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Model For Assessment And Evaluation Of Tensile Strength Based On Applied Load, Percent Elongation And Change In Length Of Mild Steel Weldment

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Abstract

The objective of the study is to establish mathematical relationship between process parameters (inputs) and process responses (outputs) which correctly predict the tensile behaviour of arc- welded mild steel plate employing shielded metal arc welding process. The derived model; $\beta = ɤ(\frac{\delta}{\alpha})^{2.0001}$ show that tensile strength is dependent on the load applied, change in length and percent elongation. Correlation of tensile strength with the independent variables suggest that the load applied have strong influence on the predicted parameter (tensile strength) most compared to other variables (change in length and percent elongation). Model predicted values were compared with the corresponding experimental data, the closeness in the values is indicative of the proximate agreement between both. The maximum deviation of model predicted data from the corresponding experimental value is 0.35% which is quite within the acceptable deviation range of experimental results and so the model is considered reliable. The developed model can be used effectively at 99.65% confidence level.

Keywords: Model, evaluation, tensile strength, mild steel, weldment.

Introduction

There is scarcely any steel structure or component that could be fabricated without welding. Welding being an important fabrication process, is used in every industry large or small for the joining of metals/alloys and plastics (Khanna, 1990). The process is efficient, economical and dependable as a means of joining materials (Duggal, 2006). All types of welded structures and likewise the welded joints in these structures or components are designed for service related capabilities or properties. The response of a weldment to external force should be a primary concerned to an engineer, therefore it is necessary to know something about the limiting values which can be withstood by the weldment without failure (Dieter, 1986). Present day engineering industry relies heavily on the integrity of the welds for adequate and reliable performance of components, structures or plants. Weld integrity is dependent on the base metal, specifications and welding processes. Reliability of weld performance is evaluated by measurement and control of weld properties. It is accepted widely that testing, measurement and control of welds should be optimized based on fitness-for-purpose approach taking into account the welding processes and economical aspects of ensuring the desired levels of reliability. Recent advances in test techniques for ensuring the desired quality have not met high technological demands (Raj et al., 2012). Mechanical property assessment and evaluation of weldment of a given material is essential in assessing the quality of the weld. However, in many cases, like in the case of thin weldments or weldments of costly materials, it may not be possible to carry out mechanical testing using specimens of size and geometry as per standards/codes, because the volume of material available is not adequate. Again, in the case of service exposed components, when it is necessary to find out the strength of the welded joint without jeopardizing the functional capabilities of the components. In view of this, several authors have designed models that have been used effectively in

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predicting the mechanical behaviour of weldment in service. Mathematical modeling is very important because it allows some rather expensive and repetitive experimentation to be avoided (Turner and Perre, 1997). Nwoye (2011) formulated model for assessing and predicting the hardness of HAZ of aluminium weldment cooled in groundnut oil in relation to similarly cooled mild steel and cast iron weldments. Palaniel et al (2011) developed a mathematical model to predict the mechanical properties of friction stir welded AA6351 aluminium alloy. Narongchai et al (2006), investigated the optimal factors of flux cored arc welding process for steel ST37 applying composite design method. Fassani and Trevisan (2003), investigated the thermal cycles obtained from concenteated heat source and distributed heat source in multipass welding process using analytical model to predict the temperature field away from the fusion zone and heat affected zone. Wen et al (2001) demonstrated that finite element analysis can be applied to better understand the Submerged arc-welding process with the view of reducing geometrical distortion, residual stresses and strains caused by welding.

The works by these authors have shown that models are reliable tools that could be safely used in the prediction of weldment properties of interest provided the independable variables are known, hence depicting the usefulness of models in engineering. The present study is aimed at deriving a model that could be used to evaluate tensile strength in a cost effective way based on known values of applied load, percent elongation and change in length of welded mild steel.

Materials and methods

The major materials and equipment used for the study were mild steel plates, SMAW Unit (AC), welding transformer (STICK and TIG Mode with inbuilt-rectifier), 3.2 ×350mm electrode (rutile), electrode drying oven, stop watch, digital multimeter, metallurgical cut-off wheel and tensometer. The chemical composition and tensile properties of the base material used in this study are presented in Tables 1 and 2 respectively. The full details of the experimental procedures are presented in (Adzor, 2012).

