A Comparative Investigation to Process Parameter Optimization for Spot Welding Using Taguchi Based Grey Relational Analysis and Metaheuristics

A. K. Pattanaik[1*], S. N. Panda[2], B. P. Mishra[3], K. Pal[4], D. Mishra[5]
[1]Assistant Profesor, Department of Mechanical Engineering, Government College of Engineering, Kalahandi, Odisha, India. Email: ajitpuce@gmail.com .
[2,3]Research Scholar, Production Engineering Department, Veer Surendra Sai University of Technology, Burla, Odisha, India. Email: [2]suryanarayan.uce@gmail.com, [3]bishnudugu@gmail.com
[4,5]Professor, Production Engineering Department, Veer Surendra Sai University of Technology, Burla, Odisha, India.
*Corresponding Author

Abstract: The present work investigate on parametric study and optimization of process parameter in resistance spot weld efficiency of chromate micro-alloyed cold rolled mild steel sheets using L_{25} Taguchi design of experiments. The output responses are being studied as tensile shear strength of the weldment and nugget diameter which is affected by the input variables like weld current, electrode force and weld time. Both output responses were optimized to achieve effective values by using conventional Taguchi based Grey Relational Analysis and a Metaheuristics method as Genetic Algorithm. Here in present work two main goals specifically tensile shear strength and nugget diameter simultaneously optimized using multiobjective genetic algorithm. The analytical results were validated with experimental run so to analyse the efficiency of methods.

Keywords: Genetic algorithm, Grey relational analysis, Orthogonal array.

I. Introduction

Spot welding is kind of the adaptable resistance welding forms. The spot welding procedure is utilized to join sheet materials using copper cathode with applied force and pass the current through the work pieces. In resistance welding, the components are locally heated. The material between the anodes yields, the current is then switched off and the "nugget" of liquid materials cements shaping the joint. The material has a higher electrical resistivity and lower thermal conductivity than the electrode utilized is reasonable to pick such as steel making welding moderately simple. it is generally utilized joining process for creating sheet metal congregations like in automobiles, truck lodges and home applications because of its focal points in welding productivity and appropriateness for mechanization.

In contemporary days many researchers have done works on failure mechanisms for one of a kind style of spot weldment and its modelling. Chao [1] dealt with disappointment component of resistance spot welding subjected to tensile, shear or combination of tensile \ shear and found that the shear failure is in light of established Von-Mises failure conception but however at the same time spot weld in a lap-shear scan pattern is subjected to a global shear load the failure system of the weld at the microstructure degree is actually tensile. In contrast, while the spot weld in a cross tension pattern is deal with normal load. The failure system of the weld is governed by shear. Ferrasse *et al.* [2] analysed the failure performance of spot welds experimentally and numerically for weldment of material like TRIP980 (Transformation induced plasticity steel) sheets. Dancette *et al.* [3] explored on demonstrating of failure method of laser welds in lap-shear example of HSLA steel sheets. He demonstrated that the laser welds failed in a ductile necking / shear failure form and the ductile failure was started at separation far from the crack tip close to limit of the base metal and warmth influenced zone. Liang *et al.* [4] took a investigation to quality forecast of sheet tube. In his work, the failure execution of spot welds has been tentatively and numerically analyzed for welds in TRIP980 sheet utilizing inverse technique in view of the standard and smaller than usual tensile tests alongside the lap-shear tests. Wang *et al.* [5] directed tests to look at the fatigue qualities of resistance spot welds and laser welds under lap-shear stacking. However, limited researches are available for analysis of spot weldment output responses and how it can be modelled for input parameters.

In this research investigation to design effective output responses with variable input parameters has been studied. A new response as nugget diameter has been studied as it also describe parallely the ultimate tensile shear strength of weldment [1]. Analysis is done experimentally by spot welding of chromate micro-alloyed cold rolled mild steel sheets and analytically by taguchi based grey relational analysis and a evolution based metaheuristic method, multiobjective Genetic Algorithm [6]. L_{25} orthogonal array is used for design of experiments with three factors and five levels.

