A Review on Resistance Spot Welding for Similar and Dissimilar Joints

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Abstract:

Resistance spot welding is one of the primary welding techniques used as a successfully joining method for variety of jobs in the automobile structural body manufacture, rail vehicle construction, electronics manufacture, battery manufacture, aerospace industries etc. Welding input parameters plays a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld-bead geometry, mechanical properties, and distortion. However, the resulted joints are affected by some parameters such as quality, mechanical and metallurgical properties using various similar and dissimilar metals. Total 50 research papers were selected for our consideration after thorough investigation of several such papers.

***Keywords* —** Resistance spot welding, Process parameters, Microstructure, Weld quality, Weld nugget, Properties of structure.

1. Introduction

Resistance spot welding (RSW) or simply spot welding is widely employed in automotive and aeronautical industries.This type of welding employs a tremendous amount of current and a very low voltage. Numerous types of metals like different grades of steels, aluminum (Al), magnesium (Mg), titanium (Ti), copper (Cu), and their alloys. Generallythin sheets of similar or dissimilar metals are joined by RSW in lap joint configuration. Resistance spot welding has excellent benefits such as low cost, uniform joint, no distortion, high production rate and adaptability for automation which make it an attractive choice for auto-bodyassemblies, truck cabins, rail vehicles and home appliances.Furthermore, two or more sheet metals can be joined by mechanical means more economicallybyusing RSW.

2. Working principle of resistance spot welding

Resistance spot welding is a fusion welding process thatworks on the principle of Joule's law of heating, whichstates that: $Q = I^2Rt$, where 'Q' is the amount of heat generated during RSW, 'I' denotes the welding current used, 'R' is the resistance setup at the interface of the metalsheets, and 't' is the welding time employed. RSW technique uses two truncated cone/dome-shaped copper alloy electrodes to concentrate the welding current into afixed small spot and to simultaneously clamp the sheetstogether without any misalignment. Thin sheets of metalsused as work pieces are held together under pressure exerted by the electrodes. The enforcement of a large amount of current through the spot will melt the metal and form a weld. RSW allows a large amount of energy to bedistributed to a specific location in a short period. Thisallows the welding to take place without overheating the rest of the metal sheet.

The resistance between the electrodes and metal sheets, aswell as the amplitude and duration of the welding current,control the amount of heat energy transferred to the produced spot. The amount of energy is chosen to match the sheets' material properties like thermal conductivities, coefficient of thermal expansion, electrical conductivity, etc. Applying too little energy will not melt the localized region and sufficient strength will not be developed. Whereas, applying too much energy will melt too much metal, eject molten material and make a void rather than a spot.

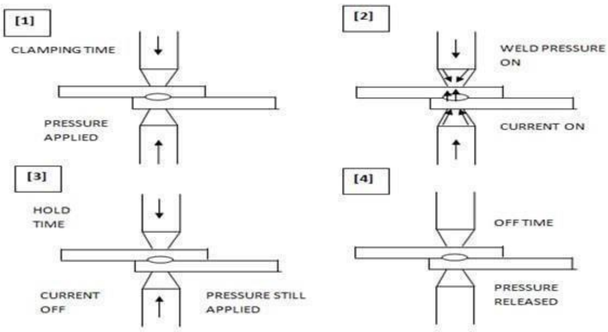

Fig. 2.1 Block diagram of resistance spot welding.

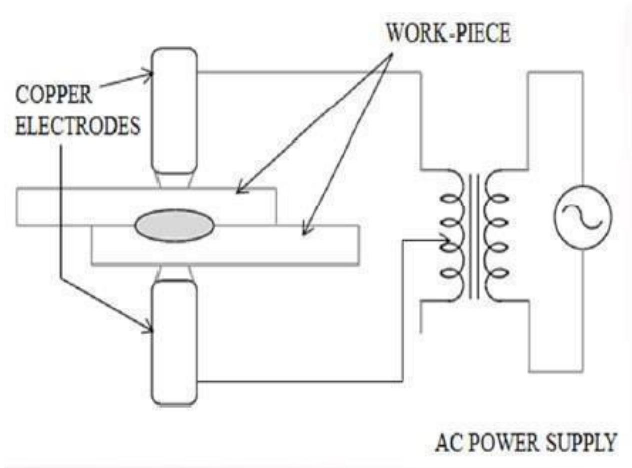

Fig. 2.2 Resistance spot welding setup

3. Process parameters of resistance spot welding

The determination of appropriate welding parameters for spot welding is a very complex issue. A small change of one parameter will affect all other parameters. The various parameters which affect the RSW are as follows.

- Electrode force
- Diameter of electrode contact surface
- Squeeze time
- Weld time
- Hold time
- Weld current

4. Literature review

Prof.B.S.Gawai et al. The aim is to identify the optimal welding parameters that produce high-quality welds. The process parameters can be optimized using various methods, such as the Taguchi method, response surface methodology (RSM), and artificial neural network (ANN). The Taguchi method is efficient in identifying the optimal welding parameters and reducing the number of experiments required. The RSM method is efficient in determining the optimal welding parameters and can handle a larger number of variables than the Taguchi method. ANN is efficient in identifying the optimal welding parameters, and it can handle a larger number of variables than the Taguchi and RSM methods. In conclusion, the analysis and optimization of process parameters in resistance spot welding of low carbon steel is crucial in producing high-quality welds. The optimal welding parameters can reduce the number of defects and increase the production efficiency [1].

