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# Taguchi Method and Analysis of Variance Optimization of Tensile Strength in TIG Welding

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**Abstract:**

The primary criteria mentioned in this study relate to the tensile strength of duplex stainless steel (grade IS 5986; ISH360S), when it is welded with tungsten inert gas using Taguchi technique and analysis of variance. To define the problem that occurs during the welding process and to decrease the error that occurs in the neural network for the prediction of output, the Taguchi technique of orthogonal L27 design experiment is used. The back-propagation algorithm optimization approach uses a neural network as a mathematical prediction model. Analysis of variance (ANOVA) is a statistical approach for determining the ideal level of components for the verification of the ideal design parameters through confirmation studies. It is used as a decision tool for identifying variation in process parameters. By changing the parameters such as current, time, speed, modification of oxide fluxes, electrode diameter, and gas flow rate, the goal of this study is to enhance the tensile strength, hardness, and depth of the weld. Welding current has the most significant impact on ATIGW, according to ANOVA an increase in welding current has been shown to enhance UTS. Impact strength is discovered to be controlled by the welding current; when the welding speed decreases, the value of impact strength rises.

**Keywords:** Welding, Taguchi technique, hardness, Tungsten Inert Gas Welding, Tensile strength.

**Introduction**

The production sector's expansion has received strong backing from the present administration. To fulfil the rising demand in the production industry, manufacturers will need to implement cutting-edge manufacturing technology on the shop floor. [1] The activities and tactics used in the manufacturing technology/process are intended to generate a certain product or component. The approaches and the organisation of those methods are highlighted in this context. A wide range of production techniques have been developed, from basic to complicated geometries with outstanding physical properties. [2]

There was a considerable demand for materials with high thermal conductivity and low thermal expansion rates. Such materials have low thermal fatigue or stress corrosion susceptibility. Examples of materials that can withstand higher operating pressures and temperatures include stainless steel, hot-rolled steel, titanium, silver, bronze, graphite, and tungsten. These materials have special properties that allow them to resist cracking. [3,4] One such substance is hot rolled steel, which finds extensive use in the auto sector. The majority of automotive components are made using welding processes with varying operating conditions. It must be possible to tolerate changes in temperature and operational pauses. Despite these abrupt stops or starts of operation, welded structures are not dangerous. As a result, when they are welded, heat resistant steel joints should have sufficient impact resistance and resistance to brittle failure. Welding is the most common joining method used in the power, petrochemical, automation, and maintenance handling industries. This is a much quicker and less expensive process than casting and riveting. [5] Using localised heat, conventional welding involves melting filler materials and joining surfaces.

The schematic Diagram above in Fig.1, represents the evolved model of TIG welding process known as A-TIG welding which involve the application of various fluxes on the joint surface before the welding is initiated. Based on the characteristic sensitivity of the TIG process to variations in chemical composition of the base material, this technique was developed. Evaporation of acetone / methanol occurs within a short period, leaving weld joint surface with a thin layer of flux.[6.7] This is followed by Autogenous TIG welding process. This process brings about an enhanced penetration depth in a single pass without the use of bevel penetration as a configuration on a square butt joint and with/without the use of filler wire. It was observed that some batches of steel exhibit lower penetration than normal, while other batches exhibit higher, despite a minor change in chemical composition.[8]

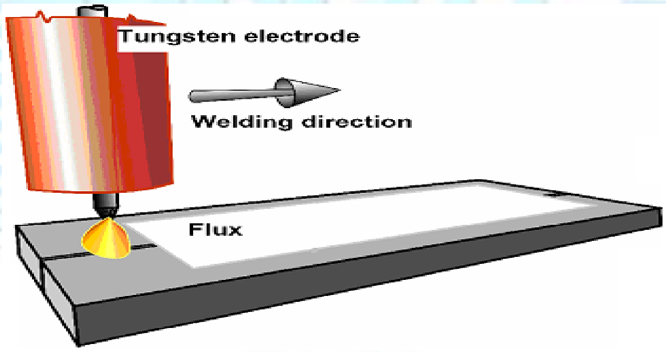


**Fig. 1: Schematic Diagram A-TIG Welding Process**

In order to investigate the effect of process parameters on the quality weld bead by ATIG welding process, it is essential to understand all the facets of ATIG process and analysis tools, which have already been attempted by different researchers in this field. The collected literature, on relevant aspects of the ATIG process analysis is presented here in the form the review analysis. [9]

## Materials and methods

The experiments were conducted on the semiautomatic "TRITON 220AC/DC machine. The schematic diagram of the gas tungsten arc welding (GTAW) setup is shown in Figure 2. The GTAW is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. It is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, and copper alloys. [10]

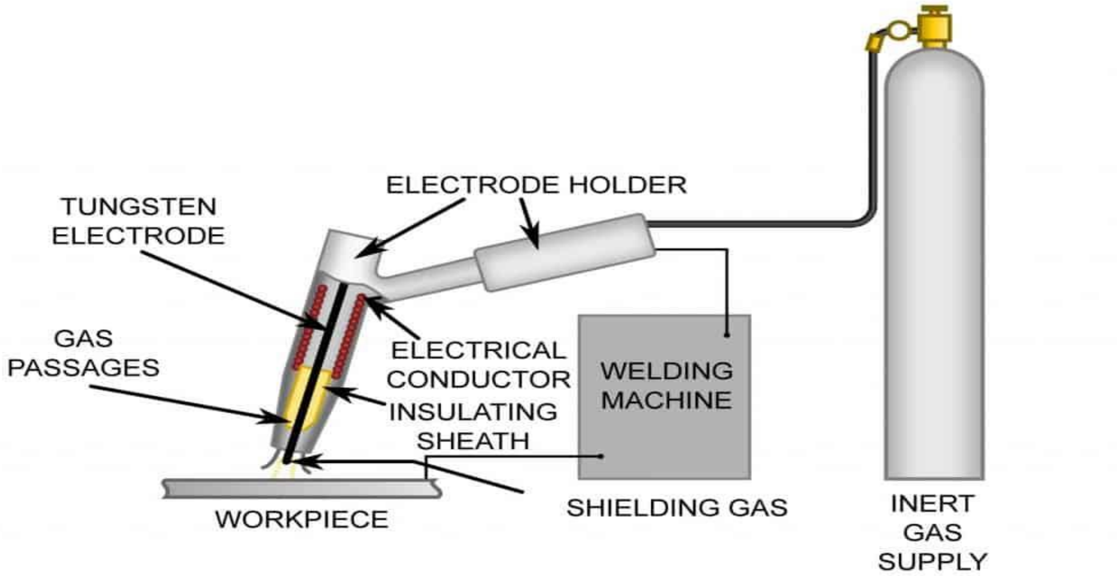


**Fig. 2: The setup of ATIGW/GTAW**

The ASTM C1010 Hot rolled steel (grade IS 5986; ISH360S) were used in this investigation. The chemical composition & Properties of Hot rolled steel (grade IS 5986; ISH360S) is listed in Table 1 and Table 2.

