PULSED TIG WELDING PROCESS PARAMETERS OPTIMIZATION FOR WELD STRENGTH PROPERTY OF ALUMINUM AA 6061 T6 ALLOYS

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Abstract: *The current investigation is intended to discover the effect of pulsed current TIG welding process parameters on tensile properties of Alloy AA6061 T6 material. Peak current, base current and frequency were cautiously decided with the intention of producing complete penetrate joints.Taguchi method was used to prepare the experimentation design and statistical methods such as ANNOVA and regression technique were employed to obtain optimized weld parameters. At 180 A Ip, 60 A Ib and 6 Hz frequency the tensile and yield properties is better and the value are 185.55 Mpa and 156.62 Mpa respectively. This is due to the fact that equiaxed dendrite structures can be observed during higher Ip and f.*

Keywords: Pulsed TIG, AA 6061 T6, ER 4043

1. INTRODUCTION

The one of richest element in the shell of earth available is aluminum having 8 % wt. which is second after ferrous alloy like steel between inexpensively significant metal. Some other non ferrous elements like copper, tin, lead were used from many years. In 1808, Sir Humphrey Davy (Britain) has identified metal called Aluminum[1].

Aluminum (Al) is low density metal used in many industries like automobile, transportation, aerospace, civil constructions, packaging, storage, bridges etc. Aluminum is higher corrosive resistant metal. Some alloying elements are added like silicon, copper, zinc, Magnesium, Manganese to improve its properties. Aluminum & Aluminum alloys have wide use because of many technological developments in it that provides quality & productivity. The total consumption of Aluminum alloys by various industries are tabulated in table 1[2]

Table 1. Apparent consumption of Al alloys by market (Millions of pound)

Major Market	2016	% of total
Building & construction	3234	12.2
Transportation	9311	35.2
Consumer durables	1750	6.6
Electrical	1843	7.0
Machinery & equipment	1728	6.5
Containers & packaging	4758	18.0
Other	687	2.6
Domestic total	23311	88.2
Exports	3117	11.8
Total shipment	26428	100

Especially welding technology is recognized to be vital in storage and automobile industries.[3] The specific application related to aluminum alloy is in engine cooling systems includes radiators, charge air coolers, oil coolers, fuel coolers etc.[4] The enormous challenge for engineers and researchers are to welding of Al metals. As a matter of fact, many intricacy are connected with the type of welding methods are oxide films, thermal conductivity, coefficient of thermal expansion, solidification shrinkage, solubility of hydrogen, and distinct gases.[5]

The industries have specifically adopted tungsten inert gas welding (TIG) and metal inert gas welding (MIG) process for welding of different joints of Al-Mg-Si alloys. These processes give precise welding with better weld quality products. It consumes shielding gases like argon, helium or combination of them for protecting the weldment from atmosphere. Advanced processes like pulsed current processes are also introduced by many researchers and opted by industries namely Pulsed current TIG (PCTIG) welding and pulsed current MIG (PCMIG) to get superior quality weld with grain refinement, less residual stresses, shorter heat affected zone (HAZ), less chances of distortion and low racking susceptibility.[6][7].throughout welding of aluminum alloys, alloying elements of them like Manganese is fused and lost. The chemistry of pool is change and joints loses its mechanical properties[8].

The main aim of this research paper is to identify suitable pulsed TIG welding process parameters for optimum mechanical properties like tensile strength, yield strength, hardness and joint efficiency by using statistical method especially Taguchi method.

