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Influence of Mg_2Si on the grain refinement of TIG welded AA6082 Aluminium alloy using Taguchi method

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Abstract : The effect of grain refining element such as Mg_2Si present in the Tungsten Inert Gas (TIG) welded AA6082 Aluminium alloys in as-welded condition was studied. Taguchi orthogonal array method was used to optimize the welding current, voltage, welding speed and shielding gas flow rate for maximizing the tensile strength. The optimal experimental conditions obtained from this study were voltage 13 volts, welding speed 140mm/min, shielding gas flow rate 10 litre/min and welding current 140 amps. According to Taguchi method, the welding voltage played the most important role in the maximizing the tensile strength. Finally, the tensile strength was improved to 200MPa with the optimal conditions of the control parameters which were obtained by Taguchi method.
Key words: TIG welding, AA6082 aluminium alloy, Taguchi method, tensile strength, optical microscopy and SEM.

Introduction

In the present world scenario welding is widely employed in aerospace, automotive industries, ship building etc. Among the various welding processes, tungsten inert gas (TIG) welding plays a major role in the welding of aluminium alloys. Nowadays aluminium alloys are widely used in different application because of its light weight, high specific strength and excellent resistance to corrosion. Aluminium alloys are available in various series such as 5000, 6000 and 7000 etc Which may differ from each other based upon their alloying elements [1,2]. Tungsten inert gas welding is an arc welding process wherein fusion is produced by heating the job with an electric arc established between a tungsten electrode and the base metal [3-5]. Tungsten inert gas (TIG) welding uses a non-consumable tungsten electrode and an inert gas for arc shielding. The molten metal in TIG welding are shielded by an inert gas, which may be argon, helium, hydrogen, nitrogen or mixtures of some of these gases.[3,5].

Ahmet Durgutlu [6] has investigated the effect of Hydrogen in Argon as shielding gas for TIG welding of 316L Austenitic stainless steel. The microstructure, penetration and mechanical properties were examined. The conclusion given in the investigation was that the mean grain size in the weld metal along with its penetration depth and width is increased with increasing hydrogen content.

G. Magudeeswaran et.al [7] optimized the process parameters of TIG welding for Duplex Stainless Steel welds using Taguchi method. The weld process parameters such as electrode gap, voltage, weld speed and current was varied and found that the better results were obtained for 1mm electrode gap, 130 mm/min travel speed, 140 A current and 12 V voltage.

G. Mallaiah et.al[8] studied the influence of grain refining elements such as copper, titanium and aluminium on the mechanical properties such as tensile strength, ductility, toughness, hardness of TIG welded AISI 430 ferritic stainless steel weldments using Taguchi approach. They stated that the highest mechanical properties was obtained for the combination of 3gm copper, 2gm Titanium and 1gm Aluminium welded joint.

M. koilraj et.al[9] carried out research work on joining of dissimilar metals using Friction Stir Welding technique and Taguchi method was used to optimize the weld process parameters. They concluded that the rotational speed, transverse speed, tool shoulder diameter to pin diameter are 700 rpm, 15 mm/min and 3 respectively are found to be an optimum value for which the highest mechanical properties were obtained.

S.C. Juang and Y.S Tarng [10] conducted experiments by varying the weld process parameters using TIG welding process for welding of stainless steel in order to get the optimized weld pool geometry. The modified Taguchi method was adopted in their work for solving the optimal weld pool geometry with better quality weld pool characteristics such as front height, front width, back height and back width. The optimized result was confirmed by conducting experiments and the result shows the weld pool in the TIG welding of stainless steel are greatly improved by using modified Taguchi method. From the above literatures, it is observed that TIG welding has been widely used in welding of different materials like austenitic stainless steel, ferritic steel, magnesium alloys, Titanium alloys and aluminium alloys etc. Only a few works have been identified in TIG welding of 6082 Aluminium alloy, especially in optimizing the weld process parameters on the mechanical and metallurgical properties of the welded joints. Hence this work mainly concentrates in welding of 6082 aluminium alloy using TIG welding process.