**Table 1: Chemical Composition of the Hot rolled steel (grade IS 5986; ISH360S)**

| Elements | C | Si | Mn | N | S |
|---|---|---|---|---|---|
| (Wt %) | 0.1000 | 0.200 | 0.700 | 120 (PPM) | 0.030 |
| Elements | Ti | Al | Nb | P | V |
| (Wt %) | 0.0450 | 0.0200(min) | 0.0550 | 0.030 | 0.0950 |

**Table 2: Properties of Work piece Materials**

| **Material Designation** | **Properties** | | | |
|---|---|---|---|---|
| | **Tensile Strength $N/mm^2$** | **Yield Strength $N/mm^2$** | **Hardness** | **Elongation** |
| ASTM C1010 (IS5986; ISH360S) | 330-440 $N/mm^2$ | 205 $N/mm^2$, min | 100-140HV | 18% to 28% |

The Work pieces were cut in plate form of size 100 mm x 40 mm x 8mm by EDM wire cut machine has been used as base material for this study. Fig. 3 shows the photograph of Work pieces used in the present investigation. [11-13]

**Fig. 3: Welding Job All Sample Picture Used In the Present Investigation**

**Welded Samples**

The experiments were conducted against each of the trial conditions on semiautomatic TRITON 220 AC/DC machine. In the present research work single butt joint was made. The photographs of welded Jobs are shown in Figure 4.

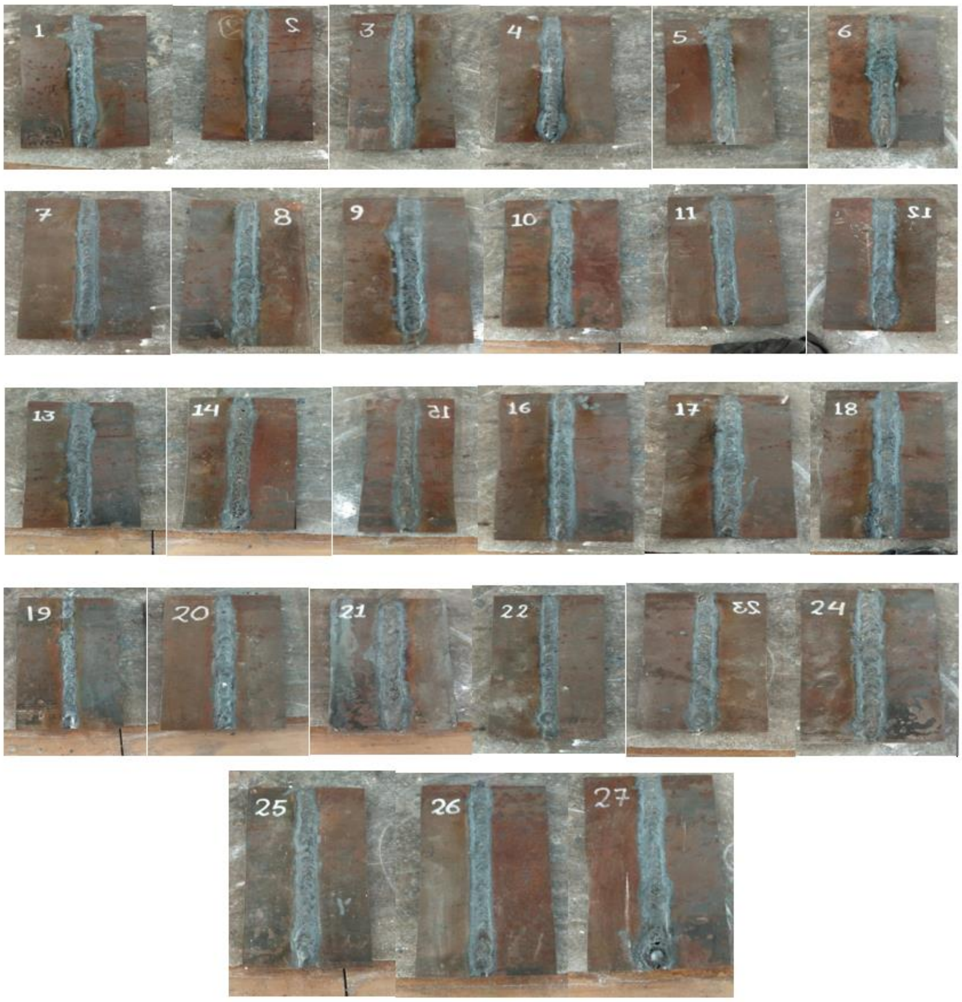


**Figure 4: Welding Job Sample for Present Investigation**

## Experimental Procedure

The preliminary setup was done in accordance with the instructions provided in the instruction manual for AWS. TIG welding experiments are carried out for all the plates in the flat position with a torch angle of around 50 degree the experiment was performed using TRITON 220AC/DC with straight polarity (DCEN). [14,15]

The parent material used for the present research work is ASTM C1010 **Hot rolled steel (grade IS 5986; ISH360S)** of size 150 mm x 100 mm x 8mm, & the filler wire of mild steel with 1.6 mm diameter and The tungsten electrode ( a non-consumable) EWTh-2% has been used (1.6 & 2.4 mm). Pure argon has been used as the shielding gas (25 % helium and 75 % argon mixture used when deeper root penetration and reduced porosity are desired), simple butt weld joints were prepared. The welding of specimens has been carried out by the TIG setup in Department Of Industrial & Production Engineering, College of

Technology,GBPUAT, Pantangar and samples preparation with EDM wire cut for UTS, Hardness Testing, Impact testing, Sector IIDC (SIDCUL) Pantnagar, Rudrapur (U.S Nagar), India.

