International Journal of Engineering Innovation & Research
Volume 9, Issue 3, ISSN: 2277 – 5668

Effect of Shielding Gas on the Tensile Properties of High Carbon Steel Weldment using Gas Tungsten Arc Welding in Combination of Argon and Carbon (IV) Oxide Gases

Paul Chukwulozie Okolie [1*], **Christopher Igbinosa Eboigbe** [2], **Sylvester Emeka Abonyi** [1] **and Ugwuegbu Duke Chiagoro** [3]
[1] Department of Mechanical Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.
[2] Department of Production Engineering, University of Benin, Edo State, Nigeria.
[3] Department of Mechanical Engineering, Federal Polytechnic Nekede, Imo State, Nigeria.
*Corresponding author email id: pc.okolie@unizik.edu.ng

Date of publication (dd/mm/yyyy): 02/06/2020

Abstract **– The research was carried out with the aim of statistically investigating the effect of shielding gas on the tensile properties of high carbon steel weldment using Tungsten Inert Gas (TIG) in combination of argon and carbon (iv) oxide gases. TIG welding technique was used to join the weld. An experiment was designed using the design expert software 10.0.1 version, which developed a combined mixture design of twenty seven experimental runs. The combined and process factor design was applied to statistically analyze the effect of shielding gas on the yield strength of the weldment. The statistical evaluation consists of mixture and process variable, having current, voltage, argon and carbon (iv) oxide gases as input parameters and yield strength as the response. The result obtained from the design summary gave minimum value of tensile strength as 280MPa and maximum 485MPa while mean value was 369.82 and standard deviation of 46.94. Fit Summary statistics which gave quadratic by quadratic order having sequential p values of less than 0.0001 for both mix and process orders with predicted R squared value of 0.9823 and Adjusted R squared value of 0.9959 which shows that the model is significant. Analysis of Variance (ANOVA) also showed that the model is significant while the Goodness of fit statistics obtained showed adequate precision value of 80.710 which showed that the signal to noise ratio was adequate and can be used to navigate the design space. The normality plot revealed that the computed residuals are approximately normally distributed an indication that the model developed is satisfactory while the presence of outliers were not noticed in the cook's distance plot. This study reveals that argon gas combining with carbon (iv) oxide will produce weldments with high tensile strength as could be seen in the statistical analysis.**

Keywords **– Effect of Shielding Gas, Shielding Gas, High Carbon Steel Weldment, Tungsten Inert Gas, Combination, Argon and Carbon.**

I. INTRODUCTION

Gas shielding protects the molten metal from atmospheric contamination and also has a great effect on the overall performance with respect to improving the weld metal properties, such as strength, corrosion resistance and toughness. The common shielding gases which are argon, helium and carbon dioxide can also change the weld bead shape and size; improve the weld quality by reducing defect and scrap rates; increase welding speeds and also lower production times [1, 2, 3]. All these performance enhancements can result from the use of the correct shielding gas which can be directly translated into tangible savings and improved weld quality. Welding is one of the well-known manufacturing processes of joining metals because of the low price and high quality of the welding process. Oxygen, nitrogen and water vapour are always present in ambient air and can cause weld contamination. Shielding gases prevents reactive gases from the vicinity of the weld, thereby averting the detrimental effects on the molten metal of the surrounding atmosphere. Reference [4, 5, 6] stated that shielding gas also interacts with the base and filler metal and can thus change basic mechanical properties of the weld area, such as strength, toughness, hardness and corrosion resistance. The application of different shielding gases can result in different penetration and weld bead profiles. The shielding gas composition affects the material transition from the molten electrode to the weld pool, which in turn influences the amount and size of the spatter created. The metal transfer phenomenon and bead formation are strongly influenced by the composition and flow rate of shielding gases [7]. Number of investigations has been performed to study the effect of shielding gas composition on mechanical properties of steel weldments, but its effects on the tensile properties of high carbon steels have not been established [8, 9].

From literature several statistical techniques can be used to determine the required output responses through the development of mathematical equations to postulate the relationships between the input parameters and output variables in TIG welding process [10-11].

Reference [12] had carried out experimental analysis to study the effects of the welding process parameters on welding of material AISI 1020 using gas metal arc welding process by Taguchi method combined with grey relational analysis. This study was carried out with the aim of statistically analyzing the effect of shielding gas on the tensile strength of high carbon steel weldment so as to produce high quality welds.

