OPTIMIZATION OF PARAMETERS FOR GAS METAL ARC WELDING OF MILD STEEL USING TAGUCHI'S TECHNIQUE

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Abstract
Welding is a process that joining the similar and non-similar metals by the application of coalescence. Modern welding techniques are used to ensure the optimum production. This research paper represents the optimization of welding input process parameters for obtaining greater weld strength in the Gas Metal Arc Welding (GMAW) of Mild Steel (1018) is presented. The Taguchi method is used to analyze the effect of welding process parameter on the weld strength, and considered process parameters are optimized to achieve greater weld strength. L9 Orthogonal array was selected for analysis of data. From the investigation of research paper we found that the influence of Current, Voltage & Gas Flow Rate on Tensile Strength, Hardness of Weld Zone & Heat Affected Zone during welding process was validated by ANOVA using Minitab Software for each response were developed. Experimental results are provided to represent the proposed approach. From the investigation found that when increases the current, voltage and GFR tensile strength decreases but in case of hardness, the value of hardness increases due to high input rate.
Keywords: GMAW, Taguchi method, Tensile strength and Hardness of the welded zone & Hardness of Heat affected zone.

I. INTRODUCTION

Welding is a process of joining two materials. It is a faster process and more economical compared to both casting and riveting. Welding find applications in the manufacture of many products around us name few ships, rail road equipments, launch vehicles, boilers, nuclear power plants, building construction, pipelines, aircrafts, automobiles etc. Various welding methods available are: Tungsten Inert Gas (TIG) Welding, Metal inert gas (MIG) welding, Shielded Metal Arc Welding (SMAW), Plasma Arc Welding (PAW), Flux Cored Arc Welding (FCAW), Submerged Arc Welding (SAW), Gas Metal Arc Welding (GMAW), Electro Slag Welding (ESW) and Oxyacetylene (OA) Welding [22].

Welding processes play an important role in metal fabrication industries. There are various welding techniques, but the most commonly used types are tungsten inert gas (TIG) and metal inert gas (MIG/MAG) welding process. In the TIG welding process a non-consumable electrode is used but in case of MIG welding a consumable wire is used to joining the metal. A metal inert gas (MIG) welding process consists of AC motor for heating, electrode for melting, water tube for cooling 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.[24]

All commercially important metals such as stainless steel, aluminium, carbon steels, high strength low alloy steel, nickel alloys, copper and titanium, 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:

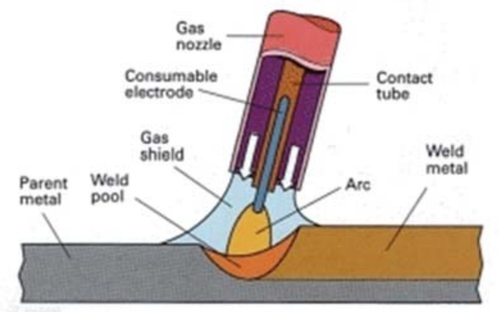

Figure 1: MIG welding Process [27]

II. DESIGN OF EXPERIMENT

The Design of experiment is one of the important and powerful statistical techniques 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. In the designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. In the 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 conducting phase, the planning phase and the analysis phase. The DOE process is the determination of the combination of factors and levels which will provide the desired information [21, 24]

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.[25]

III. MATERIAL SELECTION

Mild Steel 1018 and ER 70 S6 are selected as a base metal and electrode or filler metal respectively for performing the experimental work. The composition of base metal and the electrode are given below in table 1 or table 2:

Table 1: Chemical Composition of Base Metal- MS 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	V	Mb	Fe
(0.06-0.15)%	(0.8-0.15)%	(1.40-1.85)%	0.025 % max	0.035% max	0.50% max	0.15% max	0.03% max	0.15% max	Balance

IV. SIGNAL TO NOISE RATIOS (S/N) FOR TAGUCHI TECHNIQUES:

Noise factors are uncontrollable factors whose influences are not known. The ideal product will only respond to the operator's signals and will be unaffected by random noise factors. Therefore, the goal of our quality improvement effort can be stated as attempting to maximize the s/n ratio for the respective product. Taguchi developed a formulation which is a ratio of controllable factors (signal factors) to uncontrollable factors (noise factors). Signal to noise ratio based on variance is independent of target value and is consistent with Taguchi's quality objective.

