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RESEARCH ARTICLE

Soft Computing Modeling Including Artificial Neural Network, Non-linear, and Linear Regression Models to Predict the Compressive Strength of Sustainable Mortar Modified with Palm Oil Fuel Ash

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ABSTRACT - Producing sustainable concrete and mortar is the idea that have been investigated by many researchers in the world through using waste materials in the mortar or concrete compositions to reduce the thread on the environment. In order to predict the compressive strength of mortar, this article proposes statistical models utilising linear regression (LR), nonlinear regression (NLR), and artificial neural network (ANN) based on experimental data collected from prior research in the field. The pozzolanic material used in mortar is agricultural waste, specifically Palm Oil Fuel Ash (POFA). In order to choose the most efficient model, the proposed models were evaluated using several statistical parameters. When compared to alternative models (Linear regression, nonlinear regression, and ANN), the one developed using ANN proved to be the most efficient in terms of approach, giving lower values for root mean square error (RMSE) and mean absolute error (MAE) which were 5.11, and 4.175 respectively. The suggested ANN model performed well according to the scatter index (SI), and the coefficient of determination value (R^2) value was 34% more than the R^2 in the LR model and 23% greater in the NLR model.

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1.0 INTRODUCTION

Concrete and mortar are the primary materials used in construction and are major contributors to the emission of carbon dioxide into the atmosphere [1, 2]. This is particularly true for the manufacturing process of cement, which requires a significant amount of energy [3, 4]. The cement sector is accountable for about 8% of the total carbon dioxide emissions in the atmosphere. For every tonne of cement produced, one tonne of carbon dioxide is released into the air [5, 6]. The manufacture of cement is directly proportional to the progress of building, resulting in a corresponding rise in the release of carbon dioxide into the atmosphere [7, 8]. Given that the construction industry is a major consumer of raw materials and a significant source of environmental hazards, there is growing interest in adopting sustainable materials to mitigate the negative impact on the environment [9]. Several studies have been conducted to achieve sustainable concrete or mortar by including waste materials as a substitute for aggregate or employing pozzolanic materials as a substitute for cement [10, 11]. Pozzolanic materials, when used as cementitious additives, provide protection to concrete or mortar by preventing carbonation or chloride attack. This is achieved through their reaction with calcium hydroxide, resulting in the formation of calcium silicate hydroxide. This reaction enhances the compressive strength of the material and inhibits the reaction between carbon dioxide from the air and calcium hydroxide in the concrete [12-14]. Utilising byproduct pozzolanic cementitious material is a very effective method for environmental protection and reducing energy consumption in cement manufacturing. This approach involves cleansing the environment by utilising these byproduct wastes, while also enhancing the compressive strength of the resulting mixture [15, 16]. Various types of pozzolanic materials are globally accessible, including fly ash, silica fume, rice husk ash, and pulverised granulated blast furnace slag [17, 18]. Pozzolanic materials with smaller particles will have a greater impact on the parameters of the mixture, particularly its compressive strength [19].

Agricultural wastes, such as palm oil fuel ash, are a significant source of pozzolanic material. These wastes are mostly found in Malaysia and Thailand [20, 21]. In 2020, Malaysia's palm oil production reached over 100 million tonnes [22]. Following the extraction of oil from the palm oil tree product, the remaining solid waste consists of empty bunches with inside shells [23]. Extensive studies have been conducted on the use of palm oil shells as aggregate in mortar or concrete [24-28]. Additionally, another approach involves utilising them as fuel in a controlled environment power plant [29]. The product obtained after the burning process is ash, which mostly consists of siliceous and aluminous components. These components make the ash active pozzolanic materials [30, 31]. The weight of the ash is about five percent of the weight of the soil waste utilised in the burning process [32]. In Thailand alone, the annual amount of POFA exceeded 130 thousand tonnes, a quantity that has been shown to rise over time [33]. The fuel ash that was obtained with smaller particles exhibited a greater level of activity in the reaction [34]. Extensive research has been conducted to investigate the

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impact of utilising POFA as a substitute for cement in various types of concrete, including regular concrete [35-38], high strength concrete [39-42], self-compact concrete [43-46], geo-polymer mortar [47-50], self-compact mortar [51], and mortar [52]. The findings of these studies provide valuable insights into the effectiveness of POFA in these applications.

Lim et al., 2015[53], examine the utilisation of POFA at three distinct proportions (60, 80, and 100%)) and three different durations of curing (7, 14, and 28 days) as shown in Table A. The compressive strength of all mixes including POFA (60, 80, and 100%) was shown to be lower than the control mix after 7 days of curing by 18, 49, 79.5% respectively, since with the decrease of cement contents decrease the amount of C3S which is responsible on the early age strength after hydration process [63]. However, after 14 days of curing, the mix with 60% POFA as a partial substitute for cement exhibited a 14.7% greater compressive strength compared to the control mix. After 28 days of curing, mortar containing 60% and 80% POFA as a partial substitute for cement exhibit increased compressive strength compared to the control mix by 27, and 16% respectively. However, the mix containing 100% POFA shows a drop in compressive strength and becomes lower than the control mix by 74%. Mo et al., 2017 [55], conducted an experiment where they used two different rates of POFA (50% and 70%) and tested them at three different curing times (7, 28, and 90 days). The results obtained at various curing times indicate that mixes containing 50% and 70% POFA exhibit reduced compressive strength compared to the control mix by 48, and 61.9% at 28 days curing time respectively. Wi et al., 2018 [56], conducted an experiment to evaluate the effectiveness of POFA at various rates (10, 20, 30, 40, 70, 80, and 90%) and varied curative durations (7, 14, 28, and 56 days). After 7 days of curing, only the mixture that includes 10% of POFA as a partial substitute for cement exhibits a compressive strength greater than the control mixture. After 14 days of curing, mixes that include 10% and 20% of POFA as a partial substitute for cement exhibit greater compressive strength compared to the control mix by 8.3, and 5.5% respectively. After 28 days of curing, mixes with 10, 20, and 30% POFA as a partial replacement for cement exhibit greater compressive strength compared to the control mix. Similarly, after 56 days of curing, mixes with 10, 20, and 30% POFA as a partial replacement for cement demonstrate higher compressive strength than the control mix. This suggests that over time, POFA becomes more effective in enhancing compressive strength. This paper focuses on gathering empirical data from prior research that utilised POFA as a substitute for cement in mortar. The objective is to develop a robust and effective model for predicting the compressive strength of mortar that has been modified with POFA as a partial replacement for cement. The aim is to reduce the time required for conducting trial mixes and waiting for the results to be obtained after 28 days. Models that have a greater coefficient of determination and a lower scatter index are more effective [61, 62].

