Prediction of Bead Width In Submerged Arc Welding Of Low Carbon Steel (AISI 1005)

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ABSTRACT

This paper used Taguchi technique to determine the optimal SAW parameters, an effort has been made to study the effect of SAW process parameters (current *I*, voltage *V*, speed *S*) on the weld bead width (*W)* of low carbon steel AISI 1005. S/N ratios are computed to determine the optimum parameters. Statistical model were checked by used multiply regression method; the adequacy and significance of the model were checked by using ANOVA technique. The model employed easily in form of executed program designed by using visual basic 6 software, the objective of designed program is to predict and control weld bead width, which enable to put in the desired weld parameters and select the weld bead width. Main and Interaction effects of the process parameters on bead width presented graphically. The experimental results were analyzed by using Minitab 16 software.

KEYWORDS: SAW, Design of experiment, Taguchi method, ANOVA, S/N ratio.

التنبؤ بعرض بركة اللحام بالقوس الكهربائي المغمور للفولاذ منخفض الكربون (AISI 1005)

الخلاصة

هذه الورقة أستخدمت تقنية تاكوتشي لتحديد المتغيرات الأمثل للحام بالقوس المغمور، لقد تم بذل جهد لدراسة تأثير متغيرات العملية (التيار *I*، الفولتية *V*، السرعة *S*) على عرض بركة اللحام (*W*) للفولاذ المنخفض الكربون (AISI 1005). حسبت نسبة S/N لتحديد متغيرات اللحام الأمثل. وضع نموذج إحصائي باستخدام أسلوب الانحدار الخطي المتعدد، تم التحقق من مدى ملائمة وأهمية النموذج باستخدام تقنية تحليل التباين ANOVA. وظف النموذج بسهولة في شكل برنامج مصمم وذلك بأستخدام برنامج Visual Basic 6، هدف البرنامج المصمم هو التنبؤ والتحكم بعرض منطقة اللحام، والذي يُمكن من وضع متغيرات اللحام المطلوبة وتحديد عرض اللحام. قدم بيانيا التأثير الرئيسي والمشترك لمتغيرات العملية على عرض منطقة اللحام. تم تحليل النتائج التجريبية باستخدام برنامج Minitab 16.

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INTRODUCTION

Submerged arc welding (SAW) process features high production rates, high quality welds, ease of automation and low operator skill requirement. In the SAW process the arc and the weld pool are shielded from atmospheric contamination by an envelope of molten flux to protect liquid metal and a layer of unfused granular flux which shields the arc [1].

SAW is widely used for butt and fillet welds in heavy industries, it is used to join thick steel sections, shipbuilding, pressure vessel, wind tower, rail-road tank cars, structural and construction engineering, pipe welding, hard surfacing, agriculture, and for making tankers for very large and ultra large crude-oil carriers tanker [2].

The SAW process employs a continuous solid wire electrode that is consumed to produce filler, the arc is submerged in the flux, As a result, the process is relatively free of the intense radiation of heat and light, and resulting welds are very clean [3]. The quality of weld depends on bead geometry of the weld which in turn depends on the process parameters, selection of appropriate parameters is essential, to control bead size and quality; condition must be selected in order to ensure a predictable weld bead which is important for obtaining high quality.

The weld quality can be assessed in terms of properties such as weld bead geometry, Best quality welds can be achieved by proper understanding the influence of welding parameters,

A lot of work has been done in past years for the modeling of bead geometry & shape relationships in terms of submerged arc welding process parameters. Various statistical and modeling technique have been used by different researchers. Engineers and researchers in the manufacturing industries and training centers often face the problem of selecting appropriate or optimum combinations of input welding parameters for achieving the required weld quality. This problem can be solved through effective planning and implementation of precisely designed experiments utilizing statistical model equation in form of program.

The bead geometry plays an important role in weld joint evaluation. Researchers Pranesh B. Bamankar and S.M. Sawant [4] studied the effect of process parameters on bead width in SAW process, mild steel plates of (12 mm height) were used as base metal, design of experiments (DOE) was conducted with Taguchi design (L9) orthogonal array, the process parameters used are current, voltage, and travel speed. DOE uses a statistical measure of performance called signal-to-noise ratio (S/N) for optimization. The results show that Current is main factor which influence on the bead width. Bead width almost linearly increases with arc voltage and current and decreases with welding speed.

