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GMAW process parameter Taguchi based optimization of aluminium alloy

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ABSTRACT

Welding is the manufacturing method, which is carried out by joining two similar and dissimilar metals. GMAW welding is one of the most widely used processes in industry. The GMAW welding parameters are the most important factors affecting the quality, productivity and cost of welding. We studied input parameters of welding such as welding current, arc voltage, welding speed, root gap and output parameter are hardness and tensile strength. This review is based on optimization techniques and analysis tools used by researchers to optimize the parameters. In this research paper, a review has been presented on GMAW welding. The previous literature has been discussed along with the future aspects included in the field of GMAW welding.

Keywords— *GMAW, Strength, Mechanical properties, Review*

1. 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 the 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 workpieces which after solidification gives a strong bond between the workpieces. Weldability of a material depends on various factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, the extent of oxidation due to the reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position. Gas Metal Arc Welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. Originally developed for welding aluminium and other non-ferrous materials in the 1940s, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility.

2. REVIEW OF PAST STUDIES

James, M.N. et al. (2008) investigation of the single-line residual stress profiles for 8 mm 5083-H321 aluminium plates joined by gas metal arc (MIG) welding. The data were obtained by synchrotron diffraction strain scanning. Weld metal stresses (up to 7 mm either side of the centreline) are quite scattered and unreliable because of the large epitaxial grain size in the fusion zone. The effect on residual stress and strain values of a sequence of applied fatigue loads was also considered and reported. Wang Rui, et al. (2008) carried out the dynamic progress and residual distortion of out-of-plane of aluminium alloy 5A12 was investigated under different welding conditions of TIG welding. The dynamic out-of-plane distortion was measured by the self-developed distortion measuring system. Out-of-plane distortion mechanism and the effecting parameters on distortion process were analyzed, and the effect of plate thickness and welding heat input on distortion was discussed. Simone Matteı, et al. (2009) studied in the order to deepen the understanding of the differences between laser and laser-arc hybrid welding, comparisons were undertaken using thermograph. The experiments were carried out for a T assembly of aluminium alloy plates. Modelling, based on the finite element method approach, was realized using IR temperature measurements and seam geometry. Manoj Singla, et al. (2010) discussed Gas Metal Arc Welding is a process in which the source of heat is an arc format between the consumable metal electrode and the workpiece with an externally supplied gaseous shield of gas either inert such as argon, helium. This experimental study aims at optimizing 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.

3. MATERIAL USED

Commercial Aluminium plate of thickness 3 mm was selected as workpiece material for the present experiment. Al 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 composition and material properties of aluminium alloys are given in table 1 and table 2 respectively.

4. PROCESS VARIABLES AND THEIR LIMITS

The working ranges of the parameters for the subsequent design of the experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study spindle speed, feed rate and tool profile have been considered as process variables. The process variables with their units and notations are listed in Table 1.

Table 1: Process variables and their limits

Parameters/Factors		Level		
		1	2	3
A	**Welding current (Amp)**	180	200	220
B	**Welding voltage (Volt)**	24	26	28
C	**Electrode feed rate (m/min)**	5	5.5	6

5. EXPERIMENTAL PROCEDURES

Commercial Aluminium plate of thickness 3 mm was selected as workpiece material for the present experiment. Al plate was cut with a dimension of 120 mm x 50 mm with the help of band-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.

Fig. 1: GMAW setup

After sample preparation, Aluminium plates are fixed in the working table with flexible clamp side by side and welding did so that a butt joint can be formed. TIG welding with Alternate Current (AC) was used in experiments as it concentrates the heat in the welding area. Zirconiated tungsten electrodes of diameter 3.4 mm were taken as an electrode for this experiment. The end of the electrode was prepared by reducing the tip diameter to 2/3 of the original diameter by grinding and then striking an arc on a scrap material piece. This creates a ball on the end of the electrode. Generally, an electrode that is too small for the welding current will form an excessively large ball, whereas too large an electrode will not form a satisfactory ball at all.

For the first phase of experiment welding parameters selected are shown in table 2. Before performing the actual experiment a number of trial experiments have been performed to get the appropriate parameter range where welding could be possible and no observable defects like undercutting and porosity occurred.

Experiments have been carried out using Taguchi's L9 Orthogonal Array (OA) experimental design which consists of 9 combinations of welding current, welding voltage and electrode feed rate. According to the design catalogue prepared by Taguchi, L9 Orthogonal array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in table 2.

