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Optimization Techniques and Methodology Used For Resistance Spot Welding

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ABSTRACT: Resistance spot welding process is most commonly used for joining of sheet metal in automobile and aerospace industries. For the fabrication of sheet metal assemblies resistance welding used. Around 6000-8000 spot welds are required in any car, which shows the level importance of the resistance spot welding. It is a complicated process, as it involves interactions of the mechanical, thermal, electrical and metallurgical phenomenon. Resistance welding methods are inexpensive and efficient which has made them highly popular in the making of sheet joints. For producing continuous and pressure tight joints on overlapped materials various types of resistance welding are developed. Controlling the welding parameters plays an important role in the quality of the weld. This paper reviews on various effects of process parameters (like welding current, welding time etc.) on response variables. Various optimization methods like Taguchi, ANOVA and GRA have been most efficient and powerful tool for optimization of resistance welding response parameters which produce high weld quality parts rapidly and low cost are discussed in this paper.

KEYWORDS: optimization methods, Resistance spot welding, weld quality, welding current, welding time.

I. INTRODUCTION

Resistance spot welding (RSW) is one of the oldest processes used to join sheet metal parts using series of spot welds. This process is enormously used in mass production of vehicles, metal furniture, and appliances. Automotive manufacturing uses about 6000 – 8000 spot welds for a vehicle body. As automotive body need to sustain various types of loading therefor a large number of spot welds are required for an automotive. Manufacturing cost for the spot welding process has increased tremendously because of the more number of welds. Along with this industries are facing the quality related problem. Quality of Spot weld categorized in terms of the weld strength and spot weld nugget diameter. Cost reduction is achieved by strict quality control which leads to improve the quality of each spot weld which also reduce the number of spot welds required for an automotive. Weld quality governed by proper control of the three main parameters i.e. current, time and force. Development of spot weld nugget is achieved by generating the required heat for melting the metal; this is done by Control of these process parameters. Major advantages of resistance welding are it can easily automate. It is high-speed welding, Suitable for high rate production, low fumes, low distortion. [1-2]

1.1 Resistance spot welding process

In resistance spot welding (RSW) heat is generated because of the contact resistance to the flow of electric current. In RSW process fusion of metal is produced at the faying surface by heat generation and applying pressure on the electrode materials to be joined are brought together. High electric current passes through the electrode and workpieces hold between the electrodes which generates heat. A molten weld nugget is formed in the workpieces because of the contact resistance and Joule heating localized heat generated. Amount of heat produced between the workpiece is controlled by current, time and resistance. It is desirable to have the maximum temperature at the interface of the parts to be joined. Therefore, the resistance of the workpieces and the contact resistance between the electrodes and work

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should be kept as low as possible with respect to the resistance between the faying surfaces. [3] The principle of operation is as shown in Fig. 1.

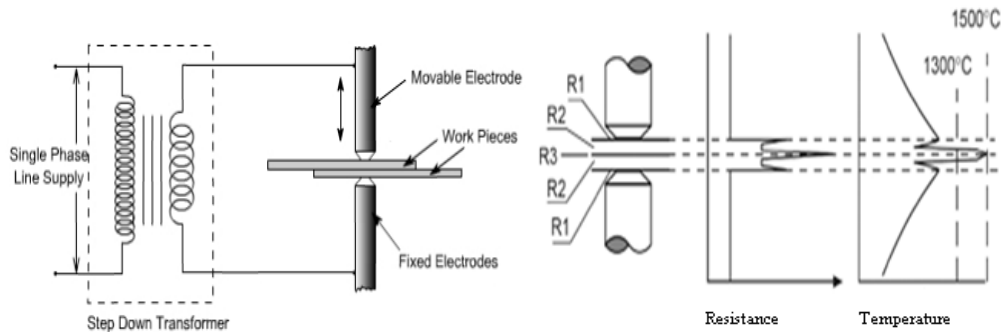


Fig. 1: Working of resistance spot welding

Fig. 2: Resistance and Temp. Distribution Curve

As the name indicates, it uses the resistance of the materials to the flow of current that causes localized heating between the parts to be joined. Excessive heat in the electrodes reduces the electrode cap life and deteriorates the weld quality. Hence, the electrodes are cooled via water circulation through channels opened inside them. The temperature and resistance obtained during resistance spot welding operation are as shown in Fig. 2. Where R1, R2, R3 are the resistances at the Electrode tip and plate surface, Resistance of joining plates, Resistance at the interface of two plates respectively.