Kamble Vijay Ananda et al. aim is to optimize the effectof process parameters on resistance spot weld shear strength. Several process parameters can affect the shear strength of a spot weld, including welding current, welding time, electrode force, and electrode size. A higher weldingcurrent can result in a stronger weld, but it can also cause excessive heating, which can lead to defects such as burn-through or expulsion. A longer welding time can result in a stronger weld, but it can also increase the risk of overheating and deformations. A higher electrode force can result in a stronger weld, but it can also cause electrodewear and deformations. A larger electrode size can result in a stronger weld, but it can also increase the risk of electrode wear and reduce the precision of the welding process. To optimize the shear strength of a spot weld joint, it is essential to carefully control the welding parameters and select the optimal values for each parameter. This canbe done through experimentation and analysis of the weld results. By adjusting the welding current, welding time, electrode force, and electrode size, it is possible to achievea strong, durable weld joint that meets the specific requirements of the application [2].

Safaa M Hassoni et al. The aim of this research is to analyze the mechanical properties and corrosion resistance of spot welding of stainless steels AISI 316L using the process parameters of resistance spot welding. The mechanical properties of 316L stainless steel are influenced by the welding current, welding time, electrode force, and electrode tip diameter. Higher welding current and longer welding time can result in larger heat-affected zones and higher distortion, which can negatively affect the mechanical properties of the welded material. On the other hand, a higher electrode force and smaller electrode tip diameter can lead to better mechanical properties due to thereduced heat input and smaller heat-affected zones. The corrosion resistance of 316L stainless steel is affected by thewelding parameters in a similar way. Higher heat input from the welding process can result in the formation ofundesirable phases, such as chromium carbides, which can lead to reduced corrosion resistance. Additionally, welding- induced residual stresses can contribute to the initiation and propagation of corrosion. Therefore, optimizing the welding parameters to minimize the heat input and residual stresses is crucial to maintain the corrosion resistance of 316L stainless steel [3].

Kamal Abdulkareem Mohammed et al. studied the effect ofwelding parameters on the nugget diameter and strength of welded joints using low carbon steel sheets. The results indicate that the quality and performance of spot welds are determined by the nugget size and joint strength, which increase proportionally. The welding parameters (current, time, pressure force) have a significant effect on the nugget diameter and strength of the weld joint, and the suitable combination of welding parameters is needed to obtain higher strength. Analyzing tensile strength tests indicates that increasing any one of the welding parameters will increase the failure load joints, and welding current is the most effective parameter on the required strength of the weld joint. Uncontrolled welding parameters such as high welding currentand longer welding time will result in electrode indentation, excessive heat generation, and expulsion, causing a decrease in the strength of the weld joint [4].

Mr.B.S.Gawai et al. Studied the tensile strength of resistancespot welded HR E-34 grade material sheets. The study involved joining two sheets of 2.0 mm using resistance spot welding with varying welding currents, weld cycle time, and pressure. Response surface methodology was used to determine the optimal welding parameters, and analysis of variance was used to analyze the significant level of these parameters. The input parameters significantly influence nugget size and weld strength, and residual analysis can satisfactorily predict nugget diameter and tensile strength. Confirmation tests show negligible differences between actual and predicted responses. Weld current and pressure are the most significant factors, with a percentage contribution of 37.23% and 36.2%, respectively, while weld cycle is less significant with a contribution of 23.29% [5].

H. J. Abid, Hassanein I. Khalaf et al. In this study, the effect of welding process parameters on the ultimate tensile strength and micro hardness of AISI 304 stainless steel resistance spot welded joints was investigated. Three welding parameters (welding power, sheet thickness, and welding time) with three levels were used in the experimental work, and the Surface Response Method (SRM) was used to determine significant process parameters and their optimal levels. The results showed that the tensile strength decreased with increasing welding current or welding time or both, while micro hardness increased slightly with increasing thickness and on-time duration. Nugget diameter also increased with increasing welding time. Analysis of variance (ANOVA) was used to determine the level of importance of welding parameters on tensile strength and micro hardness. The study highlights the importance of selecting optimal welding parameters for resistance spot welding to achieve high-quality welded joints[6].

Mehdi Safari et al. studied on experimental investigation of dissimilar resistance spot welding (RSW) of AISI 304 and AISI 1060 steel sheets and its impact on the tensile- shear strength (TSS) of the welded joints. The study uses an adaptive neuro-fuzzy inference system (ANFIS) to model and predict the TSS based on welding current, welding cycle, electrode force, and cooling cycle, and a Sobol sensitivity analysis method to quantify the effect of each input parameter on the TSS. The study finds that all process parameters, including the squares of welding current and cooling cycle, and the interaction of welding cycle and cooling cycle, influence the TSS of the dissimilar spot welds. Increasing welding current and welding cycle enhances TSS due to the generated heat, penetration depth, and spot area. In contrast, increasing electrode force and cooling cycle reduce TSS by decreasing electrical resistance and spreading heat to the electrodes. The study concludes that the ANFIS model can accurately predict TSS with high coefficient of determination and mean absolute percentage error, and welding current, welding cycle, cooling cycle, and electrode force have the most significant impact on the TSS of dissimilar RSW joints [7].