The each of these response parameters was varied at 3 levels. The range and levels of these response parameters were decided on the basis of preliminary experiments conducted by using one variable at a time approach. The feasible range for ATIG process by varying welding current (190-195 Amps), welding voltage (20-30 Volts), gas flow rate (12-15 Lit/min), root gap (2.0-5.0 mm), & Flux combination for the welding of selected parent material and the filler wire. According to the number of input factors and their levels $L_{27}$ orthogonal array is selected from the Taguchi‟s special set of standard arrays used MINITAB-21.

The tensile test was carried out to determine the ultimate tensile strength on the weld section and the sample of the test specimen is given in figure 5, i.e., heterogeneous in nature, containing weld metal, base metal and the welded joint. For evaluating the weldments, various types of tensile tests were carried out including, all-weld metal test, longitudinal butt-weld test, transverse butt-weld test, transverse butt weld with notch test and tension-shear test. The transverse tensile test is a standard test for procedure qualification and is also used to indicate whether the weld strength equals that of the base metal tensile strength or less (Anderson 1988). In the present investigation, the tensile test is conducted as per the ASTM standard. All experiments were performed at room temperature.[16-17]

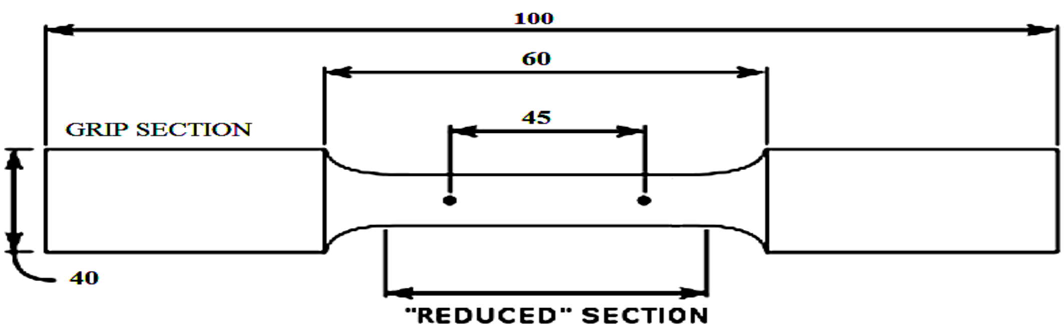


**Fig. 5 : UTM speciemen**

Hardness is not an absolute measurement, and it can only be compared when the Penetrators, loads, and types of materials tested are the same. Several scales are Available to the metallurgist. The Rockwell computation is a hardness scale based on the indentation hardness of the material. This test determines the hardness by measuring the depth of penetration of an indenter under a high load applied compared to the penetration made by preload. The tests were conducted to determine the hardness values of Hot Rolled ATIG weldments at different welding speeds in a Rockwell Hardness Tester, and the hardness sample is shown in figure 6.

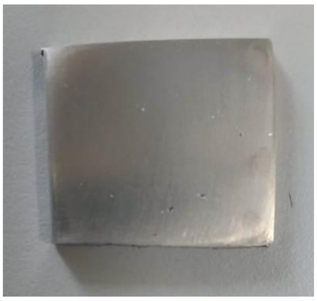

**Fig.6: Hardness Test Sample**

**Data analysis:**

**Signal–to–Noise (S/N) Ratio**

The loss-function discussed above is an effective figure of merit for making engineering design decisions. 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 for the loss-function which is named as the signal-to-noise (S/N) ratio (Barker 1990). [19]

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

A high value of S/N implies that the signal is much higher than the random effect of noise factors. Process operation consistent with highest S/N, always yields optimum quality with minimum variation (Baker 1990).[20]

The S/N ratio consolidates several repetitions (at least two data points are required) into one value. The equations for calculating S/N ratios for Lower-is-better (LB), Higher-is-better (HB) and Nominal-is-best (NB) type of characteristics are (Ross 1988):

(i) Lower is better (LB)

$$(S/N)_{LB} = -10 \log \left[ \frac{1}{R} \sum_{j=1}^{R} y_j^2 \right] \quad (3.1)$$

where $y_j$ = value of the characteristic in an observation j

R = number of observation or number of repetitions in a trial

Alternatively, equation 3.4 may be written as (Roy 1990),

$$(S/N)_{LB} = -10 \log (MSD_{LB}) \quad (3.2)$$

where $MSD_{LB} = \left[ y_1^2 + y_2^2 + .......... + y_R^2 \right] / R$

Here target value m=0.

(ii) Higher is better (HB)

$$(S/N)_{HB} = -10 \log \left[ \frac{1}{R} \sum_{j=1}^{R} \frac{1}{y_j^2} \right] \quad (3.3)$$

where $y_j$ = value of the characteristic in an observation j

R = number of observation or number of repetitions in a trial

Alternatively equation 3.6 may be written as (Roy 1990),

$$(S/N)_{HB} = -10 \log (MSD_{HB}) \quad (3.4)$$

where $MSD_{HB} = \left[ \frac{1}{y_1^2} + \frac{1}{y_2^2} + ............... + \frac{1}{y_R^2} \right] / R$

Here target value m = 0

(iii) Nominal is best (NB)

$$(S/N)_{NB} = -10 \log \left[ \frac{1}{R} \sum_{j=1}^{R} \left( y_j - y_0 \right)^2 \right] \quad (3.5)$$

where $y_j$ = value of the characteristic in an observation j

R = number of observation or number of repetitions in a trial

$Y_0$ = nominal value of the characteristic

Alternatively, equation 3.8 may be written as (Roy 1990),

$$(S/N)_{NB} = -10 \log (MSD_{NB}) \quad (3.6)$$

where $MSD_{NB} = \left[ (y_1 - y_0)^2 + (y_2 - y_0)^2 + \ldots\ldots\ldots\ldots + (y_R - y_0)^2 \right] / R$

The Mean Squared Deviation (MSD) is a statistical quantity that reflects the deviation from the target value. The expressions for MSD are different for different quality characteristics. For the Nominal-is-best characteristic, the standard definition of MSD is used. For the other two characteristics the definition is slightly modified. For Lower-is-better, the unstated target value is zero. For Higher-is-better, the inverse of each large value becomes a small value and again, the unstated target value is zero.[21,22]

**Relationship between S/N Ratio and Loss-Function**

Fig 3.2 (a) shows a single sided quadratic loss- function with minimum loss at the zero value of the desired characteristic. As the value of y increases, the loss grows. Since, loss is to be minimized the target in this situation for $y_j$ is zero.

