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RESISTANCE SPOT WELDING AND OPTIMISATION TECHNIQUES USED TO OPTIMISE ITS PROCESS PARAMETERS

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Abstract— **Resistance spot welding process is one of the oldest methods used to join sheet metals using a combination of heat,pressure and time parameters.It is an economical and highly productive process and is, therefore, being used in various manufacturing industries and has a great future ahead.The present discussion deals with a critical review of spot welding carried out by different investigators.The review also includes the various methods of optimization of process parameters.The sheets to be welded are clamp together between the electrodes and current is allowed to flow.The plates get heated at the interface due to the resistance in the path of current flow.The pressure applied on the electrodes causes the heated region to yield and get squeezed together to form a weld nugget.**

I. INTRODUCTION

Resistance spot welding (RSW), is one of the oldest techniques widely being used for joining sheet metals in various industries because of its simplicity, easy for automatation and reliability for mass production. RSW is an autogenous welding process, meaning that unlike other methods, it does not require filler metal. RSW uses the metal's natural electrical resistance and constriction in the path of current flow, to generate heat at the interface .The procedure begins with electrodes which clamp two metal sheets . The current flows through the sheets from one electrode to the other, and the resistance to this flowing current generates heat. A temperature is reached where the metal sheets fuse at the faying surfaces and a molten region is generated in between two sheets. As the current shuts off, the melt rapidly solidifies , forming a solid nugget. Ever since the original invention by Professor Elihu Thomson in 1877, the process has been applied actively for the assembly of metal sheets in the automobile and aircraft industries [1].

The level of importance of the resistance spot welding can be judged from the fact that in the body of a car there are more than 3000-6000 spot welds.It has excellent techno economic benefits such as low cost, high production rate and adaptability for automation.These features make it an attractive choice for auto-body assemblies, truck cabins, rail vehicles and home appliances
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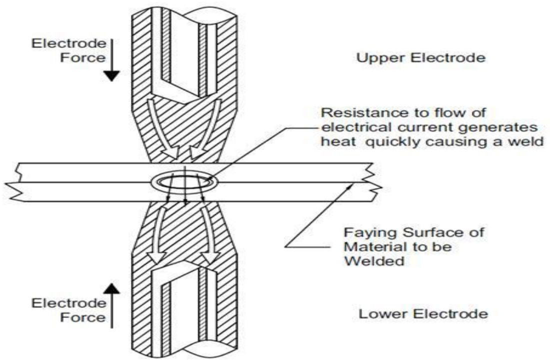
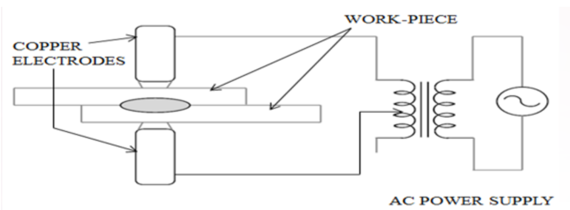
Furthermore, other metal-to-metal connections, such as wire-to-wire joints in the electronic industry, are accomplished by resistance spot welding. Application-specific measures, such as the diameter of the weld nugget, determine the quality of the joint.



A. PRINCIPLE OF RESISTANCE SPOT WELDING

Resistance spot welding process uses heavy current which is passed for a short period of time through the area of interface of metals and the application of pressure on the sheets to be joined. In resistance spot welding process flux is not used, and the use of filler metal is very rare[2]. Resistance welding operations are normally automatic and, therefore, all process parameters are pre-set and maintained constant. Heat generated in a localized area is enough to raise the temperature at interface, so that the parts can be joined with the application of pressure.



B. HEAT GENERATION IN RESISTANCE SPOT WELDING

Heat generation in resistance spot welding is based on the Ohm's law. The amount of heat generated in an electrically conductive work piece depends on mainly three parameters welding current,resistance of work piece and time of current flow.
The heat generated by resistance is expressed as below [3]

$$Q\alpha(R1+R2).I^2.s.r^{-4}$$

Here *R1* is the contact resistance of two metal sheets, *R2* the metal's electrical resistance, *I* the weld current, *s* the weld time and *r* the contact diameter of two sheets. *R1* and *R2* are approximately constant, so the current, weld time and contact diameter determined by the electrical force are known to be important in determining the welding condition [3].

