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Evaluation of the Compressive Strength and Sorptivity of Pozzolanic Concrete Containing Calcined Termite Mound

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RESEARCH ARTICLE

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ABSTRACT

Pozzolans have long been established as viable materials for the partial replacement of cement in concrete. However, the extent to which they can be used is still under investigation. Pozzolans do not in themselves have cementitious value but can react chemically with calcium hydroxide and moisture to produce cementitious compounds. Pozzolanic concretes have been reported to have varied properties in term of compressive strength and durability properties which need to be ascertained. This research focuses on Calcined Termite Mound (CTM) and its influence on the compressive strength and sorptivity of concrete. Several tests were carried out to ascertain the physical, chemical, and mineralogical properties of CTM and conventional concrete constituents. Some of these tests include bulk density, setting time, aggregate crushing value (ACV), aggregate impact value (AIV), slump test, X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD), sorptivity, and compressive strength tests. Compressive strength tests results for concrete containing Ordinary Portland Cement (OPC) and CTM cement blends show that CTM has higher silica content compared to OPC and can be classified as Class-N pozzolans It is also richer in calcium oxide. The study also reveals that CTM has an optimum replacement level of 5% with strength of 13.4 MPa at 28 days, which is higher than the 12.4 MPa of control concrete. Also, the result of sorptivity test for OPC-CTM blended concrete gave lower resistance to sorptivity. Regression models were developed to predict the compressive strengths of OPC-CTM concrete as a function of % replacement level and curing age.

Keywords: Calcine termite mould; Compressive strength; Pozzolanic concrete; Sorptivity.

INTRODUCTION

Concrete, an essential for construction material, poses significant environmental challenges due to material consumption and CO2 emissions from Portland cement manufacturing. Therefore, transitioning to sustainable concrete construction practices is imperative to mitigate these impacts. This involves reducing concrete usage in buildings and replacing Portland cement with supplementary cementitious materials derived from industrial by-products, such as fly ash and slag. Altwair and Kabir (2010) asserts the increasing use of pozzolans in the cement industry due to their environmental sustainability. Natural pozzolans help reduce carbon dioxide emissions by decreasing cement production and consumption, thereby mitigating the release of greenhouse gases into the atmosphere. Sapal and Wegner (2017) reveals that for a long time, the practice of combining Portland cement and pozzolanic materials for the purpose of construction has been prevalent. Albeit, in time past, an advanced knowledge of the characteristics of these materials and their impact on concrete had not been completely understood. However, studies are now being carried out to determine the physical, chemical, and mechanical properties of these pozzolans, and how they affect the performance of concrete mixes.

Pozzolans are solid materials with little or no cementitious value, composed of aluminous, siliceous, or amorphous siliceous content. When these materials react with calcium hydroxide [Ca $(OH)_2$] in the presence of water, they form compounds with properties like that of cement through cement hydration reactions (Bumanis *et al.*, 2020). This pozzolanic reaction leads to increase in some mechanical properties of concrete such as compressive, tensile, and flexural strength, modulus of elasticity and durability (Dembovska *et al.*, 2017). Pozzolans occur naturally and industrially. Examples of natural pozzolans are zeolite and volcanic pumice. On the other hand, artificial pozzolans include agricultural and industrial byproducts such as rice husk and fly ash. No matter the form in which they occur, these materials find use in being added to cement, as they produce some added benefits to a concrete mix.

Khan and Alhozaimy (2011) opine that pozzolans offer economic benefits by replacing the expensive portion of Portland cement with a more affordable natural or artificial pozzolan. They also postulated that pozzolans increase the strength and durability of concrete mixes, enhancing their resistance to sulfate and thermal attack, as well as improving chemical durability. The performance of concrete mixes produced from the use of pozzolanic materials depends on the type of pozzolan, each possessing its unique characteristics, including fineness ratio, surface area, thermal properties, corrosion resistance, and mechanical properties like compressive strength, flexural strength, shrinkage and creep, and modulus of elasticity. These properties influence the characteristics of concrete (Al-chaar and Alkadi, 2013).

