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Research Article

Optimization of Process Parameters for Gas Tungsten Arc Welding of AA1100 Aluminium Alloy

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Abstract

This paper aims at optimization of process parameters for gas tungsten arc welding (GTAW) of sheet samples of Aluminium alloy AA1100 using AC wave with Argon as inert gas. Tensile properties of parent and welded specimens were determined as per ASTM-E8M standard. Taguchi approach was applied to determine most influential control parameters which will yield better tensile strength of the joints of GTAW welded Aluminium alloy AA1100. Taguchi design was followed by ANOVA and Regression analysis to determine the effect of the individual parameters and a suitable combination was found out. The predicted optimum value of tensile strength of the weld joint is 91.35 MPa which was further confirmed by experiments and found to be in close agreement.

***Keywords**: Aluminium alloy AA1100, Pulsed GTAW, Taguchi Approach, ANOVA, Regression, Tensile strength.*

1. Introduction

Aluminium is the world's most abundant metal and is the third most common element, comprising 8% of the earth's crust. The versatility of aluminium makes it the most widely used metal after steel. In any structural application of Aluminium alloys consideration of its weldability is of utmost importance as welding is largely used for joining of structural components. The preferred welding process of aluminium alloy is gas tungsten arc welding (GTAW) due to its comparatively easier applicability and better economy. GTAW process parameters are many and different for different materials, therefore for efficient use of the process it is required to optimize the parameters. Since a large number of experiments are required to be conducted to identify various parameters, therefore for successful optimization, design of experiments needs to be planned carefully. *Design of experiments,* is the design of all information-gathering exercises where variation is present, whether under the full control of the experimenter or not. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences.

Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost. The experimental design proposed by Taguchi involves orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources (Vuchkov , *et al* 2001), (Montgomery, 1997).

Kumar and Sunderrajan (2009) conducted experiments on optimization of pulsed GTAW welding process parameters and studied the effects on mechanical properties of AA 5456 aluminium alloy weldments using Taguchi technique. Ravisankar *et al* (2006) and Lakshminarayanan and Balasubramanian, (2008) implemented Taguchi approach to determine the most influential control factors which will yield better tensile strength of the joints of friction stir welded RDE-40 aluminium alloy.

Zhang and Zhang (1999) performed welding of Aluminium alloy AA6061 using Opposing Dual torch GTAW process. They disconnected the workpiece from the power supply and placing a second torch on the opposite side of the workpiece. Such a modification changed the direction of current flow, improved the weld penetration and reduced the heat input. This reduced the crack sensitivity of AA6061 and the alloy could be welded without filler metal.

Senthil Kumar *et al* (2007) studied influences of pulsed current tungsten inert gas welding parameters on the tensile properties of AA 6061 aluminium alloy. The use of pulsed current parameters was found to improve the mechanical properties of the welds compared to those of continuous current welds of this alloy due to grain refinement occurring in the fusion zone.

Luijendijk (2000) investigated welding of dissimilar Aluminium alloys and found that due to welding, the strength of the material in the HAZ was reduced. This reduction in strength was smaller for solution hardened

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and strain hardened alloys, than for precipitation hardened alloys.

Naa and Lee (2009) studied parameter optimization in the circumferential welding of aluminium pipes using a semi-analytical finite-element method.

In the present work Taguchi method was employed to optimize the GTAW process parameters of AA1100-O Aluminium alloy welds for obtaining maximum strength. Regression model was developed and Analysis of variance was employed to check the adequacy of developed models. The result was verified with Confirmation test.

2. Experimental Procedure

The base material employed in this study is 1.5 mm thick Al alloy cold rolled sheet in as annealed state. The base metal was tested for elemental composition using inductively coupled plasma atomic emission spectrometer (ICP-AES) and is shown in Table 1.

Table 1: Chemical Composition of Base and Filler material (wt %).

Elements	Cu	Mg	Si	Fe	Mn	Zn	Ti	Cr
% by weight	0.01	0.02	0.28	0.29	0.02	0.01	0.02	0.01

The filler metal used to weld Aluminium 1100 alloy under the trade name *EUTECROD 190* of size 1.6mm manufactured by Larsen and Turbo limited. The selection of filler material is based on the mechanical properties and resistance to cracking in the weld.

2.1 Selection of process parameters

The most important parameters which are having greater influence on the weld bead geometry are Current, Shielding gas flow rate and Welding Speed. A large number of trials have been conducted by varying one of the process parameters and keeping the others constant. The working range of current, flow rate and welding speed has been explored by inspecting bead appearance and the full penetration. The mode was AC and frequency was set at 175 Hz. The working range of the process parameters selected under the present study and the constant process parameters are shown in Tables 2 and 3 respectively.

