*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 2 Ver. II (Mar. - Apr. 2016), PP 48-54*
*www.iosrjournals.org*

# 'Experimental Investigation And Optimization Of Welding Parameters On Tig Welding Of 7005 Aluminium Alloy'.

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***Abstract:*** *Aluminium alloys are alloys in which aluminium is the predominant metal. TIG welding process is used to analyzed the data and evaluate the influence of input parameters on tensile strength and hardness of aluminium specimen .Welding current, gas flow rate and welding speed are the input parameters which affect output responses of aluminium welded joints .7005 AL alloy are alloy are alloyed with zinc and have highest strength of any easy weldable aluminium alloy. 7005 aluminium alloy is relatively soft, easily machined, durable, recycle, light weight, ductile and malleable metal with appearance silvery. It is non magnetic and does not easily ignite. In this work to perform welding of 5 mm thickness 7005 aluminium alloy plate, TIG welding setup will use. Welding of the 7005 AA plate will do by changing the welding parameters. Effect of welding parameters on the tensile strength and hardness of weld joint will analyze.*

***Keywords:*** *Aluminium alloy 7005, hardness, Minitab 14 software.TIG welding, Taguchi method, tensile strength.*

## I. Introduction

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weld ability of a material depends on different factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position.

TIG welding was, like MIG/MAG developed during 1940 at the start of the Second World War. TIG's development came about to help in the welding of difficult types of material, eg aluminium and magnesium. The use of TIG today has spread to a variety of metals like stainless mild and high tensile steels. GTAW is most commonly called TIG (Tungsten Inert Gas). The properties of 5356 AA and 7005 aluminium alloy are as follow:

**Table 1. Chemical properties of 7005 aluminium alloy**

| Alloy | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Zr | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| 7005 | ≤0.35 | ≤0.40 | ≤0.10 | 0.20-0.70 | 1.0-1.8 | 0.06-0.20 | 4.0-5.0 | 0.010-0.060 | 0.080-0.20 | Remainder |

**Table 2. Physical properties of 7005 aluminium alloy**

| Alloy | Phase | Atomic Number | Standard atomic weight of Al | Appear-ance | Melting point | Boiling point | Density | Specific mass |
|---|---|---|---|---|---|---|---|---|
| 7005 | Solid | 13 | 26.9815 | Silvery | 532°C - 635°C | 2470°C | 2.375 gm/cm3 | 960 J/Kg-K |

**Table 3. Chemical properties of 5356 aluminium alloy**

| Alloy | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| 5356 | 0.25 | 0.40 | 0.10 | 0.050-0.20 | 4.50-5.50 | 0.050-0.20 | 0.1 | 0.060-0.20 | Remainder |

The mechanical properties of 7005 aluminium alloys are as follow:
I Lightness**,** II Corrosion resistance**,** III Suitability for surface treatments**,** IV Ease of use**,** V Recycling

**Fig.1 Specimen with double V groove joint**

## II. Taguchi Method For Optimization Of Process Parameters

Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing. Optimization of process parameters is key step in Taguchi method to achieving high quality without increasing cost. The Taguchi method uses a special orthogonal array to study all the designed factors to minimum experiment levels. In orthogonal array each factor is independently evaluated and the effect of one factor does not interface with another factor.

**Table 4. Steps of Taguchi method**

| | |
|---|---|
| 1 | Identify the important process parameters. |
| 2 | Finding the levels of process control parameters. |
| 3 | Selection of experimental design matrix. |
| 4 | Conducting experiment as per design. |
| 5 | Recording responses and evaluating the signal to noise ratio. |
| 6 | Analysis of variance (ANOVA). |
| 7 | Selection of the optimum level of the factors |
| 8 | Confirming experiment |

The orthogonal array experimental design method with L9 ($3^4$) is used to determine experimental plan. The L9 ($3^4$) means that to investigate 4 factors on a qualitative index with 3 levels of each factor. Totally nine experiments were conducted. For this most influencing four different process parameters welding current, arc gap, travel speed and gas flow rate are selected. Taguchi method recommends the signal to noise ratio (S/N) ratio, which is a performance characteristic, instead of average value. S/N ratio is used to determine optimal conditions of experimental results. There rate three S/N ratios commonly used for optimization of statistical problems i.e. nominal is better (NB), higher is better (HB) & lower is better (LB). The larger S/N ratio represents the better performance characteristic. The mean S/N ratio at each level of experiments for various factors was calculated. Analysis of variance (ANOVA) indicates which process parameter is statistically significant.

