

Multi Response Optimization of Tungsten Inert Gas (TIG) Welding of Al6063/15%SiCp Metal Matrix Composites.

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Abstract

Material scientists and researchers in this area have been fulfilling the demand of the engineering sector since decades in synthesizing materials to attain the demanded properties to enhance efficiency and cost savings in the manufacturing sector. Aluminium metal matrix composites (AMMCs) are becoming more popular as structural materials and joining them is therefore of paramount importance. Joining of advanced materials plays an increasingly important role in modern manufacturing industries. AMMCs have a unique combination of mechanical and physical properties, such as high specific strength, specific modulus of elasticity, low thermal expansion coefficient and good wear resistance; these are being widely used in aerospace engineering, automotive industry, electronic packaging, medical appliances, heat exchanger fins and other related industries. As these new materials become available it is necessary to define and optimize joining techniques, and a thorough understanding of process. The present work first deals with the fabrication of SiCp reinforced AMMCs (Al6063/15%SiCp) with Liquid Processing Technique, i.e. Stir casting method and later to seek for possibilities of successful joining with TIG process, for possible structural applications. The present study deals with an experimental study carried out in order to optimize the process parameters namely Frequency (Hz), Current (A), Shielding gas flow rate (l/m), Percentage time electrode positive (μ s). The performance measures evaluated are namely Micro-hardness, (VHN) and Impact strength, (Joule), for TIG welding of Al6063/15%SiCp. The results have been analysed using Taguchi's methodology. The optimal values of micro-hardness are A1B3C3D1 (frequency HF Hz, current 105 A, shielding gas flow rate 14 l/m, percentage time electrode positive 60 μ s). The optimal values for impact strength are A2B1C1D3 (frequency LF Hz, current 85 A, shielding gas flow rate 10 l/m, percentage time electrode positive 70 μ s).

Keywords: TIG joining; MMCs; Taguchi's methodology; Design of experiments; Optimal parametric settings

Introduction

A "composite" is when two or more different materials are combined together to create a superior and unique material. This is an extremely broad definition that holds true for all composites, however, more recently the term "composite" describes reinforced plastics. One constituent is called the reinforcing phase and one which it is embedded is called the matrix, the reinforcing phase material may be in the form of particles fibers or flakes the matrix materials are generally continuous phase, Aluminum based metal matrix composites (MMCs) reinforced with ceramic particles (Al_2O_3 , SiCp, Graphite etc.) have developed considerable interests in modern industry due to light weight of aluminum and its expensive as compared with other metals such as Titanium and Magnesium [1].

Types of composites

- (i) Matrix material (ii) Reinforcements

On the basis of matrix material composites are classified as follows:

- (a) Metal matrix composites (b) Polymer matrix composites
(c) Ceramic composites (d) Carbon composites

On the basis of Reinforcements composites are classified as follows:

- (a) Particle-reinforced (b) Whisker-or short fibre-reinforced
(c) Continuous fibre-reinforced (d) Mono filament-reinforced

Classification of metal matrix composites (MMCs): AMMCs can be classified into four types depending on the type of reinforcement [2].

- (a) Particle-reinforced AMCs (PAMCs)
(b) Whisker-or short fibre-reinforced AMCs (SFAMCs)

- (c) Continuous fibre-reinforced AMCs (CFAMCs)
(d) Mono filament-reinforced AMCs (MFAMCs)

Particle reinforced aluminium matrix composites (PAMCs):

These composites generally cover equiaxed ceramic reinforcements with an aspect ratio less than about 5. Ceramic reinforcements are normally oxides or carbides or borides (Al_2O_3 or SiC or TiB_2) and present in volume fraction less than 30% when used for organizational and wear resistance applications.

Short fibre-and whisker-reinforced aluminium matrix composites (SFAMCs):

These have reinforcements with an aspect ratio of greater than 5, but are not continuous. Short alumina fibre reinforced aluminium matrix composites is one of the first and most popular AMCs to be developed and used in pistons. These were produced by squeeze infiltration process. Whisker reinforced composites are produced by either by PM processing or by infiltration route.

