Survey of Welding Voltage from Welding Current and Arc Length in SMAW Process

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Abstract
The relationship between welding voltage, welding current and arc length was investigated in this study. Shielded metal arc welding (SMAW) process was used to weld API 5L X65 line pipes at welding current of 80 – 200A and arc length of 1.5 – 3.5mm. First and second order polynomial equation and Amson models were also used to study the welding voltage as a function of current and arc length. The results revealed that increase in current and arc length lead to corresponding increase in voltage. The welding voltage increased from 19.48 – 23.82V at constant arc length of 1.5mm and from 22.25 – 26.77V at 3.5mm arc length, as current increased from 80 – 200A. Voltage increase was more influenced by increase in arc length than increase in current. Welding currents between 140A and 180A and arc length between 2mm and 3mm are recommended for optimum quality welded joints. The analysis of the model performance showed that there was high correlation between the predicted and the measured welding voltage values (R^2 up to 99%). However, the predictions from the second-order polynomial model slightly edged the Amson and the first-order polynomial models. Therefore, using either of these models could be helpful in making a decision on the range of welding input parameters that can be used to optimise welding quality and productivity in the SMAW process.

Keywords: *Shielded Metal Arc Welding, Welding Voltage, Welding Current, Arc Length and Model*

1. INTRODUCTION

Welding is a process of joining or bonding of similar and dissimilar materials. The joining between materials often occurs via pressure or heat fusion. Welding and related thermal processes utilize compressed gas and/or electric current to provide a concentrated heat source which melts or burns based materials (Wilhelmsen, 2017). Welding is favoured over other joining process like riveting, nut bolting and other joining techniques (Shivakumara *et al*., 2013). Welding has applications in almost all mechanical and structural industries for the fabrications of automobile, transmission mast, aircraft, ship, electronic equipment, machinery, and home applications (Kachhoriya *et al*., 2012; Singh, 2018).

For a particular task or application, a welding process can be optimized to give better results. Notwithstanding this, sustaining the quality of welding is still a challenging task due to many variables at play, such as variation in raw material (composition, thickness and internal defects), variation in surface condition (presence of dust, grease, oil and others), operator skills and gap between workpiece (Shivakumara *et al.*, 2013). Welding variables such as current, voltage or arc length can be adjusted in other to produce good welded joints (Sathya & Jaleel, 2010). The control variables can be adjusted directly or indirectly from the welding machine. So, every welding process is intended to obtaining welded joints that produce efficient weld bead geometry and mechanical properties with minimum distortion, thereby improving the weld quality (Ravikumar & Vijian, 2014; Singh & Sharma, 2016). Therefore, it is very important to select the range of welding process parameters that will give good weld bead geometry and weld properties with no defect. One of the ways of making good decision for the choice of input variable section is through experimental formulation involving the input variables.

This investigation is focused on the Shielded Metal Arc Welding (SMAW) process, as it is the welding process adopted by the company in which this case study is chosen. The Shielded Metal Arc Welding process is a low cost, flexible, portable and versatile welding process mostly used in the small scale industries (Shivakumara *et al.*, 2013; Patel *et al.*, 2017**)**. It is also called stick welding. SMAW is a manual welding process whereby an arc is generated between a flux-covered consumable electrode and a workpiece (base metal). It uses the decomposed flux covering to generate a shielding gas and then, provides fluxing elements that protects the molten weld metal droplets and the weld pool (Ravikumar & Vijian, 2014; Patel *et al.*, 2017).
Like other arc welding process, SMAW input parameters also affect welding quality and productivity. Several studies have used various mathematical models to studies welding variables (Ghetiya & Pandya, 2014; Tiwari *et al.*, 2018; Desai *et al.*, 2019; Moghaddam & Kolahan, 2020). Hence, this study investigated the relationship between welding voltage, welding current and arc length such that the welding quality and productivity can be improved. Values recorded from the experiment were used to also study the relationship between welding voltage, welding current and arc length using mathematical models.

2. RESULTS AND DISCUSSION

2.1 Influence of Welding Current and Arc Length on the Voltage

The resultant effect of varying the current at a specified arc length on the voltage has been studied as shown in Figure 1. This investigation was carried out to ascertain whether changes in welding current at various arc lengths can significantly affect the weld quality on API 5L X65 line pipes. A range of current, 80 to 200A was independently adjusted and kept constant while the arc length of 1.5mm to 3.5mm was varied at every welding current adjusted via the current control button on the welding machine.