SAW of pipes were studied by N. Murugan and V. Gunaraj [5]. They used statistically DOE based on five level factorial techniques, Regression analysis was used to develop mathematical models to relate the process variables to the weld bead parameters to predict weld bead dimensions and shape relationships and also to control of the weld bead quality by selecting appropriate process parameter values. Steel plates of (6 mm height) were used with bead on joint welding; analysis of variance (ANOVA) technique was used to check the adequacy of models. The results of these experiments show that arc voltage had a positive effect on bead width, Bead width increases with the wire feed increasing rate for all values of welding speed but this increasing rate gradually decreased with the increase in speed.

The application of Taguchi technique (L8) orthogonal array and multiple regression analysis to determine the optimal process parameters method for SAW was presented by S. Kumanan et al [6]. The experiments were conducted with mild steel plates of (6 mm height); the S/N ratios are computed to determine the optimum parameters. The percentage contribution of each factor is validated by ANOVA technique. The mathematical model is built to predict the bead geometry for any given welding conditions. Their results found that welding current and arc voltage are significant welding process parameters that affect the width of weld bead.

In another study Saurav Data And Asish Bandyopadhyay [7] used grey- based taguchi method for optimization of bead geometry in SAW, used bead on plate welding, Taguchi design (L25) and S/N ratio have been used to derive bead width to be optimized within experimental domain. The significance of the factors has been evaluated by ANOVA. It was concluded that Taguchi method is very efficient for process optimization that can be performed in a limited number of experimental runs. This method applied to evaluating optimal parametric combination to achieve acceptable lower bead width.

An effort has been made by Deepak Kumar Choudhary [8] to investigate the effect of welding parameters on bead geometry. Mathematical models were developed using 2- level half factorial technique to predict the effect of welding parameters on weld bead geometry of beads on steel plates in SAW process, The adequacies of the models were tested using ANOVA, welding variables were (I, V, S, nozzle-to-plate distance). It was found that, weld bead width increases with increase in voltage and decrease with increase in speed.

This study works on the relationship between the welding parameters and bead width in SAW, mathematical models has been developed for optimization and prediction, the models employed easily in form of program designed by used visual basic 6 software. The program helps in control of the optimal welding parameters and will give the best properties of the weld and reduce welding time and cost by limits the extent of trial and error activities.

Engineers and researchers in the manufacturing industries and training centers often face the problem of selecting appropriate or optimum combinations of input welding parameters for achieving the required weld quality. Optimal control of the welding parameters will give the best properties of the weld and reduce weld time and cost and limits the extent of trial and error activities.

To the best of the researcher's knowledge there is no available literature on the effect of SAW parameters (current, voltage and travel speed) on the bead width (W) of low carbon steel AISI 1005, also there is no available literature on the design program used Visual Basic 6 to predict weld bead width from welding parameters for SAW process, SAW of this grade of steel is very common in the industry. Figure 1. Show the diagram of a typical weld specimen before welding used in this work. Figure 2. Show the weld bead geometry diagram of a typical weld specimen (after welding).

