Experimental Study and Optimization of Gas Metal Arc Welding Process Parameters using Taguchi Method

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ABSTRACT

Gas metal arc welding (MIG/GMAW) is currently one of the most popular welding methods, especially in industrial environments. In order to meet the global competition and the survival of products in the market a new way of thinking is necessary to change and improve the existing technology and to develop products at economical price. It means not only to invest in procuring new equipments but also effectively control the process variables involved in any manufacturing process. These process variables must be measured and controlled to get the desired valuable outputs. In the present work, the mechanical behavior of MIG welded joints of similar materials was studied using the plates of Mild Steel having 12 mm thickness each. The mechanical property impact toughness of the welded joints are evaluated using Taguchi method using (welding current, Arc voltage and gas flow rate) as three input parameters each having three levels each (low, medium and high). A plan of experiments based on Taguchi technique has been used to acquire the data. An Orthogonal array and signal to noise ratio are employed to investigate the welding characteristics of mild Steel and optimize the welding parameters. The impact strength of the weld metal have been identifying using Charpy test. The results indicates that impact stregth of welded joints are maximum at current 200 Amp, Arc Voltage 25 V and gas flow rate 14 lit/min than values at 130A and 170A, thus impact strength becomes 40.97 Jule.

Main effects plots from the ANOVA were obtained and studied. The quadratic models were found to be significant with a p-value of 0.500, 0.592 and 0.751. Results showed that voltage is the most significant and current is least significant factor affecting Impact strength.

Therefore the present work was focused on finding the optimal parameters combination of current, Arc Voltage and gas flow rate for maximizing the Impact strength.

Keyword: - *Taguchi, mild steel, Orthogonal array, MIG, Charpy, Impact Strength etc….*

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1. INTRODUCTION

Welding is the simplest and easiest way to join sections of pipe. Welded pipe has reduced flow restrictions compared to mechanical connections and the overall installation costs are less. Two common processes welding of pipe are MIG and TIG. MIG welding also known as GMAW [1]. The metal arc inert gas shielded process also known as MIG, [MAGS] Metal Arc Gas Shielding and [GMAW] Gas Metal Arc Welding, All commercially important metals such a carbon steel, high strength steels, low alloy steels, stainless steels, Aluminum, copper, Titanium and Nickel alloys can be welded in all positions with GMAW by choosing a appropriate shielding gas electrode and welding variables. It offers advantage of high welding speeds, smaller heat affected zone than TIG welding, excellent oxide film removal during welding. For these reasons MIG welding is the most widely used [2].

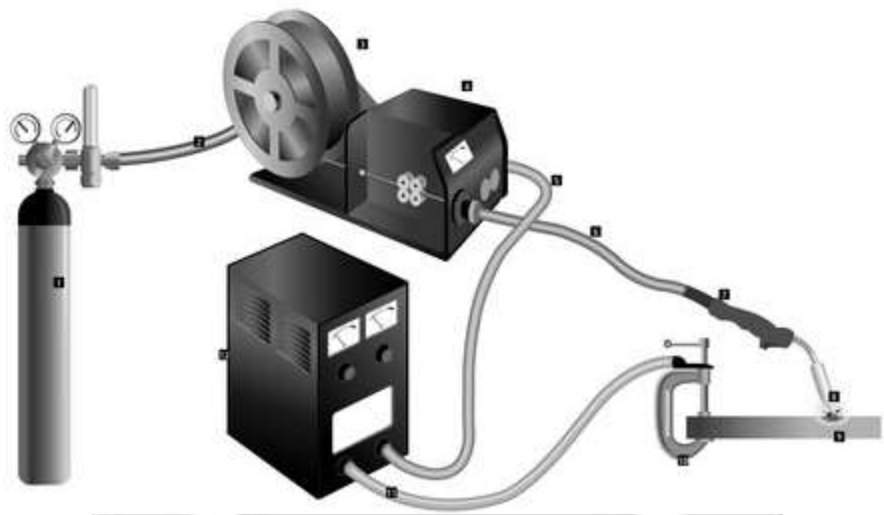

Fig -1: Schematic diagram of MIG [3]