II. MATERIALS AND METHOD

Materials

The key parameters considered in this work are argon, carbon (iv) oxide gases, welding current and welding voltage. The range of the input variables used is shown in table 1. 135 pieces of high carbon steel coupons, measuring 60mm x 40mm x10mm each were used for the experiment. The experiment was performed 27 times, using 5 specimens for each run. Figure 1 shows the TIG welding setup. The welding process combined two types of shielding gases to protect the weld specimen from atmospheric interference. In this paper, argon and carbon (iv) oxide were used at different compositions.

Figure 2 shows the shielding gas cylinders and regulators housing the two types of gases used. Figure 3 shows TIG welding torch which is fixed with it using a clamp at a particular angle so that during welding a stable and continuous arc is formed. Welding speed can be changed using a regulator. The distance between the torch tip and work piece can be controlled using the adjustable knob. The torch is fixed with the movable tractor unit. A tungsten electrode is fixed in the torch and the gases flows through it. This is the main part of TIG welding setup which controls the amount of current and voltage supplied during welding. The torch was maintained at an angle of approximately 90° to the work piece. Figure 4 shows the TIG welding torch. Plate 4 shows the samples after welding, weld specimen are shown in figure 5. Figure 6 shows the universal testing machine which was used to obtain the response. The Initial randomized design employed for data collection was developed using the design expert software (Combined Mixture Design), producing 27 experimental runs. The input parameters and output parameters make up the experimental result and the response recorded from the weld specimen were used as the data. Table 2 shows the experimental data.

Table 1. Range and levels of input variables.

Mixture Component	Unit	Lower Level	Upper Level
Argon	%	10	90

Mixture Component	Unit	Lower Level	Upper Level
Carbon (iv) Oxide	%	10	90

Process Factors	Unit	Lower Level	Upper Level
Current	Amp	140	170
Voltage	V	20	22

Fig. 1. TIG Equipment (P.C. Okolie et al, 2019).

Fig. 2. Shielding Gas (P.C. Okolie et al, 2019).

Fig. 3. TIG Welding Torch (P.C. Okolie et al, 2019).

Fig. 4. Weld samples (P.C. Okolie et al, 2019).

Fig. 5. Weld specimen (P.C. Okolie et al, 2019).

Fig. 6. Universal Tensile Testing Machine (P.C. Okolie et al, 2019).

III. RESULTS AND DISCUSSION

Table 2. Experimental data (P.C. Okolie et al, 2019).

S/N	Argon (%)	Carbon Dioxide (%)	Current (Amp)	Voltage (V)	Tensile Strength (MPa)
1	50	50	155.00	21.00	410
2	10	90	140	20	454
3	10	90	170	20	345
4	10	90	140	22	400
5	10	90	170	22	485
6	10	90	155	20	360
7	10	90	140	21	370
8	10	90	170	21	354
9	10	90	155	22	405
10	10	90	155	21	324
11	90	10	140	20	380
12	90	10	170	20	305
13	90	10	140	22	410
14	90	10	170	22	350
15	90	10	155	20	280
16	90	10	140	21	372
17	90	10	170	21	315
18	90	10	155	22	322
19	90	10	155	21	285
20	50	50	140	20	380
21	50	50	170	20	350
22	50	50	140	22	389
23	50	50	170	22	370
24	50	50	155	20	380
25	50	50	140	21	405
26	50	50	170	21	390
27	50	50	155	22	395

Table 3. Combine mixture design summary (P.C. Okolie et al, 2019).

Component	Name	Units	Type	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Argon	%	Mixture	10	90	0.000 = 10	1.000 = 90	50	33.282
B	B	%	Mixture	10	90	0.000 = 10	1.000 = 90	50	33.282

Component	Name	Units	Type	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
				Total =	100.00	**L_Pseudo Coding**			

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
C	Current	Amp	Numeric	Continuous	140	170	-1.000 = 140	1.000 = 170	155	12.4808
D	Voltage	V	Numeric	Continuous	20	22	-1.000 = 20	1.000 = 22	21	0.83205

Response	Name	Unit	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Tensile Strength	MPa	27	Polynomial	280	485	369.815	46.9435	1.73214	None	Quadratic x Quadratic

The model summary which shows the mixture components, the process factors and the lowest and highest values of the response including the mean and standard deviation is presented as in Table 3 below. Result of Table 3 revealed that the model requires the polynomial analysis order. The minimum value of tensile strength was observed to be 280MPa, with a maximum value of 485MPa, mean value of 369.82 and standard deviation of 46.94 and a ratio of 1.73.

