

# Optimization of Process Parameter in TIG Welding Using Taguchi of Stainless Steel-304

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## Abstract

The purpose of this study is to propose a method to decide near optimal settings of the welding process parameters in TIG welding. The properties of the welded joints are affected by a large number of welding parameters. Properties include Tensile strength, Impact force, Hardness etc. Modeling of weld bead shape is important for predicting the quality of welds. In an attempt to model the welding process for predicting the bead shape parameters (also known as bead geometry parameters) of welded joints, modeling and optimization of bead shape parameters in tungsten inert gas (TIG) welding process has been tried in the present work. TIG welding process, considering the effects of main variables on weld strength. Also by using the same experimental data, an attempt has been made to predict the bead shape strength. In the study which parameter is most effectively effect the weld strength. Weld strength varies under various conditions. By using Taguchi and ANNOVA technique an optimal solution is find out, which provides us an optimal results of the varying condition.

## Keywords

TIG welding Setup, Stainless Steel-304, Universal Testing Machine, Minitab, Taguchi, L9 Array

## I. Introduction

Modern welding technology started just before the end of 19th century with the development of methods for a generating high temperature in localized zone. Welding generally requires a heat source to produce a high temperature zone to melt raw material, though it is possible to weld two metal pieces without much increasing temperature. There are different methods and standards adopted and there is still a continuous search for new and improved method of welding. As the demand for welding new materials and larger thickness components increase, mere gas flame welding, which was first known to the welding engineer, is no longer satisfactory and improved such as metal inert gas welding, tungsten inert gas welding, electron and laser beam welding have been developed [1]. Welding is the process of joining two pieces of metal by creating a strong metallurgical bond between them by heating or pressure or both. A welded joint is obtained when two clean surfaces are brought into contact with each other and either pressure or heat, or both are applied to obtain a bond. The tendency of atoms to bond is the fundamental basis of welding. The basic equipment for TIG welding comprises a power source, a welding torch, a supply of an inert shield gas, a supply of filler wire and perhaps a water cooling system. For welding most materials the TIG process conventionally uses direct current with the electrode connected to the negative pole of the power source, DCEN. Welding on this polarity does not give efficient oxide removal. A further feature of the gas shielded arc welding processes is that the bulk of the heat is generated at the positive pole. TIG welding with the electrode connected to the positive pole, DCEP. BayramKocabekir et.al [2] This paper aims to investigate the effect of weld time, different weld atmospheres and Weld cooling conditions on the resistance spot-

weld quality of 316L stainless steel. M. Balasubramanian et.al [3] This paper analyzed that Increase in use of pulsed current process creates dependency on the use of mathematical equations to predict the weld pool geometry. Hence, the development of mathematical models using four factors, five levels, central composite design was attempted. The developed models were checked for their adequacy. P. Sathiya et.al [4] The purpose of this study is to propose a method to decide near optimal settings of the welding process parameters in friction welding of stainless steel (AISI 304) by using non-conventional techniques and Artificial Neural Network (ANN). The methods suggested in this study were used to determine the welding process parameters by which the desired tensile strength and minimized metal loss were obtained in friction welding. K. Shanmugam et.al [5]. This paper concluded the effect of filler metals such as austenitic stainless steel, ferritic stainless steel and duplex stainless steel on fatigue crack growth behavior of the gas tungsten arc welded ferritic stainless steel joints was investigated. A. Kumar et.al [6]. The present work pertains to the improvement of mechanical properties of AA 5456 Aluminum alloy welds through pulsed Tungsten Inert Gas (TIG) welding process. Taguchi method was employed to optimize the pulsed TIG welding process parameters of AA 5456 Aluminum alloy welds for increasing the mechanical properties. D.S. Nagesh et.al [7] This paper explains an integrated method with a new approach using experimental design matrix of experimental designs technique on the experimental data available from conventional experimentation, application of neural network for predicting the weld bead geometric descriptors and use of genetic algorithm for optimization of process parameters. Kuang-Hung et.al [8] This paper explain the effect of oxides on an autogenously TIG welding applied to 6mm thick stainless steel plates through a thin layer of flux to produce a bead-on-plate welded joint. The oxide fluxes used were packed in powdered form. The experimental results indicated that the SiO<sub>2</sub> flux facilitated root pass joint penetration, but Al<sub>2</sub>O<sub>3</sub> flux led to the deterioration in the weld depth and bead width compared with conventional TIG process. M. Aghakhani et.al [9] In this research paper using Taguchi's method of design of experiments a mathematical model was developed using parameters such as, wire feed rate (W), welding voltage (V), nozzle-to-plate distance (N), welding speed (S) and gas flow rate (G) on weld dilution. After collecting data, signal-to-noise ratios (S/N) were calculated and used in order to obtain the optimum levels for every input parameter.

