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Modelling and Validation of The Production Parameters of Unalloyed Aluminium Sheets

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Keywords

Mechanical Properties
Modelling
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Abstract

Modelling of process parameters and its validation in Aluninium production industries poses great challenges in the production of Aluminium sheets in Aluminium Manufacturing companies. This research therefore focused on the modelling and validation of production parameters of unalloyed Aluminium sheets in Aluminium manufacturing industries. The process parameters investigated were temperature (T), pressure (P) and percentage by volume of Aluminium (A_p) used. The effects of these process parameters on the mechanical properties of the developed unalloyed Aluminium sheets were modelled to ease Aluminium manufacturing processes in Aluminium industries. From the plots obtained, it was observed that the optimal tensile strength, young modulus of elasticity, shear modulus and Brinell hardness number were 621MPa, 69GPa, 25.5GPa, and 61 at temperature of 1921°C, 1610°C, 1442°C and 1800°C respectively. In comparison with pressure, the obtained values for optimal tensile strength, young modulus of elasticity, shear modulus and Brinell Hardness Number were 562MPa, 68GPa, 26.2GPa and 61 at pressure of 72GPa, 69.5GPa, 69.5GPa and 69.5GPa respectively. Moreover, empirical Models were also developed for predicting the mechanical properties such as tensile strength, young modulus of elasticity, shear modulus and hardness for the produced unalloyed Aluminium sheets. The models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination (R^2) obtained ranges from 0.9213 (92.13%) to 0.9911 (99.11%) which indicates that a substantial good fit was achieved by the regression models developed. The mean absolute percentage error of the developed models also ranges from 0.46% to 3.38% which was below 10% recommended. The values obtained from the validation of these models were therefore found to be satisfactory, and shows good predictability of the model and its adequacy. Finally, the results obtained show that temperature and pressure had great effects on the mechanical properties of the produced unalloyed Aluminium sheets.

Cite

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1. INTRODUCTION

The research and development of new materials together with its design is the engine that drives economic progress. That is to say, today, technology depends greatly on scientific research of materials, and this contributes to economic growth of any nation. Moreover, there are inadequate empirical and interactive models to predict mechanical properties and determine the interaction of some process variables of the manufacturing processes in Aluminium production industries. This had resulted to most failure in the manufacture of these materials as a roofing material and other engineering applications. The utilization of process control and process monitoring are rarely fully implemented for the production of Aluminium sheets. This may be due to a poor scientific understanding of the manufacturing processes based on the

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complexities of the process containing multiple variables affecting the final products (Olodu and Osarenmwinda, 2018).

Kok (2005) examined the mechanical properties of Al_2O_3 particle reinforced 2024 Al alloy composites produced through vortex method. It was noted that optimum conditions of the production process were 700°C for pouring temperature, 550°C for preheated mold temperature, 900 rev/min for stirring speed, 5 g/min for particle addition rate, 1 min for stirring time and 6MPa for applied pressure respectively. Kumar et al. (2013) stated that the hardness and tensile strength of A359/Al_2O_3 MMC increases as temperature increased. In their study, it was also observed that electromagnetic stirring action adopted during the fabrication resulted in smaller grain size and good particulate matrix interface bonding. Venkatesh and Harish (2015) examined Al/SiC composites produced through the powder metallurgy route to achieve the desired properties and also to improve the mechanical properties of Aluminium. According to Nieh and Chellman (1984); Friend (1987), they observed that reinforcement of aluminium improves its strength, fatigue, modulus, wear resistance and creep. Studies on trimodal aluminium metal matrix composites and the factors affecting their strength were reported by Yao et al. (2010), they noted that among these factors, tensile strength was the most convenient and widely quoted measurement which is of central importance in many applications. Saravanan et al. (2015) observed that there is an increase of 30% in hardness and an increase in tensile strength that is almost twice that of base aluminum alloy for TiB_2 particulate reinforced composites. The influence of stirring speed and stirring time on the distribution of particles in SiC AMC has been analyzed by Prabu et al. (2006). Nieh et al. (1985) also observed that in the early stages of processing a non-uniform distribution of reinforcement, which persists to the final product in the forms of steaks or clusters of reinforcement with their attendant porosity all of which lowered the strength, ductility, and toughness of the Aluminium material. Furthermore, for a given matrix alloy, the elongation to failure is reduced by increasing volume fraction (Crowe et al., 1985). Rozovsky et al. (1973) reported that the compression of a short cylinder between anvils is a much better test for metal working applications. The deformation behavior of solid cylinders of an aluminum alloy metal matrix composite under dry condition was estimated by Joardar et al. (2012). Orbulov and Ginsztler (2012) observed that engineering factors such as the aspect ratio (height/diameter ratio) of the specimens and the temperature of the tests have significant effect on the compressive strength and properties of Aluminium. The effect of reinforcing particle shape and interface strength on the deformation and fracture behavior of an Al/Al_2O_3 composite was investigated by Romanova et al. (2009), they observed that interface debonding and particle cracking were the two mechanisms for a particle fracture.

This study therefore, focuses on the modelling and validation of production process parameters of unalloyed Aluminium sheets.

2. MATERIALS AND METHODS

The material used in this study is unalloyed Aluminium sheet obtained from Differential Aluminium Company located in Benin City, Edo State, Nigeria. This material was subjected to various temperatures and pressures ranging from 670°C to 2400°C and from 20 Gpa to 78 GPa respectively. These materials produced at various temperatures and pressures were evaluated for mechanical properties after cooling.

2.1. Method of Data Collection

The various samples of the developed unalloyed Aluminium sheets that were produced at various temperature and pressure were tested according to American Society for Testing and Materials (ASTM) using the tensometer and Charpy Impact Test machines respectively. The data obtained were further evaluated for mechanical properties for the developed Unalloyed Aluminium sheets. Furthermore, Samples were also tested on a 10 ton DAK tensile testing machine at a constant cross head speed of 1 mm/min. Standard samples of tensile specimens ASTM-E8M are prepared for testing. A total of 6 samples were tested in each case and average values were obtained.

