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# Parametric Optimization of Gas Metal Arc Welding For Stainless Steel (Ss304) Using Taguchi Design Method

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***ABSTRACT:*** *In the present work, the optimization of welding parameters (Welding Current, Welding Voltage, and Electrode feed Rate) for SS 304 is investigated. Taguchi method is used to formulate the experimental design. A total number of 9 experimental runs have been designed using L9 orthogonal array. Stainless steel of thickness 3mm was selected as work piece material for the present experiments. The gases used during this welding process were mixture of Argon (25%) and helium (75%). 18 plates of 3mm thickness were taken and then coalescence is produced by using GMAW to form 9 butt welded plates. The required dimension welding samples for mechanical testing is prepared from these plates to perform tensile and hardness test on it. A total number of 9 tensile specimens and 9 hardness specimens were prepared for the study. By using ANOVA in mini tab software mechanical properties of the specimen's i.e. ultimate tensile strength, Brinell hardness of SS 304 were validated. After collecting the data from the mechanical testing signal-to-noise ratios will be calculated and used in order to find out percentage contribution of each parameter. A confidence interval of 95% has been taken for analysis. The maximum tensile strength were achieved while welding with welding current 200A, welding voltage 28V and Electrode feed rate 6m/min. The most effective parameter for achieving maximum tensile strength is Welding current with 64.05% and followed by welding voltage 25.2% and Electrode feed rate 10.5%. The maximum hardness value achieved while welding with welding current 180A, welding voltage 28V and Electrode feed rate 6m/min. The most effective parameter for achieving maximum hardness value is welding voltage with 44.11% and followed by welding current 29.55% and Electrode feed rate 23.46%.*

***Keywords:-****SS 304, Taguchi method, Coalescence, ANOVA, Tensile strength, Brinell hardness, GMAW*

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## I. Introduction

Gas metal arc welding (GMAW) is one of the most widely used processes 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 there by construction and manufacturing costs of steel structures and Mechanical devices. Therefore, these parameters affecting the current, voltage and feed rate and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results; infect the a results can be achieved when all the parameters are in conformity. Parameters like welding current, welding voltage and electrode feed rate will affect the weld characterstics 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.In leterature review studied this work, the influence of heat input was studied on depth of penetration while depositing bead on AISI 304 stainless steel using an indigenously fabricated automatic gas metal arc welding (GMAW) movement setup. Depth of penetration and fusion zone profiles were predicted at different conditions by the bond graph modeling approach and validated using measured depth of penetration and fusion profile. The effects of heat input on toughness and metallurgical behavior are analyzed while joining AISI 304 plates using automatic GMAW. Heat input and gas flow rate significantly influence the toughness at room temperature and at −20°C. Metallurgical observations by scanning electron microscopy are carried out and it is observed that high heat input and lower cooling rate increase grain size. High heat input and rapid cooling prevent grain growth and lead to grain refinement. [15]This work deals with optimization of welding process variables by using Metal inert gas welding. In this process input variables are voltage (V), current (A) and welding speed(S) with tensile properties, hardness, and penetration as responses of low carbon steel (ASTM A29). The design of experiments based on Taguchi orthogonal array [L9], acquires Analysis of variance (ANOVA) to determine the influence of parameters with the optimal condition. [29]

## II. Taguchi Method

In the Taguchi method the desirable value (mean) for the output characteristics is represented by the term Signal and the undesirable value (standard deviation) for the output characteristics is represented by the term noise. The minimum residual stresses and maximum hardness are chosen as the two main quality objectives of welded materials specimens' .The Signal to Noise ratio were used to transform the experimental results. The deviation of quality characteristics from the desired value were measured b the use of the S/N ratio which was proposed by Taguchi. The quality characteristics in the analysis of S/N ratio are categorized into three different categories like Larger the better, nominal the best and smaller the better. The S/N analysis was used for calculation of S/N ratio for each level of process parameters. It was observed that better quality characteristics related with the highest S/N ratio of the process parameters. Therefore the level of highest S/N ratio with minimum variance was selected the optimal level.

