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# Optimization of Process Parameters of Manual Arc Welding of Mild Steel Using Taguchi Method

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**Abstract** This study was based on design of experiment (DOE) using Taguchi method with four welding parameters namely; welding current, (ii) welding speed, (iii) root gap and (iv) electrode angle considered for experimentation. An orthogonal array of $L_9$ experimental design was adopted and ultimate tensile strength was investigated for each experimental run. The tensile test was carried out on extracted welded and unwelded specimens using universal testing machine (UTM). Microstructures of the welded specimens were carried out and analyzed. Statistical analysis (ANOVA) and signal to noise ratio were used to study the significant effect of input parameters on ultimate tensile strength and optimized conditions for the process performance respectively. The results showed that experiment number 7 has the highest ultimate tensile strength (UTS) of 487MPa and S/N ratio of 53.74 dB. The S/N ratio of higher value indicates better characteristic of optimum MMAW process performance. The study shows that the optimum condition is $A_3B_1C_3D_2$ at welding current 100A, electrode angle of $70^0$, root gap of 3.3 mm and a welding speed of 3.6 mm/s.

***Keywords:*** *ANOVA, welding speed, current, electrode*

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## 1. Introduction

Welding process is very critical to the development of a nation because it is the hub on which modern industries revolve. Messler [1] stated that no secondary process has been and continues to be more important to the survival, comfort and advancement of mankind than welding. According to him, welding has made it possible to build our world. It is in view of this that many researchers have employed various optimization techniques to improve different welding process parameters on both semi and full automated welding processes. Although, the semi and full automatic welding processes are more productive, experience has shown that due to complexity and economic cost of the equipment and their operations, the choice of manual metal arc welding (MMAW) process is very popular in developing countries. This is so because of its several advantages such as low cost and simple operation. The MMAW process is portable and it can easily be used in places where other welding methods are not possible.

Manual metal arc welding is also known as shielded metal arc welding (SMAW), or stick welding process. It is one of the oldest and most widely used arc welding processes. The process involves the use of arc current to strike an arc between the base material and a consumable electrode rod. The electrode rod is made of a metal that is compatible with the base material being welded and it is covered with a flux. The heat generated melts a portion of the tip of the electrode, its coating and the base metal just below the arc. As the coating on the electrode melts, the flux gives off vapours that serve as a shielding gas and provide layer of slag, both of which protect the weld from atmospheric contamination. The slag formed during welding is chipped off from the weld after cooling. MMAW process can operate with both direct current (DC) or alternating current (AC) power supply depending on coating design. The process is portable, versatile, inexpensive equipment and requires little operator training. Also, the electrode produces and regulates its flux, it has lower sensitivity to wind and draft than gas shielded welding process and the process is applicable in all positions. On the hand, the process is slow and time wasting due to frequent changing of electrode and chipping of slag. Also, it is characterized with excessive spatter, arc stability and rough surface of weld bead and provides limitation deposition rates compared to other arc welding processes.

With the incorporation of automation into the arc welding process, many production companies adopted complete experimental designs and mathematical models to investigate the relevant process parameters to obtain quality weld [2]. Ajay et al., [3] stated that high quality can be achieved by optimizing various quality attributes or by selecting an optimal process environment that is efficient enough to fetch the desire requirements for quality. Taguchi method has been found to be a powerful tool to improve overall process quality by optimizing the welding process parameters in a way that variation is reduced to the barest minimum. Design of experiment (DOE) techniques had been used to carry out such optimization in the last two decades with a view to improving on the mechanical properties of weld materials. Yoon et al., [4] optimized the parameters of welding 7075-T6 aluminum alloy using Taguchi method. Among other investigators who have also worked on the optimization of welding variables using Taguchi method are Kim and Lee [5]. They used the method to suggest optimal combinations for process factors of hybrid welding methods to optimize the welding parameters of resistance spot welding process.

In this study, the application of Taguchi $L_9$ orthogonal array for the selection of manual metal arc welding process parameters of welded mild steel plates was investigated. The ultimate tensile strength and the microstructures analysis were carried out on each samples and analyzed. Signal-to-noise (S/N) ratio to determine the optimal parameters that affect the response and ANOVA analysis to determine the significant effect of the input variables on the ultimate tensile strength were both investigated.