Ikumapayi *et al*., (2023) highlighted the potential use of termite mounds as pozzolans, both in calcined and uncalcined forms, for concrete production. The results indicate that calcined termite mounds exhibit comparable compressive strengths to control mixes, suggesting their potential for concrete applications, while uncalcined termite mounds show lower strengths, making them more suitable for termite mound blocks. Similar study on the potential of uncalcined soldier-ant mound clay in improving the strength characteristics of cement concrete beam was investigated. The results showed that while SAMC reduced concrete density and increased setting times, with increase in SAMC content (Ikponmwosa *et al*., 2019). An optimal 5% SAMC content improved structural performance compared to normal concrete. The performance of blended cement mortar mixtures containing termite mound and lime for building construction was assessed. Tests conducted on 50 x 50 x 50 mm cube specimens evaluated compressive strength, water absorption, and resistance to magnesium sulphate exposure. Results demonstrated that compressive strength increased with age but decreased with higher percentage replacements of cement with lime and termite mound. Notably, at 25% termite mound content, compressive strength increased by 66.73%, 69.23%, 84.62%, and 100% at curing ages of 7, 14, 21, and 28 days respectively, suggesting that up to 25% replacement of termite mound and lime is suitable for mortar composition (Olanrewaju *et al*., 2019).

Guyo *et al*., (2019) explores the potential of calcined termite hill clay powder (CTHCP) as a partial replacement for ordinary Portland cement in C-25 grade concrete production. The research involved collecting samples from the Bokuluboma vicinity, calcining them at 650°C, and assessing their chemical composition. Various properties of concrete mixes with CTHCP replacing cement were investigated, revealing that up to 11.3% replacement achieved the target compressive strength of 34MPa at 28 days. Moreover, the mix remained workable up to 25% replacement, with faster setting times compared to the control mix, suggesting CTHCP as a suitable partial cement replacement, especially at 11.3% for C-25 grade concrete production.

It is a known fact that pozzolanic materials improve the properties of concrete mixes such as durability, compressive strength, and workability. However, the extent to which these pozzolanic materials influence the performance of concrete when they partially replaced with of Portland cement in concrete mixes has not been fully explored. Also, the effects of some pozzolanic materials like rice husk ash, sugarcane bagasse ash, fly ash, palm oil fuel ash on the properties of concrete has been studied considerably to a great extent. Meanwhile, little or no research has been done on calcined termite mound to determine its influence on the performance of concrete. This study focuses on evaluating the sorptivity and compressive strength performances of concrete mixes with calcined termite mound blends with the view of establishing its industrial acceptability. This study also provide regression models for the prediction of the compressive strength of the resulting pozzolanic concrete.

MATERIALS AND METHOD

Materials

The materials used for this study were sourced from Akure, Nigeria and tested to ensure that they meet all the necessary standards. Dangote Portland cement, grade 42.5, type 1 general-purpose cement as per the American Society for Testing and Materials Standards - ASTM C150, (2012) was obtained from a retail shop outlet within Akure metropolis, Ondo State, Nigeria. Termite mound was obtained from a farmland in the Federal University of Technology Akure and heated at a controlled temperature of 600°C to produce calcined termite mound, which was used as the pozzolanic material. The portion of the calcined termite mound (CTM) finer than sieve No 425 were used. Also, an X-ray Fluorescence (XRF) analysis, and X-ray diffraction (XRD) test were carried out to determine the chemical and the mineralogical composition of the calcined soil. The physical properties of the binder are shown in Table 1.

Table 1. Physical properties of the binders

Properties / Parameters	OPC	CTM
Specific gravity (kg/m^3)	3.02	2.53
Initial setting time (minutes)	75	-
Final setting time (minutes)	270	-
Normal consistency (%)	26	-
Moisture content (%)	-	16.35
Dry density (g/cm^3)	-	0.458

The oxide composition of calcined termite mound are presented in Table 2. Based on ASTM C618 (2019), the calcined termite mound is Class N; since the sum of SiO_2, Fe_2O_3, and Al_2O_3 is greater than 70% and the composition of SO_3, is not up to 4%. Notably silica content is significantly higher (56.176%) than any other oxide in the material.

Table 2. Chemical composition of the calcined

Composition	Concentration (%)
SiO2	56.176
Al_2O_3	19.49
Fe_2O_3	13.079
CaO	0.949
MgO	0.00
SO_3	0.181
TiO_2	4.517
LOI	3.86
$SiO_2+Al_2O_3+Fe_2O_3$	88.742

