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Parametric Optimization of Resistance Spot Welding Process

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ABSTRACT

In any manufacturing process the process parameters plays the vital role in manufacturing of the product which has the direct impact on the product and process also resulting in the burdensome loss to the industries implementing those processes. In resistance spot welding process the weld quality depends on a large degree of the weld penetration and weld geometry which is largely influenced by various process parameters in the process. Inadequacy of weld penetration and weld bead dimensions may lead to failure of the welded structure. Also the geometry of the flat surfaces may damage due to inadequate or incorrect input parameters. This paper is a study of optimization of process parameters using Taguchi methodology. Experimentation is carried out with the settings obtained by design of experiments were considered for the study. Response as weld time indicating weld quality is studied and mathematical model were developed correlating the important controllable spot welding process parameters like Voltage (V), wire diameter(D) and welding current (I), with weld bead time. Using these models the direct and interaction effects of the process parameters on weld bead time were studied and further the process parameters were optimized. The obtained results of mathematical model helped in selecting quickly the process parameters to achieve the desired quality.

Keywords: Resistance Spot Welding, Taguchi Methodology, Design of Experiments, Process Parameters

I. INTRODUCTION

The resistance spot welding process is generally accepted as the preferred joining technique and is mostly chosen for welding large metal structures such as bridges, automobiles, aircraft and ships due to its joint strength, reliability, and low cost compared to other joining processes[7]. Resistance spot welding is one of the major welding process used in industries like automobile, aircraft industries, railway industries due to its cheaper rates, ease of availability and good deposition rate. Weld strength is one of the most important term in welded joints. The life of the welded joint depends on the weld strength, higher the weld strength higher is the life of the joint. Weld strength also increases the load bearing capacity of the welded joint, less load bearing capacity is the most undesirable property in automobile industries. Pinholes, cracks and porosity are the influential factors for the decrease in weld strength, therefore while welding operation care must be taken to minimize these defects or eliminate it [4]. Inadequate weld bead dimensions such as shallow depth of penetration may contribute to failure of a welded structure since penetration determines the stress carrying capacity of a welded joint. To avoid such occurrences the input or welding process variables which influence the weld bead penetration must therefore be properly selected and optimized to obtain an acceptable weld bead penetration and hence a high quality joint [2].Taguchi proposed that engineering optimization of a process or product should be carried out in a three-step approach: system design, parameter design, and tolerance design. The steps included in the Taguchi parameter design are: selecting the proper orthogonal array (OA) according to the numbers of controllable factors (parameters); running experiments based on the OA; analyzing data; identifying the optimum condition; and conducting confirmation runs with the optimal levels of all the parameters[2].Regression techniques cannot describe adequately the arc welding process as a whole. Mathematical models of the above type, using regression techniques, have limitations, as welding parameters and weldability are highly non-linear[9].GMAW welding process overcome the restriction of using small lengths of electrodes and overcome the inability of the submerged-arc process to weld in various positions. By suitable adjusting the process parameters, it is possible to weld joints in the thickness range of 1-13 mm in all welding position. GMAW (MIG/CO2) is also used in mechanized and automatic forms to eliminate the operator factor and to increase the productivity and consistency of quality [11].

