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Parametric Optimization of TIG Welded Aa6351 Joints Using Taguchi Method

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Abstract:
Aluminium and its alloys play a critical role in engineering material field due to its low weight and resistance to corrosion. The welding of aluminium alloys is challengeable by conventional arc welding processes and generally welded by Tungsten Inert Gas (TIG) welding. An attempt has been made to achieve better mechanical properties of welded joint that are nearer to the properties of base metal. This paper describes the parametric optimization of TIG welded plates of AA6351 alloy by using Taguchi method.. Taguchi Design of Experiments (L9 0rthogonal Array) was taken for systematic conduction of experiments using MINITAB software. The performance is measured in terms of ultimate tensile strength, impact strength and hardness with varying parameters as welding current, shielding gas flow rate and bevel angle. S/N ratio plots and regression equations were generated for the responses. After obtaining the results, the optimal process parameters were determined using Taguchi method. The results show that with increase in welding current and gas flow rate, the tensile strength of welding joint is increases. Hence, in this investigation an attempt has been made to examine the influence of TIG welding parameters on Mechanical properties of AA 6351 aluminium alloy weldments and its effects.

Keywords: TIG Welding, Welding current, Tensile strength, Impact strength, hardness, Taguchi method , AA6351.

I.INTRODUCTION

Aluminum alloys are used in many applications in which the combination of high strength and low weight. AA 6351 is known for its light weight and good corrosion resistance.

Si	Fe	Cu	Mn	Mg	Ti
0.8	0.12	0.051	0.52	0.75	0.017
Pb	Ca	Zr	Sn	Sb	Al
0.017	0.001	0.003	0.004	0.015	97.51

