An Experimental Study on the Effect of MIG Welding Parameters on Mechanical Properties of Mild Carbon Steel

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Abstract: ***This work investigates the influence of welding parameters on the impact strength of welded Mild Steel joint, providing valuable insights for the manufacturing and construction industries. The specimens having dimensions of 55 mm× 10 mm× 10 mm were welded by metal inert gas welding (MIG) for single V - Butt joint. The selected levels for welding current are 240 A, 250 A, 260 A; while the levels of wire feed rate 2 m/min, 3 m/min and 5 m/min. Statistical analysis of the experimental results show that welding current, wire feed rate and their interaction have significant effect on the toughness of the welded joint. The optimal set of process parameters for optimal toughness. (299 joules) found to be 240 welding current and wire feed rate of 3 m/min.***

Keywords: MIG, Mild Carbon Steel, impact strength, welding current, wire feed rate

1. Introduction

One important engineering material with many practical applications in every aspect of life is Steel It has been applied in many areas such as vehicle parts, truck bed floors, automobile doors, domestic appliances etc. [1]. Its favorable properties have made it the first choice among the goods. It is capable of presenting economically a very wide range of mechanical and other properties [2].

According to the percentage of carbon content, steel could be classified into low carbon steel, medium carbon steel and high carbon steel. In low carbon steel, carbon content ranges from 0.15% to 0.45%, while in medium carbon steel carbon content lies between 0.45% to 0.8% and high carbon steel have carbon content of 0.8% to 1.5%. Dead or mild steel have carbon content that is below 0.15% [3]. Low carbon steel imposes properties similar to iron. As the carbon content increases, the hardness consequently increases, the metal becomes harder and stronger but less ductile and more difficult to be weld [3].

Carbon steels have been utilized in different applications relevant to some industries such as marine industry, construction and automotive industry, chemical and petroleum industry etc. [4].

One of the main factors to evaluate the quality of steel component parts is from the joint. One of famous jointing technique is by welding. Welding is one of the major fabrication techniques available to industry [5]. Mikell P. Groover defined welding as “a permanent process for connecting two or more pieces of metal together localized coalescence resulting from a desirable combination of temperature, pressure and metallurgical condition” [6]. Many products could not be fabricated without welding such as guided missile, nuclear plants, jet aircraft, transportation vehicle and literally thousands of others [6]. Welding of steel is not always easy, although, many problems that inherent to welding can be overcome by appropriate setting of welding parameters for a given task to provide a good weld quality [7].

The major welding parameters that influence the change in mechanical properties of the welded material are current (effecting the heat input), voltage usage, polarity, welding filler type, welding filler size, arc length, electrode angle, arc travel speed and welding technique [8]. Gas Metal Arc Welding (GMAW) process is leading in the development in arc welding process which is higher productivity and good in quality. In this process both the arc and the molten weld pool are shielded from the atmosphere by a stream of gas. The arc may be produced between a continuously feed wire and the work [9].

In this study, the effects of different parameters on welding strength measurements of mild steel with 10 mm thickness of base metal by using metal inert gas arc welding (MIG) will be investigated. The selected factors in this work are welding current, with three levels 240, 250 and 260 A and wire feed rate 3, 4 and 5 m/sec. The impact strength, as a response, will be measured for each specimen after the welding process. The mild carbon steel used in Benghazi local shops was chosen as the work pieces. A design of experiment technique namely analysis of variance

(ANOVA) is utilized to statistically evaluate the effect of the selected factors on the impact strength of the welded joint area.

Experimental Work &Methodology

The material used in this work was cut from a plate of commercial mild carbon steel obtained from local workshops in College of Mechanical Engineering Technology – Benghazi for all necessary processing and testing. The plate was cut into smaller pieces with dimensions of 50 mm for width and length of 100 mm. After cleaning the specimens from the impurities and dirt. They were grooved to have a single V – shape with an angle of 45˚ using milling machine, then, each was cut into two pairs as a preparation to the welding process. The welding processes were implemented according to the randomized design obtained from Design Expert software.