Table 2: Working Range of Process Parameters

Symbols	Process Parameters	Units	Lower Level	Higher Level
C	Current	Amp	62	67
FR	Flow Rate	Lt/min	8	11
WS	Welding Speed	mm/sec	2.5	3.5

Table 3: Constant Process Parameters

Process Parameter	Constant Value
Polarity	AC
Open Circuit Voltage (V)	45
Filler Rod Diameter (mm)	1.6
Electrode Material	Tungsten (2% Thoriated)
Electrode Diameter (mm)	1.6

Number of process parameters considered under this study is 3 and the level of each parameter is 3. Each condition of experiments was conducted twice to reduce the noise/error effects. The selected orthogonal array L9 is presented in Table 4.

Table 4: L9 Orthogonal Array, Factors = 3 and Runs = 9

S.No.	Current	Flow Rate	Weld Speed
1.	62	8	2.5
2.	62	10	3.0
3.	62	11	3.5
4.	65	8	2.5
5.	65	10	3.0
6.	65	11	3.5
7.	67	8	2.5
8.	67	10	3.0
9.	67	11	3.5

2.2 Preparation of specimens by GTAW

The base metal sheets of dimension 100 mm x 50 mm x 1.5 mm as shown in the Fig.1 were prepared in the sheet metal shop using shearing machine. The butt joints were made using the experimental layout shown in Table 4. TRITON GTAW welding machine was employed for conducting the welding experiments. Before conducting the experiments the base metal sheets were cleaned with sand paper to remove the oxide layer. The sheets to be welded were kept on steel backing bar and ends were clamped to maintain the alignment and gap. Argon gas is used for shielding. The weld joint is completed in a single pass.

Fig.1 Butt welded specimen prepared by GTAW

2.3 Tensile properties of welded specimens

Specimens for tensile testing were prepared by wire cut EDM as per ASTM E8M standards (subsized scale 1:2) with the weld line in the middle of the specimens.

Fig.2 A 50kN UTM table top facility at DTU

Tensile testing was conducted using a computer controlled UTM of capacity 50kN Tonnes as shown in Fig. 2. The cross head speed of 2.54 mm/min was adopted for all the experiments. Each experiment was conducted thrice for better reproducibility of results.

The quality characteristics were evaluated for all the conditions and are presented in Table 5.

Table 5: Quality Characteristics Data

S.No.	Current (Amp.)	Flow Rate (Lt/min)	Weld Speed (mm/sec)	UTS1 (MPa)	UTS2 (MPa)
1.	62	8	2.5	70.3	71.0
2.	65	10	3.0	74.5	73.9
3.	67	11	3.5	62.8	61.3
4.	62	8	2.5	94.6	96.3
5.	65	10	3.0	88.4	87.7
6.	67	11	3.5	99.3	102
7.	62	8	2.5	76.3	74.2
8.	65	10	3.0	90.6	93.5
9.	67	11	3.5	88.4	86.1

3. Experimental Results

3.1 Optimization using Taguchi Technique

Minitab is leading statistical analysis software used for design and analysis of experiments to perform Taguchi technique, ANOVA and develop regression models. Minitab's logical interface makes it easy to use and its outstanding support features makes it easy to get results.

Table 6: Response Table for Signal to Noise Ratios Larger is better

Level	Current(A)	Flow(Lt/min)	Speed (mm/sec)
1	36.75	38.03	38.77
2	39.51	38.52	38.60
3	38.54	38.24	37.42
Delta	2.76	0.49	1.34
Rank	1	3	2

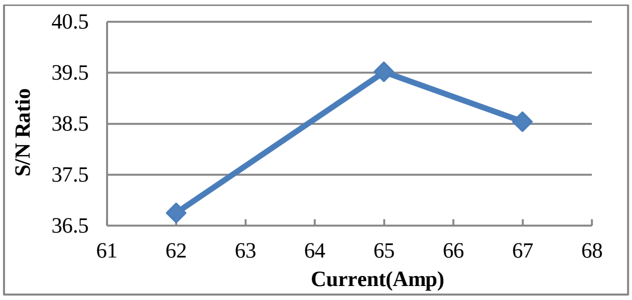

Fig.3 Main effect plot between S/N ratio and Current

The optimization of process parameters using Taguchi method permits evaluation of the effects of individual parameters independent of other parameters on the identified quality characteristic i.e. Ultimate tensile strength (UTS). The statistical analysis of variance (ANOVA) was carried out. Based on the ANOVA, the contribution of each parameter in influencing the quality characteristic is evaluated .The ANOVA also provides an indication of which process parameters are statistically significant. Signal to noise ratios are maximized using Larger the Better criterion and rank of each parameter influencing the ultimate tensile strength is found by using Taguchi method. Response for signal to noise ratio is shown in Table 6 and plots are shown in Fig. 3, 4 and 5. Similarly response for mean UTS is shown in Table 7 and plots are shown in Fig. 6, 7 and 8.