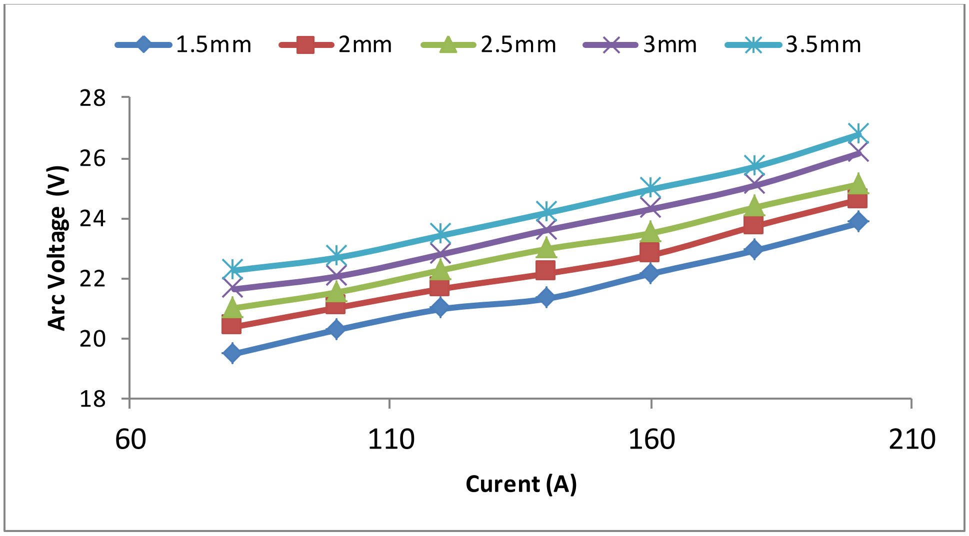

Figure 1: Effect Arc Current on the Arc Voltage at Varying Arc Length

Figure 1 shows the profiles of voltage versus current applied for the welding of X65 pipeline at arc length of 1.5 – 3.5mm. From the investigation, it was observed that increase in welding current increased the voltage at constant arc length. Accordingly, at 1.5mm arc length, the value of voltage increased from 19.48 to 23.82V as the current increased from 80 – 200A, while at 3.5mm arc length and same range of current, the voltage increased from 22.25 to 26.77V. This implied that the voltage increased by 22.28% and 20.31% at 1.5mm and 3.5mm arc length respectively. Similarly, for a given current, the welding voltage increased with increase in arc length. For instance, at 80A constant current, the voltage ranged from 19.48 – 22.25V, while at 200A, it ranged from 22.82 – 26.77V when arc length was increased from 1.5mm – 3.5mm, which represents 14.22% and 17.31% increase in voltage at 80A and 200A respectively. The analysis, as indicated by the percentage increase, shows that the voltage increase was most influenced by increase in arc length than increase in welding current. The result is in agreement with previously reported studies (Weglowski *et al*., 2008; Ikpe *et al*., 2017).

Observation from the welded joint showed that at 1.5mm arc length, there was increase in the number of spatters on the work-piece, and the width of the welding bead also reduced. That is, increasing the arc length will equally result to increase in the bead width. It was also noticed that at lower arc length at constant welding current, the number of spatters on the pipe surface increased, which reduced as the arc length was increased. The smoothness of the welding beads also increased with increasing arc length, especially at higher welding currents between 140A and 180A. Alfaro and Franco (2010) also observed changes in the welding bead width while using the Gas Tungsten Arc Welding (GTAW) method, which they attributed to involuntary change in some of the welding parameters. According to Ikpe *et al.* (2017), balancing the welding current and voltage will result in little or no spatter on the base metal and the weldment, and the increase in number of spatters produces a rough surface on the base metal, which was caused by excessive or low current input. When the welding current is increased, the arc penetration will equally increase, but very high welding current at other constant welding parameters can influence the depth of fusion or penetration such that the weldment will melt through the metal being welded, and this could also result in wastage of electrodes and undercuts (Weglowski *et al*., 2008).