Impact Testing

The Charpy impact test, also known as the Charpy V - notch test, is a standardized high strain - rate test which determines the amount of energy absorbed which can be used to measure the toughness of the material was conducted on the welded steel. The specimens were cut into the standard specimen size for Charpy impact testing which is 10 mm × 10 mm × 55 mm. The impact strength of Three specimens for each thickness without welding was measured to be used as a reference.

2. Data Presentation and Analyses

The impact strength test was conducted on the welded specimens and the result are shown in Table 1.

Table 1: The impact strength results

Std	Current (A)	wire feed rate (m/min)	Response impact Strength (joule)
1	240	3	299
2	240	5	280
3	260	5	56
4	260	3	33
5	250	5	259
6	250	5	222
7	240	5	230
8	260	3	34
9	250	3	62
10	250	3	54
11	260	4	291
12	240	3	299
13	250	4	166
14	240	4	162

Statistical Analysis of the response

Statistical analysis using the ANOVA test was performed on the results obtained from Charpy Impact 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 ofthe current and wire feed rate on the impact strength of the steel, Table2 shows the coded design of the input variable of metal inert gas welding.

Table 2: The coded of the input variables of MIG process

Code Variables	Current (A)	Wire feed rate (m/sec)
- 1	240	3
0	250	4
1	260	5

The **F** test was used to examine the amount of variation within each of the samples relative to the amount of variation between the samples. When the F - test is applied to the ratio of Mean Square (**MS**) of columns to MS of residual, it indicates whether a significant difference exists between the columns (or various levels of a factor). (27) 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, namely; current (**240 A, 250 A, and 260 A**), and the wire feed rate (**3 m/min, 4 m/min, & 5 m/min**) to investigate which factor is significantly affect the quality characteristics. Design Expert 9® software was utilized to test the significance of the individual coefficients and ANOVA for the developed model illustrated in table3 with response variable, namely; (Impact Strength).

Table 3: Designed matrix of ANOVA and observed values of the Impact Strength

Std	Factor 1 A: Current	Factor 2 B: wire feed rate (m/min)	Response impact Strength joule
1	-1	-1	299
2	-1	1	280
3	1	1	56
4	1	-1	33
5	0	1	259
6	0	1	222
7	-1	1	230
8	1	-1	34
9	0	-1	62
10	0	-1	54
11	1	0	291
12	-1	-1	299
13	0	0	166
14	-1	0	162

Table 4: ANOVE results of the impact strength for response surface factorial model.

Source	Sum of Squares	df	Mean Square	F - value	p – value Prob > F	
Model	14740	8	18427.67	46.84	0.0003	**Significant**
A - Current	50233.09	2	25116.55	63.84	0.0003	**Significant**
B – Wire Feed	16992.59	2	8496.3	21.6	0.0035	**Significant**
AB	76266.61	4	19066.65	48.47	0.0003	**Significant**
Pure Error	1967	5	393.4			

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The Model F - value of 46.84 implies the model is significant. There is only a 0.03% 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 current (A), the wire feed rate (B) and the interaction between them (AB) are significant model terms as s which means they have a significant effect on the mechanical properties as illustrated in table 4 (presented by impact strength of the welding metal) of the welded joint of steel using metal inert gas welding process.

Goodness of fit measures

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

Table 5: Goodness of fit measures results of the impact strength for response surface factorial model

Statistics	Impact strength model
Mean	19.83
Standard deviation	174.79
C. V %	11.35
R - squared	0.9868
Adj R - squared	0.9658
Prediction R - squared	16.695

As shown in table 5, the coefficient of determination (R^2) of the impact strength model was 0.9868 this means that 98.68% the variation of the impact strength was attributed to the selected process variables and the developed regression model is capable accurate prediction of the impact strength. Also, theAdjusted R^2 for the impact strength model was 0.9658 which is very close to the R^2 value 0.9868, this indicates that the sample size and terms of the model are satisfactory. Furthermore, “Adeq Precision” which measures the signal to noise ratio in this design was 16.695 which indicates an adequate signal.