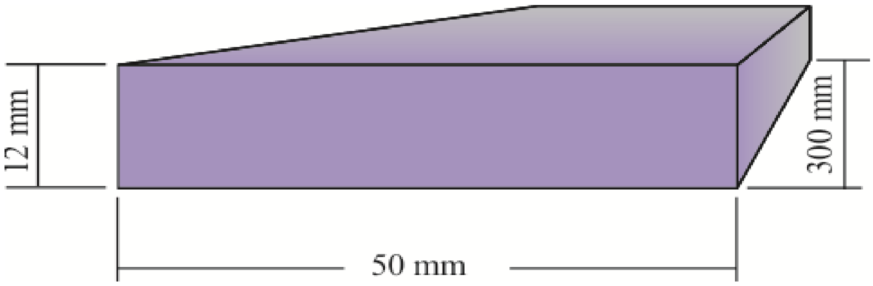


Figure 1. Steel strip dimensions before welding

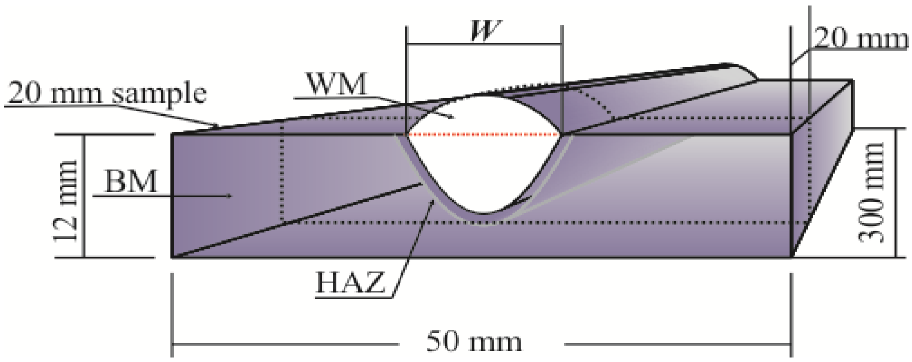


Figure 2. Typical weld bead geometry (after

Experimental Work

Process parameter levels

Three input parameters of SAW were used to weld the steel plates, and four levels for each parameter Table 1. Show the parameters and their levels. In this work Taguchi L16 orthogonal array was chosen to design of experiment DOE, which was created by used Minitab 16 software. Table 2 and 3 show the chemical compositions of the AISI 1005 steel and electrode.

Table (1). SAW input parameters levels.

Level	Current (I) amp	Voltage (V)	Speed (S) mm/s
1	280	26	3.3
2	340	29	5
3	400	32	6.6
4	460	35	8.3

Welding Procedure

All the plates were welded by the staff of (Welding Workshop at Baghdad Oil Training Institute) with the following experimental setup:

The equipment used: Lincoln IDEALARC DC-1000 SAW equipped with NA-5 control panel.

Work samples: AISI 1005 low carbon steel plates of 300×50×12 mm size.

Welding electrode used: EM12K, 2.4 mm diameter.

Table 2 and 3 show the chemical compositions of the AISI 1005 steel and electrode, respectively.

Type of joint: Single pass one side, bead on plate 12 mm-thick.

Electrode to work angle: 90^o

SAW technique was used to weld all weld samples in this work, the polarity was DC+ (electrode positive). The plates were firmly fixed to a base plate by means of tack, at the end of welding process the slag was removed and the plates were allowed to cool down. Test Samples of (20 mm) width were cut transverse to the weld plates with a saw band. These sample were prepared by a standard metallographic process. The samples were first roughly ground using a file. Then different grades of emery papers were used to increase fineness from (320, 400, 600, and 1000). Grinding was done until all the scratches on the samples surface disappeared. Polishing of the samples was performed with diamond paste (3micron) on a polishing wheel; the samples were rinsed with methanol. Light optical microscope was used to monitor the sample preparation process. The polished samples were etched with (2% Nital) solution for about (5 to 10) second to reveal the weld profile. The prepared samples were dried by blowing hot air, and then Photomacrograph were obtained using (Nikon D90 digital camera). Measurements were performed from transverse cross sections by using the (COREL DRAW X6) software, and measurements were obtained as the pictures were downloaded into this software. Figure 3 shows the cross section pictures of bead width dimensions, the L16 orthogonal array and the experimental measured values of the weld bead width are given in Table 4.

Table (2). Chemical compositions of base metal

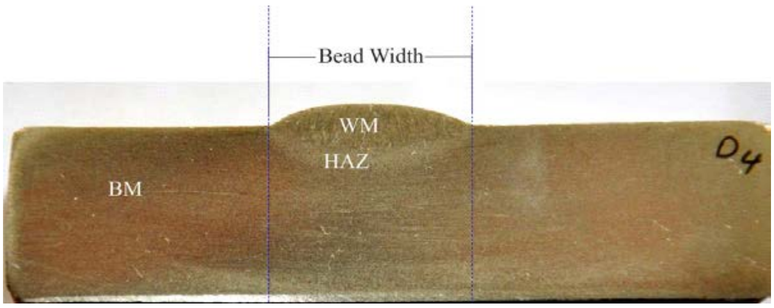
%C	%Si	%Mn	%P	%S	%Mo	%Cu	%Fe
0.033	0.009	0.35	0.008	0.009	0.002	0.022	Bal.