1) **Larger the better:**

n = -10 Log10 [mean of sum of squares of reciprocal of measured data]

$$\left({}^{S}/_{N}\right)_{LB} = -10\log\left(MSD_{LB}\right)$$

Where, $MSD_{LB} = \frac{1}{R}\sum_{j=1}^{R}\left(1/Y_j^2\right)$

2) **Smaller the better:**

n = -10 Log10 [mean of sum of squares of measured data]

$$\left({}^{S}/_{N}\right)_{SB} = -10\log\left(MSD_{SB}\right)$$

Where, $MSD_{SB} = \frac{1}{R}\sum_{j=1}^{R}\left(Y_j^2\right)$

3) **Nominal the best:**

n = 10 Log10 [square of mean /variance]

$$\left({}^{S}/_{N}\right)_{NB} = 10\log\left(MSD_{NB}\right)$$

Where, $MSD_{NB} = \frac{1}{R}\sum_{j=1}^{R}\left({}^{Y^2}/_{S^2}\right)$

Where, MSD= mean square deviation (which presents the average of squares of all deviations from the target value rather than around the average value).

R = Number of repetitions

Y_j= Measured data

Y= Mean of measured data

S= Variance

V. EXPERIMENTATION

5.1 Selection of process parameters & their levels:

In the present study, three 3-level process parameters i.e. Current, Voltage and Gas Flow Rate are considered. The values of the welding process parameters are shown 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	250	300	350
Arc Voltage(volt)	B	30	35	40
Gas Flow Rate (kg/hr)	C	20	25	30

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	250	30	20
2	250	35	25
3	250	40	30
4	300	30	25
5	300	35	30
6	300	40	20
7	350	30	30
8	350	35	20
9	350	40	25

VI. RESULT & DISCUSSION

The aim of the experimental plan is to find the optimize parameters those are influencing the Tensile Strength, Hardness of Welded Zone & Heat Affected Zone of the weldment. The experiments were developed based on an orthogonal array, with the aim of relating the influence of Welding Current, 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 Taguchi analysis for tensile strength

The results of tensile strength on different set of combination of parameters are shown in the table 5. On the basis of these results, the S/N ratio has been calculated separately for every single no. of experiments with the help of Minitab software.

Table 5: Tensile Strength Readings & S/N ratio

S. no.	Current (Amp)	Voltage (Volt)	Gas Flow Rate (lpm)	Tensile Strength (MPa)	S/N Ratio
1	250	30	20	355	51.0046
2	250	35	25	372	51.4109
3	250	40	30	385	51.7092
4	300	30	25	372	51.4109
5	300	35	30	378	51.5498
6	300	40	20	395	51.9319
7	350	30	30	360	51.1261
8	350	35	20	369	51.3405
9	350	40	25	392	51.8657

6.1.1 Response Tables for Tensile Strength:

Larger is better

Table 6: Response Table for S/N Ratio of Tensile Strength

Level	Current	Voltage	Gas Flow Rate
1	51.37	51.18	51.43
2	**51.63**	51.43	**51.56**
3	51.44	**51.84**	51.46
Delta	0.26	0.66	0.14
Rank	2	1	3

The response tables shows the average of each response characteristic (S/N ratios, means) for each level of each factor.

The table includes 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.

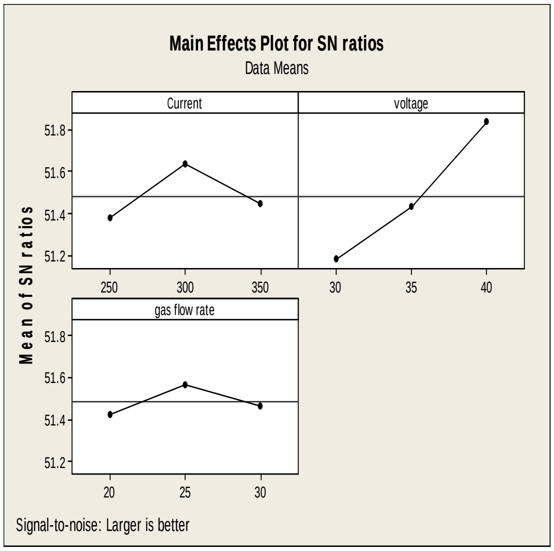

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Figure 2: Main effects plot for S/N Ratios of tensile strength

In the experimental analysis, the ranks indicate that voltage has the greatest influence on the S/N ratio followed by current and gas flow rate. In Taguchi's experiment, the S/N ratio must be maximized. The level averages in the response tables shows that the S/N ratios and the means were maximized when the voltage was 40Volts, current was 300Amp and gas flow rate was 25 lpm. So these are the optimum welding parameters on which the highest tensile strength is obtained.

