ISSN 2056-5860

DEVELOPMENT OF PREDICTION MODELS USING LINEAR ADAPTIVE FILTERS FOR SOME PROPERTIES OF A NEWLY DEVELOPED THERMO-REGULATED BRICK

Ihom, A. P.*, Aniekan Offiong*, Bassey, O. B., and Ezenkwu, C. Pascal*****
*Department of Mechanical Engineering
** Department of Civil Engineering
***Department of Electrical/Electronics and Computer Engineering
University of Uyo, Uyo, PMB 1017 Uyo Akwa Ibom State, **NIGERIA**

ABSTRACT

The development of prediction models using linear adaptive filters for some properties of a newly developed thermo-regulated brick has been carried out. The research started with the development of the bricks using anthill clay a material known for its thermoregulation property. The bricks were subjected to various tests to ensure that they conform to specifications and standard for thermo-regulated bricks and also to ensure that the thermal conductivity does not differ so much from that of bricks from virgin anthill clay. The tests data upon which the developed prediction models in this work were based were those of water absorption test, compression test and by extension abrasive index. Two models were developed for the prediction of water absorption and abrasive index properties of the developed thermo-regulated bricks. Plots of the predicted values of water absorption and the actual values of water absorption on the same graph showed a tight fitting curve indicating a high degree of accuracy for the prediction model. The plots of the predicted values of abrasive index and the actual values of abrasive index on the same graph showed a tight fit at some points and variations at other points. The performance evaluation of the prediction models showed that the model for the prediction of water absorption had a mean square error of 8.3521E- 4 and the model for the prediction of abrasive index had a mean square error of 0.0225. The performance evaluation has indicated that the two models have not done badly, though the accuracy of the water absorption model is higher than that of the abrasive index.

Keywords: Models; Bricks; Thermoregulation; Prediction; Properties; Linear adaptive filters.

INTRODUCTION

The use of prediction or predictive models have today found wide applications in fields such as Engineering, Science, Business management, Accounting and Social sciences. According to Asuquo and Ihom [1], a model is any representation of reality and may be in graphical, physical or mathematical terms [1]. Mathematical model is commonly used because it tries to show the workings of the real world by means of mathematical symbols, equations, and formulae. Although mathematical or symbolic models are the more usual, other types of models e.g iconic, analogue, simulation and heuristic sometimes have applicability [1-3]. Model may be further classified into normative and descriptive. Normative models are concerned with finding the best, optimum or ideal solution to a problem. Many mathematical models fall into this classification. Descriptive models, as their name implies, describe the behavior of a system without attempting to find the best solution to any problem. For example simulation tends to fall within this category. Perhaps the most important point to appreciate is not so much what a model is called, but what it does in helping an engineer to attain the goals that they have set [1-3]. In engineering predictive models have helped in predicting future outcomes, results of tedious tests and have provided quick insight into the

ISSN 2056-5860

future of various engineering occurrences, failures, characteristics, and properties. In this work Adaptive Linear Neural Network Filter is used to develop the prediction model.

This is a form of neural network with linear activation function that is controlled by variable parameters or weights which are adjusted according to an optimization or a learning algorithm. Adaptive filters are required for some applications because some parameters of the desired process are not known in advance or are changing in a stochastic manner. The closed loop adaptive filter uses feedback in form of an error signal to refine its activation function. Furthermore, the closed loop adaptive process involves the use of a cost function or an objective function, which is a criterion for evaluating the optimum performance of the filter. A learning or optimisation algorithm which determines how to modify the filter transfer function in order to minimize the cost function on the next iteration is adopted. The most common cost function is the mean square of the error signal [4].

The idea behind a closed loop adaptive filter is that a variable filter is adjusted until the error (the difference between the filter output and the desired signal) is minimized. The Least Mean Squares (LMS) filter and the Recursive Least Squares (RLS) filter are types of adaptive filter. Fig. 1 presents the Compact representation of a closed loop linear adaptive filter. k represents the sample number; x is the reference input; d is the desired input; ε is the error output; f is filter impulse response; Σ is the summation; and the box represents the linear filter and adaption algorithm. In this research, the LMS algorithm was adopted. The LMS algorithm or Widrow-Hoff learning algorithm is based on an approximate steepest descent procedure [5-6].