After performing the welding, welded specimens were cut with a dimension of 100 mm x 25 mm for tensile test, which was further cut into I shape. The tensile test was performed with a universal tensile testing machine (Instron-600) with a maximum load capacity of 600 KN.

Table 2: Experimental planning

Experiment no.	Welding current (Amp)	Welding voltage (Volt)	Electrode feed rate (m/min)
1	180	20	5
2	180	30	5.5
3	180	40	6
4	200	20	6
5	200	30	5.5
6	200	40	5
7	220	20	6
8	220	30	5
9	220	40	5.5

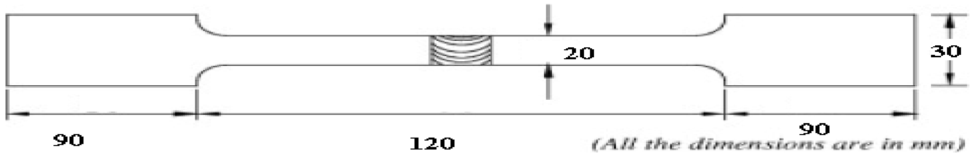

Fig. 2: Sample dimension for GMAW

Fig. 3: Sample ready for welding

After sample preparation welding will be done according to Taguchi's design of experiment using a different setting of welding parameters. After welding nine samples these were tested on UTM machine for measuring tensile strength and hardness by Brinell hardness test machine.

Fig. 4: Sample ready for testing

Fig. 5: Sample after testing

6. RESULTS AND DISCUSSIONS

6.1. ANOVA for tensile strength

Results obtained for the tensile strength are shown in Table 3.6. The results for tensile strength were obtained from the 9 experiments performed of Taguchi. The experimental results analysed with ANOVA are shown in Table 1. The F value calculated through

MINITAB 18 software is shown in the second last column of ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%). The results show that the electrode feed rate is the most significant factor. In Table, 3 ranks have been given to the various factors. Higher is the rank higher is the significance so electrode feed rate is the most significant factor.

Fig. 6: Fixing the specimen

Table 3: Analysis of Variance for Means of tensile strength

Source	DF	Seq SS	Adj MS	F	P	Percentage Contribution
Welding current (Amp)	2	5.354	2.676	0.20	0.833	13%
Welding voltage (Volt)	2	1.934	0.967	0.07	0.932	5%
Electrode feed rate (m/min)	2	10.121	5.060	0.38	0.725	23%
Error	2	26.706	13.35			
Total	8	44.11				
S = 0.5867 R-Sq = 74.92 % R-Sq (adj) = 0.25 %						

