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Spot Welding Electrode Analysis:A Review

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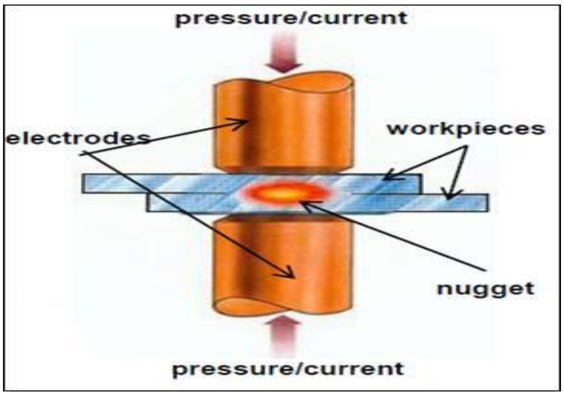
***Abstract* — Resistance Spot Welding (RSW) consists of mechanical-thermal-metallurgical-electrical phenomenon in which investigation of heat generation, current and resistance plays a key role. In this work, a review about material, nugget, and electrode has been carried out, which is the main point of concern in resistance spot welding. In industry, any small modification in the above concerned points may result in reduction of cost and time as well as increase in electrode life and strength of nugget.**

Keywords—RSW, Electrodes, Time Cycle, Thermal Analysis, Nugget Formation, HAZ

I. INTRODUCTION

Welding is a fabrication or sculptural process that joins materials by fusion. The different types of welding processes are Gas welding, Resistance welding, Arc welding and Solid State welding. Out of these, one of the oldest process used today is Resistance welding.

Resistance welding is the process of joining metal pieces together by increasing their temperature to fusion point and applying mechanical pressure to join them. In the context of commercial importance, the most widely used resistance welding processes are **Spot, Seam and Projection welding.** In this group, Resistance Spot Welding (RSW) is by far the predominant one.



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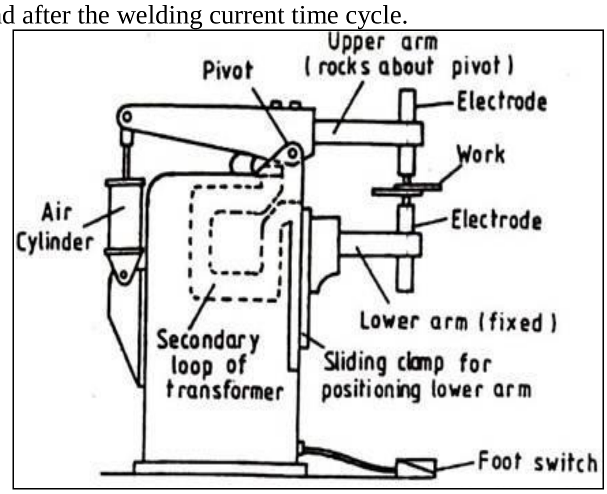
Resistance spot welding is the process in which fusion of the faying surface of a lap joint is achieved when current is caused to flow through the electrode tips. The resistance of the base metal to the electrical current flow causes localized heating in the joint. In this, a strong electric current (A.C.) of high amperage and low voltage is passed through the pieces held together to be joined. A resistance is offered to the flow of current when it passes from one piece to the other resulting in raising of temperature of the two pieces till fusion at their junction. The tongs and the electrode tips (through which current flows) hold the parts together to impart pressure and make the weld in close and intimate contact before, during, and after the welding current time cycle.



http://www.yourarticlelibrary.com/welding/resistance-welding/machines-used-for-spot-welding-3-types-metallurgy/97097

The concept of heat generation can be stated by using a modification of Ohm's law i.e. when current passes through a conductor then the electrical resistance of the conductor will oppose the current flow and results in heat generation as

$$H = I^2R$$

With the addition of time factor, the heat generation follows the formula :- $H = I^2RTK$