## 2. Materials and Methods

### 2.1 Materials

The base material used for this study is mild steel (AISI C1020) of 100 x 75 x 5 mm plate. Its chemical composition analyzed by the Defence Industry Corporation of Nigeria, Kaduna is approximately 0.23% C, 0.35% Mn, 0.28% Si, 0.02% S, 0.04% P and 99.08% Fe. Mild steel was considered for this study because of its availability in the market and low cost. Mild steel electrodes of 350 mm long and 3.25 mm diameter (E6010 and E6013 steel grade 2, Oelikon) were used for the root running and weld deposits respectively.

### 2.2. Methods

#### 2.2.1. Welding Process

A mild steel plate was cut into 100 × 75 × 5 mm (length and breadth and thickness) using cut-off machine. This was followed by edge preparation and a single groove butt joint was selected for the joining process in flat position. The surfaces and the prepared edges of the samples were thoroughly cleaned with wire brush to remove any dirt or unwanted inclusion that could affect the weld. In this study, the welding process was a bit different from the normal convectional manual welding process as the electrode (electric arc) was constrained in stationary position while the workpiece moved relative to it. This help to maintain relative stable welding speed and improve the quality of the weld. A 400A capacity manual metal arc welding machine with direct current (DC) straight polarity was used for the welding operations. This is because with DC, it is easier to maintain short arc in the starting stage of welding operation. The E6010 electrodes were first applied for the root running. Thereafter, the grooves were cleaned before the E6013 electrodes were used for the weld deposits in 2 – pass. Fifty four workpieces were used for this experiment that was carried out in the Department of Mechanical Engineering workshop, Federal University of Technology Minna, Nigeria.

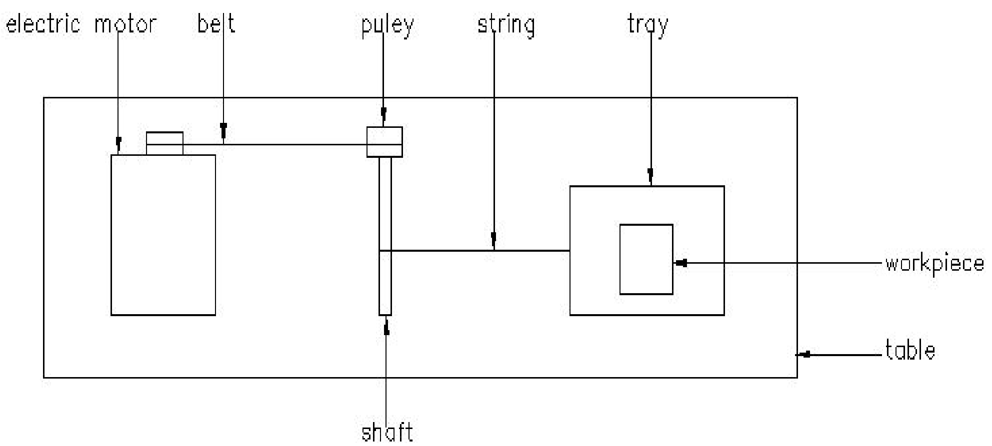


**Figure 1.** Welding Rig

#### 2.2.2. Welding Rig

The welding rig consists of a speed reduction electric motor (1hp), three different sizes of belts and corresponding pulleys, a shaft, tray, string, six ball bearings and the stand. The main feature of the rig is the variable speed of workpiece relative to a stationary electrode or electric arc. The rotation of the electric motor was converted to linear motion through the belt drive system and guided string as shown in Figure 1.

Input welding parameters selected from the structural codes of American Welding Society [6], and manuals of metal arc welding system for this study are: welding current, welding speed, root gap and electrode angle. Even though, arc length is one of the critical welding parameters, it cannot be used as welding parameter in manual metal arc welding process. An orthogonal array of $L_9$ was selected for experimentation as shown in Table 1. Based on the Taguchi orthogonal array designed, nine (9) experimental runs were conducted and each welding process was repeated three (3) times under the same conditions. These welding input parameters and their levels are shown in Table 2.

