# Modeling of Arc Metal Welding Process of Low Carbon Steel (304)

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**ABSTRACT**

This work includes an investigation of the effect and optimization of welding parameters on the tensile strength in the arc metal welding process. The experimental studies were conducted under varying welding currents, wire diameters, and heat input. The settings of welding parameters were determined by using the Taguchi experimental design method. The level of importance of the welding parameters on the tensile strength is determined by using analysis of variance (ANOVA). The optimum welding parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio. The tensile strength model was formulated based on Analysis of Variance (ANOVA) using Minitab® statistical package. The experimental results confirmed the validity of the used Taguchi method for enhancing the welding performance and optimizing the welding parameters in the arc metal welding process.

**Keywords*:*** Arc Metal Welding, Tensile Strength, Modeling.

# نمذجة طريقة لحام القوس المعدني للفولاذ المنخفض الكاربون نوع (304)

**الخلاصة**

يتضمن هذا البحث دراسة تاثير عوامل لحام القوس المعدني على مقاومة الشد للفولاذ (304) بالاضافة الى ايجاد العوامل المثلى , وتم اجراء الدراسات التجريبية تحت تاثير التغير في قيم تيار اللحام , قطر السلك , بالاضافة الى الدخل الحراري. اما اعداد معاملات اللحام فقد تم تحديدها وفقا لطريقة تاكوجي(اي تصميم التجارب وفقا لطريقة تاكوجي). اما مستوى تاثير هذه المعاملات فقد تم تحديده وفقا لتحليل التباين ANOVA . كما تم الحصول على عوامل اللحام المثلى باستخدام تحليل نسبة الاشارة/الضوضاء S/N, اما الموديل الرياضي لمقاومة الشد فقد تم نمذجتة وفقا لتحليل التباين باستخدام الحزمة الاحصائية لبرنامج MINITAB, واظهرت النتائج التجريبية صحة استخدام طريقة تاكوجي لرفع اداء اللحام وتحديد العوامل المثلى لطريقة لحام القوس المعدني للفولاذ نوع304.



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## INTRODUCTION

Metal arc welding is one of the most widely used process in industry. The input parameters play a very significant role in determining the quality of a welded joint. In fact, weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and Mechanical devices. Therefore, these parameters affecting the arc and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results, in fact a perfect arc can be achieved when all the parameters are in conformity. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process. Former are welding current, arc voltage and welding speed. These parameters will affect the weld characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation. Their values should be recorded for every different type of weld to permit reproducibility [1].

An investigation according [2 – 5] studies show that there is good correlation between tensile strength and welding parameters such as welding current ,electrode diameter, and welding time. The DOE using Taguchi approach can significantly reduce time required for experimental investigations [6 – 8]. In this paper, the use of the Taguchi method to determine the welding process parameters with the optimal tensile strength is reported.

### Taguchi Approach

Taguchi Technique is applied to plan the experiments. The Taguchi method has become a powerful tool for improving productivity during research and development, so that high quality products can be produced quickly and at low cost. Dr.Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain best results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results [9].

### Signal-to-Noise Ratio

There are 3 Signal-to-Noise ratios of common interest for optimization [9]:

**(I) Smaller-The-Better:**

n = -10 Log10 [mean of sum of squares of measured data]

**(II) Larger-The-Better:**

n = -10 Log10 [mean of sum squares of reciprocal of measured data]

**(III) Nominal-The-Best:**

n = 10 Log10 (square of mean/ variance)

## EXPERIMENTAL PROCEDURE

Low carbon steel ASTM A 304 is extensively used for deep drawing of motor car bodies, motor cycle parts, and other domestic applications. Therefore, the present work was planned to optimize the arc metal welding parameters of 304 steel sheets as shown in flow-chart of Response Modeling:

The specimens were prepared by cutting the work piece material into the suitable dimensions (ASTM A370) as shown in Figure (1) and then cleaned and abraded to prevent high contact resistance which is created due to an oxide layer [10]. The chemical composition (percent by weight), of the work piece material is given in Table (1).