- **Final Equation in Terms of Coded Factors:**

Table 6: Final Equation in Terms of Coded Factors

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High
Intercept	173.44	1	5.62	159.00	187.89
A [1]	65.22	1	7.79	45.19	85.25
A [2]	- 18.61	1	7.79	- 38.64	1.42
B [1]	- 43.28	1	7.31	- 62.07	- 24.49
B [2]	32.89	1	8.68	10.59	55.19
A [1]B [1]	103.61	1	10.22	77.34	129.88
A [2]B [1]	- 53.56	1	10.22	- 79.82	- 27.29
A [1]B [2]	- 109.56	1	12.17	- 140.84	- 78.27
A [2]B [2]	- 21.72	1	12.17	- 53.01	9.56

Toughness=+173.44+65.22A [1] - 18.61* A [2] - 43.28* B [1]+32.89* B [2]+103.61* A [1]B [1] - 53.56* A [2]B [1] - 109.56* A [1]B [2] - 21.72* A [2]B [2]

The equation in terms of coded factors can be used to make predictions about the response forgiven levels of each factor. By default, the high levels of the factors are coded as +1 and thelow levels of the factors are coded as - 1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Final Equation in Terms of Actual Factors:

Current: 240 - Wire Feed: 3

Toughness = 299 joule

Model validation

Several statistical analysis techniques were used in order to check the validity of fitted models using analysis of variance.

1) Scatter plots

The validity of model can be judged from the scatter plotshown in figure 1, it helps in detecting a value and/or group of values that are not easily predicted by the model. [10] The scatter plots indicate that, the predicted values of impact strength model are in good agreement with the experimental values.

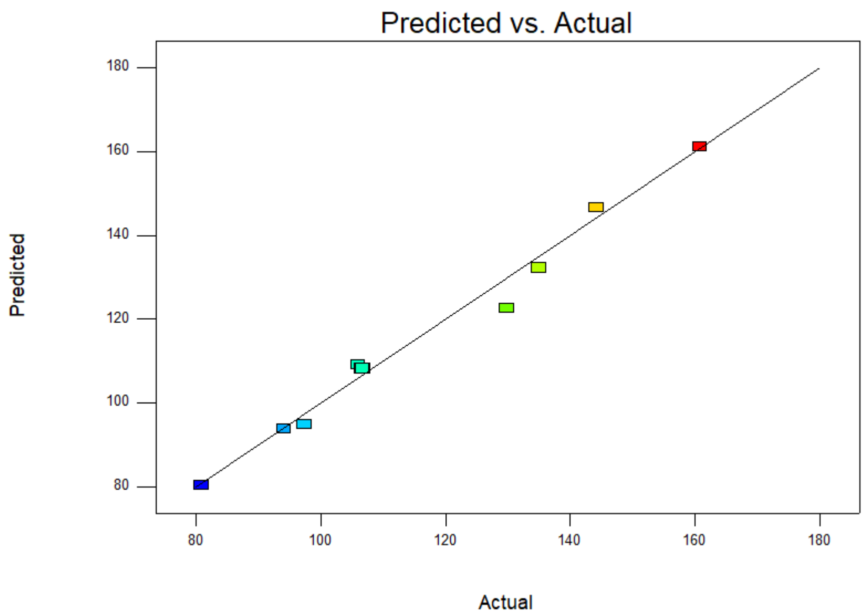

Figure 1: Scatter plots of the observed and the predicted values for the tensile strength.

2) Normal probability plots

In order to be able to test the validity of the regression model, it's necessary to test the required multiple regression assumptions that the residual values are normally distributed and the regression function is linear in nature. The normal probability plot of the residuals provides a quick way for visually inspecting to what extent the pattern of the residuals follows a normal distribution. If the residuals are normally distributed, then the points will cluster around the straight line. [10]

The normal probability plots shown in figure 2 were generated by using computer software design expert 9 ®. it can be seen from the figure the points distributed close to the line, and hence, the data are approximately normally distributed.

