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Parametric Optimization of GMAW Welding Process

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***Abstract*— The study aimed at the investigation of the effect of preheating, shielding gas flow rate and heat input on the hardness of weldment. In this study, 304 stainless steel was bonded by MIG welding with Argon as a shielding gas and hardness properties of the welded samples at different points from the weld center line was investigated. For that purpose welding was done with different level of preheat, shielding gas flow rate and heat input. Welding samples were characterized by means of hardness test on optical Brinell hardness tester. Hardness test revealed that for all welding parameters hardness in HAZ and weld metal was higher than parent metal.**

With application of design of experiment (DOE) mathematical relationship between the welding process input parameters and output variable like hardness of welded joint in order to determine the welding input parameters that lead to desired weld hardness. Preheat, shielding gas flow rate, and heat input are selected as input parameter and hardness as output parameter. By application of response surface methodology and Tanguchi method of DOE, relationship between these parameters and Hardness was developed.

The experiment result show that the heat input has greatest effect. Gas flow rate has second largest effect on hardness and preheat has very little effect on hardness of weldment.

Keywords*— *MIG, SS 304, Preheat Gas flow rate, Heat input; Hardness.

I. Introduction

The GMAW welding process is easily found in any industry whose products require metal joining in a large scale. It establishes an electric arc between a continuous filler metal electrode and the weld pool, with shielding from an externally supplied gas, which may be an inert gas, an active gas or a mixture. The heat of the arc melts the surface of the base metal and the end of the electrode. The electrode molten metal is transferred through the arc to the work where it becomes the deposited weld metal (weld bead).

The quality of the welded material can be evaluated by many characteristics, such as bead geometric parameters (penetration, width and height), hardness, residual stresses and deposition efficiency (ratio of weight of metal deposited to the weight of electrode consumed). These characteristics are controlled by a number of welding parameters, and, therefore, to attain good quality, is important to set up the proper welding process parameters. Out of these properties hardness is important property because hardness determines the impact strength, toughness and crack susceptibility of welded joint.

Unfortunately, an underlying mechanism connecting welding parameters and quality characteristics is usually not known. Traditionally, it has been necessary to determine the weld input parameters for every new welded product to obtain a welded joint with the required specifications. To do so, requires a time-consuming trial and error development effort, with weld input parameters chosen by the skill of the engineer or machine operator. Then welds are examined to determine whether they meet the specification or not. Finally the weld parameters can be chosen to produce a welded joint that closely meets the joint requirements. Also, what is not achieved or often considered is an optimized welding parameters combination, since welds can often be produced with very different parameters. In other words, there is often a more ideal welding parameters combination, which can be used if it can only determined.

In order to overcome this problem, various optimization methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables. In the last two decades, design of experiment (DoE) techniques has been used to carry out such optimization.

The Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development so that high quality products can be produced quickly and at low cost.

One of the most widely used methods to solve this problem is the response surface methodology (RSM), in which the experimenter tries to approximate the unknown mechanism with an appropriate empirical model, being the function that represents it called a response surface model Identifying and fitting from experimental data a good response surface model requires some knowledge of statistical experimental design fundamentals, regression modeling techniques and elementary optimization methods

II. GAS METAL ARC WELDING (GMAW) OF AISI 304

Gas Metal Arc Welding (GMAW) is a welding process which joins metals by heating the metals to their melting point with an electric arc. The arc is between a continuous, consumable electrode wire and the metal being welded. The arc is shielded from contaminants in the atmosphere by a shielding gas.

A. Objective solution to be used

There remains a continuing requirement in the art of TIG welding to achieve even greater penetration levels of welding involving penetration activating fluxes without affecting the quality of the weld to end use and applications and also to improve upon the productivity for welding by greater penetration of weld without degrading the microstructure and mechanical properties. Hence need of optimization rises.

1. Comparative study of coated uncoated sample.
2. Find out the most effective parameter by Taguchi Method.
3 .Enhancement of weld Penetration.
4. Study the effect on tensile strength on welded sample.

B. Different Phase of Experimentation

Phase-I

1. Development of experimental setup providing varying range of input parameters in ATIG Welding and measuring the various responses.
2. Investigation of the working range and the level of ATIG Welding parameter (pilot run) affecting the selected quality characteristics, by using one factor at a time approach.