1.2 Heat Generation

Heating phenomenon plays important role in heat generation in resistance welding. The heat generated depends upon the current, the time the current is passed and the resistance at the interface. The resistance is a function of the resistivity and surface condition of the parent material, the size, shape, and material of the electrodes and the pressure applied by the electrodes.

$$Q = I^2 R t \quad \dots\dots\dots (\text{Eq. 1})$$

Where I is the current passing through the metal combination, R is the resistance of the base metals and the contact interfaces, and t is the duration/time of the current flow.

The amount of resistance at the interface of the workpiece depends on the heat transfer capabilities of the material, the material's electrical resistance, and the combined thickness of the materials at the weld joint.

1.3 Evaluation Criteria of Resistance Spot Welding

To determine weld quality a number of parameters can be used as indicators. The following geometrical features and quality parameters are most commonly examined.

- a) Weld nugget size
- b) Nugget penetration
- c) Electrode indentation
- d) Cracks (surface and internal)
- e) Porosity/voids
- f) Sheet separation/distortions
- g) Surface appearance
- h) Location accuracy

Many of the parameters are illustrated in the cross-section of fig. 1.5. Of the parameters listed in fig, nugget size is the most indicative of weld strength and thus most frequently measured. However, it is not sufficient to describe weld quality by itself and for a complete understanding of the properties of a weld, several parameters need to be measured.

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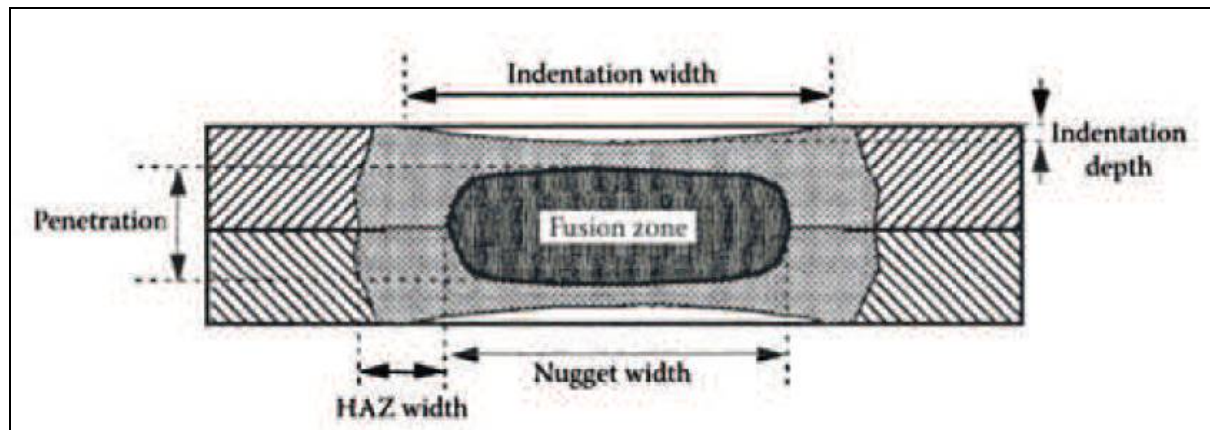


Figure 3: Typical Cross Section and Evaluation Criteria of Spot Weld [5]

For example, penetration depth indicates the volume of material which melted during the welding process. Insufficient penetration indicates too low heat input while excessive penetration results in softening of the material and large indentation. Another, an indication of weld penetration is the magnitude of the process margin. While a larger penetration does not automatically result in higher strength, it shows that certain variations of weld output may be allowed with maintained results.

1.4 Process Parameters

There are many parameters which control the quality of resistance seam welding. The spot welding process parameters have their own importance. A small change of one parameter will affect all the other parameters. These parameters will determine the quality of the welds. The appropriate combination of the spot welding parameter will produce strong joining and good quality of welding. Various parameters are shown in fig. 5.1.

a) Weld Current

The amount of weld current is controlled by two things:

- i. The setting of the transformer tap switch determines the maximum amount of weld current available.
- ii. The percent of current control determines the percent of the available current to be used for making the weld.