Taguchi is a systematic approach to design and analyze experiments for improvement of quality characteristics. It allows to evaluate the effect of individual parameters on the characteristics of quality like ultimate tensile strength, yield strength, hardness etc.ths method become popular tool amongst researchers to improve quality of the output by reducing number of experiments without increasing the cost.[9]

2. Experimental work

For the investigating the effect of weld parameters on weld qualities Aluminum AA 6061 T6 alloys with 3.2 mm thickness has been identified and welded with ER 4043 filler material with 2 mm root gap and without any edge preparation. The chemical composition of base material and filler material is collected from performing the spectroscopy test by optical emission spectrometer (ASTM E1251:2013Z) and is illustrated in table. It is matched with the chemical composition given in American welding society (AWS) handbook.[3]

Table 2. Chemical composition of AA 6061 T6

Content	(Si)	(Cu)	(Mg)	(Zn)	(FE)	(Ti)	(Mn)	(Cr)	(Al)
% elements	0.662	0.222	1.03	0.013	0.26	0.011	0.107	0.126	97.47
Set value	0.40-0.80	0.15-0.40	0.80-1.30	0.25 max	0.70 max	0.15 max	0.15 max	0.04-0.35	remaining

Table 3. Chemical composition of ER 4043

Content	Al	Si	Fe	Cu	Mg	Cr	Zn	Ti
% elements	93.84	5.82	0.09	0.02	< 0.001	< 0.001	< 0.001	0.04

The experiments are set by using Taguchi approach and is used for designing experiments, l9 orthogonal array was applied which contains three columns and nine rows, which means total 9 experiments were designed and performed. Design of experiment was chosen based on three welding parameters having 3 level of each. i.e. Peak current, base current & frequency.[10][11][8], [12].Input parameters and design of experiment are shown in table. Statistical tool MINITAB software was used to prepare design of experiment and for the analysis purpose. The results of experimental data are analyzed by different method like regression analysis and analysis of variance (ANNOVA).ANNOVA gives individual response to check the significant parameter and prediction of optimum combination of the process parameters statistically.

Figure 1. Universal Testing Machine setup

Table 4 shows the mechanical properties of AA 6061 material.

Table 4. Mechanical properties of AA 6061

Alloy Series	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Vickers Hardness (0.05Kg)
AA 6061	310	270	240

The experimental work was carried out on plate of aluminum alloy AA 6061 artificial heat treated having 3.2 mm thickness. The mechanical properties of AA6061 T6 are listed in table 4. The plates are welded with pulsed current tungsten inert gas welding (PCTIG) process by "Fronius" made Magicwave 3000 water cooled Alternate current source machine with filler material of ER 4043.

Figure 2. Pulsed TIG welding Machine setup

Table 5 shows the range of parameters for Ip, Ib and f is identified based on previous research [13][14][8], [12], [15] and standard welding book[16].The different constant and working parameters with working range were used to carry out the9 experiments. They are listed in table 6 and table 7.

Table 5. Working range of process parameters

Sr No	Parameters	Range		
		Low	Medium	High
1	Peak current (Ip)	120 A	150 A	180 A
2	Base current (Ib)	60 A	80 A	100 A
3	Pulsed frequency (f)	2 Hz	4 Hz	6 Hz

Some parameters during welding experimentations were kept constant. They are illustrated in table 6.

Table 6. Constant parameters during experimentation

Sr No	Parameter	Constant value
1	voltage	15-18 volts
2	Tungsten electrode & size	98 % W, 2 % Zr, 3.2 mm dia.
3	Shielding Gas	Argon
4	Shielding gas flow rate	5 lit./min.
5	Nozzle diameter	9 mm ceramic cap

6	Filler metal	ER 4043
7	Welding position	1G
8	Welding speed	4-6 mm / sec.
9	Cleaning cycle	40 %
10	Welding cycle	60 %
11	Current wave	Square
12	Pulse on time	50 %

The design of experiment by Taguchi L9 array was employed during experimentation. The illustration is as below in table 7.

Table 7. L9 orthogonal array

Trial No	Ip(A)	Ib (A)	f (Hz)
1	120	60	2
2	120	80	4
3	120	100	6
4	150	60	4
5	150	80	6
6	150	100	2
7	180	60	6
8	180	80	2
9	180	100	4

3 Results and discussion

The transverse joints are prepared and its mechanical properties such as Tensile strength, yield strength, of AA 6061 T6 aluminum alloys were estimated. The average values are taken by using three results and tabulated in table the tensile strength and yield strength of base metal or unwedded metal are 330 MPa and 302 MPa respectively.