Phase-II

1 .Investigation of the effect of the ATIG process parameter on quality characteristics that is welding penetration.
2. Optimization of quality characteristics of ATIG Welding.

a) Prediction of optimal sets of ATIG Welding process parameter

b)Prediction of optimal value of quality characteristics welding penetration.

c)Determination of confidence interval (95%).

3. Experimental verification of optimized quality characteristics.

The Taguchi's parameter design approach has been used to obtain the above objective.

III.SYSTEM DEVELOPMENT

To study the effect of Welding Process parameter on weld Penetration in TIG Welding a heat source is required. Heat source produce an electric arc to generate heat to melt the metal and form a weld for this purpose continuous supply of either direct or alternating electric current. The experiments were carried out on INARC400-i series IGBT Inverter based arc welding power source with soft switching technology

This TIG welding machine has fallowing technical specifications

Input power	18.4 KVA
Current range	20A-400 A
Duty cycle	60%
Weight	43 Kg
Input supply	380-440 V
Efficiency at full load	89%
Power factor	0.95
Ambient Temperature	40 degree C

A. Details of Test Specimens

AISI304 Steel material plate is used, as it has a very large scale application in the process industry. Sample of 100mm×70mm×5mm size has been used as a work piece material and bead on welding is done for present experiments.

The SS304 sheet is converted in the desired work pieces size by using shearing operation. After shearing the work pieces are straighten by holding them in a press. The burr from the cut edges of the work pieces is removed by manual filing.

Table I- Chemical Composition of Test specimens

Chemical Analysis	C	Si	Mn	P	S	Cr	Ni
%	**0.036**	**0.066**	**1.57**	**0.017**	**<0.03**	**18.05**	**8.57**

C. Activated Flux Powder

Activated flux can increase the joint penetration, mainly because the surfactant (surface-active element) in the molten pool switches the surface tension gradient, and consequently reverses the Marangoni convection pattern, resulting in a deep-penetration weld. To clarify this uncertainty, this study used following flux powder.

Table II- Activated Flux Powder Used

Sr. No	1	2	3	4	5
Activated Flux Powder	Cr2o 3	Tio2	Al2o3	Cao	Sio2

c. Preparation of Specimens

The SS304 sheet is converted in to the desired 100mm×70mm×5mm size by using shearing operation. After shearing the work pieces are straighten by holding them in a press. The burr from the cut edges of the work pieces is removed by manual filing the plate surface was ground using 400 grit (silicon carbide) flexible abrasive paper to remove impurities, and then cleaned with acetone .The Thirty number of SS304 plate of are prepared. The various flux powders were mixed with acetone to make a paint-like consistency. A brush was used to apply the mixture on the joint surface to be welded. The mean coating density of flux powder was 4.3 mg/cm2.The four set of plates are made from thirty plates.

Table III- Chemical Composition of Test specimens

Sr.No	1	2	3	4	5	6
Sample	TiO2 Coated	Cr2O3 Coated	Al2O3 Coated	Uncoated	CaO Coated	SiO2 Coated

D. Effect of current on weld penetration

Welding current is the most influential parameter because it affects bead shape, controls the rate at which electrode is melted and therefore also controls the deposition rate, heat affected zone, the depth of penetration, and the amount of base metal melted. For studying the effect of current on weld penetration with following parameter constant.

Gas flow rate 10 LPM, Welding speed 1.6 mm/s and torch angle 60 degree. Following result are observed for various current.

Table IV: Effect of Welding Current on Weld Penetration

Sr.No	***Welding current A***	***Weld penetration in mm***
1	150	2.5
2	200	3.1
3	250	4.1
4	300	5.0

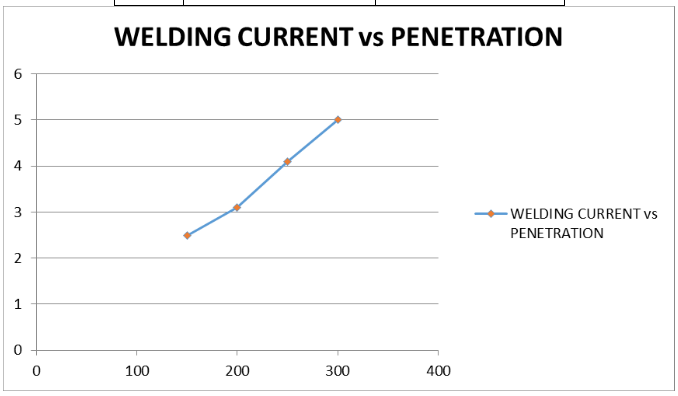


FIG-I Graph Effect of Welding Current on Weld Penetration

E. Effect of gas flow rate on weld penetration

In the second case Shielding gases are used in GTAW in order to prevent atmospheric contamination of the weld metal. This contamination can produce porosity, weld cracking, scaling and even change in the chemical composition of melted material. Besides shielding

