Effects on hardness and Penetration on changing process parameters in TIG welding using optimization techniques.

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***Abstract –*** *An optimization problem has been created in search of an ideal parametric combination to yield good bead geometry on plate element. Taguchi L9 orthogonal array design and the concept of signal-to-noise ratio have been utilized to derive objective functions to be enhanced within the experimental zone. In this trial, we utilize three kinds of oxide fluxes TiO2, SiO2, and Al2O3 as examining the impact of activated tungsten inert gas of mild steel. We applied for 6 mm thick plates through a slim layer of flux to make bead-on-plate welded joint. In this analysis, SiO2 flux easier joint penetration, but Al2O3 flux led to better weld depth and bead width compared with conventional TIG process. So we can say that Activated tungsten inert gas welding can expand the joint penetration and weld depth-to-width ratio. The objective functions have been chosen as the parameters of bead geometry viz. hardness, reinforcement, penetration and depth-to-width ratio. The factors on overall output feature of the component have been assessed quantitatively by analysis of variance method. The optimal result has been verified through experiment which shows to progress as product quality in a manufacturing industry and Light optical microscope analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality.*

***Keywords*** ***Orthogonal array, signal-to noise ratio, Hardness, Reinforcement, Penetration, depth-to-width ratio, Light optical microscope***.

 **INTRODUCTION**

Basic mechanism of TIG welding-

TIG welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inertshielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is

then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapour [4]. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to 20,000 0C and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding is shown in figure.1

 **Fig 1: basic principle of TIG welding.**

**PROCESS PARAMETERS OF TIG WELDING**

**1.Welding Current:**

Higher current in TIG welding can lead to splatter and work piece become damage. Again lower current setting in TIG welding lead to sticking of the filler wire. Sometimes larger heat affected area can be found for lower welding current, as high temperatures need to applied for longer periods of time to deposit the same amount of filling materials. Fixed current mode will vary the voltage in order to maintain a constant arc current.

**2.Welding Voltage:**

Welding Voltage can be fixed or adjustable depending on the TIG welding equipment. A high initial voltage allows for easy arc initiation and a greater range of working tip distance. Too high voltage, can lead to large variable in welding quality.

3. **Inert Gases:**

The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, splatter, electrode life etc. it also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon or Helium may be used successfully for TIG welding applications. For welding of extremely thin material pure argon is used. Argon generally provides an arc which operates more smoothly and quietly. Penetration of arc is less when Argon is used than the arc obtained by the use of Helium. For these reasons argon is preferred for most of the applications, except where higher heat and penetration is required for welding metals of high heat conductivity in larger thicknesses. Aluminium and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections.

4. **Welding speed:**

Welding speed is an important parameter for TIG welding. If the welding speed is increased, power or heat input per unit length of weld is decreases, therefore less weld reinforcement results and penetration of welding decreases. Welding speed or travel speed is primarily control the bead size and penetration of weld. It is interdependent with current. Excessive high welding speed decreases wetting action, increases tendency of undercut, porosity and uneven bead shapes while slower welding speed reduces the tendency to porosity.

5. **Electrode:**

The electrode used in GTAW is made of tungsten or tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,400 °C. As a result, the electrode is not consumed during welding although some erosion (called burn-off) can occur. Electrodes can have either a clean finish or a ground finish. Clean finish electrodes have been chemically cleaned, while ground finish electrodes have been ground to a uniform size and have a polished surface, making them effective for heat conduction. The diameter of the electrode can vary between 0.5 and 6.4 millimetres, and their length can vary from 75 to 610 millimetres. A number of tungsten alloys have been standardized by the International Organization for Standardization and the American Welding Society in code ISO 6848 and AWS A5.12, respectively, for use in GTAW electrodes, and are summarized below. Pure tungsten electrodes (classified as WP or EWP for general purpose and have low cost.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sr. No. | AWS Classification | Material | Thorium | Zirconium | Tip Colour |
| 1 | EWP | Pure tungsten | ------- | -------- | Green |
| 2 | EWTh-1 | Tungsten + 1% Thorium | 0.8-1.2 | -------- | Yellow |
| 3 | EWTh-2 | Tungsten + 2% Thorium | 1.7-2.2 | -------- | Red |
| 4 | EWZr | Tungsten + Zirconium | -------- | 0.15-0.40 | Brown |