2.2. Evaluation of Developed Unalloyed Aluminium Sheets for Mechanical Properties at Various Temperatures and Pressures

The developed unalloyed Aluminium sheets samples were evaluated for mechanical strength (tensile strength, young modulus of elasticity, Brinell hardness and shear modulus) using Equation 1 to 4 respectively (Idicula et al., 2009).

$$\text{Tensile strength} = \frac{\text{Maximum Load}}{\text{Original Cross - Sectional Area}} \tag{1}$$

$$\text{Young's modulus of Elasticity} = \frac{Stress}{Strain} = \frac{FL_o}{L_m - L_o} \tag{2}$$

Where, F = Applied force, L_o = Original length; L_m = Final length

$$\text{shear modulus} = \frac{\text{shear stress}}{\text{shear strain}} = \frac{\frac{F}{A}}{\frac{x}{y}} \tag{3}$$

Where, F = Applied force, A = Cross-sectional area; x = Extension; y = Original length

$$\text{Brinell Hardness Number (BHN)} = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]} \tag{4}$$

Where P is the load in kilogram, D is the steel ball diameter in millimeter, and d is the depression diameter or indentation diameter.

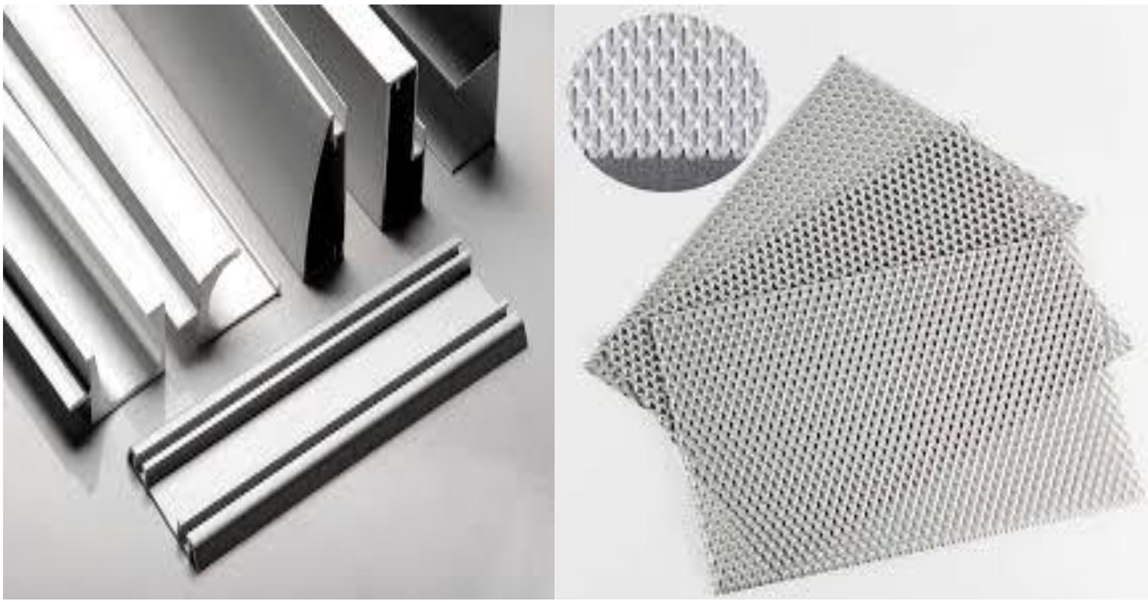

Figure 1. *Developed Aluminium Sheets*

2.3. Empirical Model Development of the Manufacturing Process of Unalloyed Aluminium Sheets

In this research work, all empirical models were developed using experimental values (E) obtained from the produced unalloyed Aluminium sheets using tensile strength, modulus of elasticity, shear modulus and Brinell hardness number results. The empirical model was used to predict the mechanical properties of the unalloyed Aluminium sheet material (tensile strength, modulus of elasticity, shear modulus and Brinell hardness number) by taking the inputs as percentage by volume of Aluminium, Pressure, percentage by volume of impurities and temperature respectively. The objective of the experiment is to allow an estimation of interactive and quadratic effects and therefore provide a predictive model that will find an improved, as well as represent the experimental observations as an empirical mathematical function. This is expressed in the form shown in equation 5 and 6.

$$\mathrm{Y} = \mathrm{Constant} + \alpha_1\mathrm{T} + \alpha_2\mathrm{M} + \alpha_3\mathrm{A}_p + \alpha_4\mathrm{TM} + \alpha_5\mathrm{TA}_p + \alpha_6\mathrm{MA}_p + \alpha_7\mathrm{T}^2 + \alpha_8\mathrm{M}^2 + \alpha_9{\mathrm{A}_p}^2 \quad (5)$$

$$\mathrm{Y} = \mathrm{Constant} + \alpha_1\mathrm{P} + \alpha_2\mathrm{M} + \alpha_3\mathrm{A}_p + \alpha_4\mathrm{PM} + \alpha_5\mathrm{PA}_p + \alpha_6\mathrm{MA}_p + \alpha_7\mathrm{P}^2 + \alpha_8\mathrm{M}^2 + \alpha_9{\mathrm{A}_p}^2 \quad (6)$$

Where, M= Percentage by volume of other impurities present in unalloyed Aluminium sheets (%)

A_p = percentage by volume Aluminium (%)

T = Temperature (°C)

P = Pressure (MPa)

Y = Output (Mechanical Properties)

and α_1, α_2, α_3, α_4, α_5, α_6, α_7, α_8, and α_9 are the coefficient of T, M, A_p, TM, TA_p, MA_p, T^2, M^2, and A_p^2 or P, M, A_p, PM, PA_p, MA_p, P^2, M^2, and A_p^2 respectively.

The output was obtained through the interaction between M, A_p and T or M, A_p and P. A quadratic model of second order regression was obtained for unalloyed Aluminium sheets for mechanical strength (tensile strength, modulus of elasticity, shear modulus and Brinell hardness number). A code was written in a MATLAB program (MATLAB software, version 7.5.0 (R2007b) to investigate the interactions of the various parameters of the developed empirical model.

