Experimental Investigation and Optimization of TIG Welding Parameters on Aluminum 6061 Alloy Using Firefly Algorithm

Rishi Kumar, Ramesh N Mevada, Santosh Rathore, Nitin Agarwal, Vinod Rajput, AjayPal Sinh Barad
Assistant Professors, Department of Mechanical Engineering, Smt. S. R. Patel Engineering College-Unjha, Gujarat, India.

Abstract: To improve Welding quality of aluminum (Al) plate, the TIG Welding system has been prepared, by which Welding current, Shielding gas flow rate and Current polarity can be controlled during Welding process. In the present work, an attempt has been made to study the effect of Welding current, current polarity, and shielding gas flow rate on the tensile strength of the weld joint. Based on the number of parameters and their levels, the Response Surface Methodology technique has been selected as the Design of Experiment. For understanding the influence of input parameters on Ultimate tensile strength of weldment, ANOVA analysis has been carried out. Also to describe and optimize TIG Welding using a new metaheuristic Nature-inspired algorithm which is called as Firefly algorithm which was developed by Dr. Xin-She Yang at Cambridge University in 2007. A general formulation of firefly algorithm is presented together with an analytical, mathematical modeling to optimize the TIG Welding process by a single equivalent objective function.

Keywords: Optimization, Spattering, Taguchi method, TIG welding.

1. INTRODUCTION

TIG welding is a thermal process that depends upon heat conducted through the weld joint materials to attain the penetration. The melting temperature necessary to weld materials in the TIG welding is obtained by inducing an arc between a tungsten alloy electrode and the work piece and the weld pool temperatures can advance up to 2500°C [1]. In TIG welding, a non-consumable tungsten electrode of diameter between 0.5 to 6.5 mm is employed with a cover of inert gas shielding (argon) around it as shown in Figure 1. As the process consumes a non-consumable electrode hence the extra filler material is usually added. The shielding gas shields both the tungsten electrode and the weld pool from the detrimental effects of surrounding atmosphere gases. Argon is most commonly employed shielding gas in welding unalloyed, low alloyed and stainless steels. Both power supply sources (AC or DC) can be used in this process. In general, this process uses a direct current (DC) arc, where the tungsten electrode has a negative polarity, consequently the tungsten electrode turns into the cathode and the work piece turns into the anode and the polarity is known as straight polarity or direct current electrode negative (DCEN). All welding position capabilities are present in this process while others are limited to one or a few welding positions. TIG welding finds its application in pressure vessels, aero, rocket, and missile, nuclear and marine industries.

The welding torch is used to hold the tungsten electrode which conducts welding current to the arc and also act as a means of conveying shielding gas in the arc zone. Torches are rated according to the maximum welding current that can be used without overheating. The tungsten electrode serves as one of the electrical terminals of the arc which supply the heat required for welding. Its melting point is 3500°C. Depending on the weld preparation and the workpiece thickness, it is possible to work with or without a filler wire. The shield gas is generally selected according to the material to be welded.
2. PROCESS VARIABLES

2.1 Material
The most influential parameter can be grouped under base metal properties like material composition and material properties such as thermal conductivity, coefficient of thermal expansion, reaction with atmospheric oxygen and crack sensitivity.

2.2 Weld geometry
It is used for selecting the welding process. There can be various joints such as butt, lap, fillet or T-joint. Bevel may be single-V, double-V or U shape. Weld geometry has a direct influence upon weld quality. There can be various Welding positions such as flat, horizontal, vertical, or overhead, etc. Vertical and horizontal welding positions are most commonly used. If the welding position is difficult, then it increases the problems in achieving the required weld quality. Weld bead geometry is also influenced by the position in which the workpiece is held with respect to the welding gun.

2.3 Shielding Gas (lit/min)
It acts as protective gas to prevent atmospheric contamination. TIG welding process is mostly performed under the cover of shielding gas as a result it also enhances weld quality. The shielding gas flow rate has a dominant effect on weld bead shape which in turn affects the distortion, residual stresses, heat affected zone (HAZ) and mechanical properties of the material to be welded.

