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Optimization of Tungsten Inert Gas Welding Process Parameters of Al6063/15%Sicp Metal Matrix Composites

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***Abstract*— 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 (Al6063/15percent 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 (µs). 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 Taguchis methodology.**

Keywords— Metal matrix composites (MMCs), Tungsten inert gas (TIG) joining, Design of experiments (DOE), Taguchi's methodology, Optimal parametric settings, Micro-hardness.

I. INTRODUCTION

1.1 CompositeA composite is a structural material that consists of two or more combined constituents that are combined at a microscopic level and are not soluble in each other having superior properties than those depicted by any of its individual composites. One constituents 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 fibres or flakes the matrix materials are generally continuous phase, Aluminium based Metal Matrix Composites (MMCs) reinforced with ceramic particles (Al2O3, SiCp, Graphite etc.) have developed considerable interests in modern industry due to light weight of aluminium and its expensive as compared with other metals such as Titanium & Magnesium. [1]. Favorable 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, [2].

1.2 Processing Of Aluminium Matrix Composites (Amcs) Using Liquid State Fabrication

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 [3], good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibres). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix [4].

1.3 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 [5]. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies.

Alloy Type	Composition wt%										
6063	Si	Mn	Mg	Fe	Cu	Ni	Zn	Sn	Ti	Cr	Al
	0.42	0.03	0.90	0.54	0.05	0.01	0.02	0.02	0.00	0.01	Balance

II. DESIGN OF EXPERIMENTS

Design of Experiment (DoE) is a useful method in identifying the significant parameters and in studying the possible effect of the variables during the runs [6]. This method can also developed experiment between a ranges from uncontrollable factors (noise factor), which will be introduced randomly to carefully controlled parameters. The factors must be either quantitative or qualitative. The range of values for quantitative factors must be decided on how they are going to be measured and the level at which they will be controlled during the trials. Meanwhile, the qualitative factors are parameters that will be determined discretely [7].

2.1 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. 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 [8]. For our experimentation, we use L18 orthogonal array.

III.Experimental Procedures

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 L_{18} (2^1x3^3) 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.

3.1 Matrix material

The matrix material used in the investigation is AA6063. Chemical Composition of Aluminium Alloy 6063 are given in (Table 1) and mechanical properties are given in (Table 2).

Table 1: Mechanical properties of AA6063 Matrix Material

Table 2: Mechanical properties of AA6063 Matrix Material

Density	**2700 Kg/m^3**
Shear Strength	**70 MPa**
Modulus of Elasticity	**69.5 GPa**
Tensile Strength	**105 MPa**
Elongation (%)	**27**
Hardness Vickers	**25 HV**

3.2 Factors and levels of TIG welding machine

Joining of aluminium based metal matrix composites is done using TIG welding machine. The welded specimen of AMMCs is shown in (Figure 1).

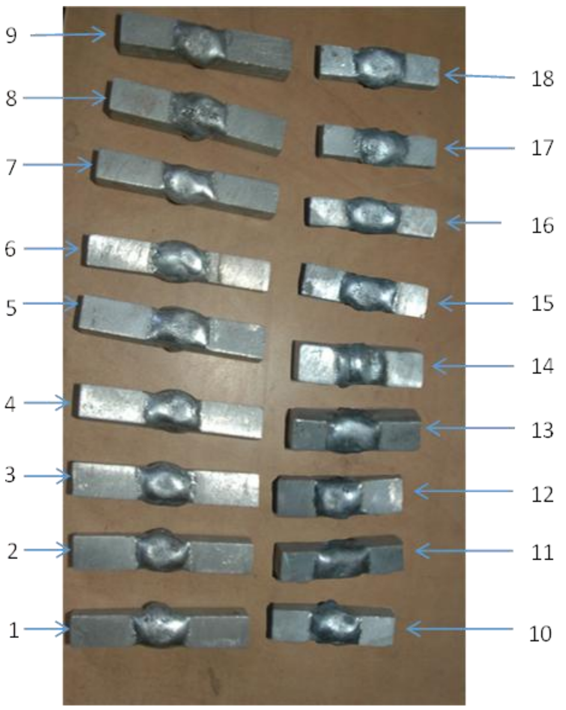

Figure 1: Welded specimens

(a) Noise factor: Frequency (Hz)

Level=2 (Low frequency, LF and High frequency, HF)

DOF=1

(b) Control factors: Current (A), Shielding gas flow rate (l/m), Percentage time electrode positive (µs)

Level=3 and 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 listened in (Table-3).