Table (3). Chemical composition of AWS (EM12K) electrode

%C	%Mn	%Si	%S	%P	%Cu
0.05-0.15	0.80-1.25	0.1-0.35	0.030	0.030	0.35

Table(4). Taguchi Design (L16) and measured values of bead width dimensions.

No.	Current (I) amp	Voltage (V)	Speed (S) mm/s	Width mm	S/N ratio
1	280	26	3.3	10.98	-20.8120
2	280	29	5	11.58	-21.2742
3	280	32	6.6	11.67	-21.3414
4	280	35	8.3	12.41	-21.8754
5	340	26	5	11.33	-21.0846
6	340	29	3.3	12.55	-21.9729
7	340	32	8.3	12.17	-21.7058
8	340	35	6.6	13.25	-22.4443
9	400	26	6.6	10.88	-20.7326
10	400	29	8.3	11.85	-21.4744
11	400	32	3.3	13.14	-22.3719
12	400	35	5	13.10	-22.3454
13	460	26	8.3	10.76	-20.6362
14	460	29	6.6	12.40	-21.8684
15	460	32	5	12.19	-21.7201
16	460	35	3.3	13.77	-22.7787

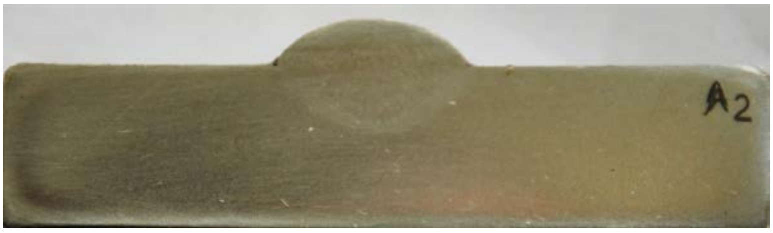


a. *I*=340 amp, *V*=35 v, *S*=6.6 mm/s, *P*=2.36mm,*W*=13.25mm, HAZ *w* =1.27mm

b. *I*=280 amp, *V*=26 v, *S*=3.3 mm/s, *P*=1.45mm, *W*=10.98mm, HAZ *w* =1.31mm

c. *I*=280 amp, *V*=29 v, *S*=5mm/s, *P*=2.03 mm, *W*=11.58mm , HAZ *w* =1.23mm

e. *I*=400 amp, *V*=29 v, *S*=8.3 mm/s, *P*=2.62mm, *W*=11.85 mm, HAZ *w* =1.36mm



f. *I*=460 amp, *V*=29 v, *S*=6.6 mm/s, *P*=4.21mm, *W*=12.40mm, HAZ *w* =1.46mm

Figure (3). Selected specimens with their welding conditions and corresponding average bead dimensions

Results And Discussion

The analysis of the results will lead to a better understanding of the relationship between SAW process parameters and weld bead width, statistical analyses used, such as ANOVA to analyze the significance of SAW parameters, S/N ratio for optimization (Table 2), regression model for prediction. A confidence level of 95% has been taken for these analyses.

ANOVA for Bead Width

Table 5 shows printout for ANOVA, the Table indicates the significance value of various input parameters. From Table 5 the *p* – value for voltage and speed is 0.000, 0.010, respectively which is lesser than 0.05, Hence, voltage and speed is the significance factor that effect on bead width, this is consistent with the study conducted by Deepak Kumar Choudhary [8]. *F* – value given in ANOVA Table for the voltage is also maximum, which indicates the significance of factors, higher *F* – value is the significance of that factor.