The model fit summary presents some unique matrix of probabilities that helps determine the best crossed model for mixture and process combinations. The highest order polynomial where the additional terms are significant for both the mixture and process factors and the model is not aliased was selected as the best fit model. In addition, the selected model must have insignificant lack of fit and must focus on maximizing the adjusted R^2 value. Table 4 presents the computed fit summary for yield strength. In Table 4, the quadratic by quadratic model was obtained for mix and process order respectively and it gave an adjusted R-square value of 0.9959, a predicted R-square value of 0.9823 and was selected as the best fit model for optimizing the tensile strength of high carbon steel weldment. The reason for selection was the reasonable agreement between the predicted R-square value and the adjusted R-square value.

Table 4. Fit summary statistics for validating the model significance towards maximizing the tensile strength (P.C. Okolie et al, 2019).

Combined Model Mixture Process Fit Summary Table						
		Sequential p-value			**Summary Statistics**	
Mix	**Process**	**Mix**	**Process**	**Adjusted**	**Predicted**	
Order	**Order**			**R-Squared**	**R-Squared**	
M	M					
M	L		0.1106	0.0983	-0.0491	
M	2FI		0.1584	0.1386	-0.0534	
M	Q		0.1868	0.1959	-0.0777	
M	C	*	* 0.9914	0.1121	-0.2835	Aliased

Combined Model Mixture Process Fit Summary Table

		Sequential p-value			**Summary Statistics**	
Mix	**Process**	**Mix**	**Process**	**Adjusted**	**Predicted**	
Order	**Order**			**R-Squared**	**R-Squared**	
M	M					
L	M	0.0132		0.1904	0.0661	
L	L	0.0487	0.1600	0.2857	-0.0585	
L	2FI	0.0255	0.0709	0.4025	0.0657	
L	Q	0.0323	0.1498	0.5045	0.2652	
L	C	* 0.1897	* 0.9997	0.3271	-0.4866	Aliased
L	M					
Q	M	0.1790		0.2190	0.0876	
Q	L	0.4607	0.3025	0.2753	-0.2733	
Q	2FI	0.3824	0.1022	0.4176	-0.7270	
Q	Q	< 0.0001	< 0.0001	0.9957	0.9823	Suggested

In assessing the strength of the quadratic by quadratic model towards maximizing the tensile strength, one way analysis of variance (ANOVA) was generated for tensile strength response variable and result obtained is presented in Table 5.

From the results of table 5, the Model F-value of 355.63 implies the model is significant. There is only a 0.01% chance that a "Model 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 Linear Mixture Components, AB, AC, AD, BC, ABC, ACD, BCD, AC^2, AD^2, BC^2, BD^2, ABCD, ABC^2, ABD^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

Table 5. Anova table for validating the model significance towards maximizing the tensile strength (P.C. Okolie et al, 2019).

	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	significant
Model	57210.91	17	3365.35	355.63	< 0.0001	
Linear Mixture	12693.56	1	12693.56	1341.39	< 0.0001	
AB	13795.93	1	13795.93	1457.89	< 0.0001	
AC	6144.00	1	6144.00	649.27	< 0.0001	
AD	2281.50	1	2281.50	241.10	< 0.0001	
BC	266.67	1	266.67	28.18	0.0005	
BD	2860.17	1	2860.17	302.25	< 0.0001	

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	significant
ABC	300.44	1	300.44	31.75	0.0003	
ABD	711.11	1	711.11	75.15	< 0.0001	
ACD	56.25	1	56.25	5.94	0.0375	
BCD	9409.00	1	9409.00	994.30	< 0.0001	
AC^2	7120.22	1	7120.22	752.43	< 0.0001	
AD^2	589.39	1	589.39	62.28	< 0.0001	
BC^2	2938.89	1	2938.89	310.57	< 0.0001	
BD^2	6922.72	1	6922.72	731.56	< 0.0001	
ABCD	1457.04	1	1457.04	153.97	< 0.0001	
ABC^2	5348.15	1	5348.15	565.17	< 0.0001	
ABD^2	5180.59	1	5180.59	547.46	< 0.0001	
Residual	85.17	9	9.46			
Cor Total	57296.07	26				

To validate the adequacy of the quadratic by quadratic model based on its ability to maximize the tensile strength the goodness of fit statistics is presented in table 6.

