**MULTI OBJECTIVE OPTIMIZATION OF TIG WELDING PROCESS PARAMETERS ON ALLOY 61s USING TAGUCHI**

**BASED GREY RELATIONAL ANALYSIS**

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**Abstract**

Aluminium Alloy 6061 (Alloy 61s) sets the standard for a medium-to-high strength, lightweight and economical material. The properties of 6061 aluminium include its structural strength and toughness, its machinability, and its ability to be easily welded and joined. 6061 aluminium is used extensively as a construction material, most commonly in the manufacture of automotive components. This study focuses on the multi-objective optimization of [tungsten](https://www.sciencedirect.com/topics/materials-science/tungsten) inert [gas welding](https://www.sciencedirect.com/topics/materials-science/arc-welding) process on Aluminium alloy 6061 using grey relational analysis. The welding input parameters play a vital role in determining desired weld quality. The experiments were conducted according to L9 orthogonal array. The input parameters chosen for the analysis were the [welding current](https://www.sciencedirect.com/topics/materials-science/welding-current), Gas flow rate and double ‘V’ Groove angle. The output response for the quality targets chosen were the ultimate [tensile strength](https://www.sciencedirect.com/topics/materials-science/tensile-strength) and [hardness](https://www.sciencedirect.com/topics/materials-science/yield-stress) (at room temperature). Grey relational analysis was applied to optimize the input parameters simultaneously considering multiple output variables. ANOVA was performed to reveal the order of influence of each input factors on the responses. Regression analysis has also been made for attaining the statistical models of the input – output relationships. 3D surface plots were analyzed for understanding the relationship between combinations of input factors with the output responses.

**Keywords:** TIG welding, Alloy 61s, Aluminium alloy 6061, Optimization, Regression analysis, Grey Relational Analysis, Double V Groove angle.

1. Introduction

Welding process is the most important phenomenon in any sort of higher level industrial requirement. The process of welding does not involve the step by step procedure only; in addition to that it involves the need to concentrate on the various influencing process parameters since they determine the strength of the weldments. TIG welding is one among the welding process which is known for its better strength enhancing characteristic. G.Magudeeswaran et al. have researched on the activated TIG (ATIG) welding process in which increasing the depth of penetration was mainly focused; and the reduction in the width of weld bead was not paid much attention [1]. V.Anand Raoa et al. has focused on the analysis and optimization of joining similar grades of stainless steel by TIG welding. The parameters like current, filler materials and welding speed were the variables in their study[2]. Nabendu Ghosh et al. have focused on the study of visual inspection and X-ray radiographic tests for detecting surface and sub-surfaced effects of weld specimens made of AISI 316L austenitic stainless steels. They analyzed the effects of gas flow rate, current and the distance between nozzle and plate distance on quality of weld in MIG welding of AISI 316L austenitic stainless steel through experiments and analyses [3]. Arun Kumar Srirangan et al. have investigated on Inconel alloy 800HT which is a suitable material for fourth generation power plant, can exhibit appreciable strength, good resistance to corrosion and oxidation in high temperature environment [4]. P. Bharath et al. have determined the influence of various welding parameters on the weld bead of AISI 316 welded joint. In this research work the ANOVA technique was used to identify the influence of the welding speed, current, electrode and root gap on the strength of the material [5].

G. Rambabu et al. have researched on aluminium alloy 2219 which is widely used in the fabrication of lightweight structures with high strength-to-weight ratio and good corrosion resistance [6]. S.C Juang., et al. have analyzed the selection of process parameters for obtaining optimal weld pool geometry in the tungsten inert gas (TIG) welding of stainless steel [7]. A. Kumar et al. have worked on improving the 5456 Aluminum alloy weldments’ mechanical properties through pulsed tungsten inert gas (TIG) welding process. They used Taguchi method for optimizing the influencing factors of pulsed TIG welded on AA5456 joints [8]. Joby Joseph et al. in their work concentrated on optimizing the activated TIG welding parameters for improving the strength of AISI 4135 PM steel weldments with the help of genetic algorithm. They reported that voltage and current have a maximum influence on tensile strength in A-TIG-welded joint [9]. RaviShanker Vidyarthy et al. investigated the TIG welding process parameters on 9 to 12 % Chromium Ferritic Stainless steel by using Central Composite Design; and reported that welding speed, welding current and flux coating density have the direct influence on the weld strength [10].