The conventional parametric design of experiment approach is time consuming and calls for enormous resources. Taguchi statistical design approach is a powerful tool to identify significant factor from many by conducting relatively less number of experiments. However, this design fundamentally does not account for the interaction among processing parameters. In terms of cost and time saving, occasionally these interactions can be neglected. If mandatory, the missing interactions can be analyzed by further running the required experiments. Though research work applying Taguchi methods on various manufacturing process has been reported in literatures[7-10], it appears that the optimization of TIG welding process parameters of AA6082 aluminium alloy using Taguchi method has not been reported yet. In this regard the Taguchi

L_9 method is adopted to analyze the effect of each processing parameters (i.e. welding current, voltage, speed and shielding gas flow rate) for optimum tensile strength of TIG welded joints of AA6082 aluminium alloy joints.

2. Scheme of investigation

In order to maximize the quality characteristics, the present investigation has been made in the following sequence.

- Selection of base material and filler material.
- Identify the important TIG welding process parameters.
- Find the upper and lower limits (i.e. range) of the identified process parameters.
- Select the orthogonal array (design of matrix).
- Conduct the experiments as per the selected orthogonal array.
- Record the quality characteristics (i.e. mechanical property).
- Find the optimum condition for maximizing the mechanical property (ie tensile strength)
- Conduct the confirmation test.
- Develop the regression models to predict the mechanical properties within the selected range.
- Identify the significant factors
- Check the adequacy of the developed models.

2.1 Materials

Materials employed in this study are AA 6082 aluminium alloy in the form of 3mm thick plates and 4043 as filler material. The chemical composition and mechanical properties of base material are given in Table1 and Table2 respectively.

Table1 Chemical composition of AA6082 aluminium alloy (wt %)

Alloy	Mg	Si	Fe	Cr	Cu	Mn	Ti	Zn	Al
6082	0.97	1.10	0.40	0.01	0.08	0.56	0.01	0.17	Balance

Table2 Mechanical properties of AA6082 aluminium alloy

Material	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
AA 6082	346.66	280	12

2.2 Welding process

In this study, the size of the AA 6082 aluminium alloy base material chosen for this investigation was 300 x 125 x 3 mm^3 sheets are welded to each other by automatic TIG welding process (HOBART Cyber-TIG 300 series) as shown in Fig.1 and 2 respectively. The butt welding process was performed with 4043 filler metal.

Fig. 1.Macro image of Base material before welding

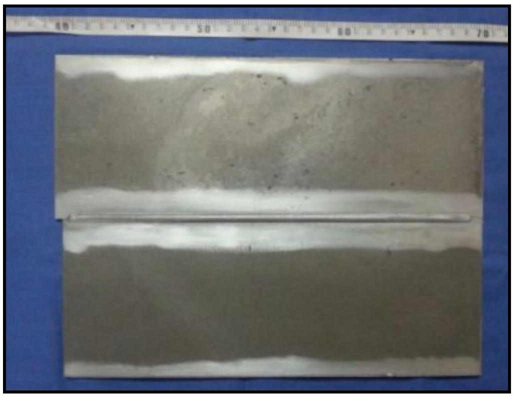


Fig. 2. Macro image of the Welded sample after welding

2.3 Tensile testing

The tensile testing samples were prepared from the welded specimens according to ASTM E8M-04 guidelines. The tensile tests were carried out in 400KN Universal Testing Machine (FIE) and the tensile strength of the joints was evaluated.

2.4 Metallography testing

Specimens for metallographic investigation were taken at the middle of all the joints. The specimens were suitably sectioned, mounted in transverse direction of the welding, mechanically polished according to standard metallographic procedures, and etched using Keller's reagent (2 ml HF, 3 ml HCl, 20 ml HNO_3 and 175 ml H_2O). Microstructures were observed and recorded using an optical microscope.

3.Design of Experiment for the Optimization of tensile strength of the welded joints

The design of experiment used a statistical technique to investigate the effects of various parameters included in experimental study and to determine their optimal combination. The design of the experiment via the Taguchi method uses a set of orthogonal arrays for performing of the fewest experiments. That is, the Taguchi method involves the determination of a large number of experimental situations, described as orthogonal arrays, to reduce errors and enhance the efficiency and reproducibility of the experiments. Orthogonal arrays are a set of tables of numbers, which can be used to efficiently accomplish optimal experimental designs by considering a number of experimental situations [11,12]. An experimental design methodology adopting the Taguchi approach was employed in this study, with the orthogonal array design used to screen the effects of four parameters.

