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Effect of Welding Current on the Hardness of Austenitic Stainless Steel Weld Joints

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ABSTRACT:

A mathematical model for predicting the hardness of GTAW welded austenitic stainless steel joint was developed. Deviational and statistical analyses as well as scatter diagrams were used to test and confirm its validity and accuracy. The maximum deviation between the model-predicted and actual experimental values was less than .06%, in absolute terms, and the R^2 *values were above 95%. Also the scatter diagram showed that the predicted and experimental values were close to the* 45^o *line.*

Keywords: welding current, mathematical model, hardness

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Introduction

Welding can trace its historical development back to ancient times, more than 2000 years, when small gold circular boxes were made by pressure welding lap joints (Carry, 1998). Many tools and other materials made by welding, approximately 1000 BC, have been found and are on exhibit in the British Museum in London.

Welding is the most economical and efficient way to join metals permanently. It is the only way of joining two or more pieces of metals to make them act as a single piece or monolithic structure. It can be used to join all types of commercial quality metals and strength. It is very important in manufacturing and construction and therefore vital to economic development and growth. The advantages of welding as a joining process include high joint efficiency, simple set up, flexibility and low fabrication costs (Armentani, Esponsito and Sepe, 2007).

In welding practice a good quality weld joint is one which has its physical and mechanical properties, at least, equal to those of the parent metals being joined. The physical properties considered essential are macrostructure and microstructure while essential mechanical properties are strength, elongation, hardness and toughness. The studies of Bang et al, (2008) and Tewari, Gupta and Prakash (2010) have shown that these properties are influenced by welding parameters such as welding voltage, welding current and welding speed.

Many researchers, Vercesi and Surian (1996), Vercesi and Surian (1998), De Rissone et al, (2005) and Lang et al, (2008) have investigated the effect of these parameters on microstructure and mechanical properties of weld metal, using various materials and various welding processes by varying them simultaneously to change heat input. However, very little attempt has been made to evaluate the effect of each parameter separately and no attempt at all has been made to study the effect of electrode type (Nnuka, Ovat and Oseni, 2005) especially, on stainless steel welds using gas tungsten arc welding (GTAW) process.

Hardness

This is the capacity of metal to resist abrasion, indentation (or penetration) and scratching by harder bodies and it is influenced by welding current and microstructure.

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Effect of Welding Current on Hardness

In their study on the effect of TIG welding on microstructure and mechanical properties of a butt-joined-unalloyed titanium, Uygur and Dogan (2005) revealed that increase in welding current resulted in coarse grains with resultant decrease in hardness. This agreed with the observation of Zou et al (2004) in their study of the microstructure and properties of welded joint of magnesium alloy, AZ31B, that increase in welding current resulted in increase in grain size and decrease in hardness.

Therefore this work is aimed at establishing the effect of welding current on the hardness of stainless steel weld joints using GTAW process.

Table 1. Composition of Base Metal and Filler Metals

Material	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V	Al	SN	N	Ti
Base metal	0.02	0.42	0.05	0.031	0.001	18.80	7.18	0.008	0.029	0.079	0.013	0.004	0.042	0.005
Filler Metal Type														
ER308L	0.013	0.43	1.86	0.023	0.002	19.85	9.95	0.05	0.07					
ER309L	0.016	0.41	1.84	0.019	0.002	23.28	13.68	0.03	0.04					
ER316L	0.014	0.41	1.74	0.023	0.002	19.22	12.29	2.19	0.11					

DEVELOPMENT OF MATHEMATICAL MODEL

The data for the formulation of this model was obtained from the work of Okonji, Akaluzia and Utu (2016) and shown in Tables 1 and2.