2.4 Welding Speed (cm/min)
It varies with the weld penetration and width of beads. Maximum weld penetration is achieved at a specific welding speed and decreases with the speed variation. The increased input heat per unit length due to reduced speed results in increase of weld width and vice versa. Variations in travel speed at a set current and voltage also affect bead shape. As the welding speed decreases, the heat input per length of joint increases, and the penetration and bead width increase. If the travel speeds are excessively high, then it results into a crowned bard as well as the tendency to undercut and porosity.

2.5 Material thickness
Material thickness plays a critical role in process selection and setting of parameters. Material thickness decides the input heat required and to control the cooling rate. Higher thickness means the higher cooling rate, ensuing increase in heat affected zone (HAZ) and hardness of weld metal.

2.6 Welding Current (Amp)
Welding current is one of the most significant parameters that directly affects the penetration and lack of fusion by affecting the speed of welding. Welding current is the presently being used in the welding circuit during the making of a weld. If the current is very high at a given welding speed, the depth of fusion or penetration will also be very high. If the plates are thinner, then it tends to melt through the
metal being joined. It also leads to excessive melting of filler wire, resulting in excessive reinforcement. Hence, additional heat input to the plates being welded results into increased weld induced distortions and if the welding current is too low, it may lead to lack of fusion or inadequate penetration.

2.7 Welding Voltage (V)

Welding Voltage is defined as the electrical potential difference between the tip of the welding wire and the surface of the molten weld pool. It decides the shape of the fusion zone and weld reinforcement. Depth of penetration attains maximum at optimum arc voltage and directly affects the bead width. It also affects the microstructure and even the success and failure of the operation. Like current, welding voltage influences the bead shape and the weld deposit composition. When there is an increase in the arc voltage then it results in a long arc length and a correspondingly wider, flatter bead with less penetration. A slight increase in the arc voltage results the weld to bridge gaps when welding in grooves. Excessive high voltage gives rise to a hat shaped concave weld and found to have low resistance to cracking and a tendency to undercut. Lower voltages reduce the arc length and there is an increase in penetration. Excessively low voltage results in an unstable arc and a crowned bead, which has an uneven contour where it meets the plate.

3. SELECTION OF INPUT PARAMETERS AND THEIR EFFECT ON WELDING

3.1 Welding Current

Welding current is the most significant variable in arc welding process which influences the electrode burn off rate, the depth of fusion and the geometry of the weldments. The current to be used depends on many factors such as electrode type, size, welding position, joint design.

3.2 Current Polarity

The Current Polarity influences the weldments properties. Ac & DC current can be used for welding. The straight and reverse polarity affects the penetration in DC current. The Workpiece is attached to the positive terminal and the electrode to the negative terminal in Direct Current Straight Polarity (DCSP) whereas in Direct Current Reverse Polarity (DCRP) workpiece is negative and electrode is positive.

3.3 Gas Flow Rate

With the increase in gas flow there is a change in bead geometry of the welded joint which dominates the weld characteristics such as weld height, weld bead.

4. PROPOSED DESIGN OF EXPERIMENTS

The design of experiments (DOE) is a technique used to plan, conduct and analyze the experiments to have the efficient and economical conclusions. The orthogonal array (OA) provides a set of well balanced (minimum experimental runs) experiment plan. Welding process input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of tensile strength. The table shows the Experimental layout using L20 orthogonal array.
Table I: Experimental layout using L20 orthogonal array

| Factors level | Experimen t no. | A. Welding current | B. Gas flow Rate | C. Current Polarity |
|---------------|-----------------|-------------------|------------------|---------------------|
|               |                 | 1                 | 3                | 1                   |
| 1             | 2               | 1                 | 1                | 3                   |
| 2             | 3               | 2                 | 3                | 2                   |
| 3             | 4               | 3                 | 3                | 3                   |
| 4             | 5               | 3                 | 2                | 2                   |
| 5             | 6               | 2                 | 2                | 1                   |
| 6             | 7               | 2                 | 2                | 2                   |
| 7             | 8               | 2                 | 2                | 2                   |
| 8             | 9               | 3                 | 3                | 1                   |

5. EXPERIMENTAL STEPS
In the present study 20 pairs of Double V shaped butt joint specimens of dimensions 150mm× 50mm× 6 mm has been prepared. The plate’s edges were cleaned and grinded along the weld line to ensure full contact prepared. The plate’s edges were cleaned and ground along the weld line to ensure full contact. The table shows the Range of input variables for welding.