Table 3: Process parameters considered and their levels

Factors	Unit	Levels		
		1	2	3
Frequency	Hz	HF	LF	-
Current	A	85	95	105
Shielding gas flow rate	l/m	10	12	14
Percentage time electrode positive	µs	60	65	70

3.3 Design of Taguchi's Orthogonal Array

In the present study, L18 (2_1x3_3) 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. Lay out of orthogonal array is shown in (Table 4).

Table 4: Experimental lay out using L18 (2^1x3^3) orthogonal array

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

3.4. 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 these can be thought of as penetration hardness, wear hardness, and rebound hardness [9]. 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 [10].

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 [11].

3.5 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.

3.5.1 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 metalographically analysed.

Micro-hardness tester was used to measure micro-hardness at different weld-ments. A load of 100 gf and dwell time 10 second were used for these studies. Micro-hardness testing was extensively carried out on each weld-ment surface in the longitudinal direction each consecutive indent was made at a distance of 1mm, the indenter used in Vicker micro- Hardness test a square-based diamond pyramid, containing 136^0 angle between opposite faces it assures a higher accuracy. It is because the diagonals of a square can be measured more

accurately than the diameter of a circle. Therefore, the results obtained are more accurate. Another advantage of this test is that plastic deformation is caused even by lighter loads.
Dwell time-20sec and at load -500g testing is done as shown in (Figure 2).

Figure 2: Testing of micro-hardness.

3.5.2 Impact testing

Charpy impact specimen were prepared in accordance with ASTM E-23 standards which is charpy V notch testing of metallic materials. V- notch was prepared in the weld metal so as to make an assessment of the weldmetal toughness. Since the area affected by using different process parameter so it was important to study how the weldmetal impact strength changed due to change in process parameter during welding of joints the charpy V- notch values indicating the impact energy absorption by each of the welded specimen were recorded.
Micro-hardness and Impact strength of tested work specimen is shown in (Table 4)

Table 4: Micro-hardness and Impact strength.

Freque-ncy (HZ)	Curr-ent (A)	S.G.F.R (l/m)	% Time electrode + (μs)	Mean Micro Hardness (VHN)	Mean Impact Strength (joules)
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

IV. RESULT AND DISCUSSION

4.1 Experimental results- The results obtained after performing welding and testing of AMMCs (Al6063/15%SiCp) metal matrix composite, work specimens is listed in (Table 5).

Table 5: Experimental Results

Frequency (HZ)	Current (A)	S.G. F.R (l/m)	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	69.82	6	36.8796	15.5630
HF	85	12	65	71.04	6	37.0301	15.5630
HF	85	14	70	73.2	5	37.2902	13.9794
HF	95	10	60	79.5	4	38.0073	12.0412
HF	95	12	65	81.86	4	38.2614	12.0412
HF	95	14	70	83.32	4	38.4150	12.0412
HF	105	10	65	89.0	3	38.9878	9.5424
HF	105	12	70	89.5	3	39.0365	9.5424
HF	105	14	60	101.4	2	40.1208	6.0206
LF	85	10	70	57.56	7	35.2024	16.9020
LF	85	12	60	69.0	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	83.9	4	38.4752	12.0412
LF	105	10	70	86.6	4	38.7504	12.0412
LF	105	12	60	87.04	3	38.7944	9.5424
LF	105	14	65	88.86	3	38.9741	9.5424

4.2 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/m) 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 following (Table-6).

