Parameters Optimization For Gas Metal Arc Welding of Mild Steel Using Taguchi's Technique

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Abstract: Welding is a basic manufacturing process for making components or assemblies. Recent welding economics research has focused on developing the reliable machinery database to ensure optimum production. In this paper, the optimization of welding input process parameters for obtaining greater weld strength in the Gas Metal Arc Welding (GMAW) of Mild Steel is presented. The Taguchi method is adopted to analyze the effect of each welding process parameter on the weld strength, and the optimal process parameters are obtained to achieve greater weld strength. A L9 Orthogonal array was selected for analysis of data. Investigation to find out the influence of Arc Current, Arc Voltage & Gas Flow Rate on Tensile Strength, Hardness of Parent Metal, Weld Zone & Heat Affected Zone & Microstructure during welding process was carried out using ANOVA and Regression equations for each response were developed. Experimental results are provided to illustrate the proposed approach.

Keywords: GMAW welding, Taguchi method, Tensile strength and Hardness of the weld, Microstructure.

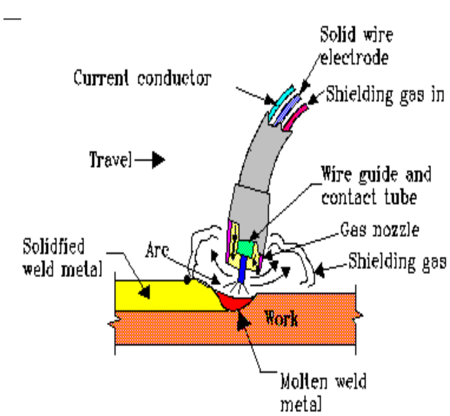
1. INTRODUCTION

Welding is a process of joining two materials. It is more economical and faster process compared to both casting and riveting. Welding find applications in the manufacture of many products around us name few ships, rail road equipments, building construction, boilers, launch vehicles, pipelines, nuclear power plants, aircrafts, automobiles, pipelines. Various welding methods available are: Shielded Metal Arc Welding (SMAW), Submerged Arc Welding (SAW), Tungsten Inert Gas (TIG) Welding, metal inert gas (MIG) welding, Plasma Arc Welding (PAW), Gas Metal Arc Welding (GMAW), Flux Cored Arc Welding (FCAW), Electro Slag Welding (ESW), and Oxyacetylene (OA) Welding.[2]

Welding processes play an important role in metal fabrication industries. There are various welding techniques. The two most commonly used types are tungsten inert gas (TIG) and metal inert gas (MIG/MAG) welding process. The two processes differ in that the TIG process uses a non consumable electrode, while the MIG/MAG process utilizes a consumable electrode for joining. A metal inert gas (MIG) welding process consists of heating, melting and solidification of parent metals and a filler material in localized fusion zone by a transient heat source to form a joint between the parent metals. MIG welding parameters are the most important factors affecting the quality, productivity and cost of welded joint. Factors such as arc current, arc voltage and welding speed and their interactions play a significant role in the welding process.[5]

All commercially important metals such as carbon steels, high strength low alloy steel, stainless steel, aluminium, copper, titanium, and nickel alloys can be welded in all positions with GMAW process by choosing appropriate shielding gas, electrode, and welding variable. The process is illustrated in Figure 1.[8]

Figure 1: MIG welding process



2. DESIGN OF EXPERIMENTS (DOE)

Design of experiment is one of the important and powerful statistical technique to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield and improved understanding of process performance. All designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. Taguchi approach relies on the assignment of factors in specific orthogonal arrays to determine test combinations. The DOE process is made up of three main phases: the planning phase, the conducting phase and the analysis phase. A major step in the DOE process is the determination of the combination of factors and levels which will provide the desired information.[1,5]

Analysis of the experimental results uses a signal to noise ratio to aid in the determination of the best process designs. In the present work, a plan order for performing the experiments was generated by Taguchi method using orthogonal array and analysis of parameters was done using ANOVA technique. This method yields the rank of various parameters with the levels of significance or influence of a factor on a particular output response.[14]