Gas also has a large influence on the stability of the electric arc. Gases with low ionization potential facilitate the ignition of the electric arc and those with low thermal conductivity tend to increase the arc stability. Argon is the most used GTAW shielding gas. It has low ionization potential and is heavier than air, providing an excellent shielding of the molten weld pool.

To study the effect of gas flow rate on weld penetration with following parameter constant Current 200 A, Welding speed 1.6 mm/s and torch angle 60 degree. Following result are observed for various Gas flow rate.

Table V: Effect of Welding Current on Weld Penetration

Sr.No	***Gas flow rate(LPM)***	***Weld penetration in mm***
1	5	3
2	10	3.5
3	15	5.0

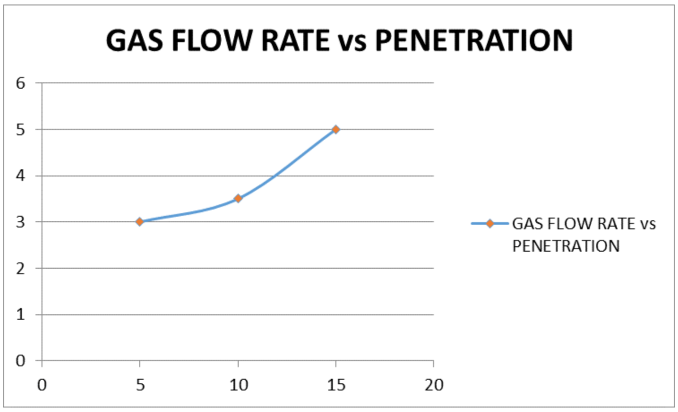


Fig II: Graph Effect of Welding Gas Flow Rate on Weld Penetration

F. Effect of welding speed on weld penetration

In the third case, the effect of time on undercut Welding speed is the linear rate at which an arc is moved along the weld joint. With any combination of welding voltage and welding current, the effect of changing 106 the welding speed confirms to a general pattern. To study the effect of Welding speed on weld penetration with following parameter constant Current 200 A, Gas flow rate 10 LPM and torch angle 60 degree. Following result are observed for various Welding speed.

Table VI: Effect of Welding Speed on Weld Penetration

Sr.No	*Welding speed*	*Weld penetration in mm*
1	6.66	3
2	3.33	3.5
3	1.66	5.0

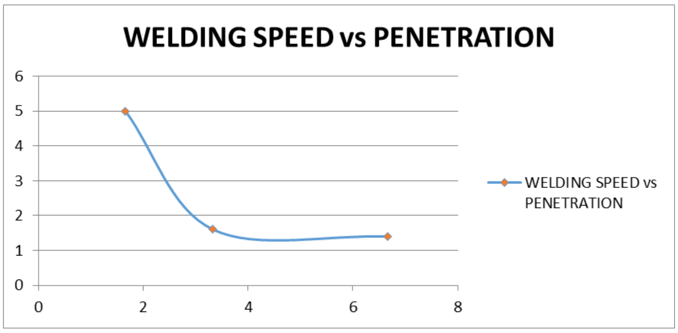


FIG III. Graph Effect of Welding speed on Weld Penetration

G. Effect of torch angle on weld penetration

In the third case, the effect of the torch may be held perpendicular to the work piece or, tilted forward or backward with respect to the weld pool. As the arc stream tends to align itself along the axis of the electrode, the weld pool shape is different in each case, and so is the shape of the weld bead. To study the effect of torch angle on weld penetration with following parameter constant Current 200 A, Gas flow rate 10 LPM, 1.6 mm/s and torch angle 60 degree. Following result are observed for various torch angles on weld penetration.