II. Experimental Methodology

The experiments were carried out using resistance spot welding machine 120 kVA capacity, a timer, current controller and a pneumatic mechanism integrated lever for welding of 1.2 mm thick galvanized low carbon cold rolled mild steel sheets (AISI 1008). The series of experiments have been executed to study the effect of various welding aid criterion on welding process. Various input parameters selected to investigate the tensile shear strength and nugget diameter using copper electrode. The standard specification were maintained for process as for work piece materials is 1.2 mm thick and diameter of the electrode tip is 8 mm respectively. The control parameters taken as welding current, electrode force and weld time in five different levels (Table I), whereas the impact of these, studied on response characteristics as tensile shear strength value and nugget diameter.

A. Taguchi Based Grey Relational Analysis

Taguchi introduces techniques to enhance the way toward designing experimentation. He established that the most ideal approach to improve quality was to outline and incorporate it with the item. Taguchi saw quality enhancement as a continuous exertion. He ceaselessly strived to decrease the variety around the objective esteem. initial move towards enhancing quality is to accomplish the population distribution as near to the objective esteem as would be prudent. The taguchi technique includes decreasing the variety in a procedure through vigorous plan of examinations.

The design of examination is a viable instrument to plan and direct the trials with least assets. Orthogonal Array is a measurable technique for characterizing parameters into factors and levels. Here, L_{25} Orthogonal Array plan lattice is utilized to set the control parameters to assess welding execution.

The experiments were done for welding process for each blend of parameters treated by Orthogonal Array. Tensile tests were performed by a universal testing machine (INSTRON 3382) to investigate tensile shear strength, mean time the nugget diameter were noted.

The Grey framework gives multidisciplinary ways to deal with examination and unique demonstrating of system for which the data is constrained, fragmented and described by arbitrary vulnerability. Grey relational analysis investigates all impact of various factors and and their connection, which is established as whitening of factor relation. It utilize the data from the Grey framework to progressively look at every factors quantitatively, in view of the level of comparability and changeability among variables to set up their relation. GRA analyzes the social review for discrete sequences.

Information pre-preparing is regularly required, since the range and unit in one information succession may vary from others. It is likewise vital when the succession diffuse range is too vast, or when the headings of the objective in the groupings are distinctive. In this study, a linear normalization of the experimental outcomes for Tensile shear strength and nugget diameter were performed in scope somewhere around zero and one, called as the grey relational generation.

The normalized output parameter relating to the larger-the-better criterion can be formulated as (Eqn. 1),

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1, 2...n)}{\max(y_{ij}, i = 1, 2...n) - \min(y_{ij}, i = 1, 2...n)} \quad (1)$$

The grey relational coefficient is ascertained to express the relationship between the best and real standardized trial comes about. Sooner the deviation sequence for the reference and comparability sequence were discovered. The grey relational grade was resolved by balancing the grey relational coefficient corresponding to each performance characteristic. In the grey relational analysis, the grey relational grade is used to show the relationship among the sequences.

B. Genetic Algorithm

Without worldwide streamlining devices, specialists and analysts are regularly compelled to settle for practical arrangements, frequently ignoring the ideal qualities. In useful terms, this suggests substandard outlines and operations, and related costs as far as unwavering quality, time, cash and different sources. The evolutionary approach depicts the explanation for the upon said issues. The target of worldwide improvement is to locate the best possible solution in decision models that as often as possible have a number of local solutions. The genetic algorithm tackles optimization problems by simulating the principles of biological evolution, repeatedly modifying a population of individual points utilizing rules formed on gene combinations in biological reproduction. Because of its arbitrary nature, the genetic algorithm enhances the odds of locating a global solution. Thus it turn out to be exceptionally productive and stable in for hunting of global optimum solutions. The mathematical model that best describes the relationship between Input and output parameters has to be developed in order to be used as objective function in GA to aid the global optimization.