An L-9 orthogonal array is shown below

| Experiment No. | P1 | P2 | P3 |
|---|---|---|---|
| 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 |

## III. Signal To Noise Ratio

Parameters that affect the output can be divided in two parts: controllable (or design) factors and uncontrollable (or noise) factors. The difference between controllable and uncontrollable factors is that the value of controllable factors can be adjusted by the designer but the value of uncontrollable factors cannot be changed because they are the sources for variation because of operational environment. The best setting of control factors as they influence the output is determined by performing Taguchi's design of experiments. Bigger-the-Better is used for tensile strength and hardness value.

$$\frac{S}{N_{(Bigger\ )}} = -10\ \log\left(\frac{\Sigma\left(\frac{1}{y_i^2}\right)}{n}\right)$$

## IV. Experimental and data collection

**Selection of process parameters**

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study welding current, welding voltage and electrode feed rate and have been considered as process variables. The process variables with their units and notations are listed

**Process variables and their limits**

| Parameters/Factors | | Level | | |
|---|---|---|---|---|
| | | **1** | **2** | **3** |
| **A** | **Welding current (Amp)** | 180 | 200 | 220 |
| **B** | **Welding voltage (Volt)** | 24 | 26 | 28 |
| **C** | **Electrode feed rate (m/min)** | 5 | 5.5 | 6 |

## V. Material used

Stainless steel 304 plate of thickness 3 mm was selected as work piece material for the present experiment. SS plate was cut with required dimension with the help of power-saw and grinding done at the edge to smooth the surface to be joined. After that surfaces are polished with emery paper to remove any kind of external material. The composition and material properties of stainless steel

**Chemical Composition by wt%**

| Material | Cr | Ni | Mn | Si | C |
|---|---|---|---|---|---|
| **SS 304** | **17-19.5%** | **8-10.5%** | **2%** | **1%** | **0.07%** |

**Mechanical Properties (Mpa)**

| Material | UTS (MPa) | Yield Strength (MPa) | % Elongation(Min) | Hardness (HV) |
|---|---|---|---|---|
| SS 304 | 517 | 205 | 40 | 92 |

**Sample ready for testing**

## VI. Weld Testing Procedure

After GMAW welding, tensile test is performed on universal testing machine. If A is the cross sectional area and F is the maximum force and tensile strength calculated by:Tensile strength=F/A

**S/N ratio for tensile test result**

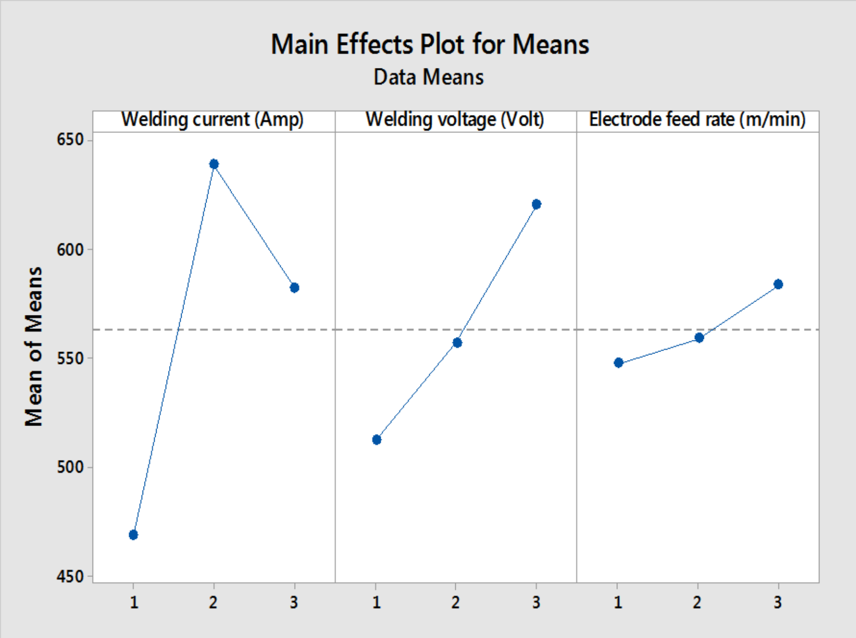
| Experiment no. | Welding current (Amp) | Welding voltage (Volt) | Electrode feed rate (m/min) | Tensile strength (MPa) | S/N ratio |
|---|---|---|---|---|---|
| 1 | 180 | 24 | 5 | 385.43 | 51.72 |
| 2 | 180 | 26 | 5.5 | 448.58 | 53.04 |
| 3 | 180 | 28 | 6 | 571.35 | 55.14 |
| 4 | 200 | 24 | 5 | 608.99 | 55.69 |
| 5 | 200 | 26 | 5.5 | 636.21 | 56.07 |
| 6 | 200 | 28 | 6 | 669.91 | 56.52 |
| 7 | 220 | 24 | 5 | 541.91 | 54.68 |
| 8 | 220 | 26 | 5.5 | 586.22 | 55.36 |
| 9 | 220 | 28 | 6 | 618.42 | 55.83 |