Table VI: Effect of Torch Angle on Weld Penetration

Sr.No	*Torch Angle in degree*	*Weld penetration in mm*
1	60	5
2	75	3
3	90	1.6

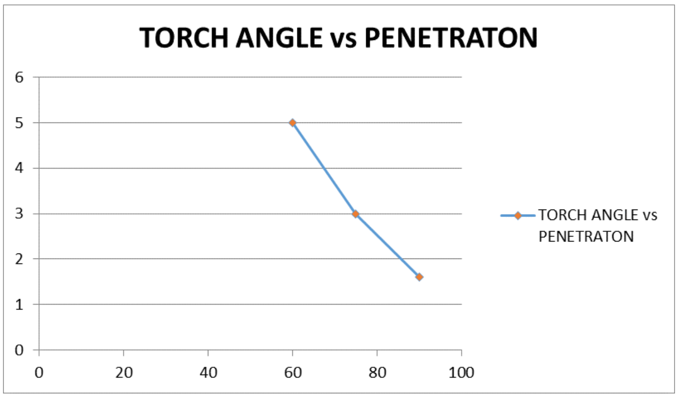


FIG IV: Graph Effect of Torch angle on Weld Penetration

III. Taguchi's Experimental Design and Analysis

Taguchi's comprehensive system of quality engineering is one of the greatest engineering achievements of the 20^{th} century. His methods focus on the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and remain cost-effective, and robust design for large –scale production and market place. Shop-floor techniques provide cost based real time methods for monitoring and maintaining quality in production. The farther upstream a quality method is applied, the greater leverage it produces on the improvement, and the more it reduces the cost and time. Taguchi's philosophy is founded on the following three very simple and fundamental concepts (Ross, 1988; Roy 1990):

1. Quality should be design into the product and not inspected into it.

2. Quality is best achieved by minimizing the deviations from the target. The product or process should be so designed that it is immune to uncontrollable environmental variables.

3. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi proposes an "off-line" strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. He observed that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality back into the product. Taguchi's recommends a three stage process: system design, parameter design and tolerance design. In the present work Taguchi's parameter design approach is used to study the effect of process parameters on the depth of penetration of the Metal Inert Gas Welding process.

A. Loss function

The Taguchi loss function recognizes the customer's desire to have products that are more consistent, part to part, and a producer's desire to make a low-cost product. The loss to society is composed of the costs incurred in the production process as well as the costs encountered during use by the customer (repair, lost business, etc.). To minimize the loss to society is the strategy that will encourage uniform products and reduce cost at the point of production and at the point of consumption.

The heart of Taguchi method is his definition of the nebulous and elusive term 'quality' as the characteristic that avoid loss to the society from the time the product is shipped (Braker, 1986). Loss is measured in terms of monetary units and is related to quantifiable product characteristic.

Taguchi defines quality loss via his 'loss function'. He unites the financial loss with the function specification through a quadratic relationship that comes from a Taylor series expansion. The quadratic function takes the form of a parabola. Taguchi defines the loss function as a quality proportional to the deviation from the nominal quality characteristic (Roy, 1990). He has found the following quadratic form to a useful workable function (Roy, 1990):

$$L(y) = k(y-m)^2 \quad (1)$$

Where,

L = Loss in monetary units

M = value at which the characteristics should be set

Y = actual value of the characteristic

K =constant depending on the magnitude of the characteristics and the monitory unit involved

The characteristics of loss function represented as below:

1. The farther the product's characteristic varies from the target value, the greater is the loss. The loss must be zero when the quality characteristic of a product meets its target value.

2. The loss is a continuous function and not a sudden step as in the case of traditional (goal post) approach. This consequence of the continuous loss function illustrates the point that merely makes a product within the specification limits does not necessary mean that product is of good quality.

A. Average loss-function for product population

In a mass production process, the average loss per unit is expressed as (Roy, 1990):

$$L(y) = (1/n)*\{k(y_1-m)^2 + k(y_2-m)^2 + \ldots\ldots + k(yn-m)^2\} \quad (2)$$

Where,

y_1, y_2, y_n = Actual value of the characteristic for unit 1, 2, 3…….n respectively.

n = Number of units in a given sample

k = Constant depending on the magnitude of the characteristic and the monetary units involved.

m = Target value at which the characteristic should be set.

The eq^n can be simplified as,

$$L(y) = k(MSDNB) \quad (3)$$

Where,

MSDNB =Mean squared deviation or the average of squares of all deviation from the target or nominal value

NB = "Nominal is Best"

B. Signal to noise ratio

The loss function discussed above is an effective figure of merit for making engineering design decision. However, to establish an appropriate loss-function with its k value to use as a figure of merit is not always cost-effective and easy. Recognizing the dilemma, Taguchi created a transform function for the loss-function which is named as signal-to-noise ratio(S/N ratio) (Barker, 1990).

