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Optimisation of Process Parameters for MIG Welding byUsing Grey Relational Analysis

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Abstract-The welding of Aluminium is a big challenge by conventional arc welding process and repeatability of welding depends on its control on welding speed and other processing parameters. In this study, GMAW welding of 5 mm thick mild steel was done by changing the welding current, gas flow rate and nozzle to plate distance to get a high strength joint. To get better strength welding of the MS plate is done from both side. The main aim of the study was to analyse the Effect of welding current, gas flow rate and nozzle to plate distance on the tensile strength of weld joint, micro hardness of the weld pool and macrostructure of the joint. The mechanical properties under consideration for present work were the Tensile Strength and Hardness. Tensile Strength and Hardness were determined using UTE100, with capacity of 100kN and Rockwell hardness tester respectively. It was found that preheat temperature has the most significant effect on the tensile strength and hardness. The maximum tensile strength and hardness achieved was welding current 124 A, gas flow rate 15 l/min and preheat temperature 275°C.

Keywords- GMAW welding, tensile strength, hardness, preheat temperature, UTE100, Rockwell hardness

I.INTRODUCTION

Welding is a process used to permanently join the different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and pressure. During welding process, the work-pieces which have to be joined are melted and after solidification of this melted metal a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material in between the two or more work pieces which after solidification gives a strong bond between the work pieces.

Gas Metal Arc Welding is a process in which the source of heat is an arc format between consumable metal electrode and the work piece, and the arc and the molten puddle are protected from contamination by the atmosphere (i.e. oxygen and nitrogen) with an externally supplied gaseous shield of gas either inert such as argon, helium or an argon-helium mixture or active such as carbon dioxide, argon-carbon dioxide mixture, which is chemically active or not inert. Initially GMAW was called as MIG Welding because only inert gasses were used to protect the molten puddle.

The application of this process was restricted to aluminum, deoxidized copper and silicon bronze. Later it was used to weld ferrite and austenitic steels, and mild steel successfully by using active gasses in place of inert gasses and hence was term MAG (Metal Active Gas) welding. In the GMAW (MAG) process, the metal transfer from the electrode tip to the weld pool across the arc is either globular, spray type or short-circuiting type depending upon many factors, which are the magnitude of welding current, Shielding gas, Current density, Electrode extension and, Electrode chemistry. With CO2 shielding, the globular and non-axial, whatever may be the value of the welding current, current density and other factors. Hence there is considerable spatter. Drops become smaller in size as the current increases and they continue to be directed axially and non-axially.

II. LITERATURE REVIEW

Sudhir Kumar et al. (2019) research work, AISI 1018 mild steel samples have been welded in V-butt joint configuration using MIG welding. The design of experiment is Taguchi based Orthogonal Array (L9). Effect of process parameters such as current, voltage and preheat temperature has been studied and welds are examined using X-ray radiographic tests. Weld quality has been assessed in terms of tensile properties of weldments such as ultimate tensile strength and percentage elongation. Process parameters have been optimized using grey based Taguchi methodology.

Himanshu Yadav, et al. (2019) focused on the optimization of these parameters to obtain best parameter combination for the target quality. For optimization of these parameters, Taguchi method has emerged as the widely accepted method for optimization by the researchers across the globe.

Ravinder Kumar, et al. (2019) studied most commonly mixture of Argon and Helium are favored to use for enhanced welding quality because they do not react with each other. Argon and Helium gases protect the welding area from outer environment and helps to maintain a stable arc due to low ionization potential.

Prakash BabuKanakavalli, et al. (2019) discussed application of Taguchi and Grey relational analysis methodologies in determining optimal process parameters for MIG Welding are presented. In the present work welding current, voltage, speed, bevel angle were considered as input parameters in joining two dissimilar metals (AISI1010 & AISI1018), as these influence the output characteristics like tensile strength and hardness, these parameters need to be optimized.

Ashish Chafekar, at al. (2019) discussed on semi-automatic pulse MIG welding machine according to the L9 orthogonal array with replication. The process parameters viz. welding voltage, wire feed rate and dynamic is significant in intelligent MIG welding machine have been considered as variables.

Dharmendra B.V. et al. (2019) discussed multi-objective optimization technique for identifying a set of optimum abrasive water jet machining (AWJM) parameters to achieve maximum material removal rate (MRR) and minimum surface roughness.

Priyanka Devidas Shinde, et al. (2018) presented the effect of welding parameters such as welding current, welding voltage and gas flow rate on depth of penetration and ultimate tensile strength using Taguchi technique. Two types of oxides $MgCO_3$ and Cr_2O_3 were used to examine the effects of activating flux on penetration in mild steel Fe 410 of size 100×65×6 mm by GMAW with a V-groove weld joint design.

Nabendu Ghosh et al. (2018) discussed dissimilar joints between AISI 409 ferritic stainless steel and AISI 316L austenitic stainless steel, are made by GMAW (Gas metal arc welding) using ESAB AUTO Rod 316L as filler wire. Welding has been conducted as per L9 orthogonal array of Taguchi method. Three levels of the input parameters: welding current, gas flow rate and nozzle to plate distance, have been selected.

