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Review Article

Review on Various Optimization Techniques used for Process Parameters of Resistance Spot Welding

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Abstract

Optimization of process parameters and their levels are essential from time and economical constraints, which fully utilizes the resources and optimize the output quality of product/process required. In many industries, such as the automobile, domestic appliances, air craft and space craft fabrications, Resistance spot welding (RSW) is a major sheet metal joining process. Resistance spot weld joining process widely used for the fabrication of sheet metal assemblies. In any car, there are 3000-6000 spot welds which show the level importance of the resistance spot welding. It is a complicated process, which involves interactions of thermal, mechanical, electrical and metallurgical phenomenon. Controlling the welding parameters plays an important role on the quality of the weld. In this paper, 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).

Keywords: *Resistance Spot Welding (RSW), Taguchi method, Cause and effect diagram, ANN, optimization.*

1. Introduction

Resistance spot welding (RSW) process in which coalescence of metal is produced at the faying surface by the heat generated at the joint by the contact resistance to the flow of electric current. The materials to be joined are brought together under pressure by a pair of electrodes. A high electric current passes through the work pieces hold between the electrodes. Due to contact resistance and joule heating, a molten weld nugget is formed in the work pieces. The amount of heat produced is a function of current, time, and resistance between the work pieces. It is desirable to have the maximum temperature at the interface of the parts to be joined. Therefore, the resistance of the work pieces and the contact resistance between the electrodes and work should be kept as low as possible with respect to the resistance between the faying surfaces. The principle of operation is as shown in Fig. 1.

RSW has excellent techno-economic benefits such as low cost, high production rate and adaptability for automation which make it an attractive choice for auto-body assemblies, truck cabins, rail vehicles and home appliances. As the name implies, 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 is 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.

The weld strength is measured by a number of standardized destructive tests, which subject the weld to different types of loading. Some of these are tension-shear, tension, torsion, impact, fatigue, and hardness. The stiffness and the operating strength of sheet metal parts are strongly influenced by the welding parameters andlocation of the spot welding. It is very important to select the welding process parameters for obtaining optimal weld strength. The desired welding process parameters are determined based on experience or from a handbook. However, this does not ensure that the selected welding process parameters can produce the optimal or near optimal weld strength for that particular welding machine and environment. Various aspects of modeling, simulation, and process optimization techniques are used in the resistance spot welding process. Detailed analysis has been made to establish relationships between welding parameters weld strength, weld quality, and productivity to

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select welding parameters leading to an optimal process (Norasiah muhammad *et al*, 2011), (Ugur Esme, 2008).

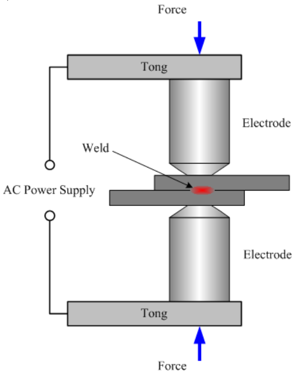

Fig.1 Resistance spot welding principle

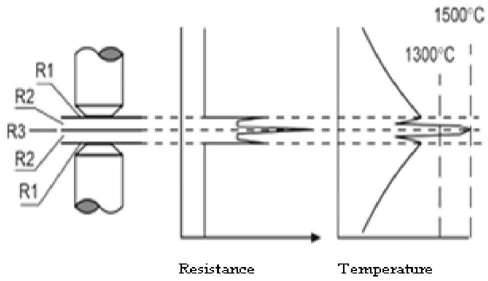

Fig.2 Resistance and temperature distribution curve

2. Spot welding parameters and heat generation

The three main parameters in spot welding are current, contact resistance and weld time. In order to produce good quality weld the above parameters must be controlled properly. The amount of heat generated in this process is governed by the formula,

$$Q = I^2RT \qquad (1)$$

Where Q is heat generated (J);
I is welding current (A);
R is resistance of the work piece(Ω);
T is time of current flow (Sec).