2.4. Validation of the Models Developed

The mean absolute percentage error, and coefficient of determination was to validate the model. They were determined using equation 7 and equation 8 respectively.

$$\text{Absolute percentage error} = \frac{Experimental\ value - Predicted\ Value}{Experimental\ Value} \mid \quad (7)$$

$$\text{Coefficient of Determination}, R^2 = \left[1 - \frac{\sum(Y_i - \hat{Y})^2}{\sum(Y_i - \bar{y})^2}\right] \quad (8)$$

Where Y_i = Experimental value

$\hat{Y}$ = Predicted values

3. RESULTS AND DISCUSSION

The Empirical Model Developed for unalloyed Aluminium sheets (tensile strength, modulus of elasticity, shear modulus and Brinell hardness number) is shown in equation 9-16 respectively.

$$\text{Tensile Strength of Unalloyed Aluminium Sheet with Respect to Temperature } (6_{\mathrm{T}}) \\ = -93.4725 - 0.0629\mathrm{T} + 0.5717\mathrm{M} + 0.8493\mathrm{Ap} + 0.0069\mathrm{TM} + 0.0105\mathrm{TAp} \\ - 0.0376\mathrm{MAp} - 0.0014\mathrm{T}^2 + 0.0204\mathrm{M}^2 - 0.0356\mathrm{T}^2 \quad (9)$$

$$\text{Tensile Strength of Unalloyed Aluminium Sheet with Respect to Pressure } (6_{\mathrm{P}}) \\ = -61.6083 - 0.0264\mathrm{P} + 0.4261\mathrm{M} + 0.2420\mathrm{Ap} + 0.0044\mathrm{PM} + 0.0070\mathrm{TAp} \\ - 0.0213\mathrm{MAp} - 0.0010\mathrm{P}^2 + 0.0124\mathrm{M}^2 - 0.0192\mathrm{P}^2 \quad (10)$$

$$\text{Modulus of Elasticity of Unalloyed Aluminium Sheet with Respect to Temperature}(E_T) \\ = -24.3775 - 0.0130\mathrm{T} + 0.1316\mathrm{M} + 0.1362\mathrm{Ap} + 0.0018\mathrm{TM} + 0.0028\mathrm{TAp} \\ - 0.0083\mathrm{MAp} - 0.0004\mathrm{T}^2 + 0.0050\mathrm{M}^2 - 0.0085\mathrm{T}^2 \quad (11)$$

$$\text{Modulus of Elasticity of Unalloyed Aluminium Sheet with Respect to Pressure}(E_P) \\ = -26.8877 - 0.0596\mathrm{P} + 0.5647\mathrm{M} + 0.4228\mathrm{Ap} + 0.0033\mathrm{PM} + 0.0055\mathrm{PAp} \\ - 0.0212\mathrm{MAp} - 0.0007\mathrm{P}^2 + 0.0071\mathrm{M}^2 - 0.0116\mathrm{P}^2 \quad (12)$$

$$\text{Shear Modulus of Unalloyed Aluminium Sheet with Respect to Temperature}(\partial_{\mathrm{T}}) \\ = -172.4409 - 0.0460\mathrm{T} + 0.7486\mathrm{M} + 0.4670\mathrm{Ap} + 0.0137\mathrm{TM} + 0.0274\mathrm{TAp} \\ - 0.0445\mathrm{MAp} - 0.0033\mathrm{T}^2 + 0.0291\mathrm{M}^2 - 0.0768\mathrm{T}^2 \quad (13)$$

$$\text{Shear Modulus of Unalloyed Aluminium Sheet with Respect to Temperature}(\partial_{\mathrm{T}}) \\ = -172.4409 - 0.0460\mathrm{T} + 0.7486\mathrm{M} + 0.4670\mathrm{Ap} + 0.0137\mathrm{TM} + 0.0274\mathrm{TAp} \\ - 0.0445\mathrm{MAp} - 0.0033\mathrm{T}^2 + 0.0291\mathrm{M}^2 - 0.0768\mathrm{T}^2 \quad (14)$$

$$\text{Brinell Hardness Number of Unalloyed Aluminium Sheet with Respect to Temperature}(BHN_T) \\ = -3.3481 + 0.0010\mathrm{T} + 0.0295\mathrm{M} - 0.0123\mathrm{Ap} + 0.0003\mathrm{TM} + 0.0006\mathrm{TAp} \\ - 0.0007\mathrm{MAp} - 0.0001\mathrm{T}^2 + 0.0005\mathrm{M}^2 - 0.0017\mathrm{T}^2 \quad (15)$$

$$\text{Brinell Hardness Number of Unalloyed Aluminium Sheet with Respect to Pressure } (\mathrm{BHN}_P) \\ = -65.3512 - 0.3944\mathrm{P} + 1.3150\mathrm{M} + 1.2742\mathrm{Ap} + 0.0007\mathrm{PM} + 0.0053\mathrm{PAp} \\ + 0.0059\mathrm{MAp} + 0.0004\mathrm{P}^2 + 0.0012\mathrm{M}^2 + 0.0074\mathrm{P}^2 \quad (16)$$

Table 1. *Effect of Temperature on Tensile Strength for Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Temperature (°C)	**Tensile Strength (MPa) Experimental (E)**	**Tensile Strength (MPa) Predicted (P)**	**Absolute Percentage Error (%)**
1024	342	345	0.87
1200	469	472	0.64
1442	543	546	0.55
1610	452	455	0.66
1800	600	600	0.00
1921	621	624	0.48
2001	612	614	0.33
2112	602	604	0.33
2200	594	596	0.34
Mean Absolute Percentage Error (%)			**0.47**
Coefficient of determination = 0.9536			