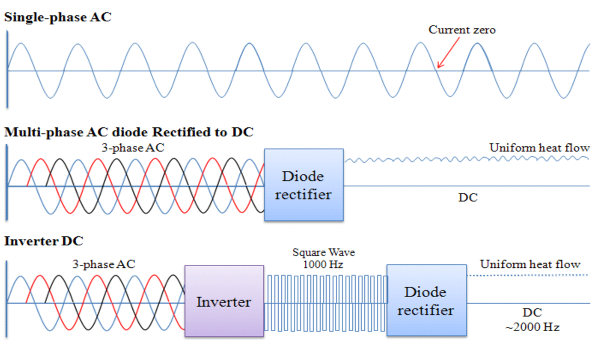
Thus,optimisation of such welding parameters for each material is the key for controlling weld quality.

C. WELD PARAMETERS

During welding, molten zone at the faying sheet surfaces forms the weld nugget. Thus if more heat can be generated, a larger volume of metal can be melted, resulting in a bigger nugget size. Larger weld nuggets are generally good for weld performance [4-6]. The weld nugget size should be large enough for better impact property as well as preferable weld failure mode [4, 6].

D. Current

In RSW, the heat generated is directly proportional to the welding current. Two types of current wave forms are available for conventional RSW processes; they are AC (alternating current) and DC (direct current) wave forms. In the automotive industry, the spot welding process with single-phase AC has been predominant [7]. DC systems can be used by rectification of single-phase or multi-phase AC into DC. Inverter equipped spot welders can provide very high frequency (2000 Hz) DC, which is effective in terms of energy use [7]. Also, DC system-based spot welding usually requires more equipment, thus bringing reliability problems, and is more costly [8], but it minimizes the heat loss and provides uniform heat flow.



It should be carefully manipulated because too low current will not provide sufficient heat to create a nugget while a too high current will result in the expulsion of molten metal from the weld zone. Expulsion decreases the nugget size and may also cause harm to surrounding equipment and parts and If the boiling point is reached, there is higher risk for porosity in the finished weld. Another result of using too high currents is too large indentations in the metal surface. The current level also affects the distortion of the base metal and the size of the heat affected zone (HAZ).Results of research indicate that the common welding current amplitude lie in the range of 5kA - 10kA depending on sheet configuration, other process parameters and the weld requirements. [9]

Time

Spot welding process generally consists of 4 steps, which are squeezing, welding, holding and final releasing [10]. In AC systems, the weld time is expressed in cycles (one cycle is 1/50 of a second in a 50 Hz power system), while millisecond is used for DC systems.The time for each step should be set according to the material, thickness and the coating conditions used[8]. A minimum welding time is needed to make high quality weld.

Welding current and welding time have been indicated as highly effective parameters for tensile shear strength.[15-24]

E. Electrode Force

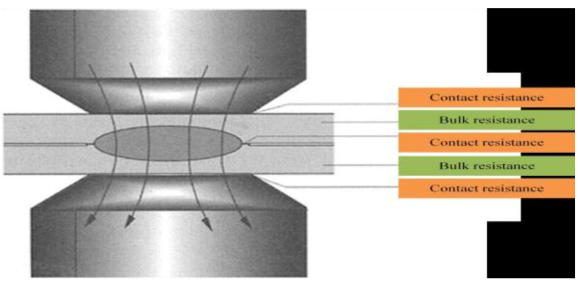
Force is applied on the electrodes to press and keep the metal sheets in position. Electrode force *P* is expressed as:

$$P = 2.5.t.\left(\frac{TS}{300}\right)\text{^}(0.5)$$

Where, *t* is the metal thickness in mm, *TS* tensile strength of the steel sheets in MPa [11].
According to the above equation, stronger steels will require greater electrode force. If the force is insufficient to keep the two metal sheets mutually tight together , a small contact diameter results, which alters the amount of heat that is generated.

F. Resistance

It is one of the most important factors which effects the weldability in RSW.
In the case of AC welding, resistance drops rapidly at the initial stage because of the decreased contact resistance from the high current peak that is absent in DC. Highly concentrated current generates great heat and brakes down the contact surface, destroying possible oxide phases on the interface that act as insulators [7].