3. The principle test methods used for spot weld quality

Various test methods used for RSW quality checking are,

2.1 Destructive Tests

Destructive tests are those in which specimen is tested for quality by means its destructions to loading etc. These are classified as follows,
i) Tension-Shear Test, ii) Tension Test, iii) Impact Test, iv) Torsional Test, (v) Twist Test, (vi) Torsional Shear Test, (vii) Peel Test, (viii) Fatigue Test, (ix) Bend Test, (x) Chipping Test, (xi) Hardness Test.

2.2 Non-Destructive Tests

In this method of testing quality evaluation is done without destruction of specimens. Non-Destructive test methods used for quality evaluation are as follows,

i. Visual Test
ii. Radiographic Test
iii. Ultrasonic Test

4. Resistance spot welding parameters

There are various parameters which directly or indirectly controls the quality of resistance spot welding. These are diagrammatically as shown in Fig. 3

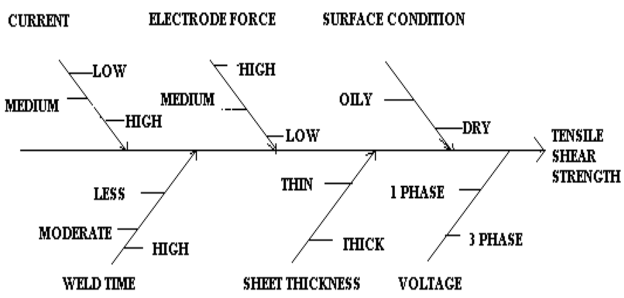

Fig.3 Cause and effect diagram

4.1 Effect of welding current

The current has more influence on the amount of heat generated. Tensile shear strength increases rapidly with increasing current density. Excessive current density will cause molten metal expulsion (resulting in internal voids), weld cracking, and lower mechanical strength properties. In case of spot welding, Excessive current will overheat the base metal and result in deep indentations in the parts.

4.2Effect of weld time

The total heat developed is proportional to weld time. During a spot welding operation, some minimum time is required to reach melting temperature at some suitable current density. Excessively long weld time will have the same effect as excessive amperage on the base metal and electrodes.

4.3Effect of welding pressure

As the pressure is increased, the contact resistance and the heat generated at the interface will decrease. To increase the heat to the previous level, amperage or weld time must be increased to compensate for the reduced resistance. Contact resistance will be high. As the pressure is increased, the high spots are depressed and the actual metal-to-metal contact area is increased, thus decreasing the contact resistance (Ugur Esme, 2008).

4.4Effect of welding voltage

Welding voltage don't have the significant affect on the heat developed, cleared by the heat develop formula. It is used to choose the welding operation on single or double phase mode.

5. Various optimization tools and technique

Various tools and techniques used for optimization of processes and process parameters. Generally, Trial and error method based experimentations are carried out which takes much more productive time and economical investment. The results obtained after experimentation are not up to the mark, leads to unsatisfactory results. To overcome these losses various optimization techniques are used for efficient experimentation and analysis though which satisfactory results can be achieved. Following are various methods used for optimization of process and parameters.

5.1 Spot Welding Simulation

Simulation and optimization of spot weld process parameters can be done by using SORPAS simulation software. SORPAS is professional weld simulation software used by engineers in industry (including automotive, steel making, welding equipment, electronics and other metal processing industries) to support design and evaluation of material weld ability. In this software, combinations as well as design and selection of electrodes and general optimization of welding process parameters can be done. It can be used to compare theoretical and practical results (M A Al-Jader, *et al* 2009).

5.2Genetic Algorithm

Genetic algorithms (GAs) are subclass of evolutionary algorithms (EAs). Evolutionary algorithms (EAs) are population-based higher level optimization algorithms in which biology-inspired mechanisms and survival of the fittest theory is used to refine the solution iteratively. Genetic algorithms (GAs) are computer based search techniques. Developed on the basis of Genetic mechanisms of biological organisms that have adapted and flourished in changing highly competitive environment. Last decade has witnessed many exciting advances in the use of genetic algorithms (GAs) to solve optimization problems in process control systems. The solutions for optimization of hard problems are quickly, reliably and accurately obtained by genetic algorithm. As the complexity of the real-time controller increases, the applications of genetic algorithms (GAs) have grown in more than equal measure.