Table II Range of input variables for welding

| S No. | Variables       | Unit    | Minimum Value | Maximum Value |
|-------|-----------------|---------|---------------|---------------|
| 1     | Welding Current | Amper e | 150           | 200           |
| 2     | Gas flow Rate   | Lt/min  | 8             | 10            |
| 3     | Current Polarity|         | -1            | 1             |

In the Response Surface Methodology, welding current, welding speed, gas flow rate was used as input variables. The combination of these variables has been used to predict weld tensile strength. Table shows the Control factors and their level used in the experiments and Table depicts the Experimental results for the Ultimate Tensile Strength.

Table III Control factors and their Levels

| Sl. No. | Factors       | Unit    | Level 1 | Level 2 | Level 3 |
|---------|---------------|---------|---------|---------|---------|
| 1       | Welding Current | Ampere | 150     | 175     | 200     |
| 2       | Gas flow Rate  | Lt/min  | 8       | 9       | 10      |
| 3       | Current Polarity |        | -1      | 0       | 1       |
In addition, a statistical analysis of variance (ANOVA) has been also performed to determine which process parameters are statistically significant i.e more influential for selecting optimal combination of the process parameters has been predicted. The experimental result of the tensile strength has been shown in Table 4. Maximum value of Ultimate tensile strength is 137.104 Mpa and the minimum value is 46.619 Mpa. The analysis of variance is carried in Minitab software. The percentage contribution of each parameter on ultimate tensile strength is obtained. Firefly Algorithm is used for finding out the optimum values of the parameter. The programming of firefly algorithm is done in Matlab software. The best value of the operation parameter that would be selected in order to get maximum value of ultimate tensile strength is given by Firefly Algorithm. The output given by Firefly Algorithm is shown by Table V. Confirmatory test results shown in Table VI proved that the determined optimal combination of welding parameters, with respect to the reference parameters, satisfies the real requirement of welding operations of Al-6061 alloy.

### Table IV Experimental results for the Ultimate Tensile Strength

| Exp. p. | A. Welding current | B. Gas flow | C. Current Polarity | Ultimate Tensile Strength Mpa |
|---------|------------------|-------------|---------------------|-------------------------------|
| 1       | 150              | 10          | -1                  | 98.896                        |
| 2       | 150              | 8           | 1                   | 68.613                        |
| 3       | 175              | 10          | 0                   | 58.340                        |
| 4       | 200              | 10          | 1                   | 83.899                        |
| 5       | 200              | 9           | 0                   | 48.866                        |
| 6       | 175              | 9           | -1                  | 122.712                       |
| 7       | 175              | 9           | 0                   | 137.104                       |
| 8       | 175              | 9           | 0                   | 48.370                        |
| 9       | 200              | 10          | -1                  | 122.712                       |
| 10      | 175              | 9           | 0                   | 68.514                        |
| 11      | 175              | 9           | 0                   | 122.704                       |
| 12      | 175              | 9           | 0                   | 122.712                       |
| 13      | 175              | 9           | 1                   | 43.011                        |
| 14      | 200              | 8           | 1                   | 122.712                       |
| 15      | 150              | 10          | 1                   | 46.619                        |
| 16      | 175              | 9           | 0                   | 122.712                       |
| 17      | 150              | 8           | -1                  | 81.657                        |
| 18      | 175              | 8           | 0                   | 60.270                        |
| 19      | 200              | 8           | -1                  | 122.712                       |
| 20      | 150              | 9           | 0                   | 60.350                        |