 Table 1: tungsten electrode specification for GTAW

\**Welding torch**

GTAW welding torches are designed for both automatic and manual operation and are equipped with cooling systems using air or water.. Water cooling is required for high-current welding (up to 600 Amp.), while air cooling systems are most often used for low-current operations (up to about 200Amp.). The torches are connected with cables to the power supply, with hoses to the shielding gas source and where used, with pipe to the water supply. The internal metal parts of a torch are made of copper or brass (of hard alloys) in order to transmit current and heat effectively. The tungsten electrode must be held strongly in the centre of the torch with an appropriately sized collect and ports around the electrode provide a regular flow of shielding gas. The diameter of the tungsten electrode decides the collect size as it holds the electrode.

  **MATERIAL AND METHODOLOGY**

**1.Materials:**

Mild steel is used for the present investigation. The chemical compositions of the base material (mild steel) as given in Table 2.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Component | C% | Mn% | P% | S% | Si% | Cu% | Ni% | Cr% | Al% |
| Weight % | 0.18 | 1.02 | 0.02 | 0.005 | 0.14 | 0.0108 | 0.0038 | 0.0014 | 0.052 |

 **Table 2: Chemical composition of Mild Steel.**

For mild steel parent material, a copper coated mild steel electrode wire ER70S3 is used which supplied by **Raghuvir ferro Alloy Pvt. Ltd Raipur**.  Wire diameter

is 2 mm and its chemical composition is given in Table 3.2. A fused flux [TiO2, SiO2 and Al2O3] of grain size 0.2 to 1.6 mm with basicity index 1.6 is used to perform the welding.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Element | C | Mn | Si | P | Cr | S |
| MS ER70S3 | 0.08 | 1.05 | 0.65 | 0.025 | 0.023 | 0.035 |

**Table 3:Chemical composition of MS material wire consumable.**

The flux used for welding is TiO2 and Chemical Composition of flux is

**Chemical Composition of TiO2 Flux**

Purity as TiO2: 99.9%

Fe2O3: 0.01%

CaO: 0.0033%

Al2O3: 0.013%

**Physical Properties TiO2 Flux**

Oil absorption value: 15-20 ml/ 100 gm

Sp. gravity: 2.65

Refractive index: 1.55

Loss on ignition: 0.3%

PH of 10% aqueous solution:

**Welding Parameters and Procedure**

The goal of the present work is to see the effect of titanium dioxide (TiO2), silicon dioxide (SiO2) and aluminium dioxide (Al2O3) powder additions in the flux on the microstructure and bead geometry i.e. bead reinforcement, depth of penetration and depth-to-width ratio in Tungsten inert Gas welded metals. For that purpose, the welding process parameters are kept constant. But the selection of process parameters is a major problem.

|  |  |  |  |
| --- | --- | --- | --- |
| Parameters | Units | Notation |  |
| Welding Current | Amp. | I | 180 |
| Welding Speed | mm/sec. | S | 3 |
| Gas Flow Rate | Lit./min. | Fr | 10 |

 **Table 4:welding process parameter.**

The welding parameters are chosen on the basis of the trial-and-error method by varying one factor at a time. Previous literature survey helps to identify many factors.

 **METHODOLOGY**

For the present work, experimental has done in two phase. In the first phase, welding of mild steel plate (6 mm thickness) done at different types of oxide flux i.e. SiO2, TiO2, and Al2O3 on weld bead with constant welding process parameters (welding current, welding speed and gas flow rate)

In the second phase, the welding of mild Steel plate done with best oxide flux TiO2 and varying welding process parameter i.e. welding current, welding speed and gas flow rate. Commercial mild steel plate of thickness 6mm has selected as work piece material for the present experiment. A mild steel plate is cut with a dimension of 8060 (in mm) with the help of hacksaw machine and grinding done at the edge to the smooth weld surface. After that surfaces are polished with emery paper to remove any kind of external material. After sample preparation, mild steel plates are fixed in the working table with flexible clamp both sides and welding done so that weld bead geometry can be formed. Tungsten inert gas welding with direct current has used in experiments as it concentrates the heat in the welding area. Zirconiated tungsten electrodes of diameter 2.4 mm has taken as an electrode for this experiment. The end of the electrode has prepared by reducing the tip diameter to 2/3 of the original diameter by grinding and striking an arc on a scrap material piece.