It can be observed from the above review of literatures that the optimization for input process can be calculated for Stainless Steel using Taguchi.

## II. Workpiece Material

Stainless steel-304 has lower carbon to minimize carbide precipitation. It is less heat sensitive than other 18:8 steels. Used in high-temperature applications. Its wide application in Food processing equipment, particularly in beer brewing, milk processing & wine making, Kitchen benches, sinks, troughs, equipment and appliances, Springs, Heat Exchangers.

Table 1: Composition of Stainless Steel-304

Elements	C	Cr	Ni	P	Mn	Si
Composition	.08	20	10.5	.045	2	.75

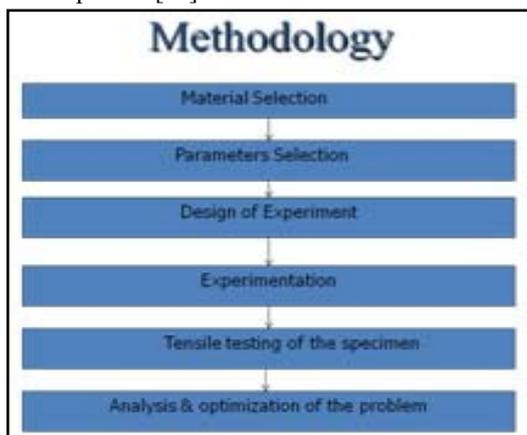
### III. Taguchi's Philosophy

Taguchi's comprehensive system of quality engineering is one of the great engineering achievements of the 20th 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 designs for large-scale production and marketplace. 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 leverages it produces on the improvement, and the more it reduces the cost and time.

Quality should be designed into the product and not inspect into it.

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

Taguchi's proposes an "off-line" strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. It observed that the process of inspection, screening and salvaging, cannot improve poor quality. No amount of inspection can put quality back into the product [10]. Taguchi 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 Tensile strength by varying different parameter such as welding current, voltage, gas flow. Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques which is useful for developing, improving and optimizing processes. It also has important applications in the design, development and formulation of new products, as well as in the improvement of existing product designs. The field of RSM consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistic modelling to develop an appropriate approximating relationship between the yield and process variables, and optimization methods for finding the levels or values of the process variables that produce desirable values of the responses [11].



Methodology of Experiment

### IV. List of Equipment

- Welding machine
- Gas cylinder
- Welding torch
- Electrode & filler rod

#### A. TIG Welding Machine

It is precision engineered range of inverter based TIG machines, which are in compliance with set industrial benchmarks. Fabricated from superior quality raw materials, these machines are used to weld mild steel, stainless steel, copper & titanium. Our Inverter TIG Welding Machines are known amongst clients for accurate dimension and capability to deliver optimum performance for long time.



Fig. 1: TIG Welding Machine

#### B. Gas Cylinder

A compressed gas is any gas which when enclosed in a container gives:

An absolute pressure reading greater than 276 kPa (40 psi) at 21°C (70°F)

An absolute pressure greater than 717 kPa (104 psi) at 54°C (129.2°F)

Any flammable liquid having a vapor pressure greater than 276 kPa (40 psi) at 38°C (100.4°F).

#### PARAMETER VALUE UNITS

Physical state (gas, liquid, solid): Gas

Vapor density (Air = 1) : 1.38

Boiling point : -302.6

: -185.9 F

Freezing point : -308.9

: -189.4F

Solubility (H<sub>2</sub>O) : Slight

Odor and appearance : Colorless, odourless gas

#### C. Welding Torch

TIG Torches feature Silicone Rubber torch bodies to reduce accidental damage during use and the loss of high frequency signal due to torch body cracking related to hard body plastic torch. SR series TIG torches are built with reinforced cable assemblies constructed of light weight, hi-flex materials. Water cooled torches have three piece cable assemblies in standard lengths of 12' or 25'. GTAW welding torches are designed for either automatic or manual operation and are equipped with cooling systems using air or water. The automatic and manual torches are similar in construction, but the manual torch has a handle while the automatic

torch normally comes with a mounting rack. The angle between the centerline of the handle and the centerline of the tungsten electrode, known as the head angle, can be varied on some manual torches according to the preference of the operator. Air cooling systems are most often used for low-current operations (up to about 200A), while water cooling is required for high-current welding (up to about 600A). The torches are connected with cables to the power supply and with hoses to the shielding gas source and where used, the water supply.