Continuous fibre-reinforced aluminium matrix composites (CFAMCs): Here, the reinforcements are in the form of continuous fibres (of alumina, SiC or carbon) with a diameter less than 20 μ m. The

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fibres can either be parallel or pre woven, interweaved prior to the production of the composite [3].

Mono filament reinforced aluminium matrix composites (MFAMCs): Monofilaments are large diameter (100 to 150 μm) fibres, usually formed by chemical vapour deposition (CVD) of either SiC or B into a core of carbon fibre or W wire. Bending flexibility of monofilaments is low compared to multi filaments.

Properties

Favourable properties of AMMCs are high strength, high stiffness, high temperature stability, improved wear resistant, corrosion resistant, adjustable coefficient of thermal expansion etc. SiCp reinforced aluminium metal matrix composites (SiCp/Al MMCs) have a unique combination of mechanical and physical properties, such as high specific strength and specific modulus of elasticity, low thermal expansion coefficient and good wear resistance [4].

Processing of metal matrix composites (MMCS)

Manufacturing of MMCs at industrial scale can be classified into two main groups [5-7].

- (i) Liquid state processes (ii) Solid state processes

Liquid state processes: Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained.

Liquid state processes are also classified as follows: (a) Stir casting (b) Infiltration (c) Gas pressure infiltration (d) Squeeze infiltration casting (e) Pressure die Infiltration

Stir casting method of fabrication of MMCs: Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibres) is mixed with a molten matrix metal by means of mechanical stirring.

Solid phase processes: Solid state fabrication of Metal MMCs is the process, in which Metal Matrix Composites are formed as a result of bonding matrix metal and dispersed phase due to mutual diffusion occurring between them in solid states at elevated temperature and under pressure.

- They are classified as following (a) Diffusion bonding
- (b) Sintering

Joining metal matrix composites (MMCS)

There are a number of methods available for joining MMCs, some being more successful than others (Table 1). Relative ratings for processes used for bonding MMCs.

Tungsten inert gas welding

Tungsten Inert Gas (TIG) welding (Figure 1). Also known as Gas Tungsten Arc Welding (GTAW) is a process that produces an electric arc maintained between a non-consumable tungsten electrode and the part to be welded. The heat-affected zone, the molten metal, and the tungsten electrode are all shielded from atmospheric contamination by a blanket of inert gas fed through the TIG torch.

Inert gas (usually Argon) is inactive or deficient in active chemical

Process	Sheet	Extrusion	Casting
TIG	Good	good	good
MIG	Good	good	good
Resistance	Fair	n/a	n/a
Laser	Poor	poor	poor
Electron Beam	Poor	poor	poor
Friction Welding	n/a	good	good
Diffusion Bonding	Fair	fair	fair
Flash Welding	n/a	good	good

Table 1: Relating ratings for processes used for bonding MMCs [6]. Form of MMCs.

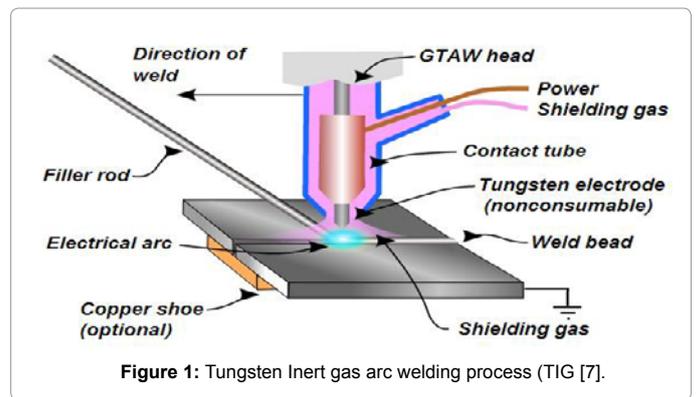


Figure 1: Tungsten Inert gas arc welding process (TIG) [7].