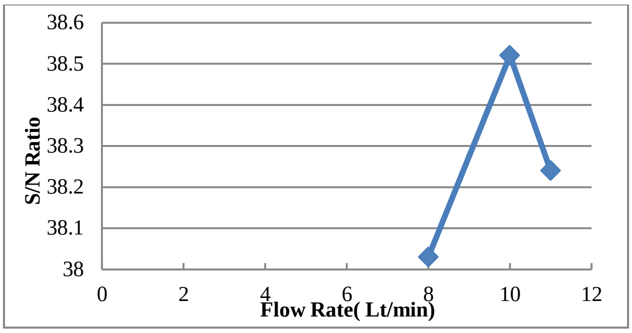

Fig.4 Main effect plot between S/N ratio and Flow rate

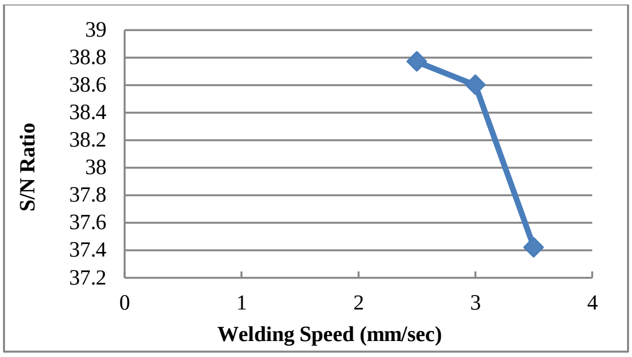

Fig.5 Main effect plot between S/N ratio and welding speed

Table 7: Response Table for Means (UTS)

Level	Current (Amp)	Flow (Lt/min)	Speed (mm/sec)
1	68.97	80.48	87.79
2	94.73	84.78	85.64
3	84.88	83.32	75.15
Delta	25.75	4.30	12.64
Rank	1	3	2

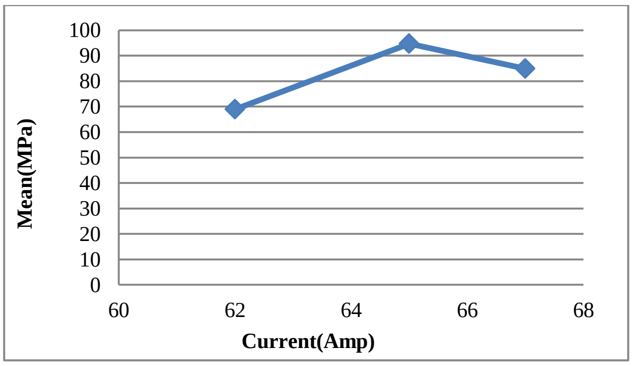

Fig. 6 Main effects plot between MeanUTS and current.

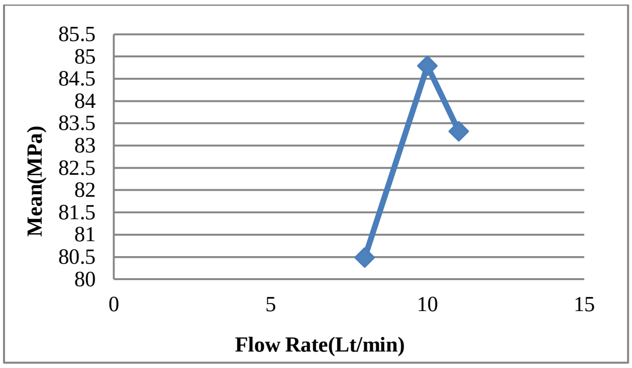

Fig. 7 Main effects plot between Mean -UTS and flow rate

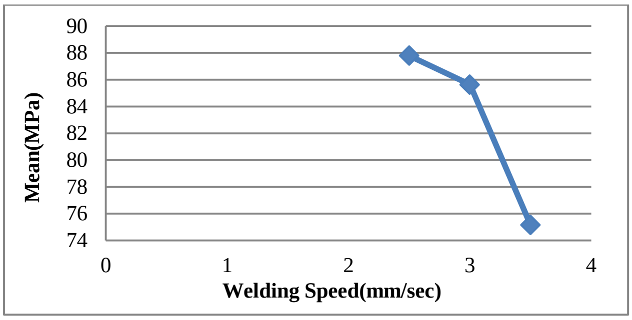

Fig. 8 Effects plot between Mean UTS and welding speed

3.2 Analysis of Variance

Results of ANOVA for mean UTS is shown in the Table 8, Where, DOF-Degrees of freedom (no of independent comparisons that can be made), Error- represents the unexplained variability in UTS, Seq SS- Sequential sum of Squares, Adj SS- Adjusted Sum of Squares, Adj MS-Adj Mean Squares.