G. Material Properties

Normally properties of materials change with change in temperature. Resistivity of material, thermal conductivity and heat capacity of the material affects the heat generation during welding process. Hardness of the material also affects the contact resistance at weld surface. Harder materials cause high contact resistance for the same weld force.Therefore material selection is based on the above parameters.

- **Mild Steel**

Mild or low-carbon steel comprises the largest percentage of materials welded with the resistance spot welding process. All low-carbon steels are readily weldable with the process if proper equipment and procedures are used.[12]

- **Low Alloy and Medium Carbon Stee*l***

Difference in resistance spot welding of low alloy and medium carbon steels as compared to mild or low carbon steels is the resistance factor which is high for low alloy and medium carbon steel therefore, the current requirements are slightly lower. There is certainly more possibility of weld embrittlement than there is with mild steel.[12]

- **Stainless Steel**

The chrome-nickel steel alloys (austenitic) have very high electrical resistance and are readily joined by resistance spot welding. The consideration of great importance with these materials is rapid cooling through the critical range.[12]

- **Steel, Dip Coated OR Plated**

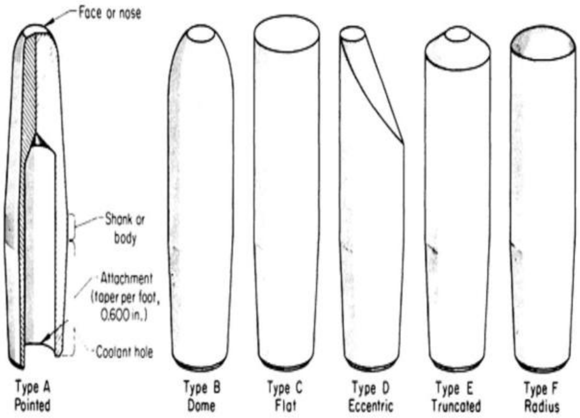
Material in this category are galvanized, or zinc-coated steel. Some galvanized steel sheets are electroplated, the dip-coated steel costs less and is predominantly used but the resistance factor will vary from weld to weld, and it is very difficult to set conditions for the materials.[12]

- **Aluminum and Aluminum Alloys**

The electrical conductivity of aluminum is high, and welding machines must provide high currents and exact pressures in order to provide the heat necessary to melt the aluminum and produce a sound weld.[12]

H. ELECTRODE

Materials for RSW electrodes should have sufficiently high thermal and electrical conductivities and sufficiently low contact resistance to prevent burning of the workpiece surface or alloying at the electrode face. In addition, the electrode should have adequate strength to resist deformation at operating pressures and temperatures. Because the part of the electrode that contacts the workpiece becomes heated to high temperatures during welding, hardness and annealing temperatures must also be considered. Electrode materials for RSW have been classified by RWMA and in International Standards Organization (ISO) standard ISO 5182.



I. SURFACE COATING

All metals develop oxides which can be detrimental to resistance spot welding. Some oxides, particularly those of a refractory nature, are more troublesome than others. Separate adjustments of process parameters are made according to the individual type of surface coatings. Surface coatings are selected systematically to make the favourable welding conditions at weld surface.

J. MONITORING AND CONTROL

The objective of monitoring and controlling can be summarized as:

- Weld size estimation.
- Expulsion detection and its severity evaluation.
- Process fault diognisis.
- Process control.

Gedeon et al., presented a work on monitoring the parameters and showed that displacement curves and dynamic resistance provides significant information for evaluating weld quality.[13]

K. TEST METHODS FOR EVALUATION

To find the relevant testing parameters for evaluation, an accurate, relevant and well-defined standard testing procedure should be carried out. Testing procedures are divided into two main categories: destructive and nondestructive testing. The main destructive testing types are coach-peel tests and metallographic tests. Regarding non destructive testing, the main types are usually ultrasonic or x-ray but neither has reached the same level of accuracy or reliability as the destructive test methods [14].

OPTIMISATION TECHNIQUES USED TO OPTIMISE THE PROCESS PARAMETERS OF RSW

In this area the work carried out by different investigators is discussed in the following paragraphs.