The S/N ratio, as stated earlier, is a concurrent statistic. A concurrent statistics is able to look at two characteristics of a distribution and roll these characteristics into a single number or figure of merits. The S/N ratio combines both the parameters (the mean level of the quality characteristics and variance around this mean) into a single metric (Barker, 1990).

The S/N ratio consolidate several repetition (at least two data point are required) into one value. The equation for calculating S/N ratios for 'smaller is better' (LB), 'large is better' (HB) and 'nominal is best' (NB) type of characteristics are as follows (Ross, 1998):

1) Larger the Better: $(S/N)\ HB = -10 \log(MSDHB)$ (4)

Where, $MSDHB = (1/R)\ \Sigma\ (1/y^2_j)$

2) Smaller the Better: $(S/N)\ LB = -10 \log(MSDLB)$ (5)

Where, $MSDLB = (1/R)\ \Sigma\ (y^2_j)$

3) Nominal the Best: $(S/N)\ NB = -10 \log(MSDNB)$ (6)

Where, $MSDNB = (1/R)\ \Sigma\ (y_j-y_0)^2$

R= Number of repetitions. The mean square deviation (MSD) is a statistical quality that reflects the deviation from the target value. The expressions for MSD are different for different quality characteristics. For the 'nominal is best' characteristics, the standard definition of MSD is used. For the other two characteristics the definition is slightly modified. For 'smaller is better', the unstated target value is zero. For ‘larger is better’ the inverse of each large value becomes a small value and again, the unstated target value is zero. Thus for all three expression, the smallest magnitude of MSD is being sought.

C. Steps in experimental design and analysis

I) Selection of orthogonal array (OA)

In the selecting an appropriate OA, the pre-requisites are (Roy1990, Ross, 1988):

a) Selection of process parameters and/or interactions to be evaluated

B)Selection of number of levels for the selected parameters

The determination of which parameter to investigate is depend upon the product or process performance characteristics or response of interest (Ross, 1988). Several methods are suggested by Taguchi for determining which parameters to include in an experiment. These are (Ross, 1988):

1. Brainstorming
2. Flow charting
3. Cause effect diagrams

The total Degree of Freedom (DOF) of an experiment is a direct function of total number of trial. If the number of levels of a parameter increases, the DOF of the parameter also increases because the DOF of a parameter is the number of level minus one. Thus, increase the number of levels for a parameter increases the total degree of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment (Ross, 1988). If curved or higher order polynomial relationship between the parameter under study and the response is expected, at least three level of each parameter should be considered (Barker, 1990).

The standard two levels and three level arrays (Taguchi and Wu, 1979) are:

1. Two level array: L4, L8, L12, L16, and L32.
2. Three level array: L9, L18, and L27.

The number as subscript in the array designation indicates the number of trial in that array. The total degrees of freedom (DOF) available in an OA are equal to the number of trial minus one (Ross, 1988):

$$f_{LN} = N-1 \quad (7)$$

Where,

f_{LN} = Total degree of freedom of an OA

LN = OA designation

N = Number of trial

When a particular OA is selected for an experiment, the following inequality must be satisfied (Ross, 1988):

$f_{LN} \geq$ Total degree of freedom required for parameters and interaction

Depending on the number of level of the parameters and total DOF required for the experiment, a suitable OA is selected.

D) Assignment of Parameters and interaction to the OA

The OA’s have several columns available for assignment of parameters and some columns subsequently can estimate the effect of interaction of these parameters.

Taguchi has provided two tools to aid in the assignment of parameters and interactions to arrays (Ross, 1988; Roy, 1990):

1. Linear graphs
2. Triangular tables

Each OA has a particular set of linear graphs and a triangular table associated with it. The linear graph indicates various columns to which parameters may be assigned and the columns subsequently evaluate the interaction of these parameters. The triangular table contains all the possible interaction between parameters (columns). Using the linear graphs and or the triangular table of the selected OA, the parameters and interactions are assigned to the columns of the OA. The linear graph of L09 OA is given in Table.