**Parametric Optimization**

The parametric optimization for better bead geometry of the joint has been carried out by adapting the Taguchi method. Taguchi Method is a robust method for single objective optimization. In the present investigation four response parameters i.e. Hardness, reinforcement, depth of penetration and depth-to-width ratio of the welded joints are considered, the multi-objective optimization problem has been converted into a single objective optimization problem by using utility theory

Taguchi Design of Experiment

Taguchi’s method for engineering system design and process control has been used successfully by many industries in Japan and elsewhere. It uses experimental

designs primarily as a tool to make products more robust. That is, it considers experimental design as a means for reducing the sources of variation on process. Taguchi’s philosophy is an efficient tool for the design of high-quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides a much-reduced variance for the experiment with an optimum setting of process control parameters. Thus the integration of the design of experiments with parametric optimization of the process to obtain desired results is achieved in the Taguchi method. The orthogonal array provides a set of well-balanced experiments and Taguchi’s signal-to-noise ratios (S/N), which is logarithmic functions of desired output serve as objective functions for optimization. This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, the Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product to be optimized [2]. The standard S/N ratios generally used are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio. Design of experiment is used in many industrial sectors, for instance, in the development and optimization of manufacturing processes. Other types of application where DOE is useful is robustness testing and mixture design. For the variation of the Process parameter is given in Table 5..

|  |  |
| --- | --- |
| Parameters Notation Unit | Level of Factors |
| **1** | **2** | **3** |
| Welding Current | I | Amp. | 170 | 180 | 190 |
| Welding Speed | S | mm/sec. | 2 | 4 | 6 |
| Gas flow rate | Fr | Lit./min. | 8 | 10 | 12 |

**Table.5: Process parameters and their levels of Taguchi L9 DOE**

Taguchi method is the most efficient method in which many control parameters can be studied simultaneously without making the experiment very large. However, the application of the Taguchi method is limited to the solution of single response only and for multi-response problems, it relies on the judgment of people involved with the process and usually leads to a solution. The Utility method is useful for dealing with multi-response problems.

The experimental design is completed using the Taguchi’s orthogonal array design matrix. In the present experiment situation, three factors are varied during the experiment. Three factors (current, gas flow rate and speed) are varied at three levels as shown in Table 3.4. A possible matrix for studying a combination of three factors and three levels is a nine trial orthogonal array labelled as L9matrix. The final form of the L9 orthogonal array that is developed for conducting the trials is represented in Table.5.

**Orthogonal Array**

The Taguchi method utilizes orthogonal arrays from experimental design theory to study a large number of variables with a small number of experiments. The conclusions drawn from small-scale experiments are valid over the entire experimental region spanned by the control factors and their level settings. However, Taguchi has simplified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects.The orthogonal array is shown in Table 6.

|  |  |  |  |
| --- | --- | --- | --- |
| Sr. No. | I | S | Fr |
| 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 |

**Table.6: Taguchi’s L9 orthogonal array design.**

**Signal-to-noise ratio**

Taguchi proposed the concept of a signal-to-noise (S/N) ratios meant to be used as measures of the effect of noise factors on target characteristics.

**Larger-the-better**

S/N ratio = 

Where n = number of experiments

 = observed data at i, this equation is used for solving problems where maximization of the performance characteristic is desired.

**Smaller-the-better**

S/N ratio = 

This equation is used for solving problems where minimization of the performance characteristic is desired.

**Nominal-the-best**

S/N ratio = 

Where, mean

Standard deviation

This equation is called nominal-the-best which is used for the problem where minimization of the mean squared error around a specific value is sought.

