International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 02 | February - 2024 SJIF Rating: 8.176 ISSN: 2582-3930

Taguchi Parametric Optimization of Mild Steel Weld-Strength in Arc Welding Process

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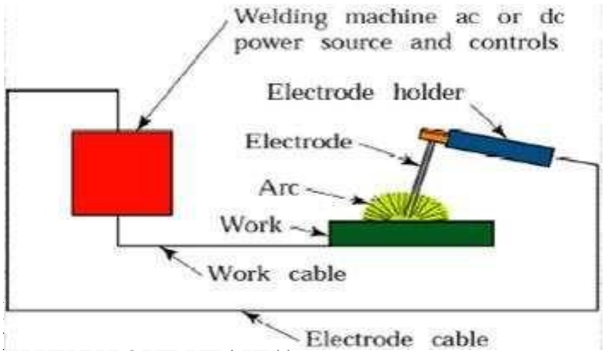
Abstract—In the welding process, the major factors whose selection contributes to the welded product as they all affect the strength and quality of the weld strength to a larger extent are hardness, electrode diameter and weld design (edge preparation). The purpose of this thesis is to efficiently determine the optimum welding operation parameters for achieving the highest breaking strength in the range of parameters. In order to meet the purpose in terms of both efficiency and effectiveness, this study will utilize the Taguchi parameter design methodology. The study includes selection of parameters, utilizing an orthogonal array, conducting experimental runs, data analysis, determining the optimum combination, verification experimentally finally the Modelling of input parameters (Hardness, Diameter of Electrode & Weld Design) and output parameter (Breaking Strength) is done using Taguchi optimization technique.
Key words: Welding Parameters, Electric Arc Welding, Taguchi Method, welding design, hardness.

INTRODUCTION

Electrical arc welding is the procedure used to join two metal parts, taking advantage of the heat developed by the electric arc that forms between an electrode (metal filler) and the material to be welded. The welding arc may be powered by an alternating current generator machine.

Fig. 1: AC or DC welding machine



Nabendu Ghosh et.al. presented the parametric optimization of gas metal arc welding process by using grey based Taguchi method on AISI 409 ferrite stainless steel. In the present work, X-ray radiographic test has been conducted in order to detect surface and sub-surface defects of weld specimens made of Ferrite stainless steel. Results of visual inspection and X-ray radio-graphic tests are compared, some consistency are founds. The best result is obtained for the sample no.9. [1]

Aleem Pasha et.al. have worked on optimization of process parameters of arc welded joint by taguchi. Process parameters were optimized by Taguchi design of experiments. Regression equation has been stated by regression analysis for tensile strength & impact strength to predict the tensile & impact strength for various process parameters. According to the result, mechanical behavior of the MMA welded joint for mild steel was studied by the Taguchi design of experiment and observed that the MMA weld joint exhibited comparable strength with the base material. [2]

Prof. S.D. Ambedkar et.al. have described the Parametric Optimization of Gas metal arc welding process by using Taguchi method on stainless steel AISI 410. The present study is to investigate the influence of welding parameters on the penetration. The optimization for Gas metal arc welding process parameters (GMAW) of Martensitic Stainless steel work piece AISI 410 using Taguchi method is done. Sixteen experimental runs (L16) based on an orthogonal array Taguchi method were performed. This work presents the effect of welding parameters like welding speed, welding current and wire diameter on penetration. The ANOVA and signal to noise ratio (S/N ratio) is applied to identify the most significant factor and predicted optimal parameter setting. An L16 orthogonal array was adopted to conduct the experiment suggested by MINITAB14 Statistical software. [3]

VibhorPadhare et.al. have determined The Significant Factors Affecting the Bending Strength of Weld Joint Prepared by Gas Metal Arc Welding. In this study weld joints of low carbon steel, medium carbon steel and die steels are prepared by Gas Metal Arc Welding (GMAW) process with varying process parameters of welding current, welding voltage and welding speed. The bending strength of the weld joints are measured using universal testing machine. The effects of various welding parameters is analyzed using Design of Experiment on ReliaSoft DOE++ software to determine the significant factors affecting the bending strength of the weld joint. Among the chosen different process parameters welding voltage is found to be the most significant factor affecting the bending strength of the weld joints. [4]

Deepak Kumar et.al optimized the Process Parameters of Gas Metal Arc Welding by Taguchi's Experiment Design Method. In this work, experiments were carried out on 1018 mild steel plates using gas metal arc welding (GMAW) process. L9 orthogonal array of Taguchi`s experimental design was used for optimization of welding current, voltage and gas flow rate on welded joints. L9 Orthogonal Array was selected to study the relationships between the tensile strength and the three controllable input welding parameters. Voltage is the significant factor for tensile strength but current and gas flow rate are the non- significant parameters in GMAW. [5]