3. MATERIAL SELECTION

Mild Steel is selected as a base metal for performing the experimental work.The following tables shows the composition of base metal and welding electrode

Table 1: Chemical Composition of Base Metal(Mild Steel 1018)

C	Mn	P	S	Fe
0.18	0.6-0.9	0.04 max	0.05 max	98.81-99.26

Table 2: Chemical Composition of Electrode- ER 70 S6

C	Si	Mn	P	S	Cu	Cr	Vanadium	Mb	Fe
0.06-0.15	0.8-0.15	1.40-1.85	0.025 max	0.35	0.05 max	0.15 max	0.03	0.15 max	Balance

4. METHODOLOGY

The following are the steps which were followed to achieve the objective:

1) Selection of process parameters & their levels
2) Selection of quality characteristics
3) Selection of Orthogonal Array
4) Selection of Parent Metal & Filler Material
5) Preparation of steel plate specimen
6) After performing GMAW operation, the specimens were cut from the welded plate to carry out various tests.

The following are the tests carried out to achieve the objective:

- Tensile Test on UTM
- Vicker Hardness Test
- Microstructure Study

5. EXPERIMENTATION

5.1 Selection of process parameters & their levels

In the present study, three 3-level process parameters i.e. Arc current, Arc voltage and Gas Flow Rate are considered. The values of the welding process parameters are listed in Table 3.The ranges and levels are fixed based on the screening experiments. The interaction effect between the parameters is not considered. The total degrees of freedom of all process parameters are 8. The degrees of freedom of the orthogonal array should be greater than or at least equal to the degrees of freedom of all the process parameters. Hence, L9 (3^3) Orthogonal array was chosen which has 8 degrees of freedom.

Table 3 Selected Process Parameters and their Levels

Parameters	Code	Level 1	Level 2	Level 3
Welding Current (Amp)	A	120	140	**160**
Arc Voltage (Volt)	B	35	38	**40**
Gas Flow Rate (kg/hr)	**C**	**25**	**28**	**32**

Nine Experiments are conducted based on the orthogonal array, instead of 27 possibilities.

Table 4 Orthogonal array after assignment of parameters

RUN	CURRENT (amp)	VOLTAGE (volt)	GFR (kg/hr)
1	120	35	25
2	120	38	28
3	120	40	32
4	140	35	28
5	140	38	32
6	140	40	25
7	160	35	32
8	160	38	25
9	160	40	28

6. RESULT & DISCUSSION

The aim of the experimental plan is to find the optimize parameters those are influencing the Tensile Strength, Hardness of Parent metal, Weld Zone & Heat Affected Zone and microstructure of weldment. The experiments were developed based on an orthogonal array, with the aim of relating the influence of Welding Current, Arc Voltage and Gas Flow Rate. These design parameters are distinct and intrinsic feature of the process that influence and determine the composite performance.

6.1 Results of Statistical Analysis of Experiments

The results for various combinations of parameters were obtained by conducting the experiment as per the orthogonal array. The measured results were analyzed using the commercial software MINITAB 14 specially used for the design of experiment applications.
To measure the quality characteristics, the experimental values are transformed into signal to noise ratio. The influence of control parameters such as Arc Current, Arc Voltage & Gas Flow Rate on Tensile Strength & Hardness of parent metal, weld zone & heat affected zone has been analyzed using Response table for signal to noise ratio.

The response tables show the average of each response characteristic (S/N ratios) for each level of each factor. The tables include ranks based on Delta statistics, which compare the relative magnitude of effects.

The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values; rank 1 to the highest Delta value, rank 2 to the second highest, and so on. Use the level averages in the response tables to determine which level of each factor provides the best result.