2.0 RESEARCH SIGNIFICANT

This study focuses on gathering experimental data from Lim et al., [53], Lim et al., [54], Mo et al., [55], Wi et al., [56], Hosen et al., [57], Nayaka et al., [58], Hussin et al., [59], Sumesh et al., [60], specifically 142 data points. The objective is to analyse the impact of each independent parameter (w/b, cement content, POFA content, sand content, and curing time), on the dependent parameter (compressive strength). Statistical models will be developed using the training data, and then validated using the testing data. The selection of the most efficient model will be based on many statistical characteristics. The optimum percentage of POFA that may be used to enhance the strength of the mortar will be determined.

3.0 METHODOLOGY

A total of 142 data points was gathered from Lim et al., [53], Lim et al., [54], Mo et al., [55], Wi et al., [56], Hosen et al., [57], Nayaka et al., [58], Hussin et al., [59], Sumesh et al., [60]. Statistical analysis was conducted for each independent variable, including water-to-binder ratio, cement content, POFA content, sand content, and curing duration. Each independent variable has been individually correlated with the dependent variable (compressive strength) to determine the specific relationship between each independent variable and the dependent variable. The collected data is separated into two groups: the training data, consisting of 107 data points, and the testing data, consisting of 35 data points [64, 65]. The training data has been used to suggest several models, such as linear regression, nonlinear regression, and artificial neural network. Subsequently, these proposed models were evaluated using testing data. The models have been evaluated using various statistical factors in order to identify the best effective model, as seen in the flow chart below:

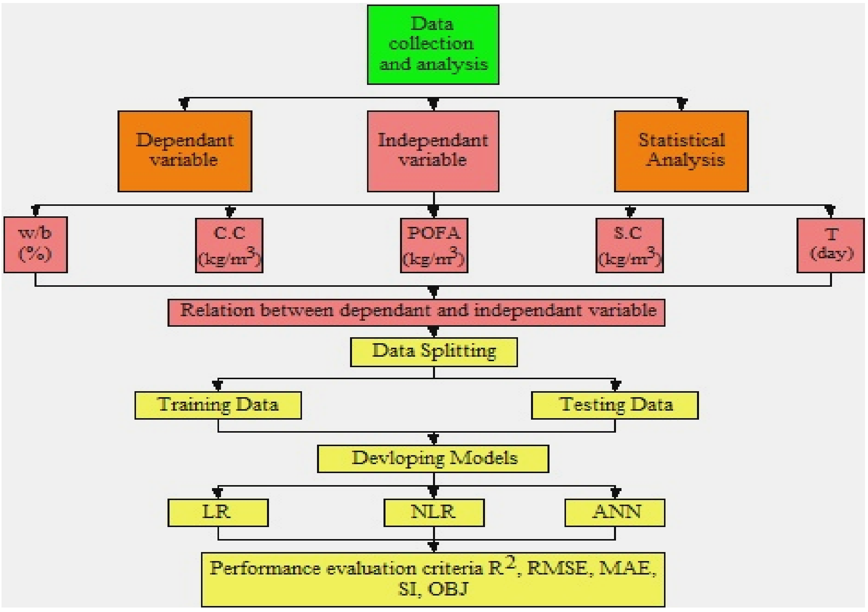

Figure 1. Flow chart explaining article methodology

4.0 DATA ANALYSIS

4.1 Data Collection

From the reviewed experimental work, all the experimental article which contain numerical detail about used material and mix with obtained results have been selected with collecting their data and expressing them in the form of Table. As seen in the table below, labelled as Table 1:

Table 1. Collected Data

References	w/c	OPC Content (kg/m^3)	POFA Content (kg/m^3)	Sand Content (kg/m^3)	Curing Time (days)	Compressive Strength (MPa)
[53]	0.400	525	0	1578	7	24.50
	0.400	210	315	1578	7	20.00
	0.400	105	420	1578	7	12.50
	0.400	0	525	1578	7	5.00
	0.400	525	0	1578	14	29.00
	0.400	210	315	1578	14	34.00
	0.400	105	420	1578	14	26.00
	0.400	0	525	1578	14	7.00
	0.400	525	0	1578	28	31.00
	0.400	210	315	1578	28	39.50
	0.400	105	420	1578	28	36.00
	0.400	0	525	1578	28	8.00
[54]	0.400	525	0	1578	7	24.00
	0.400	105	420	1578	7	25.00
	0.400	525	0	1578	14	29.00
	0.400	105	420	1578	14	36.00
	0.400	525	0	1578	28	30.00
	0.400	105	420	1578	28	46.00
[55]	0.645	520	0	1290	7	28.89
	0.645	260	260	1290	7	12.28
	0.645	156	364	1290	7	7.85
	0.645	520	0	1290	28	38.12
	0.645	260	260	1290	28	19.72
	0.645	156	364	1290	28	14.52
	0.645	520	0	1290	90	42.36
	0.645	260	260	1290	90	27.05
	0.645	156	364	1290	90	18.14

Table 1. (cont.)