Table 6: Analysis of variance for S/N ratios

Parameters	Degree of Freedom (DF)	Sum of Squares (SS)	Mean Squares (MS)	F-Value	P-Value
Frequency	1	1.3267	1.3268	13.51	0.006
Current(A)	2	18.0047	9.00234	91.69	0.000
SGFR (l/m)	2	1.7998	0.89990	9.17	0.009
PTEP (µs)	2	0.6027	0.30135	3.07	0.102
Frequency *Current(A)	2	0.1853	0.09263	0.94	0.429
Residual Error	8	0.7854	0.09818		
Total	17	22.7046			

Since the P-value in the Table 6 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/m) and percentage time electrode positive (µs) are studied to test the significance and to develop the model.

4.2.1 Main Effects Plot for S/N ratios

The main effect plots for S/N ratios are shown in Figure 3. These show the variation of micro-hardness (VHN) with the four parameters i.e. frequency (Hz), current (A), shielding gas flow rate (l/m) 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:

a. Micro-hardness (VHN) Vs Frequency (Hz)
b. Micro-hardness (VHN) Vs Current (A)
c. Micro-hardness (VHN) Vs Shielding gas flow rate (l/m)
d. 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 3 shows the main effects plot for S/N ratios which shows that the current (A) has more significant effect on the micro-hardness. Micro -hardness increases linearly with the increase in frequency. The main effects plot between micro-hardness (VHN) and current (A) shows that micro-hardness increases with increase in current. The plot between micro-hardness (VHN) and shielding gas flow rate (l/m) shows that micro-hardness increases, with increase in shielding gas flow rate. The main effects plot between micro-hardness (VHN) and percentage time electrode positive (µs) shows that the micro-hardness decreases linearly with increase in percentage time electrode positive.

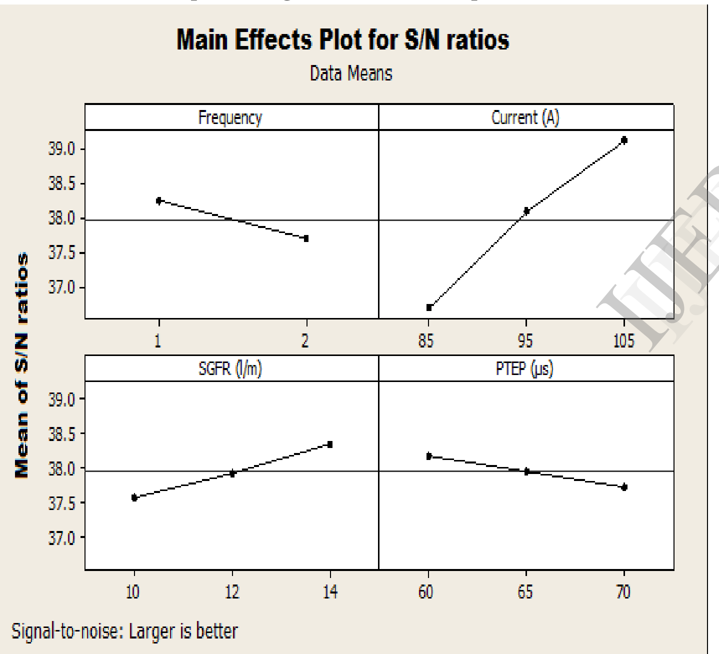

Figure 3: Main Effects Plot for S/N ratios

The optimal parameters of micro-hardness are A1B3C3D1(Frequency 60 (Hz), current 105A, shielding gas flow rate 14 l/m, percentage electrode positive 60 µs). According to the present study, it can be inferred that the parameter current (A) have the most significant effect on micro-hardness (VHN).