## III. Experimental Work

The metal used in this experimental study is 7005 aluminium alloy plate of 5 mm thickness. The plate is cut into eighteen specimens of size 130×30×5 mm and cleaned to remove dust, dirt etc. The welded joint selection and preparation plays very important role in welding process, in this double V welded groove of butt joint preferred. The following welding specifications are used for the welding of specimens.

| | |
|---|---|
| Shielding gas | Argon |
| Electrode diameter | 3/32" |
| Joint design | Butt joint |
| Root gap | 0 mm |
| Filler material | 5356 AA |
| Filler material diameter | 1.5-2.4 mm |
| Welding voltage | 50-100 volts |
| Power source | AC power source |
| Electrode angle | 70° from welding bead axis to welding torch axis |
| Welding groove | Double V welded groove |
| Oxide flux powder | $SiO_2$ along with acetone |

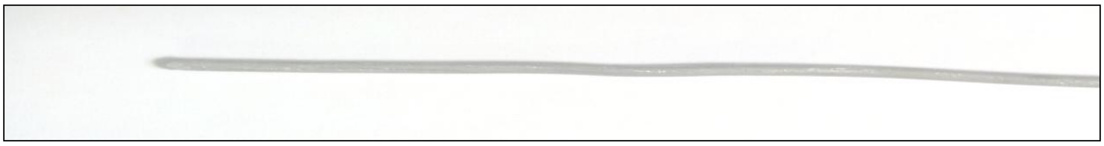

**Fig.2 Filler rod**

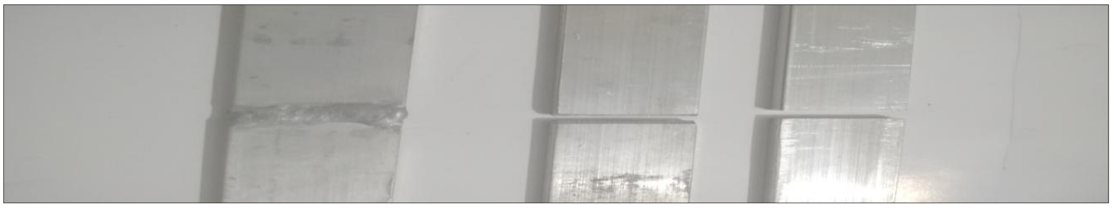

**Fig.3 Aluminium alloy 7005 specimens**

### 3.1 Taguchi design of experiment

As per Taguchi design of experiment four process parameters each having three different levels was selected for welding.

**Table 5. Levels of process parameters**

| Process Parameters | Original Level | | | Coded Level | | |
|---|---|---|---|---|---|---|
| | Low | Medium | High | Low | Medium | High |
| Electrode Gap (mm) | 1 | 2 | 3 | 1 | 2 | 3 |
| Welding Speed (mm/sec) | 4 | 5 | 6 | 1 | 2 | 3 |
| Welding Current (amp) | 130 | 140 | 150 | 1 | 2 | 3 |
| Gas flow rate(lit/min) | 8 | 9 | 10 | 1 | 2 | 3 |

In this study, an L9 ($3^4$) orthogonal array with 4 columns and 9 rows was used. This array can handle three level process parameters. Nine experiments were necessary using this orthogonal array. In order to evaluate the influence of each selected parameter on the responses, the S/N ratios and means. The experiments were conducted by using process parameters given in table 6 of design of experiment

.