Table (5). Analysis of Variance ANOVA for width (mm)

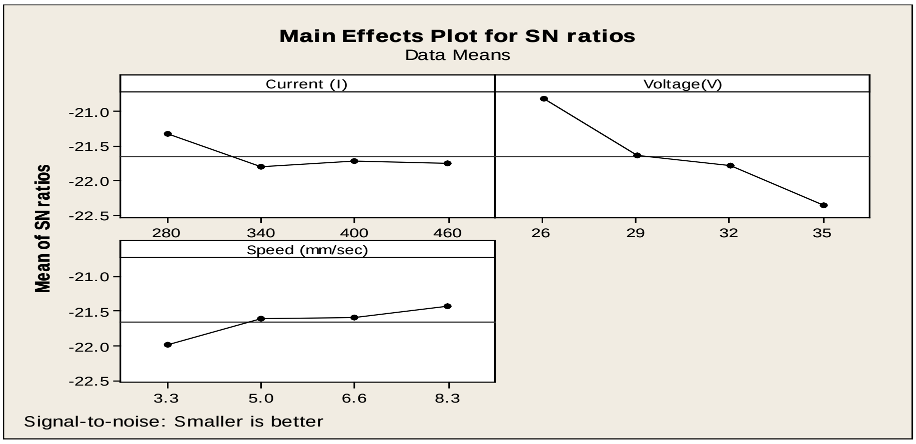
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Current (*I*)	3	1.1762	1.1762	0.3921	8.13	0.016
Voltage (*V*)	3	9.3516	9.3516	3.1172	64.61	0.000
Speed (*S*)	3	1.4149	1.4149	0.4716	9.77	0.010
Error	6	0.2895	0.2895	0.0482		
Total	15	12.2321				

Optimization for Bead width by using S/N ratio

The calculation of S/N ratio for bead width depending on the results in Table 4, smaller is better quality has been selected because it is desirable property of the weld. Figure 4 shows the main effects plot of average S/N at different levels of a factor versus the factor levels. ANOVA for S/N ratio is given in Table 6, From Figure 4, optimal parameters setting for smaller width are, current = 280 amp, voltage = 26 v, Speed = 8.3 mm/s.

Table (6). Analysis of Variance for S/N ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Current (*I*)	3	0.57969	0.57969	0.19323	7.54	0.019
Voltage (*V*)	3	4.87428	4.87428	1.62476	63.37	0.000
Speed (*S*)	3	0.67107	0.67107	0.22369	8.73	0.013
Error	6	0.15383	0.15383	0.02564		
Total	15	6.27886				



Figur(4). Main effects plot for S/N ratios for bead width

Multiple Regression Analysis

The regression equation (model) obtained for weld bead width by used multiple regressions are given in equation 1. From regression Table 7. Indicates the *p* – value of voltage and speed has the minimum value; it means voltage and speed is the most significant factor affecting the bead width. From Table 7. R-sq value 86.9 % shows that the model is suitable for prediction.

The regression equation (model) is:

Width (mm) = 5.14 + 0.00296 (*I*) + 0.221 (*V*) - 0.147 (*S*)……… (1)

where

I = Current (amp)

S = Speed (mm/s)

V = Voltage (volt)

$280 \leq I \leq 460$

$26 \leq V \leq 35$

$3.3 \leq S \leq 8.3$

Table (7). Regression table for width

Predictor	Coef	SE Coef	T	P
Constant	5.143	1.017	5.05	0.000
Current (*I*)	0.002962	0.001363	2.17	0.050
Voltage (*V*)	0.22108	0.02726	8.11	0.000
Speed (*S*)	-0.14741	0.04925	-2.99	0.011
S = 0.365668 R-Sq = 86.9% R-Sq(adj) = 83.6%				

Prediction Program Designing

One aim of this study was to use model (regression equations) in executed program to predict the weld bead geometry; this was achieved by feeding the model into a computer system to develop an expert welding program, the program can be used by welding engineers associated with industrial facilities, welding training centers, also researchers and students. The program presented in this study will provide some guidance on predicting the as-welded bead width dimension for SAW and considerable information about the quality of a given weld before final welding, it is necessary to arrive at optimum welding conditions. This program limits the extent of trial and error and help in experimental verification. Visual Basic 6 was chosen for design and programming the program (see Appendix 1).

