Study on the Effect of SMAW Parameters on the Tensile Strength of Low Carbon Steel

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ABSTRACT

In order to understand the effect of shield metal arc welding (SMAW) process parameters on the mechanical characteristics of low carbon steel, this work tries to, statistically, investigate the influence of some welding parameters namely the welding current and electrode type, on the tensile strength of Mild Steel. Specimens having dimensions of 200 mm× 50 mm× 4 mm, which were welded by shield metal arc welding (SMAW) with single V-Butt joint, were used for the burps of study. Three different types of electrodes, E6010, E6013 and E7018 and three levels of welding current 90A, 110A and 130A were set to carry out the experiment. The Design Expert® software was utilized to conduct the statistical analysis using the ANOVA test on the tensile strength of the welded joint area. The results showed that the selected welding variables had significant effects on the tensile strength of the specimens. According to the results, the strength of the joint area increased with increasing the welding current. The optimum tensile strength produced was 169.8 MPa when using welding electrode E7018 at 130A, while the lowest value was 80.9 MPa obtained when using electrode E6010 at current of 90A.

Keywords:

SMAW, Tensile Strength, Design Expert, welding current, electrode type.

1. Introduction.

The rapid advancement in technology has penetrated the different industrial fields that apply the use of welding processes for various jobs in steel construction, especially mild carbon steel. [1]. Welding is commonly performed on ferrous and nonferrous steel materials.[2]

Welding is a dominant metal connecting technique. It is considered as one of the most important means of fabrication available to industry welding has been widely applied in the construction of ship, bridges, steel frame, pressure vessel, rail, pipeline and so forth

Joining processes, in general, are considered the most important techniques to evaluate steel components parts. [3]

Welding is a joining process in which heat, pressure or a combination of both, is applied to join two or more adjacent parts to become as a single object [4].The Deutche Industrie Normen (DIN) defined the welding as, “a metallurgical bond on metal joints or combination that carried out in melting or liquid conditions". [5]

Shielded Metal arc Welding (SMAW) is one of the most commonly used welding process. It has been widely applied in the construction industries and in repairing, as it induces more flexibility and portability.[6]

SMAW is also known as “stick welding”, as it uses a consumable electrode that is coated with a layer of flux which provides a protection to the electrode and shields the joint from the atmospheric contamination during the welding process.[7]
One of the most widely used materials in the disciplines of Mechanical Engineering is steel. It has been contributing in the manufacture of vehicle parts, truck bed floors, automobile doors, domestic appliances and in many other applications. [8]. Because of its high machinability, steel is considered very versatile material; it can be effectively formed into many different shapes by processes such as rolling and forging, furthermore, steel can be treated to develop a wide range of mechanical properties which enable it to be used for a wide range of applications [9].
With accordance to the percentage of carbon content, steel is categorized into three different levels; low carbon steel, in which carbon represents less than 0.3%, medium carbon steel, where carbon content of 0.0.3% to 0.69% and high carbon steel that have carbon content of 0.7% to 2.2%.[10].

2. Experimental Work

The methodology and work plan used in executing the research work and the challenges encountered. This part describes
this work is an experimental research to examine the strength of the welded joint, therefore, three different grades of welding electrode E6010, E6013 and E7018 were used with three different levels of welding current 90,110 and 130 Amperes. The experiment was conducted to find out the influence of individual treatment on others under control conditions namely tensile strength of the welded joint and the interaction effect between these factors.
The material utilized in this research work was low carbon steel with the dimension of (1000 mm * 200 mm *4 mm) obtained from local workshops in Benghazi. The chemical composition of the basic material is presented in table 1.

Table (1) The chemical composition of the base material

Element	**Fe%**	**Mn%**	**Pb%**	**C%**
Content	99.095	0.782	0.091	0.032

2.1 Sample Preparation:

Sheet of low carbon steel metal with 4 mm thickness was cut to 36 equal pieces with dimensions of 200x50 mm /each using CNC plasma cutting machine.
The specimens were further cut into two equal pairs as preparation for welding to form 100*50 mm, then fay surfaces were cleaned using abrasive sand paper to eliminate all possible coatings, corrosion or rust that may have accumulated on the material, furthermore, the specimens were chamfered to produce 30° half groove angle on one side with the aid of a milling machine to have smooth and uniform surfaces.

2.2 Welding procedure.

The welding was carried out using shield metal arc welding process with 26 specimens, the plates properly clamped to avoid misalignment during welding process. Before welding, surface of each specimens was grinded and cleaned using acetone in order to eliminate surface contamination, welding was applied to fuse the two flat plates together with an included angle of 60. Welding of butt joint samples in horizontal position was performed continuously. Single-pass; autogenous, bead-on-plate SMAW welds were made along the center line of the specimens a shown in figure 1.