It has higher strength among the 6000 series alloys. This alloy is most commonly use for machining. Even if relatively a new alloy, the high strength of 6351 has replaced 6061 alloy in many industrial applications. Mechanical properties can be easily obtained at tensile tests, with great accuracy. The AA 6351 aluminum alloy is used in manufacturing due to its strength, bearing capacity, ease of work& weld ability. It is also applicable in construct boat, column, chimney, mould, pipe, tube. One of the most important properties of AA 6351 aluminum alloy is that the treatment of solid solution is not so critical. In this paper the experimental investigation was done on the mechanical properties of AA6351 welding plates. Is not only used for pressure vessels, rail and road bridges but also may be used for aerospace structures. Thus the experimental investigation is provided with the results of tensile strength, impact strength, and hardness. Tungsten Inert Gas (TIG) or Gas Tungsten Arc welding (GTAW) is the arc welding process in which arc is generated between non-consumable tungsten electrode and work piece. The shielding gas protects the tungsten electrode and the molten metal weld pool from the atmospheric contamination. The shielding gases commonly used are argon, helium or their mixtures. A constant current AC power source with a continuous high frequency is used with air-cooled TIG torch. The electric arc can generate temperatures of up to 19,400ºC. M.V. Niranjan Reddy et al [1] investigated the tensile strength on circular rod specimen of Al 6351 is finding out by applying the loads on universal testing machine with various dimensions. The experimental results were found satisfactory to propose the alternative alloy for aircraft structures. Tensile strength of the Al 6351 to best suit for the aerospace structures. this alloy may also be used for the aerospace structures as the production rate is highly available at lowest possible cost From this investigation the important conclusions derived are 250MPa tensile strength and 20% elongation of Al 6351 is nearer to the required strength for aerospace structures. Manpreet Singh et al [4] investigated on the process parameters of aluminum alloy 6061 when its undergoing on tig welding The performance is measured in terms of ultimate tensile strength with varying parameters like welding current, shielding gas flow rate and preheating. Micro structural characterization of welded joint was carried out to understand the structural property correlation with process parameters. The results show that with increase in welding current and gas flow rate, the tensile strength of welding joint is increases. Parthiv T.Trivedi, et. Al [2] investigated input parameters such as current, welding speed and gas flow rate were controlled using the control panel of the automatic welding set up for welding aluminium alloy AA6063. GTAW process is well known for narrow welds that means deeper penetration and narrower weld width. By consider these quality characteristics a constrained problem is formulated. Indira Rani M et al [3] studied the mechanical properties of the weldments of AA6351 during the Gas Tungsten Arc Welding (GTAW)/Tungsten Inert Gas Welding (TIG) with non-pulsed and pulsed current welding at different frequencies 3Hz and 7Hz is attempted in this work. The radiography and mechanical properties of the weldments have been examined and compared with non-pulse and pulsed current welding (PCW) at two different frequencies 3Hz and 7Hz. The mechanical properties like tensile strength, % of elongation, 0.2% yields strength of AA6351. No defects were found in the weldments of AA6351 and tensile strength of the joints was more in the case of pulsed current welding. R. Adalarasan et al [6] conducted the experimental investigation of the bond strength and hardness of the friction welded joints involving AA 6061 and AA 6351 alloys by conducting experiments designed by Taguchi's L9 orthogonal matrix array. A systematic approach becomes essential to find the optimal setting of friction welding parameter. K. Kishore1 et al [5] Researched on the welding of materials like Aluminum alloys is still critical and ongoing. An attempt has been made to analyze the effect of process parameters in qualitative manner for welding of Aluminum alloy (AA 6351) using Gas Shielded Metal Arc Welding (TIG). Taguchi's method is used to formulate the experimental layout. Exhaustive survey suggest that 5-7 control factors viz, arc voltage, arc current, welding speed, nozzle to work distance and gas pressure predominantly influence weld quality, even plate thickness and backing plate too have their own effect. T. Senthil Kumar et al [7] made an attempt to study the influence of pulsed current TIG welding parameters on tensile properties of AA 6061 aluminium alloy weldments. They find the pulsed current has been found beneficial due to its advantages over the conventional continuous current process. The use of pulsed current parameters has been 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. M. Peel et al [8] reported the results of microstructural, mechanical property and residual stress investigations of four aluminium AA5083 friction stir welds produced under varying conditions. It was found that the weld properties were dominated by the thermal input rather than the mechanical deformation by the tool. Lalit Narwar et al [9] proposed in the literature to solve the problems related with optimization of these parameters. It is felt that a review of the a variety of approaches developed would help to compare their main features and their relative advantages or restrictions to allow choose the most suitable approach for a particular application and also throw light on aspects that needs further consideration. In view of above, this paper presents a review of development happened in optimization of TIG welding related process parameters. Pawan Kumar1 et al[10] formulate experimental layout and to study effect of process parameter optimization on mechanical properties of the weld joints. Micro structural characterization of weld joint was carried out to under-stand the structural property correlation with process parameters. The present work pertains to the investigate the mechanical properties of AA 6351 welding joint .with varying bevel angle, weld current, gas flow rate. AA6351 Aluminum alloy welds through tungsten inert gas (TIG) welding process. Until now aluminum alloy 6061 is widely used in industrial &aerospace applications because of its high tensile strength, due to that the demand of that alloy gradually increases. So present research is to find an alternative to 6061.

II. EXPERIMENTAL WORK

Experiments designed by Taguchi's L9 orthogonal matrix array. A systematic approach becomes essential to find the optimal setting of TIG welding parameters.

In the present work the process parameters are taken as

1. Welding current.
2. Gas flow rate.
3. Bevel angle.

The material under investigation is 6.00 mm thick Aluminium alloy 6351. A non-consumable tungsten electrode of 3.15 mm shielded by argon gas is used to strike the arc with base metal. Filler rods (3 mm) of Aluminium alloy 4047 are recommend for welding of this alloy for getting maximum strength. The chemical composition of base metal already mentioned in introduction. Sample plates of size 150 x 100 x 6mm were prepared by milling machine. TIG 250 AC welding set is used in experiments as it will be provide required welding current, voltage, required flow rate of argon gas which concentrates required heat input in the welding area. . The preparation of specimen for welding and parameters are discussed in following subsections. After conducting some trail experiments process parameters range obtained satisfactorily.