II. METHODS AND MATERIAL

1. Literature Review

After Studying the Literature it can be concluded that a lot of work has been done in the field of process parameter optimization of good quality weld. Aghakhani M. et al. [1] studied proper selection of input welding parameters is necessary in order to obtain a good quality weld and subsequently increase the productivity of the process. In order to obtain a good quality weld, it is therefore, necessary to control the input welding parameters. One of the important welding output parameters in this process is weld dilution affecting the quality and productivity of weldment. Author also use Taguchi's method of design of experiments a mathematical model was developed using parameters such as, wire feed rate (W), welding voltage (V), nozzle-to-plate distance (N), welding speed (S) and gas flow rate (G) on weld dilution. After collecting data, signal-to-noise ratios (S/N) were calculated and used in order to obtain the optimum levels for every input parameter. Finally a mathematical model based on regression analysis for predicting the weld dilution was obtained. author found that Increasing the wire feed rate and the arc voltage increases the weld dilution whereas increasing the nozzle-to-plate distance and the welding speed results in the decrease in weld the dilution Mostafa N.B. et al. [2] describes prediction of weld penetration as influenced by FCAW process parameters of welding current , arc voltage , nozzle-to-plate distance, electrode-to - work angle and welding speed . Optimization of these parameters to maximize weld penetration is also investigated. He also observed that penetration will be maximum when welding current , arc voltage, nozzle-to-plate distance and electrode-to-work angle are at their maximum possible value and welding speed is at its minimum value. In addition to that, author focused on increase in nozzle-to-plate distance (N) also causes an increase in depth of penetration (P) which may be due to higher temperature of the droplets impinging on the weld pool because of more resistance heating of the wire at higher nozzle-to-plate distances. Sapkal S. V. et al. [3] conducted experiment in which an orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of MS C20 material & optimize the welding parameters. Finally the conformations tests have been carried out to compare the predicated values with the experimental values confirm its effectiveness in the analysis of penetration. Shukla B. A, et al. [4] focused on the investigation of CO welding parameters to maximize the weld strength using Response Surface Methodology. Welding current, welding voltage, wire feed rate and gas pressure was taken as input parameters while the response was only weld strength. Central Composite Design was chosen for the experimental design. RSM based model has been developed to determine the weld strength attained by various welding parameters. The quadratic models developed using RSM shows high accuracy and can be used for prediction within the limits of the factors investigated. Jadeja Digvijay V. et al. [5] studied that factorial designs are efficient. Instead of conducting a series of independent studies we are effectively able to combine these studies into one. Finally, factorial designs are the only effective way to examine interaction effects. Naitik S Patel [6] identified in TIG welding process most of welding parameters like welding current, welding speed, depth to width ratio are generally used in research work. Also identify TIG welding carried out on different materials like mild steel , titanium alloy, brass, carbon, stainless steel etc. Dr. K. Lalit Narayan [7] studied optimization of process parameters using Response Surface Methodology. Experiments were conducted based on central composite Face Centered Cubic design and mathematical models were developed correlating the important controllable resistance spot welding process parameters like Voltage (V), Travel speed (S) and welding current (I) with weld bead penetration. author also examine the models direct and interaction effects of the process parameters on weld bead penetration were studied and further the process parameters were optimized. The obtained results help in selecting quickly the process parameters to achieve the desired quality. The optimized values of the various input parameters can be summarized as like Optimum arc voltage. Optimum travel speed. Optimum welding current. Shoeb Md. et al. [8] used welding parameters such as welding speed, voltage and gas flow rate were varied on HSLA steel and the effects of these parameters on weld bead geometry such as penetration, width & height have been studied. Mathematical equations have been developed using factorial technique. Pal amit [10] found that input parameters in MIG welding play a significant role in deciding the weld quality, strength, cost and speed. and effect of different welding parameters like welding voltage, filler wire rate and v-butt angle on the strength of the weld joint and elongation produced during the tensile test. These all parameters have different effect on welding quality. In order to optimize these parameters for better weld quality Taguchi Orthogonal array has been used. The medium carbon steel slabs have been used as welding material. The ANOVA is also employed to predict the percentage effect of each parameter on results. Singla manoj et al. [11] experimentally studied optimization of various Gas Metal Arc welding parameters including welding voltage, welding current, welding speed and nozzle to plate distance (NPD) by developing a mathematical model for sound weld deposit area of a mild steel specimen. Factorial design approach has been applied for finding the relationship between the various process parameters and weld deposit area. The study revealed that the welding voltage and NPD varies directly with weld deposit area and inverse relationship is found between welding current and speed with weld deposit area. He also concluded that For a constant heat input, welds made using electrode negative polarity (DCEN), a small diameter electrode, long electrode extension, low voltage and low welding speed produce large bead area.

2. Methodology

A Scientific approach to plan the experiments is a necessary for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analyse by statistical methods resulting in valid and objective conclusion. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus there are two aspect of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed. Taguchi is a comprehensive system of quality engineering. This method substantially focuses on the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and remain cost-effective, and robust design for large –scale production and market place. Shop-floor techniques provide cost based real time methods for monitoring and maintaining quality in production.

The first step in solving such a complex problem is the design of experiment and the second is analyze the taguchi design.

TABLE I

RESISTANCE SPOT WELDING PARAMETERS

Serial No.	Parameter	Unit
1	Welding Current	Ampere
2	Welding Voltage	Volt
3	Wire Diameter	mm

These parameters has a drastic impact on the weld time but optimize setting of these parameters results in the required weld time depth obtaining which is very difficult and hence statistical and experimental way to resolve the problem is considered. The DOE process is divided into three main phases which encompass all experimentation approaches. The three phases are: 1. Planning Phase 2. The conducting phase 3. The analysis phase.