properties. The shielding gas serves to blanket the weld and exclude the active properties in the surrounding air. Inert gases, such as Argon and Helium, do not chemically react or combine with other gases. They pose no smell and are transparent, permitting the welder maximum visibility of the arc. In some instances Hydrogen gas may be added to enhance travel speeds [8]. TIG is used to weld steel, stainless steel, nickel alloys, titanium, aluminium, magnesium, copper, brass, bronze, and even gold. TIG can also weld dissimilar metals to one another such as copper to brass and stainless steel to mild steel [9].

Direct current electrode negative (DCEN): Direct current (DC) is an electrical current that flows in one direction only. DCEN is not used due to no cleaning of aluminium oxide layer

Direct current electrode positive (DCEP): When welding with direct current electrode positive (DCEP), the torch is connected to the positive terminal on the welding power source and the ground or work lead is connected to the negative terminal. The electron flow is still from negative to positive; the electrons are now leaving the work

Taguchi orthogonal array

Orthogonal arrays are two dimensional arrays of numbers which possess the interesting quality that by choosing any two columns in the array you receive an even distribution of all the pair-wise combination of values in the array, here is some terminology for working with orthogonal array.

Runs: The number of rows in the array. This directly translates to the number of test cases that will be generated the OATS technique.

Factors: The number of columns in an array. This directly translates to the maximum number of variables that can be handled by this array.

Levels: The maximum number of values that can be taken on by any single factor. An orthogonal array will contain values from 0 to levels 1.

Taguchi orthogonal array are experimental design that usually require only a fraction of the full factorial combination. The arrays are design to handle as many factors as possible in a certain number of runs. Create Taguchi design by assigning some or all of the array columns to the factors in your experiment. The columns of the arrays are balanced and orthogonal. This means that in each pair of columns, all factor combinations occurs the same number of times. Orthogonal designs allow estimating the effect of each factor on the response or performance measures independently of all other factors.

For our experimentation, we have used L18 orthogonal array. The standard L18 orthogonal array is shown in Table 2, where A is noise factor having two levels and B, C and D being control factors having three levels each.

Here factor A has 2 levels, whereas factor B, C and D have three levels each. Interaction between column 1 and 2 is orthogonal to all columns and hence can be estimated without sacrificing any column [10].

Experimentation

The objective of the experimentation is to optimization of tungsten inert gas (TIG) welding process parameter during welding of Al6063/15%SiCp metal matrix composites. A L18 (21 × 33) orthogonal array was employed to study the effect of Frequency, Current, Shielding gas flow rate, Percentage time electrode positive. The performance measures considered were Micro Hardness and Impact Strength The Experimentations were carried out in two steps first is processing of MMCs and then secondly is joining of MMCs by TIG process.

Work material

Matrix material: The matrix material used in the investigation is AA6063 (Table 3). Chemical Composition of Aluminium Alloy 6063 (Source: Munjal Casting Pvt. Ltd.) (Figure 2).

Factors				
Runs	A	B	C	D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

Table 2: Standard layout of L18 (21 × 33) orthogonal array.

Alloy Type						Composition wt%					
6063	Si	Mn	Mg	Fe	Cu	Ni	Zn	Sn	Ti	Cr	Al
0.42	0.03	0.9	0.54	0.05	0.01	0.01	0.02	0.02	0	0.01	Balance

Table 3: Matrix material.



Figure 2: Small pieces of AA6063 for melting in crucible.



Figure 3: Stir casting apparatus in CFI Lab in NML Jamshedpur.



Figure 4: Stir casted Al6063/15% SiCp MMCs after machining.

Processing of MMCS

Stir casting was used here in preparing composite samples (Figure 3). This method could distribute silicon carbide particles homogenously in the alumina microstructure by forming vortex in molten metallic. Metallic and distributed them homogenously. Stir-casting improve mechanical and physical properties of the aluminium matrix [11].