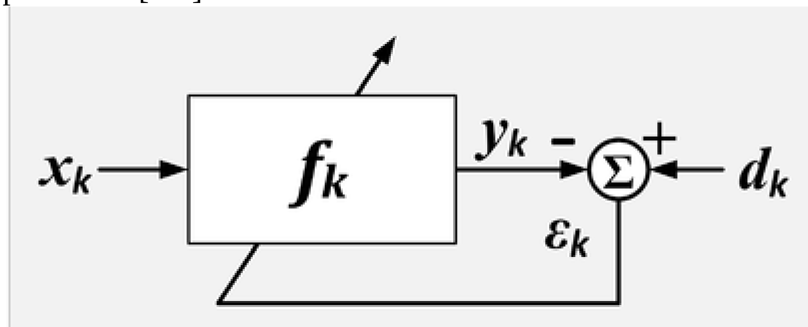

Fig. 1: Compact representation of Adaptive Filter

A new thermoregulatory brick has been developed using anthill clay and cement additive. Anthill structure has been known to have thermoregulatory property. The structure has the ability to regulate its own internal temperature. No matter the external temperature; the temperature within the anthill structure hardly exceeds 27^{o}C. This secret was long realised by the rural dwellers of Northern Nigeria. For so many centuries they have been using this anthill clay for building of their huts and barns for storage of their food crops and grains. Because of the thermoregulatory properties of the barns they were able to preserve these food crops till the following season [7].

Of recent some section of the Northern part of Nigeria have been able to produce fired bricks using this anthill clay in order to improve on the resistance to water wettability by the clay. Water reduces the strength of buildings built using anthill clay and for such buildings to last the water absorption ability of the clay must be reduced. This was accomplished in this present work also by the addition of controlled amount of cement to anthill clay, instead of firing the bricks. This was however, done at a cost and the cost was the slight change in the thermal conductivity of the anthill clay which is very important in its thermoregulation property [7].

Global warming and its attendant effects have become a world problem today. The year 2015 has been declared an El-nino year (El Niño, oceanic and atmospheric phenomenon in the Pacific Ocean, during which unusually warm ocean conditions appear along the western coast of Ecuador and Peru, causing climatic disturbances of varying severity.), most parts of the world are experiencing one or both of the following: extreme temperatures, drought, storms, floods, etc. In the month of May, 2015 not less than 2500 people in India lost their lives due to heat waves in that country with temperatures reaching 48^{o}C. In the same month and year, in the USA State of Texas – Houston, not less than 25 people lost their lives to floods and storms excluding millions of Dollars worth of properties destroyed in the natural disaster [8-9]. These incidences were preceded by extensive drought in the area. The Philippines and Australia have also been having their share of the effects of global warming. North- Korea is currently experiencing drought and this is threatening the availability of food, UN, 2015 [10]. Nigeria is another country where some part of the country is yet to receive rain for farming activities even after the month of May, 2015. The temperatures in most part of the country are as high as 37^{o}C and sometimes more [11]. This year has been declared by Nigerians as the hottest year as compared to last year. The years 2012 and 2013 in Nigeria witnessed serious floods that destroyed lives and properties worth billions of Dollars. These disasters informed this research work. The world today needs thermo-regulated houses for comfort; houses that will not be easily soaked by water during flooding. Strong houses that will not be pulled down easily by storms. This can only be achieved by the development of intelligent materials and by mimicking and copying from bio-systems [7, 15].

The objective of this research work is to develop prediction models using adaptive neural network filters which will be used in predicting some properties of thermo-regulated bricks right at the production stage.