The planning phase is by far the most important phase for the experiment to provide the expected information. An experimenter learns something from any experiment; sometime the information is in positive sense and sometime in negative sense. Positive information is an indication of which factor and which level lead to improved product or process performance. Negative information is an indication of which factors doesn't lead to an improvement, but no indication of which factors do. If the experiment includes the real, yet unknown, influential factors and appropriate levels, the experiment will tends to yield positive information. If the experiment does not include the real influential factors, the experiment will yield negative information. The planning phase is when factors and levels are selected and, therefore is the most important stage of experimentation. Also, the correct selection of factors and levels is dependent upon product and process expertise. The second most important phase is the conducting phase, when test results are actually collected. If experiments are well planned and conducted, the analysis is actually much easier and more likely to yield positive information about factors and levels. The analysis phase is when the positive or negative information concerning the selected factors and levels is generated based on the previous two phases. The analysis phase is least important in terms of whether the experiment will successfully yield positive results. This phase, however, is the most statistical in nature of three phases of DOE by a wide margin. Because of the heavier involvement of statistics, the analysis phase is typically the least understood by the product or process expert. Taguchi recommends orthogonal array (OA) for lying out of experiments. To design an experiment is to select the most suitable OA and to assign the parameters and interaction of interest to the appropriate columns. The use of linear graph and triangular table suggested by Taguchi's makes the assignment of parameters simple. The array forces all experiments to design almost identical experiments. In the present investigation, the raw data analysis and S/N data analysis have been performed. The effects of the selected resistance spot welding process parameters on the selected quality characteristics have been investigated through the plots of the main effects based on data. The optimum condition for each of the quality characteristics has been established through S/N data analysis aided by the data analysis. No outer array has been used and instead, the experiments have been repeated.

TABLE II

EXPERIMENTAL VALUES AND S/N RATIO

S. N.	Welding Current	Welding Voltage	Wire Diameter	Welding time	S/N Ratio
1	180	12	5	1.2	-
2	180	13	6	1.8	-
3	180	14	7	2.4	-
4	190	12	6	1.6	-
5	190	13	7	1.9	-
6	190	14	5	1.8	-
7	200	12	7	1.7	-
8	200	13	5	1.9	-
9	200	14	6	2.3	-

Table II shows the values for the various process parameters selected for study and the possible arrays obtained through the design of experiments. The value of the weld time is obtained through the 25 experiments and accordingly S/N ratio is calculated. The *S/N* ratio, as stated earlier, is a concurrent statistic. A concurrent statistics is able to look at two characteristics of a distribution and roll these characteristics into a single number or figure of merits. The *S/N* ratio combines both the parameters (the mean level of the quality characteristics and variance around this mean) into a single metric. The *S/N* ratio consolidates several repetition into one value. The equation for calculating *S/N* ratios for 'smaller is better' (SB) is as follows,

$(S/N)\ SB = -10 \log (MSDSB)$ …. (I)

Where, $MSDHB = (1/R)\ \Sigma\ (y^2 j)$

TABLE III

RESPONSE TABLE FOR MEANS

Level	Current	Voltage	Wire Diameter
1	-4.76443	-3.4200	-4.08805
2	-4.92097	-5.4185	-5.47414
3	-5.80620	-6.64808	-5.92943
Delta	1.04177	3.22308	1.84138
Rank	3	1	2

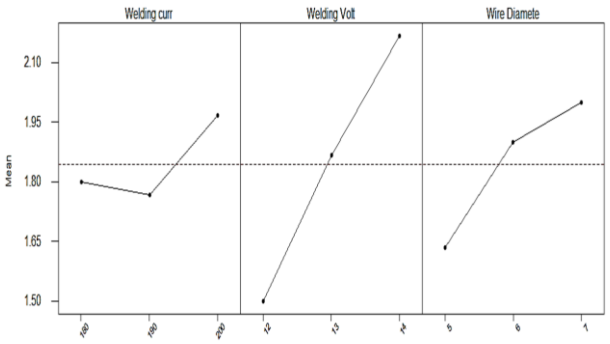
Table III shows that the voltage proves to be most significant for weld time followed by wire diameter and then current.