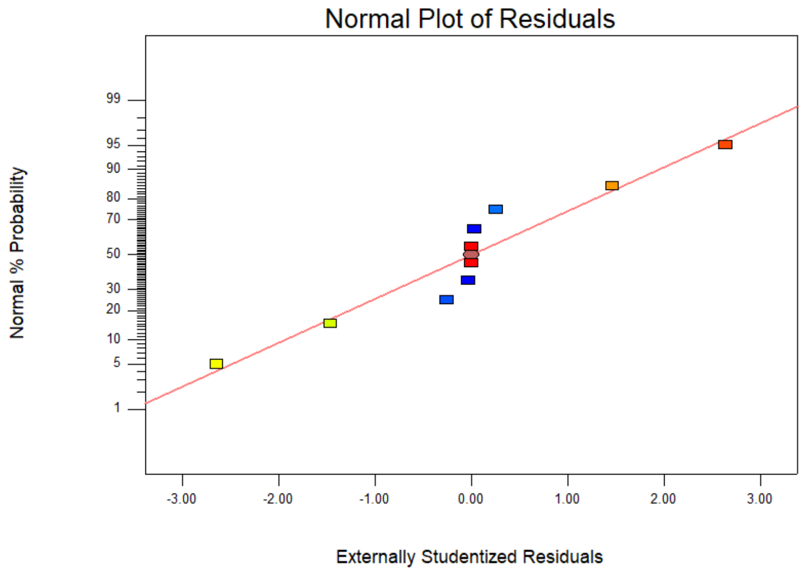

Figure 2: Normal probability plot of residuals for the tensile strength

Direct effect of process parameters on the impact strength of the welded area

1) Direct effect of current on the impact strength of the welded area.

From the figure 3 its apparent that, the toughness of the welded area decreased with increasing the current while keeping the wire feed rate constant at the average. This is due to the fact that, increasing the current increases the heat input which makes the heat affected zone bigger and the metal around the welded area brittle.

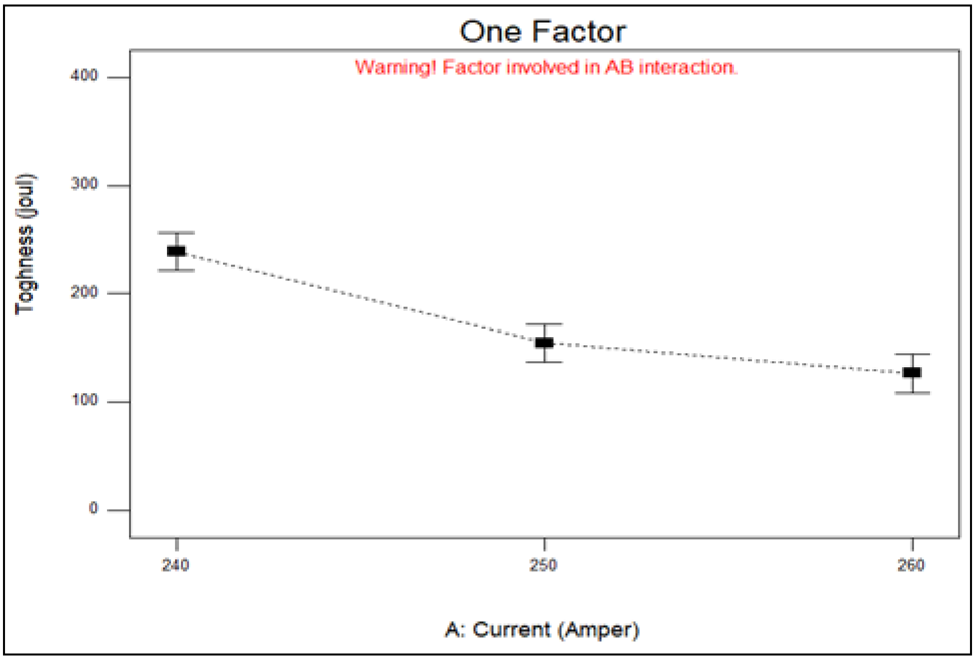

Figure 3: The effect of a current on the actual toughness of welded steel

2) Direct effect of wire feed rate on the impact strength of the welded area.