MATERIALS AND METHOD

Materials and Equipment

The materials for this study were Anthill Clay (primary), Cement (secondary) and distilled water. Samples of the primary material were collected from different locations in the selected study area, Uyo and Port Harcourt, while the additive sample was obtained from the concrete laboratory in the University of Uyo, Akwa Ibom State. The grade of additive used in the experiment was Cement grade 42.5 with high alumina content for general purpose engineering applications. Other materials were: distilled water, releasing agent (engine oil), filter papers, cellotape, labelling materials, chemical reagents, cleaning cloth and fumigation chemicals (DDT).

Equipment

Equipment used were as follows: Atomic absorption spectroscope, Ignition burner, Analytical weighing balance (0.1g sensitivity) and weight box, Multi-purpose digital pH meter, Reciprocating shaker, Dispensing bottles, pipettes, beakers, Erlenmeyer and volumetric flasks (125ml), Thermometer (Hand thermo flash, max. 40^{0}C and Digital Sensor, 200^{0}C), Water distillation unit and evaporation dishes (aluminium), Drying oven (controlled at 105 -110^{0}C) and hot plate (150^{0}C). Others were Refrigerator and desiccators, I.S set of sieves, metal cans (lid), glass plate, measuring cylinder, oven, measuring pan, limit device, grooving tools and

ISSN 2056-5860

spatula, cylindrical steel mould, rammer, trowel, mixing pan, water cans, steel straight edge, steel ruler, Brick mould 215 x 102.5 x 65mm, Detachable steel moulds of 100 x 100 x 100mm, Computerized universal testing machine (DIGIMAX 3 Control, capacity of 3000kN), and Electrical furnace (max. 1200^0C).

Method

With the materials and equipment listed above thermoregulated bricks were produced. Both the raw materials and the produced bricks were subjected to various tests ranging from chemical analysis to physical and mechanical tests. The control brick upon which the development revolved had no cement additive. Details of the work can be seen in ref.[7], however, procedure for generating the data for the modelled properties is described below:

Water Absorption

This test was done in accordance to Standard specification (IS 3495, 1992). The cylindrical test specimens were completely dried in an oven at temperature 110^0C for 48 hours and their weights measured (W_1). After which they were completely submerged in a bucket of clean cold water at temperature 29^0C for 5 hours. The specimens were removed and traces of water were wiped out using absorbent material. The specimens were immediately weighed 3 minutes after damping (W_2). The water absorption was then calculated with the formula:

$$Water\ Absorption\ (\%) = \frac{W2 - W1}{W1}\ x\ 100 \quad \text{-------------------------} \quad (1)$$

Where;

W_2 = weight of wet specimen, W_1 = weight of oven dried specimen after 5 hours.

Compressive Strength

The failure response of the prepared specimens to loading was tested in accordance with American Standard specification (ASTM 1982) [12]. The cube shaped specimens obtained from a mixed mass of 2 kg of the control sample and admixtures, were air dried for 28 days, then placed between two plates of the compression strength tester. An axial load was applied at uniform rate of 14 N per minute until the maximum load at failure was realized. The crushing process is as shown in Plate 1, the computerized universal testing machine (DIGIMAX 3 control, capacity of 3000KN) which was used is also shown.

28 Days air dried specimens   weighing of specimen   crushing of specimen

Plate 1: Preparation of Cube Specimens, Weighing and Final Crushing Process.

Tables 1 and 2 were data generated from the above tests and are used as input parameter for the development of the prediction models.

Table 1 Water Absorption Result of Anthill Clay + Cement (0-20% additives)

Brick Specimen, PA	Oven Dried Weight (Kg)	Soaked Weight(Kg)	Water Absorption (%)
Anthill Clay +Additive (0%)	1714	1810	5.601
Anthill Clay +Additive (5%)	1648	1739	5.522
Anthill Clay +Additive (10%)	1643	1712	4.200
Anthill Clay +Additive (15%)	1660	1716	3.373
Anthill Clay+Additive (20%)	1690	1726	2.130

Table 2 Compressive Strength Results of Anthill Clay + Cement (0-20% additives)