The basic loss-function (equation 3.1) is:

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

If m = 0,

$L(y) = k\,(y)^2$

The loss may be generalized by using k = 1 and the expected value of loss may be found by summing all the losses for a population and dividing by the number of samples (R) taken from this population. This in turn gives the following expression (Barker 1990).

$$EL = \text{Expected Loss} = \left[\frac{\sum y^2}{R}\right] \qquad (3.7)$$

The above expression is a figure of demerit. The negative of this demerit expression produces a positive quality function. This is the thought process that goes into the creation of S/N ratio from the basic quadratic loss-function. Taguchi adds the final touch to his transformed loss-function by taking the log (base 10) of the negative expected loss and then he multiplies by 10 to put the metric into the 'decibel' terminology (Barker 1990). The final expression for Lower-is-better S/N ratio takes the form of the equation 3.4. The same thought pattern follows in creation of other S/N ratios.[23]

**Result and Discussion:**

Statistically, an analysis of variance is a technique used to interpret data and decide based on it. ANOVA is a tool that can identify differences in the average performance of items based on statistics. ANOVA has been applied to the mean in order to identify the critical parameters that influence the performance characteristics of the ATIG Welding Process in the current study. The experimental data for the mean and S/N ratio of ultimate tensile strength is given in Table 3 and 4 for the ATIG welding process, respectively

The ultimate tensile strength of a material is the maximum stress that the material can tolerate when stretched or pulled before breaking under a tensile load. Presents the results of ultimate tensile strength and the results of S/N ratios obtained by the software MINITAB-21 using

ATIG welding processes. It also contains the data analysis of optimal settings, ANOVA, prediction of mean, determination of confidence interval, and effect of process parameters.[24]

**Table 3: Raw or mean data response for UTS on ATIG Process**

| Response Table for Mean | | | | | |
|---|---|---|---|---|---|
| **Level** | **WELDING CURRENT (A)** | **WELDING VOLTAGE (B)** | **GAS FLOW RATE (C)** | **ROOT GAP (D)** | **FLUX USED (E)** |
| **1** | 369.7 | 371.3 | 382.5 | 379.7 | 380.3 |
| **2** | 385.4 | 384.1 | 383.6 | 386.3 | 384.8 |
| **3** | 396.5 | 396.2 | 385.6 | 385.6 | 386.5 |
| **Delta** | 26.8 | 24.9 | 3.1 | 6.6 | 6.2 |
| **Rank** | 1 | 2 | 5 | 3 | 4 |

**Table 4: S/N response Table for UTS on ATIG Process**

| Response Table for Signal to Noise Ratios (Larger is better) | | | | | |
|---|---|---|---|---|---|
| **Level** | **WELDING CURRENT (A)** | **WELDING VOLTAGE(B)** | **GAS FLOW RATE(C)** | **ROOT GAP(D)** | **FLUX USED (E)** |
| **1** | 51.35 | 51.38 | 51.63 | 51.57 | 51.59 |
| **2** | 51.71 | 51.68 | 51.67 | 51.73 | 51.7 |
| **3** | 51.96 | 51.96 | 51.72 | 51.72 | 51.74 |
| **Delta** | 0.62 | 0.57 | 0.09 | 0.16 | 0.15 |
| **Rank** | 1 | 2 | 5 | 3 | 4 |