**Table (1) Chemical analysis of work piece material.**

| Element | C | Mn | Mo | Cu | Cr | V | Fe |
|---|---|---|---|---|---|---|---|
| Percent composition (%) | 0.13 | 1.8 | 0.03 | 0.7 | 0.19 | 0.25 | Rem. |

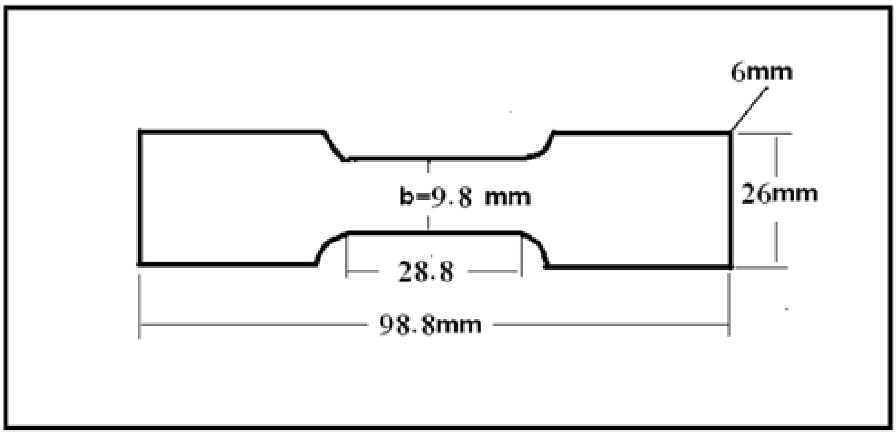


**Figure (1) Dimensions of tensile specimen.**

## ORTHOGONAL ARRAY EXPERIMENT

In the present study, three three-level process parameters, *i.e.* welding currents, electrode diameters, and heat input, are considered. The value of the welding process parameter at the different levels is listed in Table (2).

**Table (2) Welding parameters and their levels.**

| Symbol | Welding parameter | Level | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| A | Welding current Amp | 65 | 110 | 145 |
| B | Wire diameter mm | 1.2 | 2.5 | 3.5 |
| C | Heat input J/mm | 0.9 | 1.06 | 1.4 |

**L9 3 Level Taguchi Orthogonal Array**

Taguchi's orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process responses). The corresponding OA is selected from the set of predefined OAs according to the number of factors and their levels that will be used in the experiment. Below Table (3) shows L9 Orthogonal array from Table (2).

**Table (3) L9 Orthogonal Array.**

| Exp. No. | Process parameters | | |
|---|---|---|---|
| | Welding current | Wire diameter | Heat input |
| 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 |

**RESULTS & DISCUSSIONS**

**Analysis of S/N Ratio**

In the Taguchi Method the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard Deviation) for the output characteristic. Therefore, the S/N ratio is the mean to the S. D. S/N ratio used to measure the quality characteristic deviating from the desired value. The S/N ratio S is defined as [9]:

S= -10 log (M.S.D.)

Where, M.S.D. is the mean square deviation for the output characteristic. To obtain optimal welding performance, higher-the better quality characteristic for penetration must be taken. The M.S.D. for higher-the –better quality characteristic can be expressed:

$$M.S.D = \frac{1}{m}\sum \frac{1}{\sigma_i^2}$$

Where the value of $\sigma_i^2$is the tensile strength. Table (4) shows experimental results for tensile strength and S/N ratio.

**Table (4) Experimental results for tensile strength and S/N ratio.**

| **Exp. No.** | **Process parameters** | | | **Tensile Strength MPa** | **S/N ratio** |
|---|---|---|---|---|---|
| | **Welding current Amp.** | **Wire diameter mm** | **Heat input J/mm** | | |
| 1 | 1 | 1 | 1 | 339.5 | 50.6168 |
| 2 | 1 | 2 | 2 | 386.0 | 51.7317 |
| 3 | 1 | 3 | 3 | 370.0 | 51.3640 |
| 4 | 2 | 1 | 2 | 378.2 | 51.5544 |
| 5 | 2 | 2 | 3 | 378.2 | 51.5544 |
| 6 | 2 | 3 | 1 | 414.0 | 52.3400 |
| 7 | 3 | 1 | 3 | 431.6 | 52.7016 |
| 8 | 3 | 2 | 1 | 417.5 | 52.4131 |
| 9 | 3 | 3 | 2 | 420.0 | 52.4650 |

Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The S/N response table for penetration is shown in Table (5). Figure (2) shows the S/N ratio graph. Basically, the larger the S/N ratio, the better is the quality characteristic for the tensile strength.
Taguchi Analysis: Tensile Strength versus Current; Wire diameter; Heat input

**Table (5) S/N Response for tensile strength.**

| **Level** | **Current Amp.** | **Wire diameter mm** | **Heat Input J/mm** |
|---|---|---|---|
| 1 | 51.24 | 51.62 | 51.79 |
| 2 | 51.82 | 51.90 | 51.92 |
| 3 | 52.53 | 52.06 | 51.87 |