1. Gas Cylinder	2. Gas Hose	3. Continuous Wire	4. Wire feed unit
5. Power Cable	6. Torch Candice	8. Welding Torch	9. Arc
10. Work piece	11. Earth Clamp	12. Return Cable	13. Power Source

A manufacturer focuses on the quality, quantity and product dimensional accuracy during the manufacturing. They always try to reduce manufacturing time, wear rates (of machine and tool used), high productivity to reduce cost of manufacturing and maintenance cost [4].

2. MATERIALS AND METHOD

Mild steel contains approximately 0.05–0.25%carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form; surface hardness can be increased through carburizing. It is often used when large quantities of steel are needed, for example as structural steel [5].

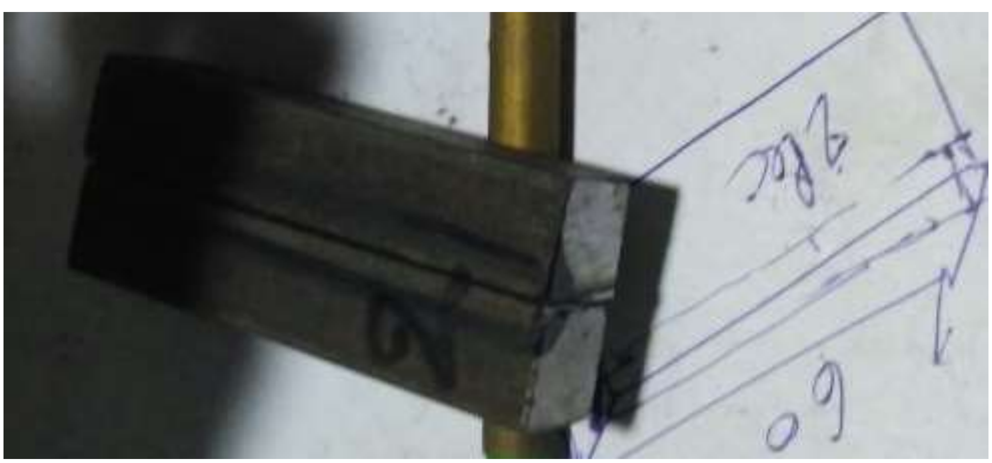

Fig -2: Mild steel work piece before welding

Table -1: Chemical Composition of Mild steel

Constituent	Carbon, Max	Manganese, Min	Silicon, Max	Sulphur, Max	Phosphorous, Max	Aluminum, Min
%	0.16	0.30	0.25	0.030	0.030	0.02

Table -2: Physical Properties of Mild steel

Physical Properties	**Value**
Melting point	1427°C
Density	7480-8000 kg/m^3
Tensile strength	440 MPa
Yield strength	370 MPa
Elastic modulus	205 GPa
Hardness (HRB)	71
Electric resistivity	1590 nΩ.m

2.1 Electrode

The commonly used electrode for Mild Steel is ER70S-6.
ER— stands for filler electrode.
70—Strength of the weld in case of mild steel, the weld has a minimum of 70.000pound tensile strength per square inch of the weld.
S— stands for solid rod.
6- Represent s the amount of cleaner added to the wire to improve the weld quality.