The welded work pieces are than cut for tensile (ASTM E8M-04). Standard tensile test specimen is cut from the weld component such a way that transverse tensile strength of weld component can be evaluated which is shown in figure 3.

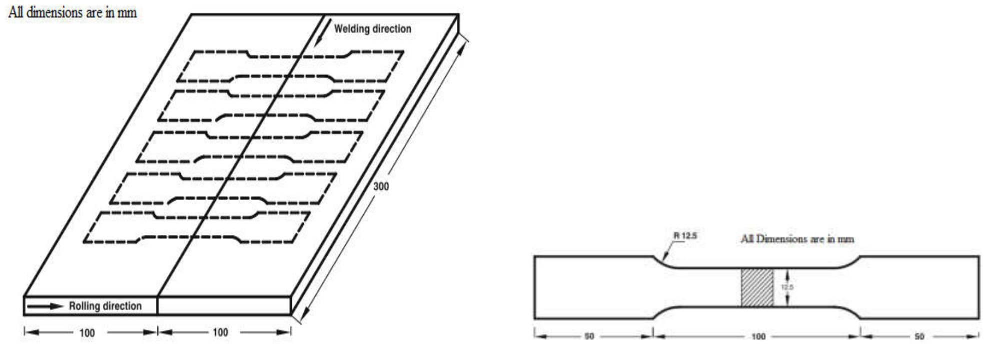


Figure 3. Configuration of plain Tensile Specimen

The results are showing in table 7 indicate that when Ip is 120 A, Ib is 100 A and f is 2 Hz then the tensile strength and yield strength are 140.66 MPa and 116.74 MPa respectively. As the Ip goes higher somewhat the tensile strength and yield strength is increases. During Ip is 180 A, Ib is 80 and f is 2 Hz then the values of tensile strength and yield strength are 185.55 and 156.62 respectively. Corresponding hardness values for three zones i.e. weldment (WM), Heat affected zone (HAZ) and Base Metal (BM) are evaluated. All the values for different parameters are covered in table 7.

Table 8. Input parameters and output results

Joint No	Ip A	Ib A	f, Hz	TS, Mpa	YS, MPa	Heat input KJ/mm	Joint (η) (%)	Hardness		
								WM	HAZ	BM
1	120	100	6	140.66	116.74	0.20	42.62	42.15	53.65	54
2	120	80	4	124.36	97.10	0.20	37.68	55.65	60.58	53.95
3	120	60	2	123.54	97.54	0.20	37.44	55.96	60.65	54.84
4	150	100	2	137.50	113.60	0.25	41.67	45.67	58.33	53
5	150	60	4	132.68	109.60	0.25	40.21	55	56.33	60.33
6	150	80	6	119.03	96.83	0.25	36.07	72.67	81.33	69.66
7	180	80	2	185.55	156.62	0.30	56.23	72	74.33	64.66
8	180	100	4	133.24	95.96	0.30	40.38	59.33	62.33	70
9	180	60	6	123.00	113.01	0.30	37.27	56.33	61.67	55.33

[16]have give equation for the joint efficiency and heat input of pulsed TIG welding process is written. By using these equations the results are evaluated

$$Joint\ efficiency(\eta) = \frac{Tensile\ strength\ of\ welded\ joint}{Tensile\ strength\ of\ base\ metal} \tag{1}$$

$$Heat\ Input = \frac{v \times I \times \eta_t \times 60}{s \times 1000} \tag{2}$$

Where

v = welding voltage in volts.

I = Welding current in Amp.

η_t = thermal efficiency of welding process

For TIG 0.75

s= welding speed in mm/min

4 Analysis of results

4.1 ANNOVA Method

Many analysis methods are available to optimize the welding process parameters. In these experiments results are analyzed using Taguchi method. ANNOVA is a statistical techniques is used to analysis the each process parameter to provide a measure of confidence.[17] The percentage contribution for tensile strength, yield strength is calculated by ANNOVA method. Table 8 shows investigation in which the main significant process parameters or combination of parameters for tensile strength are Ip, Ib, Ip*Ib, Ip*f and I_b*f. The corresponding contributions are 14.56, 49.49, 12.26, 5.44, 12.15, 5.04, and 1.05 respectively. The weld efficiency and heat input is also calculated. The p values for corresponding parameters are also mentioned. It shows each parameter is significant.