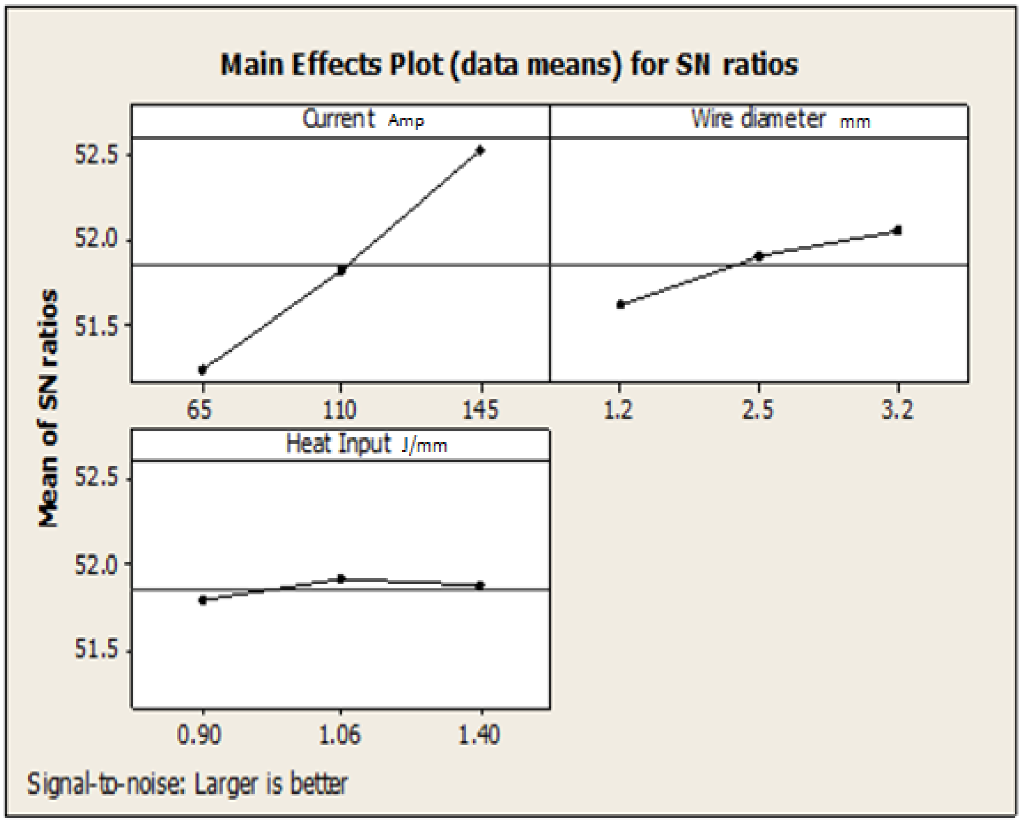


**Figure (2) Main effects plot for SN ratios.**

**ANOVA (Analysis of Variance)**

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error [9]. A better feel for the relative effect of the different welding parameters on the tensile strength (TS) was obtained by decomposition of variance. The relative importance of the welding parameters with respect to the TS was investigated to determine more accurately the optimum combinations of the welding parameters by using ANOVA. The results of ANOVA for the welding outputs are presented in Table (6). Statistically, *F*-test provides a decision at some confidence level as to whether these estimates are significantly different [9]. Larger *F*-value indicates that the variation of the process parameter makes a big change on the performance. According to this analysis, the most effective parameters with respect to tensile strength is welding current, wire diameter, and heat input. Analysis of Variance for Tensile Strength.

**Table (6) Results of ANOVA for tensile strength.**

| Source | DF | Seq SS | Adj SS | Adj MS | F |
|---|---|---|---|---|---|
| **Current** | 2 | 5054.3 | 5054.3 | 2527.1 | 3.26 |
| **Wire diameter** | 2 | 504.3 | 504.3 | 252.2 | 0.33 |
| **Heat input** | 2 | 30.1 | 30.1 | 15.1 | 0.02 |
| **Error** | 2 | 1549.3 | 1549.3 | 774.7 | |
| **Total** | 8 | 7138.1 | | | |

## RESPONSE MODELING

A statistical regression analysis was performed to analyze the tensile strength of steel (304) welds in terms of the welding currents, Wire diameters, and heat input. The relationships among the welding currents, Wire diameters, and heat input welding parameters were characterized using mathematical model. The response variables of the models were different at different stages of the experiment. The independent variables were entered into the regression model one by one depending on their probabilistic significance to the response variable. The obtained model is as follows:

***Tensile strength=291+9.01wire diameter+4.3 Heat input+0.175 Current***

The standardized regression coefficients are listed in Figure (3). These coefficients can be used to interpret the significance of individual parameters. Flow chart is shown in Figure (4).