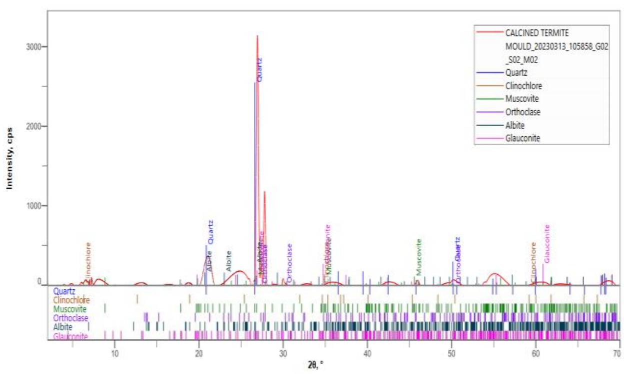

Figure1. XRD Analysis of Calcined Termite Mound

The minerals found in the CTM sample are outlined in Figure 1. Quartz was identified as the primary crystalline phase, followed by Orthoclase. Traces of minerals such as Muscovite, Albite, Clinochlore, and Glauconite were also present in the specimen, exhibiting smaller but well-dispersed peak intensities compared to Quartz and Orthoclase. However, the highest peak intensities were detected at approximately 2ϴ = 27° and 28° for Quartz and Orthoclase, respectively.

The aggregates used in this study include fine and coarse aggregate. The coarse aggregate consists of crushed granite with maximum sizes of 12.5mm, sourced within the Akure metropolis and used in all concrete mixes. These coarse aggregates conform to the recommendations of British Standards - BS 882, (1992). The fine aggregate comprises sand with particle sizes finer than 4.75mm, sourced from a local quarry in Akure, Ondo State, Nigeria. The physical properties of both the coarse and fine aggregates used for the tests are presented in Table 3.

Potable water, sourced from a borehole in a construction site within the Federal University of Technology Akure, was used to cast and cure the concrete specimens. This water meets the requirements of concrete mixing water as per British Standards (BS EN, 1997).

Table 3. Physical properties of coarse and fine aggregates

Properties	Result
Specific gravity (kg/m^3) of sand	2.35
Aggregate crushing value (ACV) of granite	21.44%
Aggregate impact value (AIV) of granite	11.34%
Bulk density (kg/m^3) of granite	1528.7

Method

- Mix design:

A series of trial mixtures was conducted to establish the suitable mix design for the proposed concrete mixtures of grade 20 MPa. Dangote Portland cement was partially replaced with the Calcined Termite Mound (CTM), in a level of 5% to 20% at a 5% step size increment. A total of 45 concrete cube test specimens were produced to evaluate the compressive strength and 45 cylindrical test specimens for sorptivity evaluation. These concrete cube test specimens were produced using a mix ratio 1:2:4, and a constant water-binder ratio of 0.55.

- **Preparation, casting and curing of pozzolanic concrete:**

The cement, CTM, fine and coarse aggregates were measured by weight and then manually mixed. The mixing was done very well to achieve a thorough mix. Slump and compacting tests were used for the workability assessment (British Standards - BS 1881-103, 1993). For each test day and replacement level, a total of 3 concrete cubes with side dimension of 150mm x 150mm x 150mm were cast for the compressive strength test; while 3 cylindrical concrete samples with 100mm diameter and 50mm thickness were cast for the sorptivity test. The cast samples were left for 24 hours before being demolded from its form and placed in a water tank. The concrete samples were cured (by immersion in water) for 7, 28, and 56days. For each curing age, 15 test specimens for compressive strength and 15 test specimens for sorptivity test were evaluated.

- **Test on hardened concrete:**

Compressive strength of the concrete samples were determined with the use of universal compressive machine with a load capacity of 1000kN, and load rate of 0.5MPa/s. The test procedure was in accordance with the standard (ASTM C 39, 2001). At each test day, three test specimens from each mixes were tested and the average of these readings was taken as the compressive strength of that mix.

The sorptivity test was carried out as per the requirements of American Society for Testing and Materials Standards - ASTM C1585, (2013). This test allows for one directional flow of water through the unsealed end of the concrete. *The setup for sorptivity test is shown in Figure 2.* Before this test was carried out, the weight and diameters of all the test specimens were measured. A plastic tray of water to a depth of 3mm was held to the ground and the unsealed surface of the specimens was placed over steel supports inside the tray.

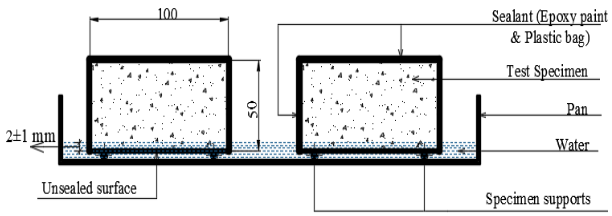

Figure 2. Setup for water absorption test (Ohwofasa et al., 2023).