**Table 1. An orthogonal array of $L_9\,(3^4)$ matrix**

| Experimental trial | Process parameters | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

**Table 2. Process parameters and their levels**

| Input parameter | Symbol | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Welding current (A) | A | 80 | 90 | 100 |
| Electrode angle (($0^0$) | B | 70 | 75 | 80 |
| Root gap (mm) | C | 3.0 | 3.2 | 3.3 |
| Welding speed (mm/s) | D | 2.6 | 3.6 | 4.4 |

### 2.2.3. Determination of Ultimate Tensile Strength

The ultimate tensile strength of welded samples was determined using universal tensile machine (UTM) (model: TERCO$^{CE}$ MT 3037) in the Department of Mechanical Engineering laboratory, Federal University of Technology, Minna- Nigeria. The tensile test specimens were extracted from the welded base metal with hacksaw and prepared to standard size according to American Welding Society [7] and universal tensile machine manual. The weld reinforcement and backing strip were removed, flushed with the surface of the specimen by grinding and filing with a smooth file. The stress- strain curve was used to determine the force and the ultimate tensile strength (UTS) was evaluated using equations 1 and 2

$$UTS\ \ (\sigma) = \frac{F}{S} \qquad 1$$

where $F$ is the maximum loaded force, $S$ is the cross-sectional area and for rectangular test specimen used in this experiment

$$Cross\,sectional\ area\ \ (S) = wt \qquad 2$$

where $w$ is the width and $t$ is the thickness

### 2.2.4. Determination of Microstructure of Welded Joint

The micro-examination operation includes: grinding, polishing, etching and viewing. Hand hacksaw was used to cut test specimens from the welded plates as required. Grinding of each specimen was carried out using hand grinding deck of abrasive papers of different grade. Universal rotary wheels polishing machine of emery sheet type was used to carry out the polishing of the surface of each specimen to mirror-like in nature. The polished surfaces were etched with a natal (2% $HNO_3$ + 98% alcohol) regent and thereafter, the specimens were washed in running water and dried. An Optika (N- 400 POL) metallurgical microscope (bench type) was used to examine the specimens under magnification of x 400. The limitation of Optika (N-400 POL) metallurgical microscope is the none availability of micron marker to identify details in the microstructures.

## 3. Results and Discussion

The results of ultimate tensile strength as obtained using equations 1 and 2 for the experimental runs are show in Table 3. The values shown are the average of three reading recorded for each experimental trial. The signal- to- noise ratios for each ultimate tensile strength are equally included.

**Table 3. Ultimate Tensile Strength (UTS) and S/N ratio values**

| Experimental trial | UTS (Mpa) | | | | |
|---|---|---|---|---|---|
| | $L_1$ | $L_2$ | $L_3$ | Average value(Mpa) | S/N ratio (dB) |
| 1 | 435.0 | 396.0 | 415.0 | 416.0 | 52.35 |
| 2 | 420.0 | 442.0 | 426.0 | 429.0 | 52.65 |
| 3 | 429.0 | 433.0 | 438.0 | 433.0 | 52.74 |
| 4 | 467.0 | 440.0 | 442.0 | 453.0 | 53.11 |
| 5 | 471.0 | 460.0 | 442.0 | 458.0 | 53.20 |
| 6 | 453.0 | 476.0 | 455.0 | 461.0 | 53.27 |
| 7 | 489.0 | 487.0 | 484.0 | 488.0 | 53.74 |
| 8 | 471.0 | 435.0 | 438.0 | 448.0 | 53.13 |
| 9 | 435.0 | 433.0 | 449.0 | 439.0 | 52.85 |
| Unwelded sample | 429.0 | 411.0 | - | 420.0 | - |

### 3.1. Analysis of Variance (ANOVA)

The effect of each input parameters on the ultimate tensile strength was evaluated using variance analysis (ANOVA). The level of contribution of each of the input parameter to the strength of the welded point is shown in Table 4. In the analysis of variance in this study, pooling method was adopted; this is because pooling is a process of disregarding an individual's parameter's contribution and thereafter adjusting the contributions of other process parameters [8]. Pooling is employed when there is indeterminate situation and the effect of parameter in a process is insignificant. This is done to obtain new non-zero estimates of sum of square and DOF of variance respectively. Pooling process increases the percentage contribution error because the sum of square for the parameter being pooled is usually added to the sum of square error. In this study, the pooling effect is on parameter B (electrode angle) being the least effect on the welding process.