### Table V Optimum Values of Parameter

| Sr. No | Parameter       | Value |
|--------|-----------------|-------|
| 1      | Welding Current | 150   |
| 2      | Gas Flow Rate   | 10    |
| 3      | Current Polarity| -1    |

### Table VI Conformation Test

| Optimal Experimental Combination | Experimental Value | Model Prediction | Prediction Error (%) |
|----------------------------------|--------------------|------------------|----------------------|
| Welding Current                  | Ultimate Tensile Strength Mpa | Ultimate Tensile Strength Mpa | Ultimate Tensile Strength Mpa |
| 150                              | 98.896             | 104.124          | 5.284                |
6. CONCLUSION

In this study the parameter optimization of TIG welding parameters using Firefly Algorithm on Aluminum Alloy 6061 is carried out. The input parameters are welding current, gas flow rate and current polarity with three levels for each parameter. The output parameter is the ultimate tensile strength. 15 specimens were welded according to specific values of the parameter given by RSM and tensile strength was measured by tensile testing machine. ANOVA analysis using response surface methodology is effectively carried out. Percentage Contribution of the parameters in the ultimate tensile strength of the weldments is obtained by using RSM Mathematical model showing the relationship between input and output parameter is obtained using bounded points. Various contours and surfaces are plotted in order to understand the relationship between input and output parameters. Optimization is carried out using Firefly algorithm. The optimum values of welding parameters are obtained. Confirmatory test results proved that there was good agreement between the experimental and predicted results.

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• Prof. Rishi Kumar has completed his masters in Industrial Design from Maulana Azad National Institute of Technology, Bhopal in the year 2014. He has published 4 research papers in international conferences and journals and 11 research papers in national conferences. He has
EMERGING TECHNOLOGIES (NCIET-2016) from 2nd & 3rd June-2016. He has teaching and research experience of 2 years and 6 months at Smt. S.R. Patel Engineering College, Unjha, and Gujarat. He is a Life Member of Indian Society of Technical Education (ISTE) and Life Member of International Association of Engineers (IAE).

• Prof. Ramesh N. Mevada has been working as a Head of Mechanical Engineering Department at Smt. S.R. Patel Engineering College, Unjha since 2012. He has very vast experience of 25 years. He has coordinated 1st NATIONAL CONFERENCE ON INNOVATIVE & EMERGING TECHNOLOGIES (NCIET-2013). He has published and presented 15 research papers in various journals and conferences. He is a Life Member of Indian Society of Technical Education (ISTE).

• Prof. Santosh K Rathore has completed his masters in Design and thermal engineering 1 Institute of Engineering and Technology, DAVV Indore in the year 2011. He has teaching and research experience of 5 years and 3 months at Engineering College, and currently he is working as Assistant Professor Smt. S.R. Patel Engineering College, Unjha, Gujarat. He has done his research work in “solar energy and its application”. He has published research papers in 2 international and 4 national conference. He is a Life Member of ISHRAE and IAE.

• Prof. Vinod Rajput has completed his masters in Thermal Engineering from Gujarat Technological University, Gujarat in the year 2013. He has done his research work in “Heat Pump analysis”. He has teaching and research experience of 4 years and 6 months at Engineering College, and currently he is working as Assistant Professor Smt. S.R. Patel Engineering College, Unjha, Gujarat. He has published research papers in 2nd international and 4th national conference. He is a Life Member of ISTE and IAE.

• Prof. Nitin Agrawal has completed his masters in Stress and Vibration Analysis from Maulana Azad National Institute of Technology, Bhopal in the year 2016. He has done his research work in “Vibration Analysis of Railway Bridges”. He started his teaching at Smt. S.R. Patel Engineering College, Unjha, Gujarat. He is a Life Member of IAE.

• Prof. Ajaypalsinh Barad has completed his masters in Thermal Engineering from Parul Institute of Technology, Vadodara in the year 2012. He has teaching and research experience of 4 years as an Assistant Professor at Smt. S.R. Patel Engineering College, Unjha, Gujarat. He has done his research work in “Solar Energy and Its Application”. He has published 3 research papers in national conferences.