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Development of Hardness Distribution, Thermal, and Tensile Analysis of Resistance Spot Welding

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Abstract— **Process planning is more important than ever in production engineering because it enables process optimization, which saves costs, has a smaller environmental impact, and uses time more efficiently. Widespread usage of resistance spot welding (RSW) as a large-scale joining technology shows process optimization is possible.**
This thesis seeks to improve RSW process planning in industrial applications. The objective is expressed by two study topics: process variance and numerical techniques for RSW. Research questions are centred on weld size in RSW process planning.
Weld size changes due to process parameters and unintentional fluctuations in welding circumstances, as with any large-scale production process. Physical and numerical analyses have been done to comprehend such oscillations.
Both laboratory and industrial welding were used to explore unintended variances that contribute to varied weld thicknesses in seemingly identical conditions. The study revealed weld sizes and standard deviations in each environment. Weld sizes match the Normal and Weibull distributions, and standard deviations in industrial production and controlled laboratories are 0.3 mm and 0.9 mm, respectively.

INDEX -**Resistance Spot Welding, Heat, Friction, Temperature, Tensile strength, Tool pin profile, welding speed, etc.**

I. INTRODUCTION

The joining of materials that are not similar will have a number of benefits, one of which is the creation of complex mechanical properties, which will result in a reduction in the cost and weight of the welded parts. This is something that is very necessary in the fields of automotive and aerospace manufacturing. Because it is difficult to form bonds between two different materials using fusion welding, metallurgical incompatibility can be induced. This can include characteristics such as the formation of a brittle phase, the induction of a high residual stress caused by a physical mismatch, and the segregation of high melting phases from low melting phases caused by a mismatch in the chemical composition[1-2]. The creation of these intermetallic compounds, which have a high level of hardness but almost no plasticity, leads to a major decrease in the mechanical properties of materials such as titanium and stainless steel, which are in great demand. Resistance spot welding (RSW), which is both more cost-effective and more productive, is the method of combining materials that is utilised the most frequently in the automotive industry. The surface is linked in a limited number of points in this type of resistance welding, which is the simplest and most popular form of the technique [3]. As a result of the flow of current through the work pieces that are being held together by the use of pressured electrodes, the heat that is generated by the resistance causes coalescence to occur within a relatively limited region. The amount of heat that is produced is determined by the current that is flowing between the workpieces, as well as the duration and resistance [4]. It is essential to keep the temperature at the interface of the work piece at which the welding will take place at its maximum. In order to accomplish this, it is necessary to ensure that the resistance of the work piece, as well as the contact resistance that exists between the electrode and the work piece, are as low as they can possibly be in comparison to the resistance of the bonding surface. This can be accomplished by exercising control over the contact area, the pressure that is delivered, the material of the electrode, its size, and the quality of its working surface [5].

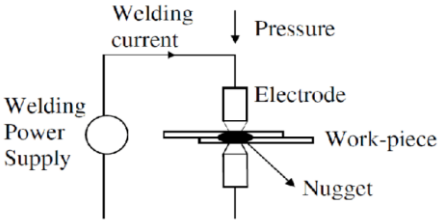

Fig. 1: Resistance Spot Welding

The temperature of the work piece and the electrode both grow as a result of the heat that is acquired during the finishing process of the weld. As a result of the distribution of heat, it is possible to notice microscopic structural changes in the area surrounding the weld zone. In the welds, the heat affected zone (HAZ) needs to be minimized to the greatest extent possible [6-7]. Alternately, if there is an excessive amount of heat in the electrode, it will degrade the quality of the weld and shorten the life of the cap. As a result, the water that circulates via the channel that was opened inside the electrode helps to keep it cold. Research that is connected to this topic demonstrates that the flow rate and water temperature will have an effect on the electrode life and the quality of the welding. In addition, the amount of time spent welding and the amount of pressure that is applied are the two most essential elements in determining the quality of the weld as well as the longevity of the electrode [8-9]. The dimensions of the heat affected zone and the mechanical qualities of a spot-welded connection are what determine the quality of the joint. The strength of a weld can be determined through a series of destructive tests that are performed in a consistent manner on the weld under a variety of various loads. Tension shearing, tension, fatigue, impact, and also the hardness of the material are some of the others. The quality of the welding can be significantly impacted by how well the various welding parameters are controlled. The welding variables and the location of the spot welding have a significant impact on the operating strength and stiffness of sheet metal parts [10]. In order to achieve the highest possible welding strength, it is necessary to carefully select the parameters of the welding process. In general, either expertise or following a handbook is necessary to determine the necessary welding parameters. Despite this, there is no assurance that the welding factors chosen will produce the best or near-best welding strength for the particular environment and welding machine in question.