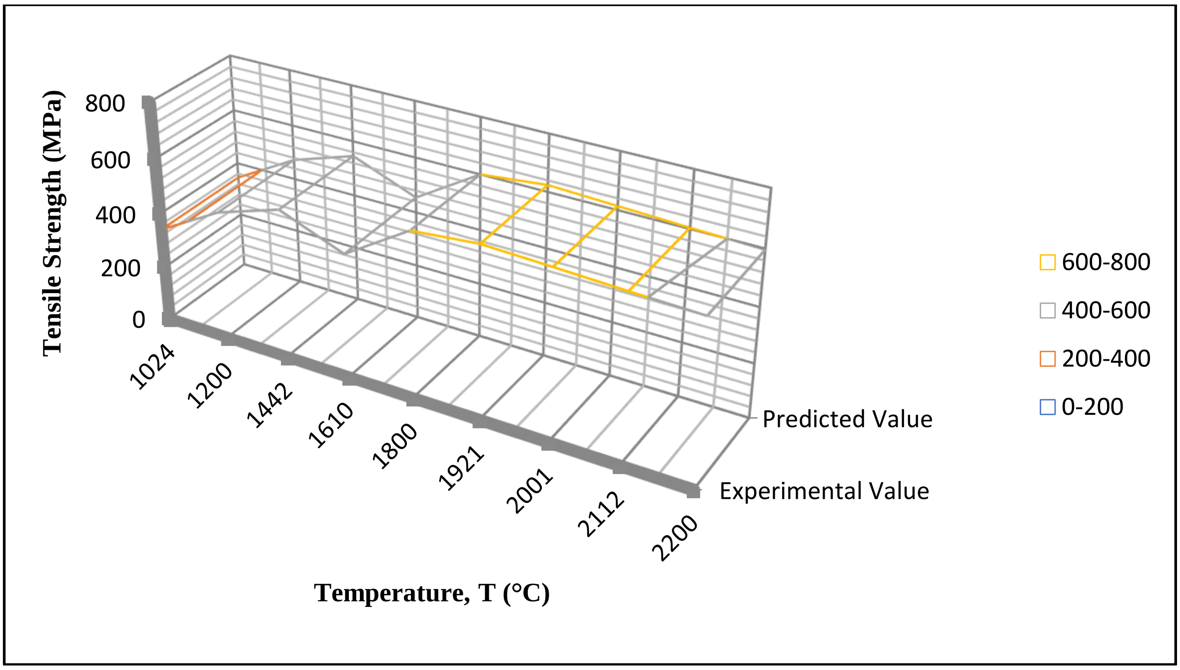

Figure 2. *Graph of Effects of Temperature on the Tensile Strength of Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

Table 2. *Effect of Pressure on Tensile Strength for Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Pressure (GPa)	**Modulus of Elasticity (MPa) Experimental (E)**	**Modulus of Elasticity (MPa) Predicted (P)**	**Absolute Percentage Error (%)**
40	342	343	0.29
56	480	483	0.63
62	510	511	0.20
65	452	455	0.66
69.5	543	545	0.37
72	562	568	1.07
74	555	554	0.18
76	548	550	0.37
78	546	548	0.37
Mean Absolute Percentage Error (%)			**0.46**
Coefficient of determination = 0.9531			

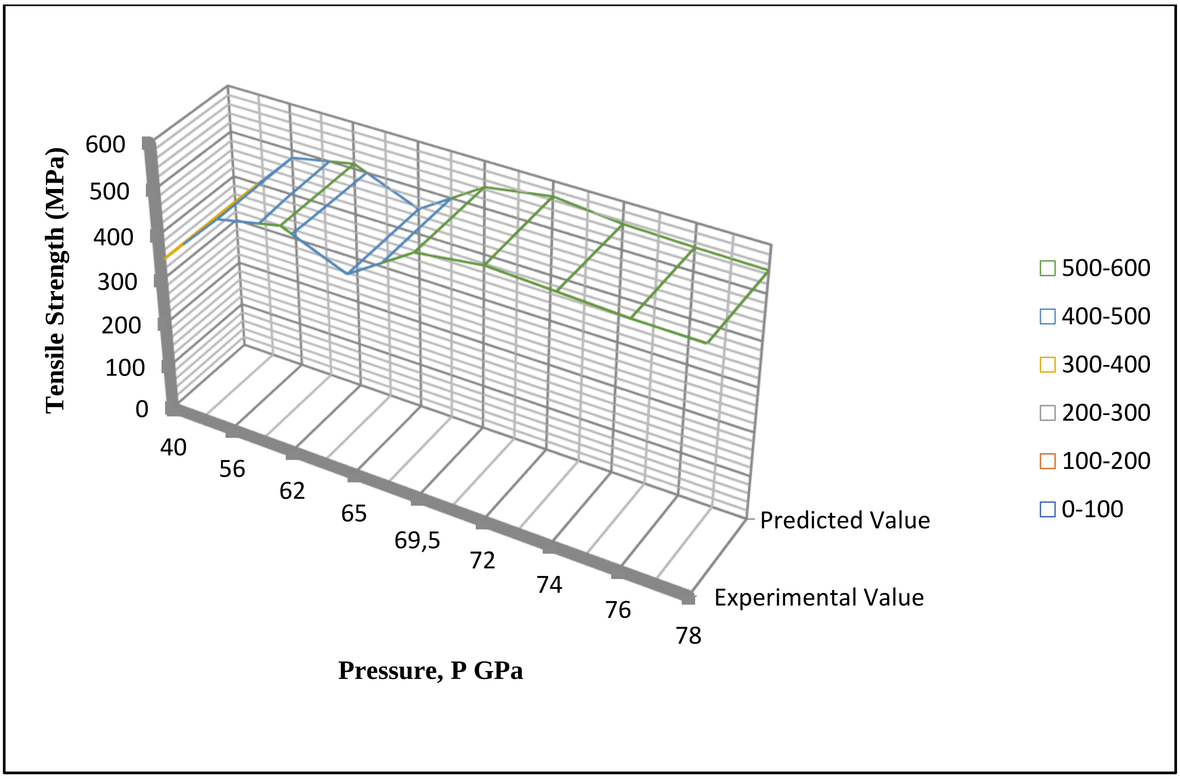

Figure 3. *Graph of Effects of Pressure on the Tensile Strength of Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

Table 3. *Effect of Temperature on Modulus of Elasticity for Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Temperature (°C)	Modulus of Elasticity (GPa) Experimental (E)	Modulus of Elasticity (GPa) Predicted (P)	Absolute Percentage Error (%)
1024	42	41	2.38
1200	47	46	2.13
1442	52	51	1.92
1610	69	68	1.45
1800	62	61	1.61
1921	59	58	1.69
2001	63	63	0.00
2112	64	63	1.56
2200	54	53	1.85
Mean Absolute Percentage Error (%)			**1.62**
Coefficient of determination = 0.9536			