Table IV

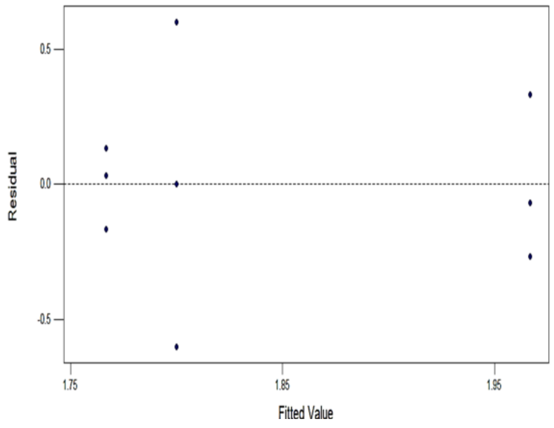
REGRESSION ANALYSIS

Control factors	DOF	Sum of Squares	Mean Square	F	P
Welding Current	2	0.069	0.034	0.22	0.811
Welding Voltage	2	0.6689	0.3344	5.68	0.041
Wire Diameter	2	0.216	0.108	0.80	0.491
Error	6	0.3533	0.0589		

S = 0.1808 R-Sq = 86.2% R-Sq(adj) = 83.4%



Graph 1: Main Effect Plot for S/N Ratio



Graph 2: Residuals verses fitted values

Graph 2 shows the residuals versus the fitted values which are fairly positive and negative alternately and scattered randomly about zero. Graph shows the order of the data it is also fairly positive and negative alternately. For the response, the residuals appear to be randomly scattered about zero.

III. RESULTS AND DISCUSSION

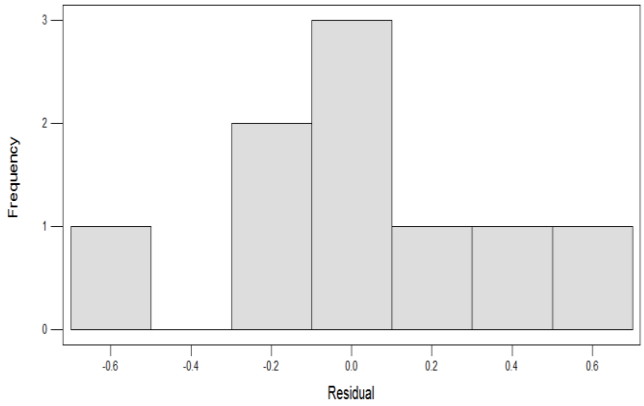
Table V shows the results of analysis of variance (ANOVA) for the S/N ratio of the surface roughness. The ANOVA shows the significance of various factors and their interactions at 95 % confidence level. ANOVA shows the "model" as "significant" which are desirable from a model point of view. The probability values < 0.05 in the "P<F" column indicates the significant factors and interactions.

TABLE V

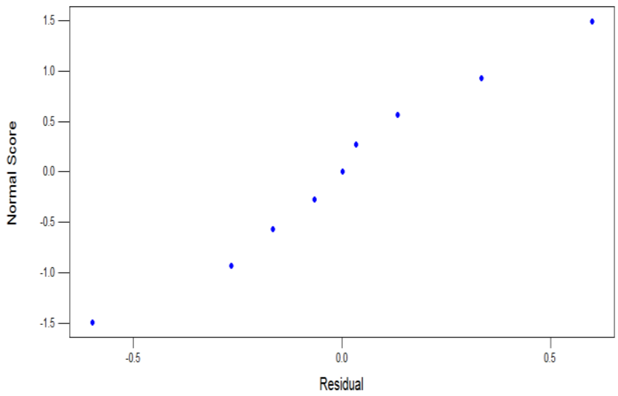
OPTIMAL VALUES OF PROCESS PARAMETER

Sr. No.	Parameter	Value
1	Welding Current	200
2	Welding Voltage	14
3	Wire Diameter	7

Graph 3 shows Histogram of the residuals showing the influence of various process parameters on response (Welding time) obtained in the skewed zone is presented.



Graph 3: Histogram of the Residuals



Graph 4: Normal Probability Plot of the Residuals

Graph 4 shows the normal probability plot of the residuals, it is a linear graph. For the response, the residuals appear to follow a straight line.

The mathematical relationship established for correlating the thickness and the machining parameters. The thickness model so generated is given below. The regression equation is;

Welding Time (Wt) = - 5.17 + 0.00833 Welding current + 0.333 Welding Voltage + 0.183 Wire Diameter

This mathematical model can be implemented for successful prediction of the weld time values and its impact on the weld quality and surface to be welded.

IV. CONCLUSION

Taguchi optimization method was applied to find the optimal process parameters for penetration. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

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