Residual plots can be used to examine the goodness of model fit through following residual plots as shown in Figure (4):

**- Histogram of residuals.** An exploratory tool to show general characteristics of the data, including typical values .Long tails in the plot may indicate skewness in the data. If one or two bars are far from each other's, those points may be outliers. Because the appearance of the histogram changes depending on the number of intervals used to group the data, use the normal probability plot and goodness-of-fit tests to assess the normality of the residuals.

**- Normal plot of residuals.** The points in this plot should generally form a straight line if the residuals are normally distributed as shown in Figure (3) . If the points on the plot depart from a straight line, the normality assumption may be invalid.

**- Residuals versus fits.** This plot should show a random pattern of residuals on both sides of 0. Also, there should not be any recognizable patterns in the residual plot. The following may indicate error that is not random:

**- Residuals versus order.** This is a plot of all residuals in the order that the data was collected and can be used to find non-random error.

As a result, it showed that predicted values were distributed around measure values within the small error range.

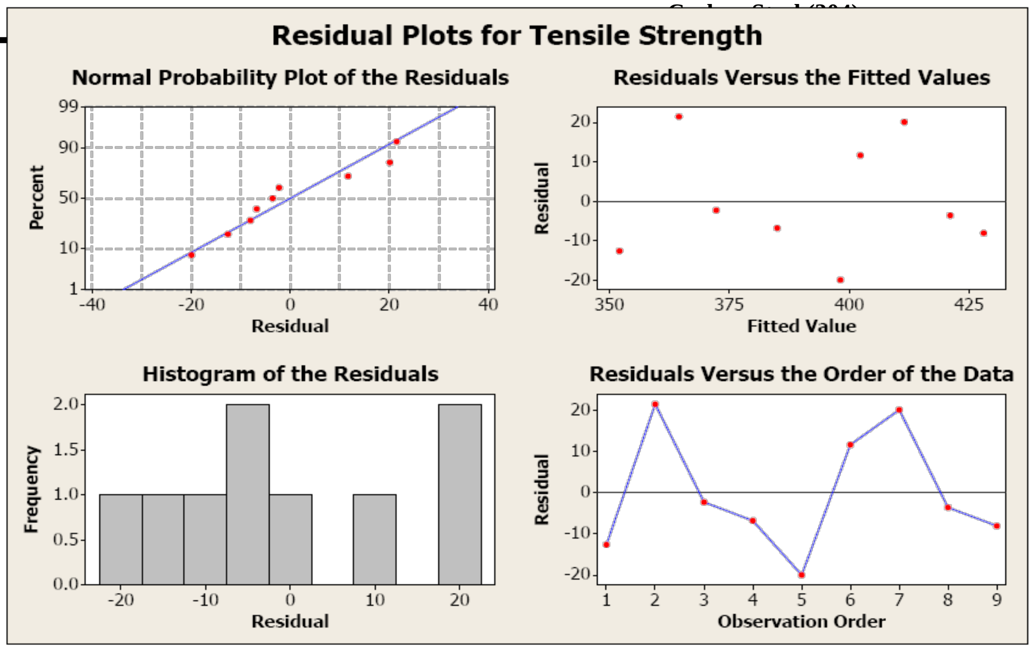


**Figure (3) Residual plots for tensile strength.**

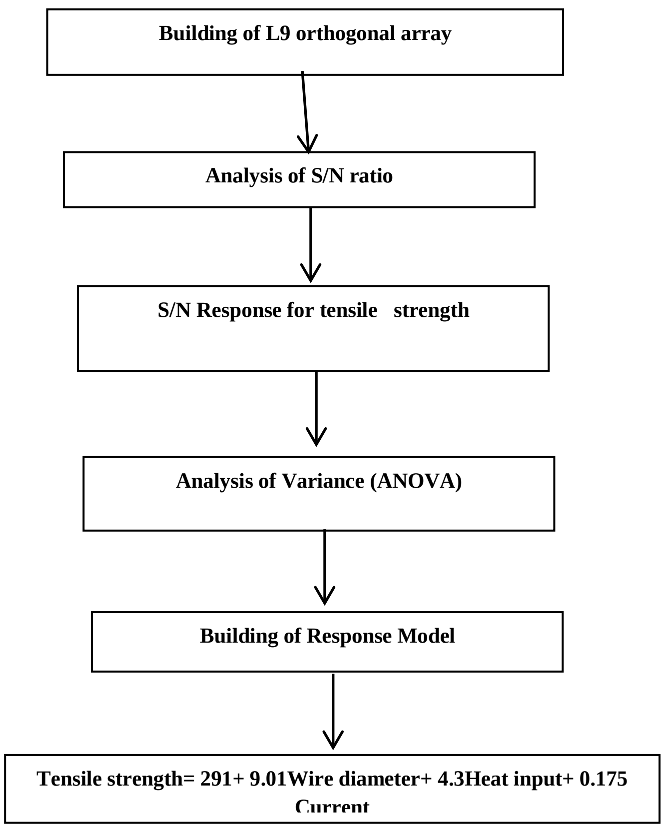

**Figure (4) Flow-chart of response modeling.**

## CONCLUSIONS

This work has presented an investigation on the optimization and the effect of welding parameters on the tensile strength of arc metal welded 304 steel sheets. The level of importance of the welding parameters on the tensile strength is determined by using ANOVA. Based on the ANOVA method, the highly effective parameters on tensile strength were found as welding current and wire diameter, whereas heat input was less effective factors. The results showed that welding current was several times more important than the second ranking factor (wire diameter) for controlling the tensile strength. An optimum parameter combination for the maximum tensile strength was obtained by using the analysis of signal-to-noise (S/N) ratio. The experimental results confirmed the validity of the used Taguchi method enhancing the welding performance and optimizing the welding parameters in arc metal welding operations.