From the result of table 6, it was observed that the "Predicted R-Squared" value of 0.9823 is in reasonable agreement with the "Adj R-Squared" value of 0.9957. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The computed ratio of 80.7110 as observed indicates an adequate signal. This model can be used to navigate the design space and adequately maximize the tensile strength.

Table 6. GOF statistics for validating model significance towards maximizing the tensile strength (P.C. Okolie et al, 2019).

Std. Dev.	**3.08**	**R-Squared**	**0.9985**
Mean	369.81	Adj R-Squared	0.9957
C.V. %	0.83	Pred R-Squared	0.9823
PRESS	1015.32	Adeq Precision	80.711
-2 Log Likelihood	107.64	BIC	163.67
		AICc	209.64

To accept any model, its satisfactoriness must first be checked by an appropriate statistical analysis output and to diagnose the statistical properties of the combined mixture and process factor design using the quadratic by quadratic model, the normal probability plot of residual for tensile strength is presented in Figure 7.

The normal probability plot of studentized residuals was employed to assess the normality of the calculated residuals. The normal probability plot of residuals which is the number of standard deviation of actual values based on the predicted values was employed to ascertain if the residuals (observed-predicted) followed a normal distribution. It is the most significant assumption for checking the sufficiency of a statistical model. Result of Figure 7 revealed that the computed residuals are approximately normally distributed an indication that the model developed is satisfactory.

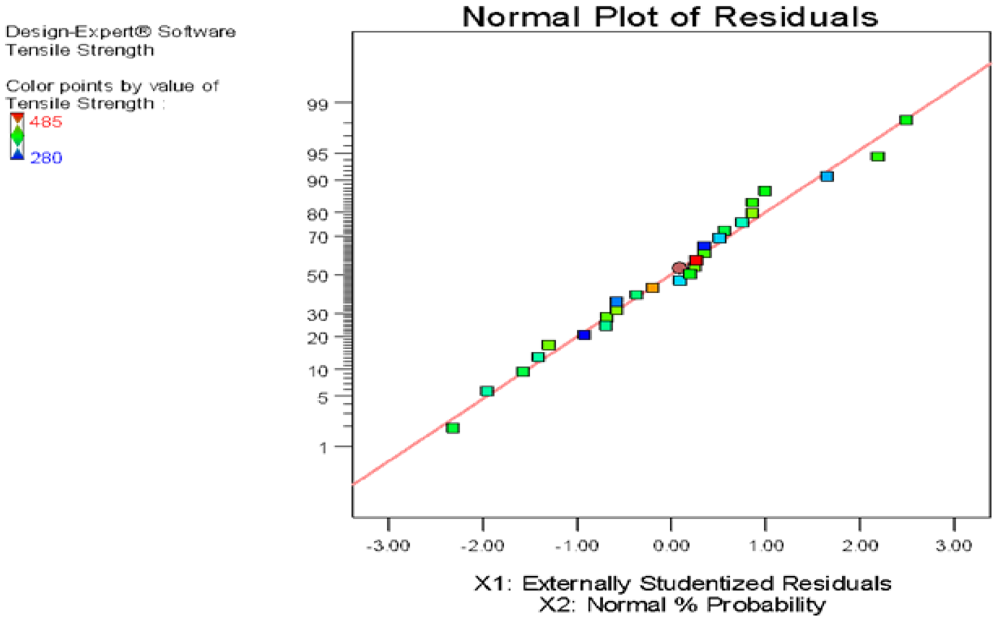

Fig. 7. Normal probability plot of studentized residuals for maximizing tensile strength.

To determine the presence of a possible outlier in the experimental data, the cook's distance plot was generated for the response. The generated cook's distance plot for the tensile strength is presented in Figures 8.

The cook's distance plot has an upper bound of 1.00 and a lower bound of 0.00. Experimental values smaller than the lower bound or greater than the upper bounds are considered as outliers and must be properly investigated. Result of figure 8 indicate that the data used for this analysis are devoid of possible outliers thus revealing the adequacy of the experimental data.

