Resistance welding on tiny and micro scales can benefit from the CD power supply.

Lee et al. [24] Inverter DC resistance-spot-welding systems can now be controlled by a fuzzy controller, allowing for the adaptive regulation of the welding process. This results in a lower power consumption, a reduced electrode wear, and a more uniform nugget size due to the better energy efficiency of the DC resistance spot welding process. AC welding machine quality monitoring is well-documented, but few studies have examined a system specifically designed to anticipate and assess the quality of welding produced by a DC welding machine..

Summerville et al. [25] The diameter of a nugget was determined directly from its dynamic resistance by analysing the dynamic resistance curve. It has been discovered that this curve can be used to reduce the time and cost of making nuggets. Xing et al. [26] developed a method based on dynamic resistance signals for evaluating the quality of the resistance spot welding process online using random forest classification. In order to characterise each dynamic resistance plot, a number of variables were collected and used as inputs into a random forest classification model, which produced three types of welds as outputs: cold welding, excellent welding, and ejection welding.

Wang et al. [27] dynamic resistance signals were used in conjunction with a quick classification of welding-quality signals based on a map and windowed feature extraction. The classification accuracy was 92.9 percent, according to the findings of the spot-welding studies performed.

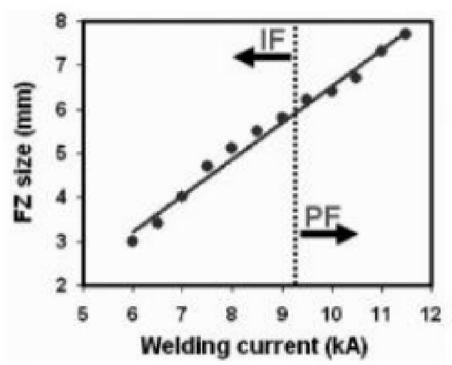

Figure 4. Spot weld failure modes at different currents and weld diameters.

Research on the test samples used to examine spot weld failures has been published in a number of places. Several researchers have employed the lap-shear test in their spot weld failure investigations. Pouranvari performed a lap shear test on HSLA 420 steel weld joints to investigate the reason of weld failure. The interfacial and pull-out failure modes were shown to be related to welding current, weld diameter, or the size of the fusion zone, as shown in Figure 4.

Rajarajan, C., et.al [28], Welding is commonly used to unite metals in automobiles. In the automotive sector, welding technologies such as arc welding, friction welding, laser beam welding, and a variety of other methods have been used. When it comes to body-in-white fabrication (BIW) and automotive industry, resistance spot welding (RSW) still reigns supreme (RSW). Known as "spot welding," the welding method has grown in popularity because it is a low-cost, easily automated procedure that produces large quantities of high-quality parts with little distortion. A total of 2000-5000 spot welds are employed in automotive BIW to unite the various metal sheet kinds and forms. Multi-materials lightweight (MML) design, which combines lightweight metals such as advanced high-speed steels (AHSS), aluminium, and magnesium, has been the subject of numerous studies.

Kim, G.-C., et.al, [29], The weld strength of a spot weld is directly related to the quantity of heat generated during the welding process. Welding current, electrode force, and weld time are all examples of process variables. If the weld current and electrode force remain constant, or if weld time is prolonged without affecting the weld current, the amount of heat generated during spot welding can be raised in one of two ways. This is based on research. Weld diameter and strength increased as a result of the elevated temperature.