Figure (1) specimens welded using SMAW process

2.2 Tensile Testing

Tensile Test was conducted on the welded samples having dimensions of 200 × 50 × 4 mm using a hydraulic extensometer. The tensile testing was done in accordance to ASTM A370-14 standard. The standard shape is obtained using CNC plasma cutting machine.

Statistical Analysis of the response

Statistical analysis using the ANOVA test was performed on the results obtained from the tensile test. ANOVA is a powerful technique for analyzing experimental data involving quantitative measurements. It is useful in factorial experiments where several independent sources of variation may be present. **(2 factors-3 levels) factorial design experiment** ANOVA test (F-test) was used to evaluate the single and combined effects of the current and welding electrode on the tensile strength of the welded steel, Table 5 shows the coded design of the input variable of shield metal arc welding.

Table 2. the coded levels of input variables of SMAW process.

Code Variables	**Current**	**Electrode type**
-1	90	E7018
0	110	E6013
1	130	E6010

Twenty-six specimens were prepared to generate experimental data according to the randomized design matrix of statistical design of experiment (DOE) which comprised of two input variables. Design Expert 9® software was utilized to test the significance of the individual coefficients and ANOVA for the developed model illustrated in table 6 with response variable, namely; (Tensile Strength).

Table 3. designed matrix of ANOVA and observed values of the tensile strength.

Std	Run	Factor 1 A: Electrode Type	Factor 2 B: Current	Response Tensile Strength MPa
2	1	0	-1	**97.2**
9	2	1	1	**135**
5	3	0	0	**106.7**

`11	4	0	0	**106.7**
10	5	0	0	**106.6**
1	6	-1	-1	**106**
6	7	1	0	**94.1**
7	8	-1	1	**169.8***
12	9	0	0	**106.8**
4	10	-1	0	**129.8**
13	11	0	0	**106.7**
3	12	1	-1	**80.9 ***
8	13	0	1	**144.2**

Since the material used in this research work (low carbon steel) is commercial at the workshop industries in Benghazi city, therefore, the tensile test was conducted on the specimen before welding to measure the tensile strength as shown in figure 2 which found to be on average of 200 MPa, which indicate that, the tensile strength of the specimen decreased after welding for all measured parameters, indicating that the examined welding parameters had an effect on the measured mechanical properties of the base metal.

Figure (2) low carbon Steel specimen tested without welding.

Table 4 ANOVE results of the tensile strength for response surface quadratic model.

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value Prob > F**	
Model	5816.09	5	1163.22	109.34	<0.0001	**Significant**
A-Electrode	1249.93	1	1249.93	117.49	<0.0001	**Significant**
B-Current	4040.41	1	4040.41	379.77	<0.0001	**Significant**
AB	0.12	1	0.12	0.012	0.9176	
A^2	19.47	1	19.47	1.83	0.2182	
B^2	365.59	1	365.59	34.36	0.0006	**Significant**

The Model F-value of 109.34 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case the type of the electrode (A) and the current (B, B^2) are significant model terms, which means they have a significant effect on the mechanical properties (presented by tensile strength of the welding metal) of the welded joint of steel using shield metal arc welding process. Values greater than 0.1000 indicate the model terms are not significant such as AB which means there is no interaction between the welding current and welding electrode.

Goodness of fit measures

The statistics of the tensile strength model shown in table 5 was calculated using the computer software design expert 9®.

Table 5 goodness of fit measures results of the tensile strength for response surface quadratic model

statistics	Tensile strength model
Mean	113.98
Standard deviation	3.26
C.V %	2.86
R- squared	0.98
Adj R-squared	0.97
Prediction R-squared	0.88

Standard deviation: root MSE square root of the residual mean square. It is the standard deviation associated with experimental error.

Mean: overall average of all response data.

C.V: coefficient of variation, the standard deviation expressed as a percentage of the mean. Calculated by dividing the standard deviation by the mean and multiplying by 100.

Multiple coefficient of determination (R^2): is a useful measure of how much is the variability in the observed response values can be explained by the selected experimental variables. The R^2 value is always between 0 and 1. The closer the R^2 value to 1, the stronger the model and the better it predicts the response.[11]

For instance, the coefficient of determination (R^2) of the tensile strength model was 0.98 this means that 98% the variation of the tensile strength was attributed to the selected process variables and the developed regression model is capable of accurate prediction of the tensile strength

Adjusted R-squared:

A measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. If there are many terms in the model and the sample size is not very large, the Adjusted R^2 may be noticeably smaller than the R^2.[11]

the Adjusted R^2 for the tensile strength model was 0.97 which is very close to the R^2 value 0.98. this is indicating that the sample size and terms of the model are satisfactory.

prediction R-squared:

A measure of the amount of variation in new data explained by the model.[11] The value of prediction R-squared of the tensile strength model was 0.88, which means that the full model would be expected to explain 88 % of the variability in new data.