6.1.2 Analysis of Variance for S/N ratios (Tensile Strength):

Each linear model analysis provides the coefficients for each factor at the low level, their p-values and an analysis of variance table. Use the results to determine whether the factors are significantly related to the response data and each factor's relative importance in the model. The order of the coefficients by absolute value indicates the relative importance of each factor to the response, the factor with the biggest coefficient has the greatest impact. The sequential and adjusted sums of squares in the analysis of variance table also indicate the relative importance of each factor, the factor with the biggest sum of squares has the greatest impact. These results mirror the factor ranks in the response tables.

The analysis of variance was carried out at 95% confidence level for the experiments. 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 the experimentation work, for S/N ratios of tensile strength, voltage (p=0.001) is the most significant parameter because its p-value is less than 0.05.

6.1.3 Percentage Contribution of Parameters for S/N Ratios of Tensile Strength:

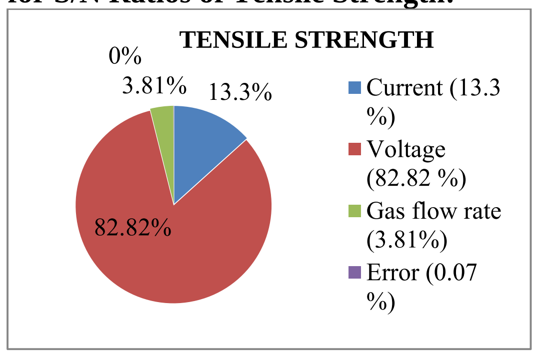

Figure 3: Pie Chart for %age Contribution of Different Parameters for S/N Ratios of Tensile Strength.

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 Signal to Noise Ratios, which is measured by the sum of squared deviations from the total mean of the Signal to noise 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 was used to evaluate the importance of the process parameters change on the quality characteristic. Fig 3 shows that voltage has the greatest effect on tensile strength with contribution of 82.82% followed by current with contribution of 13.30% and gas flow rate with contribution of 3.81%.

6.2 Taguchi Analysis for Hardness of Welded Zone:

The results for hardness of welded zone on different set of combination of parameters are shown in the table 7. On the basis of these results, the S/N ratio has been calculated separately for every single no. of experiments with the help of minitab software 15.

Table 7: Hardness of Welded Zone Readings & S/N ratio

S. no.	Current (Amp)	Voltage (Volt)	Gas Flow Rate (lpm)	Hardness of welded zone	S/N Ratio
1	250	30	20	158.83	44.0187
2	250	35	25	166.33	44.4194
3	250	40	30	170.00	44.6090
4	300	30	25	163.50	44.2704
5	300	35	30	177.33	44.9756
6	300	40	20	177.00	44.9595
7	350	30	30	171.33	44.6767
8	350	35	20	181.00	45.1536
9	350	40	25	183.73	45.2836

6.2.1 Response Tables for Hardness of Welded Zone: Nominal is best

Table 8: Response Table for S/N Ratio (Hardness)

Level	Current	Voltage	Gas Flow Rate
1	44.35	44.32	44.71
2	44.74	44.85	44.66
3	**45.04**	**44.95**	**44.75**
Delta	0.69	0.63	0.10
Rank	1	2	3

The response table 8. shows the average of each response characteristic (S/N ratios, means) 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.

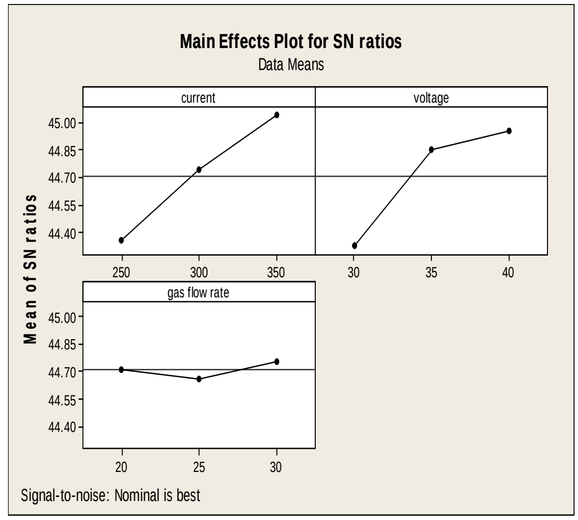

Figure 4: Graph for S/N ratio of Hardness of Welded Zone

In the experimental analysis, the ranks indicate that current has the greatest influence on both the S/N ratio and the mean followed by voltage and gas flow rate. In Taguchi's experiments, the S/N ratio must be maximized. The level averages in the response tables shows that the S/N ratios and the means were maximized when the current was 350Amp, voltage was 40Volts and gas flow rate was 30 lpm. So these are the optimum welding parameters for hardness of welded zone.