References	w/c	OPC Content (kg/m^3)	POFA Content (kg/m^3)	Sand Content (kg/m^3)	Curing Time (days)	Compressive Strength (MPa)
[56]	0.500	450	0	1350	7	17.50
	0.500	405	45	1350	7	18.00
	0.500	360	90	1350	7	17.00
	0.500	315	135	1350	7	16.50
	0.500	270	180	1350	7	15.00
	0.500	135	315	1350	7	5.50
	0.500	90	360	1350	7	4.00
	0.500	45	405	1350	7	3.00
	0.500	450	0	1350	14	18.00
	0.500	405	45	1350	14	19.50
	0.500	360	90	1350	14	19.00
	0.500	315	135	1350	14	17.00
	0.500	270	180	1350	14	15.50
	0.500	135	315	1350	14	7.00
	0.500	90	360	1350	14	5.00
	0.500	45	405	1350	14	3.00
	0.500	450	0	1350	28	22.50
	0.500	405	45	1350	28	24.50
	0.500	360	90	1350	28	24.00
	0.500	315	135	1350	28	23.00
	0.500	270	180	1350	28	21.00
	0.500	135	315	1350	28	10.00
	0.500	90	360	1350	28	7.00
	0.500	45	405	1350	28	3.50
	0.500	450	0	1350	56	26.50
	0.500	405	45	1350	56	30.50
	0.500	360	90	1350	56	32.50
	0.500	315	135	1350	56	31.00
	0.500	270	180	1350	56	25.00
	0.500	135	315	1350	56	16.50
	0.500	90	360	1350	56	9.50
	0.500	45	405	1350	56	4.00
[57]	0.350	336	144	144	28	72.00
[58]	0.400	376	0	1520	3	25.00
	0.490	338	38	1520	3	28.00
	0.570	301	75	1520	3	18
	0.570	263	113	1520	3	11
	0.580	226	150	1520	3	6.5
	0.580	188	188	1520	3	6.00
	0.600	150	226	1520	3	5.00
	0.600	113	263	1520	3	4.50
	0.600	75	301	1520	3	1.00
	0.400	376	0	1520	7	25.50
	0.490	338	38	1520	7	30.00
	0.570	301	75	1520	7	19.00
	0.570	263	113	1520	7	18.50
	0.580	226	150	1520	7	12.50
	0.580	188	188	1520	7	11.00
	0.600	150	226	1520	7	6.00
	0.600	113	263	1520	7	4.50
	0.600	75	301	1520	7	1.00
	0.400	376	0	1520	28	27.50
	0.490	338	38	1520	28	30.00

Table 1. (cont)

References	w/c	OPC Content (kg/m^3)	POFA Content (kg/m^3)	Sand Content (kg/m^3)	Curing Time (days)	Compressive Strength (MPa)
[58]	0.570	301	75	1520	28	26.00
	0.570	263	113	1520	28	24.00
	0.580	226	150	1520	28	17.00
	0.580	188	188	1520	28	14.00
	0.600	150	226	1520	28	11.00
	0.600	113	263	1520	28	7.50
	0.600	75	301	1520	28	6.00
	0.400	376	0	1520	56	31.00
	0.490	338	38	1520	56	32.00
	0.570	301	75	1520	56	30.00
	0.570	263	113	1520	56	29.00
	0.580	226	150	1520	56	22.00
	0.580	188	188	1520	56	17.00
	0.600	150	226	1520	56	11.00
	0.600	113	263	1520	56	9.00
	0.600	75	301	1520	56	8.00
[59]	0.400	525	0	1578	28	31.00
	0.400	210	315	1578	28	39.00
	0.400	105	420	1578	28	33.00
	0.400	0	525	1578	28	5.00
	0.400	525	0	1578	56	32.00
	0.400	210	315	1578	56	42.00
	0.400	105	420	1578	56	39.00
	0.400	0	525	1578	56	7.00
	0.400	525	0	1578	90	32.50
	0.400	210	315	1578	90	44.00
	0.400	105	420	1578	90	39.50
	0.400	0	525	1578	90	7.00
[59]	0.400	525	0	1578	180	33.00
	0.400	210	315	1578	180	46.00
	0.400	105	420	1578	180	40.00
	0.400	0	525	1578	180	7.00
	0.400	525	0	1578	270	33.50
	0.400	210	315	1578	270	47.00
	0.400	105	420	1578	270	41.00
	0.400	0	525	1578	270	7.00
	0.400	525	0	1578	360	34.00
	0.400	210	315	1578	360	49.00
	0.400	105	420	1578	360	46.00
	0.400	0	525	1578	360	7.50
	0.400	525	0	1578	540	34.00
	0.400	210	315	1578	540	49.00
	0.400	105	420	1578	540	50.00
	0.400	0	525	1578	540	7.00
[60]	0.450	270	180	1350	7	26.00
	0.450	300	200	1500	7	22.00
	0.450	330	220	1650	7	25.00
	0.350	270	180	1350	7	21.00
	0.350	300	200	1500	7	27.00
	0.350	330	220	1650	7	32.00
	0.320	270	180	1350	7	28.00
	0.320	300	200	1500	7	31.50
	0.320	330	220	1650	7	35.00

Table 1. (cont)

References	w/c	OPC Content (kg/m^3)	POFA Content (kg/m^3)	Sand Content (kg/m^3)	Curing Time (days)	Compressive Strength (MPa)
[60]	0.450	270	180	1350	28	36.00
	0.450	300	200	1500	28	29.00
	0.450	330	220	1650	28	35.00
	0.350	270	180	1350	28	28.00
	0.350	300	200	1500	28	35.50
	0.350	330	220	1650	28	42.00
	0.320	270	180	1350	28	35.50
	0.320	300	200	1500	28	41.50
	0.320	330	220	1650	28	45.00

4.2 Data Analysis

Following the collection of experimental data shown in Table.1, statistical analysis (including the finding the value of mean, median, standard division, variance, kurtosis, skewness, with drawing the distribution for each parameters), was conducted for each independent parameter individually. The results were then visualised in the form of histograms, as seen in Figures 2, 4, 6, 8, and 10. A correlation graph has been created to display the relationship between each individual parameter and compressive strength, to check the possibility of predicting the compressive strength with using only one of these parameters with showing their efficiency. The distribution plot of these relationships may be seen in Figures 3, 5, 7, 9, and 11.