Table 8. ANNOVA results for Tensile strength

Source	DF	Sum of square	Contribution (%)	Adj SS	Adj MS	F-value	P-Value
Regression	6	3209.18	98.95	3209.18	534.86	31.32	0.031
Ip	1	472.24	14.56	362.02	362.02	21.20	0.044
Ib	1	1605.24	49.49	408.59	408.59	23.92	0.039
f	1	397.56	12.26	393.34	393.34	23.03	0.041
Ip*Ib	1	176.57	5.44	553.28	553.28	32.40	0.030
Ip*f	1	393.98	12.15	543.89	543.89	31.85	0.030
Ib*f	1	163.59	5.04	163.59	163.59	9.58	0.090
Error	2	34.16	1.05	34.16	17.08		
Total	8	3243.34	100				

Table 9. ANNOVA results for Tensile strength

Source	DF	Sum of square	Contribution (%)	Adj SS	Adj MS	F-value	P-Value
Regression	6	2903.62	99.17	2903.62	483.94	40.0	0.025
Ip	1	489.79	16.73	32.03	32.03	2.65	0.245
Ib	1	1055.50	36.05	136.85	136.85	11.31	0.078
f	1	490.15	16.74	462.32	462.32	38.21	0.025
Ip*Ib	1	2.93	0.10	218.47	218.47	18.06	0.051
Ip*f	1	723.84	24.72	782.96	782.96	64.71	0.015
Ib*f	1	141.42	4.83	141.42	141.42	11.69	0.076
Error	2	24.20	0.83	24.20	12.10		
Total	8	2927.82	100				

4.2 Regression Analysis

Assessment of more than two process parameters with arithmetic mean is called regression analysis. The values of tensile strength and yield strength are explored and derived from regression analysis.Taguchi L9 orthogonal array is employed and input and output parameters are used to create regression equation. This formulate is possible to create the source results of particular variable ahead another[18].the equation for tensile strength and yield strength is created which is useful to find the output value for the unknown parameters with same weld conditions. The regression equation for current model is illustrated in equation (3) and equation (4).
The residual plots for tensile strength and yield strength are mentioned in figure 4 and figure 5.