6.2.2 Analysis of Variance for Hardness of Welded Zone:

Each linear model analysis provides the coefficients for each factor at the low level, their p-values and an analysis of variance table. Use the results to determine whether the factors are significantly related to the response data and each factor's relative importance in the model.

The analysis of variance was carried out at 95% confidence level. In the experimentation work, for S/N ratios of hardness of welded zone, current (p=0.017) and voltage (p=0.018) are the significant parameters because their p-values are less than 0.05.

6.2.3 Percentage Contribution of Parameters for S/N Ratios of Hardness of Welded Zone:

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 Signal to noise Ratios, which is measured by the sum of squared deviations from the total mean of the Signal to noise 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 was used to evaluate the importance of the process parameter change on the quality characteristic.

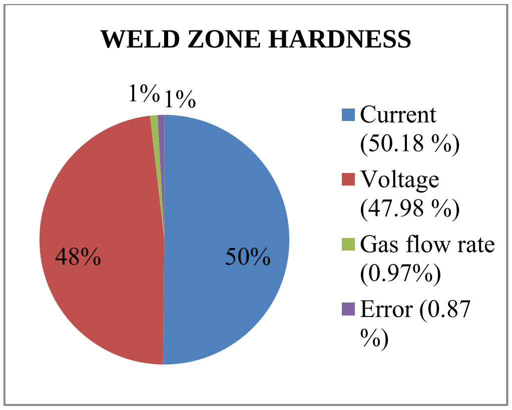

Figure 5: Pie Chart for %age Contribution of Different Parameters for S/N Ratios of Hardness of Welded Zone

Fig 5: shows that current has the greatest effect on Hardness of Welded Zone with contribution of 50.18% followed by voltage with contribution of 47.98% and gas flow rate with contribution of 0.97%

6.3 Taguchi Analysis for Hardness of Heat Affected Zone (HAZ):

The results for Hardness of Heat Affected Zone on different set of combination of parameters are shown in the table 9. On the basis of these results, the S/N ratio has been calculated separately for every single no. of experiments with the help of minitab software 15.

Table 9: Hardness of Heat Affected Zone Readings & S/N ratio

S. no.	Current (Amp)	Voltage (Volt)	Gas Flow Rate (lpm)	Hardness of heat affected zone	S/N Ratio
1	250	30	20	181.33	45.1694
2	250	35	25	186.00	45.3903
3	250	40	30	195.66	45.8300
4	300	30	25	191.00	45.6207
5	300	35	30	200.83	46.0566
6	300	40	20	198.16	45.9403
7	350	30	30	200.66	46.0492
8	350	35	20	192.00	45.6660
9	350	40	25	203.83	45.1854

6.3.1 Response Tables for Hardness of Heat Affected Zone: Nominal is best

Table 10: Response Table for S/ N Ratio of Hardness of Heat Affected Zone

Level	Current	Voltage	Gas Flow Rate
1	45.46	45.61	45.59
2	45.87	45.70	45.73
3	**45.97**	**45.99**	**45.98**
Delta	0.51	0.38	0.39
Rank	1	3	2

The response table:10 show the average of each response characteristic (S/N ratios, means) for each level of each factor. The tables include ranks based on Delta statistics, which compare the relative magnitude of effects.

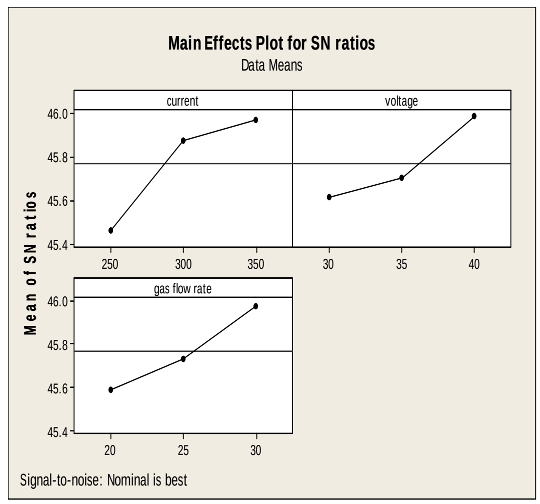

Figure 6: Graph for S/N ratio of Hardness of Heat Affected Zone

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.