  **DESIGN**

**1 Microstructure of Base metal**

In this Figure, the darker colonies are pearlite which is composed of alternating layers of alpha-ferrite (88 wt. %) and cementite (12 wt. %). The light colour region of the microstructure is the ferrite. The grain boundaries between the ferrite grains can be seen quite clearly. The dark regions are the pearlite.



**Figure.3: Microstructure of base metal (mild steel)**

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Ultimate tensile strength (MPa) | Impact toughness(J) | Hardness(HRC) |
| Mild Steel | 243 | 60 | 55 |

**Table.7: Mechanical properties of base metal (mild steel.**

**2 Process parameter optimization of Tungsten inert gas welding**

Process parameters during this experiment with their notations, unit and values at different levels are listed in Table 8.

|  |  |  |  |
| --- | --- | --- | --- |
| Parameters | Notation | Unit | Level Of Factors |
| **1** | **2** | **3** |
| Welding Current | I | Amp. | 170 | 180 | 190 |
| Welding Speed | S | mm/sec. | 2 | 4 | 6 |
| Gas flow rate | Fr | Lit./min. | 8 | 10 | 12 |

**Table.8: Tungsten inert gas welding process parameters**

Experimental data related to reinforcement, penetration and depth to width ratio have been furnished in Table No. 4.3 for mild steel. All these data have been utilized for analysis and evaluation of optimal parameter combination required to achieve desired weld quality in terms of bead geometry within experimental domain.

 **Evaluation of S/N ratio**

The Hardness, Reinforcement, Penetration and depth to width ratio of specimens is calculated after making specimen and light optical microscopy to find microstructure of specimen. Signal to noise ratio represents the desirable and undesirable values for the

output characteristics respectively. The Taguchi method uses S/N ratio to measure the quality characteristics deviating from desired values. The S/N ratio calculated from Minitab 14 software differs for different quality characteristics. In the present study reinforcement, penetration and depth to width ratio of weld specimen is response value. For Reinforcement lower-the-better (LB) and Penetration, depth to width ratio higher-the-better

|  |  |
| --- | --- |
| Exp. No. | Mild Steel |
| **Hardness** **(HRC)**  | **Reinforcement****(mm)** | **Penetration (mm)** | **Depth to Width****Ratio** |
| 1 | 46 | 0.94 | 2.76 | 0.50 |
| 2 | 41 | 0.61 | 1.80 | 0.62 |
| 3 | 43 | 0.53 | 1.35 | 0.36 |
| 4 | 49 | 0.77 | 3.25 | 1.04 |
| 5 | 35 | 0.60 | 3.55 | 0.85 |
| 6 | 50 | 1.03 | 2.72 | 0.48 |
| 7 | 55 | 1.42 | 2.98 | 0.50 |
| 8 |  53 | 1.07 | 3.35 | 0.56 |
| 9 |  56 | 1.05 | 3.02 | 0.65 |

 **Table 9: Experimental data for MS**

(HB) or larger the better (LB) criterion has been selected for analysis.

For Reinforcement, lower-the-better (LB), S/N Ratio

For Penetration and depth to width ratio, higher-the-better (HB),

S/N Ratio:

Where,

 yi represents the experimentally observed value of the ith experiment,

n is the number of repetition for an experimental combination.

**4.3.1 Main effects plot for means and S/N Ratio**

The main effect plots for means are shown in figure. The analysis is made with the help of a Minitab 14. This plot shows the variation of reinforcement, penetration and depth to width ratio with three parameters (welding current, welding speed, gas flow rate). In the plots, x-axis indicates the value of each process parameter (three levels) and y-axis indicates the mean value of reinforcement, penetration and depth to width ratio. The main effects plots are used to determine the optimal design conditions to obtain the optimum reinforcement, penetration and depth to width ratio.