From the literature survey, it can be noted that various researchers made attempt on optimizing the Tungsten Inert Gas welding process parameters. But, only few number of research works have been concentrated on optimizing the TIG welding process parameters of aluminum alloys. The nature of getting oxidized during the welding process since Aluminium alloys contain Oxygen content may be the reason for the same. But, aluminium alloys are widely preferred in many light weight applications like aero plane and ship body parts manufacturing. Hence, it is planned to perform an analysis on optimizing the process parameters of TIG welded AA 6061 plates for getting optimal mechanical properties.

1. Experimental Work

The proposed material of size 150 X 75mm with the thickness of 6mm has been chosen as master piece and V groove of various angles was formed at the edges after cleaning the surface. The welding was performed using TIG welding process along the length of 150mm. The test specimens were prepared using Wire Cut Electrical Discharge (WEDM) machining process from the master piece as per ASTM standard E-8M for performing tensile test. The Vickers hardness test was performed over the welded zone. The chemical composition and the mechanical properties of Al6061 alloy are presented in the tables 1 and 2.

Table 1. Chemical composition of Al 6061

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Element** | Cr | Cu | Fe | Si | Ti | Zn | Mg | Mn | Al |
| **Wt. %** | 0.15 | 0.21 | 0.60 | 0.38 | 0.03 | 0.01 | 1.03 | 0.06 | Bal. |

Table 2. Base Material Properties

|  |  |
| --- | --- |
| **Properties** | **Values** |
| Ultimate tensile strength (MPa) | 310 |
| Yield strength (MPa) | 270 |
| Modulus of elasticity (GPa) | 70 – 80 |

* 1. Design of Experiments (DOE)

In view of optimizing the strength and hardness of the weldments, the input parameters of TIG welding such as Weld current (WC), Shielding Gas Flow Rate (SGFR) and Double ‘V’ Groove Angle (DVGA) were considered for the analysis at three different levels which are presented in table 3. The experiments to be performed were decided based on Taguchi’s L9 orthogonal array table. The combinations of the selected parameters for performing experimentation on samples with the input parameters and their levels are presented in table 4.

Table 3. Selection of levels and parameters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Parameters** | **Units** | **Level 1** | **Level 2** | **Level 3** |
| 1. | WC | Amps | 150 | 170 | 190 |
| 2. | SGFR | Lpm | 6 | 8 | 10 |
| 3. | DVGA | Degrees | 30 | 40 | 45 |

Table 4. The Taguchi’s L9 Orthogonal Array

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.No.** | **Sample No.** | **Input Parameters** | | |
| **WC** | **SGFR** | **DVGA** |
| 1 | SA01 | 150 | 6 | 45 |
| 2 | SA02 | 150 | 8 | 40 |
| 3 | SA03 | 150 | 10 | 30 |
| 4 | SA04 | 170 | 6 | 40 |
| 5 | SA05 | 170 | 8 | 30 |
| 6 | SA06 | 170 | 10 | 45 |
| 7 | SA07 | 190 | 6 | 30 |
| 8 | SA08 | 190 | 8 | 45 |
| 9 | SA09 | 190 | 10 | 40 |

* 1. Specimen Preparation

In each category of samples three specimens were prepared and tested. Hence for nine set of parameters, as presented in Table 4, totally 27 samples were prepared using TIG welding process. The test samples were prepared from the master sample for tensile and hardness tests using Wire-cut Electrical Discharge Machine (WEDM) following ASTM Standards. The welded zone was grinded so as to make smooth surface by removing the burrs.

* 1. Tensile Test

Tensile tests on the samples were performed with computer interfaced universal testing machine of 60 tones capacity. It had the provision to extract the test data to a computer interfaced with the digital data logger. The tensile test specimens before and after the testing are shown in figure 1 and 2.

|  |  |
| --- | --- |
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| **Fig 1.** Specimens for the tensile testing | **Fig 2.** Tensile tested specimens |

* 1. Hardness Test

Hardness test was conducted on Vickers Hardness Testing machine. The hardness test was made on all the test specimens at the welded portion.