**Table 6. Taguchi design of experiment**

| Trial No. | Parameters/Factors | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Electrode gap (mm) | | Welding speed (mm/sec) | | Welding current (amp) | | Gas flow rate (lit/min) | |
| | Original value | Coded value | Original value | Coded value | Original value | Coded value | Original value | Coded value |
| 1 | 1 | 1 | 4 | 1 | 130 | 1 | 8 | 1 |
| 2 | 1 | 1 | 5 | 2 | 140 | 2 | 9 | 2 |
| 3 | 1 | 1 | 6 | 3 | 150 | 3 | 10 | 3 |
| 4 | 2 | 2 | 5 | 1 | 130 | 2 | 10 | 3 |
| 5 | 2 | 2 | 6 | 2 | 140 | 3 | 8 | 1 |
| 6 | 2 | 2 | 4 | 3 | 150 | 1 | 9 | 2 |
| 7 | 3 | 3 | 6 | 1 | 130 | 3 | 9 | 2 |
| 8 | 3 | 3 | 4 | 2 | 140 | 1 | 10 | 3 |
| 9 | 3 | 3 | 5 | 3 | 150 | 2 | 8 | 1 |

## IV. Results And Discussion (For Tensile Strength)

**Fig.4 Specimen (tensile testing)**

### 4.1 Evaluation of SN ratio

The tensile strength of specimens is calculated after testing it on servo hydraulic UTM machine having 40 Tones of capacity. All the specimens are fails at weld section because it is weaker than base metal. 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 15 software differs for different quality characteristics. In the present study tensile strength of weld specimen is response value, there for higher is a better characteristic are chosen for analysis.

Higher is better, S/N ratio = -10log$_{10}$ [ $\frac{1}{n}\sum_{i=1}^{n} Y_i^{-2}$ ]

Where, Yi represents the experimentally observed value of the i$^{th}$ experiment,
n is the number of repetition for an experimental combination.

**Table7. Experimental results and SN ratio**

| Trial No. | Electrode gap (mm) | Welding speed (mm/sec) | Welding Current (amp) | Gas flow rate (lit/min) | Tensile Strength (MPa) | S/N ratio |
|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 130 | 8 | 347 | 50.8066 |
| 2 | 1 | 5 | 140 | 9 | 352 | 50.9308 |
| 3 | 1 | 6 | 150 | 10 | 356 | 51.0289 |
| 4 | 2 | 4 | 140 | 10 | 344 | 50.7312 |
| 5 | 2 | 5 | 150 | 8 | 355 | 51.0046 |
| 6 | 2 | 6 | 130 | 9 | 348 | 50.8316 |
| 7 | 3 | 4 | 150 | 9 | 354 | 50.9800 |
| 8 | 3 | 5 | 130 | 10 | 340 | 50.6295 |
| 9 | 3 | 6 | 140 | 8 | 351 | 50.9061 |

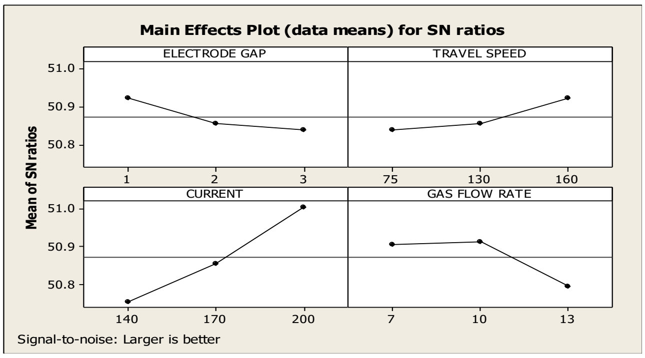


**Fig.5 Main effect plot for SN ratio.**

It is observed from the main effect plot data that as electrode gap increases from 1mm to 3mm, tensile strength decreases for all level of samples. If welding torch travel speed from 4 to 6 mm/sec there is gradually increase in S/N ratio and after that from 5 to 6 mm/sec rapidly increase in S/N ratio. The range of S/N ratio values has maximum range for welding current. For welding current increase in value, observed incresase in S/N ratio. Gas flow rate increases from 8 to 9 lit/min there is smoothly increase in S/N ratio and for 9 to 10 lit/min there is rapidly decrease in S/N ratio. It is due to fact that as gas flow rate increases then oxide flux moves away from torch because of low density. It must be necessary that oxide flux will be in contact of base metal. The optimum values of process parameters to increase the tensile strength of weld specimens are 1 mm electrode gap; 6 mm/sec travel speed, 150 A welding current and 9 lit/min gas flow rate.

The response tables 6 shows 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.