Processing steps for stir casting: Processing steps used to fabricate the Al6063/15%SiCp AMMCs as work specimen. Matrix material Al6063 was supplied from Atherva Casting Pvt. Ltd. Cut into small pieces to obtain the required weight according to reinforcement silicon carbide particles 15wt% and charge the crucible with small pieces metal matrix aluminium alloy 6063 then raised the temperature upto 730°C, matrix material starts to melt completely, addition of 1.0wt% Mg to the melt to improve the wettability (Figure 4).

Joint design and edge preparation

The joint design used in this work was a single V groove which was selected according to the thickness of the base material, the groove angle is 75° root gap of 2 mm and root face 2 mm was used other relevant information about groove design is shown in Figure 5, the edge preparation was done with the help of shaper M/C.

Pre-cleaning

Before starting welding pre-cleaning the surface of base metal and groove edges is necessary so that dust, oil, rust and other unwanted particles can be removed otherwise these particles may lead to some types of defects in the weld metal.

Factors and levels

(a) **Noise factor:** Frequency (Hz), no of levels=2

1. Low frequency, (LF) and 2. High frequency, (HF), Degree of freedom (DOF)=1

(b) **Control factors:** Current (A), no of levels=3, (DOF)=2
Shielding gas flow rate (l/m), no of levels=3, (DOF)=2

Percentage time electrode positive (μs), no of levels=3, (DOF)=2

In the present experimentation study frequency, current, shielding gas flow rate and duration of electrode positive have been considered as process parameters. Thus each process parameters were assigned three levels except frequency based upon the preliminary experiments. The process parameters along with their levels considered for the present study is listed in Table 4.

Taguchi's orthogonal array: In the present study, L18 (21x33) orthogonal array has been used. Accordingly 18 experiments were carried out to study the effect of process parameters. Each experimental runs were repeated twice in order to reduce experimental errors (Table 5).

Experimental procedure: The joint design used in this work was a single V groove which was selected according to the thickness of the



Figure 5: Joining of MMCs work specimen.

Factors	Unit	Levels		
		1	2	3
Frequency	Hz	HF	LF	-
		(Denoted as 1)	(Denoted as 2)	
Current	A	85	95	105
Shielding gas flow rate	l/m	10	12	14
Percentage time electrode positive				

Table 4: Process parameters considered and their levels.

Runs	Noise factor		Control factor	
	Frequency (Hz)	Current (A)	S.G.F.R (l/m)	%Time electrode + (μs)
1	HF	85	10	60
2	HF	85	12	65
3	HF	85	14	70
4	HF	95	10	60
5	HF	95	12	65
6	HF	95	14	70
7	HF	105	10	65
8	HF	105	12	70
9	HF	105	14	60
10	LF	85	10	70
11	LF	85	12	60
12	LF	85	14	65
13	LF	95	10	65
14	LF	95	12	70
15	LF	95	14	60
16	LF	105	10	70
17	LF	105	12	60
18	LF	105	14	65

Table 5: Taguchi's orthogonal array.

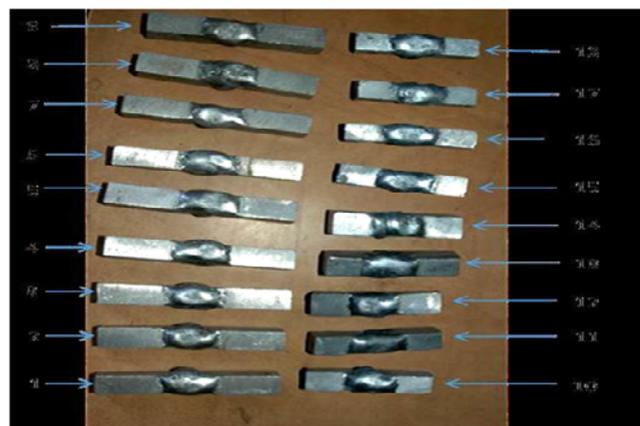


Figure 6: Welded specimens.

base material and made by shaper machine, other relevant information about groove design is shown in Figure 5. Pre-cleaning of plate and groove edges was done with the help of wire brush.