RadosławWiniczenko discussed the Effect of friction welding parameters on the tensile strength and micro-structural properties of dissimilar AISI 1020-ASTM A536 joints. A hybrid response surface methodology (RSM) and genetic algorithm (GA)-based technique were successfully developed to model, simulate, and optimize the welding parameters. The results of the metallographic study show clearly that the friction welding process was accompanied by a diffusion of carbon atoms from ductile iron to steel. [6]

Ankita Singh et.al. have used the Taguchi's Method coupled with fuzzy based desirability function approach for the Optimization of bead geometry of submerged arc weld. Fuzzy inference system has been adapted to avoid uncertainly, imprecision and vagueness in experimentation as well as in data analysis by traditional Taguchi based optimization approach. . The proposed procedure is simple and effective in developing a robust, versatile and flexible welding process. Optimization of MPCIs of the process can easily be achieved through proper system model simulation in order to fulfill customers' demand. Accuracy in prediction of the model analysis can be susequently increased by increasing number of membership function in the fuzzy system. [7]

Dharmendra Singh Jadoun et.al. have discussed the Optimization of Welding Parameter For Arc Welding Of Mild Steel Plate (Grade-40). In this work The Taguchi method is adopted to analyze the effect of each welding process parameter on the weld strength, and the optimal process parameters are obtained to achieve greater weld strength. The tensile strength of the mild steel welded plates is measured in the Universal Testing Machine (UTM). Taguchi analysis for optimization of ultimate tensile strength is applied and found to be satisfactory. [8]

LITERATURE SUMMERY

According to the survey of till presented research work it is found that in most of the cases TIG, MIG, GAS METAL ARC WELDING, SUBMERGED ARC WELDING, FRICTION STIR WELDING etc. are done on different materials. But from all of that welding technique, electric arc welding has greater welding strength. For further checking the parameters selected are satisfactory or not Taguchi Methodology is adopted.

TAGUCHI METHODOLOGY

Taguchi is a methodology which gives the optimum combination of independent parameter which has a significant role to change the value of dependent parameter. The prime objective of the method is to design best quality product at least cost of manufacturer. This method was generated by Dr. Genichi Taguchi of Japan. This method has designed to investigate how various parameters significantly affect the mean and variance of parameter pertaining to main characteristic and quality of process.
The orthogonal arrays is the prime tool which arrays to organize the parameters affecting the process and the levels at which they should be varies. Taguchi method tests pairs of combinations in place of all possible combinations. This provides the necessary data to identify the significance of factors affecting product quality with a minimum recourses and time. The arrays are selected on the basis of degree of freedom of parameter which depends on the no of parameter and their level. The data from the arrays can be analyzed by visual analysis.

Taguchi Technique

This technique is completely based on statistical concepts and. Many renowned firms have achieved great success by applying this method. Taguchi method adopted experimentally to investigate influence of parameters such as material stress, thickness and diameter of pipe on the induced stress in chassis. The Taguchi process helps to select or to determine the optimum combination for material stress, thickness of pipe and diameter of pipe and effect of these parameters on induced compressive stress on chassis during time of collision. Many researchers developed many mathematical models to optimize these parameters to get minimum induced stress in various processes.

A. Philosophy of the Taguchi Method

1) Quality of product depends on the process by which it has been produced. One can improve the quality by optimizing the parameter affects the process.
2) Best quality can be achieved by minimizing uncontrollable environmental factor which leads to deviation from a target.
3) The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide.

B. Procedure and Steps of Taguchi parameters design

***1)* Step-1: Selection of the quality characteristic:**
There are three types of quality characteristics in the Taguchi methodology, such as smaller-the-better, larger the- better, and nominal-the-best. For example, smaller-the- better is considered when measuring fuel consumption of fuel in automobile or roughness in surface finish. The goal of this research was to find the effect of parameters and achieve minimum compressive stress induced during collision

***2)* Step–2: Selection of noise factors and control factors**:
In this step, the controllable factors are material (M), Voltage (V) and diameter of electrode (D) which was selected because these are the factors which affect the induced tensile stress. Since these factors are controllable so they are considered as controllable factors in the study. Uncontrollable factor may be the ambiance temperature and Humidity

***3)* Step–3: Selection of Orthogonal Array:**
There are 9 basic types of standard Orthogonal Arrays (OA) in the Taguchi parameter design. Selection of arrays depends on the degree of freedom of selected parameter. Degree of freedom of all three parameter is 6. An L9 Orthogonal Array is selected for this work. The layout of this L9 OA is as mentioned in Table

Experiment	P1	P2	P3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 1: L_9 Orthogonal Array

***4)* Step–4: Conducting the experiments:**
Table illustrates the experimental settings in this study for maximum Breaking Strength. The parameters used in this experiment are Hardness, Diameter of Electrode & Weld Design.