The working principle of genetic algorithms is based on Darwinian's theory of survival of the fittest. It may contain a chromosome, a gene, and set of population, fitness, fitness function, breeding, mutation and selection. Genetic algorithms begin with a set of solutions represented by chromosomes, called population. Solutions from one population are taken and used to form a new population, which is motivated by the possibility that the new population will be better than the old one. Further, solutions are selected according to their fitness to form new solutions, that is, offspring's. The above process is repeated until some condition is satisfied.

5.2.1 Limitations

1) Decision of population size is an important issue while applying genetic algorithms.
2) A very big population size consumes more time for finding optimum solution, which may deteriorate the performance of genetic algorithms.
3) Genetic algorithms may suffer from the problem of premature convergence due to improper selection of crossover rates.
4) Higher crossover rate of about 85 percent to 95 percent is recommended to minimize premature convergence problems.
5) Selection method for selecting good chromosomes is another important issue while applying genetic algorithms for process control applications (Rahul Malhotra, *et al* 2011).

5.3 *Fuzzy Logic*

Fuzzy logic is a complex mathematical method in which many inputs and output variables are used for solving difficult simulated problems. Fuzzy logic is able to give results in the form of a specific interval of output state, so this is a different mathematical method from more familiar logics used, such as Boolean algebra.

Fuzzy logic is a form of many-valued logic; it gives results which is approximate rather than fixed and exact. As compared to traditional binary sets (where variables may be True or False values) fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false.

The fuzzy logic analysis and control methods can be described as;

1) Receiving one or large number of measurements or other assessment of conditions existing in some system that will be analyzed or controlled.
2) Processing all received inputs according to human based, fuzzy "if-then" rules, which can be expressed in simple language words, and combined with traditional non-fuzzy processing.
3) Averaging and weighting the results from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The result output signal is a precise defuzzified value.

5.4 Artificial Neural Network

Artificial Neutral Network (ANN) is information processing system in which their design was inspired by the studies of the ability of the human brain to learn from observations and to generalize by abstraction. The fact that neural network can be trained to learn any arbitrary nonlinear input/output relationships from corresponding data and the acquired knowledge. That's why it can be use in a number of areas such as pattern recognition, speech processing, control, bio medical engineering, RF and microwave etc.

First it is needed to select a development environment where the neural model should be developed and implemented. Therefore MATLAB simulation software is being selected to design and develop the required neural network model. The neural network is developed by generating proper program code it the MATLAB console and then decorated with proper algorithms and required problem definitions. Multilayer perception Neural Network model has been created for more accuracy with more numbers of hidden layers for quality measure [6].
Neural networks have recently gained attention as a fast, accurate and flexible tool to modeling, simulation and design. Each time a new network is trained, or an old network is retrained, the shape of the function described by the neural model changes, complicating the issue of where to place additional sample points. The neural network models provide a great deal of time savings in situations where a fixed topology must be reused and re-synthesized many times which is the primary target for modeling and synthesis of analog circuits using neural network models.

Increasing the number of hidden layers of neurons without affecting the speed factor can be done for better performance of the neural network. Reducing the mean square error can optimize the error.

Genetic algorithms, for example, use an analogy to chromosome encoding and natural selection to evolve a good optimized solution. Artificial neural networks, on the other hand process information the way biological nervous systems, such as the brain, for optimal decision making. Certain characteristics of their architecture and the way they process information makes them superior to conventional techniques on certain class of optimization problems (G.Saravana kumar and P K Kalra).

5.4.1 Limitations

The ANN model can give estimate of values that the simulator may failed to provide. However there are never any guarantees of absolute accuracy when approximating unknown functions (Mriganka Chakraborty, 2012).