2.2 Prediction of Welding Voltage

The usefulness of mathematical model to the study of engineering and scientific processes is enormous, as it saves cost and time, as well as reduction in man-hour loss. The constant coefficients in the models were determined using regression analysis, which was implemented in Microsoft Excel Tool Pack.

The coefficients in the first-order polynomial model stated in equation (1) were obtained using multiple regression analysis. Thus, the constant coefficients were obtained as: $\beta_0 = 14.5734$, $\beta_1 = 1.3527$ and $\beta_2 = 0.0357$, which upon substitution, the first order polynomial model for prediction of welding voltage was expressed as $V = 14.5734 + 1.3527 l_a + 0.0357 I$. Now, inserting the corresponding values of arc length (l_a) and current (I), the voltage was predicted for any given welding current and arc length. Some authors have equally used the first order polynomial (or linear) model to predict welding parameters (Mohd *et al*., 2014; Moghaddam & Kolahan, 2020).

Again, the coefficients in the second order polynomial model stated in equation (2) were obtained using multiple the regression analysis. Here, the constant coefficients were obtained as: $\beta_0 = 16.1226$, $\beta_1 = 1.4717$, $\beta_2 = 0.01321$, $\beta_3 = 0.0581$, $\beta_4 = 6.04 \times 10^{-5}$ and $\beta_5 = 7.9 \times 10^{-6}$. Upon substitution of the constant coefficients, the second order polynomial model for prediction of welding voltage was obtained as:

$$\begin{aligned} V &= 16.1226 + 1.4717 l_a + 0.01321 I - 0.0581 l_a^2 \\ &+ 6.04 \times 10^{-5} I^2 + 7.9 \times 10^{-6} l_a * I. \end{aligned}$$

Now, by inserting the corresponding values of the arc length (l_a) and current (I) in this second order polynomial model, the voltage was predicted for any given welding current and arc length. The degree of predictability of the second order polynomial model is in line with reported studies for the prediction of welding parameters (Ghetiya & Pandya, 2014; Tiwari *et al*., 2018; Moghaddam & Kolahan, 2020).

Like first and second order polynomial, the constant coefficients in Amson model defined in equation (3) were obtained from regression analysis as follows: $\beta_0 = 12.1074$, $\beta_1 = 1.3527$, $\beta_2 = 0.0448$ and $\beta_3 = 152.2760$. Again, by substituting the value of the constant coefficients, the Amson model was obtained as $V = 12.1074 + 1.3527 l_a + 0.0448 I - \frac{152.276}{I}$. Again, by inserting the corresponding values of the arc length (l_a) and current (I) in the Amson model, the corresponding voltage was predicted. From the predicted welding voltage, it can be concluded that the Amson model was effective, and this also agreed with other previous studies utilizing this model (Cook, 2014; Bjorgvinsson *et al*., 1993; Wang *et al*., 2019).