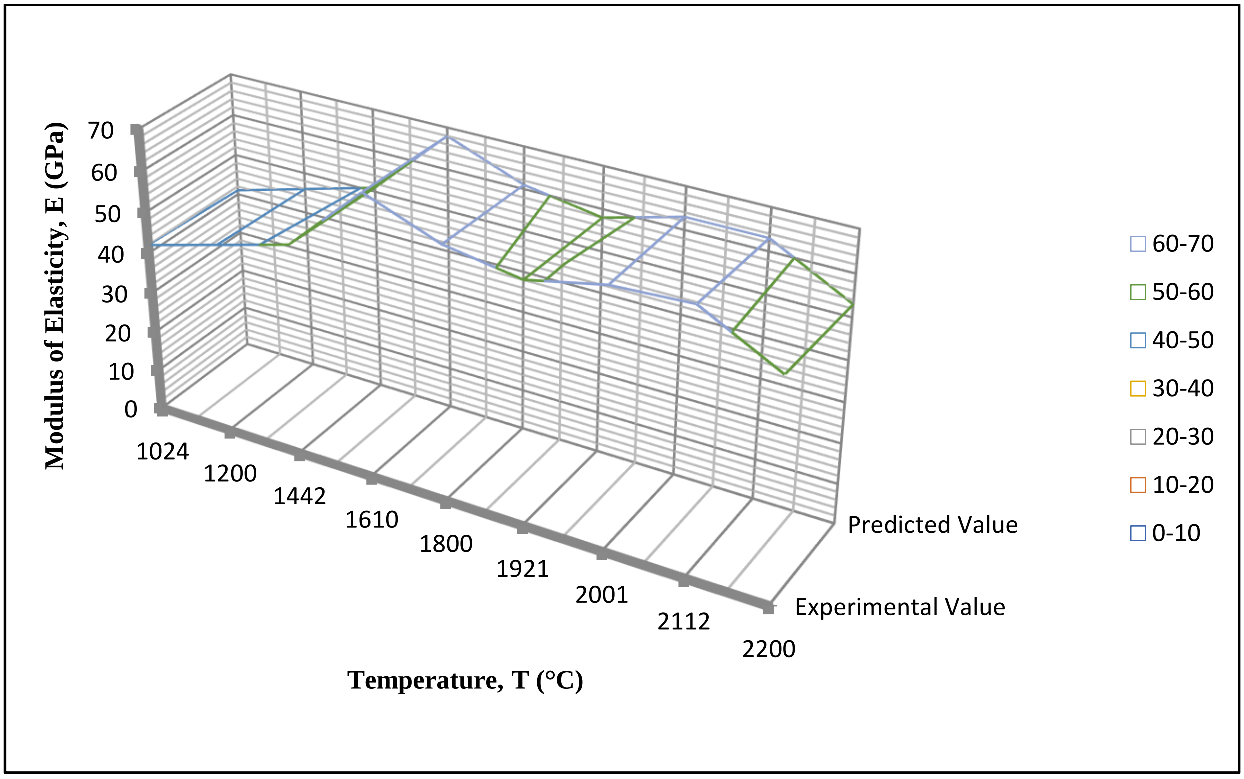

Figure 4. *Graph of Effects of Temperature on the Modulus of Elasticity of Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

Table 4. *Effect of Pressure on Modulus of Elasticity for Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Pressure (GPa)	**Modulus of Elasticity (GPa) Experimental (E)**	**Modulus of Elasticity (GPa) Predicted (P)**	**Absolute Percentage Error (%)**
40	42	41	2.38
56	47	46	2.13
62	52	51	1.92
65	60	58	3.33
69.5	68	66	2.94
72	59	57	3.89
74	63	61	3.17
76	64	62	3.13
78	60	56	6.67
Mean Absolute Percentage Error (%)			**3.38**
Coefficient of determination = 0.9411			

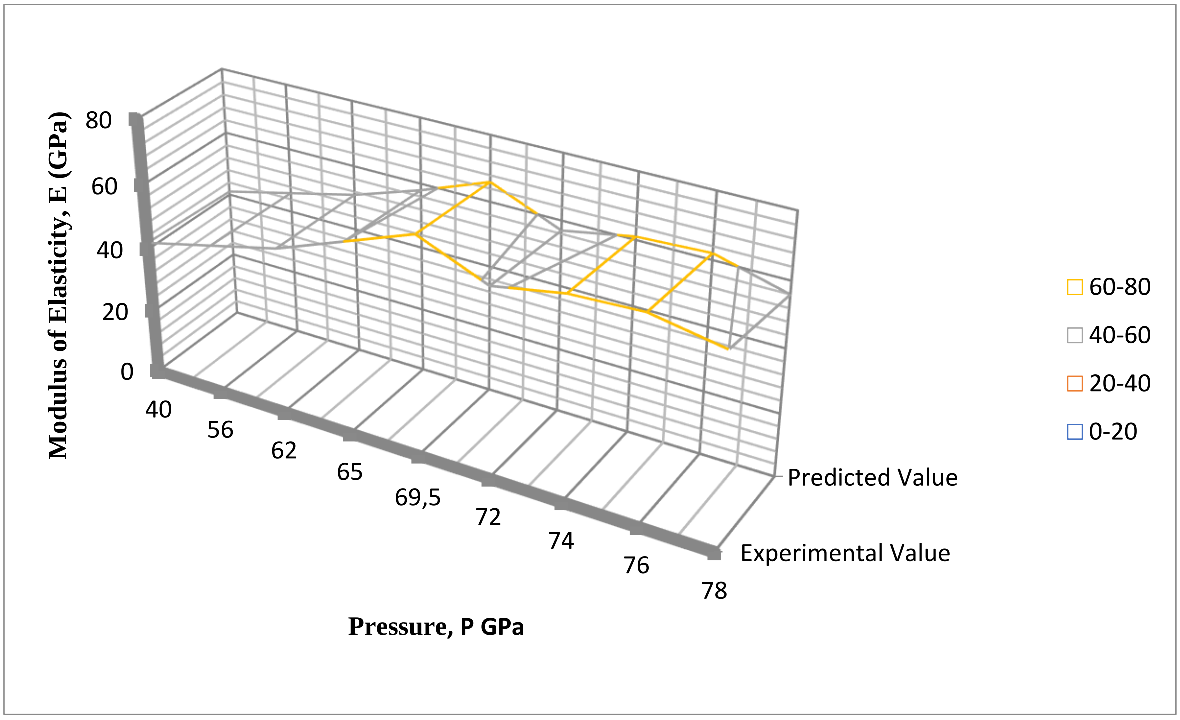

Figure 5. *Graph of Effects of Pressure on the Modulus of Elasticity for Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