Table 1: Chemical composition of the as-received mild steel plate

Elements	% Composition
C	0.158
Si	0.219
Mn	0.493
P	0.025
S	0.006
Cr	0.087
Ni	0.011
Mo	0.002
Al	0.030
Cu	0.051
Co	0.003
Ti	0.001
Nb	0.003
V	0.002
W	0.033
Pb	0.003
B	0.001
Sn	0.003
Zn	0.002
As	0.005
Bi	0.002
Ca	0.001
Ce	0.003
Zr	0.002
La	0.002
Fe	98.9

Table 2:Tensile properties of the as-received mild steel plate

Base material	Tensile strength (N/mm^2)	Elongation (%)
Mild steel	411,073	17.4

Model formulation

Experimental data obtained from research work (Adzor, 2012) carried out at the Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka were used for this work. Computational analysis of experimental data (Adzor, 2012) shown in Table 3, which gave rise to Table 4, indicates that,

$\frac{\gamma}{\beta} \approx (\frac{\alpha}{\delta})^{n}$ ....(1)

$\frac{\gamma}{\beta} = \frac{\alpha^n}{\delta^n}$ ....(2)

$\frac{\beta}{\gamma} = \frac{\delta^n}{\alpha^n}$ ....(3)

$\beta = \gamma(\frac{\delta^n}{\alpha^n})$ ....(4)

$\beta = \gamma(\frac{\delta}{\alpha})^{n}$ ....(5)

$\beta = \gamma(\frac{\delta}{\alpha})^{2.0001}$ ....(6)

n = 2.0001 ; Equalizing constant.[Determined using C-NIKBRAN (Nwoye, 2008)]

Analysis of derived model

The derived model show that, tensile strength is dependent on the load applied, change in length and percent elongation of the welded steel. On applying load to the welded steel, if change in length and the percent elongation is known, the tensile strength can be evaluated. Furthermore, with specification of a material, of known values of desirable tensile strength, change in length and percent elongation, the model could be used to predict the load which the weldment can sustained prior to failure.

The standard error (STEYX) in predicting the value of tensile strength for each value of load applied in the derived model are;

Ex = 1.5391
MoD = 2.4800
LSM = 0.2968

Correlation between tensile strength and load applied are;

Ex = 0.9999
MoD = 0.9999
LSM = 1.0000

Correlation between tensile strength and change in length are;

Ex = 0.0981
MoD = 0.1074
LSM = 0.0981

Correlation between tensile strength and percent elongation are;

Ex = 0.0980
MoD = 0.1074
LSM = 0.0980

The correlation between the tensile strength and load applied, tensile strength and change in length, and tensile strength and percent elongation were obtained using excel 2003 version software. The correlation (0.9999) and (0.9999) between the tensile strength and load applied of the derived model and experiment are quite close and approximately equal to 1, when compared to the correlation (0.1075) and (0.0981) between the tensile strength and change in length and the correlation (0.1074) and (0.0980) between the tensile strength and percent elongation of the derived model and experiment respectively, it can be concluded that the maximum load sustained by the welded specimens in tension before failure is responsible for the strong correlation between tensile strength and load compared to the correlation between tensile strength and percent elongation, tensile strength and change in length.

Boundary conditions;
Change in length = 20 - 35mm
Elongation = 8.702 - 15.218%
Load = 80878 - 89540N
Tensile strength = 426312 - 471977N/mm^2

Standard errors were evaluated for independent variables affecting the predicted parameter. In the derived model, load applied was used in the determination of the standard errors because the load applied affected tensile strength most, this is because the percent elongation and change in length resulted from load applied. The three variables (load, elongation and change in length) make up the model because when load is added, change in length will occured and then elongation can be calculated.