The initial mass and the masses of the samples after it was partially placed in water to a depth of 3mm *a*t time intervals of 1, 2, 4, 8, 10, 20, 30, 110, and 120 mins, was recorded. During the test, water was re-filled into the tray to maintain a water depth of 3mm. The water absorption rate (i) is calculated using the Equation 1.

$$i = \frac{m_b - m_a}{a \times d} \text{ mm} \quad (1)$$

Where:

$m_b - m_a$ is the change in specimen mass in grams, at the time t,

a is the exposed area of the specimen, mm^2; d = density of the water, g/mm^3

The sorptivity coefficient, S is the slope of the best fit line of a graph of water absorption rate, i against the square root of time, t in secs.

RESULTS AND DISCUSSIONS

Fresh concrete properties

The slump and compacting factor test results are shown in Table 4. The results show that the slump values and compaction factor of the cement mix decreased with an increase in the percentage replacement level of CTM. Hence, the slump value and compaction factor are highest at control (0%) and lowest at 20% replacement levels. The decrease in the slump and compacting factor values with increasing proportions of CTM is an indication of low workability of the mix (Fapohunda and Daramola, 2019).

Table 4. Effect of CTM on workability properties of concrete

Mix Designation	Slump	Compaction Factor	Workability	Type
B1 (0%)	50	0.88	Stiff Plastic	TRUE
B1-2 (5%)	45	0.82	Stiff Plastic	TRUE
B1-3 (10%)	42	0.80	Stiff Plastic	TRUE
B1-4 (15%)	40	0.78	Stiff Plastic	TRUE
B1-5 (20%)	35	0.76	Stiff Plastic	TRUE

The results of the workability from the slump test satisfied the specified range of 35mm to 50mm. Likewise the results from compacting factor test which ranges between 0.76 and 0.88 fell within the specified range of 0.7 to 0.99. The outcomes of the two tests show the workability to be satisfactory.

Hardened concrete properties

- Compressive strength:

The compressive strengths of the OPC-CTM concrete mixes at days 7, 28, and 56 of curing are depicted in Figure 3. A progressive decrease in compressive strength was observed with increasing CTM replacement. The compressive strength ranged from 8.2 to 13.4 MPa at day 28 and 8.8 to 13.9 MPa at day 56. While the compressive strength of all test samples increased with curing duration, the rate of strength development slowed after day 28. Notably, the 5% CTM replacement (designated as B1-2) exhibited the optimum compressive strength at all curing ages, with values of 10.6 MPa, 13.4 MPa, and 13.9 MPa for days 7, 28, and 56, respectively. At day 28, mix B1-2 surpassed the compressive strength of the control mix by 8%. This improvement suggests a pozzolanic reaction between CTM and the calcium hydroxide (Portlandite) released during cement hydration.

The decrease in compressive strength with higher CTM replacement levels can be attributed to the overconsumption or dilution of Portlandite, hindering the formation of additional hydration products and consequently impacting overall concrete strength. The trends in the strength development of the CTM concretes are similar to those reported in the literature (Elinwa, 2006; Olaniyi and Umoh, 2014).

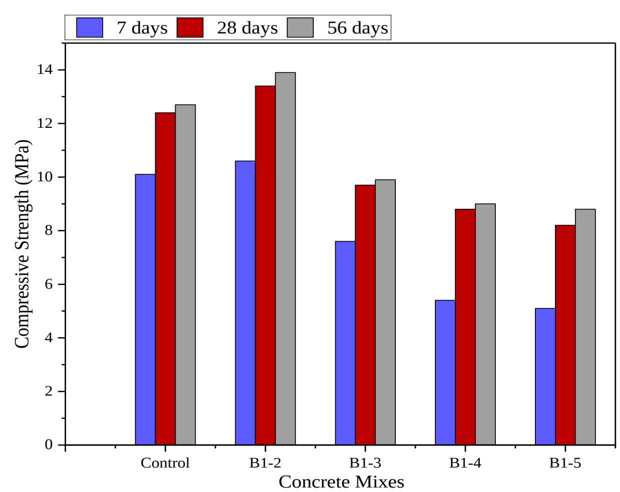

Figure 3. Compressive strength development.

- Sorptivity:

The rate of water absorption of the concrete mixes at day 28 is illustrated in Figure 4. A regression analysis was employed to fit a line to the data, plotting the amount of absorption (in millimeters) against the square root of time (in seconds). The slope of this line provides the sorptivity of the concrete mixes.