**Response table for S/N ratio for tensile strength**

| Level | Welding current (Amp) | Welding voltage (Volt) | Electrode feed rate (m/min) |
|---|---|---|---|
| 1 | 468.5 | 512.1 | 547.2 |
| 2 | 638.4 | 557.0 | 558.7 |
| 3 | 582.2 | 619.9 | 583.2 |
| Delta | 169.9 | 107.8 | 36.0 |
| Rank | 1 | 2 | 3 |

### 6.1 MAIN EFFECT PLOTS FOR TENSILE STRENGTH

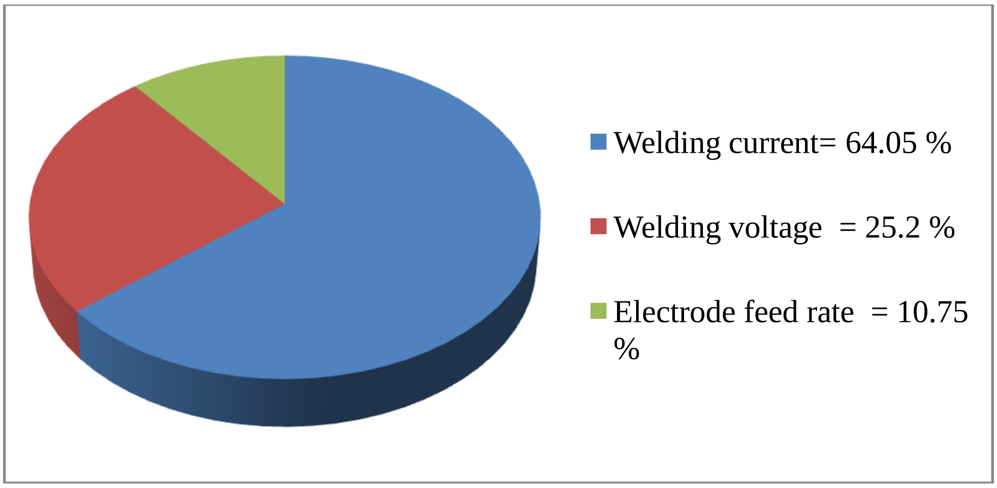
Main effect plots for tensile strength are shown in the figure 4.1. Main effect plot shows the variation of tensile strength with respect to welding current, welding voltage and electrode feed rate. X axis represents change in level of the variable and y axis represents the change in the resultant response




**Main effects plot for S/N ratio for tensile strength**

| Source | DF | Seq SS | Adj MS | F | P | Percentage Contribution |
|---|---|---|---|---|---|---|
| Weldingcurrent (Amp) | 2 | 44963 | 22482 | 14.62 | 0.064 | 64.05 % |
| Weldingvoltage (Volt) | 2 | 17588 | 8794 | 5.72 | 0.149 | 25.02% |
| Electrodefeed rate (m/min) | 2 | 2025 | 1013 | 0.66 | 0.603 | 10.75 % |
| Error | 2 | 3076 | 1538 | | | |
| Total | 8 | 67653 | | | | |
| S = 39.2187 R-Sq = 98.45 % R-Sq (adj) = 81.81 % | | | | | | |

**Analysis of Variance for Means of tensile strength**




**PIE CHART REPRESENTATION OF PERCENTAGE CONTRIBUTION OF PROCESS PARAMETERS FOR TENSILE STRENGTH**

## VII. Brinell Hardness Test

The Brinell hardness test includes indenting the test material with a diamond indenter as shown in Fig. 6, within the shape of a right pyramid with a rectangular base and a perspective of 136 degree among opposite faces subjected to a load of 1 to 100kgf.