Table 5. *Effect of Temperature on Shear Modulus for Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Temperature (°C)	Shear Modulus (GPa) Experimental (E)	Shear Modulus (GPa) Predicted (P)	Absolute Percentage Error (%)
1024	19	18	5.26
1200	23	24	4.35
1442	25.3	26	2.77
1610	23.4	24	2.56
1800	20.6	21.5	4.37
1921	19.8	20	1.01
2001	21.4	23	7.47
2112	21.6	22	1.85
2200	22	22	0.00
Mean Absolute Percentage Error (%)			**3.29**
Coefficient of determination = 0.9536			

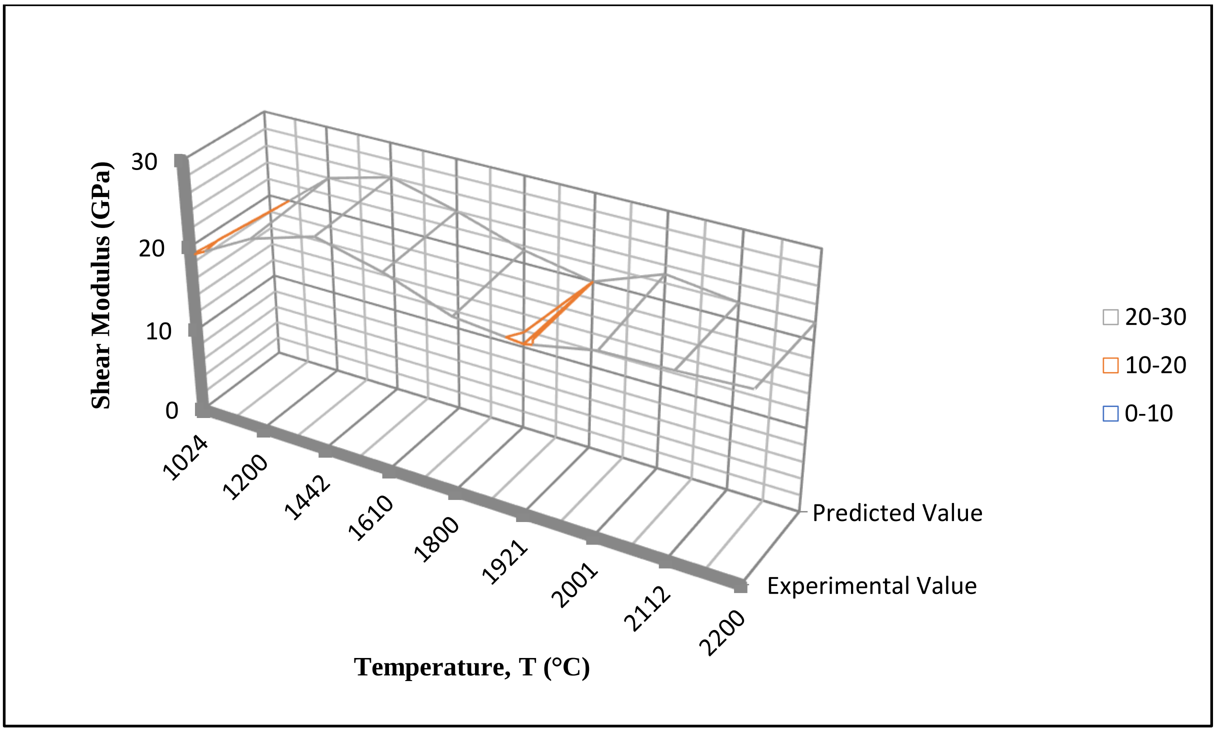

Figure 6. *Graph of Effects of Temperature on the Shear Modulus of Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

Table 6. *Effect of Pressure on Shear Modulus for Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Pressure (GPa)	Shear Modulus (GPa) Experimental (E)	Shear Modulus (GPa) Predicted (P)	Absolute Percentage Error (%)
40	19	18	5.26
56	23.8	22	7.56
62	24.5	26	6.12
65	24.9	25	0.40
69.5	26.2	25	4.58
72	19.8	20	1.01
74	22.5	23	2.22
76	22.8	23	0.88
78	23	23	0.00
Mean Absolute Percentage Error (%)			**3.11**
Coefficient of determination = 0.9531			