2.2 Shielding Gases

The gases used are combinations of two or more gases some of them are, Argon Carbon dioxide, Helium and oxygen. In most welding application a combination of Argon and Carbon dioxide gas is used. Argon gas produces a clear weld and carbon dioxide help to produce deeper penetration. 100% Carbon dioxide. 25% Carbon dioxide and 75% Argon. 2% carbon dioxide and 98% Argon. Argon is used for welding of Aluminum, copper, Nickel, Titanium

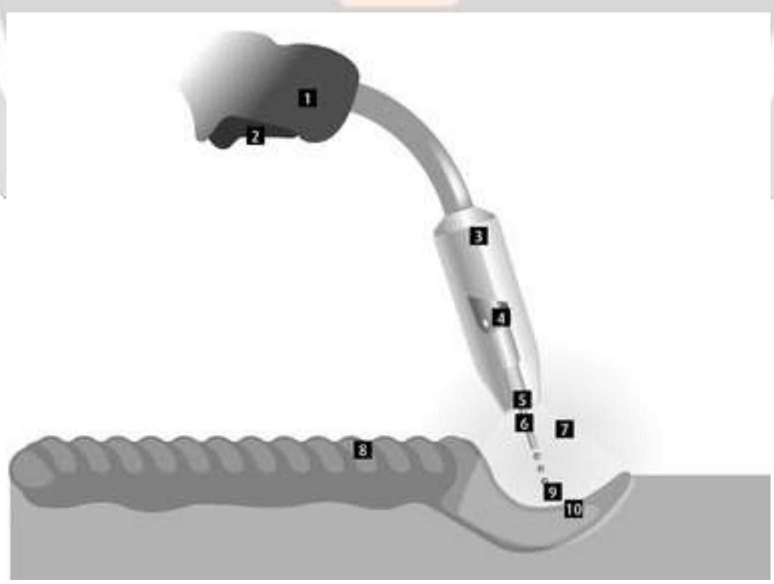

Fig -3: MIG/MAG welding torch [3]

1. Torch	2. Torch Trigger	3. Shroud	4. Gas diffuser	5. Contact Tip
6. Welding wire	7. Shielding	8. Weld	9. Droplets	10. Weld Pool

Electrode Diameter: 1.2mm was used for welding
CO_2 gas-shield welding wire ER70S-6 has excellent mechanical performance such as depositing speed and high efficiency, stable arc, little splash, good welding seam. This series of welding wires are suitable for the low carbon steel and low alloy structure, vehicle, bridge container, construction machinery, boilers and construction etc.

Table -3: Chemical Composition of Electrode

Constituent	C	Mn	Si.	P	S	Cu	Ni	R
%	0.6- 0.15	1.4- 1.85	0.80- 1.15	≤ 0.025	≤ 0.035	≤ 0.35	≤ 0.030	≤ 0.20

This is an alloy electrode, hard faced layer are resistant to wear and they are also resistant to medium impact during exploitation. This hard faced electrode is especially suitable for hard facing of parts exposed to friction of metals to minerals. This electrode is highly resistant to abrasive wear at relatively low current GMAW operates in the globular metal transfer mode. It is characterized by periodic formation of big droplets at the end of electrodes, which detach due to gravitational force into the weld pool. This metal transfer mode suffers from lack of control over molten droplets and arc instability due to formation of big droplets. At higher currents, the process transits to spray mode. This mode offers high deposition rate but due to tapering of electrode smaller diameter drops are formed. Continuous metal deposition, in form of drops, produces smooth bead and stiffer arc. Drawbacks of this metal transfer mode are:
Minimum current for spray mode's being too high for some materials, large heat input to work piece, wide bead, and only down hand positional capability. It offers advantage of high welding speeds, smaller heat affected zone than TIG welding, excellent oxide film removal during welding. For these reasons MIG welding is the most widely used.

2.3 Taguchi Method and Orthogonal Array Selection

The Taguchi method developed by Genuchi Taguchi is a statistical method used to improve the product quality. Optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the loss function is further transformed into signal-to-noise (S/N) ratio [6].

2.4 S/N Ratio

Taguchi method stresses the importance of studying the response variation using the signal-to-noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter [7].
The S/N ratio can be used in three types:
Smaller-The-Better: n = -10 Log10 [mean of sum of squares of measured data]
Larger-The-Better: n = -10 Log10 [mean of sum squares of reciprocal of measured data]
Nominal-The-Best: square of mean n = 10 Log10 Square of mean/ variance [8].