Table.1.Welding Process Parameter for Experimentation

S.NO	PARAMETER	RANGE
1	Welding current	130,140,150 Amp
2	Voltage	20V
3	Gas flow rate	5,6,7 LPM
4	Bevel angle	15,22.5,30 degrees
5	Electrode material	98% W+ 2% Zr
6	Electrode diameter	3.15mm
7	Filler rod	Al 4047
8	Filler rod diameter,	3 mm

In the experimental work pieces of aluminium alloy 6351 are prepared with required specifications .rectangular shape plate pieces are cut into a dimension of 150 x100 x 6mm by hydraulic press machine. After cutting the pieces, the edge preparation is done by grinding machine, to make V shape groove of 30,45,60º for the proper penetration of weld metal. Pictorial view of specimen shown in Figure

Figure.1. Pictorial view of specimen before welding

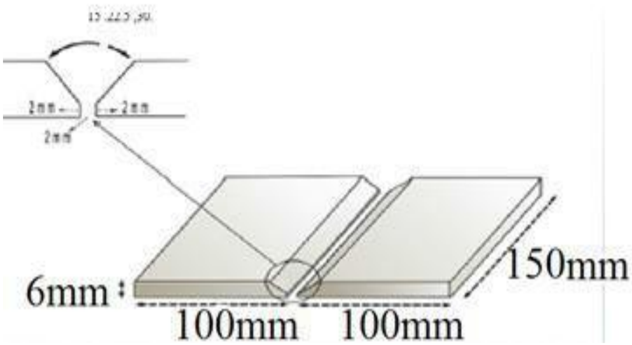


Figure.2. dimensions of the plates for welding

First of all the specimen are cleaned of dirt, grease and other foreign materials by using cleansing agents, dirt removers or other re-agents. After cleaning of work pieces, welding set-up is prepared and tested. Further, the parameters are adjusted according to required level and made ready for welding. Then two pieces are taken which are set up in such a way so as to maintain a 2 mm root gap. Then 9 numbers of welded samples are made by carrying out welding with different levels of current, gas flow rate and preheating of samples. A photographic view of welded specimen for testing are shown in Figure 2 shows the samples.

Figure.3. Pictorial view of a welded specimen for testing

III. RESULTS AND DISCUSSIONS:

▶ The following mechanical tests are performed in TIG welding process using AA6351

▶ Tensile test

▶ Impact test

▶ Rockwell hardness test

The specimens for the above mentioned tests were prepared according to ASME standards.

▶ The welded samples were tested for tensile strength using the universal testing machine (UTM). The edges of the sample were fitted into the jaws of the tensile machine and subjected to tensile stress until the sample fractured. During the test, yield strength, ultimate strength and break point are obtained to get ultimate tensile strength of each material using the formulae

Samples

Figure.4. Tensile Specimen for Testing

▶ Charpy impact test is practical for the assessment of brittle fracture of metals and is indicator to determine suitable service temperature. The Charpy test samples have 55mm x 10mm x 6mm dimensions, a 45degree V notch of 2mm depth.

▶ Root radius will be hit by a pendulum at the opposite end of the notch to produce a fractured sample. The absorbed energy required to produce two fresh fracture pieces is to be recorded in the unit of joule. Since this energy depends on the fracture area (excluding the notch area), thus standard specimen are required for the direct comparison of the absorbed energy.

Figure.5. Impact Test Samples

▶ The hardness of the piece material can be directly read from the dial scale Rockwell hardness is faster because the diameter of indentation need not to be measured and it also gives arbitrary direct reading. Rockwell needs to surface preparation of the specimen whose hardness is to be measured.

Figure.6. Hardness Sample

Table.2. Results

S. NO	Welding current (Amps)	Gas flow rate (LPM)	Bevel angle (degrees)	Hardness (RC)	Impact strength (N-M/mm^2)	UTS (MPA)
1	130	5	15	74.90	2	56.464
2	130	6	22.5	64.23	2	47.883
3	130	7	30	62.67	2	69.805
4	140	7	22.5	56.13	6	60.877
5	140	6	30	60.80	4	67.696
6	140	5	15	72.00	2	43.261
7	150	5	30	66.66	16	159.27
8	150	6	15	67.43	18	156.28
9	150	7	22.5	64.90	20	154.41

▶ From the table of values we can observe that the maximum value is obtained at sample 7 (i.e 159.271 MPA) and the next value is obtained at sample 8 (i.e 156.258 MPA) from this observation we can say that for each of variation the ultimate tensile strength is randomly various.