Brick Specimen, PA	Water Absorption (%)	Green Compressive Strength (Nmm^{-2})	Abrasion Index
Anthill Clay +Additive (0%)	5.601	1.88	2.133
Anthill Clay +Additive (5%)	5.522	1.99	1.913
Anthill Clay +Additive (10%)	4.200	3.75	0.772
Anthill Clay +Additive (15%)	3.373	5.12	0.454
Anthill Clay +Additive (20%)	2.130	9.04	0.162

Results and Discussions

Development of the prediction model using Linear Adaptive Filters

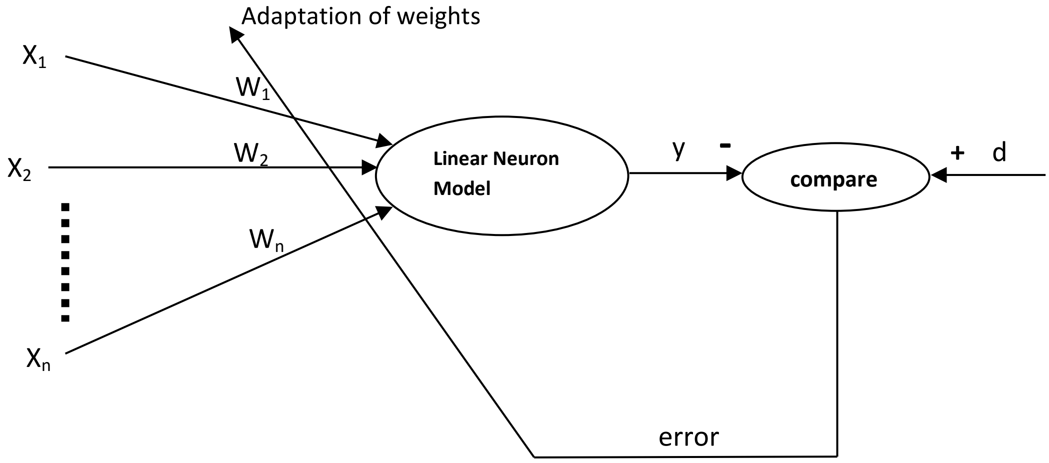

Fig.2 Adaptive Linear Neuron Model

The predicted output vector from the neuron **y** = **X w**………………………………... (1)
Where, **X** is an n-by-m data matrix; n is the number of training examples and m is the number of features. **w** is an m-by-1 weight vector.

Cost function for the prediction

Assuming an iterative batch learning, the error vector for the jth epoch becomes

$\mathbf{e}(j) = \mathbf{d}(j) - \mathbf{y}(j)$ ……………………………………………………………………. (2)

Where, **d** is the desired output vector.

The Mean square Error (MSE) = $\frac{\sum_{j=1}^{n} e^2(j)}{n}$ ………………………………… (3)

Substituting equation (1) into (2)

$\mathbf{e}(j) = \mathbf{d}(j) - \mathbf{X}(j)\mathbf{w}(j)$ ………………………………………………………………… (4)

To minimise the error function, we differentiate equation (1); thus:

$\nabla\mathbf{e}(j) = -\mathbf{X}^T(j)$

where, $\mathbf{X}^T$ means the transpose of matrix **X**

But, $\nabla\mathbf{e}(j) = \mathbf{J}(j) = \begin{pmatrix} \frac{\partial e(1)}{\partial w1} & \cdots & \frac{\partial e(1)}{\partial wm} \\ \vdots & \ddots & \vdots \\ \frac{\partial e(n)}{\partial w1} & \cdots & \frac{\partial e(n)}{\partial wm} \end{pmatrix} = -\mathbf{X}^T(j)$ ……………………………………(5)

n-by-m matrix

Where, **J**(j) is the Jacobian matrix.

From Gauss-Newton optimisation algorithm

$\mathbf{w}(j+1) = \mathbf{w}(j) - (\mathbf{J}^T(j)\mathbf{J}(j))^{-1}\mathbf{J}^T(j)\mathbf{e}(j)$ …………………………………………………...(6)

where, $\mathbf{J}^T(j)\mathbf{J}(j)$ is assumed to be non-singular and thus its inverse exists.