E. Selection of outer array

Taguchi separates factors (parameters) into two main group: controllable factors and uncontrollable factor (noise factors). Controllable factors are factors that can easily be controlled. Noise factors, on the other hand, are nuisance variable that are difficult, impossible, or expensive to control (Byrne and Taguchi, 1987). The noise factors are responsible for the performance variation of a process. Taguchi recommends the use of outer array for the noise factor and inner array for controllable factors. If an outer array is used, the noise variation is forced into the experiment. However, experiments against the trial condition of the inner array (The OA used for the controllable factors) may be repeated and in this case the noise variation is unforced into the experiment (Byrne and Taguchi, 1987). The outer array, if used, will have same assignment considerations. However, the outer array should not be complex as the inner array because the outer array is noise only which is controlled only in the experiment (Ross, 1988).

*E.*Selection of orthogonal array

Taguchi orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance. The corresponding OA is selected from the set of predefined OAs according to the number of factors and their levels that will be used in the experiment. For the present experimental work, three factors with their three levels are used for which the corresponding orthogonal array is L9 which is shown in Table.

Table 4.2: L-9 Orthogonal Array

Exp No	Process Parameter		
	Welding Current	*Gas flow rate*	*Welding Speed*
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

F.. Conduction of experiments

By putting the values of three levels of three parameters in L9 Orthogonal array , the nine set of experiments with different values of parameters are obtained as fallows

Experiment No.1 Current=150Amp.

Gas flow rate=10.0 LPM. Welding speed = 6.66 mm/s.

Experiment No.2 Current=150Amp.

Gas flow rate =12.5 LPM. Welding speed = 3.33 mm/s.

Experiment No.3 Current=150Amp.

Gas flow rate =15.0 LPM. Welding speed = 1.66 mm/s.

Experiment No.4 Current=175Amp.

Gas flow rate=10.0 LPM. Welding speed = 3.33 mm/s.

Experiment No.5 Current=175Amp.

Gas flow rate =12.5 LPM. Welding speed = 1.66 mm/s.

Experiment No.6 Current=175Amp.

Gas flow rate =15.0 LPM. Welding speed = 6.66 mm/s.

Experiment No.7 Current=200Amp.

Gas flow rate=10.0 LPM. Welding speed = 1.66 mm/s.

Experiment No.8 Current=200Amp.

Gas flow rate =12.5 LPM. Welding speed = 6.66 mm/s.

Experiment No.9 Current=200Amp.

Gas flow rate =15.0 LPM. Welding speed = 3.33 mm/s.

Table 4.3: Experimental Results

Sr No	*Welding Current(Amp)*	*Gasflow rate(LPM)*	*Welding speed(mm/s)*	*Weld Penetration(mm)*
1	150	10	6.66	1.6
2	150	12.5	3.33	2.5
3	150	15	1.66	2.7
4	175	10	3.33	3.0
5	175	12.5	1.66	5.0
6	175	15	6.66	3.0
7	200	10	1.66	2.5
8	200	12.5	6.66	2.5
9	200	15	3.33	2.0

G. Analysis of S/N ratio

In the Taguchi Method the term Signal represents the desirable value (mean) for the output characteristic and the term Noise represents the undesirable value (standard deviation) for the output characteristic. Therefore, the S/N ratio to the mean to S.D.S/N ratio used to measure the quality characteristic deviating from the desired value.

The S/N ratio is defined as n=10log (M.S.D.) Where, M.S.D is the mean square deviation for the output characteristic. To obtain optimal welding performance, higher the better quality characteristic can be taken and S/N ratio is calculated for each experiment.

Table 4.4: Analysis of S/N Ratio

Sr No	*Welding Current(Amp)*	*Gas flow rate(LPM)*	*Welding speed{mm/s)*	*Weld Penetration(mm)*	*S/N Ratio*
1	150	10.0	6.66	1.6	4.08
2	150	12.5	3.33	2.5	7.95
3	150	15.0	1.66	2.7	8.62
4	175	10.0	3.33	3.0	9.54
5	175	12.5	1.66	5.0	13.97
6	175	15.0	6.66	3.0	9.54
7	200	10.0	1.66	2.5	7.95
8	200	12.5	6.66	2.5	7.95
9	200	15.0	3.33	2.0	6.02