Aleksija Djuric et al. This study determines the optimal welding parameters for DP 500 steel using RSW welding method. The optimal parameters are a welding current of 8 kA, an electrode force of 4.91 kN, and a weld time of 400 ms. The welding current is identified as the most influential parameter with a contribution of 90.56% to the quality characteristics. The effect of welding time and force on weld quality is minimal. The welding current mainly affects the failure load, energy, and mode, and an increase in current does not necessarily result in better mechanical characteristics. Welding current and time have a greater influence on the failure mode than the welding force. The microstructure of the fusion zone (FZ) is identified as lath martensite, with a hardness of approximately 330 HV. The heat-affected zone (HAZ) has a hardness of around 260 HV [8].

Imtiaz Ali Soomro et al. investigates the modeling, optimization and welding parameters effect on tensile shear load-bearing capacity of double pulse resistance spot welded DP590 steel. The study found that the maximum average tensile shear peak load of 26.47 was achieved at optimum welding parameters, with the second pulse welding current being the most influential parameter that controls the tensile shear load-bearing capacity of the welds. Increasing the secondary pulse welding current and welding time and decreasing the first pulse holding time could lead to weld joints of high load-carrying capacity. The study also found that the ANN model predicted the output response with high accuracy even with fewer training data, and the ANN model showed a small percentage error than the regression model [9].

Jeevan A. Karande et al. focuses on the Tensile Shear (T- S) strength of resistance spot weld and presents an experimental investigation using the Taguchi method. The experiment involves varying the process parameters, such aswelding current, electrode force, squeeze time, and weld time, to determine their effect on T-S strength for spot weldson Stainless Steel (304L) and Aluminum 6061-T6 material. The study also investigates the dissimilar joining of aluminum and steel through resistance spot welding. The Taguchi quality design concept of L16 orthogonal array is used to determine S/N Ratio and Analysis of Variance (ANOVA) to identify the level of significance of welding parameters for T-S strength. The investigation concludes that the welding current is the most significant parameter controlling weld strength, while weld time, electrode force, and squeeze time have less significant effects. The optimum results for tensile shear strength are obtained using the Taguchi method at a welding current of8 kA, weld time of 39 cycles, electrode pressure of 85psi, and squeeze time of 46 cycles. The analysis also reveals that welding current has the highest contribution to T-S strength (53.33%), followed by weld time (28.78%), while pressure (10.48%) and squeeze time (4.94%) have the least impact on strength [10].

Osamah Sabah Barrak et al. This research aimed to investigate the impact of various resistance spot welding (RSW) parameters on the shear force of spot welded joints in two materials (AISI 304L and AA 6061-T6) with 0.5 and 0.7 mm thickness. Three values for each welding parameter wereused, and design of experiments (DOE) was used to determineand reduce the number of tested specimens. Experimental tests included shear, micro hardness, and microstructure examinations.

Results showed that increasing the welding current and sheet thickness increased the shear force, while an increase in electrode force, squeeze time, and welding time decreased it. The maximum shear force for similar material welding was 4.78 KN for 0.7 mm thickness, and for dissimilarmaterial welding, it was 1.42 KN for 0.7 mm thickness. These values were optimized to reach 5.13 KN and 1.54 KN, respectively, using DOE. The minimum shear force was 0.07KN for 0.5 mm thickness. Micro hardness tests indicated that the maximum value of hardness was at the center of the nuggetzone (NZ) and decreased slightly until reaching constant values away from the NZ [11].

Tota Pirdo Kasih et al. aims to optimize the process parameters of Resistance Spot Welding (RSW) of dissimilar steel sheets with unequal thickness, to achieve better mechanical properties. The selected parameters include applied current, weld time, and electrode force, each having three levels. The experiments were carried out using Taguchi experimental design of L9 orthogonal array, and the spot weld tensile strength was chosen as the response character to be optimized. Signal to noise ratio analysis and analysis of variance (ANOVA) were conducted to determine the significant effects and contribution percentage of each parameter. The results show that the current welding time isthe most important factor in controlling the spot weld performance. The study confirms the validity of robust design by Taguchi method for parameter optimization and improving the efficiency of resistance spot welding processes [12].

Amit Hazari et al. the impact of spot welding parameters, such as welding current and welding time, on the strength, productivity, and cost of various welding joint designs. The study specifically focuses on the optimization of process parameters for resistance spot welding (RSW) in the automotive industry. The goal is to understand the physics of the process and to demonstrate the effect of electrical current, weld time, and material type on the RSW process. Tensile tests and spot welding diameters were used to evaluate the quality of the welding joints. The findings suggest that these factors have a significant impact on the effectiveness of the resistance spot welding procedure [13].

Fouad Ternane et al. experimented on optimization methods used to optimize welding parameters for ResistanceSpot Welded (RSW) joints. The objective is to achieve good weld quality defined by the mechanical properties of the joint. The Taguchi method is used to measure the quality characteristic deviation from the desired value, and ANOVA is used to test the significance of main factors and their contribution to quality characteristics, particularly tensile shear strength. The results show that the welding current is identified as the main parameter controlling tensile shear strength and nugget diameter, while the size of the nugget depends on welding parameters such as indentation width and depth. The welding time has an average effect on tensile shear strength and nugget diameter [14].

Ankit Rai et al. identified the optimal combination of parameters for better joint quality, which requires analysis of the complex behavior of the process. The paper also includes Finite Element Analysis (FEA) simulation of the Resistance Spot Welding (RSW) process. The parameters that affect the quality of welds include welding current, electrode, force, and welding time, and their optimization is challenging. However, the absence of fillers makes the process cheaper, neater, and faster than most other metal joining methods. The study found that the optimal weld strength for 1mm stainless strain sheet metal was achieved at 2234A and 0.3 seconds. The study also found that the maximum temperature generated during welding was 1550 ºC, while the minimum temperature was 22.021 ºC [15].