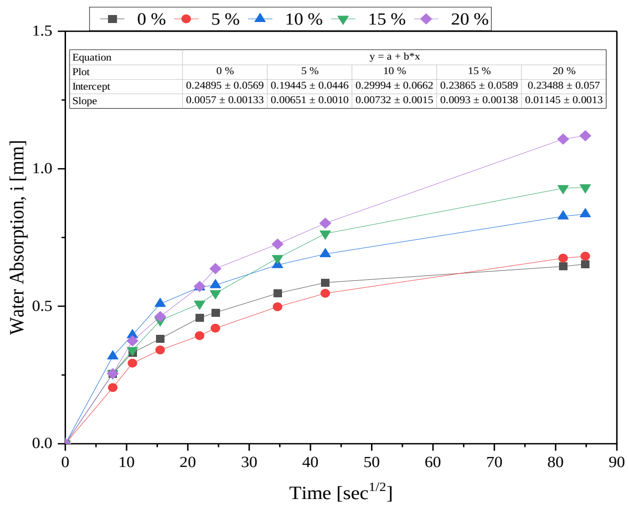

Figure 4. The rate of water absorption of the concrete mixes at day 28.

The sorptivity for all test specimens at day 28 is illustrated in Figure 5. The sorptivity coefficient generally exhibited an upward trend with an increase in CTM replacement. The control mix demonstrated the lowest sorptivity value (0.0057 mm/sec$^{\wedge 1/2}$), whereas the 20% CTM replacement level exhibited the highest sorptivity value (0.0115 mm/sec$^{\wedge 1/2}$). The percentage increase of the CTM mixes with respect to the control was 14.2%, 28.4%, 63.2%, and 100% for the mixes designated with 5%, 10%, 15%, and 20% replacement, respectively. The addition of calcined termite mound to the cement resulted in an increase in the resulting concrete's sorptivity. This outcome can be attributed to the porosity and absorbent properties of calcined clay to water. Previous studies have shown that the incorporation of calcined brick powder as a supplement for cement up to 40% led to an increase in both porosity and sorptivity (Mohan *et al.*, 2020).

- Mineralogical characterization and scanning electron microscopy:

The mineralogical composition of the calcined termite mound (CTM) concrete samples for days 28 and 56 is presented in Figures 6 and 7, respectively. It is noteworthy that the initial crystalline phases underwent considerable changes during the hydration of the CTM concrete. At days 28 and 56, Calcite, Portlandite, Quartz, and Lime were found to be widely distributed in the spectrum. However, minerals such as Muscovite, Orthoclase and Osumilite exhibited smaller constructive peak intensities compared to other minerals, possibly attributed to differences in atomic arrangement or packing patterns. Minerals such as Calcite, Portlandite, Quartz, and Lime displayed more noticeable peaks in the crystalline phase. The highest peak intensity was observed at approximately 2ϴ = 30° for Calcite, while other minerals with noticeable peaks fell within the range of 2ϴ = 18 - 50°.