Flow diagram as shown (Fig. 1). There are six steps in GA and are Problem representation, Initialization of population, Evaluation of fitness function, Constraint handling, Generation of new population, Stopping / termination criteria.

III. Analysis of Experiments

The examinations were directed in view of differing the process parameters, which influence the welding process to get the required quality attributes. Quality attributes are the response values or yield values expected out of the tests.

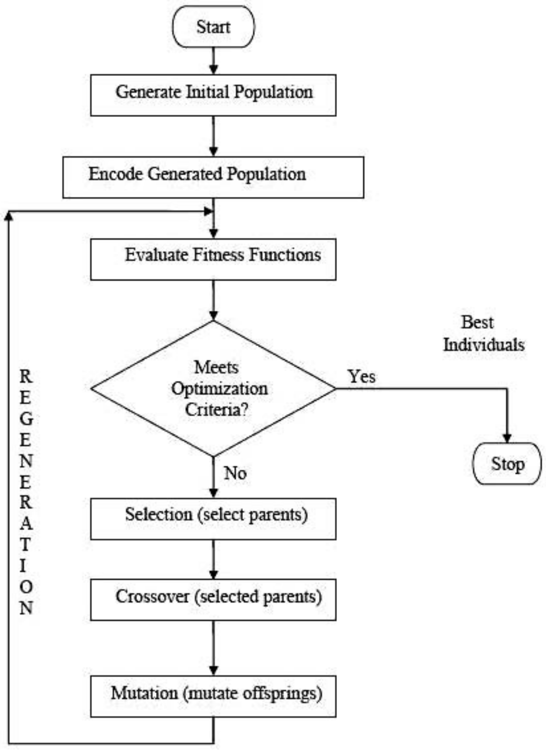

Fig. 1: Flow Chart of Genetic Algorithm

Table I: Levels of Process Parameters

Process parameters	Units	Level 1	Level 2	Level 3	Level 4	Level 5
Welding current	KA	1	1.5	2	2.5	3
Electrode force	KN	3	3.5	4	4.5	5
Welding time	Cycle	5	10	15	20	25

As the objective is to obtain the high tensile shear strength and high nugget diameter, the required quality characteristic for high tensile strength and larger nugget diameter is larger the better. Experiments were conducted as per L_{25} orthogonal array, assigning various values of the levels to the process parameters and the results found (Table II & III). The representation of S/N Ratio values from the original response values was the introductory step. For that the equations of "larger the better" is used.

$$s / n_{HB} = -10 \log_{10}\left[\left(\frac{1}{n}\right)\left(\sum \frac{1}{y_{ij}^2}\right)\right] \quad (2)$$

Grey relational coefficient (Eqn. 3) is figured to dictate the accordance between the best and actual normalized trial outcome. Prior to that the deviation sequence for the reference and comparability sequence were determined.

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \quad (3)$$

Where, $\Delta_{0i}(k)$ is the deviation sequence for the reference sequence and comparability sequence,

$$\Delta_{0i}(k)\left\|y_0(k) - y_i(k)\right\| \quad (4)$$

$$D_{\min} = \min_{\forall j \in i} \min_{\forall k} \left\|y_0(k) - y_j(k)\right\| \quad (5)$$

$$D_{\max} = \max_{\forall j \in i} \max_{\forall k} \left\|y_0(k) - y_j(k)\right\| \quad (6)$$

$y_0(k)$ and $y_j(k)$ denotes sequence and comparability sequence respectively. ζ is distinguishing or identified coefficient generally taken as 0.5. The grey relational grade was determined by equating the grey relational coefficient relating to each performance characteristic (Eqn. 7).