Substituting equations (4) and (5) into (6)

$\mathbf{w}(j+1) = \mathbf{w}(j)+(\mathbf{X}^T(j)\mathbf{X}(j))^{-1}\,\mathbf{X}^T(j)\,(\mathbf{d}(j)-\mathbf{X}(j)\mathbf{w}(j)) = \mathbf{w}(j)+(\mathbf{X}^T(j)\mathbf{X}(j))^{-1}\,\mathbf{X}^T(j)\mathbf{d}(j)-(\mathbf{X}^T(j)\mathbf{X}(j))^{-1}\,\mathbf{X}^T(j)\mathbf{X}(j)\mathbf{w}(j))$

$\mathbf{w}(j+1) = (\mathbf{X}^T(j)\mathbf{X}(j))^{-1}\,\mathbf{X}^T(j)\mathbf{d}(j)$ ………………………………………………………(7)

Using the data available in Tables 1 and 2 _ , a MatLab program (appendix A_) developed to accurately give the weight vector **w** using the normal equation (7) such that $\mathbf{y} \approx \mathbf{d}$.

The prediction models and graphs showing how close the **y** is to **d** for the empirical data in the tables are provided below:

For Table 1

Prediction model: WA = $0.0465(PA) - 0.0747(ODW) + 0.0738(SW)$ .... (8)

Where, WA is the percentage water absorption; SW is the Soaked weight; ODW is the Oven Dried Weight and PA is the percentage additive.

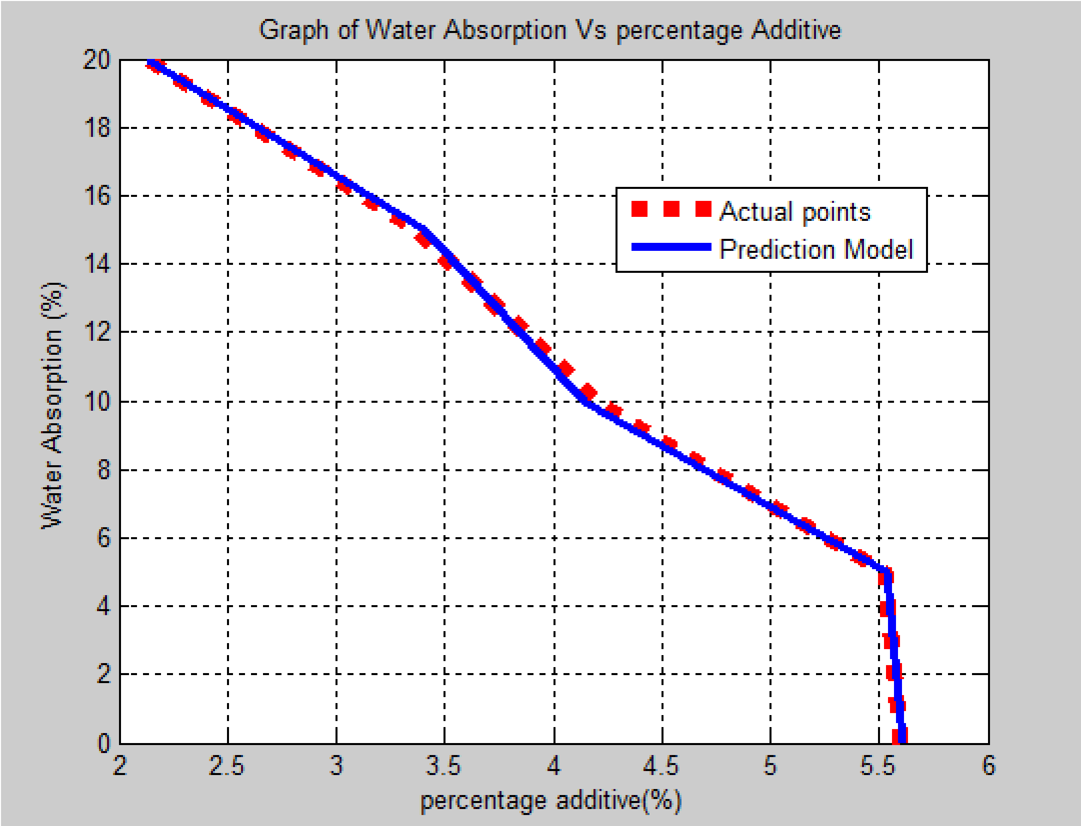

Figure 2: Comparison between the prediction model and actual output for Table 1

***For Table 2**:*

Prediction model: AI = -0.0969(PA)+ 0.3428(WA)+ 0.1450(CSG) .... (9)