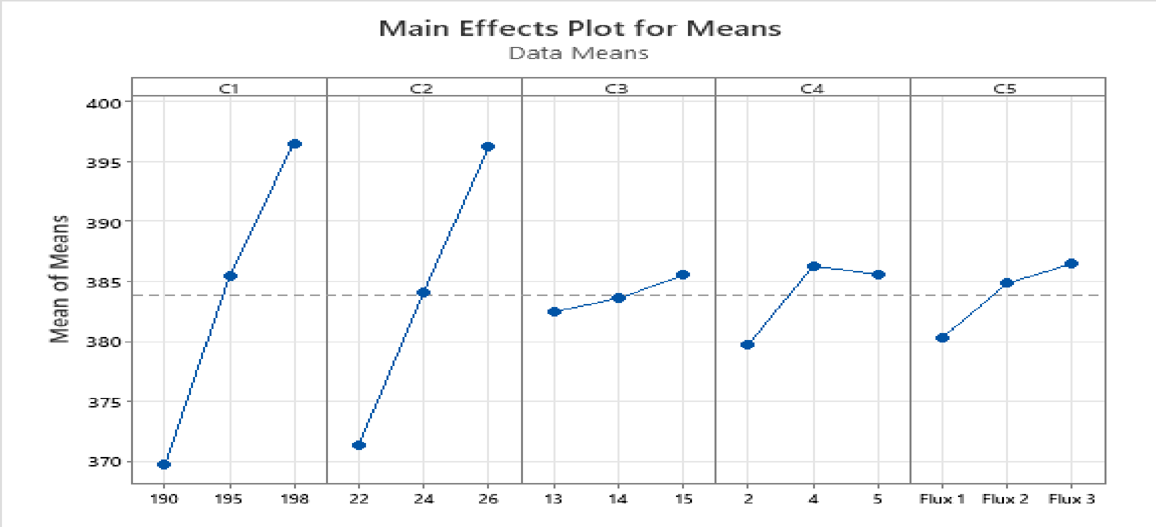


**Fig. 7: Main effects plot of mean data for UTS on ATIGW process**

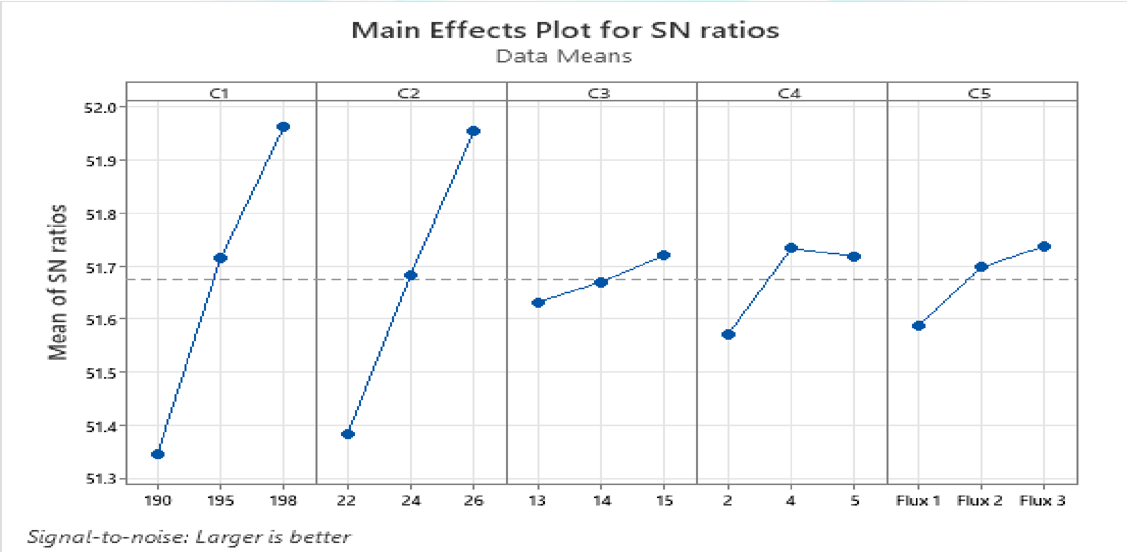


**Fig. 8: Main effects plot of S/N ratios for UTS on ATIGW process**

Statistically, an analysis of variance is a technique used to interpret data and make a decision based on it. ANOVA is a tool that can identify differences in the average performance of items based on statistics. ANOVA has been applied to the mean in order to identify the critical parameters that influence the performance characteristics of the ATIG Welding Process in the current study. [25,26]

Hardness (HRB) is a measure of how resistant materials are to penetration under localized pressure or to abrasion. Hardness tests determine a material's resistance to deformation in an accurate, quick, and economical manner. Here we discuss the analysis of data, the determination of optimal settings, ANOVA, prediction of mean, confidence interval and the effect of factors affecting the ATIG process. The results of hardness (HRC) and the observations of S/N ratios obtained by using MINITAB-21 are presented in Table 5 & 6.

**Table 5: Raw or mean data response for Hardness on ATIG Process**

| Response Table for Means | | | | | |
|---|---|---|---|---|---|
| **Level** | **WELDING CURRENT (A)** | **WELDING VOLTAGE (B)** | **GAS FLOW RATE ( C)** | **ROOT GAP (D)** | **FLUX USED (E)** |
| **1** | 106.1 | 107.6 | 107.5 | 109.3 | 108.2 |
| **2** | 108.8 | 107.2 | 108.2 | 107.9 | 107.1 |
| **3** | 108.9 | 109 | 108.1 | 106.6 | 108.4 |
| **Delta** | 2.8 | 1.7 | 0.6 | 2.8 | 1.3 |
| **Rank** | **1** | **3** | **5** | **2** | **4** |

**Table 6: S/N response Table for Hardness on ATIG Process**

| Response Table for Signal to Noise Ratios(Larger is better) | | | | | |
|---|---|---|---|---|---|
| **Level** | **WELDING CURRENT (A)** | **WELDING VOLTAGE (B)** | **GAS FLOW RATE ( C)** | **ROOT GAP (D)** | **FLUX USED (E)** |
| **1** | 40.52 | 40.63 | 40.63 | 40.77 | 40.69 |
| **2** | 40.73 | 40.61 | 40.68 | 40.66 | 40.6 |
| **3** | 40.74 | 40.74 | 40.68 | 40.55 | 40.7 |
| **Delta** | 0.22 | 0.14 | 0.05 | 0.22 | 0.1 |
| **Rank** | **1** | **3** | **5** | **2** | **4** |