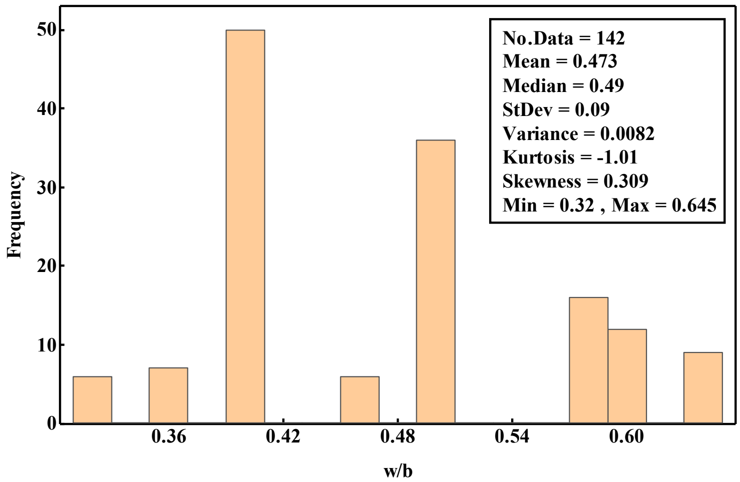

Figure 2. Histogram distribution of w/b

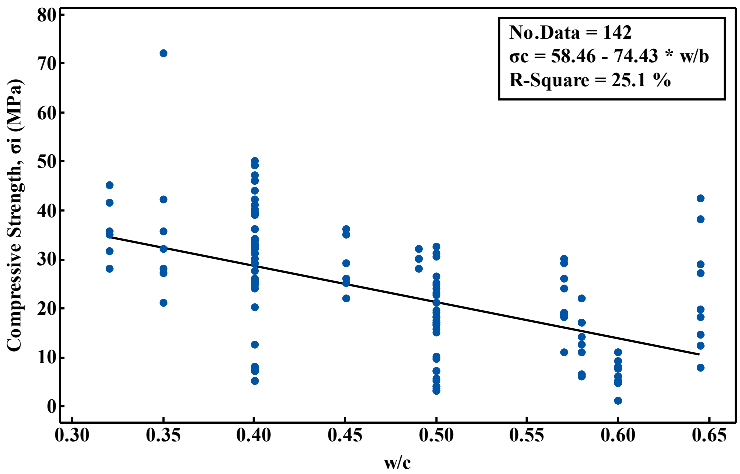

Figure 3. Correlation between w/b with compressive strength

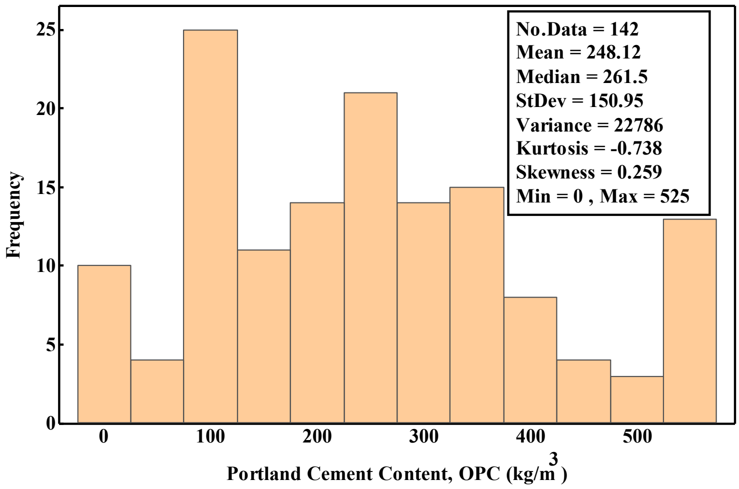

Figure 4. Histogram distribution of cement content

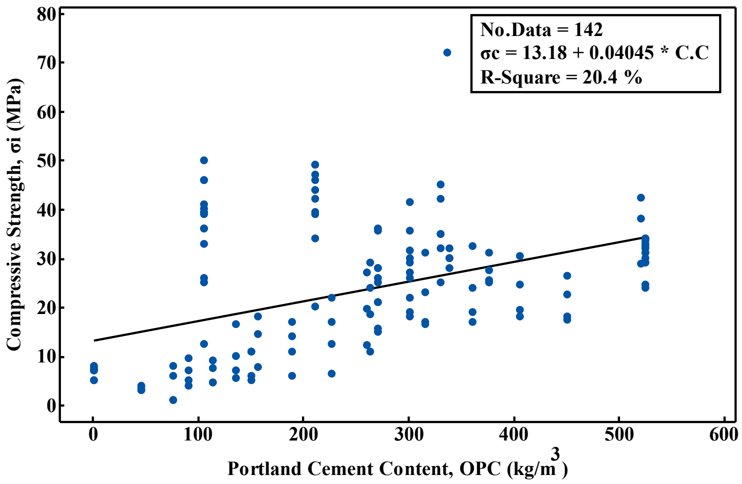

Figure 5. Correlation between compressive strength with cement content

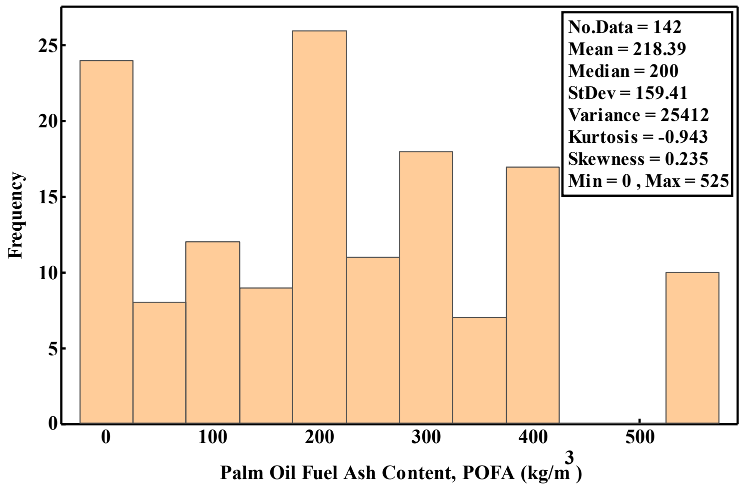

Figure 6. Histogram distribution of POFA

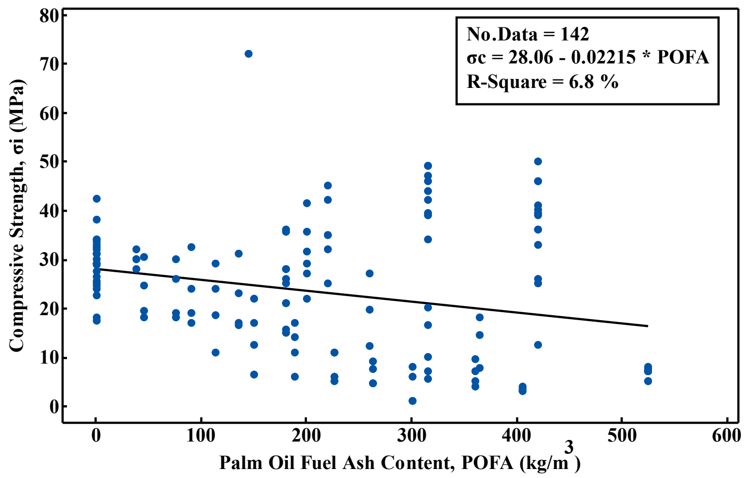

Figure 7. Correlation between POFA with compressive strength

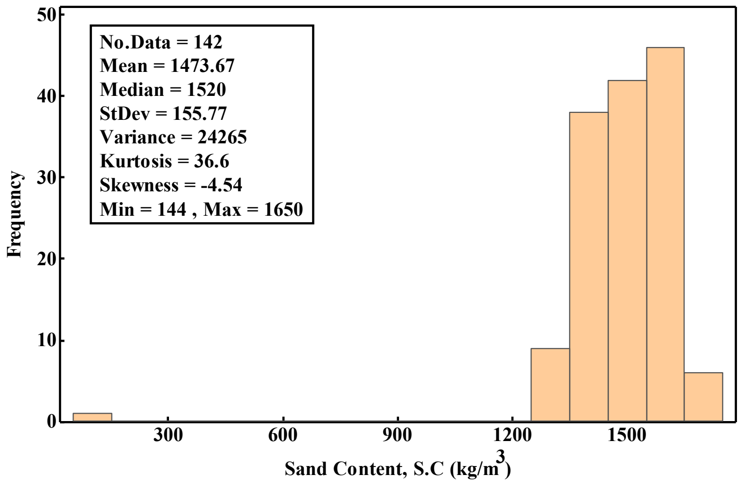

Figure 8. Histogram distribution of sand content

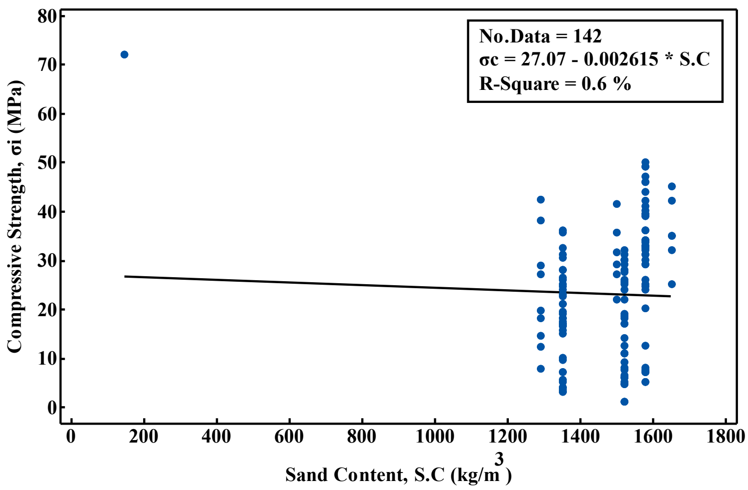

Figure 9. Correlation between sand content and compressive strength

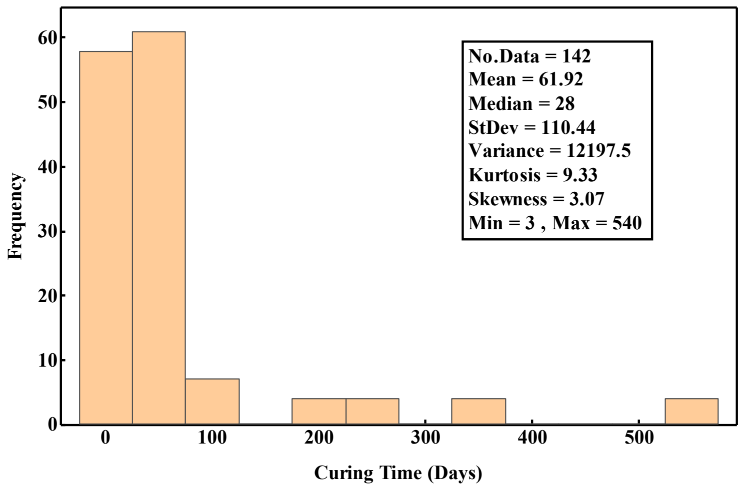

Figure 10. Histogram distribution of curing time

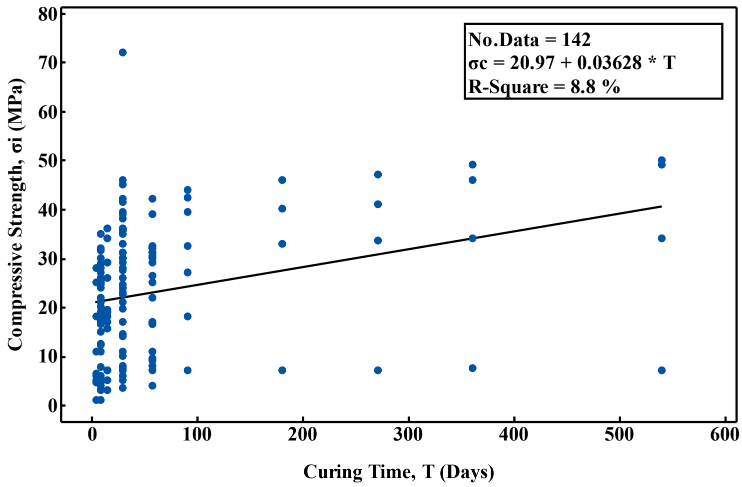

Figure 11. Correlation between curing time and compressive strength

4.3 Modeling

The data collected has been used to suggest a set of models for predicting the compressive strength of mortar that incorporates palm oil fuel ash as a partial substitute for cement. The models are as follows:

4.4 Linear Regression (L.R)