2.5 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into conurbations' by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio can be calculated as:[9].

$$SS_T = \sum_{i=1}^{n} (y_i - \bar{y})^2$$

Where:
S is the standard deviation.
y_i is the ith observation.
n is the number of observations.
$\bar{y}$ is the mean of the n observations.

3. EXPERIMENTATION

Test plates of size 60 x 12x 12 mm were cut from alloy steel plate of mild steel and one of the surfaces was cleaned to remove oxide and dirt before cladding. ER – 70S-6 deoxidized wire which provides defects free from weld deposits. A mixture of argon and carbon dioxide gat at flow rate was used for shielding. The important and most difficult parameters found from trail run is wire feed rate. The wire feed rate is proportional to current. The selection of the welding electrode wire based on the matching the mechanical properties and physical characteristics of the base metal, weld size and existing electrode inventory

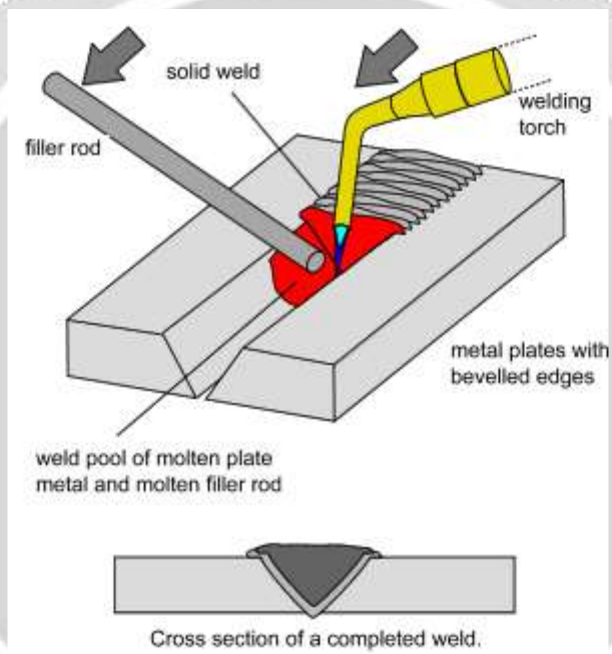

Fig -4: Mild steel plates with beveled edges [10]

Table -4: MIG Welding Parameters and Their Levels

Factors	**Levels**			
	Unit	**1**	**2**	**3**
Current	A	190	200	210
Voltage	V	20	25	30
Shielding gas flow rate	Lit/min	10	12	14

Table -5: L9 Orthogonal Array

S. no.	Current	Voltage	Gas flow rate
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4. CHARPY TEST

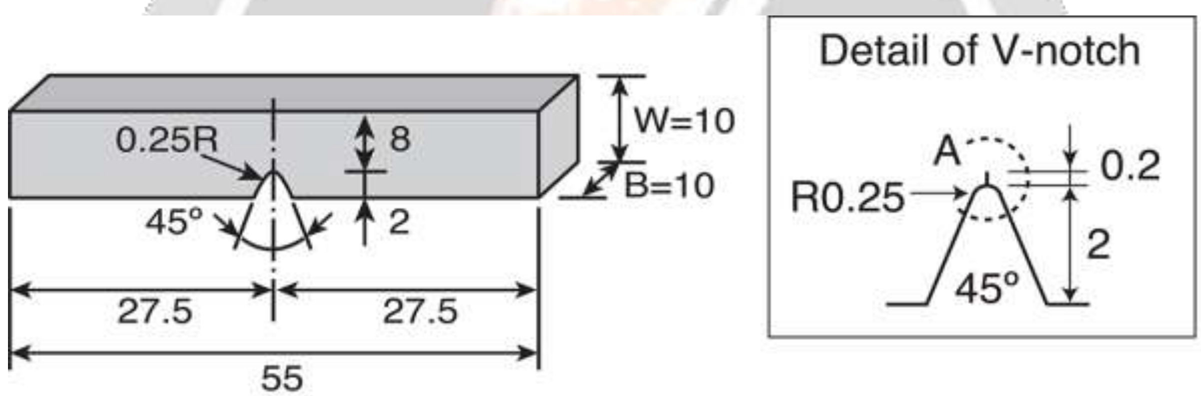

Fig -5: Charpy test specimen detail [11]