B. D. Parmar et al. investigated the effects of important process parameters of resistance spot welding on weld strength. The current and cycle time are varied at three different levels for different thicknesses of metal sheets, andmanufactured specimens are tested for weld strength. The experiment is conducted using the Taguchi method, and thelevels for the parameters are fixed. The analysis of variance(ANOVA) and F-test are used to determine the most significant parameters affecting the spot weld parameters [16].

Zoha Nasir et al. experimented on two sheets which are clamped together between the electrodes, and an electric current is allowed to flow. The current flows through the sheets, causing resistance and generating heat at the interface between the sheets. The pressure applied by the electrodes causes the heated region to yield and fuse together, forming a weld nugget. The process has been the subject of research by different investigators, and there have been various methods developed for optimizing the process parameters. These methods include the use of computer simulations, experimental design techniques, and statistical analysis [17].

Yueqiao Feng et al. has experimented with resistance plug welding and compared it with traditional resistance spot welding in which (100 X 25 X 1 mm) 7075 aluminum alloyplates with circular holes punched in the center of the lap zone and a filler rod made of 5052 aluminum alloy were used. Welding was conducted on medium frequency direct current of capacity 2 – 22 kA, welding time 200ms, and welding force of 2400N used. The formation of microstructure and its mechanical properties were analyzed. From the results it was observed that the current density is more concentrated during resistance plug welding (RPW), which leads to larger nugget diameters, higher peak loads and energy absorption in an RPW joint. Welding defects such as hot cracking and pores which is usually formed RPW[18].

Pedro Bamberg et al. have validated resistance spot welding by splitting experimental work into two parts: the preliminary assessment of the suitability of current welding procedures, norms, and respective parameters, where the process window, weld nugget quality, and electrode lifetime are evaluated. Then an innovative approach is investigated, where the use of an upslope welding schedule, CuAg0.1 electrode caps, increased force, and lower overall electric resistance could successfully validate the application. The metrological test was determined with the electron backscattered diffraction technique. The test results show that using CuAg0.1 electrode caps and increasing the electrode force seems to reduce the temperature at the contact surface, avoiding faster electrode erosion and reducing the tendency for Cu Al alloying. The weld quality is increased, and it is possible to form weld nuggets without the incidence of solidification cracks with the upslope approach [19].

Debashis Mishra et al. Conducted an experiment to weld thin sheets of mild steel (MS) and stainless steel (SS) materials by spot welding process using different process parameters is a significant step towards achieving the desired quality spot-welded joints for automotive applications. The use of Taguchi L9 orthogonal approach to design the experiment is commendable as it allows for efficient testing of multiple factors with minimum experimental runs. The variation of the three factors, namely welding current, sheet thickness, and different combinationsof mild steel and stainless steel at three levels, provides adequate information to optimize the various factors and weld nugget diameters can be obtained as a response values.The use of a copper and chromium alloy of 6 mm diameter as an electrode is also a good choice for the spot welding process. The statistical analysis of the model terms using R-square, analysis of variance (ANOVA), t and F tests, and desirability function is an essential step to determine the significant factor and interactions on the response variable. This analysis helps to identify the critical factors which affect the quality of the spot-welded joints and to optimize the process parameters accordingly. The experiment shows thatchoosing the exact combinations of process parameters to achieve the desired quality spot-welded joints for automotive applications. The information obtained from this experiment can also be used as a reference for future research on dissimilar welded joints using different grades of steels [20].

Rohit Verma et al. The present study investigates the fabrication of resistance spot weld joints between dissimilar steel sheets, namely galvanized High Strength Interstitial Free (HIF) steel sheets and Dual Phase (DP780) steel sheets.The dynamic resistance (DR) was measured during the welding process, and the variation in DR with the change in welding process parameters such as weld current, weld time, and electrode force was analyzed to establish the range of adequate weld nugget formation parameters. Furthermore, the study investigated the effect of welding process parameters on tensile strength, nugget diameter, andobserved failure mode using a one factor at a time (OFAT) approach. The microstructure and hardness of the parent metal, fusion zone, and heat-affected zone (HAZ) were also studied. Overall, the study aims to provide insights into the welding behavior of dissimilar steel sheets and optimize the welding process parameters to achieve high-quality welds with desired properties. The results of the study can have practical implications in the manufacturing of various industrial components, such as automotive body structures, where dissimilar steel sheets are often used [21].

P. Bamberg et al. conducted an experiment on Resistance spot welding (RSW) process to overcome the limitations associated in joining of aluminum alloys for structural applications. Cladding method is used in this process, which involves combining a high conductive, electric stable aluminum alloy as a covering sheet with a high strength alloyas a core sheet. Weldability of an AW-6111 core sheet cladded with an AW-4040 cover sheet is evaluated. This is achieved by establishing a proper welding lobe, analyzing the electrode erosion behavior, and characterizing the formed microstructure. The results show that the cladded sheets have improved weldability characteristics and increased electrode service life when compared to pure AW-6111 aluminum sheet.Overall, the use of cladding presents a potential solution to the challenges associated with joining aluminum alloys for lightweight structural automotive applications [22].