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\zeta_i(\mathrm{k}) \quad (7)$$

Table II: Normalised Signal-to-Noise Ratios

Run/ Expt No	Welding current (KA)	Electrode force (KN)	Welding time(cycle)	Tensile strength(KN)	Nugget diameter(mm)	Normalized S/N ratio	
						Tensile Strength	Nugget Diameter
1	1	3	5	12.25	3	0.093	0
2	1.5	3	10	12.29	3.2	0.108	0.181
3	2	3	15	12	3	0	0
4	2.5	3	20	12.39	3.2	0.145	0.181
5	3	3	25	12.35	3.2	0.13	0.181
6	1	3.5	10	12.9	3.5	0.335	0.454
7	1.5	3.5	15	12.4	3.5	0.149	0.454
8	2	3.5	20	13.3	3.9	0.485	0.818
9	2.5	3.5	25	13.26	3.1	0.47	0.09
10	3	3.5	5	13.5	3.2	0.559	0.181
11	1	4	15	13.9	3.6	0.708	0.545
12	1.5	4	20	13.4	3.2	0.522	0.181

13	2	4	25	13.35	3	0.503	0
14	2.5	4	5	13.86	3.1	0.694	0.09
15	3	4	10	14.2	4	0.82	1
16	1	4.5	20	14.68	3.8	1	0.727
17	1.5	4.5	25	14.62	4	0.977	0.909
18	2	4.5	5	12.25	3.2	0.093	0.181
19	2.5	4.5	10	12	3	0	0
20	3	4.5	15	14.6	3.5	0.97	0.454
21	1	5	25	14.32	3.6	0.865	0.545
22	1.5	5	5	13.36	3.2	0.507	0.181
23	2	5	10	13.48	3.2	0.552	0.181
24	2.5	5	15	12.36	3	0.134	0
25	3	5	20	12.82	3	0.305	0

Table III: Grey Relational Grade and Rank

Run/ Expt No	Deviation Sequence		Grey Relational Coefficient		Grey Relational Grade	Rank
	Tensile Strength	Nugget Diameter	Tensile Strength	Nugget Diameter		
1	0.907	1	0.355	0.333	0.344	22
2	0.892	0.819	0.359	0.379	0.369	19
3	1	1	0.333	0.333	0.333	23
4	0.855	0.819	0.369	0.379	0.374	17
5	0.87	0.819	0.364	0.379	0.371	18
6	0.665	0.546	0.429	0.478	0.453	11
7	0.851	0.546	0.37	0.478	0.424	13
8	0.515	0.182	0.492	0.733	0.612	8
9	0.53	0.91	0.485	0.354	0.419	14
10	0.441	0.819	0.531	0.379	0.455	10
11	0.2	0.455	0.714	0.523	0.618	7
12	0.292	0.819	0.631	0.379	0.505	9
13	0.497	1	0.501	0.333	0.417	15
14	0.306	0.91	0	0.354	0.177	25
15	0.18	0	0.62	1	0.81	4
16	0	0.273	1	0.646	0.823	3
17	0.023	0.091	0.956	0.846	0.901	1
18	0.907	0.819	0.355	0.379	0.367	20
19	1	1	0.333	0.333	0.333	24
20	0.03	0.546	0.943	0.478	0.71	5
21	0.135	0.455	0.787	0.523	0.655	6
22	0.493	0.819	0.503	0.379	0.882	2
23	0.448	0.819	0.527	0.379	0.453	12
24	0.866	1	0.366	0.333	0.349	21
25	0.695	1	0.418	0.333	0.375	16

IV. Results and Conclusion

A. Development of Mathematical Models Using RSM

Response Surface Methodology (RSM) is a blend of numerical and measurable approaches valuable for assessing issues in which various autonomous factors influence a response. In the reasonable use of RSM, it is significant to upgrade an approximating mannequin for the correct response surface. The approximating model is centered on observed information from the approach or approach and is an empirical model. A couple of regression evaluation is a collection of statistical methods priceless for constructing such varieties of empirical items required in RSM. Generally, a polynomial of second order is used in RSM (Eqn. 8), where parameters a_0, a_j, a_{jj}, a_{ij} = 0, 1,..k are called the regression coefficients.