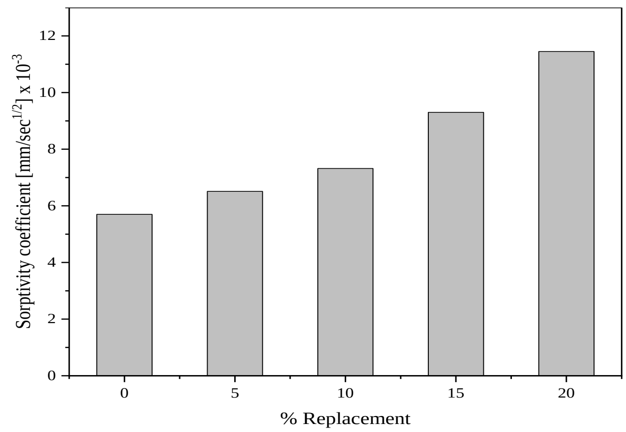

Figure 5 Sorptivity coefficients of the OPC-CTM concrete mixes at day 28

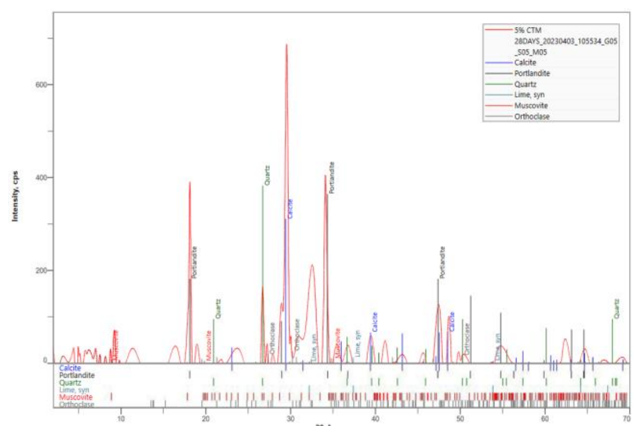

Figure 6. XRD Analysis of 5% replacement CTM concrete at day 28

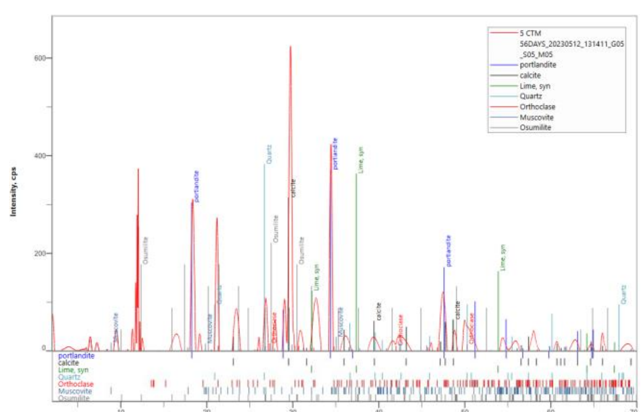

Figure 7. XRD Analysis of 5% replacement CTM concrete at day 56

The microstructure of the referenced concrete, and the 5% CTM replacement concrete at 7 and 28 days are shown in Figure 8 and Figure 9. To investigate the morphology of the test samples, the pore sizes of the samples were measured using ImageJ, and their average size was determined using Gaussian analysis on OriginPro. The larger pore sizes were observed in the control mix, compared to the 5% CTM replacement mix. However, the pore in both mixes decreased in size as the hydration days increases. At day 7, the pore sizes for the control mix and the 5% CTM replacement mix were are 3.78, and 3.08 micro meter respectively. At day 28, the pore sizes of the mixes reduced by 22% (2.93 micro meter) for the control and 43% (1.75 micro meter) for the 5% CTM replacement mix. The reduction in pore size and the densified structure in the mixes resulted from some hydration and pozzolanic activities. At the early period of hydration, it is observed that the radiating crystals of C-S-H were widely spread through the CTM blended mix. The dense structure of the mixes is evident on the compressive strength test results but not on the sorptivity. Ettringite was not observed in either mix at day 28 but there were traces of cracks; the absence of ettringite could be due to the low sulphate content in the binder which can react with the available Portlandite.