It is a commonly used model for predicting a dependent variable based on independent factors that have a linear relationship with it [62, 64]. In engineering, "L.R" may be used to forecast the compressive strength, as seen in the following format:

$$\sigma cp = a \pm b \times \left(\frac{w}{b}\right) \pm c \times (C.C) \pm d \times (POFA) \pm e \times (S.C) \pm f \times (T) \tag{1}$$

The water to binder ratio is represented by w/c. C.C represents the cement content in kilogrammes per cubic metre, S.C represents the sand content in kilogrammes per cubic metre, POFA represents the palm oil fuel ash content in kilogrammes per cubic metre, and T represents the curing period in days. The parameters a, b, c, d, e, and f are used in many models.

4.5 Non-Linear Regression (N.L.R)

A non-linear regression model is a statistical model that may be used to forecast the value of a dependent variable based on independent variables, using a non-linear relationship between them [67]. This model may be used to forecast the compressive strength of mortar that contains palm oil fuel ash. The prediction is based on the parameters that are reliant on the form specified below:

$$\sigma cp = a \times \left(\frac{w}{b}\right)^{b} \pm c \times (C.C)^{d} \pm e \times (POFA)^{f} \pm g \times (S.C)^{h} \pm i \times (T)^{j} \tag{2}$$

The water to binder ratio is represented by w/b, the cement content is represented by C.C (in kg/m^3), the sand content is represented by S.C (in kg/m^3), the palm oil fuel ash content is represented by POFA (in kg/m^3), and the curing period is represented by T (in days). The parameters a, b, c, d, e, f, g, h, i, and j, these alphabetic represented the constant coefficient value with the independent parameters used with.

4.6 Artificial Neural Network (ANN)

The ANN model was implemented using the Weka software package, namely version 3.8.5. Artificial Neural Networks (ANN) is regarded as dependable models that mimic the functioning of the human brain. They have input, hidden, and output components [68]. The structure of ANN is not standardised, and the analysis process is contingent upon the input parameters and the specific form of the given issues, as seen in Figure 12.

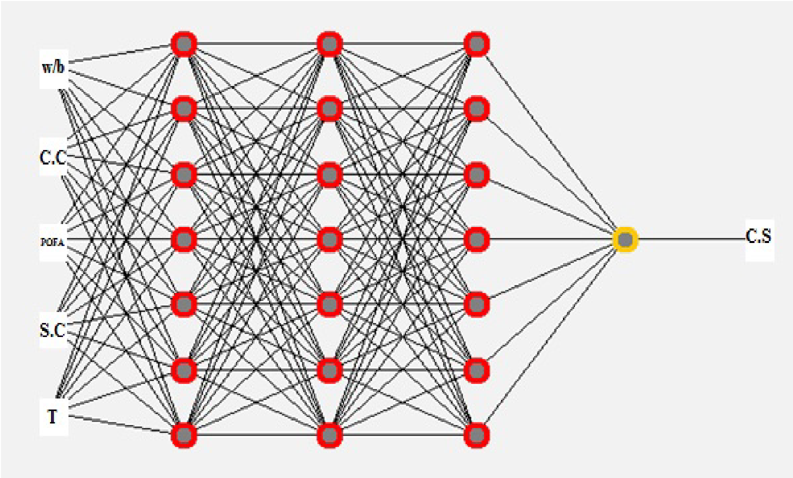

Figure 12. ANN structure for inputted problem

4.7 Models Assessment

Three distinct models (Linear, non-linear regression, ANN) have been presented for the provided data. The parameters that assess the performance of these models may be summarised using the supplied equations (3 to 7). Models that have a higher coefficient of determination (R^2), the lowest root mean square error (RMSE), and mean absolute error (MAE) are regarded to be the most dependable.