Through sensitivity analysis between process parameters and tensile strength, it has been found that tensile strength increased in its values depending on the welding process parameters .From the statistical model, it is shown that the linear effects of the model. According to Taguchi method (Table 2) the optimum Arc welding parameters for steel 304 are:

**Welding current =145 Amp**
**Wire diameter= 3.5 mm**
**Heat input= 1.4 J/mm**

In addition according to ANOVA analyses the arrangement of the most effective parameters with respect to tensile strength are welding current ,wire diameter and heat input.

## REFERENCES

[1]. Benyounis, K.Y. A.G. Olabi; "Optimization of different welding processes using statistical and numerical approaches – A reference guide." Advances in Engineering Software, 39 (2008) 483–496

[2].Ugur r Esme; "Application of Taguchi method for the optimization of resistance spot welding process." The Arabian Journal for Science and Engineering, Volume 34, Number 2B,2009.

[3]. Kishore,K. P. V. Gopal Krishna, K. Veladri and Syed Qasim Ali; " Analysis of defects in gas shielded arc welding of AISI1040 steel using Taguchi method." ARPN Journal of Engineering and Applied Sciences, Vol 5, No.1.

[4].Sourav Datta, Ajay Biswas, Gautam Majumdar; "Sensitivity analysis for relative importance of different weld quality indicator influencing optimal process condition of Submerged Arc Welding using Gray based Taguchi Method" The International Journal for Manufacturing science & production, Vol. 10 No. 2 2009

[5]. Palani, P. K. Dr. N. Murugan, "Modeling of Heat Input in Stainless Steel Cladding using Taguchi's Design of Experiments" IE(I) Journal-MC, Vol. 87, January 2.

[6].Saurav Datta & Asish Bandyopadhyay & Pradip Kumar; "Application of Taguchi philosophy for parametric optimization f bead geometry and HAZ width in submerged arc welding using a mixture of fresh flux and fused flux"

[7].N.B. Mostafa, M.N. Khajavi; "; Optimisation of welding parameters for weld penetration in FCAW" Achievements in Materials and Manufacturing Engineering Vol. 16 ISSUE 1-2 May-June 2006

[8].Serdar Karaoglu and Abdullah Seçgin; "Sensitivity analysis of submerged arc welding process parameters" journal of materials processing technology, volume 202 (2008), 500–507

[9]..Douglas C.Montgomery, Geroge C.Runger , "Applied Statistics and Probability for Engineers", 5th edition, John Wiley, 2012.

[10].S.C. Juang and Y.S. Tarng, "Process Parameter Selection for Optimizing the Weld Pool Geometry in the Tungsten Inert Gas Welding of Stainless Steel", Journal of Materials Processing Technology, 122(2002), pp. 33–37.