Fig. 2: TIG Welding Torch

**D. Electrode & Filler Rod**

The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F). As a result, the electrode is not consumed during welding, though 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 optimal for heat conduction. The diameter of the electrode can vary between 0.5 and 6.4 millimeters (0.02 and 0.25 in), and their length can range from 75 to 610 millimeters (3.0 to 24 in).

**V. Selection of Orthogonal Array OA**

The choice and the selection of the parameter were decided by considering the objective of present study. Before selecting a particular OA to be used as a matrix for conducting the experiments.

1. The number of parameters and interactions of interest.
2. The numbers of levels of the parameter of interest.

The non-linear behavior, if exists, among the process parameters can only be studied if more than two levels of the parameters are used. Therefore, each parameter was analyzed at three levels. The selected numbers of the process parameters and their levels are given in Table 2 For the sake of simplification, the second order interaction among the parameters is not considered [21].

Table 2: Parameters, Codes, and Level Values Used for the Orthogonal Array

Parameter	Code	Level 1	Level 2	Level 3
Control factors				
Welding Current(Amps)	I	100	125	150
Welding voltage (volt)	V	20	25	28
Gas flow(litre/min)	G	12	14	16

Each three level parameter has 2 degree of freedom (DOF) (Number of level – 1), the total DOF required for three parameters each at three levels is 8[=4x (3-1)]. As per Taguchi’s method the total DOF of the OA must be greater than or equal to the total DOF required for the experimentation. So an L<sub>9</sub> OA (a standard 3- level OA) having 8(=9-1) degree of freedom was selected for the present analysis. The standardized Taguchi-based experimental design used in this study was an L<sub>9</sub> orthogonal array, as described shown in Table 3.

Table 3: The Basic Taguchi L<sub>9</sub> Orthogonal Array

Run	A	B	C
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

This basic design uses up to three control factors, each with three levels. A total of nine runs must be carried out, using the combination of levels for each control factor. The addition of noise factors is optional, and requires each run to be conducted once for each combination of noise factor. The selected parameters, discussed in the introduction, are listed in Table 2 along with their applicable codes and values for use in the Taguchi model. The control and noise factors are independent variables, and the response variable is the dependent variable.

**VI. Experiment Procedure**

After the orthogonal array has been selected, the second step in Taguchi parameter design is running the experiment. The 304 stainless steel grade was used in mostly industry, homes, agriculture. All the welds were performed in plates rolled to 8 mm thick perpendicular to the rolling direction in a butt joint arrangement with straight edge preparation. Plates of 300 mm x 20 mm x 8mm were welded along their long edge. After welding, specimens were produced and mechanical tests were carried out. The uniaxial tensile tests were performed on UTM machine. Specimens were taken from each welded plate for tensile tests, with geometry. All mechanical trials were performed at room temperature.

In the experiment we take a specimen of (300x20x8) mm dimension.



Fig. 3: V-Groove Formation

A V groove formation will take place with the help of shaper machine, A total of 18 experiment were conducted during this process.

After the welding of the specimen All the Specimen are converted to the dumble shape which is the main requirement of the welded piece for testing. Specimens shall be either substantially full size or machined as prescribed in the product specification for the material being tested. On the basis of sheet thickness other dimension of product can easily be find out as given in the table.

Table 4: Dimension of the Tensile Test Specimen

Specimen thickness (T)	8 mm
Gauge length (L)	90 mm
Head width (WO)	20 mm
Total length (LO)	270 mm
Radius at shoulder (R)	35 mm

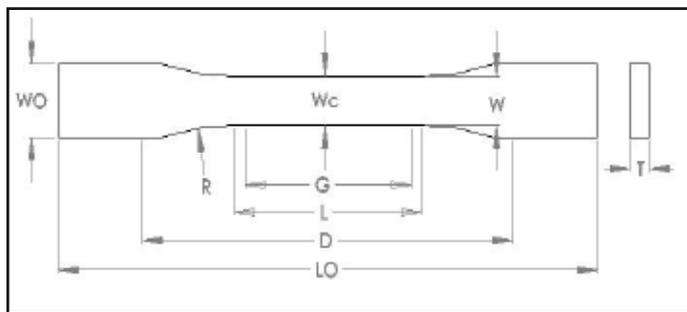


Fig. 4: Geometry of the Tensile Test Specimen



Fig. 5: Tensile Specimen (Before Tensile Test)

All the specimen are tested on the UTM machine to check the strength of each specimen.