**S/N ratio for hardness test result**

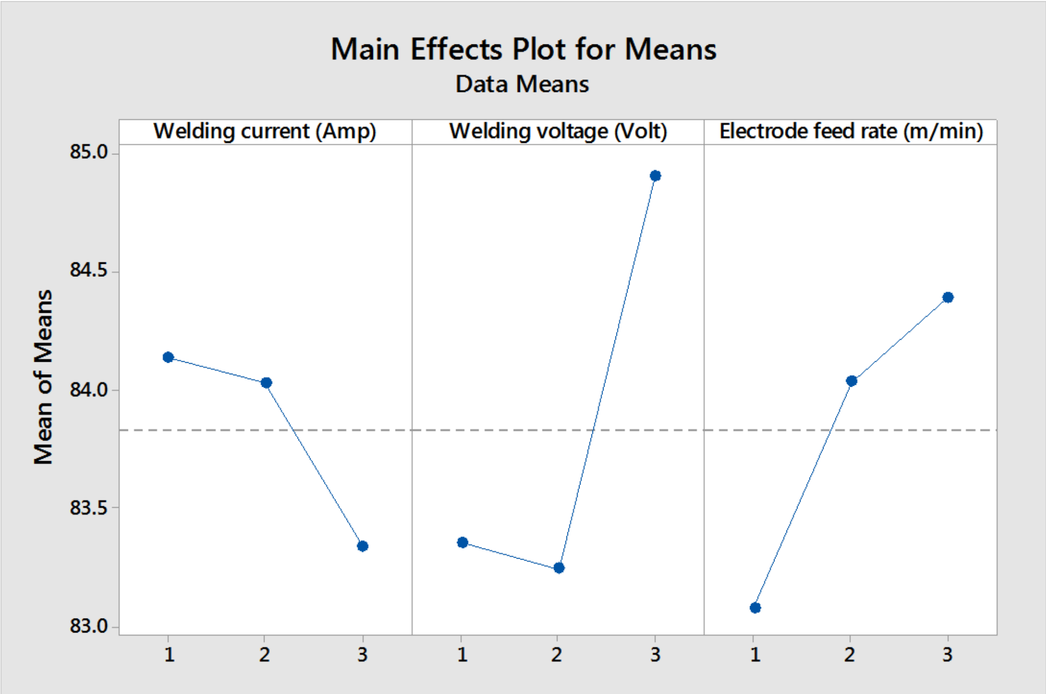
| Experiment no. | Welding current (Amp) | Welding voltage (Volt) | Electrode feed rate (m/min) | HRV | S/N ratio |
|---|---|---|---|---|---|
| 1 | 180 | 24 | 5 | 82.36 | 38.31 |
| 2 | 180 | 26 | 5.5 | 83.54 | 38.44 |
| 3 | 180 | 28 | 6 | 86.51 | 38.74 |
| 4 | 200 | 24 | 5 | 84.50 | 38.54 |
| 5 | 200 | 26 | 5.5 | 83.45 | 38.43 |
| 6 | 200 | 28 | 6 | 84.14 | 38.50 |
| 7 | 220 | 24 | 5 | 83.21 | 38.40 |
| 8 | 220 | 26 | 5.5 | 82.74 | 38.35 |
| 9 | 220 | 28 | 6 | 84.07 | 38.49 |