Thakur.et al.[15], focused to optimize tensile shear strength for galvanized steel using L27 orthogonal array method.
On the basis of ANOVA,highly effective parameters are current and time, whereas force and diameter are less effective parameters.Using S/N ratio,tests indicate tha tensile shear strength can be increased significantly(13.43%) by using the proposed statistical technique.
Niranjan Kumar Singh .et al.[16] using Taguchi method conducted experiments in two phases on Austenition stainless steel grade 301 to find the effect of process parameters(welding current,weld cycle,hold time,cool cycle) on indentation as primary and initial measure of weld quality including tensile strength,nugget diameter and penetration.L32 orthogonal array and minitab 14 software was used for analysis.
They found that the average indentation was 0.87mm and data followed normal distribution but after conducting Taguchi method,residuals followed normal distribution without any pattern with time and fitted value.The validity of Taguchi method was confirmed.
Pandey. et al.[17] used taguchi method on low carbon cold rolled 0.9mm thick mild steel sheets to find the effect of parametrers on quality of weld strength.According to the results,current contribute 61%,holding time 28.7% and pressure 4% on tensile strength.For optimum result,current should be 6.8KA,pressure 0.79KPa, and holding time of 5 sec.
Kadam. et al.[18] with the help of non-linear method like Genetic algorithm studied the effect of process parameters on nugget relation between responses and variable input parameters.They found that nugget dia.increases by by increasing the number of generation.According to them with the help of Genetic algorithm,maximum value of nugget dia. can be obtained.
Panchakshari. et al.[19] carried out a comparative study of responses on low carbon steel using three methods-Genetic algorithm,Design of experiment and Response surface method and cross validated the results by using D-optimal method.The results shows that weld cycle and welding current should be 12 cycles and 11.2KA respectively.Other parameters such as hold cycle,squeeze cycle,nugget dia., and weld strength must lie at range of 12 cycles,30 cycles,5.4mm and 290N/mm^2 respectively.
Arvinder Singh.et al.[20] used Taguchi L9 orthogonal array method to find the effect of process parameters(pressure,weld time,and welding current) on tensile strength of austenitic stainless steel AISI 316L.They found maximum tensile strength of 789.46N/mm^2 at pressure 3.1KN,welding time 4ms and current 15KA.
Darshan Shah. et al.[21] used neural network-based systems to find the optimum process parameters for resistance spot welding and weld quality assessment.Input parameters used includes are welding current,sheet thickness and cycle time. Parametric analysis is carried out for the quality of the resistance spot welding, i.e. weld strength. This parametric analysis (ANOVA) using weld strength as quality indicator shows the percentage contribution of parameters individually, i.e. welding current as 49.81 %, thickness of 37.94 % and cycle time of 2.61 % and the error is of 9.62 %. It has been found that weld strength increases as welding current increases and weld strength decreases as thickness of the material increases.
Hamed Pashazadeh.et al.[22] used full factorial design of experiments onAISI 1008 commercial steel sheets parameters (welding current, weld time,pressure) on nugget diameter and height.Best nugget size was achieved by using hybrid combination of artificial neural network and multi objective genetic algorithm.
The result shows that range of 591 to 615 spot welds can be done for tip dressing operation in studied welding operation.
Pradeep M. et al.[23] present an approach to find out the optimum weld parameters in spot welding dissimilar material thickness.Parameters for welding of dissimilar thickness material are not available beyond 4mm.Low carbon steel have been used by them having a 0.8mm thick metal strips of cross-section 10 and 5 mm having a composition of 0.101 C,.33 Mg,0.011 S,and 0.019 P (wt.%).Taguchi approach has been used for the optimization of welding current and time using L9 orthogonal array.There result indicate optimum current as 3.5KA and time 10 cycles.
Suresh R K.[24] reported a systematic approach to determine the effect of process variable(welding current,time,electrode size) on tensile shear strength properties using mild steel 1 mm thick,18mm wide and 150mm long sheets and copper electrodes.He used taguchi approach for design of optimization experiment.The input parameters used included welding current,welding time and electrode dia keeping squeezing time,hold time,electrode force,sheet thickness as constant.L27 orthogonal array was selected for this study.A total of 27 experiment with mixed combination of inputs were carried out.The results indicated maximum tensile strength at current level of 17.5A,weld time of 15 sec. and electrode diameter of 3mm.ANOVA results showed the % contribution of current as 63.7%,weld time 28.7% for maximum tensile shear strength.

II. CONCLUSION

The present study gives an overview of latest research works on resistance spot welding.It presents a brief information about the resistance spot welding,its parameters and about the techniques used to optimize the parameters and to obtain high quality welds.

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