Normally low percent current settings are not recommended because it may harm the quality of the weld. The weld current should be kept as low as possible. When determining the current to be used, the current is steadily increased until weld spatter occurs between the metal sheets. This indicates that the correct weld current has been reached. The temperature rises rapidly at the joined portion of the metal where the resistance is greatest if the current becomes too great internal spatter will result.

b) Weld Time

Weld time is the time during which welding current is applied to the metal sheets. The weld time is measured and adjusted in cycles of line voltage as are all timing functions. One cycle is 1/50 of a second in a 50 Hz power system. As the weld time is, more or less, related to what is required for the weld spot, it is difficult to give an exact value of the optimum weld time.

c) Squeeze Time

Squeeze Time is the time interval between the initial application of the electrode force on the work and the first application of current. Squeeze time is necessary to delay the weld current until the electrode force has attained the desired level.

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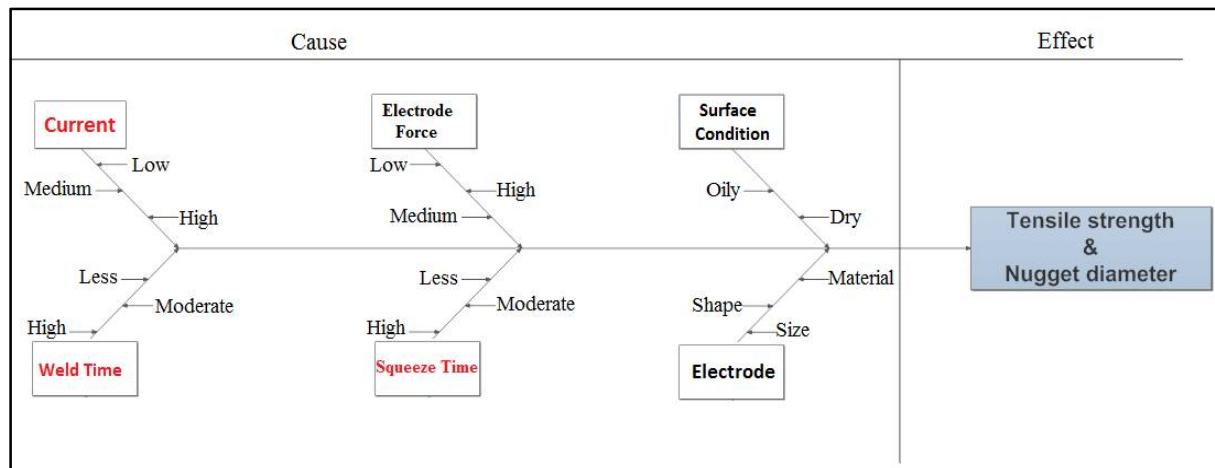


Figure 4: Cause Effect Diagram.

d) Electrode Force

The purpose of the electrode force is to squeeze the parts to be weld and the primary purpose is to hold the parts to ensure the parts in intimate contact at the joining interface. When the electrode force is increased the heat energy will decrease, a high pressure that exerted on the weld joint will decrease the resistance at the point of contact between the electrode tips and the parts surface. This means that the higher electrode force requires a higher weld current. Weld spatter can be happen because the pressure on the tips is too light or when weld current becomes too high. Too heavy pressure will cause small spot weld. In other words when the pressure increases, the electrical current and subsequent heat are transfer to a wider area, the penetration and area of the weld will reduce.

e) Hold Time (Cooling-Time)

Hold time is the time, after the welding, when the electrodes are still applied to the sheet to chill the weld. Considered from a welding technical point of view, the hold time is the most interesting welding parameter. Hold time is necessary to allow the weld nugget to solidify before releasing the welded parts, but it must not be too long as this may cause the heat in the weld spot to spread to the electrode and heat it. The electrode will then get more exposed to wear. Further, if the hold time is too long and the carbon content of the material is high (more than 0.1%), there is a risk the weld will become brittle.

f) Diameter of the Electrode Contact Surface

One general criterion of resistance spot-welding is that the weld shall have a nugget diameter of $5 \times t^{1/2}$, "t" being the thickness of the steel sheet. Thus, a spot weld made in two sheets, each mm in thickness, would generate a nugget 6 mm in diameter according to the $5 \times t^{1/2}$ -rules. Diameter of the electrode contact surface should be slightly larger than the nugget diameter.

II. LITERATURE SURVEY

A literature survey has been done for analyzing the process parameters and their effect on the response variables of the resistance welding.