Zhou, K.; [30], The electrode force is a third weld characteristic that contributes to heat generation and is directly linked to dynamic resistance. To the contrary of increasing welding current or welding time, increasing electrode force while maintaining these parameters increased heat generation during the spot welding process. When the electrode force is decreased, the resistance to current flow at the sheets' interface will increase due to surface asperities and reduced sheet-to-sheet contact. Increased current density leads to increased heat generation at the weld interface, which is necessary for the weld to grow. There will be a greater amount of sheet-to-sheet surface contact if the electrode force is raised. Heat generation will be reduced as a result of the drop in current density. Low electrode force causes expulsion due to overheating, whereas high electrode force causes undersized welds due to low heat output, hence it is best to avoid both extremes.
Jiang Yu,et.al [31], In order to join two disparate metals, Q235 mild steel and TC4 titanium alloy were resistance spot welded with NieCu alloy as filler metal (abbreviated as resistance welding with interlayer). The results were compared using normal resistance spot welding without an interlayer (abbreviated as D-RSW). Mechanical parameters (including shearing force and microhardness) of welded joints were studied in relation to the macro-, interfacial-, and microstructural effects of NieCu alloy. MSC.Marc software was used to model the temperature field throughout the welding process, and the validity of the numerical results was checked by infrared thermal imaging of the same spot. Temperatures exceeded melting points of TC4, Q235, and interlayer, according to findings.

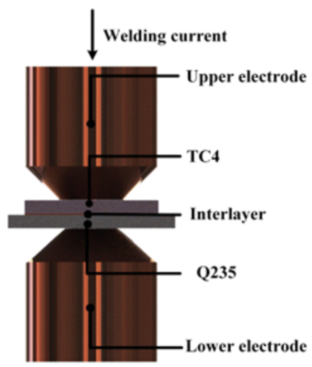

Fig. 5 The Schematic diagram of the whole RSW welding process.

The full RSW welding procedure is shown schematically in Fig. 5. In this experiment, the primary materials were TC4 titanium alloy and Q235 mild steel. Wire cutting was used to reduce the first and second to 20 mm20 mm2 mm and 25 mm25 mm2 mm, respectively. Researchers found a 3T stack-up construction by inserting an interlayer of 0.15 mm-thick Nickel Copper Alloy between TC4 Alloy and Q235 Steel in Figure 5.

P. Pitchipoo, et.al, [32], Welding occurs in the solid phase in FSW, where friction heat is used to weld the joint. It is possible to weld extremely strong and distortion-free joints with FSW. Today, the FSW method is widely used for a wide range of aerospace-related tasks. An optimization technique based on the Dragonfly Algorithm has been used to improve the weld strength of FSW in 6082-T6 aluminium alloy (DFA). For this study, the major objective is determining which input process parameters, such as tool rotation speed, welding speed, and tilt angle, yield the best possible weld tensile and impact strength. In order to verify and simulate the best process parameters, MATLAB software is utilised.

Shashi Bahl,et.al [33], These include friction stir welding, microwave hybrid heating, electron beam welding, laser beam welding, thermo-hydrogen diffusion bonding, electromagnetic welding, and ultrasonic welding. A primary goal of these newer methods of connecting is to maximise efficiency and reduce failure. Research gaps and current trends in improved joining techniques have been outlined in this review study.

Aleksija Djuric, et.al [34], This welding technology, known as RSW, has been used for decades in the automotive industry. If you're working with a dual-phase steel, you need to make sure you're selecting the right parameters for the welding process. Multi-objective RSW welding optimization of DP 500 steel is presented in this work. The failure load (F), the failure displacement (l), and the diameter of the weld nugget (D) are all considered in this study since they all play a vital influence in determining the quality of spot welding. There is a clear correlation between welding current and mechanical properties, according to these studies. Welding time has the smallest impact on weld quality.

Vignesh Krishnan, et.al [35], The resistance spot welds (RSW) are examined in this article to see how welding parameters affect the tensile shear fracture load, nugget shape, and microstructure under lap shear loading conditions. As a consequence of the macroscopic investigation, a large number of the nugget lengths tested failed under higher tensile shear loads than the AWS suggested value of 4 t. Due to the higher thermal conductivity of duplex stainless steel, the nuggets on the DSS 2205 side were taller than those on the AISI 316 L side (DSS). In order to improve the weldment's tensile shear load and microstructure, the welding current should be increased from 8 kA, and the heating cycle should be increased from six minutes to nine. Both sides of the nugget's edge shift from equiaxed to columnar grains, resulting in different levels of hardness in the fusion zone. Nearby DSS HAZ and ASS HAZ showed lesser hardness, whereas DSS HAZ and ASS HAZ reported greater.