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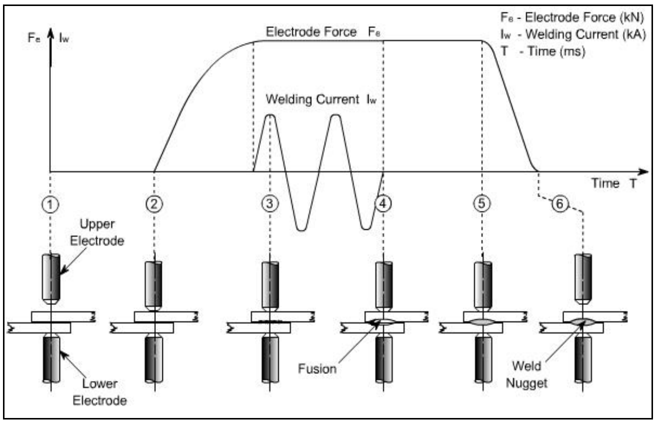
where , H = Heat , I^2 = Weld Current squared ,
R = Resistance , T = Weld time , K = Heat losses

This process is unique because the actual weld nugget is made internally in relation to the base metal surface. This process is mainly used to join in situations where an airtight assembly is not required such as sheet-metal parts of thickness 3 mm or less, using a series of spot welds. Other applications are in the mass production of automobiles, appliances, metal furniture and other products made of sheet metal, bars, tubes.

Successful application of resistance spot welding process is determined by the correct usage and proper control of the following parameters :

a) **Welding Current:** It is the electric current which is required to bring the metal to the molten state. It should be supplied enough as per demand by adjusting the current control device.
b) **Welding Pressure or Force :** In resistance spot welding, mechanical pressure is required at two stages – First, when the current flows across the pieces to hold them together (known as weld pressure) and Second, when the metals are getting melt to squeeze the pieces together for the formation of weld (known as forge pressure). It has a great effect on the weld current such as greater the pressure, lower the resistance which results in higher the welding current value.
c) **Time of application:** It is also termed as cycle time and is the sum total of different time periods allowed during different stages of welding. Different time periods are as follows:

- **WELD TIME,** The time period during which the current flows through the metal pieces to increase the temperature.
- **SQUEEZE OR FORGING TIME,** The time period during which forge pressure is applied to the metal pieces to squeeze them together to form a weld.
- **HOLD TIME,** The time period during which the weld solidifies. It is also referred as cooling time.
- **OFF TIME,** The time period between the release of electrodes and the start of next welding cycle.



https://nptel.ac.in/courses/112107144/welding/lecture11&12.htm

The contact area of electrodes: contact area of the face of electrodes affects the weld size and shape which can be varied by varying the electrode tip.

Electrode plays a key role in resistance spot welding as they have to perform three major functions :- conduct electric current, hold the workpiece together and dissipate heat from the weld zone as quickly as possible. During welding, electrodes experience high compressive stresses at increased temperatures. For successful welding, electrode should withstand these stresses without much deformation. For this, electrode should have the characteristics like good electrical conductivity, good thermal conductivity, high mechanical strength, and hardness. To achieve these characteristics, electrodes are manufactured by using copper base alloys and refractory metal alloys. In copper base alloys, the principle alloying element is copper whereas Cu-tungsten mixture, pure tungsten, pure molybdenum, etc. are used as common refractory metal alloys. As Electrode tip decides the weld nugget shape and size, most common electrode shape is round shape but hexagonal, square, and other shapes can also be used. The resulting weld nugget, with a heat affected zone extending slightly beyond the nugget into the base metal, is 5 to 10 mm in diameter. Actually, electrode tip point should be slightly more than the weld nugget diameter. If the difference exceeds the limits then it may result either in small and weak weld nugget or developing voids and gas pockets due to overheating the base metal.

The equations of spot weld parameters for welding mild steel up to a thickness of 3.2 mm are as follows :

Electrode tip diameter = 2.54 + ($t_1 + t_2$) mm
Weld time = 2.36 × ($t_1 + t_2$) cycles
Weld current = 3937 × ($t_1 + t_2$) A
Electrode force = 876 × ($t_1 + t_2$) N

Where , t_1 =thickness of first plate , mm
t_2 = thickness of second plate, mm

II. LITERATURE REVIEW

Resistance Spot Welding is the combination of electrical, thermal, mechanical and metallurgical science. The contact resistance between the electrode-workpiece interface and the faying surface is affected by the surface roughness of both workpiece and electrode. Therefore, the contact resistance of a lubricated sheet is lower as compared to an unlubricated sheet [5]. In the study of aluminum alloys with homogenous distribution, nugget formation can be squeezed with a very high value of contact resistance or with a small weld force by increasing the local current density [6],[7]. A case study of 5XXX series of aluminum alloys concluded that interfacial contact behavior plays a critical role in nugget formation while pressure and temperature observation offer understanding of electrode pitting and alloy formation mechanism. Also, weld quality is affected by weld residual stress and sheet deformation [7].