Since, there are many insignificant model terms (not counting those required to support hierarchy), and the difference between the value of prediction R-squared and the value of adjusted R-squared exceeded 0.2, therefore, reducing the model by excluding insignificant factors may improve the model. hence, AB and A^2 excluded from the mode and table 6 summarized the analysis of variance of reduced model.

Table 6 ANOVE results of the tensile strength for reduced response surface quadratic model.

Source	**Sum of Squares**	**df**	**Mean Square**	**F-Value**	**p-value**	
					Prob > F	
Model	5796.50	3	1932.17	184.86	<0.0001	**significant**
A-Electrode	1249.93	1	1249.93	119.59	<0.0001	**significant**

B-Current	4040.41	1	4040.41	386.57	<0.0001	**significant**
B^2	506.15	1	506.15	48.43	<0.0001	**significant**

The Model F-value improved after reducing the insignificant factors and become 184.86 rather than 109.34. In the case of model terms (A, B, $B^{\wedge 2}$) you can see that F-values higher than before reducing the insignificant factors specially B^2. The table 4.6 summarized the goodness of fit measures after reducing the insignificant factors.

Table 7 goodness of fit measures results of the tensile strength for reduced response surface quadratic model.

Statistics	Tensile strength model
Mean	113.98
Standard deviation	3.23
C.V %	2.84
R- squared	0.98
Adj R-squared	0.97
Prediction R-squared	0.96

"Pred R-Squared" of 0.9617 is in reasonable agreement with the "Adj R-Squared" of 0.9787; i.e. the difference is less than 0.2.

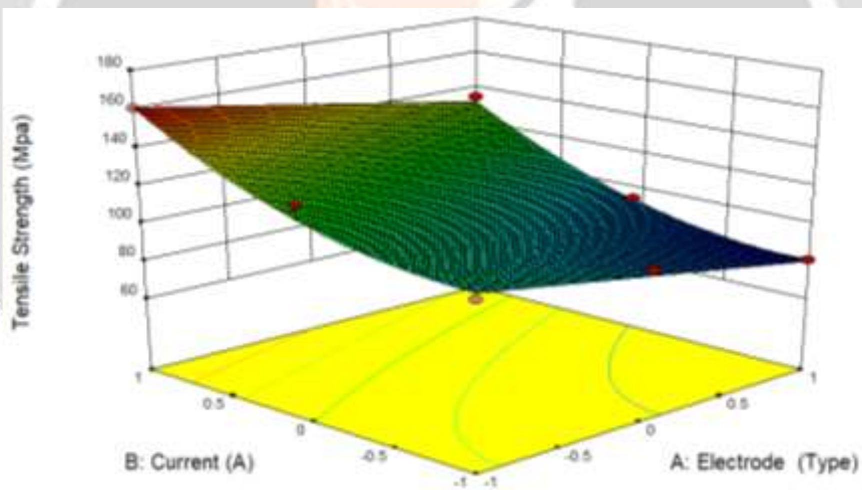

Figure (3) 3-D Response Surfaces Showing Interaction Effects of Welding Current & electrode type on Tensile Strength.

Figure 3 shows relationship between tensile strength and welding current as well as the relationship between the tensile strength and welding electrode type. It seems that relationship between the current and tensile strength of the welded joint is linear, as the current increases the tensile strength increases, furthermore, All the specimens broke in the weld region, the highest tensile strength recorded at welding electrode E7018 at each level of the current (130 A, 110 A and 90A) besides, the lowest value of tensile strength recorded at welding electrode E6010 at each level of the current the highest value of the tensile strength achieved at 169.8 MPa and current 130 A while, the lowest value achieved at welding electrode E6010 and current 90 A and its found to be 80.4 MPa.

3. CONCLUSION

The effect of varied welding parameters was examined and discussed in order to predict the service behavior (performance) of welded low carbon steel samples using shield metal arc welding. The results have shown that the selected welding parameters have significant effect on the mechanical properties of the welded samples. The strength of material before the welding process was 200 MPa and after applying the welding process decreased and varied from 80.9 MPa to 169.8 MPa. **The tensile test shows that:**

- The type of the electrode and the current have significant effect on the tensile strength of the joint welded metal according to ANOVE results of the tensile strength for response surface quadratic model, also we found that as the current increased the tensile strength increased, furthermore, changing the electrode type affecting the strength of the welded joint material.
- The maximum value of tensile strength recorded at (E7018 – 130 A), the minimum value recorded at (E6010 – 90 A).

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