Table 8: ANOVA for mean UTS

Source	DOF	Seq SS	Adj SS	F	P
Current	2	1013.41	506.71	296.62	0.003
Flow rate	2	28.74	14.37	8.41	0.106
Weld speed	2	274.37	137.19	80.31	0.012
Error	2	3.42	1.71		
Total	8	1319.94			

F value: The F-test is used to test if the variance measuring the differences between groups in a certain pre-defined grouping of observations is large compared to the variance measuring the differences within the groups: a large value would tend to suggest that grouping is *good* or *valid* in some sense, or that there are real differences between the groups. The formula for an F-test is:

$$F = \frac{\text{(explained variance)}}{\text{(unexplained variance)}},$$

Usually the change of welding process parameter has significant effect on response when the F ratio is large for ex like current in our case.

P value: The P value (alpha in the figure given below) for a F- test is the probability that a value chosen at random from a particular F distribution would be greater than or equal to the value of an observed value(the F-value)from the same distribution..For a particular confidence level, the value of P should be as small as possible for the model to be significant.

4. Results and Discussion

As per the ANOVA the optimum condition corresponds to C2 FR2 WS1 i.e. current at level 2(65 A), Flow rate at level 2(10Lt/min) and weld speed at Level 1(2.5 mm/sec). The coefficients of variables as shown in table 9 are calculated using the above model by MINITAB software and the regression equation developed is:

UTS = {- 123 + 3.61*(current) + 1.12*(flow rate) - 12.6*(welding speed)}

Table 9: Regression Analysis results

Predictor	Coeff.	SE Coeff.	T	P
Constant	-123.3	118.1	-1.04	0.344
Current	3.607	1.729	2.09	.091
Flow	1.119	2.849	0.39	0.711
Speed	-12.642	8.704	-1.45	0.206

Where, Coeff. is weight of predictor in the model, SE is Standard Error (Variability in estimates), T is Coeff. /SE (ex: -123.3/118.1 = -1.04), P is probability value for that level of T, and R-sq is validation criterion, i.e. in this case model accounts for 57% of the variance of the predictor i.e. the strength.

Table 10: ANOVA for testing regression

Analysis of Variance for testing significance of regression

Source	DF	SS	MS	F	P
Regression	3	751.7	250.6	2.21	0.206
Residual Error	5	568.2	113.6		
Total	8	1319.9			

Where, DF is degree of freedom, SS is Sum of squares, MS is Variance (=SS/DF) and P is contributed percentage.

5. Confirmation Test

The final step was to verify the improvement in the tensile strength by conducting experiment using optimal conditions.

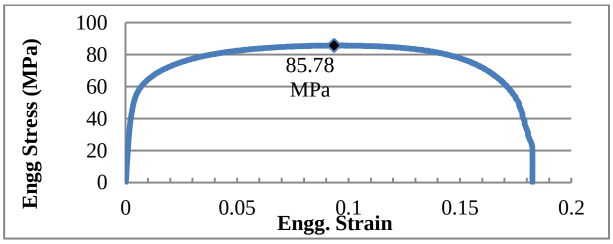

Fig. 9 Confirmation test conducted on butt welded Tensile specimen

Three specimens were tested for the set of optimized parameters and the tensile strength was found to be 85.78MPa as shown in Fig. 9, which is within the limits compared to the calculated value of 91.35 MPa obtained from the Linear equation.

Conclusions

From the above calculations and analysis we find that

- The current level for maximum strength was at 65 Amperes which could be explained as greater the value of current the easier it becomes to penetrate the hard oxide layer of Aluminium deposited on the sheet. On the other hand increase of current further would cause oxidation of Tungsten and causing its contamination.
- The flow rate was found to affect the tensile strength such that maximum strength was observed at flow rate of 10lt/hr. This could be explained as the flow rate is needed to prevent oxidation and shielding but again excess flow would be detrimental as it would cause cooling and turbulence in the weld pool.
- The speed would be optimized at level 1 i.e. 2.5 mm/sec which would facilitate proper fusion and strength.
- The value of R sq is obtained which is measure of amount of reduction in variability of tensile strength (dependent variable in this case) that the effect of parameters is 57% and the rest is unaccounted for. The unaccounted factors could be arc gap, feed angle of filler rod etc.
- There could be error in the measurements of the chosen parameters which could be beyond our control.

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