* 1. Optimization Techniques

Grey Relational Analysis (GRA) is one of the multi objective optimization techniques since it provides the optimized combination of input parameters for obtaining desirable results for all the output parameters. With the grey relational grade values obtained from the analysis, Taguchi’s approach was used to confirm the results.

Regression analysis provides the relationship between the input parameters with each output parameter in the form of statistical equations. By conducting more number of experiments, we can frame the regression equation with better accuracy.

1. Results and Discussion

The results of tensile strength test and hardness test are presented in table 5.

**Table 5.** Tensile Test Results

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S.No.** | **Sample No.** | **Ultimate Strength (MPa)** | | | | **Vickers Hardness Number (VHN)** | | | |
| **T1** | **T2** | **T3** | **Tavg** | **T1** | **T2** | **T3** | **Tavg** |
| 1 | SA01 | 123.50 | 122.70 | 123.10 | 123.10 | 87.60 | 86.60 | 87.10 | 87.10 |
| 2 | SA02 | 99.80 | 98.80 | 99.30 | 99.30 | 86.20 | 87.00 | 86.60 | 86.60 |
| 3 | SA03 | 132.60 | 133.40 | 133.00 | 133.00 | 86.10 | 85.30 | 85.70 | 85.70 |
| 4 | SA04 | 103.90 | 105.50 | 104.70 | 104.70 | 84.50 | 80.40 | 82.45 | 82.45 |
| 5 | SA05 | 110.80 | 111.20 | 111.00 | 111.00 | 82.90 | 84.30 | 83.60 | 83.60 |
| 6 | SA06 | 121.00 | 120.80 | 120.90 | 120.90 | 87.40 | 82.20 | 84.80 | 84.80 |
| 7 | SA07 | 106.20 | 105.00 | 105.60 | 105.60 | 86.50 | 82.20 | 84.35 | 84.35 |
| 8 | SA08 | 127.50 | 125.10 | 126.30 | 126.30 | 84.20 | 81.80 | 83.00 | 83.00 |
| 9 | SA09 | 138.40 | 136.50 | 137.45 | 137.45 | 84.20 | 83.10 | 83.65 | 83.65 |

* 1. Grey Relational Analysis (GRA)

With the avialable test results, the technique of GRA has been employed for predicting the best set of parameters that yields best tensile and hardness value.

The output parameters of tensile and hardness properties will have different units. In order to consider them together, the normalization of the parameters are inevitable. The normalization of the above parameters were carried out as the first step of GRA. Followed by, the deviation sequences for the considered outpt responses were predicted. Table 6 represents the normalized values and deviation sequences of each output responses.

**Table 6.** Normalized values and Deviation sequensces of responses

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Sample No.** | **Normalized values** | | **Deviation Sequences** | |
|  | **VHN** |  | **VHN** |
| 1 | SA01 | 0.624 | 1.000 | 0.376 | 0.000 |
| 2 | SA02 | 0.000 | 0.892 | 1.000 | 0.108 |
| 3 | SA03 | 0.883 | 0.699 | 0.117 | 0.301 |
| 4 | SA04 | 0.142 | 0.000 | 0.858 | 1.000 |
| 5 | SA05 | 0.307 | 0.247 | 0.693 | 0.753 |
| 6 | SA06 | 0.566 | 0.505 | 0.434 | 0.495 |
| 7 | SA07 | 0.165 | 0.409 | 0.835 | 0.591 |
| 8 | SA08 | 0.708 | 0.118 | 0.292 | 0.882 |
| 9 | SA09 | 1.000 | 0.258 | 0.000 | 0.742 |

The Grey Rlational Coefficient values and Grade Relational Grade values were computed with the help of regular formulae, which are tabulated and presented in table 7.

**Table 7.** Grey Relational Coefficient and Grey Relational Grade values of output responses

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sample No.** | **Grey Relational Coefficient** | | **Grey Relational grade** | **Rank** |
|  | **VHN** |
| SA01 | 0.571 | 1.000 | 0.785 | 1 |
| SA02 | 0.333 | 0.823 | 0.578 | 4 |
| SA03 | 0.811 | 0.624 | 0.718 | 2 |
| SA04 | 0.368 | 0.333 | 0.351 | 9 |
| SA05 | 0.419 | 0.399 | 0.409 | 8 |
| SA06 | 0.535 | 0.503 | 0.519 | 5 |
| SA07 | 0.375 | 0.458 | 0.416 | 7 |
| SA08 | 0.631 | 0.362 | 0.496 | 6 |
| SA09 | 1.000 | 0.403 | 0.701 | 3 |