Model validation

Deviational analysis

The formulated model was validated using deviational and statistical analysis. Deviational analysis involves direct analysis and comparison of model predicted values with those obtained from experiment for equality or near equality. Analysis and comparison between these values revealed deviation of model predicted values from those of the experiment as shown in Table 4. The maximum deviations of the model predicted values of tensile strength from experimental results evaluated is 0.35% was found to be very low and quite within the acceptable deviation range for experimental results. This gives confidence level of 99.65%. Hence, the model is considered reliable. The closeness in the models predicted results with those of the experimental is an indication of the proximate agreement between both. The deviations of the model predicted values of the tensile strength from the corresponding experimental values is believed to

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be due to the fact that the surface properties of the welded steel and the physiochemical interactions between the weld zones and the surrounding which played vital roles (during the welding operations) were not considered during the model formulation. It is expected that the introduction of the correction factor to the model predicted values of the tensile strength gives exactly the corresponding experimental values.

Deviation (D_v) of model predicted values from the experimental values is given by;

$$D_v = \frac{(M_oD - ExD)}{ExD} \times 100\% \quad \text{.........................(7)}$$

Correlation factor (Cf) is the negative of the deviation i.e

$$Cf = - Dv \quad \text{..........(8)}$$

Introduction of the corresponding values of Cf from equation (8) as shown in Table 4 into the model gives exactly the corresponding experimental values. Results of deviational analysis as shown in Table 4 shows that the derived model is valid since the model deviations from experimental values are generally quite within the acceptable range for experimental results.

Statistical analysis

Statistical analysis involves the evaluation of the correlations between the process variables. The correlation between tensile strength and load applied are 0.9999 and 0.9999 as obtained from experiment and derived model respectively. Similarly, the correlation between tensile strength and change in length are 0.0981 and 0.1074 as obtained from experiment and derived model respectively. While the correlation between tensile strength and percent elongation are 0.0980 and 0.1074 as obtained from experiment and derived model respectively. Based on the foregoing, it is strongly believed that the proximity of the correlations of experimental and model predicted results are indicative of the model validity.

Results and discussion

The derived model is equation (6). Computational analysis of experimental results presented in Table 3 gave rise to Table 4. A comparison of the tensile strength values from experiment and those of the model show model values are very much within the range of the experiment values. Results of this comparison as presented in Table 4 show that the tensile strength values as obtained from experiment, derived model and least square method are in close approximations. Thus, the model equation, giving tensile strength as a function of the applied load, change in length and percent elongation are demonstrably accurate and is simple enough to be of engineering usefulness in predicting the values of the tensile strength in the steel weldment. The closeness in the model predicted values of the tensile strength with those of the corresponding experimental values is an indication of the proximate agreement between the experimental and model predicted results. The maximum and least deviations of the model predicted values of the tensile strength from the corresponding experimental results are 0.35% and 0.21%, which is quite within the acceptable deviations range of experimental results.

Table 3:Tensile properties of welded steel plates at different welding conditions

Sample No.	Welding conditions	Maximum load applied (N)	Change in length (mm)	Tensile strength (N/mm^2)	Elongation (%)
TP1	120A(AC)	89,540	29	471,977	12.6
TP2	125A(AC)	86,653	20	456,759	8.7
TP3	120A(DC-)	80,878	26	426,312	11.3
TP4	125A(DC-)	83,765	34	441,535	14.8
TP5	120A(DC+)	86,653	35	456,759	15.2
TP6	125A(DC+)	83,765	24	441,535	10.4

Table 4: Tensile strength as obtained from experiment, derived model and least square method.

Tensile strength (N/mm^2)			Dv	Cf
ExD	MoD	LSM		
471,977	473,418	471,978	0.3	-0.3
456,759	457,726	456,759	0.21	-0.21
426,312	427,493	426,314	0.28	-0.28
441,535	442,854	441,534	0.3	-0.3
456,759	458,358	456,759	0.35	-0.35
441,535	443,013	441,534	0.33	-0.33

Figure. 1 show the variation of the tensile strength with load applied of welded metals as obtained from experiment, derived model and least square method. The graph indicate that, the tensile strength increases linearly to a maximun limit of $473{,}977 N/mm^2$ as the applied load was increased to 89,540N. The linear relationship exhibited between

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the tensile strength and applied load is an evidence of the high correlation existing between the parameters (tensile strength and load applied).