Yuan et al. [2] Studied welding current, welding time, and electrode force effect on the DP 600 of 1.6 mm thickness and DC540 of 1 mm thickness. When these 3 parameters increased, the tensile-shear strength of the welded spot experienced two stages of a notable increase and a subsequent decrease. Plug failure took place along the plastic deformed DC540 dominated by abnormally grown grains discovered from the interface of HAZ/BM through electron back-scattered diffraction.

Kang et al. [3] studied the load-controlled fatigue behavior of dissimilar aluminum alloy spot welds made of 2mm thick AA575 wrought sheet and 3mm thick Aural2 die casting sheet with and without the addition of adhesive prior to welding. While using adhesive in resistance spot welding to get a large nugget size electrode and the current schedule

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was applied to both welding conditions. The results show that at the edge of the nugget the main fatigue crack initiates and penetrates through the Aural2 die casting sheet in the thickness direction.

Li et.al [4] studied resistance spot welding of commercial pure titanium and aluminium alloy 6061-T6 is carried out. The microstructure and tensile shear properties of the weld joints are studied. There is a critical range of welding current at which the reaction between liquid aluminium and solid titanium changes to a reaction between liquid aluminium and liquid titanium. The welding current has the largest influence upon the tensile shear properties of the Al/Ti weld joint, while the welding time has a small effect and the electrode force has virtually no effect.

Esme [5] conducted experiments under varying electrode forces, welding currents, electrode diameters, and welding times. The material used was SAE 1010 and welding parameters were set and determined by using the Taguchi experimental design method. It proved that current and electrode force are the most dominant process parameters in case of tensile strength of spot weld whereas electrode diameter and welding time were less effective factors. For controlling the tensile shear strength the results showed that welding current was about two times more important than the electrode force.

Rawal and Inamdar [11] studied various optimization techniques are discussed and the use of the Taguchi method to determine the optimum process parameters is reported. This is because the Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality at the design stage. Welding parameters settings were determined by using the Taguchi experimental design method. The level of importance of the welding parameters on the tensile shear strength is determined by using analysis of variance (ANOVA).

III. OPTIMIZATION

Optimization of process parameters and their levels are essential from time and economic constraints, which fullyutilizes the resources and optimize the output quality of product/process required. Various optimization techniques are available out of which Taguchi and GRA studied in details

3.1 Taguchi Method

Taguchi method is the statistical tool of total quality management very much useful to improve high quality at relatively low cost. This is due to quality can be improved by process parameters optimization and the optimized input parameters are unresponsive to the variation of environmental conditions and other noise factors which obtained from the Taguchi method. Taguchi developed a method for designing experiments to determine how different process parameters effect on the mean and variance of a product or process functional characteristic. The Taguchi method uses therobust design of experiments to find controllable process parameter setting which reduces the variation in a process. The analysis of variance (ANOVA) has been used to decide the process parameters levels.

Taguchi method is focused on the mean functional characteristic value which is very close to the target value than a value within specific limits, thus it leads to improving the product quality. Taguchi's experimental design is simple to understand easy to apply the tool to many engineering applications. It can be used to quickly narrow the scope of a research area.

In the Taguchi method, the optimum level of input process parameters or control factors is decided on the basis of statistical analysis of experimental results. This allows us to study particular process and analyse the effect of process parameters on responses with a minimum amount of experimentation, which results in reduced time and resources. It uses the S/N ratio (signal to noise) to represent the quality characteristics of the responses. In S/N ratio, 'signal' is the desired value and the 'noise' is the undesirable value and S/N ratio expresses the scatter around the desired value. Hence, S/N ratio is required to be kept on the higher side in order to minimize scatter around.

Depending upon the nature of quality characteristics the quality loss function can be of several types:

- a) Smaller the better
- b) Larger the better
- c) Nominal the best

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When response variable or parameter is required to be kept at higher side to improve quality larger the better characteristics is used, when it is required to be kept at lower side to improve quality smaller the better characteristics is used and when it is required to be kept in between maximum and minimum quantity then nominal the better characteristics is used. S/N ratio is given by the equation 3.1 and 3.2 for both larger the better and smaller the better characteristics respectively.