H. S/N Response analysis

The S/N Response is calculated for each level of each parameter as fallows

[1]Welding Current

Level 1=[4.08240+7.95880+8.62728]/3=6.8894

Level 2=[9.54243+13.9794+9.54243]/3=11.0214

Level 3=[7.95880+7.95880+6.02060]/3=7.3127

[2] Gas flow rate

Level 1=[4.08240+9.54243+7.95880]/3=7.1945

Level 2 =[7.95880+13.9794+7.95880]/3=9.9656

Level 3=[8.62728+9.54243+6.02060]/3=8.0634

[3] Welding speed

Level1=[4.08240+9.54243+7.95880]/3=7.1954

Level 2 =[7.95880+9.54243+6.02060]/3=7.84601

Level 3 =[8.62728+13.9794+7.95880]/3=10.1884

Table 4.5: S/N Response Table for Weld Penetration

Symbol	*Input Parameter*	*Mean S/N Ratio*		
		Level 1	*Level 2*	*Level 3*
A	Welding Current	6.889	11.021	7.313
B	Gas flow rate	7.195	9.966	8.063
C	Welding speed	7.195	7.841	10.188

J. Finding the optimal process parameters

Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level with the greatest S/N ratio. The optimal levels of process are

Current =A 2 = 175Amp

Gas flow rate =B 2 = 12.5 LPM

Welding speed =C3 = 1.6 mm/s.

Maximum Penetration = T + (A2-T) + (B2-T) + (C3-T)

$$=A2+B2+C3-2T \qquad (8)$$

A2=Average value of penetration at the second level of current=[3.0+5.0+3.0]/3=3.66

B2=Average value of penetration at the second level of gas flow rate=[2.5+5.0+2.5]/3=3.33

C3=Average value of penetration at the third level of welding speed=[2.7+5.0+2.5]/3=3.4

T=Overall mean of penetration

=[1.6+2.5+2.7+3.0+5.0+3.0+2.5+2.5+2.0]/9=2.75

By putting the respective values, we get

Maximum penetration = 3.66+3.33+3.4-2x2.75

= 10.39 – 5.5

= 4.89 mm

I. Confirmation experiment

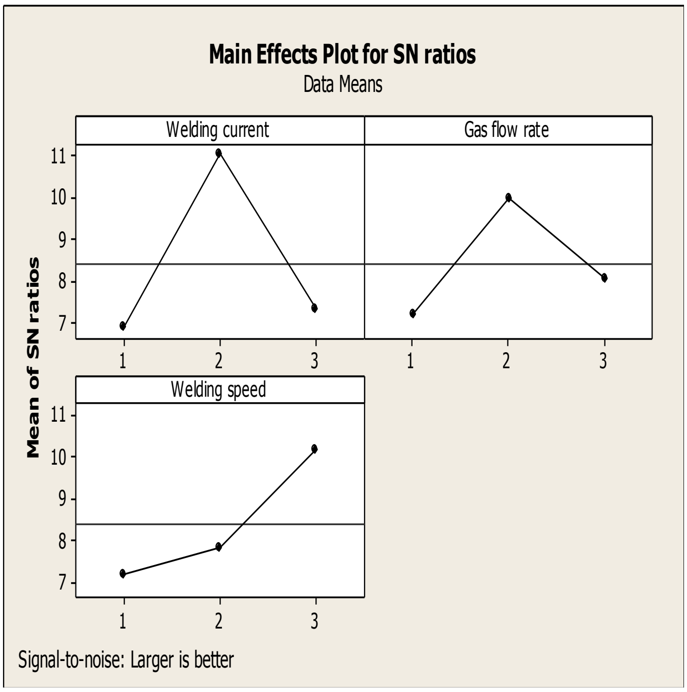
Once the optimal level of process parameters has been selected, the final step is to carry out the confirmation experiment by taking the optimal values of process parameter which are as fallows