$$Y = a_0 + \sum_{j=1}^{k} a_j x_j + \sum_{j=1}^{k} a_{jj} x_j^2 + \sum_{1<j} \sum_{j=2}^{k} a_{ij} x_i x_j \quad (8)$$

Different design proficient statistical software package used for the evaluation of measured responses and picking the mathematical items with quality fit. The final mathematical items consequently bought are shown beneath.

$$\text{Tensile Strength} = 9.732 - 5.628 * WC + 2.151 * EF + 0.491 * WT + 1.151 * WC^2 - 0.242*EF^2 + 0.006*WT^2 + 0.657 * WC * EF - 0.089 * EF * WT - 0.130 * WT * WC \quad (9)$$

$$\text{Nugget Diameter} = -1.372 - 0.341 * WC + 2.188 * EF + 0.1086 * WT + 0.235 * WC^2 - 0.231 * EF^2 - 0.002 * WT^2 - 0.128*WC*EF - 0.005 * EF * WT - 0.014 * WT * WC \quad (10)$$

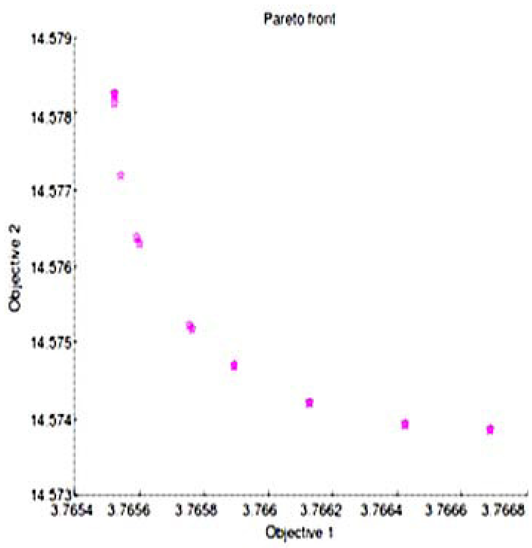

Fig. 2: Results of Genetic Algorithm

This multi-objective criterion has been solved using Taguchi method combined with Grey relation analysis and genetic algorithm for improvement issue in the field of resistance spot welding process. It is found that the largest grey relational grade, indicating the initial process parameter set of $A_2B_4C_5$ for the best multiple performance qualities among the tests. The confirmation test for Taguchi Method and genetic algorithm at the optimized process parameter levels was done and the tensile shear strength and nugget diameter were found as tabulated below.

Table III: Optimized Parameter Values

S.No.	Process Parameters	Taguchi Method	Genetic Algorithm
1	Welding current (KA)	1.5	1.823
2	Electrode force (KN)	4.5	4.512
3	Welding time (cycle)	25	24.891

Table IV: Confirmation Test

S.No.	Confirmation test	Taguchi Method	Genetic Algorithm
1	Tensile shear strength (kN)	14.13	14.574
2	Nugget diameter (mm)	3.68	3.766

From the confirmation results, it was discovered that in assessment with Taguchi approach, the genetic algorithm offers higher-optimized answer for the reward study because the element produced at the situation of confirmation test of genetic algorithm yielded better tensile shear force and nugget diameter. The optimal process parameters levels for obtaining maximum tensile shear strength was carried out using Taguchi method and Genetic algorithm approaches and the final solutions were compared. It was observed that the Genetic algorithm yielded better optimized solutions for the present research. Further, it was found that welding current was the most significant parameter of the spot welding process with the contribution to the enhancement of tensile shear strength and nugget diameter. Thus welding current can possibly assume an imperative part sooner rather than later to improve the nature of spot weldments.

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