Table 2: Hardness

Current (A)	Hardness (HBR)
91	76.50
92	76.40
93	76.30
94	76.08
95	76.00
Control	76.00

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Model Formulation

In the development of this model for the prediction of hardness (H), as a function of welding current (I), a procedure based on regression was employed and expressed as

Y= $f(I)$, where Y = Response Applying a first order response yields the following relationship

Y= $a + bI$ (1)

The coefficients a *and* b represent the free term and the linear term, respectfully, of the regression. The values of coefficients a and b were calculated by regression analysis using the following equations:

Y= $f(I)(1)$ (2)

Y= $a + bI(2)$ (3)

Taking the actual response to be Φ and the predicted Y, the standard deviation of prediction, θ will be given by

$$\theta^2 = \frac{\Sigma(Y-\Phi)^2}{n} \quad (4)$$

$$n\theta^2 = K = \Sigma(Y-\Phi)^2 = \Sigma(Y-a-bI)^2 \quad (5)$$

Differentiating with respect to a, we have

$$\frac{\delta K}{\delta a} = -2\Sigma(Y - a - bI) = 0 \text{ or } \Sigma Y - na - b\Sigma I = 0 \quad (6)$$

Where n = number of welding currents per filler metal

$$\therefore \Sigma Y = na + b\Sigma I \quad (7)$$

$$\therefore a = \frac{\Sigma Y}{n} - \frac{b\Sigma I}{n} = \tilde{Y} - b\hat{I} \quad (8)$$

Differentiating with respect to b, we have

$$\frac{\delta K}{\delta b} = 2I\Sigma(Y - a - bI) = 0 \text{or} \Sigma Y - a\Sigma I - b\Sigma I^2 = 0$$

$$\therefore \Sigma YI = a\Sigma I + b\Sigma I^2 \quad (9)$$

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Multiplying (6) by ΣI gives

$$\Sigma Y \Sigma I = na\Sigma I + b(\Sigma I)^2 \qquad (10)$$

Multiplying (8) by n gives

$$n\Sigma YI = na\Sigma I + nb\Sigma I^2$$

(10) − (11) gives

$$\Sigma Y\Sigma I - n\Sigma YI = b[(\Sigma I)^2 - n\Sigma I^2$$

$$\therefore b = \frac{\Sigma Y\Sigma I - n\Sigma YI}{(\Sigma I)^2 - n\Sigma I^2} \qquad (11)$$

The values of the coefficients were calculated using Texas Instrument, TI-84 plus and are as follows: a = 89.27; b = -0.14

Introducing the values of the coefficients, the developed final mathematical equation is given as

$$Y = 89.26+0.14I \qquad (12)$$

The calculated values are shown in Table 4.

Table 4. Calculated (Predicted) hardness values

Current (A)	Predicted Hardness (HBR)
91	76.52
92	76.38
93	76.24
94	76.10
95	75.96

Boundary and Initial Conditions

The welding process, including the cooling, was carried out under the atmospheric conditions and the values of welding current and percent elongation used are as shown in Table 1. The materials used were AISI 304L grade of stainless steel, ER308L, (2mm diameter)filler metal, 2% thoriated non-consumable electrode (2mm diameter) and high purity (99.99%) argon as shielding gas. The weld metal was cooled with natural air; no pressure and no force (tension or compression) were applied to the heat affected zone (HAZ) during or after the welding process. Also the sides and shapes of the coupons were symmetries.

Model Validation

The developed model was validated using deviation and statistical analyses as well as scatter diagrams.

Deviational analysis

This involves the direct analysis and comparison of the model-predicted values (MPV) and those of the actual experimental values (AEV) for equality or near equality. The deviation or error percent (Dv) was determined using the following equation:

$$\mathrm{Dv} = \frac{\mathrm{AEV} - \mathrm{MPV}}{\mathrm{MPV}} \mathrm{X}\ 100$$

The results are contained in Table 4.

Statistical Analysis

This was carried out to determine the correlations between process variables by calculating the coefficients of determination (R^2). Results are in Figures 1-3.

Scatter Diagrams

The formulated model was further validated using scatter diagrams, Figures 4.