Marcell Gaspar et al. conducted an experiment on AA7075 resistance spot welding by application of chemical oxide removal and post weld heat treatment process. For this 1mm thick AA7075 were used and joining of metal was done by resistance spot welding followed by artificial ageing as kindof post weld heat treatment process. The results shows that by the application of pre – heat treatment method the spattering and electrode wear can be decreased, the hardness distribution of HAZ significantly increased and also improves the properties and compensate the softening of resistance spot welding [23].

Vignesh Krishnan et al. has studied the impact of welding parameters on tensile shear fracture load, nugget geometry, and microstructure of resistance spot welding of austenitic stainless steel AISI 316L and Duplex stainless steel 2205 under lap shear loading condition. The welding parameters such as welding current, heating cycle, electrode tip diameter were considered as most effective parameters on tensile shear load. The results show that the shape of the nugget is unsymmetrical. Due to thermal conductivity, the nugget height of the DSS 2205 is relatively larger than in ASS 316L. Maximum tensile shear fracture load can be produced during the tensile shear test. DSS has higher hardness at HAZ and ASS has less hardness at HAZ [24].

Ihsan K. Al Naimi et al. has conducted an experiment on AA1050 resistance spot welding to improve the quality of weld and electrode life time by comparing welding of as- received sheet with pre - treated sheet by either pickling in NaOH or glass-blasting method. Various types of weld settings were applied with low, medium and high energy inputs. The results shows that highest value of electrical contact resistance is obtained with as – received sheet due tothicker oxide layer. Pre-treatment by pickling in 60 ºC NAOH increases weld strength and reduce scatter. Glass blasting may reduce the contact resistance results in removing of original film provides a rough surface [25].

Lei Chen et al. experimented on resistance spot-welding of low carbon steel and stainless steel plates and investigated theimpact of welding current and time on the shearing strength ofresistance spot weld joints. The study also analyses the macro characteristics, microstructure, and micro-hardness of welded joints. The results shows that weldedjoints produced with a welding current in the range of 10 kA andwelding time that of 80ms showed the greater shearing strength.The diameter of welded joints and nuggets increased with an increase in welding current and welding time. Various regions of heat affected zone such as, coarse heat-affected zone, fine heat-affected zone, base materials, and nugget were observed within the welded joints. Due to the presence of martensite, higher hardness can be seen in coarse heat-affected zone than the fine heat-affected zone and base materials. It is essential in developing resistance spot welding processes for joining dissimilar steel plates. It also provides insight into the optimal welding parameters for producing strong welded joints with suitable microstructure and hardness [26].

S. M. Manladan et al. conducted an experiment on resistance spot welding of magnesium alloys, focusing on the relationship between microstructure, properties, and performance under quasi-static and dynamic loading conditions. It also compares the resistance spot welding of magnesium-to-aluminum alloys and the various techniques used to prevent the formation of brittle intermetallic compounds. In addition, the resistance spot welding of magnesium-to-steel, weld bonding, the effects of process parameters on joint quality, and the main metallurgical defects in resistance spot welding of magnesium alloys arediscussed. Studies have shown that the pre-existence of coarse second phase particles in the base metal, the addition of particles such as titanium powder, and welding under the influence of the electromagnetic stirring effect can promote columnar-to-equiaxed transition, microstructure refinement, and improvement in mechanical properties of magnesium alloysresistance spot welds. Regarding magnesium-to-aluminum alloys spot welds, the use of interlayers such as pure nickel, gold-coated nickel foil, and zinc-coated steel was found to prevent theformation of brittle intermetallic compounds and significantly improve the joint strength [27].

Dawei Zhao et al. conducted an experiment on resistance spot welding for Dual – Phase Steel by 2D axis symmetric numerical analysis model and phase transition on thermal expansion co efficient. The size of weld nugget was predicted by various ranges of process parameters. Metallurgical test shows that the formation of nugget in theoretical analysis undergoes in three stages that is plasticity adhesion, rapid growth and slow growth. As the welding current is very large, expulsion occurs and it resultsin reduction in nugget size [28].

Sushree Sefali Mishra et al. conducted an experiment on different aspects of dissimilar metal resistance spot weldingon ferrous – non - ferrous and stainless and non – stainless steel joining. The results show that fatigue strength has an adverse effect on corrosion, as the fatigue strength of a spot welded structure increases, it increases the sheet thickness. In case of joining Al – low carbon steel, IMC layer was formed on aluminium side, by application of post weld schedule, IMC layer can be made thicker [29].

Mallaradhya h. M et al. conducted an experiment on resistance spot welding of precipitation hardening (PH) group steel. Different parameters such as surface condition, weld size, weld current, and distribution of heat affected zone were analysed. The results show that the tensile shear strength of weld is predominantly influenced by weld current. The hardness in fusion zone is higher compared to other zones of weld. As welding current increases, the hardness also increases. PH steels gives better mechanical, corrosion properties and good weld ability [30].

Lihu Cui et al. conducted an experiment on resistance spotwelding of AA6061 and mild steel Q235 sheets, and the effects of welding current on nugget size, tensile shearstrength of the joint and interfacial microstructure were analyzed. The results show that the nugget diameter of the joint increases with an increase in welding current. Shear strength increases initially with an increase in welding current, but a further increase in welding current leads to a decrease in tensile shear strength. A weld joint with a maximum tensile shear load of 1.5 kN is obtained at a welding current of 12 kA. The interfacial reaction layer thickness decreased from the central joints region to the surrounding area [31].