3.1Selection of process parameters and their range

The main operational parameters and levels were based on the experiments conducted and from previously reported studies [7-9]. In the present investigation, four process parameters with three levels, i.e. welding current, voltage, welding speed and shielding gas flow rate were considered. The working range of the process parameters selected under the present study is shown in Table 3.The diversity of the process parameters was studied by crossing the orthogonal array of the control parameters as shown in Table 4. In coded and uncoded levels. In this study, Desgin Expert which is software for the analysis of Taguchi Experiments was used to analyze the results and optimize the tensile strength of the welded AA6082 aluminium alloy joints .

Table 3 Process Parameters and their level

Parameters	Notation	Levels					
		Original			Coded		
		Low	Medium	High	Low	Medium	High
Current (Amp)	A	140	150	160	1	2	3
Volatage(volt)	B	13	14	15	1	2	3
Speed (mm/min)	C	120	130	140	1	2	3
Flow rate (ltr/min)	D	10	11	12	1	2	3

Table 4.Orthogonal array used to design experiments with four parameters at three-levels, L-9 (3^4)

Trial No	Current (Amp)		Voltage (volt)		Speed (mm/min)		Flow rate (mm/min)	
	Original value	Coded value	Original value	Coded value	Original value	Coded value	Original value	Coded value
E1	140	1	13	1	120	1	10	1
E2	140	1	14	2	130	2	11	2
E3	140	1	15	3	140	3	12	3
E4	150	2	13	1	130	2	12	3
E5	150	2	14	2	140	3	10	1
E6	150	2	15	3	120	1	11	2
E7	160	3	13	1	140	3	11	2
E8	160	3	14	2	120	1	12	3
E9	160	3	15	3	130	2	10	1

4 Results and Discussions

4.1 Signal to noise ratio

In Taguchi method, the signal-to-noise (S/N) ratio is used to measure the quality characteristics deviating from the desired value. The S/N ratios are different in terms of their characteristics, of which there are generally three types, i.e. smaller-the-better, larger-the-better and nominal-the-better [11]. According to the analysis for the case of 'larger-the-better', the mean squared deviations (MSD) of each experiment were evaluated using the following equation:

$$\mathrm{MSD} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i}\right)^2$$

where n is the number of repetitions of each experiment and yi is the output responses. Then, the S/N ratio was evaluated using the following equation:

$$\frac{S}{N}\text{ ratio} = -10\log(\text{MSD})$$

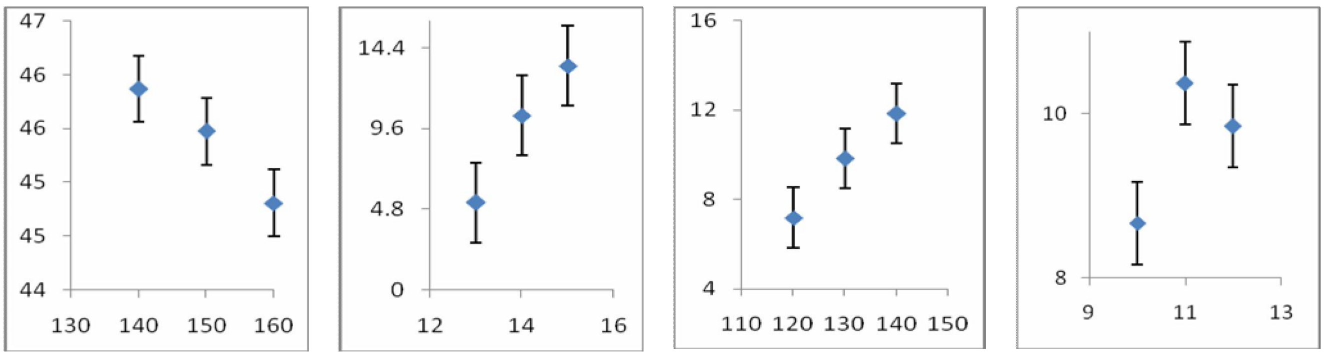
The larger S/N ratio represents to be better performance characteristic. The mean S/N ratio at each level for the different process parameters was calculated. Moreover, the optimal level, that is the largest S/N ratio among all the levels of the factors, can be determined. The experimental data are converted into mean and SN ratio. The calculated mean and SN ratio values are tabulated in Table 5. The average mean and SN ratio values of all levels are calculated and listed in Tables 6 and 7. The larger SN Ratio corresponds to the better quality characteristics. Based on mean and SN ratio values the optimal level setting is A_1 B_1 C_3 D_1. The optimal experimental conditions obtained from this study were voltage 13 volts, welding speed 140mm/min, shielding gas flow rate 10 litre/min and welding current 140 amps.