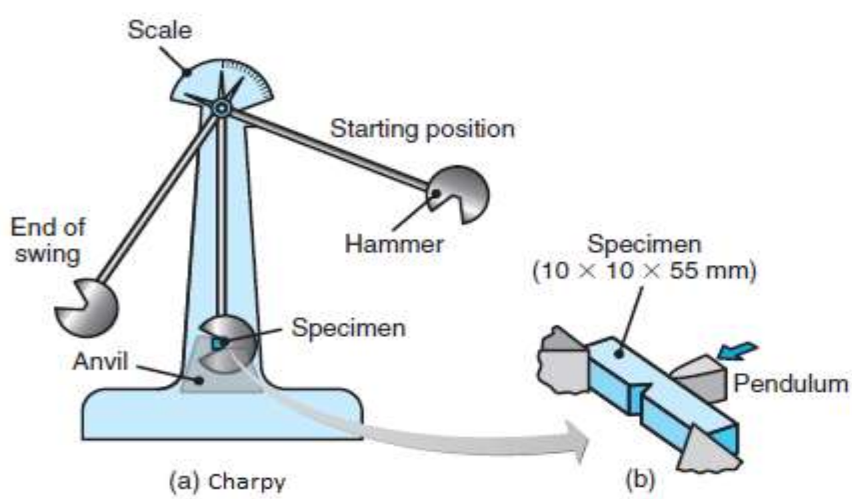

Fig -6: Charpy impact test setup [12]

Impact Testing -- To check the Strength of the weld we have done the testing in charphy method to identify the weld quality of the material. After we had finished the welding, the work piece was marked and cut the specimens of standard size 55x10x10mm placed for charpy impact test in that v-groove point where we can check the load to the area of withstand capacity in the material. Strength is, broadly, a measure of the amount of energy required to cause an item a test piece or a bridge or a pressure vessel to fracture and fail. The more energy that is required then the tougher the material. There are two main forms of impact test, the Izod and the Charpy test. Both involve striking a standard specimen with a controlled weight pendulum travelling at a set speed. The amount of energy absorbed in fracturing the test piece is measured and this gives an indication of the notch strength of the test material. These tests show that metals can be classified as being either 'brittle' or 'ductile'. A brittle metal will absorb a small amount of energy when impact tested, a tough ductile metal a large amount of energy. It should be emphasized that these tests are qualitative, the results can only be compared with each other or with a requirement in a specification they cannot be used to calculate the fracture strengths of a weld or parent metal, such as would be needed to perform a fitness for service assessment. The Charpy specimen V- notches are used for the testing of ductile materials such as cast iron and for the testing of plastics. The V- notch specimen is the specimen of choice for weld testing. The current British Standard for Charpy testing is BS EN ISO 1481: 2009 and the American Standard is ASTM E23. The standards differ only in the details of the strikers used. The standard Charpy V- notch specimen illustrated in Fig.5&6. It is 55mm long, 10mm square and has a 2mm deep notch with a tip radius of 0.25mm machined on one face.