***5)* Step–5: Predicting Optimum Performance:**
Using the aforementioned data, one could predict the optimum combination of Hardness, Diameter of Electrode & Weld Design for maximum Breaking Strength. With this prediction, one could conclude that which combination will creates the better result.

***6)* Step-6: Establishing the design by using a confirmation experiment:**
The confirmation experiment helps to verify our prediction particularly when small fractional factorial experiments are utilized. The purpose of the confirmation experiment in this study was to validate the optimum Breaking Strength.

EXPERIMENTAL SET UP

As the literature suggested, the experimental setup is constructed for the material and the various factors and their levels are chosen, which are dependent on the following properties of the material under welding:

- Structure of the material
- Hardness of the material
- Tensile Strength of the material
- Weld Design

The factor that considerably contributes to the quality of weld in welding operation is selected.

Hardness
The Hardness depends upon the type of material being used. For example the original material is taken as Medium (M), and the other two are Soft (S) & Hard (H) which is being done by heat treatment.
Selection of Ranges for hardness is as follows:

Figure 3 Work pieces for Testing

Diameter of Electrode
The second parameter is Electrode Diameter and it has three levels. The three levels are low, medium and high.

Figure 4 Different Welding Electrodes

Weld Design (Edge Preparation)
Weld design are of different types but we use here three levels called three weld designs such as V, J and Bevel type. V type of edge is one in which both the edge is at 30º angle. In Bevel type one edge is straight and the other is at

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45° angle. In J – type one edge is straight and the other is in J- shape.

Specification of Work Material

Low carbon mild steel

Breaking strength = 535.22 N/mm²

Hardness (BHN) = 292

Weight = 500 gm

Chemical Composition

Carbon(C) = 0.06 %

Silicon (Si) = 0.09 %

Manganese (Mn) = 0.37 %

Phosphorus (P) = 0.063 %

Sulphur (S) = 0.065 %

S. No	Exp. No	Hardness (A)	Electrode Diameter (mm) (B)	Weld Design (C)	Breaking Strength (N/mm²) (I)	Breaking Strength (N/mm²) (II)	Mean Breaking Strength (I + II)/2 (N/mm²)
1	1	S	D1=3.70	V	197.51	206.69	202.10
2	2	S	D2=4.70	BEVEL	220.65	220.65	220.65
3	3	S	D3=5.70	J	298.89	290.44	294.66
4	4	M	D1=3.70	J	240.97	230.08	235.52
5	5	M	D2=4.70	V	325.10	331.83	328.46
6	6	M	D3=5.70	BEVEL	375.40	369.35	372.37
7	7	H	D1=3.70	BEVEL	228.97	228.97	228.97
8	8	H	D2=4.70	J	345.55	330.30	337.92
9	9	H	D3=5.70	V	350.75	359.32	355.03

EXPERIMENTAL RESULTS

Average Mean Breaking Strength (Y)

= 286.18 N/mm²

Signal to Noise Ratio or S/N Ratio

The response variable considered in this study is Breaking Strength, which is of larger the better kind. Therefore, signal to noise ratio is defined by

S/N RATIO (H_i) = -10 Log_{10} $[(1/n) * \sum_i (1/ Y_i^2)]$

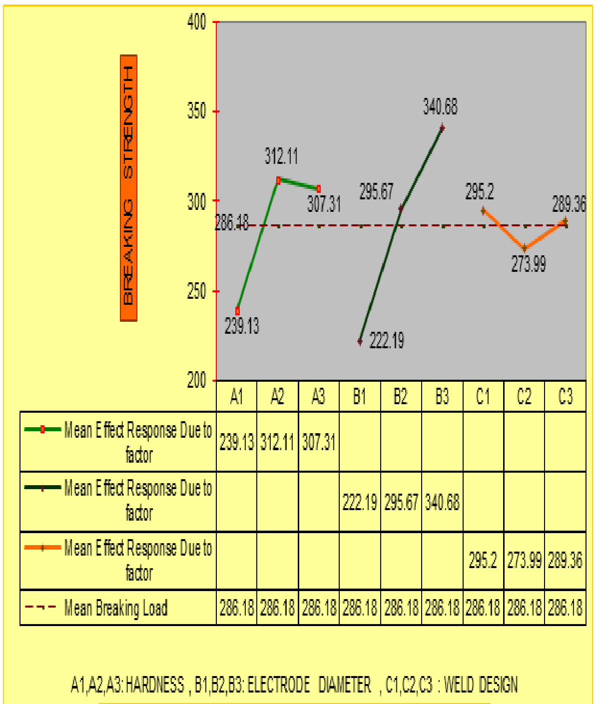
Where, Y_i are the individual measurement of Breaking Strength at each location.