Table 5 Experimental layout – L_9 orthogonal array, mean value and SN ratio value for nine set of experiments

Trial No	A:Current	B:Voltage	C:Speed	D:Flow rate	Tensile	S/N ratio
E1	2	1	2	3	185.50	45.37
E2	3	1	3	2	179.60	45.09
E3	1	2	2	2	197.70	45.92
E4	1	1	1	1	199.80	46.01
E5	2	2	3	1	194.40	45.77
E6	3	3	2	1	175.70	44.90
E7	2	3	1	2	183.60	45.28
E8	1	3	3	3	192.10	45.67
E9	3	2	1	3	166.80	44.44

4.2 Analysis of variance (ANOVA)

The purpose of ANOVA is to find the significant factor statistically. It gives a clear picture as to how far the process parameter affects the response and the level of significance of the factor considered. The ANOVA table are calculated and listed in Table 8. The main effects for mean and SN ratio are plotted in Fig.3. The higher *F* value implies that the respective term is more significant and vice versa. From the *F* values, it can be concluded that voltage contributes more to tensile strength, followed by welding speed, flow rate and welding current. The percentage contribution of each individual parameter was determined by the ratio of the pure sum to the total sum of the squares. The parameter voltage had a percentage contribution of 80.41% which was larger than any other parameter, which was in agreement with the largest slope for the voltage in the graph of the S/N ratio (Fig. 3).



Welding Current **Voltage** **Welding Speed** **Flow rate**

Fig. 3.The effects of each parameter at different levels on the tensile strength

Table 6 Response table for means

Level	A	B	C	D
1	**196.53**	**188.30**	183.40	**189.97**
2	187.83	186.30	186.30	186.97
3	174.03	183.80	**188.70**	181.47
Delta	0.59	5.11	2.26	0.72
Rank	4.00	1.00	2.00	3.00

Table 7 Response table for signal to noise ratios

Level	A	B	C	D
1	**45.868**	**45.488**	45.244	**45.560**
2	45.473	45.379	45.394	45.428
3	44.808	45.281	**45.510**	45.160
Delta	1.060	0.207	0.266	0.400
Rank	4.000	1.000	2.000	3.000

Table 8 Analysis of variance for means

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Value	p-value Prob> F
A-Current	759.38	1.00	759.38	185.44	0.00
B-Voltage	30.38	1.00	30.38	7.42	0.05
C-Speed	42.14	1.00	42.14	10.29	0.03
D-Flow rate	108.38	1.00	108.38	26.47	0.01
Residual	16.38	4.00	4.10		
Cor Total	956.64	8.00			

In order to confirm the optimal welding parmeters derived from this study, the welding of AA6082 aluminium alloy joints were welded thrice under the optimal levels. The welding current 140 amps, voltage 13 volts, welding speed 140 mm/sec and shielding gas flow rate 10litre/min. respectively. Three tensile specimens were subjected to tensile test and the average value of the TIG welded AA 6082 aluminium alloy joints was found to be 200MPa.

Microstructure of the sample welded at optimum parameter was examined using optical microscope presented in Fig 4 From the figure it is observed that the weld zone contains predominantly eutectics of Mg_2Si in primary dendritic aluminium solid solution and insoluble sludge particles are also present. The SEM analysis was carried out on the weld region of the sample welded under optimum conditions in order to identify the distribution of particles in the weld zone as shown in Fig 5. From the SEM image it is observed that the microstructure of the weld zone is further resolved to show the dendrites of Al-Si which are in uniform distribution with random orientation showing no directional solidification. The particles of Mg_2Si are fine and present inside the grains of the eutectic silicon with aluminium

4.3 Microstructures and SEM analysis of the optimised weld sample

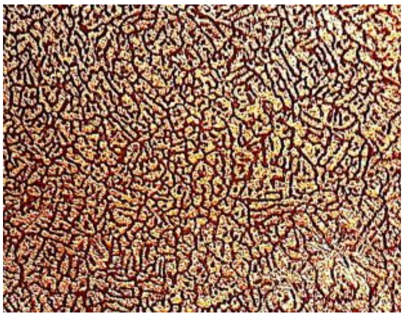


Fig 4. Microstructure of weld region on optimized TIG welded parameter

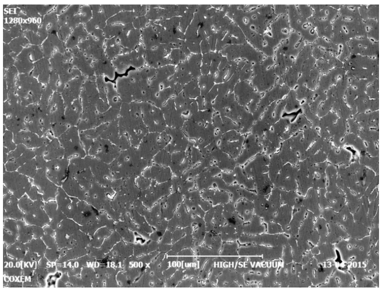


Fig 5. SEM micrographs of optimized weld samples in the fusion zone

5. Conclusions

The effect of grain refining element such as Mg_2Si present in the Tungsten Inert Gas (TIG) welded AA6082 Aluminium alloys in as-welded condition was studied and the following conclusions were drawn.