Performance measures: The various performance measures or the responses that were studied in the TIG welding of Al6063/15%SiCp metal matrix composite are:

a. Micro-hardness (VHN) hardness is the ability of a metal to resist penetration to resist abrasive wear, or to resist the absorption of energy under impact load; according to these can be thought of as penetration hardness, wear hardness, and rebound hardness [12]. Vickers hardness test uses a square based diamond pyramid so it has higher accuracy because the diagonals of a square can be measured more accurately than the diameter of a circle and hardness is present in VHN number [13].

b. Impact strength (Charpy test) the resistance of the material to fracture under impact loading, i.e., under quickly dynamic loads, the quantitative value measured in joules [14].

Testing of work specimens

Testing is considered as the necessary to the satisfactory performance of the welded joints in service for this purpose the specimen dimensions and welding conditions are set and to make the material samples for testing. Following are the different tests that are carried out in the present study (Figures 6 and 7).

Micro hardness testing (Vickers hardness): For micro-hardness testing the specimens were prepared using standard procedure like belt grinding, polishing using successively fine grades of emery up to 2500 grit size. This is help-full in removing coarse and fine oxide layer as well as scratches on the surface that were to be metal graphically analyzed (Figure 7).

Impact testing: Charpy impact specimen were prepared in accordance with ASTM E-23 standards which is charpy V notch testing of metallic materials. As shown in Figures 8-10, V- Notch was prepared the in weld metal. So as to make an assessment of the weld-metal toughness. Since the area affected by using different process parameter so it was important to study how the weld-metal impact strength

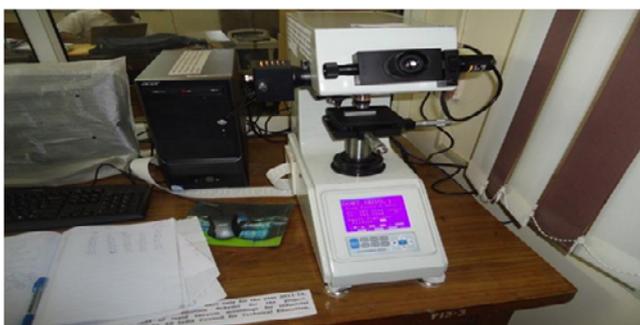


Figure 7: Micro-hardness testing machine (NML Jamshedpur).



Figure 8: Samples for impact testing.



Figure 9: Impact Testing Machine.



Figure 10: Samples after impact testing.

Frequency (Hz)	Current (A)	S.G.F.R (l/m)	% Time electrode + (μs)	Mean Micro Hardness (VHN)	Mean Impact Strength (J)
HF	85	10	60	69.82	6
HF	85	12	65	71.04	6
HF	85	14	70	73.2	5
HF	95	10	60	79.5	4
HF	95	12	65	81.86	4
HF	95	14	70	83.32	4
HF	105	10	65	89.0	3
HF	105	12	70	89.5	3
HF	105	14	60	101.4	2
LF	85	10	70	57.56	7
LF	85	12	60	69.0	6
LF	85	14	65	69.54	6
LF	95	10	65	76.32	5
LF	95	12	70	76.48	5
LF	95	14	60	83.9	4
LF	105	10	70	86.6	4
LF	105	12	60	87.04	3
LF	105	14	65	88.86	3

Table 6: Micro-hardness and impact strength.

changed due to change in process. Parameters during welding of joints the charpy V- notch values indicating the impact energy absorption by each of the welded specimen were recorded

Results and Discussion

The result obtained after performing welding and testing of MMCs (Al6063/15%SiCp) metal matrix composite, work specimens, is listed in Table 6 Micro-hardness and impact strength. The analysis of the experimental results (Table 7).