The heat produced by the constant flow of current will cause the metal to melt, which will then result in the formation of the weld junction [11]. The length of time that the current is flowing and its intensity both have an effect on the quantity of heat that it generates. The magnitude of the current as well as its duration needs to be carefully controlled, and it also needs to be matched with the type of material being used, the type of electrode, and the thickness. The quality of RSW welds, like those produced by other welding methods, is directly impacted by the welding input components used. To get a good welded joint that has the appropriate weld strength, one of the most common challenges that manufacturers must overcome is establishing and implementing the process input variables. Welders would traditionally determine the parameters of the spot welding procedure based on their own personal experience or by consulting the welding data sheet. Despite the fact that these technologies provide guidance, the procedures that are being used to produce welded joints with greater quality do not meet the needed quality at the lowest feasible cost (in terms of power consumption).

It is well knowledge that precipitation hardening (PH) steels, which are part of the growing category of light alloy steels, are important as a structural material. The usual metal working procedures are able to be utilized for the purpose of component fabrication using these PH steels. PH steels are distinguished by their light strength, ductility, and resistance to corrosion. It is common knowledge that various subcategories of precipitation-hardening stainless steel are on the market to purchase. It is well accepted knowledge that typical fusion and resistance welding processes may be used to successfully weld stainless steel PH grades. To acquire the absolute best possible mechanical qualities, special care and attention is required during the heat treatment process, which has to adhere to the most ideal heat treatment parameters for welding. The industries of aerospace, petrochemical, chemical, paper making, food processing, and general materials processing all make extensive use of 17-4 PH stainless steel, making it one of the most commonly used materials in the world. 17-4 PH is a Cr-Ni low carbon martensitic that contains the precipitation hardening metals copper (Cu) and niobium (Nb). In this work, a summary of the relevant literature has been provided regarding the mechanisms that are involved in the resistance spot welding of a variety of different types of steel. In addition to this, the optimization of the weld joint using a variety of different ways has been assessed. The parameters include things like the weld current, the applied pressure, and the heat affected zone, among other things. It is thought that this work provides a comprehensive insight into the many facets of resistance spot welding.

Requirement for Resistance Spot Welding

In addition to rivets, screws, brazing, and soldering, spot welding is another type of resistance welding that is frequently utilized. The method is frequently used to combine pieces made of low carbon steel. Commercially accessible materials for welding include high strength alloy steels, stainless steels, and aluminum, nickel, copper, and titanium alloys [12]. RSW connects two or more metal sheets by running an electric current across them. In order to tightly grip the components and weld them together, electrodes are utilized to conduct the current by pressing on the metal's surface.

This low heat capacity welding technique [13] produces heat for the passage of local current at the interface as well as from the resistance of the materials being welded together. RSW often cools at a high rate (between 1000 and 10,000 °C/s) [14]. In order to reduce grain growth, prevent the creation of dangerous secondary phases, and become a good candidate for welding FSS, RSW can be utilized as an acceptable welding technique. Numerous spot welds are found throughout the structural parts of automobiles. Since these cars transmit the load through the structure during the collision, the performance quality and failure characteristics of the resistance point are crucial in defining the safety design and durability of the vehicle [15-16].

II. LITERATURE REVIEW

To observe the phase change, resistance spot welding of ferritic AISI 430 stainless steel was done. The phase transition that takes place during the welding thermal cycle is carefully examined using the physical metallurgy technology of ferritic stainless steel welding. It was discovered that many events, including grain development, carbide precipitation, and martensite formation, had an impact on the fusion zone microstructure and the HAZ [17].

It was investigated how the mechanical characteristics of car sheet affected the welding time during resistance spot welding. A variety of chromium alloyed steels were used in this investigation and joined using RSW with fixed electrode formats, material types, electrode forces, cooling water flow, as well as by altering welding time and current. To determine joint strength, tensile peel and shear tests were performed on each series. Maximum tensile shear strength values of galvanised chromate steel sheet resistance spot welds were obtained for 12 and 15 cycle weld periods at a welding current of 10 kA. The depth of the electrode's depression on the work piece is approximately 15% of the plate thickness after 15 cycles of welding at 12kA. According to some, the above scenario is ideal for achieving the highest tensile shear strength. Two techniques work well when a necessity for surface quality exists. The first uses a welding current of 10 kA for 10 cycles, while the second uses a welding current of 9 kA for 12 cycles. The depth of the electrode's depression into the work piece is equal to 8% of the sheet's thickness. These fall under the 20 percent threshold needed to obtain a decent surface. Maximum values for the ten-time weld time at an 11 kA welding current for spot-welded chromate steel sheets. Once more, the depth of the electrode's depression into the work piece is 8% of the thickness of the sheet. To achieve surface quality, these values must be less than 20% of the steel thickness [18].