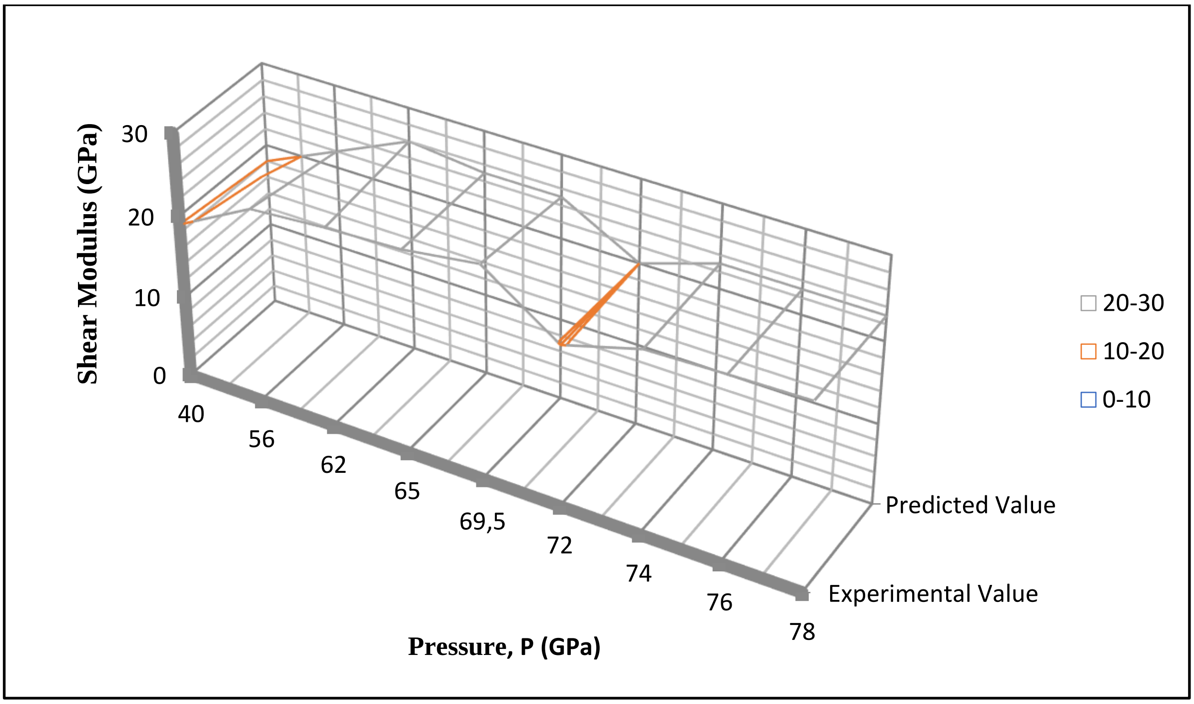

Figure 7. *Graph of Effects of Pressure on the Shear Modulus of Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

Table 7. *Effects of Temperature on the Hardness of Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Temperature (°C)	Brinell Hardness (N/mm^2) Experimental (E)	Brinell Hardness (N/mm^2) Predicted (P)	Absolute Percentage Error (%)
1024	39.00	40.00	2.56
1200	57.00	56.00	1.75
1442	62.00	62.00	0.00
1610	64.00	65.00	1.56
1800	68.00	69.50	2.21
1921	70.00	72.10	3.00
2001	75.00	74.20	1.07
2112	75.00	76.00	1.33
2200	72.00	73.00	1.39
Mean Absolute Percentage Error (%)			**1.65**
Coefficient of determination = 0.9828			

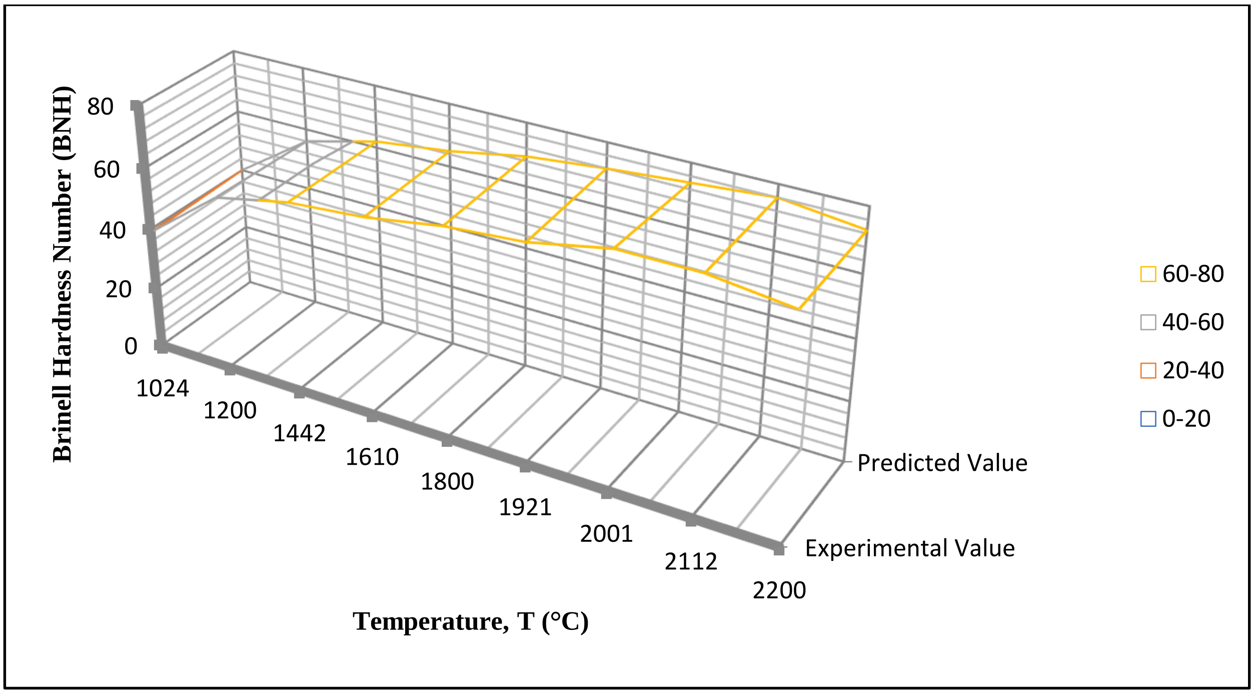

Figure 8. *Graph of Effects of Temperature on the Hardness of Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

Table 8. *Effect of Pressure on the Hardness of Unalloyed Aluminium Sheets, Experimental (E), Predicted (P), Absolute Percentage Error and Coefficient of Determination*

Pressure (GPa)	**Brinell Hardness Number Experimental (E)**	**Brinell Hardness Number Predicted (P)**	**Absolute Percentage Error (%)**
40	30	29	3.33
56	35	36	2.87
62	40	38	5.00
65	45	44	2.22
69.5	61	63	3.28
72	58	56	3.45
74	56	56	0.00
76	53	52	1.89
78	46	45	2.22
Mean Absolute Percentage Error (%)			**2.70**
Coefficient of determination = 0.9232			