6.2 Taguchi Analysis for Tensile Strength

Table 5: Results of L9 Orthogonal Array for Tensile Strength

RUN	CURRENT (Amp)	VOLTAGE (Volt)	GFR (CFH)	TENSILE STRENGTH (MPa)	S/N RATIO
1	120	35	25	361	50.7513
2	120	38	28	341.8	51.5176
3	120	42	32	552.7	54.8498
4	140	35	28	521.7	54.3484
5	140	38	32	478.2	53.5922
6	140	42	25	491.8	53.8385
7	160	35	32	476.5	53.5613
8	160	38	25	397.7	51.9911
9	160	42	28	478.2	53.5922

6.2.1 Response Table for Signal to Noise Ratios (Tensile Strength) :- Larger is better

Table 6 Response Table for S/N Ratio (Tensile Strength)

Level	Arc Current	Arc Voltage	Gas Flow Rate
1	52.37	52.89	52.19
2	**53.93**	52.37	53.15
3	53.05	54.09	**54.00**
Delta	1.55	1.73	1.81
Rank	3	2	1

Figure 2: Main effects plot for S/N ratio- Tensile Strength

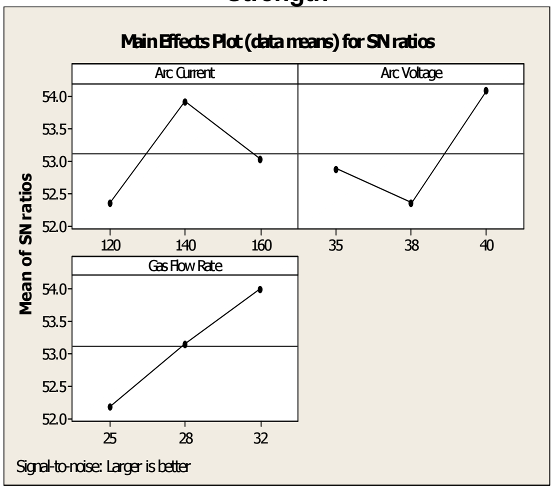


Table 6 shows the experimental analysis for Tensile Strength. In our experimental analysis, the ranks indicate that gas flow rate has the greatest influence on both the S/N ratio and the mean. For S/N ratio, arc voltage has the next greatest influence, followed by arc current. For means, arc voltage has the next greatest influence, followed by arc current. Here, because our goal is to increase the tensile strength, we want factor levels that produce the highest mean. In Taguchi experiments, we always want to maximize the S/N ratio. The level averages in the response tables show that the S/N ratios and the means were maximized when the gas flow rate was 32, the arc voltage was 40 and the arc current was 140.

6.2.2 Analysis of variance for S/N ratios (Tensile Strength)

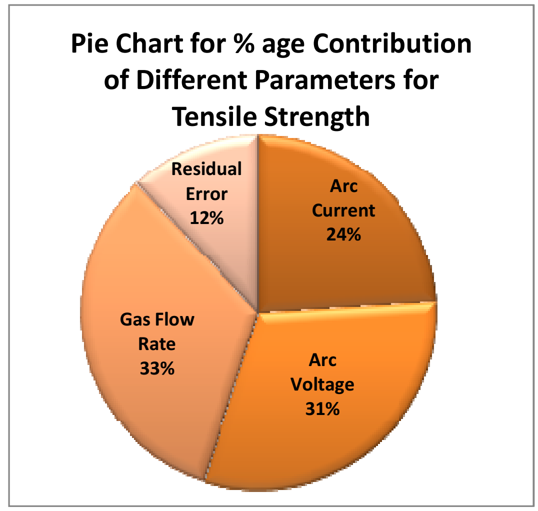
Table 7. Analysis of Variance for Signal to Noise Ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Arc Current	2	3.636	3.636	1.818	1.96	0.03	24
Arc Voltage	2	4.702	4.702	2.3508	2.53	0.03	31
Gas Flow Rate	2	4.911	4.911	2.4557	2.64	0.03	33
Residual Error	2	1.858	1.858	0.9288			12
Total	8	15.107					100

Table 7 shows the result of the analysis of variance (ANOVA) for the Tensile Strength. The analysis of variance was carried out at 95% confidence level. The main purpose of analysis of variance is to investigate the influence of the design parameters on Tensile strength by indicating that which parameters is significantly affected the quality characteristics.