S.No.	Exp. No.	Breaking Strength (N/mm²) (I)	Breaking Strength (N/mm²) (II)	Mean Breaking Strength (N/mm²) (I+II)/2	S/N ratio (dB) H_i
1	1	197.51	206.69	202.10	46.11
2	2	220.65	220.65	220.65	46.87
3	3	298.89	290.44	294.66	49.37
4	4	240.97	230.08	235.52	47.44
5	5	325.10	331.83	328.46	50.32
6	6	375.40	369.35	372.37	51.42
7	7	228.97	228.97	228.97	47.20
8	8	345.55	330.30	337.92	50.57
9	9	350.75	359.32	355.03	51.00

Analysis of means;

Symbol	Controllable Factors	Level I	Level II	Level III
A	**Hardness**	239.13	**312.11**	307.31
B	**Electrode Diameter**	222.19	295.67	**340.68**
C	**Weld Design**	**295.20**	273.99	289.36

Response Graphs for Means



MEAN RESPONSE GRAPH FOR THREE WELDING FACTORS

Confirmation of experiment:

Exp. No.	Breaking Strength (N/mm^2)	S/N ratio (dB)
1	383.61	51.67
2	380.18	51.59
Average	381.89	51.63

Level combination (A2 – B3 – C1) as suggested by Taguchi

COMPARISION OF RESULTS

The results obtained from the confirmation experiments are hereby compared by the predicted result of Taguchi Design experiment.

Actual Result

Mean of Response value (Breaking Strength) =**381.89 N/mm^2**

S/N ratio =**51.63 dB**

Predicted Result (By Taguchi Method)

Predicted mean = A2 + B3+ C1 – 2* Y

Predicted mean Breaking Strength = **375.63 N/mm^2**

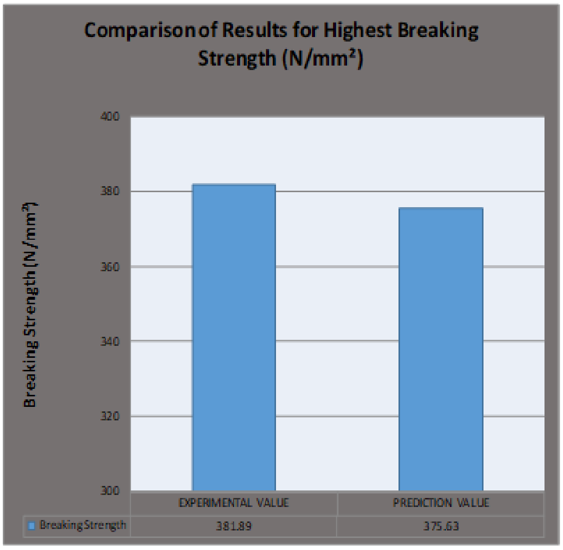
Predicted S/N ratio = $sA_2 + sB_3 + sC_1 - 2m$

Predicted S/N ratio = **51.61 dB**

Variation % = + {(381.89 – 375.63) / 381.89} × 100 = **1.639 %**

Mean of Response value (Breaking Strength) = **378.76 N/mm^2**

S/N ratio =**51.62 dB**



CONCLUSIONS

Experiments conducted and subsequently analysis performed by using the Taguchi Method. The optimum characteristics for the high Breaking Strength in welding operation are identified and the confirmation experiments are conducted, then the results obtained are compared with the above said optimization methods and are discussed as follows:

Average (Mean) Effect Response Table for the Raw Data, the factor (C) Weld Design represents the largest influence on weld strength followed by factor (B) Electrode Diameter, factor (A) Hardness and (Table5.4) Average Effect Response Table for S/N Ratio.

It is apparent that the F-ratio values of factor A (Hardness), Factor B (Electrode Diameter), and factor C (Weld Design) are all have effect.

1. From response graphs for mean and S/N ratio, observational findings are illustrated as following:
   (a) **Level I** for **Hardness A2= medium** indicated as the optimum situation in terms of mean value.
   (b) **Level III** for **Electrode Diameter B3= 5.70 mm**, indicated as the optimum situation in terms of mean value.
   (c) **Level I** for **Weld Design C1= V type**, indicated as the optimum situation in terms of mean value.

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