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Optimisation of Welding Parameters for Mild Steel using Taguchi-Grey Relation Analysis

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Abstract: Welding is one of the most popular methods of metal joining processes. The joining of the materials by welding provides a permanent joint of the components. The present work deals with the optimisation of welding parameters to study and analyse the effects of welding parameters: welding current, voltage, welding speed, flow rate, Ultimate Tensile Strength (UTS) and Yield Strength (YS) in welding of mild steels were optimized using arc welding with the help of design of experiments (DOE). The approach is based on Taguchi method using MINITAB package. Moreover, optimized values of welding process parameters to achieve desired mechanical properties were evaluated using Grey relational analysis and Taguchi method.
Keywords: Taguchi Method, Grey Relational Analysis, DOE, ANOVA, Welding, Ultimate Tensile Strength

I. INTRODUCTION

A. Welding

Arc welding is a method of joining metals accomplished by applying sufficient electrical pressure to an electrode to maintain a current path (arc) between the electrode and the work piece. In arc welding the heat source is an electric arc, which is formed either between a non-consumable electrode or a consumable electrode and the workpiece. An alternating current (AC) or direct current (DC) power supply is connected to an electrode and to the workpiece; an arc is struck between electrode and work, melting the work to make the joint. A consumable electrode, if used, will also melt and add filler metal to the weld pool. If a tungsten electrode is used, its melting point is so high (about 3200° C) that it does not melt appreciably – a 'non-consumable electrode'. The joint may be formed by melting only the parent material – 'autogenous welding' – or from a 'filler rod' melted into the joint. In the present work following tests are carried out to test the welded joints.

B. Tensile Test

Ultimate Tensile Strength (UTS), often shortened to Tensile Strength (TS), is the capacity of a material or a structure to withstand loads tending to elongate, as opposed to compressive strength which withstands loads tending to reduce size. In other words, tensile strength resists tension (being pulled apart), whereas compressive strength resists compression (being pushed together). Ultimate Tensile Strength is measured by the maximum stress that a material can withstand while being stretched or pulled before breaking. In the study of tensile strength of the weld was analyzed.

C. Bending Test

Universal testing machines were used to determine bending strength of welded work pieces. Three point bending tests are carried out using UTM.

D. Impact Test

Charpy tester is used to determine the impact strength of the specimen. This Impact Testing Machine works on pendulum principle. In this test, the difference between the height of drop of the pendulum before rupture of material and the height of the rise after rupture of the specimen is directly proportionate to the impact energy absorbed by the specimen is directly indicated by the moving pointer.

E. Hardness Test

Brenell hardness methods are commonly used to determine the hardness of the weld pool material. Brinell hardness testing machine uses a predetermined load and a carbide ball of particular diameter which is forced on to the specimen and indentation was made and observed under microscope to observe the indentation.

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II. LITERATURE REVIEW

GopalKrushnaMohanta, Ajit Kumar Senapati [1] Reported the effect of Welding Parameters on Mild Steel by MMAW and studied the welding parameters on the weld ability of mild steel which is welded by Metal arc welding, butt joints. Current and voltage are chosen as welding parameters.

ArunkumarSivaraman,SathiyaPaulraj[2] studied the Multi-Response Optimization of Process Parameters for MIG Welding of AA2219-T87 by Taguchi Grey Relational Analysis. They focuced on the optimization of process parameters for MIG welding of the material AA219-T87 using Taguchi based grey relational analysis.

Vara Prasad Vemu , Pramila Devi Maganti [3] reported Experimental study of mild steel weld bead mechanical properties in rotational arc welding process. They selected mild steel pieces of 6 mm thickness, and welded by conventional metal arc welding by means of the filler metal ER70S-6 and inert gas is carbon dioxide.

Abishekprakesh et al. [4] did work on Parametric optimisation of metal inert gas welding by taguchi approach. They have done optimisation of welding process variables . The design of experiments based on taguchi orthogonal array L9 acquires analysis of variance (ANOVA) to determine the influence of parameters with optimal conditions.