**Table 4. Analysis of Variance (ANOVA) for Ultimate Tensile Strength**

| Process parameter | Symbol | DOF | SS | V | SS' | F | P |
|---|---|---|---|---|---|---|---|
| Welding current | A | 2 | 0.38 | 0.19 | 0.36 | 19 | 31.86 |
| Electrode angle | B | | | | | pooled | |
| Root gap | C | 2 | 0.18 | 0.09 | 0.16 | 9 | 14.16 |
| Welding speed | D | 2 | 0.20 | 0.10 | 0.18 | 10 | 15.93 |
| Error | E | 2 | 0.35 | 0.01 | 0.43 | | 38.05 |
| Total | | 8 | 1.13 | | | | 100 |

## 3.2. Signal – to - noise (S/N) Ratio

The choice of the S/N ratio to be used depends on the performance quality characteristics required. In welding process, the higher the strength of the weld, the better and hence, the signal –to –noise (S/N) ratio of higher the better (HB) was used in this study as expressed in equation 3.

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum_{i-1}^{n}\frac{1}{{y_i}^2}\right) \quad 3$$

where y = responses for the given factor level combination, n = number of responses in the factor level combination and $y_i$ is the experimental results.

**Table 5. Main effect of process parameters**

| Level | Welding current A | Electrode angle B | Root gap C | Welding speed D |
|---|---|---|---|---|
| 1 | 52.58 | 53.07 | 52.92 | 52.80 |
| 2 | 53.19 | 52.99 | 52.87 | 53.22 |
| 3 | 53.24 | 52.95 | 53.22 | 52.99 |
| Max-Min | 0.66 | 0.12 | 0.35 | 0.42 |
| Rank | 1 | 4 | 3 | 2 |

Table 5 depicts the corresponding values of S/N ratios obtained from the conversion of UTS results. It was observed that experiment number 7 has the highest S/N ratio of 53.71dB, which indicates the best performance characteristic among the 9 runs of experiments conducted.

It was observed that the welding current has significant effect on the welding process while the electrode angle has the least effect. It also indicates that the combination process parameters $A_3B_1C_3D_2$ have the highest or maximum S/N ratios respectively and therefore signifies the optimum condition for the welding process.