Fig. 6: Broken Specimen in UTM Machine



Fig. 7: Tensile Specimen (After Tensile Test)

**VII. Data Analysis**

The experiment was planned by using the parametric approach of the Taguchi method. A number of methods have been suggested by Taguchi for analyzing the data: observation method, ranking method, column effect method, ANOVA, S/N ANOVA, plot of average responses, interaction graphs, etc[12]. In the present investigation, following methods are used.

1. ANOVA for raw data
2. ANOVA for S/N data
3. Plot of average response curves

**A. Analysis of Raw Data and S/N Ratios**

Table6 shows the result of the analysis of variance (ANOVA) for Tensile strength. The analysis of variance was carried out for a 95% confidence level. The ANOVA Tables 6 shows that, the F value corresponding to all parameters are greater than the tabulate value of F0.05. The main purpose of the analysis of variance is to investigate the influence of design parameters on optimal surface finish by indicating the parameters that significantly affect the quality characteristics of the machined surfaces.

Table 5: Results of Experiment

S. No.	Tensile Strength-1 (N/mm <sup>2</sup> )	Tensile Strength-2 (N/mm <sup>2</sup> )	Mean	S/N Ratio
1	115.87	116.63	116.25	41.30
2	199.5	201.63	200.56	46.04
3	240.75	238.23	239.49	47.58
4	210.64	212.54	211.59	46.50
5	280.40	282.32	281.36	48.98
6	380.86	382.74	381.80	51.36
7	219.94	220.64	220.29	46.85
8	298.40	296.43	297.41	49.46
9	398.76	399.43	399.09	52.02

Table 6: ANOVA Table for S/N ratio

Source	DOF	Sum of Square	Mean Square	(F)	Probabil-ity (P)
Welding current	2	36.66	18.33	44.15	.022
Welding voltage	2	46.26	23.13	55.71	.018
Gas flow	2	.7817	.390	.94	.515
Error	2	.8305	.415		
Total	8	84.54			

The model P value implies that points .022, .018 are significant. In this case welding current and welding voltage are significant parameter and gas flow is non-significant parameter. The value of  $P \leq .05$  indicates those models are significant.

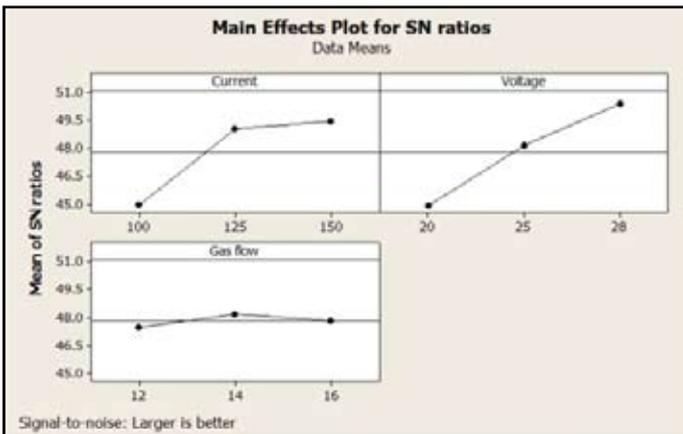


Fig. 8: S/N Ratio Graph

In ANOVA table value of F is very significant, The analysis of variance was carried out for a 95% confidence level in this we make an assumption that value of  $P < .05$  are found to be significant parameter. Gas flow is non-significant parameter also graph shows that gas voltage have a least effect on the welding specimen.

The Average effect response table for mean under the array in Table7indicates the mean of the response variable means for each level of each control factor. This specifies the mean surface roughness value that each level of each control factor produced during this experiment. The S/N effect table under the array in Table 7 indicates the mean of the S/N values for each level of each control factor Table 6 and Table 7 shows average effect response for the raw data and effect response table for S/N ratio.

Table 7: Response Table for the Mean

Source	DOF	Sum of Square	Mean Square	F	Proba-bility (P)
Welding current	2	25903.6	12951.8	44.05	.022
Welding voltage	2	37176.2	18588.1	63.21	.016
Gas flow	2	901.8	450.9	1.53	.395
Error	2	588.1	294.1		
Total	8	64569.6			