Adam Dobosy et al. has conducted an experiment on the resistance spot welding of 7075 (AlZn5.5MgCu) aluminum alloy with zinc as the primary alloying element. For the purpose of the element,-1mm thick 7075 sheets with T6 condition with different surface pre - treatment methods such as grinding and hydrogen-fluoride (HF) etching and theweld lobe was determined for constant electrode force. Macro tests, tensile shear tests, and hardness tests were conducted and compared with 6082 aluminum alloy. The results show that by applying chemical etching, the strength of the welded joints slightly increased, the standard deviation decreased, and better quality joints were achieved. By surface pre – treatment methods the electrode wear decreased and increase the electrode lifetime [32].

Seungmin Shin et al. has conducted an experiment on Deltaspot welding using the alloy combination of 6000-series aluminum alloy (Al 6K32) and 440Mpa grade steel (SGARC 440). Process parameters for delta spot welding and weldability were analyzed. Metallurgical characteristics such as the intermetallic compound layers were identified using SEM and EDS techniques. The resultsshow that the comparison of the weldability of aluminum alloy to zinc-coated and uncoated steel sheets revealed its weldability to uncoated steel sheets to be very low. This lowweldability seems to be attributable to the fact that zinc melted onto the surface of the zinc-coated steel sheet forms a compound in the IMC layer, thus improving the bonding force [33].

Diego Fonseca Silva et al. Experimented on dissimilar metalssuch as AISI 316L stainless steel and AISI 1020 low carbon steel are joined by resistance spot welding, their different thermal conductivity and electrical resistivity values can resultin an asymmetrical weld nugget. This means that the nugget may be larger on one side than on the other, which can weaken the joint and affect its mechanical properties. The results shoesthat, the thermal cycle experienced by each metal is different. The metal with higher thermal conductivity, such as the stainless steel in this case, will heat up and cool down more quickly than the metal with lower thermal conductivity, such as the carbon steel. This can lead to differences in the microstructure and mechanical properties of the joint, which can affect its performance in service. To mitigate the effects ofasymmetrical weld nugget sand differences in thermal cycle, various welding parameters such as welding current, electrode force, and welding time can be adjusted. Additionally, pre-weld and post-weld heat treatments can be applied to reduce the thermal gradients and improve the mechanical properties of the joint [34].

Teerawut Khuenkaew et al. investigates that the characteristics of resistance spot welded lap joints of SUS316L/SUS425 stainless steels under different welding currents and times. The quality of the welds was evaluated basedon the depth of fusion, indentation depths, and nugget diameter, while the mechanical properties were assessed using the tensile shear force (TSF) and micro vickers hardness. Phase transformation and solidification were analyzed using scanning electron microscopy, energy dispersive X-ray spectrometry, Schaeffler and pseudo-binary predictive phase diagrams. The results showed that increasing the weld current and welding timeled to improved weldment quality, TSF, and micro hardness. The optimal welding conditions were achieved at a 10.0 kA weldcurrent and 25-cycle welding time. The fusion zone shows compression-direction columnar grains consisting of austenite, ferrite, and martensite, and the solidification was of ferrite plus Widmanstatten austenite [35].

Fufa Wei et al. Conducted the study on resistance spot-welding of dissimilar metals, specifically medium manganese TRIP steel7Mn and DP590, and the effects of welding parameters on the quality and mechanical properties of the resulting joints. It was found that the optimal process parameters for single-pulse welding were electrode pressure of
4.5 kN, welding current of 9 kA, and welding time of 300 ms. The failure mode of the welding joint was partial pull-out failure (PF-TT). Nugget diameter and thickness reduction were greatly influenced by the welding parameters, with expulsion, crack, and shrinkage observed under high electrode pressure. Due to strong halo effect in the single – pulse weld, softening occurs in the heat-affected zone. In addition, the study found that the tempering zone on the DP590 side had a hardness of 202.49 HV, the lowest hardness point, while the hardness of the nugget zone was 450 HV. The addition of tempering current homogenized the microstructure with different failure paths andeliminated stress, resulting in a 17.13% increase in the tensile shear force of the joint. The microstructure of the joint was composed of plane crystal, cellular crystal, dendritic crystal, andcolumnar crystal, in turn, from the fusion line to the center of the nugget. Lath

martensite and small amount of residual austenite can be found at nugget zone. While fine quasi- spherical and lamellar interbedded cementites were formed in the tempering zone of the DP590-side heat-affected zone [36].

Sushree Sefali Mishra et al. have studied the optimization of resistance spot welding techniques with both similar and dissimilar metal joining with similar or dissimilar thicknesses. The results show that among all process parameters weld current and electrode force has a maximumand drastic effect on the joint strength. The S/N ratio is an important determinant in calculating the scares and disturbances [37].

A A Al-Filfily, A S Al-Adili, M H Sar et al. has conductedan experiment on resistance spot welding of aluminum alloy AA6061 to carbon steel using different filler materials suchas carbon and zinc. The characteristics of weld joint were investigated by measuring the effect of welding current and time on the nugget size and tensile shear strength of the weldment. The results show that welding current has incremental influence on nugget size, tensile shear strength for both type of filler materials than weld time. The copper filler increases the strength of the weldments more than the zinc filler, the joint with the maximum tensile shear strength of 47 kN/m2 is obtained at the condition of 15 kA welding current for copper fillerand 40 kN/m2 is obtained at the condition of 13 kA [38].