Interaction Plot for SN 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 x B) when the effect of changes in the level of A, determines the influence of B and vice versa **[12].**

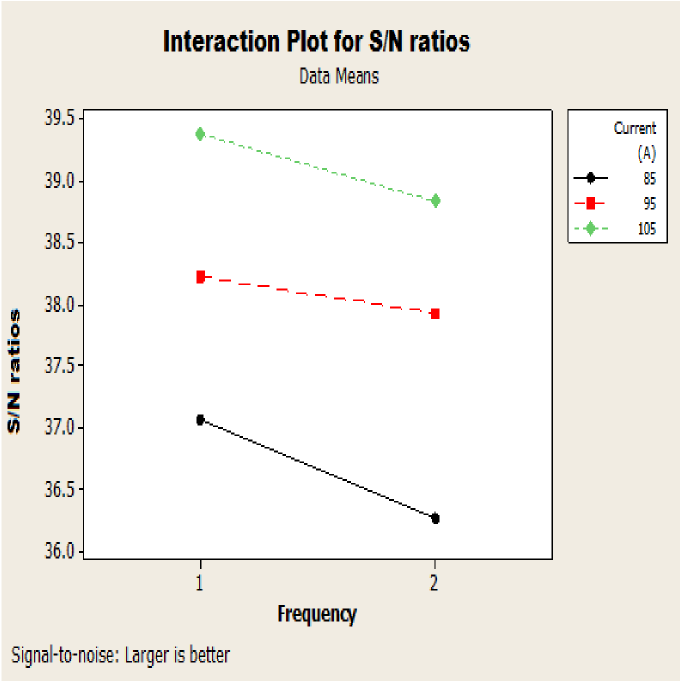

Figure 4: Interaction Plot for S/N ratios

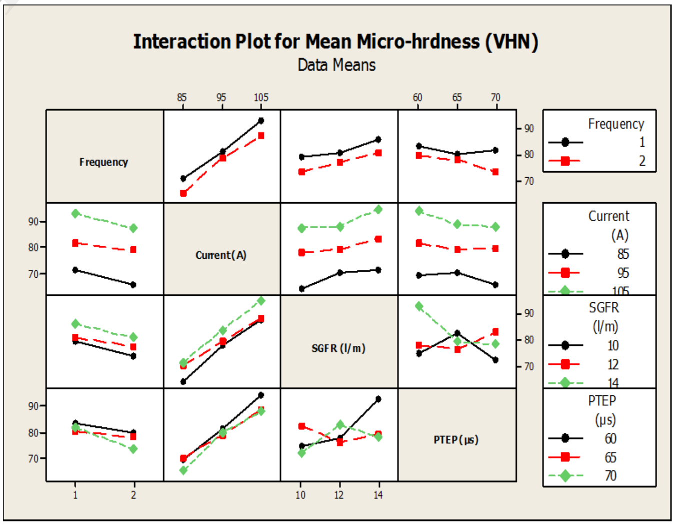

Figure 5: Interaction Plot for Mean Micro-hardness (VHN)

Figure 4 and 5 shows 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. The stronger the interaction, the more different the shapes of the lines would be. In the present study interactions are studied among frequency and current, since lines are nearly parallel, hence no interaction.

4.3 Analysis Of Impact Strength (J)

Dependable variable is impact strength and there are four factors namely frequency (Hz), current (A), shielding gas flow rate (l/m) and percentage time electrode positive (µs). It constructs various tests and graphs to determine which factors have a statistically significant effect on impact strength in following Table 7 Since the P-value in the Table 7 is less than 0.05, there is a statistically significant relationship between the variables at the 95.0% confidence level The dependable variable impact strength (Joule) and four undependable variables namely frequency (Hz), current (A), shielding gas flow rate (l/m) and percentage time electrode positive (µs) are studied to test the significance and to develop the model.