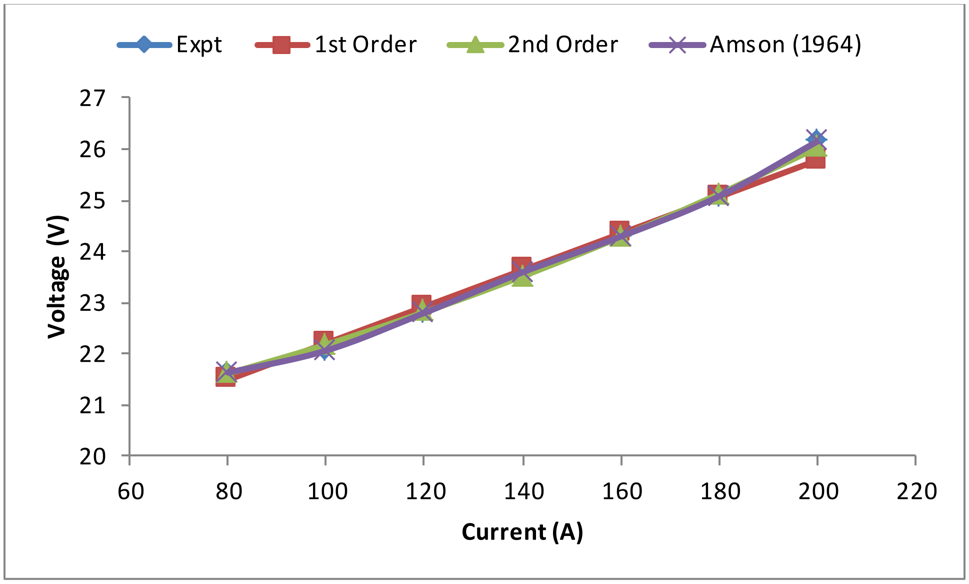

Figure 2: Comparison of Voltage Predictive Models at Varying Current

Having obtained all the constant coefficients in the models, the constants were substituted into the model equations to predict the welding voltage. Thus, the degree of voltage prediction was compared at 3mm constant arc length and welding current of 80A to 200A. This comparison is shown in Figure 2. The analysis showed that all the models: first and second order polynomial model and Amson model have high degree of voltage prediction at the specified conditions, with over 99% correlation with the experimental values. However, based on the values of correlation coefficients, the second order polynomial model ($R^2 = 0.9974$) has a slight edge over the model developed by Amson ($R^2 = 0.954$) and the first order polynomial model ($R^2 = 0.9921$). The level of performance of the second order polynomial model over other models has also been reported by Moghaddam and Kolahan (2020), while comparing the predictability of weld penetration depth and bead width by the linear, logarithmic and second order polynomial models.

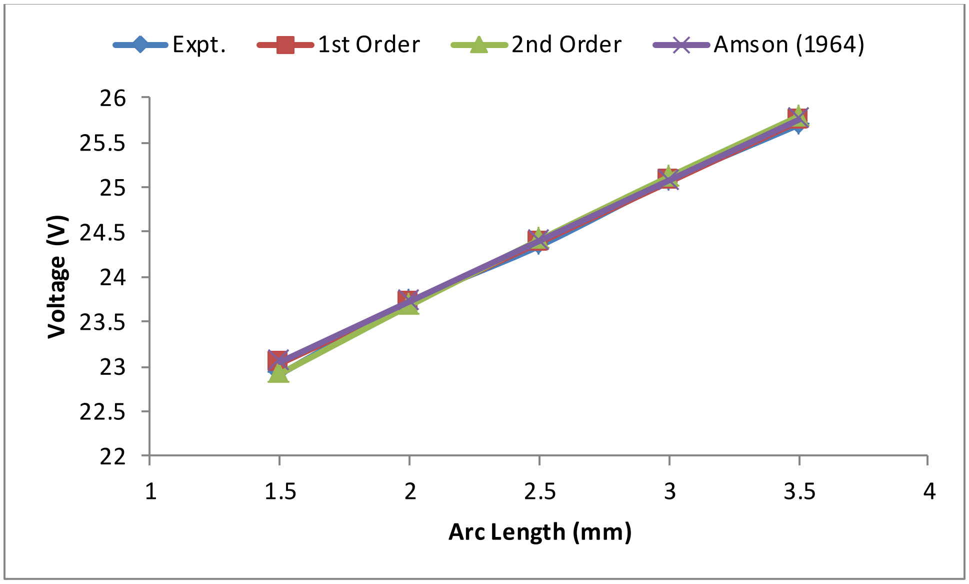

Figure 3: Comparison of Voltage Predictive Models at Varying Arc Length

Again, the values of voltage predicted by the three models were also compared at constant current of 180A, while varying the arc length from 1.5mm to 3.5mm as shown in Figure 3. The analysis, again, showed that the models have high degree of voltage prediction at the specified conditions, which correlated well with the experimental values. Therefore, the study showed that either of first and second order polynomial models, or the Amson model can be used to predict welding voltage if the welding current and arc length are given.

3. CONCLUSION

The relationship between welding voltage, welding current and arc length in shielded metal arc welding (SMAW) process has been studied using API 5L X65 line pipes. The study showed that welding voltage was significantly influenced by welding current and arc length. It was also established that lower current and shorter arc length produced lower welding voltage, while higher welding current and longer arc length produced higher welding voltage. The predicted welding voltage by the first and second order polynomial model and the Amson model, agreed with the experimental values, with correlation coefficient up to 99%. However, the second-order polynomial model fitted the experimental data better than Amson and the first-order polynomial models. Therefore, either of these models can be used to optimise welding input parameters in SMAW process such that good and acceptable welding quality and productivity can be obtained, especially for API 5L X65 line pipes.

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