Results and Discussions

Deviational Analysis

Table 4. Comparison of model-predicted and experimental hardness values

Filler Metal	Current (A)	Hardness (HBR)		Error	% Error
		Experimental	Predicted		
308L	91	76.50	76.52	-0.02	0.026
	92	76.40	76.38	0.02	0.027
	93	76.30	76.24	0.06	0.078
	94	76.08	76.10	-0.02	0.026
	95	76.00	75.96	0.04	0.053

From Table 4 above it can be seen that the deviations between actual experimental values and the predicted are very low and within acceptable range. This demonstrates the validity of the model.

Statistical Analysis and Graphical Presentation

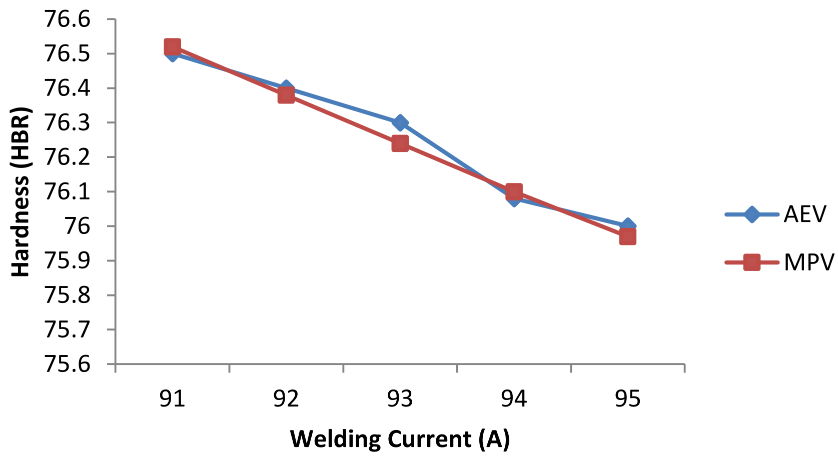

Figure 1. Interaction between hardness and welding current for 308L filler metal

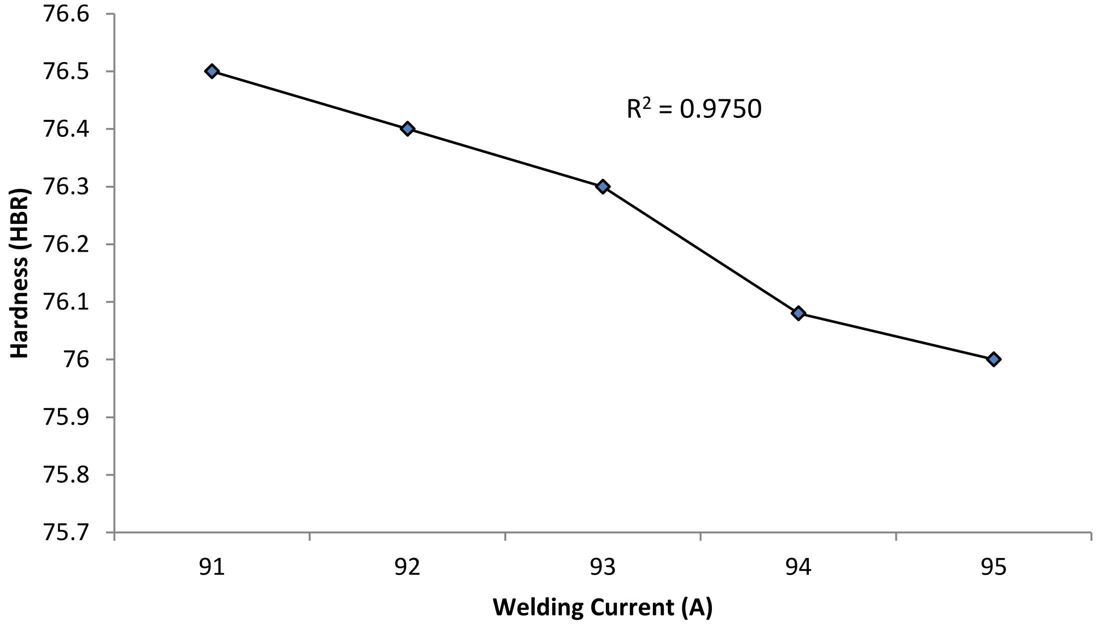

Figure 2. Interaction between actual experimental hardness value and welding current for 308L filler metal