Where, WA is the percentage water absorption; CSG is the Compressive Strength Green and PA is the Percentage Additive.

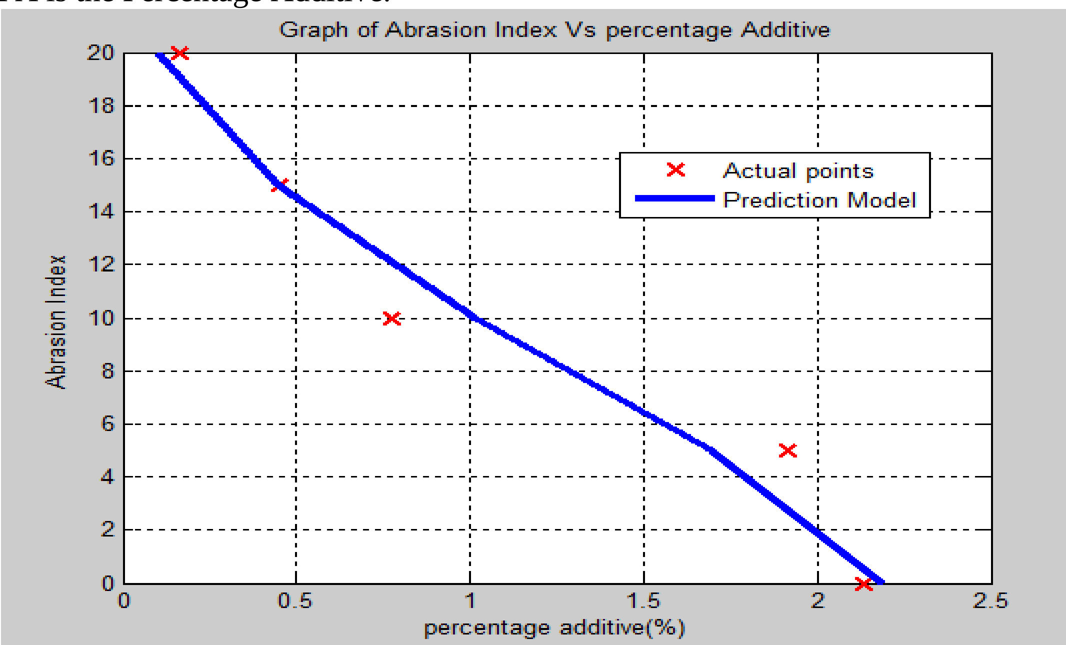

Figure 3: Comparison between the prediction model and actual output for Table 2

Performance Evaluation of the Prediction Models

The prediction models are evaluated using equation (3)

ISSN 2056-5860

$$\text{MSE} = \frac{\sum_{j=1}^{n} e^2(j)}{n}$$

But, **e**(j) = **d**(j) – **X**(j)**w**(j) from equation (4)

For Table 1:

MSE = 8.3521E - 4 .... (10)

For Table 2:

MSE = 0.0225 .... (11)