**Table8. S/N response table for mean**

| Notation | Process Parameters | Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|---|
| A | Electrode Gap (mm) | 50.92 | 50.86 | 50.84 | 0.08 | 3 |
| B | Welding Speed (mm/sec) | 50.84 | 50.85 | 50.92 | 0.08 | 4 |
| C | Welding Current (amp) | 50.76 | 50.86 | 51.00 | 0.25 | 1 |
| D | Gas flow rate(lit/min) | 50.91 | 50.91 | 50.80 | 0.12 | 2 |

**4.2 Analysis of variance**

The analysis of variance was carried out at 95% confidence level. The main purpose of ANOVA is to investigate the influence of the designed process parameters on Tensile strength by indicating that, which parameter is significantly affected the response. 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. In this study, the experimental DOF is 8 (number of trails –1), while the parameters has 2 DOF.

**Table9. Results of Analysis of variance**

| Notation | Process Parameters | Degree of freedom | Seq SS | Adj MS | Contribution % | Rank |
|---|---|---|---|---|---|---|
| A | Electrode Gap | 2 | 0.012 | 0.006 | 8.52 | 3 |
| B | Welding Speed | 2 | 0.0116 | 0.0058 | 8.09 | 4 |
| C | Welding Current | 2 | 0.0938 | 0.0469 | 65.39 | 1 |
| D | Gas flow rate | 2 | 0.0258 | 0.0129 | 17.99 | 2 |
| Total | | 8 | | 0.07175 | | |

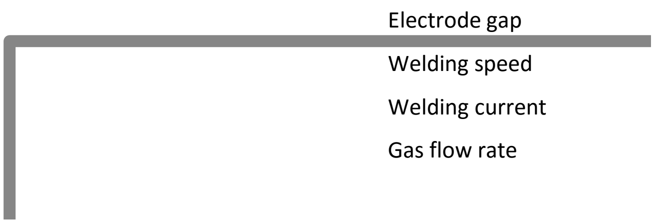


**Fig. 6 Pie chart showing percentage contribution**

## V. Results And Discussion (For Hardness)

**Fig.7 Specimen (hardness testing)**

### 5.1 Evaluation of SN ratio

The hardness of specimens is calculated after testing it on Brinell hardness testing machine. All the welded joint of specimens are tested at 500 kg load with ball diameter 10 mm. 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 15 software differs for different quality characteristics. In the present study hardness of weld specimen is response value, there for higher is a better characteristic are chosen for analysis.

Higher is better, S/N ratio = $-10\log_{10}[\frac{1}{n}\sum_{i=1}^{n} Y_i^{-2}]$

Where, Yi represents the experimentally observed value of the $i^{th}$ experiment,
n is the number of repetition for an experimental combination.

**Table 10. Experimental results and SN ratio**

| Trial No. | Electrode gap (mm) | Welding speed (mm/sec) | Welding Current (amp) | Gas flow rate (lit/min) | Hardness (BHN) | S/N ratio |
|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 130 | 8 | 92 | 39.2757 |
| 2 | 1 | 5 | 140 | 9 | 94 | 39.4625 |
| 3 | 1 | 6 | 150 | 10 | 90 | 39.0848 |
| 4 | 2 | 4 | 140 | 10 | 96 | 39.6454 |
| 5 | 2 | 5 | 150 | 8 | 94 | 39.4625 |
| 6 | 2 | 6 | 130 | 9 | 97 | 39.7354 |
| 7 | 3 | 4 | 150 | 9 | 93 | 39.3696 |
| 8 | 3 | 5 | 130 | 10 | 98 | 39.8245 |
| 9 | 3 | 6 | 140 | 8 | 93 | 39.3696 |