1. The optimal level setting is A_1 B_1 C_3 D_1 . The optimal experimental conditions obtained from this study were voltage 13 volts, welding speed 140mm/min, shielding gas flow rate 10 litre/min and welding current 140 amps.
2. From the F values, it can be concluded that voltage contributes more to tensile strength, followed by welding speed, flow rate and welding current. The percentage contribution of each individual parameter was determined by the ratio of the pure sum to the total sum of the squares. The parameter voltage had a percentage contribution of 80.41% which was larger than any other parameter
3. Microstructure of the sample welded at optimum parameter reveals that the weld zone contains predominantly eutectics of Mg2Si in primary dendritic aluminium solid solution and insoluable sludge particles.nt.
4. The SEM analysis was carried out on the weld region of the sample welded under optimum conditions reveals that the microstructure of the weld zone is further resolved to show the dendrites of Al-Si which are in uniform distribution with random orientation showing no directional solidification. The particles of Mg_2Si are fine and present inside the grains of the eutectic silicon with aluminium

References

1. Juan Zhao, Feng Jiang, HaigenJian, Kang Wen, Long Jiang, Xiaobochen. Comparative investigation of tungsten inert gas and friction stir welding characteristics of Al-Mg-Sc alloy plates. Materials and Design 2010;31:306-311
2. Z. Nikseresht, F. Karimzadeh, M.A. Golozar, M. Heidarbeigy. Effect of heat treatment on microstructure and corrosion behaviour of Al6061 alloy weldment. Materials and Design
3. D.S. Nagesh, G.L. Datta, Genetic algorithm for optimization of welding variables for height to width ratio and application of ANN for prediction of bead geometry for TIG welding process, Applied Soft Computing 10 (2010) 897–9072010;31:2643-2648.
4. A.Kumar, S.Sundarrajan. Optimization of pulsed TIG welding process parameters on mechanical properties of AA 5456 Aluminium alloy weldments. Materials and Design 2009;30:1288-1297.
5. Kuang-Hung Tseng, Chih-Yu Hsu. Performance of activated TIG process in austenitic stainless steel welds. Journal of Materials Processing Technology 2011;211:503-512.
6. AhmetDurgutlu. Experimental investigation of the effect of hydrogen in argon as a shielding gas on TIG welding of austenitic stainless steel. Materials and Design 2004;25: 19-23.
7. G. Magudeeswaran, Sreehari R. Nair, L. Sundar, N. Harikannan, Optimization of process parameters of the activated tungsten inert gas welding for aspect ratio of UNS S32205 duplex stainless steel welds, Defence Technology, Volume 10, Issue 3, September 2014, Pages 251-260.

8. G. Mallaiah, A. Kumar, P. Ravinder Reddy, G. Madhusudhan Reddy, Influence of grain refining elements on mechanical properties of AISI 430 ferritic stainless steel weldments – Taguchi approach, Materials & Design, Volume 36, April 2012, Pages 443-450.[9] M. Koilraj, V. Sundareswaran, S. Vijayan, S.R. KoteswaraRao, M. Koilraj, V. Sundareswaran, S. Vijayan, S.R. KoteswaraRao, Materials & Design, Volume 42, December 2012, Pages 1-7.
9. S.C Juang, Y.S Tarng, Process parameter selection for optimizing the weld pool geometry in the tungsten inert gas welding of stainless steel, Journal of Materials Processing Technology, Volume 122, Issue 1, 5 March 2002, Pages 33-37
10. Roy RK. Design of experiments using the Taguchi approach: 16 steps to product and process improvement. New York: Wiley; 2001.
11. Arul Franco P, ShenbagaVinayagaMoorthi N and Thomas S. D, Taguchi Orthogonal Array Based Parameter Optimization of Biodiesel Production from Fish Oil using Ultrasonic Energy, Research Journal of Applied Sciences, Engineering and Technology, 7(7): 1220-1225, 2014

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