DISCUSSION

Water Absorption

The data in Table 1 has been used to develop the model equation in equation 8. The equation is for the prediction of water absorption property of the thermo-regulated bricks. The model has been used to generate values of the predicted output of water absorption of the bricks, which are plotted on the same graph with the actual values (desired values) as shown in fig.2. The two curves lie on each other showing a tight fit which is also an indication of the high degree of accuracy of the developed model. The performance evaluation of the model was performed and is given by equation 10 which shows that the mean square error of the model is very small and negligible, thereby confirming the accuracy of the model equation. Table 1 shows that as the cement content in the bricks increase the water absorption capacity of the bricks decreases. Water absorption of the bricks and cement content has an inverse proportion. Anthill clay brick without cement has the highest water absorption value of 5.6% and anthill clay brick with 20% cement had the lowest value of water absorption of 2.1%. Cement has the ability of resisting water absorption as it forms chemical bonds with the particles of the clay resulting in the formation of a gel-like substance which is also said to be responsible for the continuous curing of cement and thereby contributing to the strength of the material [13]. According to standard, values within the range of 4.5% to 7% are recommended for structural bricks in BS EN 771-1 in [7]. This implies that the addition of cement in varied proportions improves the functional requirement of Anthill clay. It makes the clay a suitable structural brick material for construction of storage structures (silos) and shelter houses with minimal water absorption, even under intense precipitation occurrence of a period of 5 hours.

Compressive Strength and Abrasive Index

The model in equation 9 is the prediction model for abrasive index property of the thermo-regulated bricks. This equation was used in generating prediction values of abrasive index of the thermo-regulated bricks using input data from Table 2. The prediction values were used in plotting on the same graph with the actual values of abrasive index of the bricks as shown in fig.3. The graph of the abrasive index versus cement percent variation showed the two curves having a close fit at some points while showing some variations at others. The performance evaluation of the developed model was carried out and it showed that the mean square error was 0.0225 as shown in equation 11. The theoretical analysis of the data used is as explained below:

Table 2 shows that the compressive strength is directly proportional to the increase in cement content of the bricks, as the cement was increasing so was the compressive strength. The highest value of 9.04 N/mm^2 compressive strength occurred at 20 % cement content in the brick, while the lowest value of 1.88 N/mm^2 compressive strength occurred at 0% cement content in the bricks. The rise in compressive strength as clearly depicted in Table 2, is an indication that the varied proportions of the additive improved the clay material in terms of strength requirements. The results from 5-10% cement conforms to the compressive strength range of 3 to 3.5Nmm^{-2} recommended by the Nigeria Building and Road Research Institute, NBRRI in [7].

Table 2 shows an inverse relationship between cement content of the bricks and the abrasive index, as the cement content increases the abrasive index decreases thus agree with figure 3, the bricks become stronger to resist abrasion and scratching. The highest abrasive index of 2.13 occurred at 0% cement in the brick and the lowest value of 0.162 abrasive index occurred at 20% cement in the brick. The curve depicts a downward sloping graph, with a visible decrease in the abrasion tendency at 10 to 20% of the additive. The abrasive index values corresponding to 15-20% cement in the bricks are within the allowable maximum limit of 0.50 as specified in the ASTM C902. According to BS in [7, 16], bricks must have good compressive strength and low abrasive index to be able to withstand loading, abrasion and wear in building structures. The results obtained adhere to standard clay bricks requirements and are also similar to the outcomes of the research work by Olowu, *et al*, [14]. The ability of the cement to improve both the compressive strength and the abrasive index of the anthill clay bricks can be explained in terms of cement being able to resist water absorption as it forms chemical bonds with the particles of the clay resulting in the formation of a gel-like substance which is also said to be responsible for the continuous curing of cement and thereby contributing to the strength of the material [13, 17-18].

CONCLUSION

This research work the development of prediction models using linear adaptive filters for some properties of a newly developed thermo regulated brick has been extensively carried out and the following conclusions were drawn from the study:
1. Models are very important in predicting properties and using the information in producing thermo regulated bricks that conform to specifications and standards
2. The developed model for water absorption property of the thermo regulated bricks predicted the water absorption property of the brick with very high accuracy. The performance evaluation of the model indicated that the model performed very well with a mean square error of 8.3521E- 004 which is actually negligible.
3. The developed model for abrasive index property of the thermo-regulated bricks predicted the abrasive index accurately at some compositions but with little variations at others. The performance evaluation of the model indicated that the model performed moderately well with a mean square error of 0.0225. The error is not too much as too render the result inaccurate particularly where tolerance and limits are considered.
4. The developed models can be used in predicting the water absorption and abrasive index properties of the newly developed thermo regulated bricks.