Iqbaljeet Singh Grewalet al.[5] researched the mechanical properties such as tensile strength and impact toughness of the weld joints are evaluated using taguchi method using(welding current, gas flow rate and filler material) as three input parameters each having three levels each(low, medium and high).

Monika, Jagdip Chauhan[6] studied gas metal arc welding (GMAW) of mild steel 1018by using taguchi technique. They reported effect of different process parameters such as welding current, voltage, gas flow rate, welding speed and gas pressure on mechanical properties like tensile strength and percentage of elongation of GMAW welded joints of MS 1018 plates.

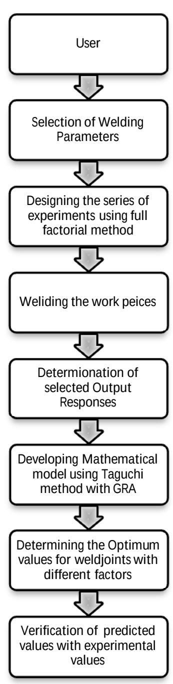
NabenduGhosh et al[7] Reported Parametric Optimization of MIG Welding on 316L Austenitic Stainless Steel by Grey-Based Taguchi Method. Their studies includes visual inspection and X-ray radiographic test in order to detect surface and sub-surface defects of weld specimens made of AISI 316L austenitic stainless steels.

Dinesh Mohan Arya, VedanshChaturvedi et al. [8] studied to investigate the optimization process parameters for Metal Inert Gas welding (MIG). The influence of welding parameters like wire diameter, welding current, arc voltage welding speed, and gas flow rate optimization based on bead geometry of welding joint are reported.

III.DESIGN OF EXPERIMENTS

Methodology, selection of material, Design of experiments. It also shows the step by step procedure to obtain Taguchi DOE and GRA.

A. Methodology



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B. Selection of Material

Mild steel is a type of carbon steel with a low amount of carbon – it is actually also known as "low carbon steel." Although ranges vary depending on the source, the amount of carbon typically found in mild steel is 0.05% to 0.25% by weight, whereas higher carbon steels are typically described as having a carbon content from 0.30% to 2.0%.

C. Design of experiments (DOE)

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product's manufacturability, reliability, quality, and field performance. Designed experiments are often called out in four phases : planning, screening, optimization and verification.

D. Taguchi Method

The Taguchi method contains system design, parameter design, and tolerance design procedures to achieve a robust process and result for the best product quality. The main trust of Taguchi's techniques is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi has used Signal-Noise (S/N) ratio as the quality characteristic of choice. S/N ratio is used as measurable value instead of standard deviation due to the fact that, as the mean decreases, the standard deviation also decreases and vice versa.

The S/N ratios can be computed for the three quality characterstics by using the following equations:

For Higher the Better,

$$\left(\frac{S}{N}\right)_{HTB} = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

For Nominal the Best,

$$\left(\frac{S}{N}\right)_{NTB} = 10 * \log_{10}\left(\frac{\overline{y}^2}{s^2}\right)$$

For Smaller the Better,

$$\left(\frac{S}{N}\right)_{STB} = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

E. Grey Relational Analysis

Data pre-processing is performed to normalize the original reference sequences to a comparable sequence within the range of zero to one. This approach of pre-processing data by normalization, into a group of sequences, is termed grey relational generation. In order to pre-process data using GRA, the response of the transformed sequences can be grouped into two quality characteristics, namely, larger-the-better or smaller-the-better. For smaller-the-better characteristic, the sequence can be normalized using:

$$x_i^*(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

where xi*(k) denotes the reference sequence after pre-processing for the ithexperiment yi(k) represents the initial sequence of the mean of the responses.