Q. B. Feng et al. Conducted an experiment on the weldability of a newly developed stainless steel and compare it with hot- dipped galvanized dual-phase and low carbon steels in a two-sheet stack-up of similar metal. The researchers looked at several factors to assess the weldability of each material, including weld lobes, mechanical properties, weld morphology, microstructures, and microhardness profiles. The result shows that the stainless steel had significant softening inthe weld nugget. This finding suggests that the stainless steel may be more prone to deformation during the welding process, which could affect the quality and strength of the weld. In terms of weld lobes, the stainless steel had a very narrow weld lobe compared to the dual-phase steel and low carbon steel. However, it required lower welding current and shorter welding time indicating that it may be more efficient to weld than the other materials.

The comparison of the mechanical properties shows that, the stainless steel performed better thanthe other materials in the case of welds with the same nugget size. However, it tended to exhibit interfacial fracture in tensileshear tests. This means that the weld joint may be weaker at the interface between the stainless steel and the other material [39].

Md Khalid Mumtaz et al. Conducted an experiment on resistance spot welding on two different types of steel, namelylow carbon steel and high strength low alloy steel. The variation in current rating was kept constant while other parameters were adjusted. The results indicate that the bearing force of the joint is linearly related to the current rating. However, at higher current ratings, a poor joint appearance is obtained, and cavities are formed in the joint. This work shedslight on resistance spot welding for dissimilar materials of higher thickness and highlights the influence of primary welding parameters on the morphology and strength of the weldment [40].

Mohammad Jameel Zedan et al. Study on resistance spot welding (RSW) dissimilar alloys, with aluminum alloy 5052 and low carbon steel alloy 1008 were conducted. By drilling a circular hole in the center of the aluminum alloy, the high thermal expansion of aluminum was overcome, allowing fora desired weld nugget to be formed using electrode force, welding current, and welding time within specific ranges. Theresults show that weld nugget had a diameter of 9.75 mm and could withstand a maximum tensile shear load of 3210 N. However, an intermetallic compound (IMC) layer was noticed with a thickness of 1-5 µm. The IMC layer had a tongue-like shape adjacent to the low carbon steel side and a needle-shaped morphology adjacent to the aluminum side. The difficulties in welding dissimilar alloys have been overcome using this technique. The presence of the IMC layer is not unusual in dissimilar alloy welds, and it's important to understand its morphology and thickness to ensure the mechanical properties of the joint are satisfactory [41].

Mathi Kannaiyan et al. has conducted an experiment on RSW process parameters of two dissimilar metals such AISI 304 and AISI 1020 grade steel. Three process parameters suchas welding current, welding pressure and welding time were taken into consideration. Mechanical and metallurgical test were conducted. The results shows that the nugget diameter and Tensile strength are proportional to weld time, pressure and current. With the increase in heat input during welding, the shear - tensile strength increases within the adequate weld range due to the enlargement of nugget size. The microstructural studies shows that the welded joints are inhigh in homogeneous solidification mode [42].

Mathi Kannaiyan et al. Experiment was conducted by comparing the performance of two modelling techniques, namely Response Surface Methodology (RSM) and Artificial Neural Network (ANN), for wear estimation. The study found that both RSM and ANN models performed well, but the ANN-based approach was better at fitting the measured output response. The study compared the productive capacity of RSM and LMBP neural network architecture for modelling the outputand found that the coefficient of determination (R2) was higher for the ANN models, indicating that they had a higher modellingability than the RSM model.

The study also compared the experimental value and predicted value obtained by the ANN and RSM models, and found that the coefficient of model determination (R2) for both models was close to unity. The comparison of specific wear rate values using ANN and RSM showed that the results obtained were close to the reading recorded experimentally with a 99% confidence level. The results show that ANN – based approach is better for wear estimation compared to RSM model [43].

Rudolf Gradinger et al. Shows that sheet metal samples ofthe high strength alloy AA7075-T6 were spot-welded usingthe innovative electrical resistance spot welding system. Delta Spot, on the one hand in a combination of two (2 mm + 2 mm) sheets, on the other hand in a mixed combination of 1.6 mm thick samples of AA6016-T4 with 2 mm sheets of AA7075-T6. The results shows that the novel features ofDelta Spot lead to spot welds which are free from any critical sizes of pores, shrinkage holes or cracks. The process parameters covered a range which can be used for industrial manufacturing under the technological as well as economical boundaries of the automotive industry. With these findings the application of the light weight potential ofAA7075-T6 in automotive structures like BIW or hang-on parts seems likely to be feasible [44].

Ihsan K Al Naimi et al. have studied that by addition of metal powders to the faying surfaces before resistance heating can increase the quality of weld joints between aluminum sheets by resistance spot welding. The results show that the formation of secondary bonding surrounds the weld nugget and increases the total weld area. This shows that the strength increases even when the nugget size is smaller than normal RSW. By this approach, weld strength is increased in RSW while welding at low current. At high welding current expulsion of melt and smaller weld nuggets is observed when adding metallic powder between the faying surfaces. This is because of increase in contact resistance and difficulties in entrapping the melt. The resultsshow that joints which are welded with added powder between the faying surfaces, fail by interfacial fracture [45].

Ladislav Kolarik et al. here the properties of two dissimilar materials such as low carbon steel and austeniticstainless steel were analyzed using the delta spot welding technique. The thickness of materials used in this process is 2mm. Welding parameters such as welding current ranged from 7 to 8 kA. The influence of welding parameters on the metal size has been evaluated. The results show that the weld metal size increases with the welding current increase. The HAZ of the low-carbon steelsheet was broader than the HAZ of the austenitic stainlesssteel. The hardness of the low-carbon steel was increased [46].