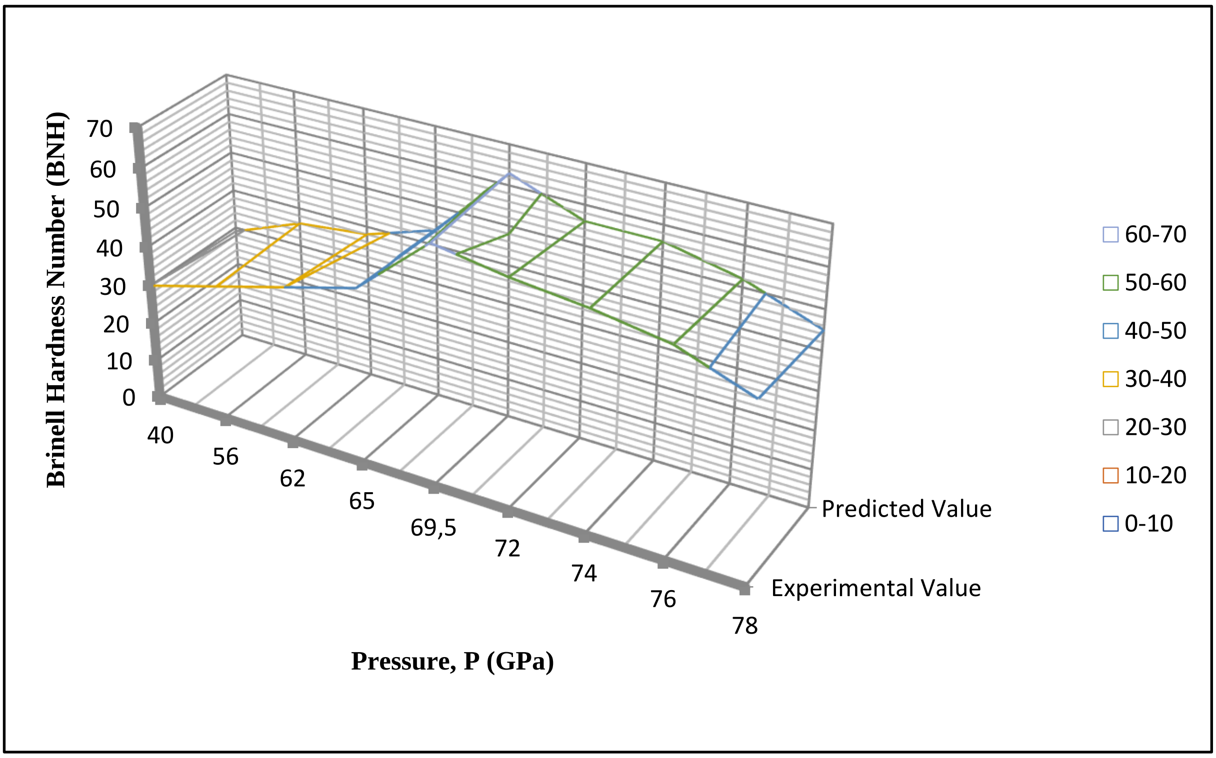

Figure 9. *Graph of Effects of Pressure on the Hardness of Unalloyed Aluminium Sheet, Experimental (E) and Predicted (P) Values*

3.1. Discussion of Results

3.1.1. Validation of Model for Unalloyed Aluminium Sheets

From the plots obtained in Figure 2-9, it was observed that the optimal tensile strength, young modulus of elasticity, shear modulus and Brinell hardness number were 621MPa, 69GPa, 25.5GPa, and 61 at temperature of 1921°C, 1610°C, 1442°C and 1800°C respectively. In comparison with pressure, the obtained values for optimal tensile strength, young modulus of elasticity, shear modulus and Brinell Hardness Number (BHN) were 562MPa, 68GPa, 26.2GPa and 61 at pressure of 72GPa, 69.5GPa, 69.5GPa and 69.5GPa respectively. The predicted values for the mechanical properties (tensile strength, modulus of elasticity, shear modulus and Brinell hardness number) of unalloyed Aluminium sheets were obtained using Equation 9-16 while the absolute percentage error and coefficient of determination was determined using Equation 7 and 8 respectively. The mechanical properties (tensile strength, modulus of elasticity, shear modulus and hardness), Experimental (E), Predicted (P), absolute percentage error values were presented in Table 1-8 and Figure 2-9.

The model was validated by comparing the predicted values from empirical models with experimental data. The predicted values were found to compare favourably with measured values. The absolute percentage error and coefficient of determination were calculated based on equation 7 and 8 respectively. The mean absolute percentage error and coefficient of determination of unalloyed Aluminium sheets is shown in in Table 1-8 and Figure 2-9 for tensile strength, modulus of elasticity, shear modulus and Brinell hardness number respectively. The models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination (R^2) were determined to be 0.9828 (98.28%) for tensile strength, 0.9385 (93.85%) for modulus of elasticity, 0.9787 (97.87%) for shear modulus, and 0.9847 (98.47%) for Brinell hardness number respectively which indicates that a substantial good fit was achieved by the regression model developed. Moreover, the mean absolute percentage error of predicted values from model when compare with the experimental values were determined to be 0.46% and 0.47% for tensile Strength, 1.62% and 3.38% for modulus of elasticity, 3.11% and 3.29% for shear modulus and 1.65% and 2.70% for Brinell hardness number respectively. These values are significantly small and below the maximum error of 10% proposed by Liping and Deku (1992) and Osarenmwinda and Nwachukwu (2010). These values were therefore found to be satisfactory and show good predictability of the model and its adequacy.

4. CONCLUSION

The modeling and validation of production process parameters of unalloyed Aluminium sheets had been achieved. Empirical Models were developed for predicting the mechanical properties (tensile strength, modulus of elasticity, shear modulus and hardness) for the produced unalloyed Aluminium sheets. The models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination (R^2) obtained ranges from 0.9213 (92.13%) to 0.9911 (99.11%) which indicates that a substantial good fit was achieved by the regression model developed. The mean absolute percentage error of the developed models ranges from 0.46% to 3.38% which was below 10% recommended. The values obtained from the validation of these models were therefore found to be satisfactory, and shows good predictability of the model and its adequacy. In addition, the developed models and the determined interactions will serve as a guide to assist researchers, industrialist and small scale manufacturers to estimate the properties of unalloyed Aluminium sheets to be produced.

CONFLICT OF INTEREST

There is no conflict of interest in this research article.

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