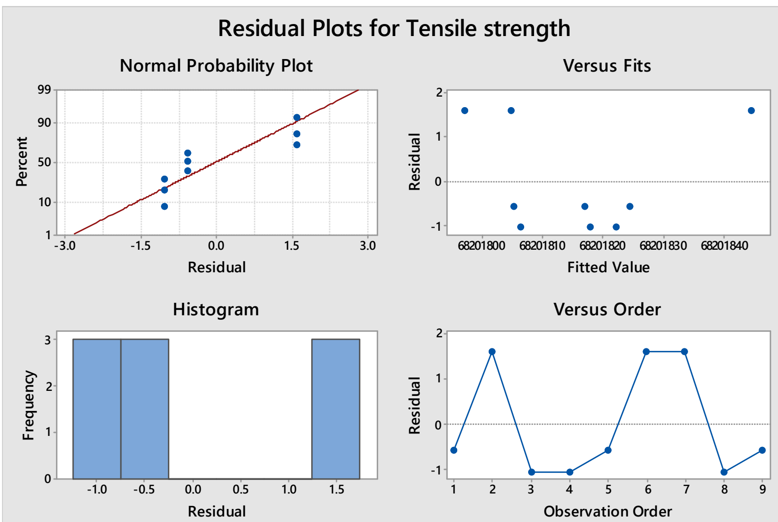


Figure 4. Residual plots for Tensile strength

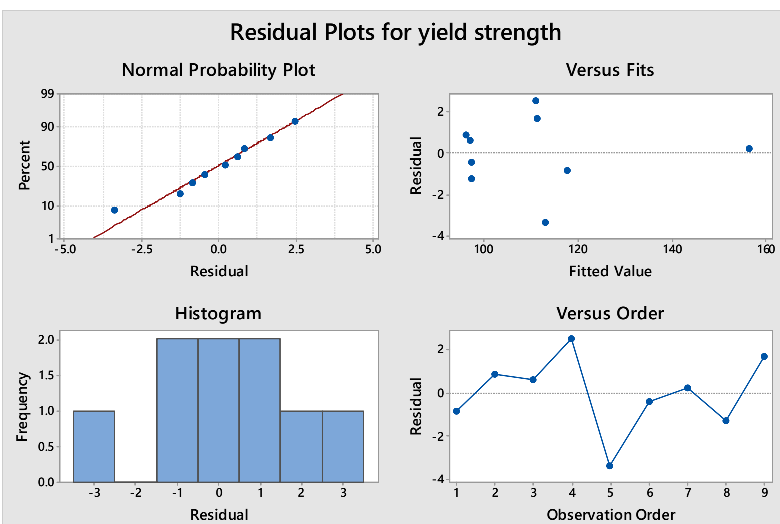


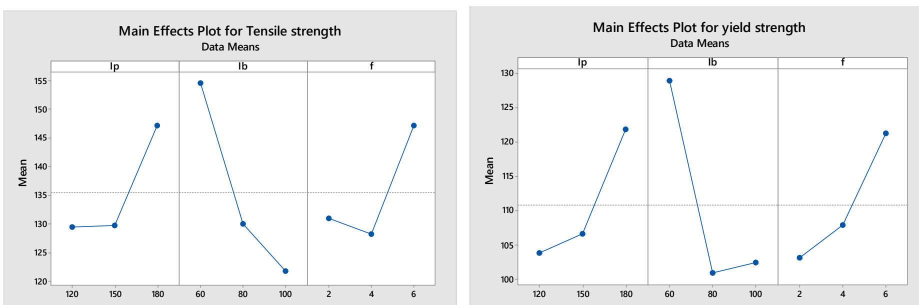
Figure 5. Residual plots for yield strength

The main effect plots are illustrated. It clearly shows that the tensile strengths and yield strength are increases with the increase of Ip and f. and they are reducing when Ib is increases. So, Ip and f are directly proportional to the strength and b is inversely proportional to the strength.

4.3 Regression Equations for strength and yield strength:

$$\text{Tensile strength} = -35.6 + 1.957\, Ip + 3.982\, Ib - 79.0\, f - 0.03630\, Ip*Ib + 0.3599\, Ip*f + 0.2960\, Ib*f \quad (3)$$

$$\text{Yield strength} = 108.4 + 0.582\, Ip + 2.305\, Ib - 85.7\, f - 0.02281\, Ip*Ib + 0.4318\, Ip*f + 0.2752\, Ib*f \quad (4)$$



a b

Figure 6. Main effect plot for Tensile strength

4. Conclusion

(1) The pulsed TIG welding process succefully performed on AA 6161-T6 aluminum alloy. The predominant parameters like Ip, Ib and f are optimized to accomplish maximum tensile and yield strength. Though the soundness of the process is restricted to the investigated considered parameters.
(2) Design of experiment concept is more the more economical method for predicting the effect of pulsed TIG parameters on tensile and yield properties.
(3) The suitable pulsed TIG process parameters for current experimentation is at 180 peak current (Ip), 60 A base current (Ib) and at 6 Hz frequency (f).higher the peak current the amount of heat generated is more and weldment trying to convert into equiaxed dendrite.
(4) Analysis also proves the significant of each parameters for tensile strength are Ip, Ib, Ip*Ib, Ip*f and Ib*f. The corresponding contributions (in %) are 14.56, 49.49, 12.26, 5.44, 12.15, 5.04, and 1.05 respectively.

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