Taguchi analysis was then made to finalize the optimal combination of input responses from the Grey Relational Grade values with the help of minitab software 14.0. The main effect plot for the S/N ratio values of the Grey Relational Grades obtained from the Taguchi analsyis is shown in the figure 4.

|  |
| --- |
|  |
| **Fig.4.** Main effects plot for S/N ratio values of Grey Relational Grade values |

As observed from figure 4, the optimal parameter combination for the TIG welding process on Alloy 61s regarding Tensile strength and Hardness were noted as: Current (150 A), Gas flow rate (10 lpm) and Double V Groove angle (45 degree). The confirmation test was conducted with the arrived optimal combination of input parameters and the results were arrived for the Tensile strength value as 136.4 MPa and Hardness value as 87 VHN. Analysis of Variance was prformed for the Grey Relational Grades corresponding to the levels of input parameters. The ANOVA table obtained for the proposed case is as shown in the table 8. From the results of ANOVA table, it was palpable that Weld current inflenced more in getting optimal output results; and the least inflencing factor was identified as Double ‘V’ Groove angle.

**Table 8.** ANOVA Results for the considered process parameters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Main Control Factors** | **Degree of**  **freedom**  **(DF)** | **Sum of squares**  **(SS)** | **Mean of squares**  **(MS)** | **P - Value** | **Contribution,**  **C (%)** |
| **WC (A)** | 2 | 0.10820 | 0.054099 | 0.209 | 57.46 |
| **SGFR (lpm)** | 2 | 0.04009 | 0.020043 | 0.417 | 21.29 |
| **DVGA (Degree)** | 2 | 0.01139 | 0.005695 | 0.715 | 6.05 |
| **Error** | 2 | 0.02861 | 0.014307 | - | 15.20 |
| **Total** | 8 | 0.18829 | - | - | 100.00 |

* 1. Regression Analysis

The tensile and hardness test results were fed into the Design Expert software with their corresponding combination of input parameters. The optimized statistical relationship between the input parameters and tensile strength as well as with hardness values were arrived as represented in equations 1 and 2 with the R-squared values of 0.9694 and 0.8768.

(Equation 1)

(Equation 2)

The 3D response plots were drawn and analyzed the effects of varying the levels input factors on the responses, which are shown in figures 5 and 6.

|  |  |
| --- | --- |
| C:\Users\MARCEL\Desktop\TS.bmp | C:\Users\MARCEL\Desktop\VHN.bmp |
| **Fig 5.** 3D surface plot of TS vs. WC & SGFR | **Fig 6.** 3D surface plot of VHN vs. SGFR & DVGA |

The 3D plots revealed that increasing the value of Weld Current, it can be achieved the TIG welded specimens with more tensile strength. Tensile strength also increased with the increase in gas flow rate. In case of achieving better hardness results, Double ‘V’ Groove angle had less siginificant effect and the increase in the gas flow rate and increase in VHN were of directly proportional.

1. Conclusion

* In this work, optimization of TIG welding process parameters was performed using Taguchi based Grey Relational analysis and Regression analysis. Three parameters with three levels were considered for the analysis. Experiments have been conducted as per the parameter combination of L9 Orthogonal Array.
* From the Grey Relational analysis, the optimal parameter combination for the TIG welding process on AA6061 are: Current (150 A), Gas flow rate (10 lpm) and Double V Groove angle (45 degree).
* The optimal results for the tensile strength and hardness values were noted for the TIG welded Aluminium Alloy 6061 joints were noted as 136.4 MPa and 87 VHN respectively.
* ANOVA results revealed that the most influencing process parameter for achieving the optimal results was Weld current (57.46%), followed by Shielding Gas Flow Rate (21.29%) and Double ‘V’ Groove angle (6.05%).
* The statistical relationships were arrived for the input parameters with each output responses with the help of Regression analysis with the R-Squared values of 0.9694 and 0.8768.
* The 3D relationship plots were drawn and analyzed. The results showed that tensile strength will be higher while increasing the values of weld current and gas flow rate. By increasing the gas flow rate, the hardness value of the welded specimens got increased.

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