 **RESULT**

**1 Hardness**

All the specimens prepared for bead geometry study in as hard faced condition were used for hardness study. To

measure the hardness of the weld metals, the top surface of the specimens was ground flat. The welds were also subjected to Rockwall hardness tests. A diamond indenter with 100 kgf load was used to make indentations on all the specimens. The tests were conducted on the weld and HAZ areas at 0.5 mm intervals from center of WZ to base metal covering HAZ. In all of the tested pieces, the hardness values in the weld zone were different due to alloying element but when test moved through HAZ from fusion line to base material, hardness values were higher than in the weld zone.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| TrialNo. | Welding Current (Amp.) | Welding Speed (mm/sec.) | Gas flow rate(Ltr. /min.) | Hardness |
| 1 | 170 | 2 | 8 | 46 |
| 2 | 170 | 4 | 10 | 41 |
| 3 | 170 | 6 | 12 | 43 |
| 4 | 180 | 2 | 10 | 49 |
| 5 | 180 | 4 | 12 | 35 |
| 6 | 180 | 6 | 8 | 50 |
| 7 | 190 | 2 | 12 | 55 |
| 8 | 190 | 4 | 8 |  53 |
| 9 | 190 | 6 | 10 | 56 |

 **Table 10: Experimental data for Hardness**

 **Table 11: Experimental data for Hardness S/N ratio**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| TrialNo. | Welding current (Amp.) | Welding speed (mm/sec.) | Gas flow rate(Ltr. /min.) | S/N ratio |
| 1 | 170 | 2 | 8 | -33.2552 |
| 2 | 170 | 4 | 10 | -32.2557 |
| 3 | 170 | 6 | 12 | -32.6694 |
| 4 | 180 | 2 | 10 | -33.8039 |
| 5 | 180 | 4 | 12 | -30.8814 |
| 6 | 180 | 6 | 8 | -33.9794 |
| 7 | 190 | 2 | 12 | -34.8073 |
| 8 | 190 | 4 | 8 | -34.4855 |
| 9 | 190 | 6 |  10 | -34.9638 |

From the above experiments table it is observed that for hardness shows that mean value increased with increase welding current from 170 Amp to 190 Amp. as shown and decrease in welding speed from 2 to 4 mm/Sec. and then increased from 4 to 6 mm/sec, but decrease from 8 Ltr./min. to 12 Ltr./min. in case of gas flow rate. In case of S/N ratio, the S/N ratio decrease with the increase of welding current from 170 Amp to 190 Amp. as shown and increase in welding speed from 2 to 4 mm/sec. and then decrease from 4 to 6 mm/sec., but increase from 8 Ltr./min. to 12 Ltr./min. in case of gas1 flow rate. The optimal result for hardness is welding current at 170 Amp, welding speed at 4 mm/sec and gas flow rate at 12 Ltr. /min

**2.Penetration**

Weld bead penetration is the maximum distance between the base plate top surface and depth to which the fusion has taken place. More the penetration, the less is the number of welding passes required to fill the weld joint which consequently results in higher production rate. The effect of welding input parameters on penetration of the weld joint is discussed as below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trial****No.** | **Welding current (Amp.)** | **Welding speed (mm/sec.)** | **Gas flow rate****(Ltr. /min.)** | **Penetration****(mm)** |
|  |
| 1 | 170 | 2 | 8 | 2.84 |
| 2 | 170 | 4 | 10 | 1.90 |
| 3 | 170 | 6 | 12 | 1.40 |
| 4 | 180 | 2 | 10 | 3.25 |
| 5 | 180 | 4 | 12 | 3.60 |
| 6 | 180 | 6 | 8 | 2.78 |
| 7 | 190 | 2 | 12 | 3.00 |
| 8 | 190 | 4 | 8 | 3.45 |
| 9 | 190 | 6 | 10 | 2.59 |

 **Table 12: Experimental data for penetration.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trial****No.** | **Welding current (Amp.)** | **Welding speed (mm/sec.)** | **Gas flow rate****(Ltr. /min.)** |  **S/N ratio** |
| 1 | 170 | 2 | 8 | 9.0664 |
| 2 | 170 | 4 | 10 | 5.5751 |
| 3 | 170 | 6 | 12 | 2.9226 |
| 4 | 180 | 2 | 10 | 10.2377 |
| 5 | 180 | 4 | 12 | 11.1261 |
| 6 | 180 | 6 | 8 | 8.8809 |
| 7 | 190 | 2 | 12 | 9.5424 |
| 8 | 190 | 4 | 8 | 10.7564 |
| 9 | 190 | 6 | 10 | 8.2660 |