For larger the better characteristics,

$$\frac{S}{N} = -10 \log \frac{1}{N} \sum_{i=1}^n \frac{1}{Y^2} \quad \dots (3.1)$$

For smaller the better characteristics,

$$\frac{S}{N} = -10 \log \frac{1}{N} \sum_{i=1}^n Y^2 \quad \dots (3.2)$$

Where, Y= value of response characteristics and N= no. of replications of experiment

Signal to noise ratio is always required to be kept on the higher side in order to get better characteristic of the response variable. The Taguchi method involves using the robust design of experiments to reduce the variation in a process. The main objective of this method is to produce a high-quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation.

With the use of design of experiments number of experiments which are required to be performed to identify relationships among the process parameters and corresponding response variable can be determined. This allows us to study particular process and analyze the effect of process parameters on responses with a minimum amount of experimentation, which results in reduced time and resources.

3.2 Selection of Orthogonal Array

Taguchi method uses a special design of arrays called as orthogonal arrays. This standard array stipulates the performing the lesser number of experiments which give full information about all parameters that affect the response parameters. Before conducting experiments, it requires being select independent parameters and number of levels. The next step is selection orthogonal the array, a total number of degrees of freedom decides the minimum number of experiments to be conducted. Depending upon the factors with two-level or three-level, whichever is predominant decides which kind of OA is selected. Once the decision regarding right OA is done, then the number of trials for that array must provide an adequate total Degree of Freedom (DoE). The degree of freedom can be calculated from the number of levels for that parameter minus one.

3.3 Grey Relational Analysis for Multi Objective Optimization

A single response parameter can be studied with the help of Taguchi method when the problem is of multiple responses it is to be converted into a single response. It can be done with the help of Grey Relational Analysis (GRA). If in the problem under study a particular set of process parameters corresponds to lower value of one response and higher value of other then the optimal condition for these two responses lies in between them. To solve this problem, the grey relational analysis is adopted.

Following are the steps performed to carry out GRA,

- a) Normalization of response parameter
- b) Computation of deviation sequence
- c) Determine grey relational coefficient (GRC)
- d) Determine grey relational grade (GRG)
- e) Optimization of Grey Relational Grade
- f) Prediction of response variables and GRG
- g) Confirmation of optimal parameters

The first step of the grey relational analysis is the grey relational generation i.e. normalization of data. During these step response parameters are normalized in the range between zero and one. For larger the better characteristics one

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value is assigned to the maximum value of response and zero to a minimum value of the response. For smaller the better characteristics, one value is assigned to the minimum value of response and zero to a maximum value of the response. Next step is to calculate deviation sequence with help of which grey relation coefficient is calculated which is the next step. At the end, the evaluation of multiple responses is governed by the grey relational grade. Grey relational grade is the average of GRC of each response considered. With the help of this technique, multiple response problems can be converted into single response optimization. A Higher value of grey relational coefficient will give an optimal combination of process parameters. The different formulae used to carry out grey relational analysis are listed below with sequential step.

a) Normalization of response parameter

In this step data is pre-processed to transform original sequence to a comparable sequence. For this purpose, the measured values of responses are normalized in the range of zero to one. There are three approaches to carry normalization. These approaches depend on whether we require smaller is better, higher is better, or nominal the best. For the response which is to be kept smaller it is done by using eq. (3.3). With help of these formulae one value is assigned to minimum response value and zero is assigned to maximum value of response.

$$Xi = \frac{\max Xi(k) - Xi(k)}{\max Xi(k) - \min Xi(k)} \quad \dots (3.3)$$

For the response which is to be kept at higher side normalization is done with the help of eq. (3.4). By the use of this formulae one value is assigned to larger value of response and zero value is assigned to minimum value of response.

$$Xi = \frac{Xi(k) - \min Xi(k)}{\max Xi(k) - \min Xi(k)} \quad \dots (3.4)$$

Where, $\max Xi(k)$ denotes maximum value of response whereas, $\min Xi(k)$ denotes minimum value of response under consideration. $Xi(k)$ is the reference value of response parameter.

b) Computation of deviation sequence

After normalization difference between reference sequence and comparability sequence gives deviation sequence. Deviation sequence is given by eq. (3.5),

$$\Delta_{oi}(k) = |Xo(k) - Xi(k)| \quad \dots (3.5)$$

Where, $Xo(k)$ is the reference sequence and $Xi(k)$ is the comparability sequence. Values of deviation sequence are used further to calculate Grey Relational Grade (GRG).

c) Determine grey relational coefficient (GRC)