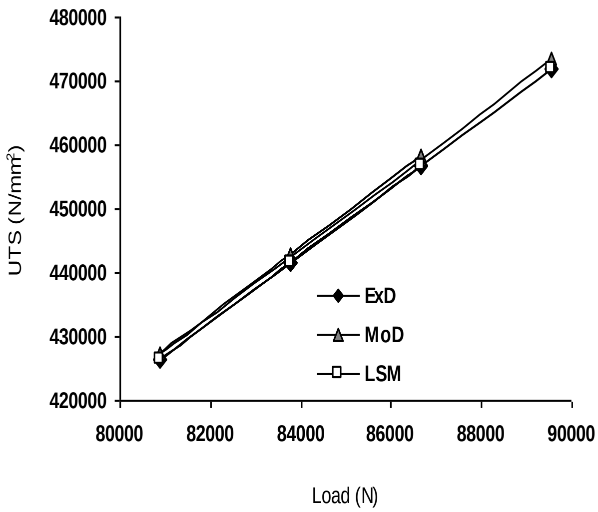

Figure 1: Variation of tensile strength of the welded metals with load applied as obtained from experiment, derived model and least square method (Adzor, 2012).

Figure. 2 show the variation of the tensile strength with percent elongation of welded metals as obtained from experiment, derived model and least square method at the different welding conditions. It is evident from the graph that, as the percent elongation decreases, the tensile strength also decreases, and as the percent elongation began to increase the tensile strength also increases and finally, as the values of the percent elongation began to decrease tensile strength also decreases. The observed trend could be attributed to the effect of thermal and cooling cycles in the welded metals and it resulting influence on the percentage elongation.

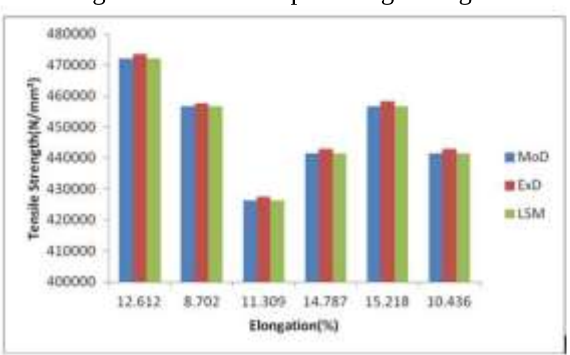

Figure 2: Variation of tensile strength of the welded metals with percent elongation as obtained from experiment, derived model and least square method(Adzor, 2012).

Figure. 3 show the variation of the tensile strength with change in length of welded metals as obtained from experiment, derived model and least square method at different welding conditions. Looking at the trend, the same argument (in Figure.2) holds for Figure 3, where (tensile strength and change in length) values are undulating.

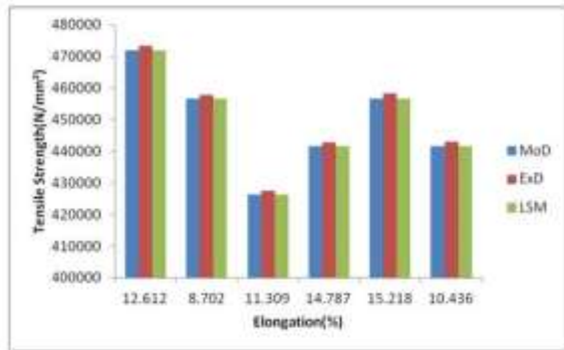

Figure 3: Variation of tensile strength with change in length of welded metals as obtained from experiment, derived model and least square method(Adzor, 2012).

Conclusion

A comparison of results obtained from the study with those estimated using the formulated model showed that the results are in proximate agreement. Hence, the derived model could serve as a useful tool in engineering for predicting tensile strength in low carbon steel weldment. It was observed that the maximum load sustained by the welded metal prior to fracture affected the predicted parameter (tensile strength) most compared to other variables (percent elongation and change in length).

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LIST OF SYMBOLS

ExD = Results obtained from experiment
MoD = Result predicted by derived model
LSM = Results predicted using least square method
Dv = Deviation (%)
Cf = correction factor (%)
ɤ = Load (N)
β = Ultimate tensile strength (N/mm^2)
α = Elongation (%)
δ = change in length (mm)
n = Equalizing constant