Analysis of micro-hardness (VHN)

Dependable variable is micro-hardness and there are four factors namely frequency (Hz), current (A), shielding gas flow rate (l/min) and percentage time electrode positive (μs). It constructs various tests and graphs to determine which factors have a statistically significant effect on micro-hardness in Table 8. Since the P-value in Table 9, is less than 0.05, there is a statistically significant relationship between the variables at the 95.0% confidence level The dependable variable micro-hardness (VHN) and four independable variables namely frequency (Hz), current (A), shielding gas flow rate (l/min) and percentage time electrode positive (μs) are studied to test the significance and to develop the model.

Frequency (Hz)	Current (A)	S.G.F.R (l/min)	PTEP % Time electrode+	Mean Micro Hardness (VHN)	Mean Impact Strength (joules)	S/N ratio Mean Micro-hardness	S/N ratio Mean Impact Strength
HF	85	10	60	68.84	6	35.8795	14.5632
HF	85	12	65	70.08	6	36.0309	15.5630
HF	85	14	70	72.25	5	38.2906	13.9794
HF	95	10	60	78.52	4	37.0073	12.0412
HF	95	12	65	82.89	4	38.2614	12.0412
HF	95	14	70	84.39	4	38.4150	12.0412
HF	105	10	65	88.08	3	38.9878	9.5424
HF	105	12	70	88.52	3	39.0365	9.5424
HF	105	14	60	102.4	2	40.1208	6.0206
LF	85	10	70	58.56	7	35.2024	16.9020
LF	85	12	60	68.09	6	36.7770	15.5630
LF	85	14	65	69.54	6	36.8447	15.5630
LF	95	10	65	76.32	5	37.6528	13.9794
LF	95	12	70	76.48	5	37.6710	13.9794
LF	95	14	60	83.96	4	38.4752	12.0412
LF	105	10	70	86.6 1	4	38.7504	11.0416
LF	105	12	60	87.04	3	39.7945	9.5424
LF	105	14	65	88.86	3	37.9746	8.5428

Table 7: Experimental results.

Parameters	Degree of Freedom (DF)	Sum of Squares (SS)	Mean Squares (MS)	F-Value	P-Value
Frequency (Hz)	1	1.3267	1.32668	13.51	0.006
Current (A)	2	18.0047	9.00234	91.69	0
SGFR (l/m)	2	1.7998	0.8999	9.17	0.009
PTEP (μs)	2	0.6027	0.30135	3.07	0.102
Frequency (x)	2	0.1853	0.09263	0.94	0.429
Current Residual Error	8	0.7854			0.09818
Total	17		22.7046		

Table 8: Analysis of variance for S/N ratios.

Parameters	Degree of Freedom (DF)	Sum of Squares (SS)	Mean Squares (MS)	F-Value	P-Value
Frequency (Hz)	1	1.3269	1.32668	13.51	0.006
Current(A)	2	17.0043	9.00234	91.69	0
SGFR (l/m)	2	1.79982	0.8999	9.17	0.009
PTEP (μs)	2	0.6027	0.30135	3.07	0.102
Frequency x	2	0.18539	0.09263	0.94	0.429
Current Residual Error		0.7854		-	
Total	8	21.7046			0.09718

Table 9: Response for signal to noise ratios larger is better.

Main effects plot S/N ratios for micro-hardness (VHN): The main effect plots for S/N ratios are shown in Figures 11 and 12. These show the variation of micro-hardness (VHN) with the four parameters i.e. frequency (Hz), current (A), shielding gas flow rate (l/min) and percentage time electrode positive (μs) separately. In the plots, the x-axis indicates the value of each process parameter at two levels for frequency and three levels for other three factors, y-axis the response value. Horizontal line indicates the mean value of the response. The main effects plots are used to determine the optimal design conditions to obtain the optimum micro-hardness (VHN). Main effects plot for micro-hardness (VHN) are plotted between Micro-hardness (VHN) Vs Frequency (Hz) Micro-hardness (VHN) Vs Current (A) Micro-hardness (VHN) Vs Shielding gas flow rate (l/min) Micro-hardness (VHN) Vs Percentage time electrode positive (μs) There are two levels for frequency and three levels of each other three factors thus effect of

each factor is plotted by the lines of graph. Figure 11 shows the main effects plot for S/N ratios for Micro-hardness.