Relation between the ideally normalized and actually normalized response values is given by GRC. If the two sequences match then their grey relational coefficient is 1. The grey relational coefficient is given by eq. (3.6),

$$\gamma(Xo(k), Xi(k)) = \frac{\Delta_{oi}(k) + \zeta \Delta_{max}}{\Delta_{oi}(k) + \zeta \Delta_{max}} \quad \dots (3.6)$$

Where, Δ_{min} denotes minimum and Δ_{max} value denotes maximum deviation sequence. $\Delta_{oi}(k)$ is the reference deviation sequence and ζ is the distinguishing coefficient. Its value can be adjusted in the range of 0 to 1. It is taken equal to 0.5.

d) Determine grey relational grade (GRG)

The overall evaluation of multiple responses is done with the help of grey relational grade. It is the average sum of grey relational coefficients of each response which is given as by eq. (3.7):

$$\gamma(Xo, Xi) = \frac{1}{m} \sum_{i=1}^m \gamma(Xo(k), Xi(k)) \quad \dots (3.7)$$

Where, $\gamma(Xo, Xi)$ is the grey relational grade for the j th experiment and m the number of quality characteristics. GRG is required to be higher in order to get optimum setting of process parameters.

e) Optimization of Grey Relational Grade

Taguchi method can be further used to optimize Grey relational grade. GRG is required to kept at higher side in order to get optimal setting of process parameters. Hence larger the better characteristic of S/N ratio is used.

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f) Prediction of responses

It is done at optimal combination of process parameters. Grey relation grade can also be predicted at optimal combination of process parameter.

g) Confirmation of optimal parameters

Validation of the results obtained is required to be carry out in order to conform results obtained.

IV. EXPERIMENTAL DETAILS

Experiment is carried out on the Al 6061-T6 and 304L Stainless steel having 1.5mm thickness. The overlap being equal to the width of the specimen i.e. 25mm according American Welding Society(AWS) recommendation, shown in fig

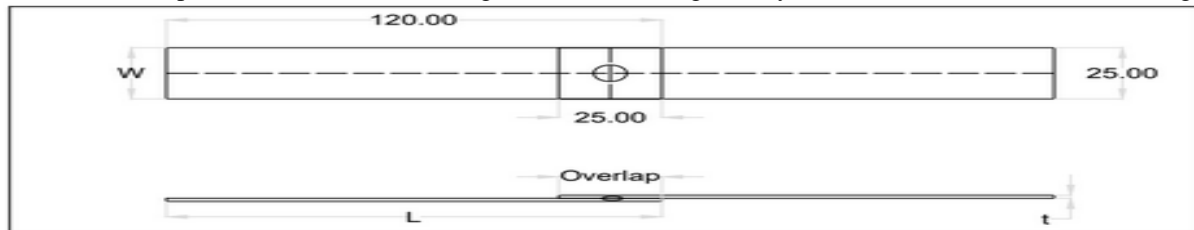


Figure 5: Standard Specimen Dimensions

Experiments were performed at Power Control Electro Systems Ltd. M.I.D.C, Kupwad, Sangli. Effects of welding current, weld time, squeeze time are studied on weld quality. Some experiments are discussed below

Table 1: Experimental Details

Sr. No.	Current (kA)	Weld Time (Cycles)	Squeeze Time (Cycles)	Observation
1	4	26	50	No weld
2	5	20	45	No weld
3	6	28	50	Stick weld
4	6.5	28	50	Under size weld
5	7	33	40	Welded
6	7.5	36	45	Welded
7	7	36	50	Welded
8	8	39	55	Welded
9	8.5	42	50	Welded
10	9	36	45	Welded
11	10	33	45	Expulsion
12	10	28	40	Expulsion

V. RESULTS AND DISCUSSION

From experiments it is found that below certain value of current weld nugget cannot formed also for certain value of current stick weld (workpieces are held together by localized fusion at the welding interface, but no weld button is formed) condition occurs. High value of current leads to expulsion of weld nugget. From Experiment it is observed that 7 kA to 9 kA is good range for Al 6061 and 304L SS. Same case is for weld time and squeeze time. Below certain value weld nugget cannot form. Less value of weld time used for trial experiments results in under size weld and no weld, while high value leads to expulsion of weld nugget so levels are selected from the range 30 to 45 cycles. Less value of squeeze time used for trial experiments results in stick weld case so levels are selected from the range 40 to 55 cycles.