Arham Khan, et al. (2018) carried out Taguchi method is used to formulate the experimental design. Design of experiments using L9 orthogonal array is employed to perform cladding operation. The input process parameters of pulse current GMAW considered include mean current, arc voltage, pulse frequency and wire feed rate.

Saadat Ali Rizvi, et al. (2018) discussed centre on optimizing different welding parameters which affect the weldability of SS304H, Taguchi technique was employed to optimize the welding parameters and fracture mode characterization was studied.

Shekhar Srivastava et al. (2017) carried out effect of the various process parameters has been studied on welding of IS:2062 mild steel plate using gas metal arc welding process with a copper coated mild steel wire of 0.8 mm diameter. A set of experimentshas been performed to collect the data using Box Behnken Design technique of Response Surface Methodology. Based on the recorded data, the mathematical models have been developed. Further an attempt has been made to minimize the bead width and bead height and maximize the depth of penetration using response surface methodology.

NabenduGhosh et al. (2017) investigated the effects of welding parameters: welding current, gas flow rate and nozzle to plate distance, on ultimate tensile strength (UTS) and Yield Strength (YS) in MIG welding of AISI409 ferritic stainless steel to AISI 316L Austenitic Stainless Steel materials. Experiments have been conducted as per L9 orthogonal array of Taguchi method. The observed data of UTS and YS have been interpreted, discussed and analyzed with use of Taguchi Desirability analyses.

ArunkumarSivaraman et al. (2017) focuses on the optimization of process parameters for MIG welding of the material AA219-T87 using Taguchi based grey relational analysis. The welding input parameters play a vital role in optimized desired weld quality. The input parameter chosen were the welding current, Voltage and welding speed. The experiments were conducted according to L9 orthogonal array.

Kumar Rahul Anand et al. (2017) studied the mechanical properties of the joint of austenitic stainless steel (AISI 316) and mild steel welded by TIG welding. In this paper with the use of Taguchi method of optimization we have tried to optimized the various process parameter such as current, voltage and gas flow ratio (GFR) which has influence on tensile strength and hardness of the joint. However, investigation is based on the Taguchi approach of orthogonal array using analysis of variance (ANOVA) to determine the influence of process parameter and to optimize them.

III. METHODOLOGY AND EXPERIMENTATION

Commercial MS plate of thickness 5 mm was selected as work piece material for the present experiment. MS plate was cut with required dimension with the help of power-saw and grinding done at the edge to smooth the surface to be joined. After that surfaces are polished with emery paper to remove any kind of external material.

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study welding current, gas flow rate and

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nozzle to plate distance have been considered as process variables. After performing the welding, welded specimens were cut with dimension of 100 mm x 25 mm for tensile test, which were further cut in to I shape. Tensile test was performed with universal tensile testing machine (Instron-600) with maximum load capacity of 600 KN.

Table 1. Tensile test result

Experiment no.	Welding current (Amp)	Gas flow rate (l/min)	Preheat temperature (°C)	Tensile strength (MPa)
1	100	10	275	257.58
2	100	15	285	244.67
3	100	20	300	251.74
4	112	10	285	260.65
5	112	15	300	245.34
6	112	20	275	258.25
7	124	10	300	256.14
8	124	15	275	255.04
9	124	20	285	258.44

Table 2. Rockwell hardness test result

Experiment no.	Welding current (Amp)	Gas flow rate (l/min)	Preheat temperature (°C)	HRC
1	100	10	275	72.36
2	100	15	285	83.54
3	100	20	300	71.12
4	112	10	285	82.07
5	112	15	300	83.45
6	112	20	275	74.14
7	124	10	300	83.21
8	124	15	275	82.74
9	124	20	285	84.07

IV. GREY RELATIONAL ANALYSIS

Table 3. The sequences process of each performance characteristic after data processing

Experiment No.	Tensile Strength Result	Hardness Value Result
Reference Sequence	1	1
1	0.81	0.09
2	0.00	0.96
3	0.44	0.00
4	1.00	0.85
5	0.04	0.95
6	0.85	0.23
7	0.72	0.93
8	0.65	0.89
9	0.86	1.00

Table 4. The Deviation Sequences

Deviation Sequences	Δ_{0i} (1)	Δ_{0i} (2)
1	0.19	0.91
2	1.00	0.04
3	0.56	1.00
4	0.00	0.15
5	0.96	0.05
6	0.15	0.77
7	0.28	0.07
8	0.35	0.11
9	0.14	0.00

Table 5. The calculated grey relational grade and its order in the optimization process

Experiment No.	Grey Relational Coefficient		Grey Relational Grade, (γi)	Rank
	Tensile Strength (MPa), $\zeta i(1)$	Hardness Value $\zeta i(2)$		
1	0.38	0.85	0.41	4
2	1.00	0.34	0.45	2
3	0.53	1.00	0.51	1
4	0.33	0.37	0.23	9
5	0.93	0.34	0.42	3
6	0.37	0.68	0.35	5
7	0.41	0.34	0.25	7
8	0.43	0.36	0.26	6
9	0.37	0.33	0.23	8