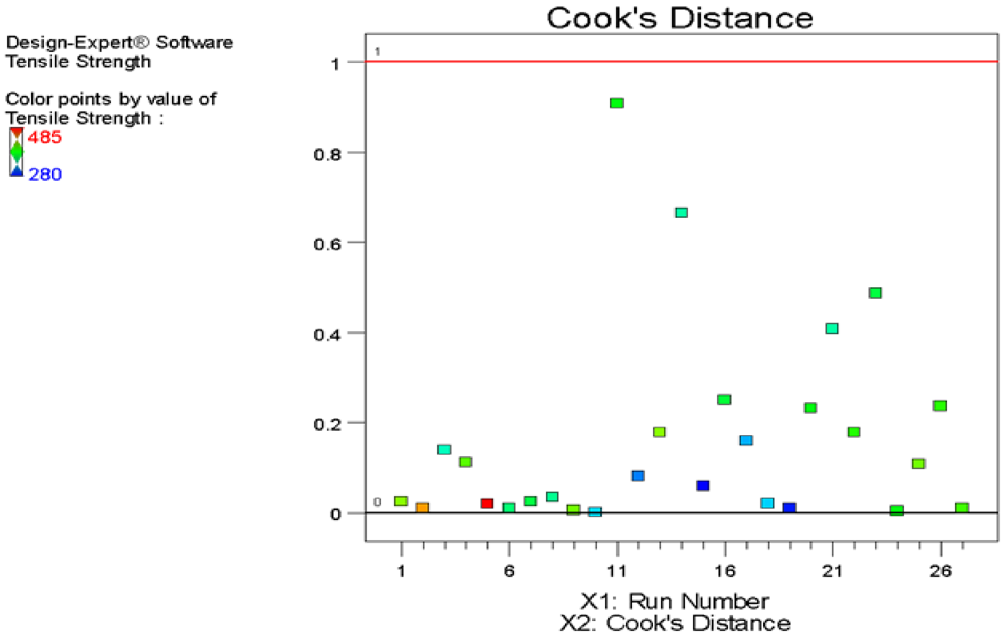

Fig. 8. Generated cook's distance for tensile strength.

In this study, the combine mixture design was used to statistically analyse the effect of shielding gas on the tensile strength of high carbon steel weldment using tungsten inert gas welding process. The statistics summary which shows the mixture components, the process factors and the lowest and highest values of the response including the mean and standard deviation revealed that the model is of the quadratic by quadratic type which requires the polynomial analysis order, which was the best model summary to be selected for the research. The model fit summary statistics was seen to be significant for both mixture and process factors while the lack of fit was seen to be insignificant which shows that the errors in the model are insignificant and the reason for selection was the reasonable agreement between the predicted R-square value and the adjusted R-square value. The strength of the quadratic by quadratic model towards maximizing the tensile strength was checked using one way ANOVA and from the results it implies the model is significant. Goodness of Fit statistics was employed to validate the adequacy of the quadratic by quadratic model based on its ability to maximize the tensile strength, and it was observed that the value of predicted R-Squared is in reasonable agreement with the Adjusted R-Squared value, while the signal to noise ratio was adequate and can be used to navigate the design space.

The normal probability plot of studentized residuals was used to check the sufficiency of the statistical model and it revealed that the computed residuals were approximately normally distributed which proved the model developed is satisfactory. The presence of possible outliers was checked with cook's distance plot and it was observed that there is one outlier out of 27 experimental runs which showed the adequacy of the experimental data.

IV. CONCLUSION

The quality of a weld is determined by the micro structural configuration of the parent metal and the weld pool protection by the shielding gases. It is also known that the choice and percentage composition of the shielding gases influences the heat input and penetration depth of the molten metal weld.

This study has shown that the voltage, current and percentage composition of shielding gases have very strong influence statistically on the tensile strength of high carbon steel weldments using Tungsten Inert Gas Welding Process.

REFERENCES

[1] R. Venkatesh, V. Vijayan, A. Parthiban, T. Sathish, S. Chandran : Comparison of different tool path in pocket milling. International Journal of Mechanical Engineering and Technology 9 (12), 2018, pp.922-927.

[2] P. Kah and J. Martikainen. : Influence of shielding gases in the welding of metals. International Journal of Advanced Manufacturing Technology Vol. 64, 2013, pp 1411–1421.

[3] S.M. Rao. S.M. Liao, and H.L. Tsai,. Effects of shielding gas compositions on arc plasma and metal transfer in gas metal arc welding. Journal of Applied Physics 107, 2010, Pp 1-11.

[4] N.R. Anand, V.M. Chavan and N.K. Sawant: The effect of shielding gases on mechanical properties and microstructure of austenitic stainless steel weldments. International journal of Mechanical Engineering and Robotics research. Vol. 2, No. 4, 2013, pp 253-262.