$$R^2 = 1 - \frac{\sum(\mathrm{Yi} - \mathrm{Yp})^2}{\sum(\mathrm{Yi} - \mathrm{Mean})^2} \tag{3}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum(\mathrm{Yi} - \mathrm{Yp})^2}{\mathrm{N}}} \tag{4}$$

$$\mathrm{SI} = \frac{\mathrm{RMSE}}{\mathrm{Mean}} \times 100 \tag{5}$$

$$\mathrm{MAE} = \frac{\sum(\mathrm{Yi} - \mathrm{Yp})}{\mathrm{n}} \tag{6}$$

$$\mathrm{OBJ} = \left(\frac{\mathrm{N.Traial}}{\mathrm{N.Total}}\right) \times \left(\frac{\mathrm{RMSE_{Traial}} + \mathrm{MAE_{Traial}}}{\mathrm{R^2_{Traial}} + 1}\right) + \left(\frac{\mathrm{N.Testing}}{\mathrm{N.Total}}\right) \times \left(\frac{\mathrm{RMSE_{Testing}} + \mathrm{MAE_{Testing}}}{\mathrm{R^2_{Testing}} + 1}\right) \tag{7}$$

According to the statistical parameters used, a higher R^2 value is considered more desirable. A model with a SI (statistical index) that greater than 0.3 is considered to have poor performance, while a SI between 0.2 and 0.3 is considered acceptable. An SI between 0.1 and 0.2 is considered good performance, and a SI between 0 and 0.1 is considered excellent performance [66, 67].

5.0 RESULT AND DISCUSSIONS

5.1 Regression Model (linear)

Since there was no significant link seen between any individual independent variable and the dependent variable (compressive strength), all the independent factors were combined into statistical models using the linear regression approach. The collected data has been partitioned into two groups: training data and testing data. The model has been formulated as equation 8, using training data. The resulting equation reveals that the w/b parameter has the most negative impact on the expected compressive strength, followed by sand content. Conversely, cement content has the greatest positive impact on the predicted compressive strength, followed by curing time and palm oil fuel ash. Equation 8 was used to determine the anticipated compressive strength for both the training and testing data. A correlation between the expected and observed compressive strength was then shown in Figure.13 to demonstrate the effectiveness of the suggested equation.

$$\sigma P = 56.7 - 61.22 \times w/b + 0.054 \times C.C + 0.019 \times POFA - 0.017 \times S.C + 0.035 * T \quad (8)$$

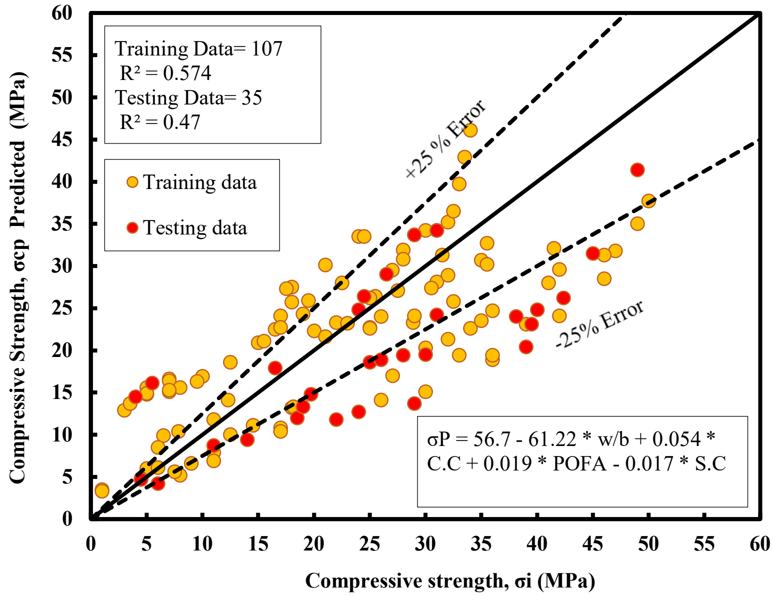

Figure 13. Correlation between measured and predicted compressive strength using linear regression method

5.2 Regression Model (non-linear)

After doing linear regression analysis, the resulting equation indicated that there is no linear relationship between the independent variables and the dependent variable. This conclusion is supported by the low coefficient of determination obtained from the linear regression approach. Nonlinear regression has been used to provide models for predicting the compressive strength value. As a consequence, equation 9 has been developed. Equation 9 is presented below. The resulting equation shows that the w/b parameter has the most negative impact on the expected compressive strength, followed by the sand content. Conversely, the cement content has the greatest positive impact on the predicted compressive strength, followed by the curing time and palm oil fuel ash. Using equation 9, the projected compressive strength values for both the training and testing data have been generated. A correlation between the expected and observed compressive strength has been shown in Figure.14 to demonstrate the effectiveness of the suggested equation.

$$\sigma P = - 0.001 \times w/b343.7 + 2.7\times C.C0.544 + 0.0335 \times POFA1.17 - 370.2 \times S.C0.023 - 0.001 + 380.9\times T0.007 \quad (9)$$

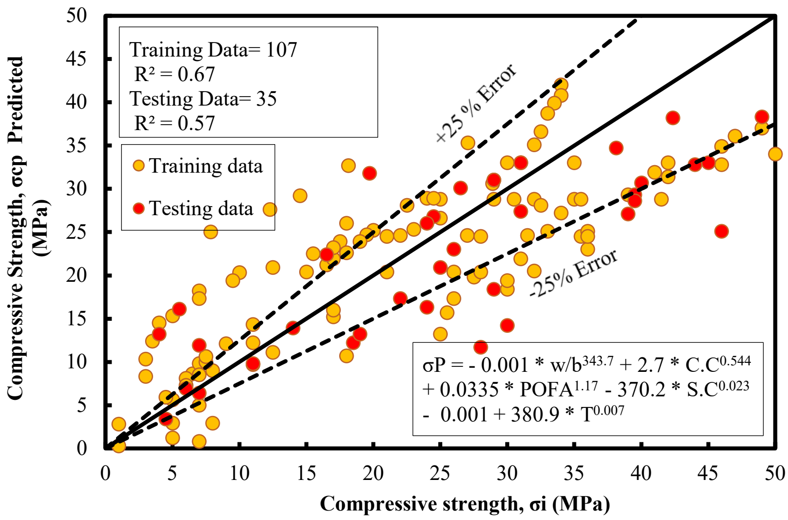

Figure 14. Correlation between measured and predicted compressive strength using nonlinear regression method