An experimental study showing the Fatigue S-N curve of galvanized steel and AISI34 steel sheet concluded that the welding of AISI304 galvanised sheet has minimum fatigue.

The crack growth rate is maximum in AISI304 steel sheet and minimum in galvanized –AISI304 steel sheet [8]. While examining the Resistance Spot Welding (RSW) process for a similar and dissimilar sheet of St12 and galvanized steel of 0.9mm thickness, the static analysis was done using MINITAB17 software. Welding time and electrode force were considered as input process parameters while tensile stress was made the process parameter response. For achieving higher tensile strength, welding experiment was done at optimized parameter setting. The end conclusion came out that the tensile shear strength was in decreasing order of Galvanized, St12, St12 and Galvanized steel. By increasing the welding time and force of electrode, tensile shear strength also increases [9].

Nugget growth and thermal interaction at the weldment interface were predicted. On comparing the experimental and theoretical results, it was found that at 1493˚C, isothermal line coincides but nugget diameter was bigger in the experiment. At 723˚C, there was some deviation in the curve of isothermal line and Heat Affected Zone (HAZ) was wider during the experiment. It happened because, during calculation, deflection due to electrode weldment was neglected [10]. Two different methods :- customized meshing method and predefined method offered by SYSWELD software tool were used for solving the Resistance Spot Welding problem. So, investigation of the weld nugget formation and HAZ in RSW using the software was performed for simulation purpose. For the experimental investigation, an actual RSW welding with similar welding parameters (like weld force, weld current, weld time and the temperature distribution of the welded sheet) was carried out. On comparing both results, it was concluded that the radius of weld nugget and HAZ developed by FEM are accurately correlated in both the cases. The approach provides precise cost and time-saving analysis in RSW process [11]. Various tests like weldability test, DOE model verification and significance of factors were carried out as the main part of experiments using FEM technique. From all these tests, an appropriate agreement between numerical and experimental result on nugget size distance effect was seen. HAZ asymmetry was observed in micrographs while the effect of segregation and concentration of alloying element along the boundaries of grains were shown in SEM images. This study showed the geometrical and metallurgical change in welding nugget and HAZ [12]. The graphical weldability lobe technique was used to study different welding parameters. Desired weld nugget formation depends on sheet material type and thickness, type of transformer used and the material of electrode tip. The highly contributing parameters are weld force, weld current and weld time. Two types of weldability lobe graph were studied. Firstly, Weld Time versus Weld Current. Secondly, Weld Force versus Weld Current. Therefore, an optimum value of these parameters is to be maintained to get the required weld quality while simultaneously decreasing the overall manufacturing cost [13].

The nugget formation in RSW of type 347 stainless steel by finite element method was done. Firstly, 347 Stainless Steel of unequal and equal thickness were taken and secondly, two dissimilar metals - AISI1045 carbon steel and 347 stainless steel were considered. Nugget formation at thinner workpiece was less than thicker workpiece because heat conduction is more in thicker workpiece as its area is greater. A workpiece which has lower thermal conductivity and high electric resistivity would form more nuggets [14]. An asymmetric finite mode was used for analyzing squeezing and welding cycles to determine the response. Temperature distribution, thermal expansion with related stress, and weld nugget growth were predicted from this model. Type 321 stainless steel sheets were used for extensive RSW to validate the FEM. In this investigation, ANSYS finite element program was used to connect the model and conduct the analysis, the FEA of RSW was done for (i) truncated (ii) spherical end electrode. The materials used were Class III Copper and type 321 Austenitic Stainless steel for electrode and workpiece [15]. The effect of shunting current on the metallurgical and mechanical behavior of AA2219 joints was experimentally analyzed. For numerical results, Finite Element Method (FEM) was used. During the experiment, welding distance was taken as the main variable for two consecutive nuggets. The growth of HAZ volume issued was more intense for shorter welding distance [16].