In our experimentation work, we have generated results for S/N ratios of Tensile Strength. For S/N ratios, all the factors and the interaction terms are significant at an α-level of 0.05. For S/N ratio, Selected parameters Arc Current (p=0.0338), Arc Voltage (p=0.0283) & Gas Flow Rate (p=0.0274) are significant because their p-values are less than 0.05.

Figure 3: Pie Chart for %age Contribution of Different Parameters for Tensile Strength



The purpose of ANOVA is to investigate which welding process parameters significantly affect the quality characteristics. This is accomplished by separating the total variability of the S/N Ratios, which is measured by the sum of squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The percentage contribution by each of the welding process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the quality characteristic.

From fig 3, we can conclude that Gas Flow rate is significantly affects the Tensile strength with contribution of 33% followed by Arc voltage with contribution of 31% and Arc current with contribution of 24%.

6.2.3 Regression Linear Mathematical Model Equation

A linear regression model is developed using statistical software "MINITAB 14". This model gives the relationship between an independent / predicted variable & a response variable by fitting a linear equation to observe data. Regression equation thus generated establishes correlation between the significant terms obtained from ANOVA analysis namely welding current (C1), arc voltage (C2) and gas flow rate (C3). In this approach, there is a single equation relating one response to the process parameters for the whole domain of investigation. The response factor involving all linear and interaction terms of the input parameters may be written as follows:

C4 = - 385 + 0.65 C1 + 10.2 C2 + 12.9 C3

6.3 Taguchi analysis for hardness (Parent Metal,Weld Zone & Heat Affected Zone)

Table 8: Results of L9 orthogonal array for Hardness

RUN	CURRENT (Amp)	VOLTAGE (Volt)	GFR (CFH)	HARDNESS WZ (HV 1)	HARDNESS PM (HV 1)	HARDNESS HAZ (HV 1)	S/N RATIO
1	120	35	25	168.5	188	196.5	22.17
2	120	38	28	198.5	210.5	204.5	30.65
3	120	40	32	220	197.5	224.5	23.4
4	140	35	28	210	204.5	212	34.61
5	140	38	32	190	217	194	22.76
6	140	40	25	219	217.5	209.5	32.5
7	160	35	32	219	217.5	209.5	32.5
8	160	38	25	182.5	163.5	172	25.17
9	160	40	28	192	172.5	184	25.41

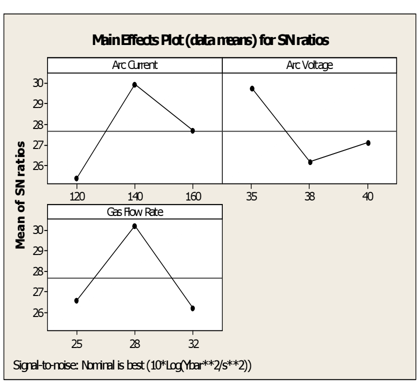
6.3.1 Response Table for Signal to Noise Ratio (Hardness)
Response Table for Signal to Noise Ratios

Nominal is best (L 10*Log (Y bar**L 2/s**L 2))

Table 9: Response Table for S/N Ratio (Hardness)

LEVEL	CURRENT	VOLTAGE	GFR
1	25.41	**29.76**	26.61
2	**29.96**	26.2	**30.23**
3	27.7	27.1	26.22
DELTA	4.55	3.56	4
RANK	1	3	2

Figure 4: Main effect plot for S/N Ratio (Hardness)



In our experimental analysis for hardness of weld zone, parent metal and heat affected zone, the ranks indicate that Arc Current has the greatest influence on the S/N ratio and Gas Flow Rate has the greatest influence on the mean having highest rank 1 respectively. For S/N ratio, gas flow rate has the next greatest influence, followed by arc voltage. For means, arc current has the next greatest influence, followed by arc voltage. Here, because our goal is to increase the weldability by keeping the hardness at nominal value, we want factor levels that produce the highest mean. In Taguchi experiments, we always want to maximize the S/N ratio. The level averages in the response tables show that the S/N ratios and Mean is maximized when the value of Arc Current was 140 A, the Arc Voltage was 35 V and the gas flow rate was 32 kg/hr.