Once the sequence is normalized, the next step is to calculate the deviation sequence of the reference sequence using :

$$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)|$$

where Δ0i(k), x*0(k) and x*i(k) refer to the deviation, reference and comparability sequences respectively. The grey relational coefficient (GRC) is then determined using :

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

where, ξi(k) signifies the GRC of individual response variables computed as a function of Δmin and Δmax, the minimum and maximum deviations of each response variable. The distinguishing or identification coefficient represented by ζ, defined in the range ζ∈[0,1], is generally set at 0.5 to allocate equal weights to every parameter. As shown in Equation(9),a composite grey relational grade (GRG), is then computed by averaging the GRC of each response variable:

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n} \xi_i(k)$$

whereγi represents the value of GRG determined for the ith experiment, n being the aggregate count of performance characteristics. Once the optimal level of the factors determined using, the final step is to predict and verify the quality characteristics using:

$$\gamma_{predicted} = \gamma_m + \sum_{i=1}^{q} \gamma_o - \gamma_m$$

Where γo denotes the maximum of average GRG at the optimal level of factors and γm represents the mean GRG. The quantity q indicates the number of factors affecting response values.

IV.RESULTS

By using the three different factors that is current, voltage and electrode diameter, we conduct the experiment in 9 different conditions. And conduct tensile test, impact test, bending test and hardness test for getting the optimum values, the results of these tests are given in the below table.

TABLE I
Experimental Results of Tensile test, Bend Test, Hardness and Impact test

Run	Current	Voltage	Electrode Dia	T(n/mm2)	B(n/mm2)	DPH	K(n/m)
1	75	20	2.50	336.84	2596	231.75	2.080
2	75	24	3.15	389.47	2714	230059	1.880
3	75	28	4.00	268.42	2950	403.88	2.130
4	90	20	3.15	352.63	2714	231.75	2.040
5	90	24	4.00	215.78	2832	230.59	1.955
6	90	28	2.50	389.47	2478	228.31	1.866
7	120	20	4.00	284.20	2596	393.42	2.080
8	120	24	2.50	352.63	2006	232.91	1.955
9	120	28	3.15	294.73	2478	376.08	1.911

A. *Multi Response Optimization using GRA*

GRA is primarily employed to solve practical problems comprising a limited set of data. It is typically utilized to approximate the behaviour of uncertain systems with no black and white solution. In the grey system, black implies having no information and white signifies having all information.

TABLE II. Reference and Deviation Sequence

	Reference Values				Deviation Sequence			
Run	T(N/mm^2)	B(N/mm^2)	DPH	K(N/mm^2)	T(N/mm^2)	B(N/mm^2)	DPH	K(N/mm^2)
1	0.69699	0.625	0.01959	0.81061	0.30301	0.375	0.9804	0.18939
2	1	0.75	0.01299	0.05303	0	0.25	0.98701	0.94697
3	0.30307	1	1	1	0.69693	0	0	0
4	0.7879	0.75	0.01959	0.65909	0.2121	0.25	0.987041	0.34091
5	0	0.875	0.01299	0.33712	1	0.125	0.98701	0.66288
6	1	.5	0	0	0	0.5	1	1
7	0.39392	0.625	0.94042	0.81061	0.60608	0.375	0.05958	0.18939
8	0.7879	0	0.0262	0.33712	0.2121	1	0.9738	0.66288
9	0.45455	0.5	0.84166	0.17045	0.54545	0.5	0.15834	0.82955
Max	1	1	1	1			Theta	0.25
Min	0	0	0	0				

TABLE III
Rank and Grey Relation Grade

	Grey Relational Coefficient					
Run	T(N/mm2)	B(N/mm2)	DPH	K(N/mm2)	GRG	Rank
1	0.6226563	0.57142857	0.337745	0.725275	0.75236824	5
2	1	0.66666667	0.336244	0.34555	0.78282026	3
3	0.4177349	1	1	1	1.13924497	1
4	0.70214658	0.66666667	0.337745	0.594595	0.76705096	4
5	0.33333333	0.8	0.335486	0.429967	0.63292899	8
6	1	0.5	0.333333	0.333333	0.72222222	6
7	0.45204469	0.571428571	0.893531	0.755275	0.88076058	2
8	0.70214658	0.333333333	0.339259	0.429967	0.60156883	9
9	0.48826087	0.5	0.759484	0.376068	0.704604454	7
Max	0.33333333	1	1	1		
Min	0.33333333	0.333333333	0.333333	0.333333		