▶ But, when considered with the reading obtained from the previous observations the obtained value will be higher. In that way we can say that by the increasing in the welding current, ultimate tensile strength increases until some point.

▶ From the table of values we can observe that the maximum values obtained for the samples 8&9 (i.e 18&20 N-M/mm^2) due to the more accumulation of the weld bead. And the minimum value is obtained for the samples 1&2 due to less accumulation of the weld bead. On the samples 8&9, the welding has been done properly and hence it can be concluded from those reading that due to the increasing in the welding current the impact strength also increases From the table of values we can observe that the hardness is being decreased gradually but at a certain point, the hardness will become higher than the previous obtained and then again the hardness will randomly various.

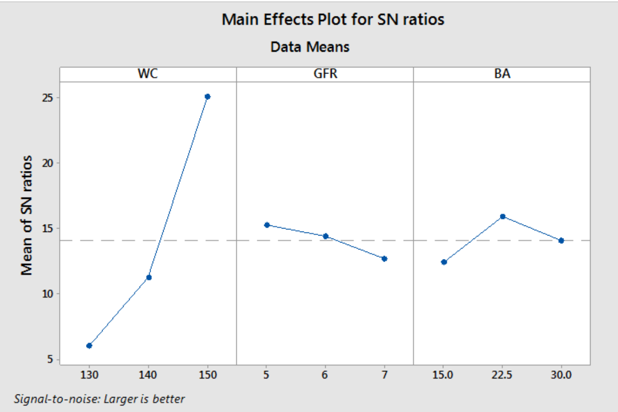
IV. OPTIMIZATION

Optimization is done by the TAGUCHI method

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
	WC	GFR	BA	UTS	IS	H	SNRA1	MEAN1	SNRA2	MEAN2	SNRA3	MEAN3
1	130	5	15.0	56.464	2	74.90	35.0354	56.464	6.0206	2	37.4896	74.90
2	130	6	22.5	47.883	2	64.23	33.6036	47.883	6.0206	2	36.1548	64.23
3	130	7	30.0	69.805	2	62.67	36.8777	69.805	6.0206	2	35.9412	62.67
4	140	5	22.5	60.877	6	56.13	35.6891	60.877	15.5630	6	34.9839	56.13
5	140	6	30.0	67.696	4	60.80	36.6113	67.696	12.0412	4	35.6781	60.80
6	140	7	15.0	43.261	2	72.00	32.7219	43.261	6.0206	2	37.1466	72.00
7	150	5	30.0	159.271	16	66.13	44.0427	159.271	24.0824	16	36.4080	66.13
8	150	6	15.0	156.285	18	67.43	43.8783	156.285	25.1055	18	36.5771	67.43
9	150	7	22.5	154.416	20	64.90	43.7738	154.416	26.0206	20	36.2449	64.90

S/N ratio response table for tensile strength.

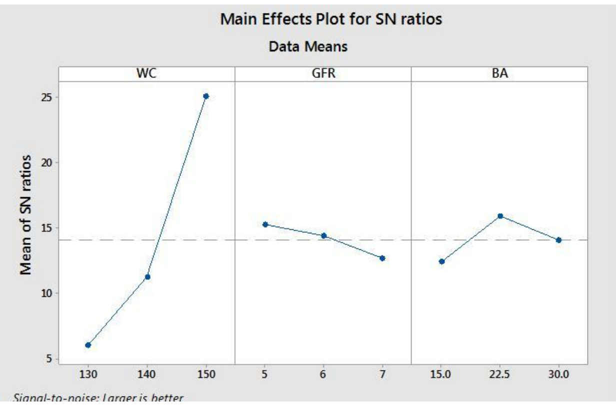
Level	WC	GFR	BA
1	35.17	38.26	37.21
2	35.01	38.03	37.69
3	43.90	37.79	39.18
Delta	8.89	0.46	1.97
Rank	1	3	2