5.3 Artificial Neural Network (ANN)

The research aimed to optimise the performance of the Artificial Neural Network (ANN) by conducting experiments with different parameters, including the number of hidden layers, neurons, momentum, learning rate, and iteration numbers. The researchers aimed to identify the optimum arrangement that would provide the most precise forecasts for the compressive strength of mortar mixes enhanced with palm oil fuel ash. The authors assessed the effectiveness of the ANN model by using distinct datasets for training and testing. They made predictions of compressive strength values using specified input parameters. Subsequently, these forecasts were juxtaposed with the empirically determined compressive strengths of conventional mortar mixes that had been altered using palm oil fuel ash. The investigation demonstrated that the Artificial Neural Network (ANN) model surpassed other created models in terms of accuracy. Figure 15 depicts a comparison between the experimentally determined compressive strength values and the values estimated by the Artificial Neural Network (ANN) model for normal mortar that has been amended with palm oil fuel ash. The comparison is made for both the training and testing datasets. The research showcases that the ANN model, with fine-tuned parameters, precisely forecasts the compressive strength of regular mortar enhanced with palm oil fuel ash. Although ANN-based models are quite effective for building applications, a significant drawback is their opaque nature. Consequently, users are restricted to just seeing the outcomes of the model after carrying out several experiments, so limiting their capacity to comprehend the internal mechanisms of the model.

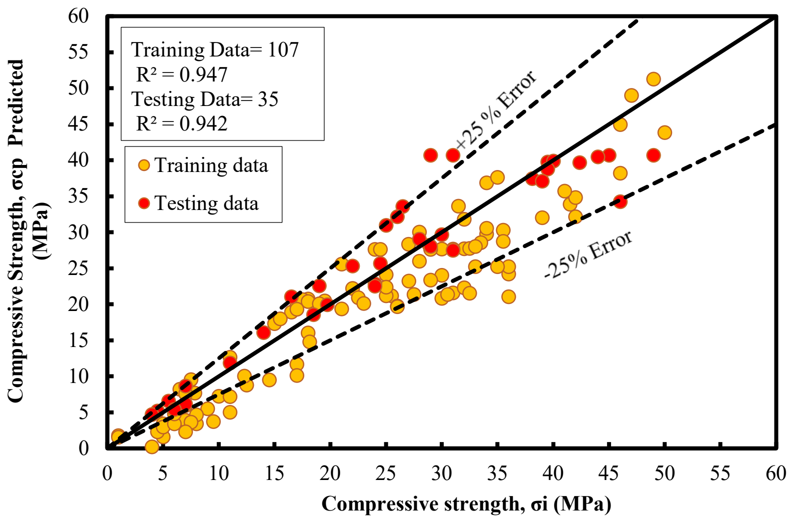

Figure 15. Correlation between measured and predicted compressive strength using ANN method

5.4 Assessment Parameters

According to the results presented in Table 2, the ANN model can be regarded as the most efficient and reliable model. This is because it has a higher coefficient of determination (R2) compared to other models and a lower root mean square error, along with a lower mean absolute error. Additionally, the value of the structural index (SI) ranges between 0.1 and 0.2 for both the training and testing data, indicating that the proposed model performs well.

Table 2. Assessment tools value for different proposed models

Models	LR		NLR		ANN	
	Training	Testing	Training	Testing	Training	Testing
R^2	0.574	0.47	0.669	0.571	0.87	0.89
RMSE (MPa)	8.8	11.9	7.74	8.54	5.11	4.4
MAE (MPa)	7.23	9.73	6.43	6.88	4.175	2.99
SI	0.39	0.42	0.34	0.33	0.17	0.15
OBJ	14.264		10.242		6.03	

6.0 CONCLUSIONS

The utilisation of palm oil combustion ash in place of cement represents an exceptionally sustainable approach to the recycling of agricultural waste. The following conclusion was reached on the basis of a comprehensive study using 142 data points to examine the incorporation of palm oil combustion ash into conventional mortar as a cement substitute and to propose three distinct models:

Among the developed models, the ANN model exhibited superior performance in comparison to the LR and NLR models. This was supported by the significantly lower RMSE, OBJ, SI, and MAE values and the higher R^2. The proposed models for forecasting the compressive strength of normal mortar composites are ranked in ascending order of performance and suitability, as determined by the statistical evaluation tools employed. The models are ranked as follows: LR (least suitable), NLR (nearest least suitable), and ANN (most suitable and superior performer).

The maximum allowable percentage of palm oil combustion ash in mortar without compromising the mechanical properties of the resulting concrete is 30%. However, based on the analysis of model parameters, the curing age of the mortar specimens has the second-largest effect on the compressive strength of normal mortar composites, after the water-to-cement ratio

The flow value of mortar is diminished when palm oil combustion ash is used as a partial cement replacement due to its coarser particles and greater surface area. Even though the rate of the hydration has been reduced due to the use of palm oil combustion ash as a partial replacement for cement results, thereby extending the setting time.

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8.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

9.0 AUTHOR CONTRIBUTIONS

Ahmad S. A: Conceptualization, Methodology

B. K. Mohammed: Data curation, Writing- Original draft preparation

K. O. Fqi: Investigation

S. Kh. Rafiq: Software, Validation

F. R. Karim: Writing- Reviewing and Editing

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