Table 7: Analysis of variance for S/N ratios

Paramet-ers	Degree of Freedom (DF)	Sum of Squares (SS)	Mean Squares (MS)	F-Value	P-Value
Frequency	1	9.130	9.1301	30.36	0.001
Current(A)	2	113.710	56.8552	189.05	0.000
SGFR (l/m)	2	10.153	5.0763	16.88	0.001
PTEP (µs)	2	5.244	2.6222	8.72	0.001
Frequency *Current(A)	2	0.839	0.4196	1.40	0.302
Residual Error	8	2.406	0.3007		
Total	17	141.482			

4.3.1 Main Effects Plot for S/N ratios

The main effect plots for S/N ratios are shown in Figure 6. These show the variation of impact strength (Joules) with the four parameters i.e. frequency (Hz), current (A), shielding gas flow rate (l/m) 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 impact strength (Joules). Main effects plot for of impact strength (Joules) are plotted between

a. impact strength (Joules) Vs Frequency (Hz)
b. impact strength (Joules) Vs Current (A)
c. impact strength (Joules) Vs Shielding gas flow rate (l/m)
d. impact strength (Joules) Vs Percentage time electrode positive (µs)

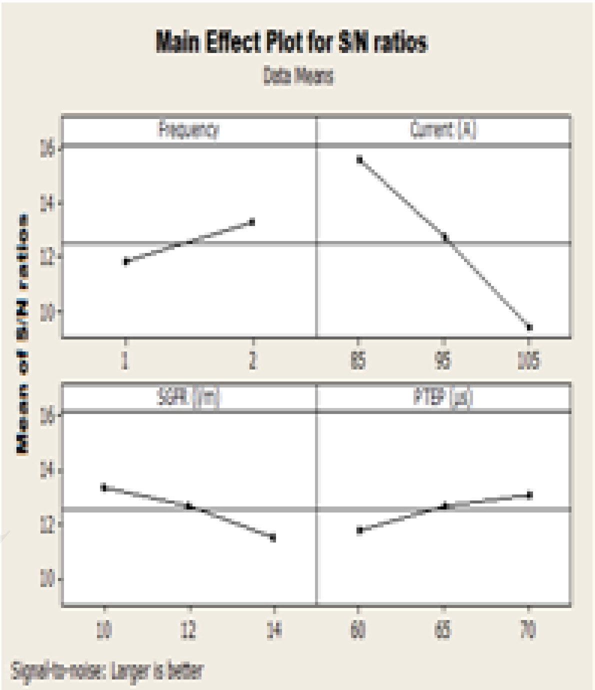

Figure 6: Main Effects Plot for S/N ratios

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 5.10 shows the main effects plot for S/N ratios which shows that the current (A) has more significant effect on the impact strength. Impact strength increases linearly with the decrease in frequency. The main effects plot between impact strength and current (A) shows that impact strength decreases with increase in current.

The main effects plot between impact strength and shielding gas flow rate (l/m) shows that impact strength increases, with decrease in shielding gas flow rate. The main effects plot between impact strength and percentage time electrode positive (µs) shows that the impact strength increases with increase in percentage time electrode positive.

The optimal parameters of impact strength are **A2B1C1D3.**

(Frequency 2 or LF as 50 (Hz), current 85A, shielding gas flow rate 10 l/m, percentage electrode positive 70 µs). According to the present study, it can be inferred that the parameter current (A) have the most significant effect on impact strength.

Interaction Plot for S/N ratios

Figure 7 and 8 shows the interaction plot for S/N ratios and mean impact strength. In the present study interactions are studied among frequency and current, since lines are nearly parallel, hence no interaction.