B. Analysis of Variance

ANOVA was used to determine the design parameters significantly influencing the Tensile strength, impact strength, Bending strength and hardness (responses). Analysis of variance (ANOVA) results of all considered strengths were shown in Table IV. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table IV shows the percentage of contribution of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained, that Electrode Diameter was the most significant parameter having the highest statistical contribution (45.78%) on the output responses followed by Current (19.65%) and Voltage (17.39%). Contribution for each source parameter is calculated as follows; % $Contribution$= ($SeqSSofeachparameter/Totalofeachparameter$) ×100

TABLE IV
Analysis of Variance for S/N ratios

Factors	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution %
Current	2	7.212	7.212	3.606	1.18	0.459	19.651
Voltage	2	6.567	60567	3.284	1.07	0.482	17.39
Electrode Dia	2	16.804	16.804	8.402	2.75	0.267	45.78
Residual Error	2	60117	6.117	3.059			
Total	8	36.700					

V. PREDICTING S/N RATIO AT THE OPTIMUM PARAMETERS

Optimum level for each factor (current, voltage and electrode diameter) was obtained from Main effects plot shown Fig-4.1. Optimum parameters obtained are listed in Table V.

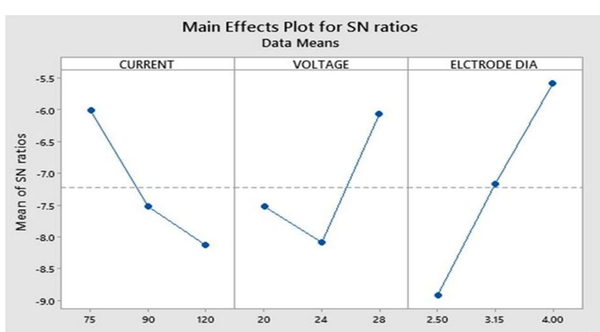

Fig. 4.1 Optimum parameters

TABLE V
Optimum parameters based on main effects plot

S.No	Factor	Level	Value of corresponding optimum level	Mean of S/N dB
1	Current	1	75A	-6.007
2	Voltage	3	28V	-6.061
3	Electrode Dia	3	4.00mm	-5.580

Predicted S/N Ratio equation is given by

$$S/N_{predict} = S/N_{Total\ Mean} + \sum_{i=1}^{n}\left(S/N_{mean\_Opt\_Factor} - S/N_{Total\ Mean}\right)$$

VI. CONFIRMATION TEST

The confirmation experiment is very important in parameter design. The purpose of the confirmation experiment in the present work was to validate the optimum factors C1V3D3.The average of three experimental results of the confirmation experiment was listed Table VI.

TABLE VI. Results of Confirmation Experiment

Current in N	Voltage in V	Electrode Dia in mm	Experimental S/N Ratio in dB	Predicted S/N Ratio in dB	% of error
75	28	4.00	-3.137	-3.208	7

VII. CONCLUSIONS

This study has presented the application of Taguchi method along with Grey relation analysis for maximizing different output responses. The following conclusions can be drawn from the experimental and predicted results.

A. Optimum parameters for maximizing Tensile strength, Impact strength, Bending strength and Hardness of the welded joint were obtained i.e Current 75A, Voltage 28V, Electrode diameter 4.00mm.
B. ANOVA results for achieving the maximum strengths were, Electrode diameter has high contribution with 45.78% followed by Current with 19.651% and Voltage with 17.39%.
C. Predicted S/N Ratio of mechanical strengths has been obtained as -3.208dB at optimum parameters.
D. Confirmation experiments for all considered strengths were conducted at optimum parameters and S/N ratio was obtained as 3.137. The predicted values and experimentally measured values are good in agreement with 7% error.

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