Thongchai Arunchai et al. The setting of RSW parameters is a challenging task, which can result in inconsistent weld quality. The important RSW parameters that affect weld quality are welding current, electrode force, and welding time. In addition, the electrical resistance of the aluminum alloy, which varies with the material thickness, is also considered to be a critical parameter. An artificial neural network (ANN) was designed and tested to predict the optimal RSW parameters for achieving high tensile shear strength. The inputdata consisted of the RSW parameters, and the output data were the tensile shear strength of the aluminum alloy.

The ANN was trained to learn the relationship between the input and output data and predict the optimal RSW parameters for achieving high tensile shear strength.
The results showed that the ANN was successful in predictingthe optimal RSW parameters. The mean squared error (MSE) and accuracy were 0.054 and 95%, respectively, indicating high accuracy in predicting the tensile shear strength output. These results suggest that the ANN can be used as a tool to optimize RSW parameters for achieving high weld quality. The application of an ANN in welding machine control can behighly successful in setting the welding parameters for achieving high tensile shear strength. This approach can lead to consistent weld quality and reduce the time and effort required for parameter optimization [47].

Mehdi Safari et al. investigates the dissimilar resistance spotwelding of two types of stainless steel sheets, namely 304 grade austenitic stainless steel and 409 grade ferritic stainless steel. The main aim is to evaluate the effects of process parameters such as welding current, welding time, and electrode force on the tensile-shear strength of the welded joints, using response surface methodology (RSM). Additionally, the microstructural changes during the welding process are analyzed using optical microscopy. The results show that increasing the welding current, welding time, and electrode force can improve the tensile-shear strength of the spot welds. The study provides insights into the behavior of dissimilar resistance spot welding of austenitic and ferritic stainless steels [48].

Haetham G. Mohammed et al. Study of mechanical and microstructure properties of resistance spot welded 316L stainless steel with a thickness of 3 mm. The study aimed to fill the gap in research on the resistance spot welding of 316Lstainless steel with a thickness of more than 2 mm. Theresearchers examined the effect of constant welding parameters on the weld properties such as weld nugget size, tensile-shear load, failure modes, microhardness, and microstructure of weld nuggets. The results of the study showed that the maximum tensile-shear load was 21.549 KN. The microhardness of the fusion zone (FZ) was 230 HV, which was higher than that of both the base metal (BM) (198.8 HV) and theheat-affected zone (HAZ) (184 HV) respectively. The optical microscopic images showed phase transformation in the FZ. The study contributes to the understanding of the resistance spot welding of 316L stainless steel with a thickness of 3 mm. the study is useful in designing welding processes and predicting the mechanical properties of welded joints. Further studies shows the effects of different welding parameters and their interactions on the mechanical and microstructure properties of resistance spot welded 316L stainless steel with a thickness of 3mm [49].

Zygmunt Mikno et al. studied the development and validation of a numerical model for an ideal spot weld, made by resistance spot welding two overlapping steel sheets with an intermediate connector. The model eliminates weldingimperfections and thermal effects to focus on the properties ofthe base material. The study uses 3D FEM numerical modelling and experimental validation to investigate various shapes and dimensions of the nugget surface, as well as different welding conditions. The analysis aims to determine the highest possible shear force generated during a static tensile test and compares the results of numerical tests with selected laboratory tests [50].

5. Conclusion

On going through the investigations done by the selected researchers some conclusions can be derived based on the weld quality, properties of weld, parameters, mechanical and metallurgical characteristics. These can be summarizedas below:

1. High-quality welding of a 7075 aluminum alloy joint can be obtained using RPW with 052 aluminum alloy filler metal. Defects such as hot cracking and pores are efficiently avoided.

2. Using CuAg0.1 electrode caps and increasing the electrode force seems to reduce the temperature at the contact surface, avoiding faster electrode erosion andreducing tendency for Cu Al alloying.

3. application of pre – heat treatment method the spattering and electrode wear can be decreased, thehardness distribution of HAZ significantly increased and also improves the properties and compensate the softening of resistance spot welding.
4. The results shows that highest value of electrical contact resistance is obtained with as – received sheet due to thicker oxide layer. Pre - treatment by pickling in 60 ºC NAOH gives high weld strength and lowest scatter. Glass blasting may reduce the contact resistance results in removing of original film provides a rough surface.
5. by the application of chemical etching the strength of the welded joined slightly increased while the standard deviation decreased, better quality of joints was achieved. By surface pre – treatment methods the electrode wear decreased and increasethe electrode life time.

6. Increased welding current of the RSW process leads to increased pitting and corrosion rate.
7. Increased electrode pressure of the RSW process leads to increased pitting and corrosion rate.
8. Resistance spot welding parameters (current, time, pressure force) are significantly affect on nugget diameter and strength of weld joint, if one of welding parameters increases the weld nugget diameter increases and this causes an increase in the strength of weld joint, therefore the suitable combination of welding parameters is needed to get higher require strength of weld joint.
9. Analyzing tensile strength testes indicates that increasing any one of welding parameters will increase the failure load joints with consideration that welding current is greatly effective parameter on require strength of weld joint morethan the other parameters.
10. Uncontrolled the weld parameters (high welding current, longer welding time) will great electrode indentation and excessive heat generation and expulsion occurred and this causes decreasing in the strength of weld joint.

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