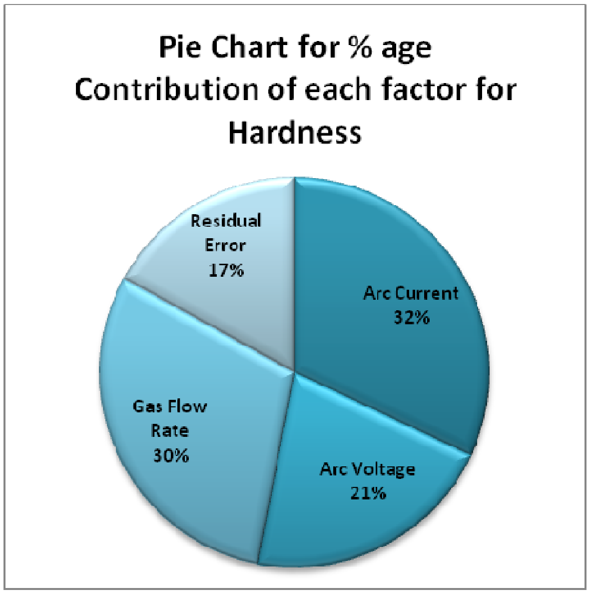
6.3.2 Analysis of variance for S/N ratios (hardness)

Table 10: Analysis of Variance Table for Signal to Noise Ratio of Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Arc Current	2	31.06	31.06	15.53	0.29	0.0474	32
Arc Voltage	2	20.58	20.58	10.29	0.19	0.0438	21
Gas Flow Rate	2	29.22	29.22	14.61	0.27	0.0485	30
Residual Error	2	16.66	16.66	13.33			17
Total	8	97.52					100

Table 10 shows the result of the analysis of variance (ANOVA) for the Hardness (PM, WZ & HAZ). The analysis of variance was carried out at 95% confidence level. The main purpose of analysis of variance is to investigate the influence of the design parameters on Hardness by indicating that which parameters is significantly affected the quality characteristics. In our experimentation work, we have generated results for S/N ratios of Hardness (PM, WZ & HAZ). For S/N ratios, all the factors and the interaction terms are significant at an α-level of 0.05. For S/N ratio, Selected parameters Arc Current (p=0.0474), Arc Voltage (p=0.0438) & Gas Flow Rate (p=0.0485) are significant because their p-values are less than 0.05.

Figure 5: Pie Chart for %age Contribution of Different Parameters for Hardness



The purpose of ANOVA is to investigate which welding process parameters significantly affect the quality characteristics. This is accomplished by separating the total variability of the S/N Ratios, which is measured by the sum of squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The percentage contribution by each of the welding process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the quality characteristic. From fig 5 we can conclude that Arc Current is significantly affects the Hardness of Weld Zone, Parent Metal & Heat Affected Zone with contribution of 32% followed by Gas Flow Rate with contribution of 30% and Arc Voltage with contribution of 21%.