In the experimental analysis, the ranks indicate that current has the greatest influence on both the S/N ratio and the mean followed by gas flow rate and voltage. In Taguchi's experiments, the S/N ratio must be maximized. The level averages in the response tables shows that the S/N ratios and the means were maximized when the current was 350Amp, voltage was 40Volts and gas flow rate was 30 lpm. So these are the optimum welding parameters for hardness of heat affected zone.

6.3.2 Analysis of Variance for S/N Ratio (Hardness of Heat Affected Zone):

Each linear model analysis provides the coefficients for each factor at the low level, their p-values and an analysis of variance table. Use the results to determine whether the factors are significantly related to the response data and each factor's relative importance in the model.

The analysis of variance was carried out at 95% confidence level. In the experimentation work, for S/N ratios of hardness of heat affected zone, current (p=0.039) is the most significant parameter because its p-value is less than 0.05.

6.3.3 Percentage Contribution of Parameters for S/N Ratios of Hardness of HAZ:

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 Signal to noise Ratios, which is measured by the sum of squared deviations from the total mean of the Signal to noise 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 was used to evaluate the importance of the process parameter change on the quality characteristic.

Fig 7. Shows that current has the greatest effect on Hardness of Heat Affected Zone with contribution of 47.61% followed by gas flow rate with contribution of 25.45% and voltage with contribution of 25.00%.

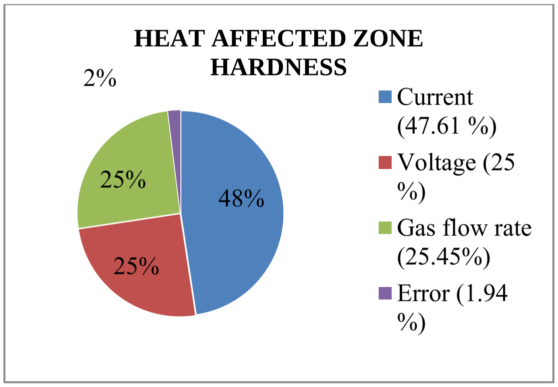

Figure7: Pie Chart for %age Contribution of Different Parameters for S/N Ratios of Hardness of Heat Affected Zone

VII. CONCLUSION

This study presented the optimization of Gas Metal Arc Welding parameters of Mild steel 1018 by Taguchi's experimental design. The process was applied using a specific set of controllable parameters Voltage, Current, Gas Flow rate for the response variables of Tensile Strength. L9 orthogonal array, S/N ratio and analysis of variance were used for this study. The study found that the control factors had varying effects on the response variables.

From the experimental results of research work we concluded the following results:

(1) Taguchi's experimental design provides a simple, systematic and efficient methodology for the optimization of the GMAW parameters.

(2) Optimum parameters for Tensile Strength are

Voltage	Level 3	40 Volts
Current	Level 2	300 Amp
Gas Flow Rate	Level 2	25 Imp

(3) For S/N Ratios of Tensile Strength, voltage has the greatest effect with contribution of 82.82% followed by current with 13.30% and gas flow rate with 3.81%.

(4) Optimum parameters for Hardness of Welded Zone are

Voltage	Level 3	40 Volts
Current	Level 3	350 Amp
Gas Flow Rate	Level 3	30 Imp

(5) For S/N Ratios of Hardness of Welded Zone, current has the greatest effect with contribution of 50.18% followed by voltage with 47.98% and gas flow rate with 0.97%

(6) Optimum parameters for Hardness of Heat Affected Zone are:

Voltage	Level 3	40 Volts
Current	Level 3	350 Amp
Gas Flow Rate	Level 3	30 Imp

(7) For S/N Ratios of Hardness of Heat Affected Zone, current has the greatest effect with contribution of 47.61% followed by gas flow rate with contribution of 25.45% and voltage with contribution of 25.00%

VIII. SCOPE FOR FUTURE WORK

This study presented an efficient method for determining the optimal Gas Metal Arc welding parameters for increasing weld ability of Mild steel 1018 under varying conditions through the use of the Taguchi's experimental design. The controllable parameters were current, voltage and gas flow rate and the response variables were Tensile Strength, Hardness of weld zone & Heat affected zone.

For future scope, Gas Metal Arc welding process can be done with more controllable parameters and other mechanical properties can also be used as output characteristics. It can also be carried out for other stainless steel material and can be compared with AISI stainless steels to recommend which material is suitable for different purposes at a minimum cost and maximum profit for the organization.

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