[5] R.M. Pires, I, Quintino , L. Miranda. Analysis of the influence of shielding gas mixtures on the gas metal arc welding metal transfer modes and fume formation rate. Mater Des J, 28(5), 2006, 1623–31.

[6] C.P. Okolie, J.I. Achebo, and J.O. Osarenmwinda , "Effect of Shielding Gas on the Tensile properties of High carbon Steel Weldment using Gas tungsten Arc Welding in combination of argon and carbon (iv) oxide gases". International Journal of Engineering and Industry. ISSN: 2191-3315, Volume 3, Issue 1, 2019, page 1-9.

[7] D.N. Deepashri, V.S. Raja, and R. Raman. : Effect of Nitrogen Addition on the Microstructure and Mechanical Behavior of 317 L and 904 L Austenitic Stainless Steel Welds. Journal of Material Science 41(7), 2006, 2097-2112.

[8] S.W. Campbell, A.M. Galloway, and McPherson. Artificial Neural Network Prediction of Weld, 2012.

[9] L.U. Shanping, L. Hidetoshi, F. Kiyoshi. Effects of CO_2 shielding gas additions and welding speed on GTA weld shape. J Mater Science 2005;40:2481–5.

[10] P. Elesztos, R. Janco, V. Vostiar. Optimization of welding process using a genetic algorithm. Journal of Mechanical Engineering – Strojníckycasopis (68), No 2, 2018, pp. 17– 24.

[11] D. Santha Rao, N. Ramanaiah. Process parameters optimization for producing AA6061 / TiB2. Composites by friction stir processing,

Journal of Mechanical Engineering-StrojnIckycasopis (67), No. 1, 2017, pp.101 – 118.
[12] A. Kumar , M. K. Khurana and P. K. Yadav : Optimization of Gas Metal Arc Welding Process Parameters.Materials Science and Engineering Vol.149, 2016, pp 1-11.

AUTHOR'S PROFILE

First Author

Paul Chukwulozie Okolie, Engr. Dr Paul Chukwulozie Okolie hails from Ndiamazu Okoroigbo Arondizuogu in Onuimo Local Government Area of Imo State. He is a holder of B.Eng. Mechanical/ Production Engineering and M.Eng. Industrial Production Engineering both from Nnamdi Azikiwe University Awka, Anambra State. Dr Paul holds a Doctor of Engineering degree from University of Benin, Edo State Nigeria. He is currently a Senior Lecturer in the Department of Mechanical Engineering Nnamdi Azikiwe University Awka. He is a member of council for regulation of Engineering in Nigeria, Nigerian Society of Engineers, Nigerian Institute of Management and Member, International As--sociation of Engineers. He has more than 50 Published Journals to his credit.

Second Author

Dr. Christopher Igbinosa Eboigbe, I am a lecturer 1 in the department of production engineering, University of Benin. I hold a Ph.D in Industrial Engineering from University of Benin, Edo state, Nigeria. email id: kristoeboi@gmail.com

Third Author

Sylvester Emeka Abonyi, Engr. Dr. Sylvester Emeka Abonyi hails from Opi, Nsukka Local Government Area of Enugu State. He attended Opi Boys Secondary School Opi, where he sat for Senor Secondary School Certificate in 1986. He studied Physics/ Chemistry at federal College of Education Eha-Amufu, Enugu State and graduated with distinction in 1993 and later went to the university and studied Electromechanical Technology and graduated in 2000 with Second Class Honor (Upper Division) at Nnamdi Azikiwe University Awka, Anambra State, Nigeria. He received his master of Technology degree from the same University in 2004. Dr Abonyi holds a Doctor of Engineering degree from University of Nigeria Nsukka, Enugu State Nigeria. He is currently a lecturer in the Department of Mechanical Engineering Nnamdi Azikiwe University Awka. He is a member of Council for Regulation of Engineering in Nigeria, Nigerian Society of Engineers, Nigerian Association of Technologist in Engineering, Solar Energy Society of Nigeria and host of others. email id: s.abonyi@unizik.edu.ng

Fourth Author

Ugwuegbu Duke Chiagoro, Engr. Ugwuegbu Duke Chiagoro is from Owerri West Local Government Area of Imo State. He is a holder of B.Eng., M.Eng. In Mechanical Engineering Majoring in Industrial Production. He is currently a Lecturer in the Department of Mechanical Engineering, Federal Polytechnic Nekede, Imo State. He is also pursuing his PhD in same field at the moment. He is an author of many journals and articles. email id: dukerealman@yahoo.com