Interaction plot for S/N ratios: The term interaction, expressed by inserting “x” mark between the two interacting factors, is used to explain a condition in which the influence of one factor upon the result, is dependent on the condition of the other. Two factors A and B are said to interact (written as (A × B) when the effect of changes in the level of A, determines the influence of B and vice versa [15].

Figures 12 and 13 show the interaction plot for S/N ratios and mean micro-hardness. Interaction plots are graphic representation of interaction information in the experiment. If there is absolutely no interaction, these lines would be parallel

Residual plots for S/N ratios: Residual plots are used to evaluate

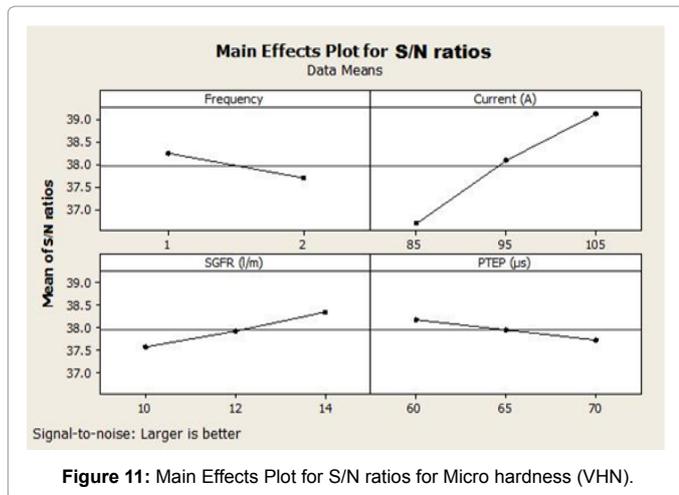


Figure 11: Main Effects Plot for S/N ratios for Micro hardness (VHN).

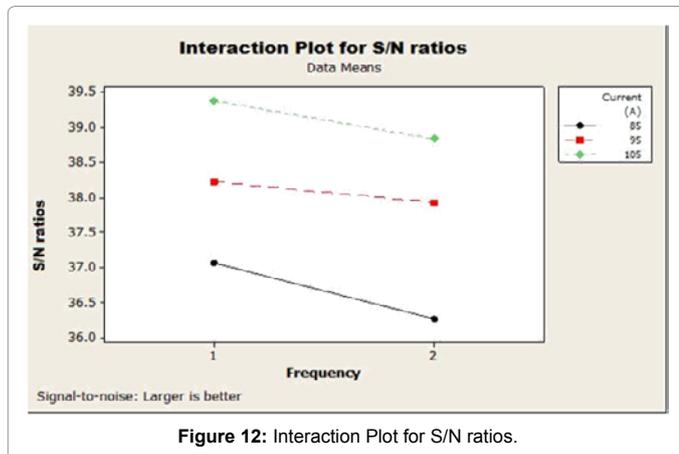


Figure 12: Interaction Plot for S/N ratios.

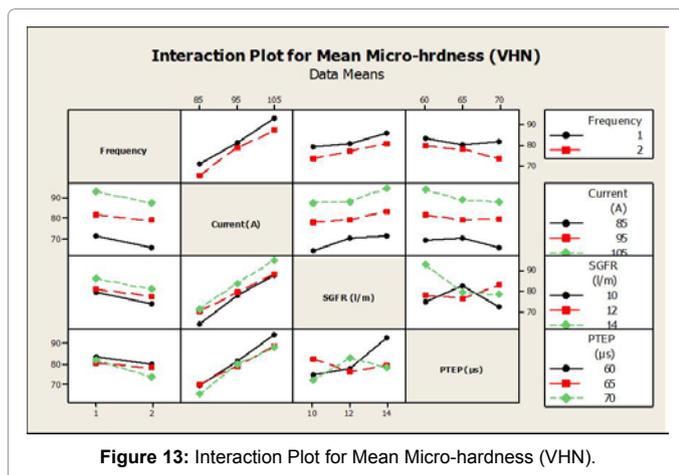


Figure 13: Interaction Plot for Mean Micro-hardness (VHN).