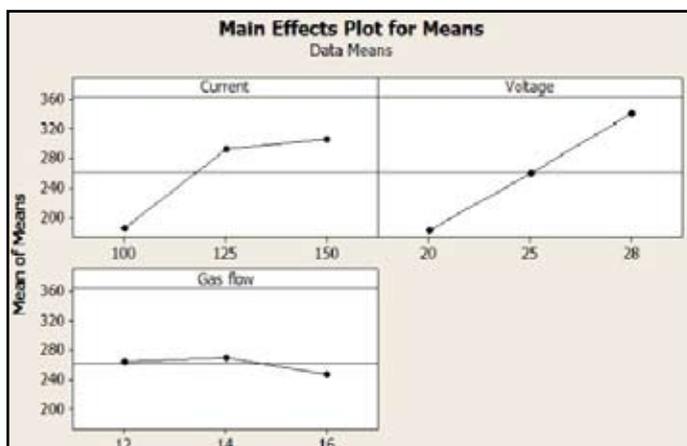


Fig. 9: Graph for Mean Values

Table 5 shows the result of experiment performs in which a total 2 runs for each experiment is perform according to the condition. The analysis of variance (ANOVA) for S/N Ratio of Tensile strength is in the Table6 the analysis of variance was carried out for a 95% confidence level. The ANOVA Tables6 shows that, the F value corresponding to all parameters are greater than the tabulate value of P0.05. This analysis provides the relative contribution of welding parameters in controlling the strength of weld piece. Table 6 shows that the P value for current and voltage lies in the significant range where as gas flow is not a significant parameter. The mean value for tensile strength is shown in table7 in which current and voltage are in significant parameter where as gas flow is non-significant parameter.

**B. Prediction of Mean**

After determination of the optimum condition, the mean of the response ( $\mu$ ) at the optimum condition is predicted. This mean is estimated only from the significant parameters. The ANOVA identifies the significant parameters. The optimum value of T.S is predicted at the selected level of significant parameters Welding current ( $I_3$ ), Welding voltage ( $V_3$ ), Gas flow ( $G_2$ ). The estimated of mean of the response characteristic (T.S) can be determined

$$\hat{\mu} = I_3 + V_3 + G_2 - 2\bar{T}$$

**C. Determination of Confidence Intervals**

The 95% Confidence Interval of Conformation Experiments (CICE) and of Population (CIPOP) was calculated by using the equation (4.5 & 4.6).

$$f_e = \text{Error DOF} = 8 - 6 = 2$$

$$n_{\text{eff}} = \frac{N}{1 + \left[ \frac{\text{DOF associated in the estimate of mean response}}{N} \right]}$$

$$N = 9, \quad n_{\text{eff}} = 1.28 \quad V_e = (588.1)$$

$$R = 2 \quad F_{0.05}(1, f_e) = 18.51$$

$$\text{So, } CI_{\text{CE}} = \sqrt{F_{\alpha}(1, f_e) V_e \left[ \frac{1}{n_{\text{eff}}} + \frac{1}{R} \right]} = 118.09$$

$$CI_{\text{POP}} = \sqrt{\frac{F_{\alpha}(1, f_e) V_e}{n_{\text{eff}}}} = 92.21$$

The predicted optimal range (for a confirmation run of ten experiments) is:

$$\text{Mean T.S} - CI_{\text{pop}} < \text{T.S} < \text{Mean T.S} + CI_{\text{pop}}$$

$$168.89 < \text{SSR} < 353.11$$

**D. Mathematical Model**

A mathematical model can be developed for the effective surface finish criteria, e.g. Ra Value during welding operation. Using multiple linear regression and correlation analysis, mathematical models for Ra is obtained as follows: As Ra is a function of more than one independent variable, the matrix equations that express the relationships among the variables can be expanded to accommodate the additional data.

$$R_a = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$

Where,

$a_0, a_1, a_2, a_3$  and  $a_4$  are the constant coefficient and  $x_1 =$  Welding current (I)

$x_2$  = Welding voltage (V)

$x_3$  = Gas flow (G)

A multivariate model of the data is multiple regressions solves for unknown coefficients by performing a least squares fit. Construct and solve the set of simultaneous equations by forming the regression matrix, X, and solving for the coefficients using the backlash operator.  $X = [\text{ones}(\text{size}(x1)) \ x1 \ x2 \ x3]$ ;

The least squares fit model of the data is to validate the model, find the maximum of the absolute value of the deviation of the data from the model.  $Y = X*a$ ;

The regression equation is

Tensile strength = - 717 + 2.52 \*Current + 24.7 \*Voltage + 2.47 \*Gas flow

### VIII. Conclusion

1. The use of the  $L_9$  orthogonal array, with three control parameters allowed this study to be conducted with a sample of 18 work pieces.
2. The study found that the control factors had varying effects on the Tensile strength, welding voltage having the highest effects.
3. Optimum parameter setting for weld strength is obtained at current of 150 amps, 28 volt, and 14-litre/min-gas flow.
4. Formulation of equation for tensile strength- Tensile Strength = - 717 + 2.52 Current + 24.7 Voltage + 2.47 Gas flow

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