A micro indentation hardness test was used to assess the softening of the base metal (BM) and the heat affected zone (HAZ) after resistance spot welding was done on dual phase steel. Investigations into the behaviour of ferrite and tempered martensite (TM) along sub-critical HAZs at various separations from the lower critical temperature line have been conducted. The findings of the nano-hardness of the TM phase along the sub-critical HAZ are compatible with the SEM data. The results of micro hardness, in contrast, indicate that there is less extension in the softening zone due to the tempering distance being shorter than Ac1. Due to the size of the indentation's ability to avoid the phase boundary's contribution and to enable the evaluation of TM at low temperatures far from Ac1, where the early stage occurs, the softening assessed by nano-indentation has a better resolution [19].

Investigations are made into the behaviour of mild steel's ultimate strength under combined shear and tension loads. According to all experiments, the heat-affected zone fracture appeared soon after the metal sheet gave way. Additionally, when the loading angle rises, the load carrying capacity of a single resistance spot weld decreases, with a strength loss of about 20% from 0° to 90° angles. It was discovered that the tensile strength of a mild steel resistance spot weld is equivalent to 80% of the shear strength. The impact of coupon length, coupon width, and nugget diameter on the ultimate strength of the welded coupon was examined using the analysis of variance method. According to the research, the experiment's only two statistically significant components were the nugget diameter and coupon width, and the nugget diameter was responsible for more than 70% of the test data's overall variation [20].

On low-carbon galvanised and austenitic stainless steels, the microstructure and failure behaviour of various resistance spot welds were examined. It was found that the strength of the galvanised steel side and the size of the melting zone determine the strength of the spot weld during drawing failure mode. The failure mode controls the size of the fusion zone on the galvanised carbon steel side, while the dilution between the two parent metals controls the hardness of the fusion zone. Low zone hardness and small zone size for spot welding at low welding current result in an interface mode during the shear tensile test. The drawing failure mode occurs during the tensile shear test despite the higher fusion zone hardness brought on by the production of martensite and the bigger melting zone when spot welding is done at high welding current [21].

Investigations were done on how welding current affected the mechanical characteristics of steel that was resistance spot welded and chromed. The maximum tensile shear strength for joining galvanised chromate steel plates is attained after 15 cycles of welding at a current of 10 kA. Because the electrode only indented the material to a depth of 15% of the sheet thickness and did not go above the 20% limit of the sheet thickness, the surface was of good quality. A welding current of 10 kA at 10 cycles of welding time or 9 kA at 12 cycles of welding time is sufficient when the surface quality is greater than the strength. The depth of the electrode indentation is 8 percent of the sheet thickness and does not go over the maximum of 20 percent of these proposed values. The maximum tensile peel strength was achieved when 10 cycles at an 11 kA welding current were used to bond the galvanised chromate steel sheet. This number, which is roughly half the tensile shear strength, shows how vulnerable the RSW-welded galvanised chromate sheet is to the tensile peel test. Because the depth of the electrode depression in the material is 8% of the sheet thickness and does not go above the permitted 20% limit of surface quality, this application area suggests using 10 cycles of welding current (11kA) [22].

To assess the joint strength, resistance spot welding was done on titanium sheets using various welding conditions. To determine the strength of the weld zone, tensile shear tests were performed on welded connections. Additionally, a hardness and microstructure examination were carried out to see how the welding parameters affected the welded junction. The findings demonstrate that the tensile shear strength rises with increasing electrode force and current time, and that the joint produced with argon atmosphere has higher tensile shear strength. According to measurements of hardness, the base metal, heat affected zone (HAZ), and weld nugget all have the highest levels of hardness. The hardness value is thought to be unaffected by the use of argon in the welding process. The weld distortion happened throughout the welding process, according to a microscopic study. Twinning happens in grains, and it is exacerbated by high electrode forces and high welding cycles [23].