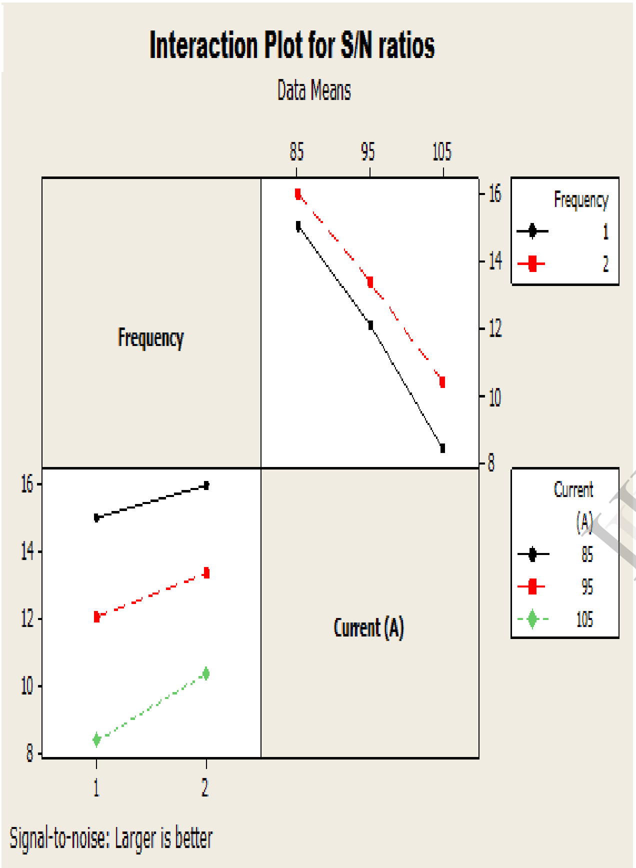

Figure 7: Interaction Plot for S/N ratios

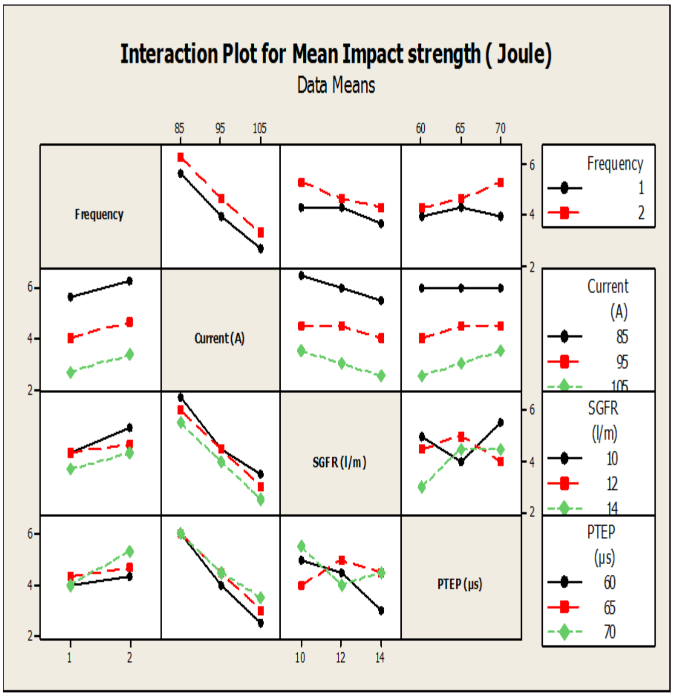

Figure: 8: Interaction Plot for Mean Impact strength (joule)

V. CONCLUSIONS

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

- Micro-hardness increases linearly from LF, 50 Hz to HF, 80 Hz
- Micro-hardness increases linearly from current 85 to 105 Amp. with slight fluctuation of linearity at 95 Amp.
- Micro-hardness increases linearly from shielding gas flow rate (SGFR) 10 to 14 Liter/min.
- Micro-hardness decreases linearly from percentage time electrode positive (PTEP) 60 to 70 µs
- The optimal parameters of micro-hardness are A1B3C3D1

(Frequency 80 Hz, current 105 A, SGFR 14 l/m, PTEP 60 µs)

- Impact strength increases linearly from HF, 80 Hz to LF, 50 Hz
- Impact strength increases linearly from current 105 to 85 Amp. with slight fluctuation of linearity at 95 Amp.

- Impact strength increases linearly from shielding gas flow rate (SGFR) 14 to10 Liter/min. with slight fluctuation of linearity at 12 Liter/min.
- Impact strength decreases linearly from percentage time electrode positive (PTEP) 70 to 60 µs with slight fluctuation of linearity at 65 µs
- The optimal parameters of impact strength **A2B1C1D3**

(Frequency 50 Hz, current 85 A, SGFR 10 l/m, PTEP 70 µs)

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