5. RESULT AND DISSCUSSION

After performing the experiments, the output responses (Impact Strength) values were calculated and the results were tabulated as given below. The density of the mild steel is taken as 7.87 x 10^{-3} gm/mm^3

Table -6: Experimental data obtained from Charpy Impact test

S. no.	Current	Voltage	Gas Flow Rate	Impact Strength	S/N Ratio
Unit	(Amp)	(V)	(Lit/min)	(Jule)	db
1	190	20	10	28.6	29.1273
2	190	25	12	40.0	32.0412
3	190	30	14	33.0	30.3703
4	200	20	12	29.3	29.3374
5	200	25	14	52.0	34.3201
6	200	30	10	37.0	31.3640
7	210	20	14	37.2	31.4109
8	210	25	10	32.3	30.1841
9	210	30	12	42.8	32.6289

Table -7: Response table of S/N Ratio

Level	Current	Voltage	Gas Flow Rate
1	30.51	29.96	30.23
2	31.67	32.18	31.34
3	31.41	31.45	32.03
Delta	1.16	2.22	1.81
Rank	3	1	2

Table -8: Response table of mean

Level	Current	Voltage	Gas Flow Rate
1	33.87	31.70	32.63
2	39.43	41.43	37.37
3	37.43	37.60	40.73
Delta	5.57	9.73	8.10
Rank	3	1	2

Table -9: Analysis of Variance for SN ratios

Source	**DF**	**Seq SS**	**Adj MS**	**F**	**P**	**% of Contribution**
Current	2	47.71	23.85	0.33	0.751	10.95
Voltage	2	144.24	72.12	1.00	0.500	33.12
Gas Flow Rate	2	99.35	49.67	0.69	0.592	22.81
Error	2	144.25	72.12			33.12
Total	8	435.55				100

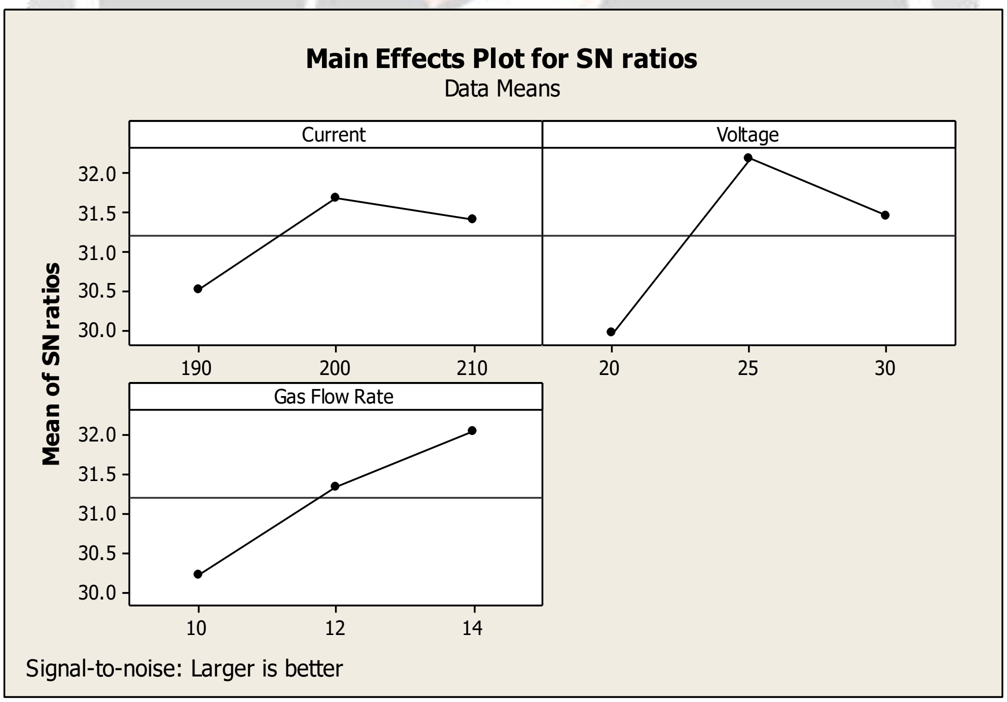

Chart -1: Main effect plot for SN Ratio

This graph is between SN ratio of Impact strengths verses the three different levels (A1,B2,C3) of the input parameters i.e. i.e. Current, voltage and gas flow rate. Greater value of S/N ratio is always considered for better performance regardless of the category of the performance characteristics. This graph shows that which level of the parameter results in maximum Impact Value. According to this graph, second level of Current results in impact value. Similarly, the second level of voltage, third level of gas flow rate for results in Impact value. So the parameters for maximum impact value (A2, B2, C3) give the maximum Impact value.