III. OPTIMIZATION STRATEGIES

Due to its straightforward theory, low cost, and other advantages, resistance spot welding is frequently employed in vehicle bodies and other steel processing sheet connections. However, even in a technique where resistance spot welding is simple to use, the variables that affect welding quality have a strong interdependence, making it challenging to achieve good welding quality. Using trial and error to establish the parameters necessary to get the requisite weld quality is a waste of time. Therefore, using a welding process model that describes the weld quality with the fewest number of experiments, it is required to identify the optimal conditions that can generate the desired weld quality [24]. For the situation of precipitation hardening stainless steel, Chinmoy Mondal et al.[25] optimised the spot welding. They employed the analytic hierarchy methodology to carry out the requirement. Through experimentation, they discovered that using a 2.5 kA welding current produced weld nuggets of a higher grade. They also changed the settings, such as the welding time from 6 to 7 cycles and another current value from 6 to 7 KA with a welding time of 5 cycles, all while maintaining a constant load of 4 KN. Their investigation makes it abundantly evident that welding factors like current, duration, and load are crucial for achieving improved weld quality. T. Wray expanded the optimization research [26-28].

Taguchi Method

Taguchi's method uses parameter optimization as a key step to produce high-class quality at no additional cost. This is due to the fact that process factor optimization can raise quality and that the Taguchi method's optimal process factors and parameters are insensitive to changes in the external environment and other variables. Typically, it is challenging and difficult to use the traditional process parameter design [29-30].

One benefit of Taguchi's approach is that it stresses the average performance characteristic value close to the objective value rather than the value inside a particular specification, enhancing the quality of the final product. Additionally, Taguchi's experimental design methodology is straightforward and simple to use in a variety of engineering situations, making it one of the effective and simple tools. This technique can be quickly used to identify or limit the scope of research topics. There are already issues with the manufacturing process [31-33]. The primary flaw in the Taguchi approach is that the results are just comparative and do not clearly state which variables have the biggest effects on performance eigen values. Furthermore, this approach cannot be applied for all relationships between all variables because orthogonal arrays cannot test all possible combinations of variables. The Taguchi technique has drawn criticism for having an illogical interaction parameter in the literature. The Taguchi approach is not online, which makes it unsuitable for dynamic procedures like mock studies. This is still another problem. Additionally, even though Taguchi's approach to design quality is subpar, it is effectively used in the initial stages of process optimization [34].

Numerous tests must be carried out when the number of process parameters is growing. Taguchi's method uses a special orthogonal array design to investigate every process parameter, requiring very little experimentation to achieve this task. In order to quickly and inexpensively examine the effects of numerous controllable factors on the average and variance in quality features, designers can use orthogonal arrays, and the product or manufacturer can benefit from employing signal-to-noise ratios to analyse experimental data. Finding the ideal combination of parameters is simple for designers. To determine the deviation between the experimental and expected value, first define the loss function [35-39].

To measure the deviation from the expected value of the quality characteristic, Taguchi will advise utilising the loss function [40]. The loss function's overall value is subsequently transformed into a signal to noise ratio (S/N). There are often three different types of quality attributes in this (S/N) ratio analysis, with the lower being better and the better being better. Based on S/N analysis, the S/N ratio of each stage's process parameters is determined. No matter what kind of quality feature is being measured, a higher S/N ratio indicates higher standards. As a result, the maximum S/N ratio represents the ideal level of process restrictions. Additionally, an analysis of variance (ANOVA) in statistics was carried out to determine whether process components were statistically significant. Then, the ideal configuration of process variables can be projected [41-45].

IV. CONCLUSION

Depending on the needs of various applications, resistance spot welding can be done on various steel kinds. A thorough grasp of the various parameters, including the surface's condition, the weld size, the weld current, the applied pressure, and the distribution of the heat-affected zone, is crucial when resistance spot welding. Numerous studies have been conducted and have documented how these characteristics have a substantial impact on the weld joint. Conclusion: In resistance welding, the interface resistance of the weld joints has very little of an impact. Furthermore, welding current has a major impact on the tensile shear strength of the welds. Compared to other weld zones, the fusion zone's hardness was a little bit higher. While the hardness distribution appears to be unaffected by the welding current, it can be inferred that the welding current is exactly related to the nugget diameter. A conclusion drawn from the literature is that 17-PH steels have superior mechanical and corrosion properties. Precipitation-hardened martensitic stainless steels' weldability has received widespread recognition in the automotive and aerospace industries.

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