The transient response during RSW was measured as a function of different process parameters i.e. coolant flow, electrode thickness, electrode force and type of zinc coating. The first method used was infrared emission monitor method. In this, the temperature of surface was measured using a thermovision system. Second method used was high-speed cinematography of a cross-sectioned welding setup. The faying interface in truncated cone electrode was the source of nugget formation whereas electrode interface was the source in the case of dome type electrode [17]. Different mechanisms involving thermal and electric resistance and their interactions in RSW were studied. For simulation, SORPAS software was used. Dual phase steels were selected for analysis because they are alloyed and cold weld to increase strength. Verification of welding model was done using weld growth curves. Material response to Resistance Spot Welding was investigated by the position of the curve which was varied accordingly by changing the different material characteristics like strength, electrical resistivity and conductivity [18].

Electrical-Thermal-Mechanical phenomena were analyzed in RSW process through a 2D axes symmetric FEM model. COMOSOL Multiphysics software was used to analyze the welding process by varying the electrode tip contact area. Assuming that electrode and workpiece behave electroplastically, it was concluded that by varying the contact area, nugget formation at the faying surface would change [19]. The effect of process parameters on nugget formation was studied during RSW process. Nugget grows rapidly if electric current exceeds the nugget growth. The nugget size decreases when load increases [20]. For improving the electrode life, the accurate thermal simulation of an electrode cap is necessary. Maximum tip surface temperature was found out to be 905K. Also, the important result obtained was that convection and radiant heat losses were insignificant. A simple linear relationship exists between the minimum temperature and input power. No significant temperature changes were formed for a decrease in water flow rate inside the electrode from 3.79 to 2.24 L/min or a decrease of the cap depth from 9.00 to 6.35mm [21]. Electrode life tests were carried out to examine the impact of electrode degradation on electrode life. A 1.5mm thick Aluminum sheet with the help of 170KVM Medium-Frequency Inverter Technique (MFDC) pedestal resistance spot welding machine was used. Welding conditions for electrode life test found out by weld lobe method. The approximate electrode life was about 400 to 900 welds, keeping process condition constant. As the contact area increased, undesired nugget was formed which resulted in joint strength reduction [22].

III. RESEARCH GAP

Many experimental and theoretical works have been performed by different researchers in the field of resistance spot welding. Mainly, Steel, Aluminium and their alloys were used to depict the results. To perform the analysis of resistance spot welding process, researchers used different types of softwares such as MINITAB17, COMSOL Multiphysics, CFE using ABAQUS code, SORPAS, ANSYS, SYSWELD (FEM) etc.

Points which were absent or which had less content covered by the reference researchers were found out to be the research gaps in the resistance spot welding study. They are as follows:

- Deflection or bending of electrode due to current and pressure.
- Generally, copper and tungsten alloys were used as electrode material. There was no study based on silver electrode.
- There was limited analysis on workpiece material (mostly stainless steel and aluminium were used).
- More analysis was required in water flow rate and cap depth.
- More research work was needed in the case of HAZ around the elecrode tip during welding.
- Further analysis is to be done using CFD tool as it has huge scope in the future.

IV. CONCLUSION

RSW is one of the most widely used joining method in industry today. Since, it can be automated easily, it is a flexible and adaptive method of fabrication of components. Therefore, it is very important for researchers to keep modifying the parameters involved, to increase the weld quality and life of electrode. It should be noted that the welding method used also contributes to the overall manufacturing cost of the material. For this cost optimumisation, various engineers and scientists have used different tools for analysis and simulation of RSW. From these, two subjects that were studied exhaustively were :- Nugget Formation and Heat Affected Zones. These were verified experimentally. Besides FEM, other methods used were :- Graphical Lobe Curves, Weld Growth Curves and Statistical methods. Transient Response of RSW which was first measured using Thermovision and High Speed Cinematography, can now be analysed using CFD softwares like ANSYS-FLUENT. Therefore, we can conclude that with the advancement of technology, more and more efficient spot weld analysis will continue to happen, thus, improving the weld quality from time to time.

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