5.5 *Finite Element Methods*

Finite Element Analysis (FEA) has been extensively used with success; however, this kind of analysis requires the generation of a large set of data in order to obtain reasonably accurate results and consumes large investment in engineering time and computer resources. Numerical methods provide a general tool to analyze arbitrary geometries and loading conditions. Many time-consuming experiments can be replaced by computer simulations. The finite element method gives an approximate solution with an accuracy that depends mainly on the type of element and the fineness of the finite element mesh.
Process modeling using FEM simulation is already used in industry in a wide variety of forming operations, no commercially available FEM code is capable of simulating, with the required degree of precision, Finite Element Method (FEM) and Design of Experiments (DoE) techniques are used to achieve the study objectives. The combination of both techniques is proposed to result in a reduction of the necessary experimental cost and effort in addition to receiving a higher level of verification (Emad Al-Momani, *et al*, 2008).

5.5.1Finite element simulation

Simulations are conducted on the commercial finite element software package ABAQUS/Explicit.

5.6 Taguchi and ANOVA approach

The quality engineering methods of Dr. Taguchi is one of the important statistical tools of total quality management for designing high quality systems at reduced cost. It is a powerful tool for the design of high quality systems. Taguchi method can be efficiently used for designing a system that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of strategically designed experiments. Taguchi recommends a three stage process to achieve desirable product quality by,

i. System design
ii. Parameter design
iii. Tolerance design

Steps followed in Taguchi method are as follows:

1) Identification of the main function, to be optimized and its side effects and failure mode.
2) Identification of noise factors, testing conditions and quality characteristics.
3) Identification of the main function to be optimized.
4) Identification of the control factors and their levels.
5) Selection of orthogonal array and matrix experiment.
6) Conducting the matrix experiment.
7) Analyzing the data and prediction of the optimum level.
8) Determining the contribution of the parameters on the performance.
9) Performing the verification experiment and planning the future action.

A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics. While using a signal-to-noise ratio to analyze the experimental data could help the designers of the product or the manufacturer to easily find out the optimal parametric combinations.The optimum condition is selected so that the influence of uncontrollable factors (noise factors) causes minimum variation to system performance. Orthogonal arrays, ANOVA, S/N ratio analysis and F-test are the essential tools for parameter design. Analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each parameter against a stated level of confidence.

Depending upon the number of process parameters and their levels, various orthogonal arrays are available. The correct selection of orthogonal array is selected done for current process. If the process parameters have mix levels, then mixed level orthogonal array is selected for experimentation. Once the decision is made about the right OA, then the number of trials for that array would provide the adequate total DoF, When required DoF fall between the two DoF provided by two OAs, the next larger OA must be chosen.

There are three categories of the quality characteristic in the analysis of the S/N ratio, *i.e.* the lower-the-better, the larger-the-better, and the more-nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted (K. Pandey, et al 2013), (UgurEsme, 2008)

5.6.1Advantages

1) It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost.
2) It gives a mean performance characteristic value close to the target value rather than a value within certain specification limits.
3) Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations.
4) Using the Taguchi techniques, industries are able to reduce product development cycle time for both design and production, therefore saving costs and increasing profit.

Conclusions

From the above study of tools and techniques used for optimization of processes and its parameters, it is come to know that,

1) A multi objective optimization has been applied with simultaneous consideration of multiple responses using Taguchi method.
2) An optimum parameter combination for the required response variable characteristic is obtained by using analysis of S/N ratio.
3) The level of importance of welding parameters on the response variable is determined by using ANOVA.
4) Taguchi method of optimization process parameters is efficient, close to target and economical.
5) It gives steady effect of process parameters which while optimizing and quickly identified its contribution of various response variables.
6) Other tools and techniques used for optimization has some limitations of application and results obtained are not close to target and satisfactory. It gives approximate results not confirm to its repeatability and consistency of operation.

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