Interaction effect on bead width (mm)

Figure 5. Shows the interaction effect of *V* and *S* on *W*, the increase in *V* increases *W* for all values of *S* approximately. The rate of increase in *W* is greater when *S* is at its lower limit (3.3mm/s), this is because *V* has a positive effect, but *S* has a negative effect on *W*, *W* is maximum (about 13.77 mm) when *V* and *S* are respectively at their upper (35v) and lower (3.3mm/s) limits. *W* is minimum (about 10.76 mm) when *V* and *S* are respectively at their lower (26v) and upper limits (8.3mm/s). These effects are further explained with the contour plot in Figure 6, it is evident that *W* is maximum (> 12.5mm) when *V* and *S* are respectively at their maximum (35v) and minimum (<4mm/s) limits, and the lowest value of width (<11 mm) is obtained when *V* and *S* are at their minimum and maximum limits, respectively.

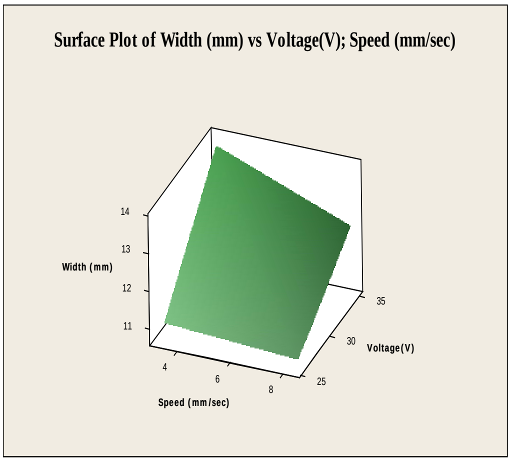


Figure 5. The effect of voltage and speed on bead width

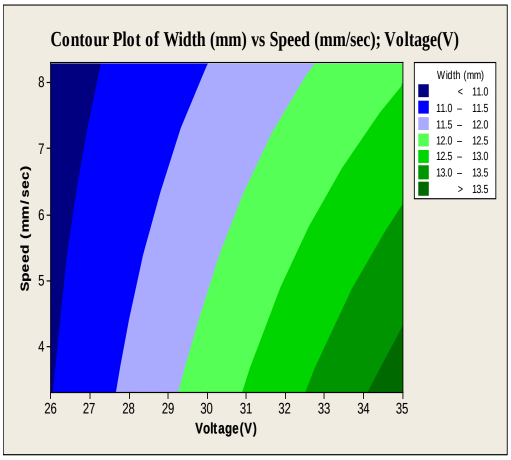


Figure 6. A counter plot of width versus voltage and speed

Use the program for prediction

The designed program was used for prediction in the two following steps:

1. Since the regression models adequate for Prediction, SAW bead geometry predictor program that was mentioned previously, used here for predict *W* form optimal SAW processes parameters that was be found earlier from optimization by S/N ratio, these values was fed to the program and then clicked the Calculate button to get their prediction results Table 8.

Table (8). Optimal SAW processes parameters

<table>
<tr><th colspan="3">Optimal SAW parameters</th><th rowspan="2">Predicted bead width mm</th></tr>
<tr><th>(I) amp</th><th>(V) volt</th><th>(S) (mm/s)</th></tr>
<tr><td>280</td><td>26</td><td>8.3</td><td>10.49</td></tr>
</table>

2. Comparison between measured and predicted values: it is useful to compare all three models predictions of SAW bead features (*W*) with experimental measurements. Generally there is good agreement is found when weld bead width features are examined, presented graphically in Figure 7 and Figure 8. Which shows comparison examples between SAW bead width measured and predicted values?