**Table 13: Experimental data for penetration S/N ratio.**

it is observed that mean value increase with increase welding current from 170 Amp to 180 Amp after that decrease from 180 Amp to 190 Amp as shown and decrease in welding speed from 2 to 6 mm/sec., but decrease from 8 Ltr./min. to 10 Ltr./min. and after that increase from 10 Ltr./min. to 12 Ltr./min. in case of gas

flow rate. In case of S/N ratio, the S/N ratio increase with increase of welding current from 170 Amp. to 180 Amp after that decrease from 180 Amp to 190 Amp as shown and continuously decrease in welding speed from 2 to 6 mm/sec., but also decrease from 8 Ltr./min. to 12 Ltr./min. in case of gas flow rate. The optimal results for penetration are welding current at 180 Amp welding speed at 2 mm/sec and gas flow rate at 8 Ltr. /min.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Source | DOF | Seq SS | Adj SS | Adj MS | F | P | % Contribution |
| Welding Current | 2 | 230.222 | 230.222 | 115.111 | 14.19 | 0.066 | 65.34% |
| Welding Speed | 2 | 93.556 | 93.556 | 46.778 | 5.77 | 0.148 | 94.75% |
| Gas flow rate | 2 | 48.222 | 48.222 | 24.111 | 2.97 | 0.252 | 12.86% |
| Error | 2 | 16.222 | 16.222 | 8.111 |  |  |  |
| Total | 8 | 388.222 |  |  |  |  |  |

 **Table 14 :ANOVA result for hardness.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Source | DF | Seq SS | Adj SS | Adj MS | F | P | % Contribution |
| Welding Current | 2 | 2.326 | 2.326 | 1.163 | 3.93 | 0.081 | 56.69% |
| Welding Speed | 2 | 1.128 | 1.128 | 0.564 | 1.14 | 0.381 | 27.49% |
| Gas flow rate | 2 | 0.331 | 0.331 | 0.166 | 0.26 | 0.777 | 8.07% |
| Error | 2 | 2.842 | 2.842 | 0.4736 |  |  |  |
| Total | 8 |  6.627 |  |  |  |  |  |

**Table 15: ANOVA result for penetration**

N-l degree of freedom corresponds to the N-l independent comparisons which can be made with N observations. Similar as factorial experiments which are designed to enable comparisons to be made between the responses to the different combinations, these comparisons can be associated with the degree of freedom occurring in the analysis of variance.

Sum of square (MS) =

Fcalculated =

Where, F is called the variance ratio.

A factor is said to have a significant effect on a response if the tabulated F value becomes less than the calculated F value. ANOVA has been performed in the statistical software package MINITAB. It uses the P value, termed as the probability of significance. P-value is calculated based on calculated based on calculated F-value. P-value is obtained then compared with the Alpha-level. The alpha-level depends on the confidence level chosen. If the P-value appears less than 0.05, then it can be concluded that the corresponding factor which influence on the selected response at 95% confidence level.

 **CONCLUSION**

In this study, parameter optimization has been done to find the optimal parameter. It has been found that current is the most important factor that affects the performance characteristics. The Taguchi method is very efficient for process optimization that can be performed in a limited number of experiments run. The main effect plots give the optimal level for each optimal process parameter. ANOVA is used to find the % contribution of each process parameter in the performance characteristic. However, it is realized that there are no single techniques that appear to be superior in solving a different kind of problem. From the experiment of TIG welding of mild Steel plate following conclusion can be made with the activated welding system

* Hardness and Penetration of the weld depend on the welding parameters like welding current, welding speed and gas flow rate.
* The optimum values of process parameters for hardness of weld specimens are 170 Amp welding current, 4 mm/sec. welding speed, and 12 lit/min. gas flow rate.
* The optimum values of process parameters for penetration of weld specimens are 180 Amp welding current, 2 mm/Sec. welding speed, and 8 lit/min. gas flow rate.
* Welding current is important factor that affects reinforcement and penetration because more contribution for experiment runs.
* Welding speed is important factor that affects hardness because more contribution for experiment runs.
* Gas flow rate is important factor that affects depth to width ratio because more contribution for experiment runs.

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