6.4 Microstructure study

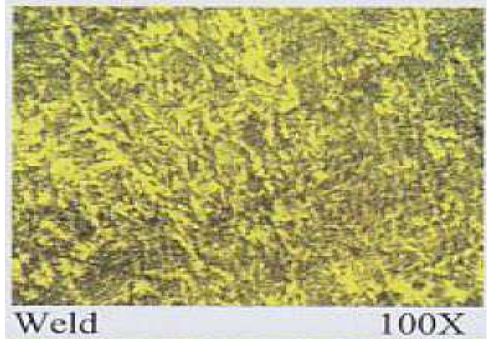


Figure 6: Microstructure of Weld Zone

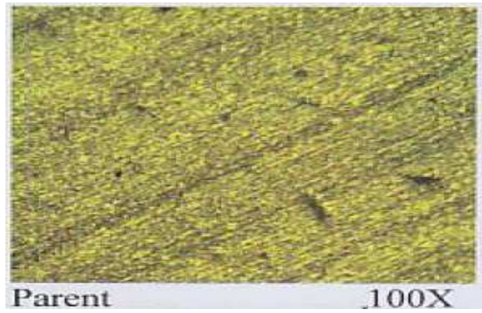


Figure 7: Microstructure of Parent Metal

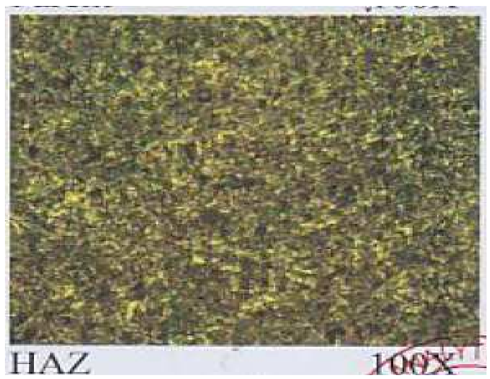


Figure 8: Microstructure of Heat Affected Zone

The study of welding metallurgy is very important because the overall mechanical properties of a weldment are determined by the characteristics properties of the individual microstructure present in the weld deposit and the weld heat affected zone. Both chemical inhomogeneity and changes in metallurgical structures are known to result during welding operation because most fusion welding processes generate high rates of heating & cooling in the weld metal and parent metal adjacent to the weld. Temperature change and change in microstructure introduce volume changes in the area surrounding the weld and hence cause straining, plastic flow, residual stresses or even cracking. Acc. to fig 6,7 & 8, microstructure of Weld Zone, Heat Affected Zone & Parent Metal consists of fine grains of Ferrite and Pearlite. No formation of Martensite takes place. So according to our results we can conclude that our weldments have lower hardness because both ferrite and pearlite are soft constituents & there is no sign of formation of Martensite.

Ferrite

- Ferrite is B.C.C iron phase with very limited solubility for carbon (max 0.025% at 723^{0}C)
- Ferrite is soft & ductile

Pearlite

- The pearlite consists of alternate lamellae of Ferrite & Cementite.
- It has properties somewhere between Ferrite & Cementite

7. CONCLUSION

The present study can be concluded in the following steps:

1. Taguchi design of experiment technique can be very efficiently used in the optimization of welding parameters in manufacturing operations
2. Gas Flow rate has the highest influence on the Tensile strength with contribution of 33% followed by Arc voltage with contribution of 31% and Arc current with contribution of 24%.
3. Arc Current is significantly affects the Hardness of Weld Zone, Parent Metal & Heat Affected Zone with contribution of 32% followed by Gas Flow Rate with contribution of 30% and Arc Voltage with contribution of 21%.
4. Thus design of experiments by Taguchi method was successfully used to find the optimum welding parameters for Tensile Strength & Hardness of Mild Steel (1018)

8. SCOPE FOR FUTURE WORK

This study presented an efficient method for determining the optimal Gas Metal Arc welding parameters for increasing weldability of Mild steel of grade SA 1018 under varying conditions through the use of the Taguchi parameter design process. This process was applied using a specific set of control and a response variable of Tensile Strength, Hardness of Weld zone, Parent Metal & Heat Affected Zone. The use of the L_9 (3^3) orthogonal array, with Three control parameters (Arc Current, Arc voltage & Gas Flow rate) used for this study to be conducted with a sample of 9 work pieces.

It is also carried out for other stainless steel material with more control factors and compared with AISI stainless steels to recommend which material is suitable process for recommending the process at a minimum cost and maximum profit for the organization and to minimize the weld defects as well as welding problems for further future work.

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