**Response table for S/N ratio for brinell hardness**

| Level | Welding current (Amp) | Welding voltage (Volt) | Electrode feed rate (m/min) |
|---|---|---|---|
| 1 | 84.14 | 83.36 | 83.08 |
| 2 | 84.03 | 83.24 | 84.04 |
| 3 | 83.34 | 84.91 | 84.39 |
| Delta | 0.80 | 1.66 | 1.31 |
| Rank | 3 | 1 | 2 |

## 7.1 MAIN EFFECT PLOTS FOR BRINELL HARDNESS

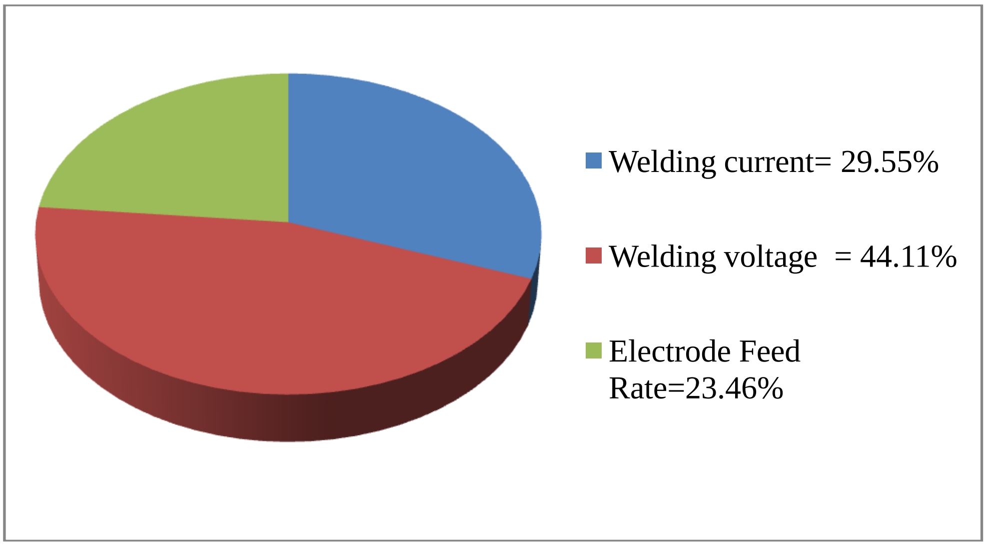
Main effect plots for Brinell hardness . Main effect plot shows the variation of Brinell hardness with respect to welding current, welding voltage and electrode feed rate. X axis represents change in level of the variable and y axis represents the change in the resultant response.




**Main effects plot for S/N ratio for brinell hardness**

| Source | DF | Adj SS | Adj MS | F | P | Percentage Contribution |
|---|---|---|---|---|---|---|
| Weldingcurrent (Amp) | 2 | 1.122 | 0.5611 | 0.42 | 0.705 | 29.55% |
| Weldingvoltage (Volt) | 2 | 5.182 | 2.5910 | 1.93 | 0.341 | 44.11% |
| Electrodefeed rate (m/min) | 2 | 2.756 | 1.3781 | 1.03 | 0.494 | 23.46% |
| Error | 2 | 2.686 | 1.3431 | | | |
| Total | 8 | 11.747 | | | | |
| S = 1.158 R-Sq = 97.12 % R-Sq (adj) = 8.53 % | | | | | | |

**Analysis of variance for means forbrinell hardness.**




**PIE CHART REPRESENTATION OF PERCENTAGE CONTRIBUTION OF PROCESS PARAMETERS FOR BRINELL HARDNESS**

## VIII. Conclusion

Taguchi's robust orthogonal array design method is suitable to analyze this problem as described in this work. The effects of electrode feed rate, welding voltage, welding current having a significant effect on the tensile strength and brinell hardness. This is consistent with the conclusions from the study of other investigators.The maximum tensile strength (669.91MPa) achieved at welding current 200 A, welding voltage 28 V, and electrode feed rate 6 m/min. This is the optimized results for achieving maximum tensile strength. The maximum hardness (86.51 HV) achieved at welding current 180 A, welding voltage 28 V and electrode feed rate 6m/min .This is optimized results for achieving maximum hardness

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