From the figure 4 its evident that the impact strength of the welded metal increases with increasing the wire feed rate, that is due to the fact that increasing the feed rate of the wire increases the deposition rate and hence the weld bead size

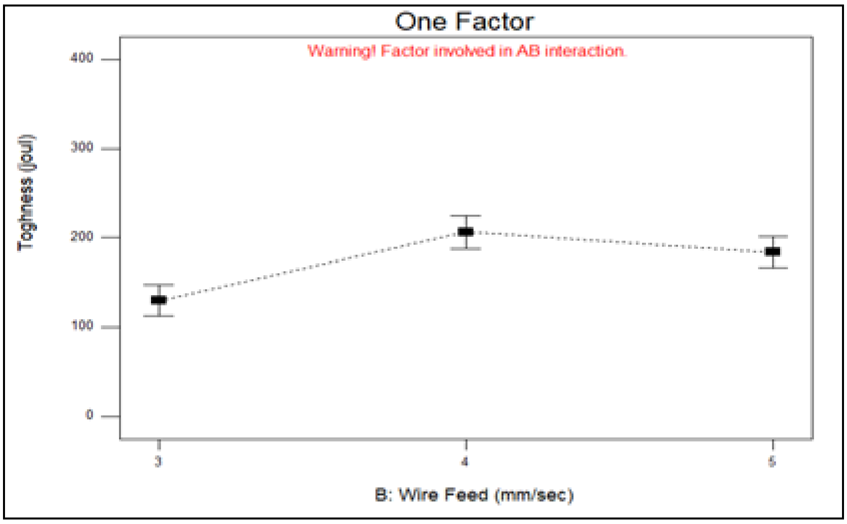

Figure 4: The effect of wire feed rate on the actual toughness of welded steel

Response surface analysis

The impact strength can be represented as solid surface in a three - dimensional space, as its plotted versus the limits of the two selected parameters as shown in Figure 5.

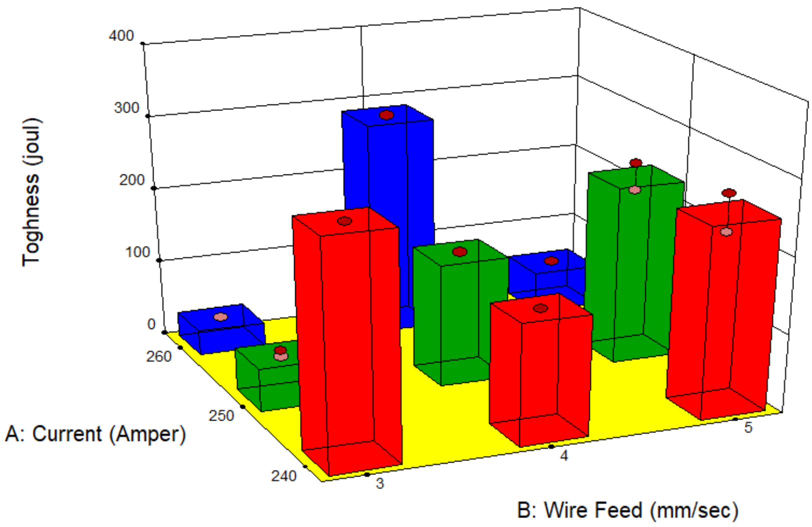

Figure 5: (3D) Response Surfaces Showing Interaction Effects of Welding Current & wire feed rate on impact Strength

Figure.5 shows the interaction effect of the welding current and wire feed rate on the impact strength of the joint welded area. It can be noticed that the highest impact strength recorded at a feed rate and current of 3 m/min and 240 A respectively, while the lowest value of impact strength recorded at 3m/min and 260 A.

3. Conclusion

The effect of varied welding parameters was examined and discussed in order to be able to predict the service behavior (performance) of welded low carbon steel samples using metal inert gas welding (MIG). The results have shown that the selected welding parameters have significant effect on the mechanical properties of the welded samples. The impact strength of material before the welding process was 24joulesand after applying the welding process increased to reach 299 joules at 240A current and 3 m/min wire feed.

The impact Charpy test shows that, the wire feed rate, the current and their interaction have significant effect on the impact strength of the joint welded metal according to ANOVA results of surface factorial model, the Adjusted R^2 for the impact strength model was 0.9658 which is very close to the R^2 value 0.9868 as shown in table 5 this indicates that the sample size and terms of the model are satisfactory and the model is capable of accurate prediction of the impact strength. Therefore, the equation in terms of coded factors can be used to make predictions about the response forgiven levels of each factor. The optimal set of process parameters for optimal toughness (299 joules) found at 240 welding current and wire feed rate 3 m/min. Further research could explore the impact of other welding parameters or the use of different types of steel to broaden our understanding of this important process.

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