Current =A 2 = 175Amp

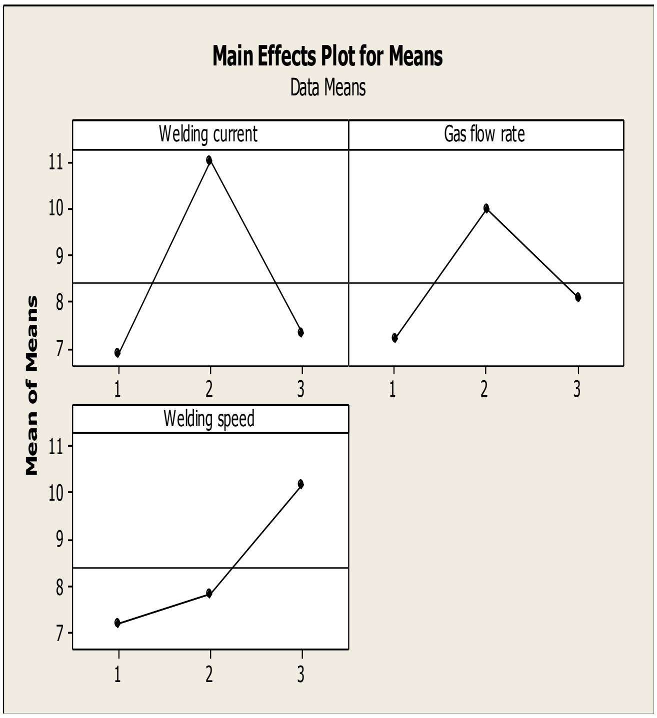
Gas flow rate =B 2 = 12.5 LPM

Welding speed =C3 = 1.6 mm/s.

The above set of optimal process parameters are not found in orthogonal array so we have to carry out confirmation experiment. After carrying out confirmation experiment the actual penetration obtained is 5.00 mm.



Graph 4.1: Main Effects Plot for S/N Ratio



Graph 4.2: Main Effect plot for Means

K. Analysis of Variance

Analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each parameter against a stated level of confidence. Analysis of Variance (ANOVA) is a statistically based objective decision making tool for detecting any difference in average performance of groups of items tested. The decision rather than pure judgments, take variation in to account. The experimental design and subsequent analysis like ANOVA are intrinsically tied to each other. Analysis of Variance (ANOVA) breaks total variation down into accountable source and total variations is decomposed into its appropriate components.

The P-value approach is widely adopted in practice risks implied by specific value or level of significance. The P- value is probability that the tests statistics will take on a value that is at least extreme as the observed value of the statistic when the null hypothesis Ho is true. Thus, the P- values convey much information about the weight of evidence against the Ho and so a decision maker can draw a conclusion at any specified level of significance. The P- value is therefore the smallest level of significance that would lead to rejection of the null hypothesis Ho. Detail step for ANOVA are given below for weld penetration in (mm). Calculation of correction factor:

1. Correction Factor (C.F.) = (Total) ²/ T.C. (9)

2. Total Sum of Square (SS_T) = $\sum y^2$ - C.F. (10)

3. Sum of Squares due to Current (SS cur) = $\sum y_{cur}^2$ - C.F. (11)

4.Sum of Squares due to gas flow rate = $\sum y_{\text{gas flow tate}}^2$ - C.F. (12)

5) Sum of Squares due to speed (SS_{speed}) = $\sum y_{speed}^2$ - C.F. (13)

6) Sum of Squares due to Error (SS_E) = SS_T - (SS_{cur} + $SS_{\text{gas flow rate}}$ + SS_{speed}) (14)

In order to statistically analyze the result, ANOVA was performed. Process variables having p-value<0.05 are considered significant terms for the requisite response characteristics. The insignificant parameters were having p value larger than 0.05.

The ANOVA.

Table 4.6 Analysis of Variance for SNRA1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS
Welding current	2	3.7422	3.7422	1.8711
Gas flow rate	2	1.5622	1.5622	0.7811
Welding speed	2	1.8956	1.8956	0.9478
Error	2	0.0622	0.0622	0.0311
Total	8	7.2622		

S = 0.176383 R-Sq = 99.14% R-Sq (adj) = 96.57%

IV. CONCLUSION

The optimum response for welding penetration by Taguchi Method is given as below

1. According to Taguchi methods, an attempt is made to determine set of values of process variable at their selected levels

2. To have predicted optimum value of welding penetration 4.89 mm but actual value of welding penetration is 5.00 mm at conditions of confidence interval as in table Conclusion according to Taguchi method.

Table 5.1: Predicted Vs Actual Value of Welding Penetration

Response	*Predicted Value*	*Actual Value*
Welding Penetration Set of optimum value of process parameter are as follows • Welding Current 175 Amp • Gas flow rate 12.5 LPM • Welding Speed 1.66 mm/sec	4.89 mm	5.0 mm

In addition to welding Penetration one additional test is performed to analyze what happened to tensile strength. The standard value of tensile strength for 5mm AISI304 Plate is in the range of 540 to 750 N/mm2 and when the Specimen is welded with Cr_2O_3 Coating and at the level of optimum Parameter in addition to full Weld Penetration the tensile strength found to be 707 N/mm2 which is within Standard range of Tensile strength.

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