REFERENCES

[1] Asuquo, L.O. and Ihom, A.P. International Journal of Metal and Steel Research Technology Vol. 1, No. 2, 2013, PP: 19 - 25 Available online at http://acascipub.com/Journals.php
[2] Ihom, A.P. (2014) Role of Age Hardening Heat Treatment on the Hardness Values of 93.95 Al-5 Zn-1.05 Sn/5 Al_2O_3- SiO_2 Particulate Composite Aceh International Journal of Science and Technology ISSN: 2088-9860 Journal homepage: http://jurnal.unsyiah.ac.id/aijst3(2): 61-66

[3] Ihom, A.P. and Offiong, A. Statistical Modeling and Analysis of Hardness Value Change with Diametric Distance of Heat Treated Steel, International Journal of Scientific & Engineering Research, Volume 5, Issue 10, 2014, 1389-1391
[4] Haykin, Simon (2002). *Adaptive Filter Theory*. Prentice Hall. ISBN 0-13-048434-2.
[5] http://www.mathworks.com/help/nnet/ug/adaptive-neural-network-filters.html. Retrieved on 19th August, 2015.
[6] Widrow, Bernard; Stearns, Samuel D. (1985). *Adaptive Signal Processing*. Englewood Cliffs, NJ: Prentice Hall. ISBN 0-13-004029-0.
[7] Mekine, A. B. (2015) Effects of Cement on the Strength and other Properties of Anthill Clay as an Engineering Material, M.Eng Degree Dissertation Presented to the PG School University of Uyo-Nigeria.
[8] BBC (2015) Heat waves kill people in some parts of India, BBC News of 27 May, 2015
[9] CNN (2015) Storms and Flooding in Texas-Houston, USA, CNN News of 26 May, 2015
[10] MSN (2015) Flooding and droughts in some parts of USA, Microsoft News, June, 2015
[11] Punch, (2015) Late Rains in Some parts of Nigeria, the punch newspaper of 28 May, 2015
[12] ASTM (1982) American Standard Specifications Handbook
[13] Lea, F. M. (1970). *The Chemistry of Cement and Concrete (3rd Edition)*. Edward Arnold (Publishers) Ltd.
[14] Olowu, O. A., Raheem, A. A., Awe, E. M. and Bamigboye, G. O. (2014). Enhancing the Mechanical properties of lateritic brick for better performance. *Int. Journal of Engineering Research and Applications*, vol. 4, issue 11, pp. 1 – 7.
[15] Ihom, A.P. (2011) Foundry Raw Material and Testing Procedure, 1st Edition, Jos: published by A^2P^2 Publishers, pp30-90
[16] Mittal, S and Shukla, J.P. (2008) Soil Testing for Engineers, 2nd Edition, New Delhi Khana publishers, pp5-50.
[17] Ndaliman, M. B. (2006). Refractory Properties of Termite Hills under Varied Proportions of Additives, *Leonardo Electronic Journal of Practices and Technologies*, pp. 161-166.
[18] Takayuki, H., Morioka, M., Yoshioka, I. and Yokozeki, K. (2014). Development of a new ecological concrete with CO_2 emissions below zero. Construction and Building Materials, vol. 6, pp. 338 – 343.

Appendix A: MatLab Code

```
clc; clear; clear all;clf;
%Water Absortion
%X = load('dataInput2.csv');
%y = load('dataOutput2.csv')
%Compressive Strength
X = load('dataInput3.csv');
y = load('dataOutput3.csv');
plot(y,X(:,1),'Xr','MarkerSize',10,'Linewidth',2)
hold on
plot(T,X(:,1),'b','LineWidth',3)
title('Graph of Abrasion Index Vs percentage Additive')
xlabel('percentage additive(%)')
ylabel('Abrasion Index ')
legend('Actual points','Prediction Model',0)
grid on
```