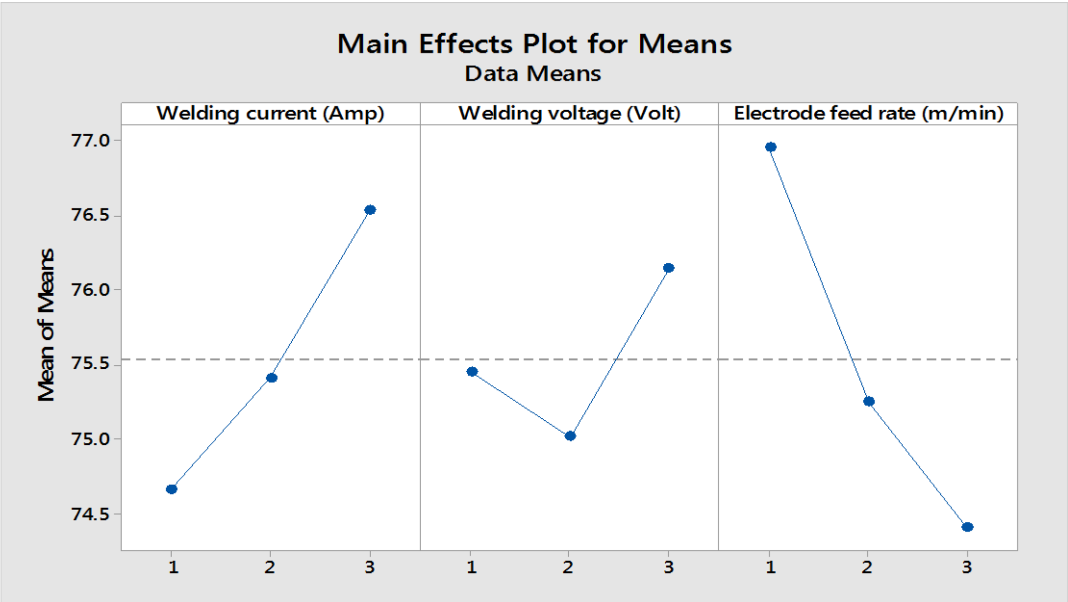

Fig. 7: Main effects plot for means for tensile strength

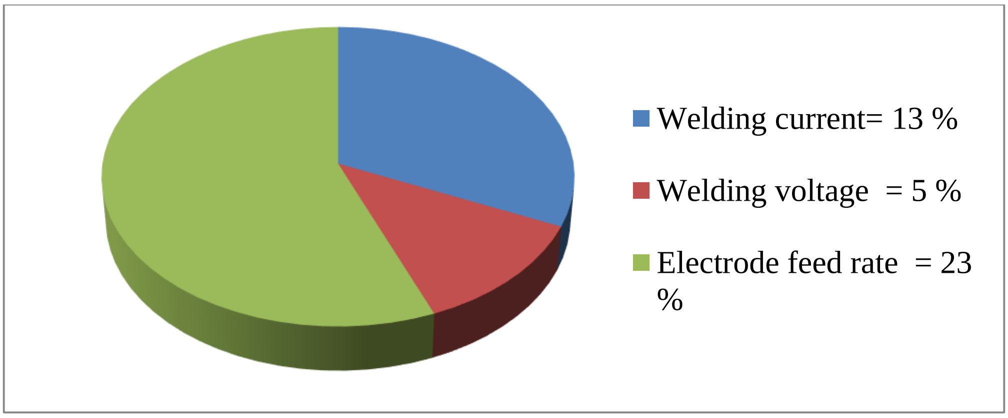

Fig. 8: Percentage contribution of process parameters on tensile strength

6.2 ANOVA for Brinell hardness

Results obtained for the hardness are shown in table 3 have been analysed with ANOVA are shown in table 4. The F value calculated through MINITAB software is shown in the second last column of ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%). The results show that only the welding current is the most significant factor. In Table 4 ranks have been given to the various factors. Higher is the rank higher is the significance.

Fig. 9: Process Setup for Hardness Test

Table 4: Analysis of variance for means for Brinell hardness

Source	DF	Adj SS	Adj MS	F	P	Percentage Contribution
Welding current (Amp)	2	1.788	0.894	0.39	0.719	23%
Welding voltage (Volt)	2	0.8205	0.410	0.18	0.848	11%
Electrode feed rate (m/min)	2	0.6595	0.329	0.14	0.874	9%
Error	2	4.5805	2.290			
Total	8	7.849				
S = 0.5867 R-Sq = 74.92 % R-Sq (adj) = 0.25 %						