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VI. CONCLUSIONS

This paper has presented an overview of the effect of resistance welding process parameters on the response variables like tensile strength, nugget width. Detail info about Taguchi and GRA and experimental analysis.

- i. Process parameters are the main factors which affects the output quality of spot weld. Root cause analysis is main tool for finding out impact of various parameters on weld quality. From analysis it is found that, welding current, electrode force, welding time, squeeze time, tool geometry and hold time are the main parameters which affect the weld quality.
- ii. The parameter levels are selected for experiments to find effect of varying conditions of process parameters. Some trial experiments are performed to find their effect on quality by varying there levels.
- iii. From experiments it is found that current value less than 7 kA is not able to produce weld nugget, while current value above 9 kA leads to expulsion of weld nugget.
- iv. If DC source is used then polarity effect need to consider but AC source is used so there is no effect of polarity on weld nugget.
- v. GRA and Taguchi have been very effective tools for parametric optimization of the effect of the process parameters on response variables such as tensile strength, nugget width.
- vi. Process modeling of resistance welding can be done with Finite element analysis tool and ANSYS software.

REFERENCES

- [1] X. Yuana, C. Lia, J. Chena, X. Lia, X. Lianga and X. Pan, "Resistance spot welding of dissimilar DP600 and DC54D steels", Journal of Materials Processing Technology, vol. 239, pp. 31-41, 2017.
- [2] J. Kang, Y. Chen, D. Sigler, B. Carlson and D. S. Wilkinson, "Fatigue Behavior of Dissimilar Aluminum Alloy Spot Welds" , 1st International Conference on Structural Integrity, vol. 114, pp. 149-156 2015.
- [3] K. Vignesh, A. E. Perumal and P. Velmurugan, "Optimization of resistance spot welding process parameters and microstructural examination for dissimilar welding of AISI 316L austenitic stainless steel and 2205 duplex stainless steel", International Journal Advance Manufacturing Technology, January 2017.
- [4] Y. Li, Y. Zhang and Z. Luo, "Microstructure and mechanical properties of Al/Ti joints welded by resistance spot welding", Science and Technology of Welding and Joining, vol. 20, No-5, pp. 385-394 2015.
- [5] A. G. Thakur, T. E. Rao, M. S. Mukhedkar and V. M. Nandedkar, "Application of Taguchi method for resistance spot welding of galvanized steel", ARPN Journal of Engineering and Applied Sciences, vol. 5, No. 11, pp. 22-26, 2010.
- [6] D. S. Sahota, R. Singh, R. Sharma and H. Singh, "Study of effect of parameters on resistance spot weld of SS316 material", Mechanical Confab, vol. 2, No. 2, pp. 67-78, 2013.
- [7] U. Esme, "Application of Taguchi method for the optimization of resistance spot welding Process", The Arabian Journal for Science and Engineering, Volume 34, Number 2B, pp. 519-528 2009.
- [8] D. Kianersi, A. Mostafaei and A. A. Amadeh. "Resistance spot welding joints of AISI 316L austenitic stainless steel sheets: Phase transformations, mechanical properties and microstructure characterizations", Materials and Design vol. 61 pp. 251-263, 2014.
- [9] M. R. Rawal and K. H. Inamdar, "Review on Various Optimization Techniques used for Process Parameters of Resistance Spot Welding", international Journal of Current Engineering and Technology, pp. 160-164 2014.
- [10] N. Ma and H. Murakawa, "Numerical and experimental study on nugget formation in resistance spot welding for three pieces of high strength steel sheets", Journal of Materials Processing Technology vol.210, pp. 2045-2052, 2010.
- [11] S. J. Sung, J. Chen and J. Pan, "Stress Intensity Factor Solutions for Similar and Dissimilar Spot Welds in Lap-Shear Specimens under Clamped Loading Conditions", Journal of Engineering Fracture Mechanics, vol. 179, pp 328-347, 2017.
- [12] M. Alizadeh-Sh and S.P.H. Marashi, "Resistance spot welding of dissimilar austenitic duplex stainless steels: Microstructural evolution and failure mode analysis", Journal of Manufacturing Processes, vol. 28, pp. 186-196, 2017.
- [13] K. Zhou and L. Cai, "Study on effect of electrode force on resistance spot welding process", Journal of applied physics, vol. 116, pp. 1-7, 2014.