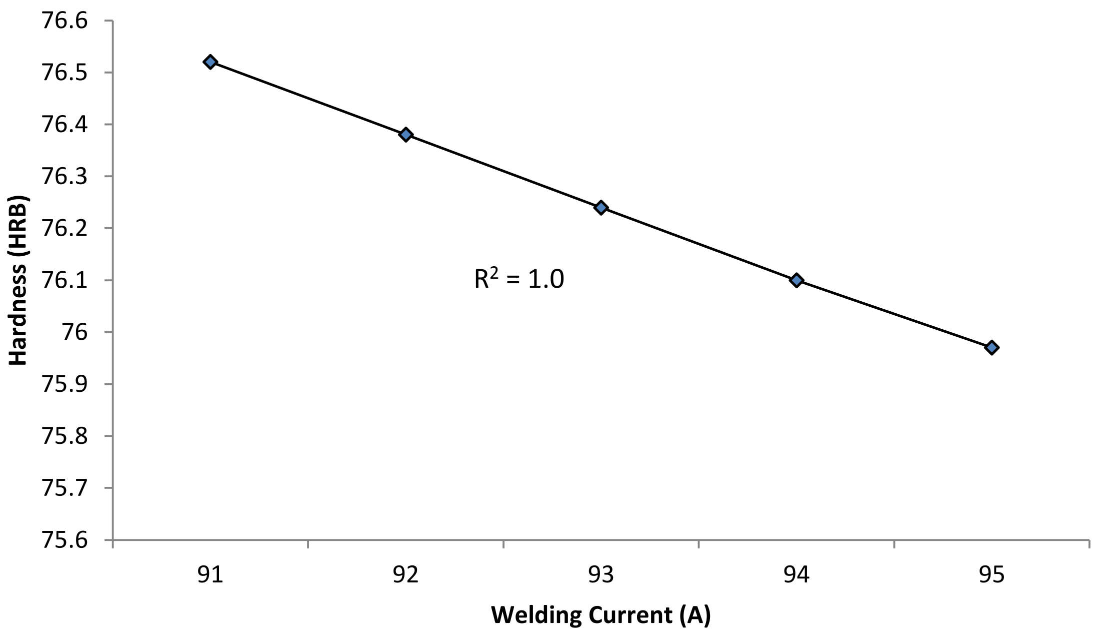

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Figure 3. Interaction between model-predicted hardness values and welding current of 308L filler metal

From Figures 1-3 the values of the coefficient of determination (R^2) for the developed model were generally above 80% indicating that the regression model was quite adequate, hence the validity. It can also be observed that the model-predictedR^2 (and indeed the R) values (1.00) are better than the values for the actual experiment. This suggests that the model predicts more accurately and reliably than the actual experiment. This further strengthens the model validity.