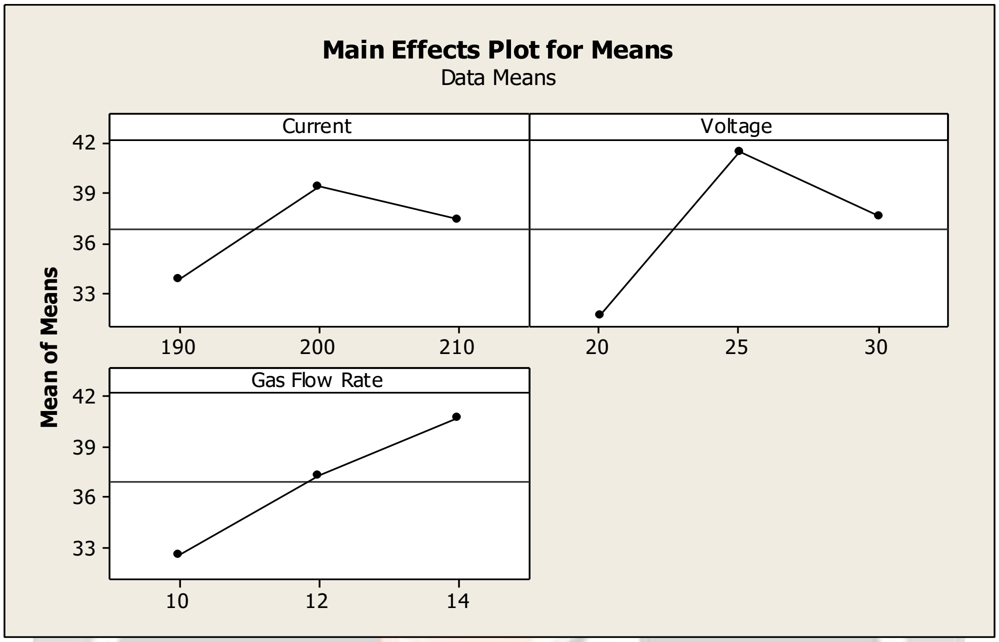

Chart -2: Main effect plot for Means

This graph is between the means of impact strength verses the three levels (A1,B2,C3) of input parameters i.e. Current, voltage and gas flow rate. This graph shows that maximum value of the means results in maximum impact value. Hence, second level of Current results in impact value. Similarly, the second level of voltage, third level of gas flow rate for results in Impact strength. So the parameters for maximum impact value (A2, B2, C3) give the maximum Impact value.