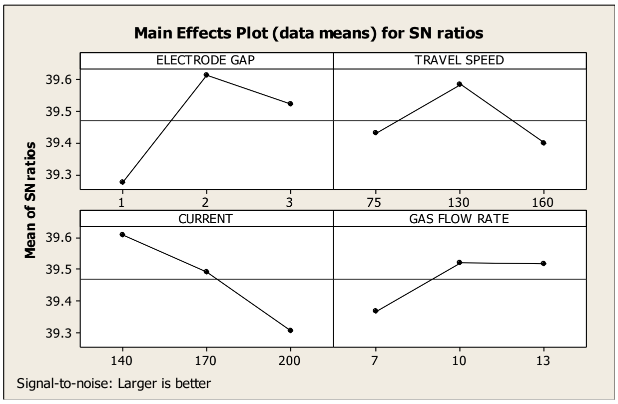


**Fig. 8 Main effect plot for means**

It is observed from the main effect plot data that as electrode gap increases from 1mm to 2mm, tensile strength increases after that there from 2 to 3 mm decrease in S/N ratio. The range of S/N ratio values has maximum range for electrode gap. If welding torch travel speed from 4 to 5 mm/sec there is gradually increase in S/N ratio and after that from 5 to 6 mm/sec rapidly decrease in S/N ratio. For welding current increase in value, observed decrease in S/N ratio. Gas flow rate increases from 8 to 9 lit/min there is increase in S/N ratio and for 9 to 10 lit/min there is smoothly decrease in S/N ratio. It is due to fact that as gas flow rate increases then oxide flux moves away from torch because of low density. It must be necessary that oxide flux will be in contact of base metal. The optimum values of process parameters to increase the hardness of weld specimens are 2 mm electrode gap; 5 mm/sec travel speed, 130 A welding current and 9 lit/min gas flow rate.

The response tables 6 shows 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.

**Table 11. S/N response table for mean**

| Notation | Process Parameters | Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|---|
| A | Electrode Gap (mm) | 39.27 | 39.61 | 39.52 | 0.34 | 1 |
| B | Welding Speed (mm/sec) | 39.43 | 39.58 | 39.40 | 0.19 | 3 |
| C | Welding Current (amp) | 39.61 | 39.49 | 39.31 | 0.31 | 2 |
| D | Gas flow rate(lit/min) | 39.37 | 39.52 | 39.52 | 0.15 | 4 |

**5.2 Analysis of variance**

The analysis of variance was carried out at 95% confidence level. The main purpose of ANOVA is to investigate the influence of the designed process parameters on hardness by indicating that, which parameter is significantly affected the response.

**Table 12. Results of Analysis of variance**

| Notation | Process Parameters | DOF | Seq SS | Adj MS | Contribution % | Rank |
|---|---|---|---|---|---|---|
| A | Electrode Gap | 2 | 0.1853 | 0.0927 | 42.77 | 1 |
| B | Welding Speed | 2 | 0.0593 | 0.0297 | 13.70 | 3 |
| C | Welding Current | 2 | 0.1429 | 0.0715 | 32.99 | 2 |
| D | Gas flow rate | 2 | 0.0457 | 0.0228 | 10.52 | 4 |
| Total | | 8 | | 0.2167 | | |

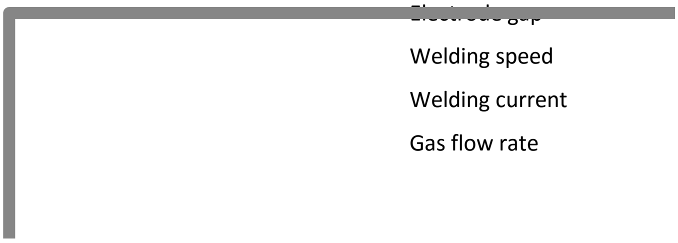


**Fig 9. Pie chart showing percentage contribution**

## VI. Conclusions

In this experimental study the effect of welding process parameters on tensile strength and hardness of 7005 aluminium alloy studied. The following conclusion can be drawn.

1) It is observed that welding parameters like welding gap, welding current, welding speed and gas flow rate greatly affect the tensile strength and hardness.
2) Good joint strength and hardness exhibited by all the joints which shows that the welding of 5 mm thick 7005 AA with TIG welding is possible with proper joint selection and welding groove preparation.
3) Taguchi design of experiment technique can be very efficiently used in optimization of process parameters.
4) For tensile strength the optimum values of process parameters for weld specimens are, 1 mm electrode gap, 6 mm/sec welding speed, 150 A welding current, 9 lit/min gas flow rate.
5) Percentage contribution of process parameters for tensile strength are, welding current 65.39%, gas flow rate 17.99%,electrode gap 8.52% and welding speed 8.09%.
6) For hardness the optimum values of process parameters for weld specimens are, 2 mm electrode gap, 5 mm/sec welding speed, 130 A welding current, 9 lit/min gas flow rate.
7) Percentage contribution of process parameters for hardness are, electrode gap 42.77%, welding current 32.99%, welding speed 13.70% and gas flow rate 10.52%.

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