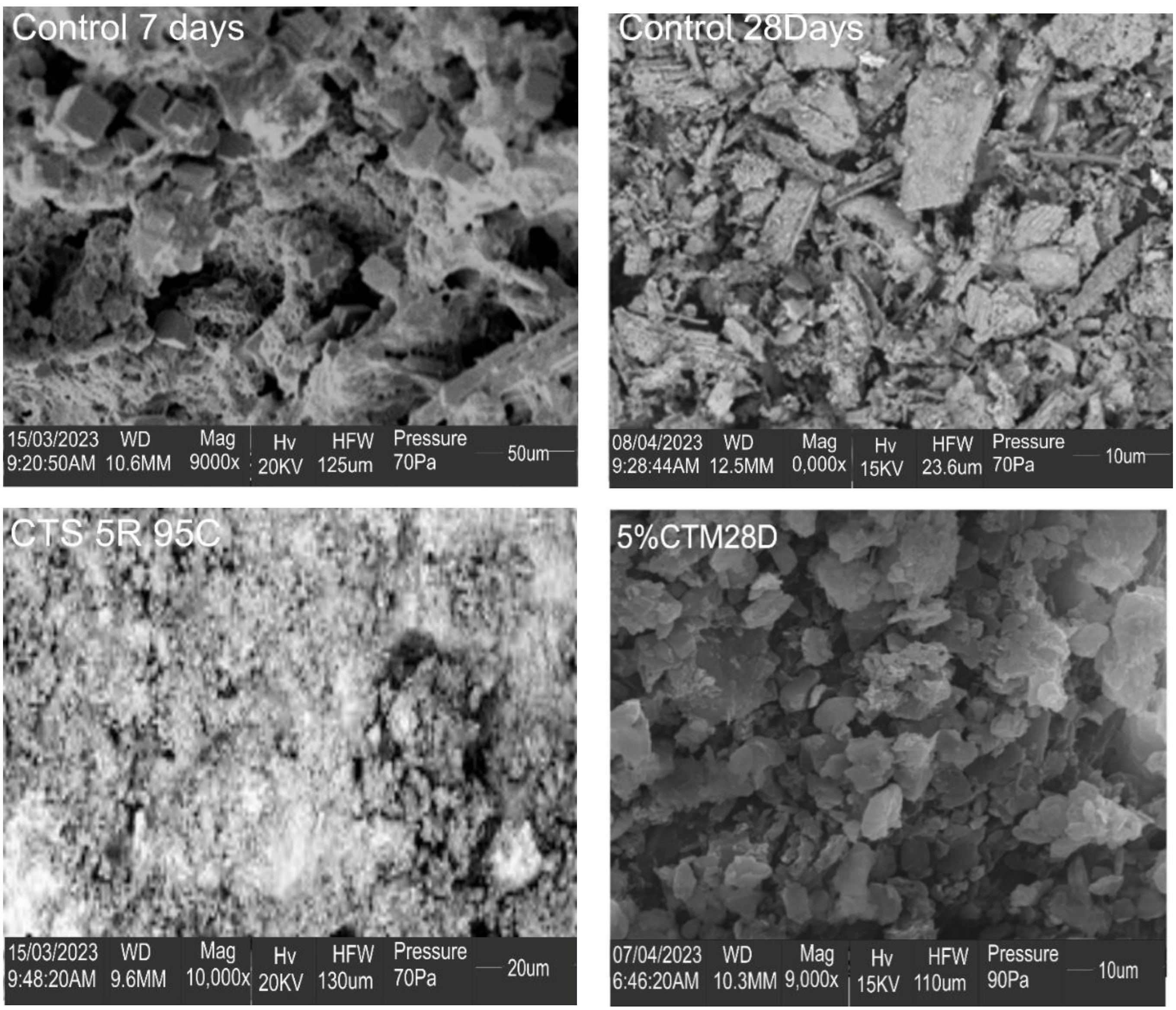

Figure 8. Scanning electron microscopy of the control specimen and 5% CTM replacement specimen at day 7 and 28