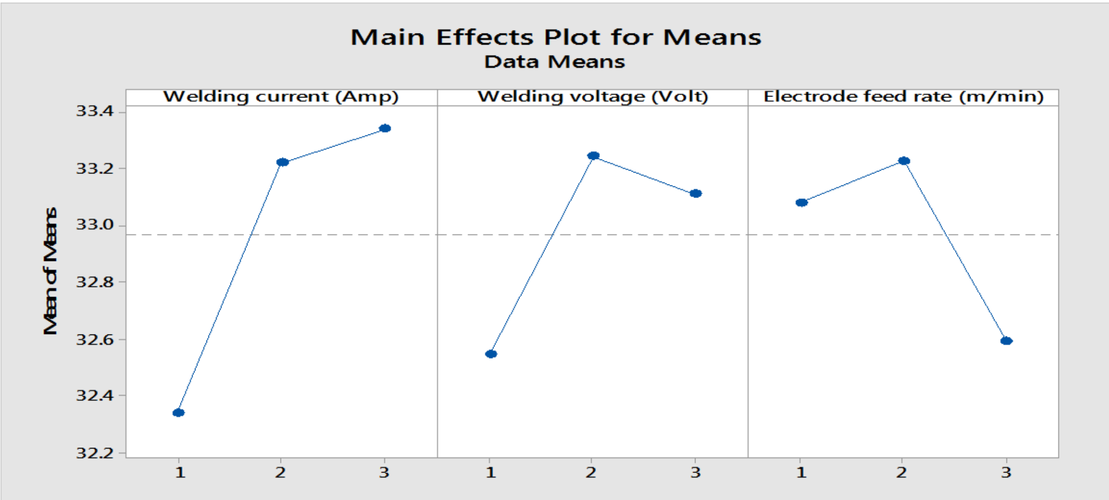

Fig. 10: Main effects plot for means for Brinell hardness

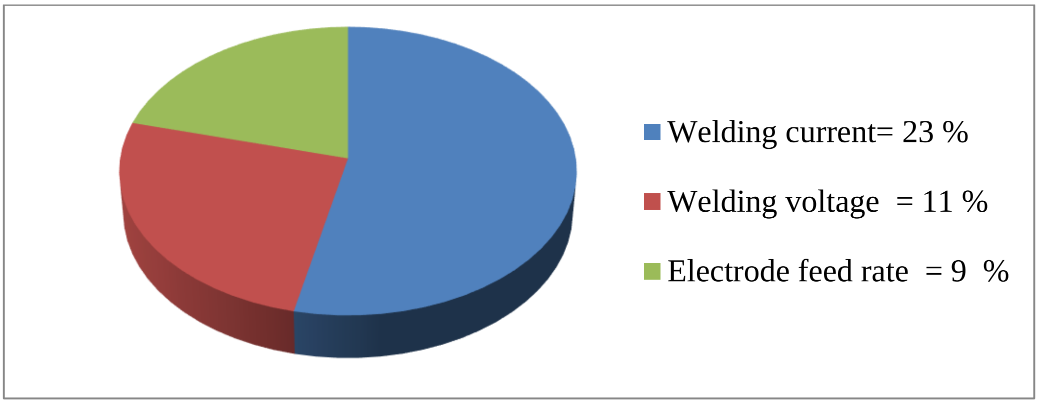

Fig. 11: Percentage contribution of process parameters on brinell hardness

7. DETERMINATION OF OPTIMUM SOLUTION

Optimum parameter setting for higher tensile strength and higher hardness value with tool profile has been identified through given figures. The best configurations are determined individually through Taguchi's approach. Table 5 and 6 indicates these individual maximum values and its related settings of the method parameters for the described performance characteristics.

Table 5: Parameters and their selected levels for maximum tensile strength

Parameter designation	Process parameters	Optimal levels
A	Welding current (Amp)	3 (220)
B	Welding voltage (Volt)	3 (28)
C	Electrode feed rate (m/min)	1 (5)

Table 6: Parameters and their selected levels for maximum hardness value

Parameter designation	Process parameters	Optimal levels
A	Welding current (Amp)	3 (220)
B	Welding voltage (Volt)	2 (26)
C	Electrode feed rate (m/min)	2 (5.5)

8. CONFIRMATION TEST

In order to test the predicted result, confirmation experiment has been conducted by running three trials at the optimal setting of the process parameters determined from the analysis that is A3, B3, C1 for tensile strength and A3, B2, C2 for hardness value.

Table 7: Confirmation test for maximum tensile strength

S.no	Trials			Avg. Tensile strength (MPa)
	1	2	3	
1	82.29	82.24	82.3	82.27

Table 8: Confirmation test for maximum hardness value

S.no	Trials			Avg. Hardness value
	1	2	3	
1	35.94	35.92	35.94	35.93

9. CONCLUSIONS

The following conclusions have been noted by applying Taguchi methodology in the experimental investigations of AA6061 T6 grade aluminium alloy by GMAW.

- Taguchi's robust orthogonal array design method is suitable to analyze this problem as described in this work.
- It is found that the parameter design of the Taguchi method provides a simple, systematic and efficient methodology for the optimization of the GMA welding parameters.
- For main effects, electrode feed rate, welding voltage, welding current have a significant effect on the tensile strength and hardness. This is consistent with the conclusions from the study of other investigators.
- The electrode feed rate has the most significant effect on the tensile strength.
- The welding current has the most significant effect on the hardness.
- The maximum tensile strength achieved was welding current= 220 A, welding voltage = 28 V and electrode feed rate = 5 m/min. This is the optimized results for achieving maximum tensile strength.
- The maximum hardness achieved was welding current= 220 A, welding voltage = 26 V and electrode feed rate = 5.5 m/min. This is the optimized results for achieving maximum tensile strength.
- The analysis of variance for the tensile result concludes that the electrode feed rate is the most significant parameter with a percentage of 23 %, followed by the welding current of 13 % and welding voltage 5 %.
- The analysis of variance for the hardness result concludes that the welding current is the most significant parameter with a percentage of 23 %, followed by the welding current of 11 % and welding voltage 9 %.

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