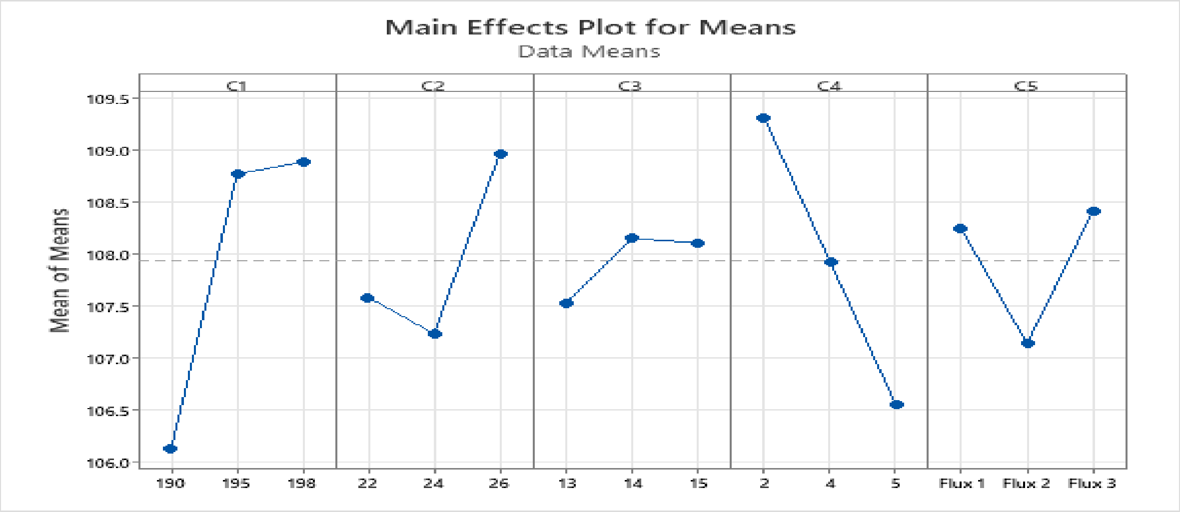


**Fig. 9: Main effects plot of mean data for Hardness on ATIGW process**

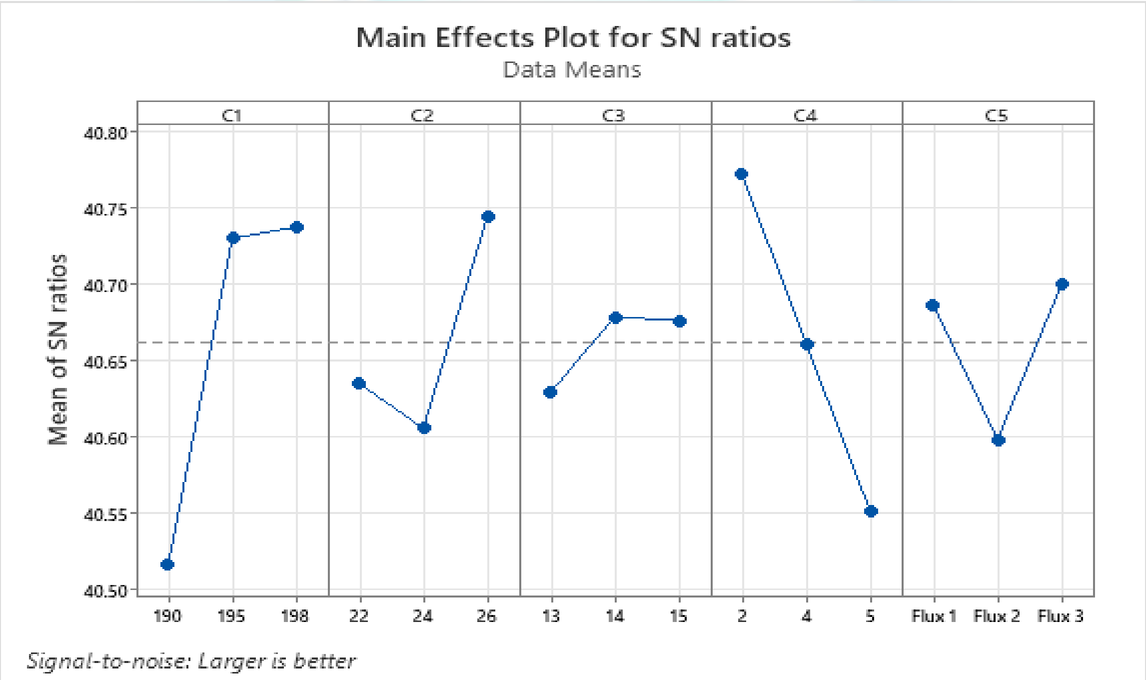


**Fig. 9: Main effects plot of S/N ratios for Hardness on ATIGW process**

Statistically, an analysis of variance is a technique used to interpret data and make a decision based on it. ANOVA is a tool that can identify differences in the average performance of items based on statistics. NOVA has been applied to the mean in order to identify the critical parameters that influence the performance characteristics of the ATIG Welding Process in the current study. [27]

The impact test uses high rates of abrupt loading, usually in tension or bending, to determine the behaviour of materials. By breaking the specimen by a high blow or impact, this test measures how much energy is absorbed. ANOVA, estimation of the mean, confidence interval determination, and the effect of the process parameters are described in this section." The results of impact strength (IS) and standard deviation ratios as determined by the software MINITAB-21 are presented in Table 7 & 8.

**Table 7: Raw or mean data response for Impact Strength on ATIG Process**

| Response Table for Mean | | | | | |
|---|---|---|---|---|---|
| **Level** | **WELDING CURRENT (A)** | **WELDING VOLTAGE (B)** | **GAS FLOW RATE ©** | **ROOT GAP (D)** | **FLUX USED (E)** |
| **1** | 1.122 | 1.856 | 1.918 | 1.966 | 1.898 |
| **2** | 2.116 | 1.908 | 1.964 | 1.849 | 1.915 |
| **3** | 2.489 | 1.963 | 1.844 | 1.912 | 1.914 |
| **Delta** | 1.366 | 0.107 | 0.12 | 0.117 | 0.016 |
| **Rank** | **1** | **4** | **2** | **3** | **5** |

**Table 8: S/N response Table for Strength on ATIG Process**

| Response Table for Signal to Noise Ratios (Smaller is better) | | | | | |
|---|---|---|---|---|---|
| **Level** | **WELDING CURRENT (A)** | **WELDING VOLTAGE (B)** | **GAS FLOW RATE ©** | **ROOT GAP (D)** | **FLUX USED (E)** |
| **1** | -1.001 | -4.969 | -5.193 | -5.351 | -5.123 |
| **2** | -6.51 | -5.13 | -5.323 | -4.919 | -5.154 |
| **3** | -7.904 | -5.317 | -4.898 | -5.145 | -5.138 |
| **Delta** | 6.903 | 0.348 | 0.425 | 0.432 | 0.032 |
| **Rank** | **1** | **4** | **3** | **2** | **5** |