S/N ratios graph for tensile strength

S/N ratio response ratio table for impact strength

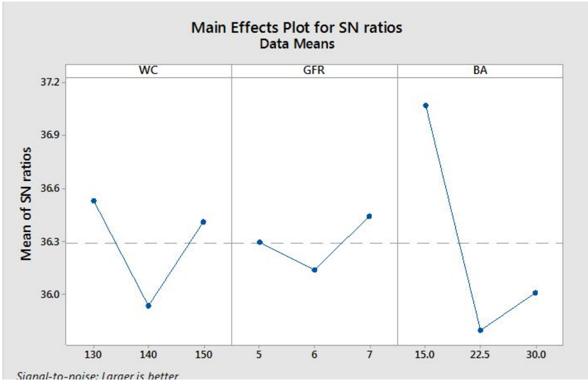
Level	WC	GFR	BA
1	6.021	15.222	12.382
2	11.208	14.389	15.868
3	25.069	12.687	14.048
Delta	19.049	2.535	3.486
Rank	1	3	2



S/N ratios graph for impact strength

- **S/N ratio response table for hardness**

Level	WC	GFR	BA
1	36.53	36.29	37.07
2	35.94	36.14	35.79
3	36.41	36.44	36.01
Delta	0.59	0.31	1.28
Rank	2	3	1



S/N ratios graph for hardness

- **The optimal input parameters obtained by Taguchi method for tensile strength are**
  - Current : A3 (150)
  - Gas flow rate : B1 (5)
  - Bevel angle : C3 (30)

- **The optimal input parameters obtained by Taguchi method for impact strength are**
  - Current : A3 (150)
  - Gas flow rate : B1 (5)
  - Bevel angle : C2 (22.5)

- **The optimal input parameters obtained by Taguchi method for hardness are**
  - Current : A1 (130)
  - Gas flow rate : B3 (7)
  - Bevel angle : C1 (15)

Confirmation Test

A confirmation test was conducted based on the optimum process parameters obtained in Taguchi method .The conducted experimental values of ultimate tensile strength, impact strength, hardness are founded closer to optimum values with minimum error of 5.3% of tensile strength, and 5.9% of impact strength,5% of hardness.

Regression equations

- UTS = -611 +4.93 welding current – 1.5 gas flow rate + 0.91 bevel angle
- Hardness = 83.7 - 0.061 welding current +0.40 gas flow rate - 0.543 bevel angle
- Impact = -104 + 0.800 welding current + 0.00000 gas flow rate + 0.000 bevel angle.

V.CONCULSION

In the present work, TIG welding of aluminum alloy 6351 is carried out by tungsten inert gas (TIG) welding, at various levels of welding current, gas flow rate and bevel angle. The responses considered are the ultimate tensile strength and impact and hardness of joints. Based on the experimental results the following conclusions are drawn. From the observation the output values are various w.r.t. input process parameters .the maximum values of out puts are: the value of ultimate tensile strength is 159.271MPa.value of impact strength is 20N-M/mm2.value of hardness is 74.90RC The s/n ratio curve obtained from the maximum ultimate strength, impact and hardness to the input values welding current, gas flow rate, and bevel angle.

- ▶ After obtaining the results, the optimal process parameters were determined using Taguchi method.
- ▶ A confirmation test was conducted based on the optimum process parameters obtained in Taguchi method .The conducted experimental values of ultimate tensile strength, impact strength, hardness are founded closer to optimum values with minimum error.
- ▶ Regression equations are evaluated.
- ▶ In this investigation an attempt was made to identify the mechanical properties of the AA6351 welding joints. To best suit for the industrial applications. We can say that this alloy may also be used for the aerospace structures as the production rate is highly available at lowest possible cost due to its earlier manufacture for the pressure vessel cylinders. AA 6351 is closer to the vital strength for aerospace structures.

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