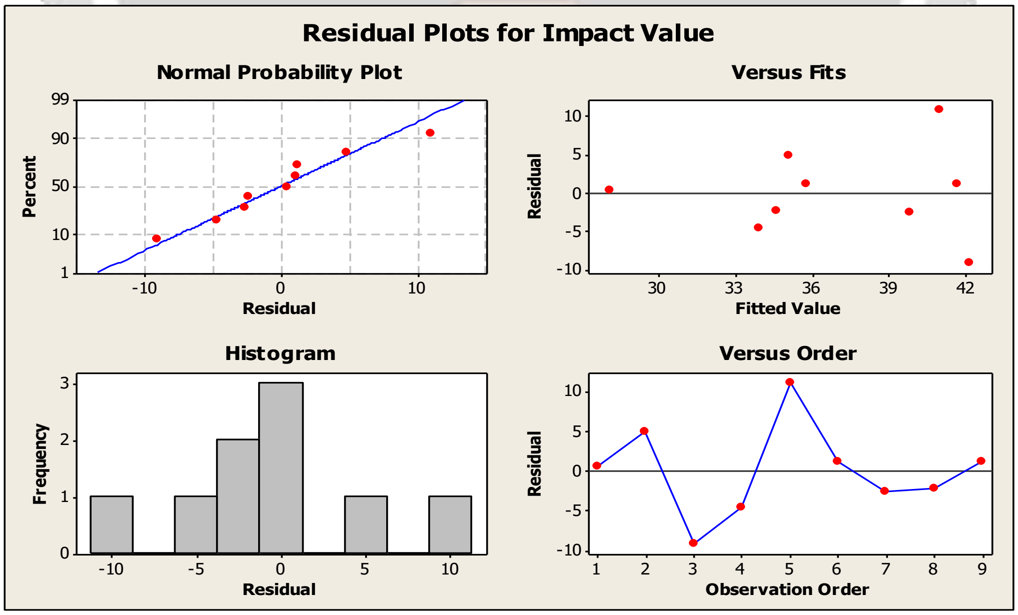

Chart -3: Residual plot for SN ratio of impact strengths

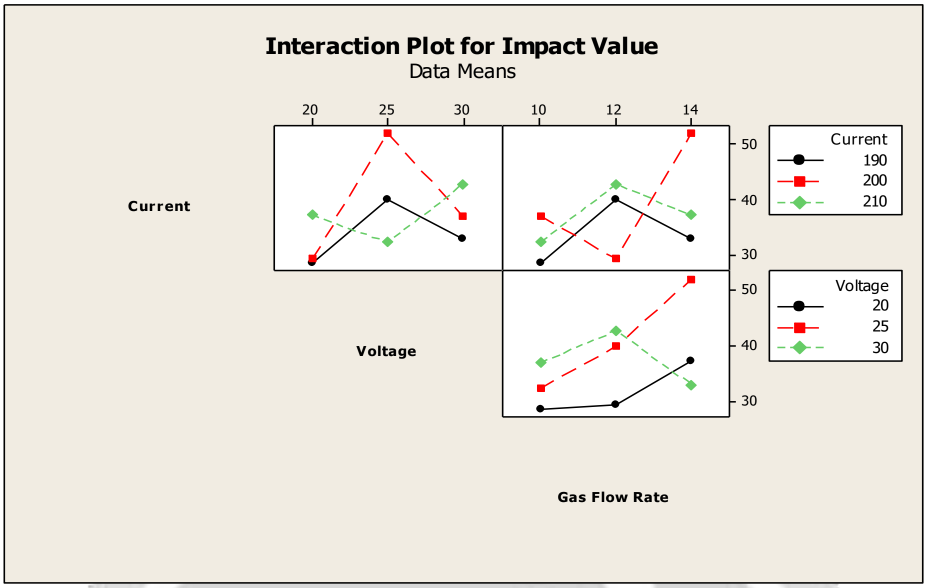

Chart -4: Intraction Plot for impact value

Optimal setting for impact value in the experiment level is as

The impact strength (the amount of impact energy the specimen absorbed before yielding) was then read off the calibrated scale on the impact testing machine.

Current = 200 Amp

Voltage = 25 V

Gas flow rate = 14 lit/min

Impact Strength = 40.97 Jules

6. CONCLUSIONS

The experimental study has focused an application of the Taguchi method for the optimization of process parameters of MIG welding operations. As discussed earlier, the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the welding parameters. The optimal combination of welding parameters and their levels for the maximum impact value of the welded specimen after cut of 2mm deep V- notch with 45^0 angles. MIG welding optimized process are A2B2C3 (i.e. Current- 200 Amp, Voltage- 25V and gas flow rate- 14lit/min The percentage contributions of Current, Arc Voltage and gas flow rate are 10.95%, 33.12% and 22.81% respectively. Hence, significant improvements in welding strength can be obtained using this approach. Finally, it can be a very useful technique for use to the industries to optimize the machining performance with minimum cost and loss of time.

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