Ming Yang, et.sl [36], A tantalum coating on a steel substrate was successfully prepared using an enhanced explosive welding approach that utilised a specific charging structure and a double-layer buffer structure to provide an optimal welding state. Microstructural analysis of the joints was done using a scanning electron microscope (SEM) and an energy dispersive X-ray spectroscopy (EDS) apparatus. These tests included three-point bend and nanoindentation to determine the mechanical characteristics of the material. The increased explosive welding process was proven to be a good way for producing Ta coatings on steel. In both microstructure and mechanical testing, Ta foil and Q235 plate showed excellent bonding quality. A new vortex structure at the Ta/Fe interface also prevented crack development from the brittle melted area. Ta foils used in explosive welding significantly increased a steel plate's corrosion resistance, according to a corrosion test.

Mathi Kannaiyan, et.al [37], In this present study, the RSW process parameters were optimised to connect two alternative combinations of AISI 304 and AISI 1020 grade steel. The trials altered the three main welding process parameters, such as welding current, welding pressure, and welding time. It was determined that the weld joints were structurally and metallurgically sound. Nugget diameter, hardness, and tensile shear fracture were examined by researchers. Macrostructure, microstructure, and scanning electron microscopy (SEM) investigations of the examined samples were performed in order to identify the kind of fracture. The greatest diameter of a nugget and the maximum tensile strength of 10.5 kN were both reached. The findings of the experiments validated the efficacy of the Response Surface Methodology utilised in the RSW process to optimise the welding process parameter. Tensile Shear Fracture Load (TSFL), nugget diameter, and weld pressure and time were shown to be the most significant factors in the RSM results.

Abhishek Tyagi, et.al, [38], The Taguchi L18 approach was used in this study to optimise the spot-welding process parameters on the JSC 590RN low carbon steel grade. An electrode's diameter, electrode force, welding current, and time are all factors in determining the quality of a spot welding joint's quality. Qualitative characteristics such as Nugget diameter (N-D), tensile strength and heat affected zone (HAZ) were taken into consideration for improvement. Taguchi L18 was chosen for testing in the lab. When examining the influence of process variables on spot welding, researchers employed the GRA method. Welding current (39.19 percent) and weld time are the two most significant independent variables in the ANOVA (23.81 percent).

CONCLUSION:

Finite element analysis was used to examine experimentally and quantitatively the failure mechanisms of spot welds in this work. The goal of this review is to give readers a complete picture of the current state of knowledge and future directions of RSW weld failure analysis. Modern vehicle metals including Advanced High Strength Steel (AHSS), Aluminum, and Magnesium have been the subject of research on spot weld failures. Material weldability and thickness, location of spot welds, parameters of welding, coatings, and loading types all have an effect on how strong a spot weld connection will be. In the current automotive design, dissimilar metal junctions, such as those produced from various metals and thicknesses, are becoming increasingly important due to the necessity for weight reduction in automobiles and the higher safety and structural integrity requirements. Welding DP 500 steel at 8 kA with an electrode force of 4.91 kN and a weld time of 400 ms yielded the best results in this study. The percentage contributions of welding current, electrode force, and welding time are 90.56 percent, 5.89 percent, and 1.71 percent, respectively. As a result, welding current is advocated as the most significant determinant of quality features in welding. Compared to other factors, welding duration and force have a very minor impact on the final weld quality. Welding current has a significant impact on the mechanical features, particularly on the failure load, failure energy, and failure mode. In other words, an increase in welding current does not necessarily indicate greater mechanical properties.

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