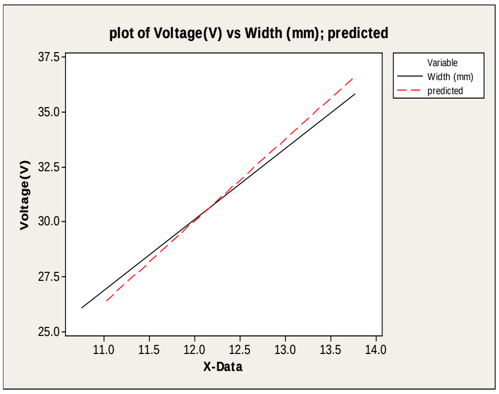


Figure 7. Comparison between measured and predicted width versus voltage

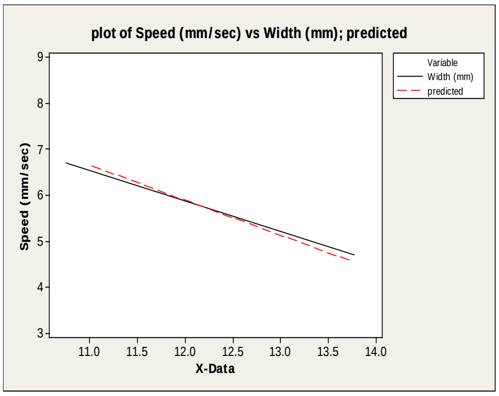


Figure 8. Comparison between measured and predicted width versus speed

CONCLUSIONS

1. Arc voltage and welding speed are the main factors influencing bead width. Bead width increases with increase in arc voltage, and decreases with increase in welding speed, Optimal parameters setting for smaller bead width is, current = 280 amp, voltage = 26 v, speed = 8.3 mm/s.
2. The designed program in this work is a useful tool used to predict weld bead width from welding parameters for SAW process. This program limits the extent of trial and error and help in experimental verification.

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Nomenclatures

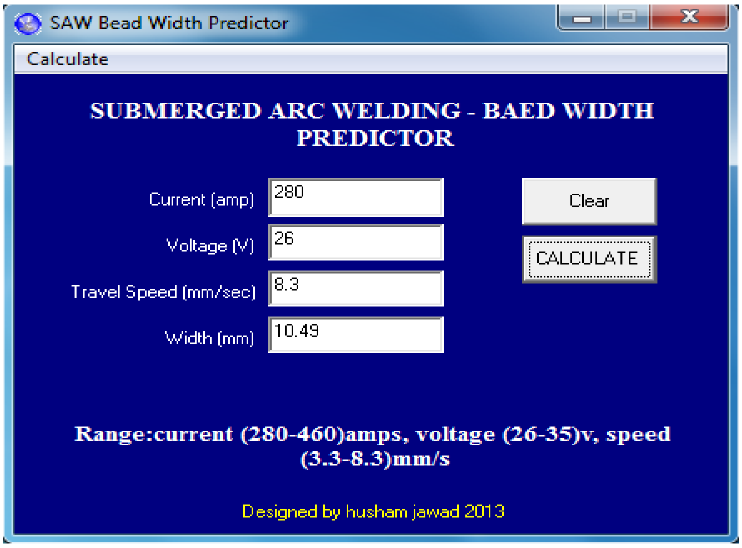
BM	Base metal	
HAZ	Heat affected zone	
I	Current	amp
S	Travel Speed (welding speed)	mm/s
SAW	Submerged Arc Welding	
V	Voltage	v
W	Weld bed width	mm
WM	Weld metal	

Appendix 1

1- Part of the source code that used in the SAW bead geometry predictor exe. program:

```
Private Sub Command3_Click()
a = Val(Text1)
b = Val(Text2)
c = Val(Text3)
d = 5.14 + 0.00296 * a + 0.221 * b - 0.147 * c
Label10 = d
Label10.Caption = Format(d, ".00")
If Text1.Text = "" Then
Cancel = True
ElseIf CDbl(Text1.Text) < 280 Or CDbl(Text1.Text) > 460 Then
Cancel = True
End If
If Cancel Then
MsgBox "Please enter a current  range [280-460]", vbExclamation
End If
If Text2.Text = "" Then
Cancel = True
ElseIf CDbl(Text2.Text) < 26 Or CDbl(Text2.Text) > 35 Then
Cancel = True
End If
If Cancel Then
MsgBox "Please enter a voltage range [26-35]", vbExclamation
End If
```

```
If Text3.Text = "" Then
Cancel = True
ElseIf CDbl(Text3.Text) < 3.3 Or CDbl(Text3.Text) > 8.3 Then
Cancel = True
End If
If Cancel Then
MsgBox "Please enter a speed range [3.3-8.3]", vbExclamation
End If
End Sub
Private Sub Command5_Click()
Text1.Text = ""
Text2.Text = ""
Text3.Text = ""
Label10.Caption = ""
End Sub
```



A.1. SAW bead geometry predictor program

2- The designed interface that called (SAW bead width geometry predictor)