Table 6. Response Table for the Grey Relational Coefficient

Level	Preheat temperature	Gas flow rate	Welding Current
1	0.4567	0.2967	0.3400
2	0.3333	0.3767	0.3033
3	0.2467	0.3633	0.3933
Delta	0.2100	0.0800	0.0900
Rank	1	2	3

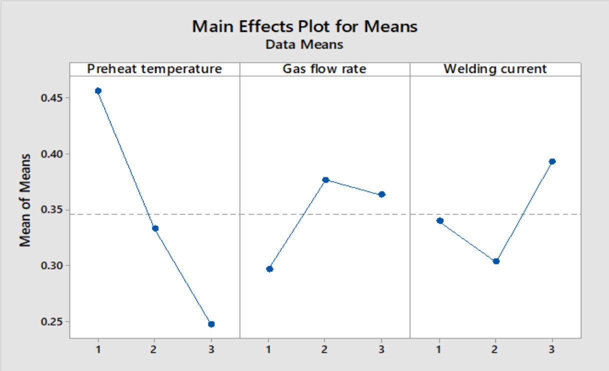

Fig. 1. Effect of welding parameters on the multi-performance characteristics

Table 7. ANOVA of grey relational grade

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage
Preheat temperature	2	0.066822	0.033411	97.00	0.041	74.22 %
Gas flow rate	2	0.011022	0.005511	16.00	0.019	12.22 %
Welding current	2	0.012289	0.006144	17.84	0.023	13.33 %
Error	2	0.000689	0.000344			
Total	8	0.090822				

1. Pie Chart Representation Of Percentage Contribution Of Process Parameters For Tensile Strength And Hardness

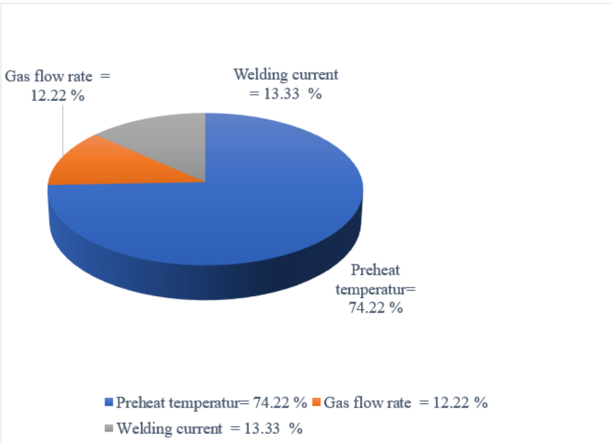

Fig 2. Percentage contribution of process parameters on tensile strength

1. **Preheat temperature** - It is denoted by dark blue colour, it contributes only 74.22 % which is the maximum.
2. **Gas flow rate** - It is denoted by red colour, it contributes 13.33 % which is the minimum contribution. It is mainly responsible to affect the tensile strength of work piece.
3. **Welding current** - It is denoted by green colour, it contributes only 12.22 % which is the minimum contribution.

Table 8. Parameters and their selected levels for maximum tensile strength and maximum hardness

Parameter designation	Process parameters	Optimal levels
A	Welding current (Amp)	3 (124)
B	Gas flow rate(l/min)	2 (15)
C	Preheat temperature	1 (275)

2. Validation

In order to test the predicted result, confirmation experiment has been conducted by running three trials at the optimal setting of the process parameters determine from the analysis i.e. A1, B2, C3 for tensile strength and hardness value.

Table 9. Confirmation test for maximum tensile strength

S.no	Predicted Tensile strength (N/mm2)
1	261.45

Table 10. Confirmation test for maximum hardness value

S.no	Predicted Hardness value
1	88

Ghosh et. al. (2015) analyzed the effects of welding parameters: welding current, gas flow rate and nozzle to plate distance, on ultimate tensile strength (UTS) and percentage elongation (PE) in MIG welding of AISI409 ferritic stainless steel materials. Predicted value of tensile strength after confirmation test is 52.8 MPa. However in our work Predicted value of tensile strength after confirmation test is 261.45 MPa.

V. CONCLUSIONS

The following conclusions have been noted by applying Taguchi methodology in the experimental investigations of MS plate by GMAW.

1. Taguchi's based Grey relational analysis is suitable to analyse this problem as described in this work.
2. It is found that the parameter design of Taguchi's based Grey relational analysis provides a simple, systematic and efficient methodology for the optimization of the GMA welding parameters.
3. From main effect plot preheat temperature, gas flow rate and welding current significant effect on the tensile strength and hardness. This is consistent with the conclusions from the study of other investigators.
4. The preheat temperature has the most significant effect on the tensile strength and hardness.
5. The maximum tensile strength and hardness achieved was welding current= 124 A, gas flow rate = 15 l/min and preheat temperature = 275°C. This is the optimized results for achieving maximum tensile strength.

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