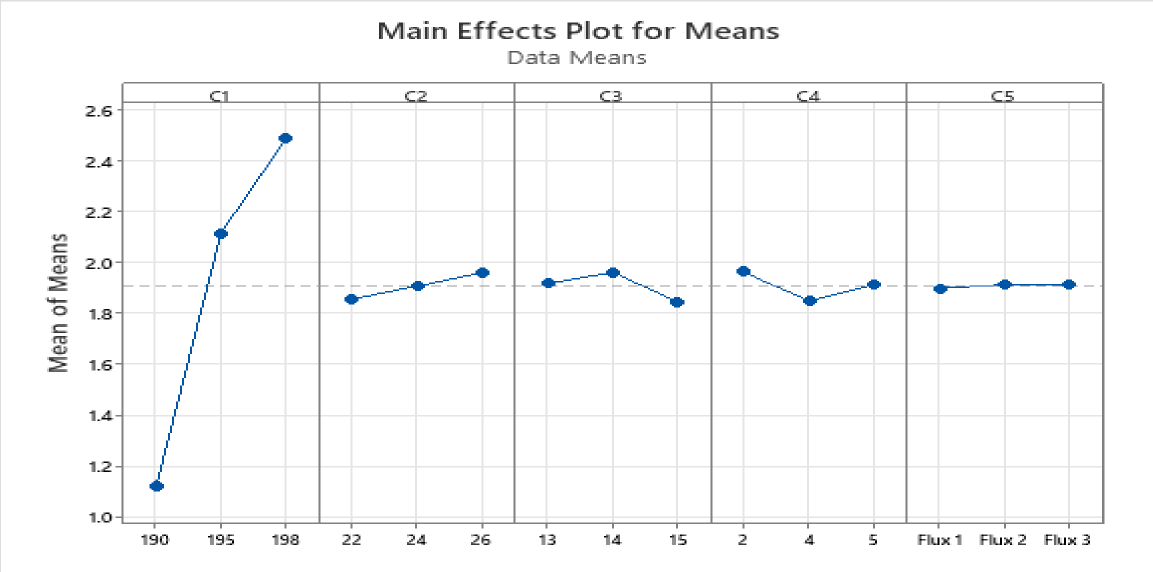


**Fig. 10: Main effects plot of mean data for Impact strength on ATIGW process**

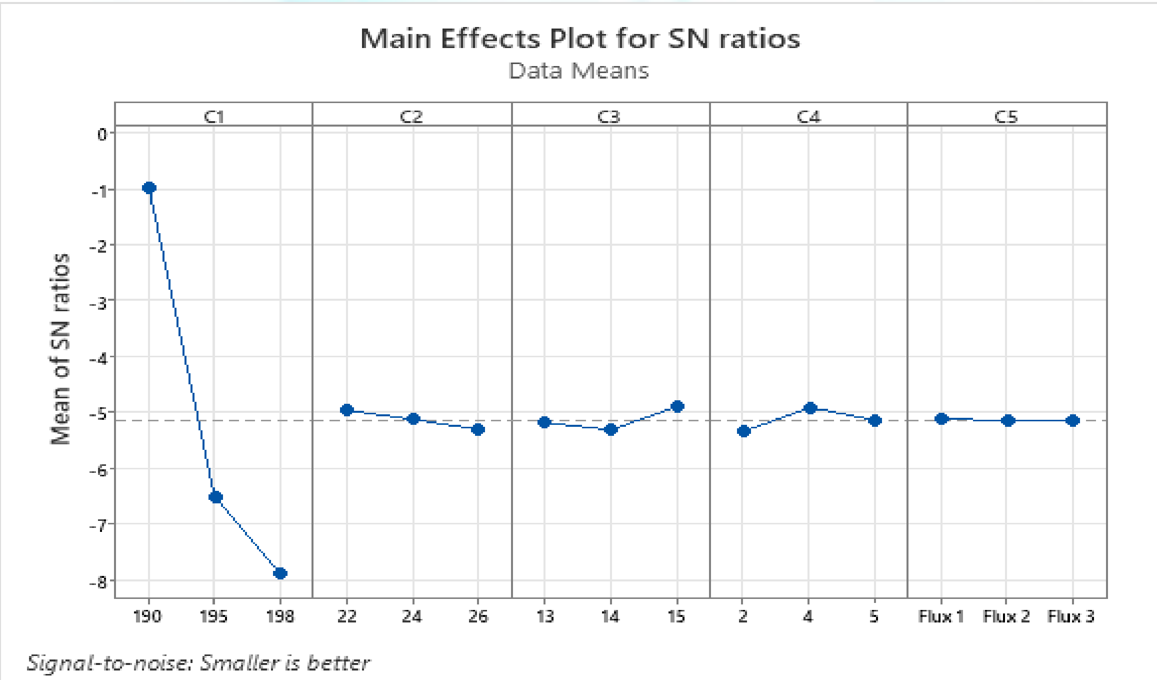


**Fig. 11: S/N response Table for Impact strength on ATIG Process**

## Conclusion

To evaluate the performance characteristics such as UTS, impact strength and hardness, an orthogonal array $L_{27}$ was used based on the requirement of various levels and input parameters. To study and evaluate the material characteristics at the weld zone for parent material, the signal to noise ratio and the analysis of variance (ANOVA) was employed. In addition to

MINITAB-21 software, confirmation experiments were conducted to verify the predicted optimum values. Following are the conclusions derived from a comparison of process parameters and output characteristics.

The percentage contribution of welding current to ultimate tensile strength during ATIGW is approximately 38.77%. Variables such as welding voltage, gas flow rate, and root gap have less effect on the total variation in ultimate tensile strength.

1. In the ATIGW process, hardness varies mainly due to current (33.31%), voltage (10.432%), & flux used (9.61%). These are the main factors responsible for variation in hardness. All other parameters have less contribution towards the total variation in hardness.
2. According to ANOVA analysis, the ATIGW percentage contribution (PC) for welding current, welding voltage, GFR, and root gap is 38.05, 33.68, and 2.63, respectively. Based on ANOVA, it can be concluded that welding CURRENT has the most significant effect on ATIGW. Welding Current has been found to affect UTS; an increase in welding current increases UTS. According to Taguchi's optimization method, the optimal parameters for ATIGW are A3B3C3D2E3 for experiment L27.
3.Impact strength is found to be affected by the welding current; with decreasing welding speed, the value of impact strength increases. Using the Taguchi optimization method, the optimal parameter is met for ATIGWare A1B1C3D2E1 at experiment L27.
4. According to the ANOVA, welding current is the most significant parameter for ATIGW. Hardness is shown to be affected by the welding current; as welding current increases, the value of hardness decreases. Taguchi's optimization method reveals that the optimal parameter for ATIGW at experiment L27 is A3B3C2D1E3.

The models developed may be used for selecting the optimum conditions and predicting the quality of ATIG welded hot rolled steel. The data generated can be used for further study and investigations. Lastly, the science of manufacturing will be enriched by the knowledge contributed by these findings of the study, how so ever small it may be.

**References:**

[1]. **Abd-Ghani, SN, Abd-Shukor, R & Kong, W 2012,** 'Effects of Fe3O4Nano Particles Addition in High Temperature SuperconductorYBa2Cu3O7-δ' *Advanced materials Research*, vol. 501, pp. 309-313.

[2]. **Abid, M, Parvez, S & Nash, DH 2013**, 'Effect of different electrode tipangles with tilted torch in stationary gas tungsten arc welding: A 3Dsimulation', *International Journal of Pressure Vessels and Piping*,vol. 1, pp. 51-60.

[3]. **AhmetDurgutlu 2004,** 'Experimental investigation of the effect ofhydrogen in argon as a shielding gas on TIG welding of austeniticstainless steel', *Materials and Design*, vol. 25, pp. 19-23.

[4]. **Anderson, PCJ &Wiktorowicz, R 1994**, 'Improving productivity withATIG welding', *Journal of Welding and Metal Fabrication.*, vol. 64,no.3, pp. 108-109.

[5]. **Arivazhagan, B &Vasudevan, M 2014** 'A comparative study on theeffect of GTAW processes on the microstructure and mechanicalproperties of P91 steel weld joints', *Journal of ManufacturingProcesses*, vol. 16, pp. 305-311.