the data for the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. The residual plot for S/N ratios shown in Figure 14. This layout is useful to determine whether the model meets the assumptions of the analysis. Figure 14 residual plots in the graph and the interpretation of residual plot given below:

I. Normal probability plot also indicates the data are normally

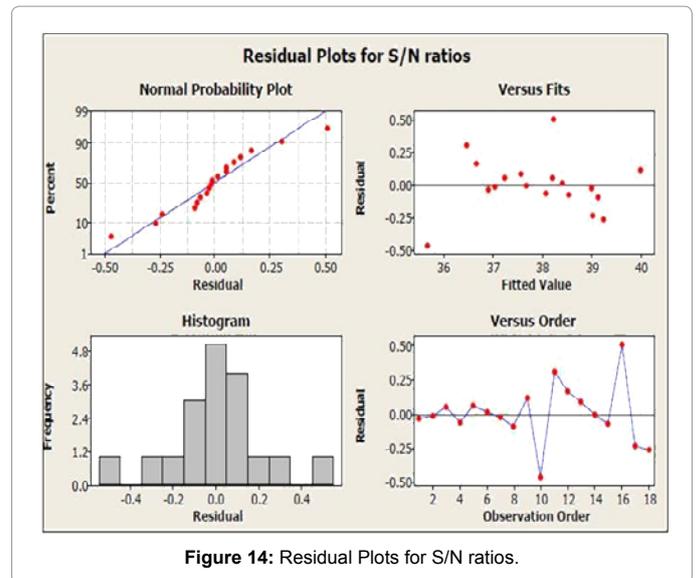


Figure 14: Residual Plots for S/N ratios.

distributed and the variables are influencing the response.

II. In normal probability plots (Figure 14), the data is spread approximately adjacent to straight line, which shows a good correlation between experimentation and predicted values, accent which shows only the minimal variation between observed and fitted value.

III. The statistics about residual are shown in Histogram plot. Histogram indicates that the residuals are normally distributed

IV. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data.

V. It is asserted that tendency to have runs of positive and negative residuals indicate the existence of certain correlation. Residual versus order of the data indicate that there are systematic effects in the data due to time or data collection order. As a whole analysis of residual plots of micro-hardness as response, the models do not reveal inadequacy.

Conclusions

The result analysis obtained from Optimization of TIG Welding Process Parameters Al6063/15%SiCp Metal Matrix Composite may be concluded as follows:

1. Micro-hardness decreases linearly from percentage time electrode positive (PTEP) 60 to 70 μ s.
2. Because decrease in heat input on work with increase in percentage time electrode positive, result coarse grain size and decrease micro-hardness
3. Micro-hardness increases linearly from current 85 to 105 Amp. Because heat input increases on work specimen due to increase in current as result grain size reduction and increase micro-hardness Micro-hardness increases linearly from LF, 50 Hz to HF, 80 Hz. Because heat input increases due to concentrated arc as result grain size reduction and increase micro-hardness.
4. Micro-hardness increases linearly from shielding gas flow rate (SGFR) 10 to 14 Litre/min.
5. Impact strength increases linearly from HF, 80 Hz to LF, 50 Hz.

Because heat input decreases due to low concentrated arc as result grain size coarse and increase impact strength.

The optimal parameters of micro-hardness are A1B3C3D1 Frequency 80 Hz, current 105 A, SGFR 14 l/m, PTEP 60 μ s.

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