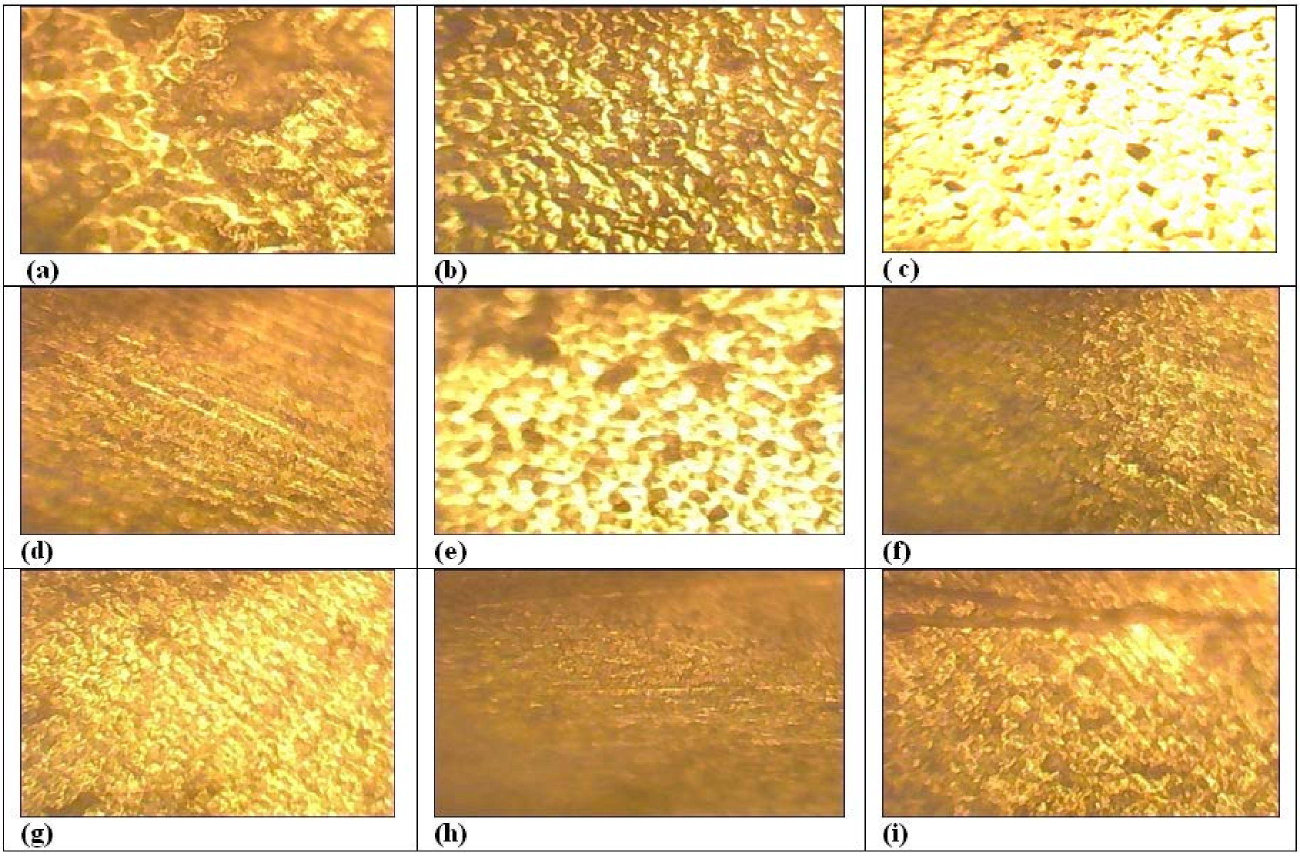


**Figure 2.** Microstructure of welded component

## 3.3. Microstructure of Welded Joint

Figure 2 (a- i) shows the microstructure of the welding joint under different welding conditions. Figure 2a shows the microstructure obtained under the condition of welding current (80 A), electrode angle (70$^{o}$), root gap (3.0 mm) and welding speed (2.6 mm/s). The grains were large and showing spheroidal globular of the photomicrograph due to low temperature and short time for nucleation. Figure 2b shows microstructure obtained under the welding condition of welding current (80 A), electrode angle ($75^0$), root gap (3.2 mm) and welding speed (3.6 mm/s). The micrograph shows deformation that produced elongated grains.

While Figure 2c shows the microstructure obtained under welding condition of welding current (80 A), electrode angle ($80^0$), root gap (3.3 mm) and welding speed (4.4 mm/s). The micrograph shows a mixture of pearlite (dark) and ferrite (light). The grains were widely spaced.

In the same vein, Figure 2d show the microstructure of the welding condition of welding current (90 A), electrode angle ($70^0$), root gap (3.2 mm) and welding speed (4.4 mm/s). The grains were cohesively arranged and fine. And Figure 2e shows the microstructure for welding condition of welding current (90 A), electrode angle ($75^0$), root gap (3.3 mm) and welding speed (2.6 mm/s). The micrograph shows partially grain-refined. Figure 2f shows the microstructure obtained under the welding condition of welding current (90 A), electrode angle ($80^0$), root gap (3.0 mm) and welding speed (3.6 mm/s). The grains were adhesively arranged and fine.

Similarly, Figure 2g shows the microstructure for welding condition of welding current (100 A), electrode angle ($70^0$), (3.3 mm) and welding speed (3.6 mm/s). The micrograph shows grain- refined, appears tiny and uniform pattern due to fast cooling rate. Figure 2h depicts the microstructure obtained under the welding condition of welding current (100 A), electrode angle ($75^0$), root gap (3.0 mm) and welding (4.4 mm/s). The grains are fine structurally. And Figure 2i shows the microstructure obtained under welding condition of welding current (100 A), electrode angle ($80^0$), root gap (3.2 mm) and welding speed (2.6 mm/s). The grains were coarse due to overheating in the weldment.

## 4. Conclusions

This study employed Taguchi method to optimize process parameters of manual metal arc welding (MMAW) process for mild steel products. From the tensile test carried out on welded samples it was observed that experiment number 7 has the highest ultimate tensile strength (UTS) and S/N ratio of 487 MPa and 53.74 dB respectively. The study indicates that the optimum condition is $A_3B_1C_3D_2$ which coincide with experiment number 7 in the orthogonal array. It was also observed that the failures of all the test specimens extracted from the welded samples did not occur at the weldment point which signifies a quality and strong weld joint. The microstructures show the various effects of the welding parameters on the weld joint.

Moreover, it was noted from results of ANOVA that the welding current, root gap and welding speed are significant parameters in the welding process while the electrode angle has least significant. Computation of the projected optimum performance of the study using S/N ratio ($Y_{opt}$) is 53.74 dB which is the same value with experiment number 7 and it serve as confirmation test. A confirmation test would have been conducted if the optimum condition was not among the experimental runs. Results from this study, indicated that Taguchi method can actually be used to optimize or improve the quality of MMAW process.

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