[6]. **Babu, AS, Ramesh Narayan, P &NarayanaMurty, SVS 2016,**'Development of flux bounded tungsten inert gas welding process tojoin aluminum alloys'. American *Journal of Mechachical andIndustrial Engineering*, vol.1, no.3, pp.58-63.

[7]. **Bhawandeep Singh &AvtarSimgh 2015,** 'Performance of activatedTIG process in mild steel welds', *IOSR Journal of Mechanical andCivil Engineering*, vol. 12, Issue 2, pp. 1-5.

[8]. **Brungraber, RJ & Nelson, FG 1973**, 'Effect of welding variables onaluminum alloy weldments', *Weld Research Council, Supplement tothe Welding Journal*, pp. 97s-103s.

[9]. **CristieneVasconcelos,Gonçalves,SolidonioRodrigues,Carvalho & GilmarGuimarães 2010** 'Application of optimization techniquesand the enthalpy method to solve a 3D-inverse problem during aTIG welding process' *Applied Thermal Engineering*, vol. 30,pp. 2396-2402.

[10]. **Dadfar, M, Fathi, MH, Karimzadeh, F, Dadfar, MR & Saatchi, A 2007**,'Effect of TIG welding on corrosion behavior of 316L stainless steel',*Materials Letters*, vol. 61, pp. 2343-2346.

[11]. **Deepashri, D, Nage, VS, Raja & Raman, R 2006**, 'Effect of nitrogenaddition on the microstructure and mechanical behavior of 317L and904L austenitic stainless steel welds', *Journal of Material Science*, vol. 41,pp. 2097-2112.

[12]. **Devendranath, K, Ramkumar, N, Jelli Lakshmi NarasimhaVarma,GangineniChaitanya, AyushChoudhary, Arivazhagan, N &Narayanan, S 2015,** 'Effect of autogeneous GTA welding with andwithout flux addition on the micro structure and mechanical propertiesof AISI904L joints', *Materials Science & Engineering A*, vol. 636,pp. 1-9.

[13]. **Dongjie Li, Shanping Lu, Dianzhong Li &Yiyi Li 2014,** 'PrinciplesGiving High Penetration under the Double Shielded TIG Process',*J. Mater. Sci. Technol.*, vol. 30, no. 2, pp. 172-178.

[14]. **FeramuzKarcı, RamazanKacar&SuleymanGunduz 2009**,'The effect of process parameter on the properties of spot welded colddeformed AISI304 grade austenitic stainless steel' *Journal of MaterialsProcessing Technology*, vol. 209, pp. 4011-4019.

[15]. **Kang, BY, Yarlagadda, Prasad, KDV, Kang, MJ, Kim, HJ & Kim, IS2009**, 'The effect of alternate supply of shielding gases in austenitestainless steel GTA welding', *Journal of Materials ProcessingTechnology*, vol. 209, pp. 4722-4727.

[16]. **Kumar, A &Sundarrajan, S 2009**, 'Optimization of pulsed TIGwelding process parameters on mechanical properties of AA 5456Aluminum alloy weldments', *Materials and Design*, vol. 30,pp. 1288-1297.

[17]. **Kundan Kumar &SomnathChattopadhyaya 2012**, 'Investigation of theTemperature Distribution Character of TIG process', *InternationalJournal of Advanced Engineering Research and Studies*, vol. 2, Issue 1,pp. 32-35.

[18]. **Linzhi Wang, Jun Shen& Nan Xu 2011**, 'Effects of TiO2 coating onthe microstructures and mechanical properties of tungsten inert gaswelded AZ31 magnesium alloy joints', *Materials Science andEngineering A*, vol. 528, pp. 7276-7284.

[19]. **Lu, SP, Fujii, H &Nogi, K 2009**, 'Weld shape variation and electrodeprotection under Ar–(Ar–O2) double shielded GTA welding', *Scienceand Technology of Welding and Joining*, vol. 14, no. 8, pp. 726-733.

[20]. **Ming Gao, XiaoyanZeng&Qianwu Hu 2007**, 'Effects of gasshielding parameters on weld penetration of CO2 laser-TIG hybridwelding' *Journal of Materials Processing Technology*, vol. 184,pp. 177-183.

[21]. **Nagesh, DS &Datta, GL 2010**, 'Genetic algorithm for optimization ofwelding variables for height to width ratio and application of ANN forprediction of bead geometry for TIG welding process', *Applied SoftComputing*, vol. 10, pp. 897-907.

[22]. **Nayak, J, Udupa, KR, Hebbar, KR &Nayak, HVS 2004**, 'Estimationof embrittlement during aging of AISI 316 stainless steel TIG welds',*Bull. Mater. Sci.*, vol. 27, no. 6, pp. 511-515.

[23]. **Qiang Zhu, Yu-cheng Lei, Xi-zhang Chena, Wen-jie Rena, XinJub&Yi-min Yea 2011,** 'Microstructure and mechanical properties in TIGwelding of CLAM steel', *Fusion Engineering and Design,* vol. 86,pp. 407-411.

[24]. **Ruckert, G, Huneau, B &Marya, S 2007**, 'Optimizing the design ofsilica coating for productivity gains during the TIG welding of 304Lstainless steel', *Materials and Design,* vol. 28, pp. 2387-2393.

[25]. **Rui-Hua Zhang, Ji-Luan Pan & Seiji Katayama 2011**, 'The mechanismof penetration increase in A-TIG welding', *Front. Mater. Sci. vol*. 5,no. 2, pp. 109-118.

[26]. **Sakthivel, T, Vasudevan, M, Laha, K, Parameswaran, P,Chandravathi, KS, Mathew, MD &Bhaduri, AK 2011**, 'Creep rupturestrength of activated-TIG welded 316L(N) stainless steel' *Journal ofNuclear Materials*, vol. 413, pp. 36-40.

[27]. **Samanta, SK, Mitra, SK & Pal, TK 2008**, 'Microstructure andOxidation Characteristics of Laser and GTAW Weldments inAustenitic Stainless Steels', *Journal of Materials Engineering andPerformance*, vol. 17, pp. 908-914.

[28]. **Tarng, YS, Tsai, HL &Yeh, SS 1999**, 'Modeling, optimization andclassification of weld quality in tungsten inert gas welding',International Journal of Machine Tools & Manufacture, vol. 39,pp. 1427-1438.