Scatter diagram

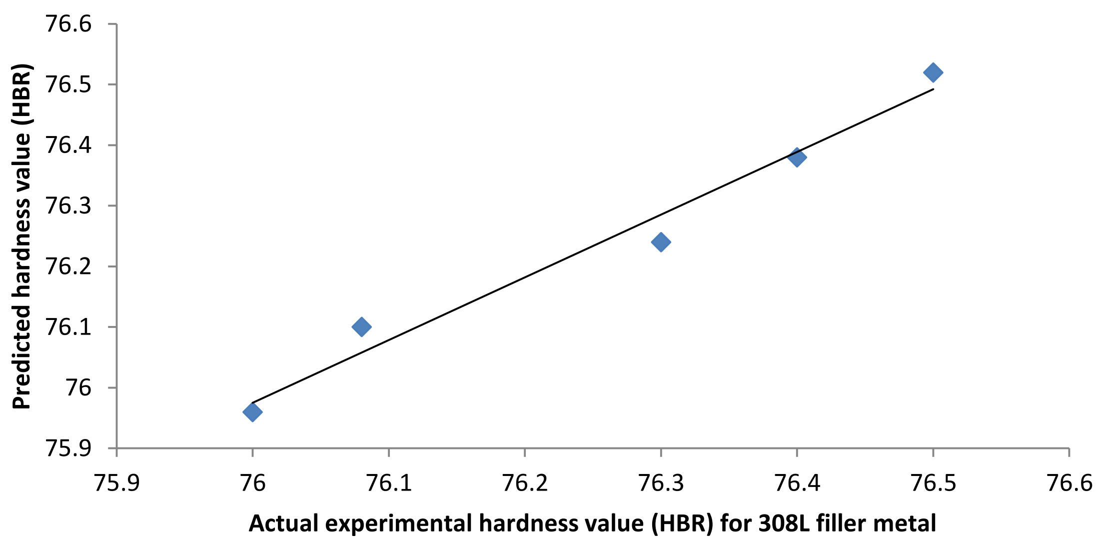

Figure 4. Scatter diagram for 308L filler metal

From Figures 4 above it can be observed that the experimentally estimated and the model-predicted hardness values are scattered close to the 45^o line, demonstrating an almost perfect fit of the developed model. This further establishes the adequacy of the derived models.

Conclusion

The results of the validity and accuracy tests of the model have demonstrated that the developed model is accurate to a very reasonable degree since the model-predicted values were in proximate agreement with the values obtained from actual experiment. Therefore the developed model can be successfully used to predict the hardness of GTAW welded austenitic stainless steel joints.

References

Armentani, E., Espositor, R. And Sepe, R. (2007).The effect of thermal properties and weld efficiency on residual stresses in welding. Journal of Achievements in Materials and Manufacturing Engineering, vol. 20, 319-322

Bang, K. S., Jung, D. H., Park, C. and Chang, W. S. (2008). Effects for welding parameters on tensile strength of weld metal in flux cored welding. Science and Technology of Welding and Joining, vol. 13, No.6, 508-514

Carry, H. B. (1998). "Historical Development of Welding", Modern Welding Technology, 4th Edition. Pp 6-7, 492-500. Prentice Hall Inc. New Jersey.

De Rissone, N. M. R., Svoboda, H. G., Surian, E. S. and de Vedia, L. A. (2005). Influence of procedure variables on C-Mn-Ni-Mo metal cored wire ferritic all welded metal. Welding Journal, 94, 139s-148s

Lang, B., Sun, D. Q., Li, G. Z. and Qin, X. F. (2008). The effect of welding parameters on microstructure and mechanical properties of resistance spot welded magnesium alloy joints. Science and Technology of Welding and Joining, vol. 13, No. 8, 698.

Tewari, S. P., Gupta, A. and Prakash, J (2010).Effect of welding parameters on the weldability of materials. International Journal of Engineering Science and Technology, Vol 2, No 4, 512-516

Uygur, I. and Dogan, I. (2005).The effect of TIG welding on microstructure and mechanical properties of butt-joined-unalloyed titanium. METAK 44 (2) 119-123.

Wikipedia (2010)."Stainless steel".Retrieved from http://en.wikipedia.org/wiki/stainless_steel on 21/8/2017.

Vercesi, J. And Surian, E. (1996). The effect of welding parameters on high-strength SMAW all welded metal, part 1. Welding Journal, 85.191s-196s.

Vercesi, J. And Surian, E. (1998). The effect of welding parameters on high-strength SMAW all welded metal, part 2. Welding Journal, 87, 164s-171s.

Wikipedia (2010).“Stainless steel".Retrieved from http://en.wikipedia.org/wiki/stainless_steel on 21/8/2017.

Zou Gui-sheng, Wu Ai-ping, Ren Jai-lie.Yang Jun and Zhao Wen-qing (2004). Effect of heat input on microstructure and properties of welded joint in magnesium alloy AZ31B.