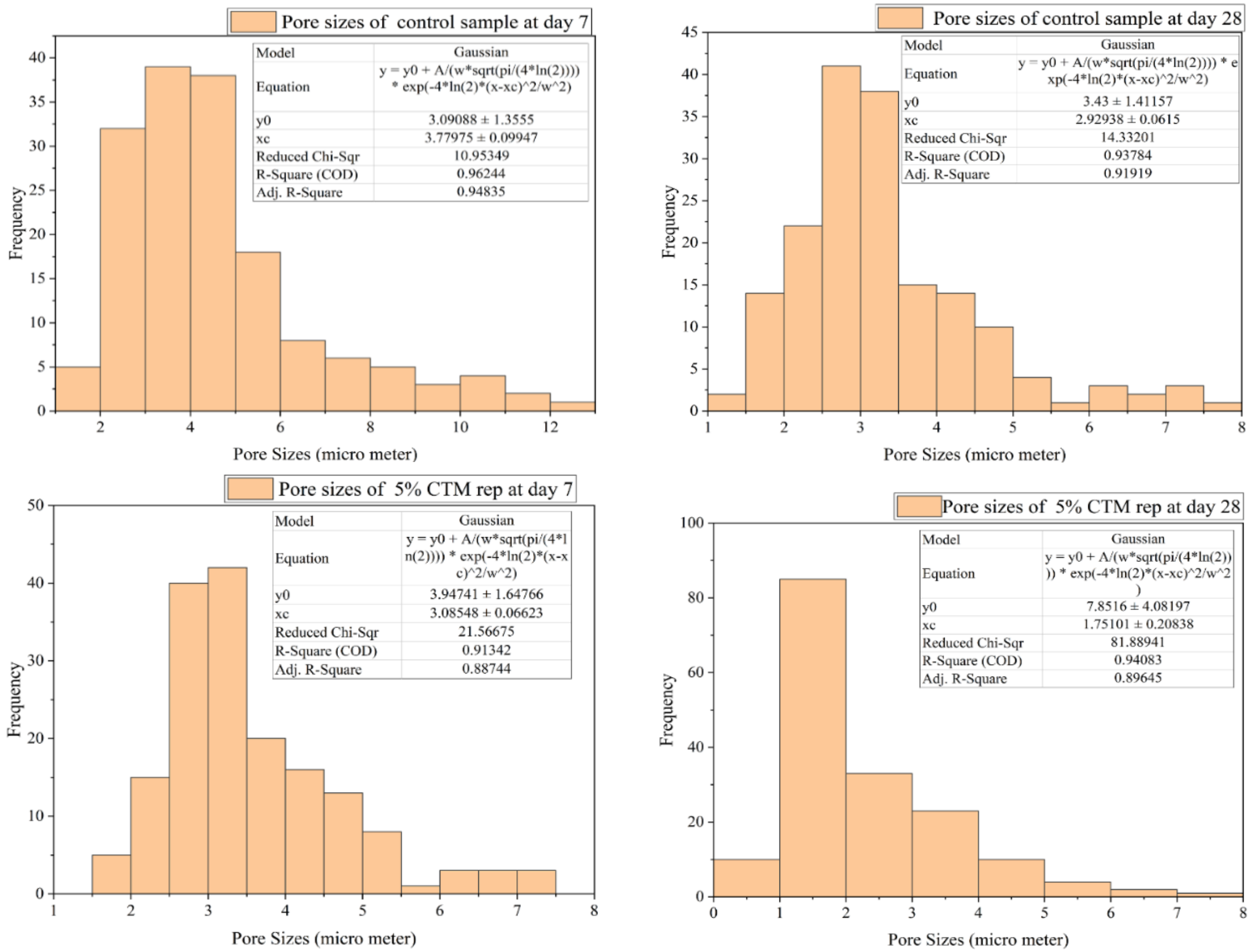

Figure 9. Pore sizes of the control specimen and 5% CTM replacement specimen at day 7 and 28

REGRESSION ANALYSIS

Linear Regression Model for Concrete Containing OPC-CTM Cement Blends:

The Linear Regression (LR) Model was constructed using a single independent variable, Calcined Termite Mound (CTM), and one dependent variable, compressive strength (CS). The mathematical model was developed to establish the relationship between the compressive strength of concrete mixes and CTM replacement levels (0%, 5%, 10%, 15%, and 20%) after 28 days of curing. The derived predictive model for the relationship between compressive strength of concrete and OPC-CTM replacement level at 28 days is as shown in Equation 2 with R^2 of 0.81 and *F (12.87)* considerably higher than *Significance F (0.037)* and *P-value (0.00067501)* significantly lower than *0.05*.

$$y = 13.1 - 0.26CTM \qquad 2$$

where:

y is the compressive strength of the concrete

CTM is Calcined Termite Mound (replacement percentage)

Multiple Linear Regression (MLR) Model Containing OPC and CTM Cement Blends:

The Multiple Linear Regression (MLR) model was constructed utilizing two distinct independent variables: Calcined Termite Mound (CTM) and Curing Age (CA), along with a dependent variable denoting compressive strength. MLR was employed to create a mathematical model aimed at predicting the compressive strength of the OPC-CTM cement blend, given specific CTM replacement levels and curing ages.

The mathematical model used for predicting the compressive strength of the CTM blended concrete samples is presented in Equation 3.

$$y = 10.592 + 0.056CA - 0.266CTM \quad 3$$

where: y is the compressive strength of the concrete

CTM is Calcined Termite Mound (replacement percentage); CA is curing age (days)

CONCLUSION

This study evaluates the effects of CTM the on compressive strength and sorptivity properties of concrete, and the following conclusive remarks were drawn from the analyzed results and discussions:

i. the compressive strength of the test concrete mixes reduced with increase in CTM replacement while the sorptivity increased with increased in CTM replacement. In terms of compressive strength, the 5% CTM replaced concrete exhibited the optimum strength value at all curing days while the control gave best results in terms of sorptivity.

ii. the linear regression model and multiple regression model developed can be used to predict the compressive strength of OPC-CTM concrete as a function of curing age and % replacement level of OPC with CTM.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Author's contribution

C. M. Ikumapayi contributed in the area of conceptuality, statistics and editing, writing original manuscript, review and editing, , C. Arum contributed to the research in the area of statistics and editing, review and editing , V. Arum contributed to the research in the area of methodology, data analysis, and manuscript writing. M. O. Omoyajowo, contributed to the research in the area of methodology, data analysis, and manuscript writing , O.O. Omotayo, contributed to the research in the area of statistics, validation and editing , and O.J.Ohwofasa, contributed to the research in the area of statistics, data analysis, and manuscript writing.

Competing interests

The authors declare no competing interests in this research and publication.

REFERENCES

Al-chaar GK, and Alkadi M (2013). Natural Pozzolan as a Partial Substitute for Cement in Concrete. *The Open Construction and Building Technology Journal*, *7*, 33–42. DOI: 10.2174/1874836801307010033,

Altwair NM, and Kabir S. (2010). Green concrete structures by replacing cement with pozzolanic materials to reduce greenhouse gas emissions for sustainable environment. *6th International Engineering and Construction Conference (IECC'6), Cairo, Egypt*, *17*(3), 269–279. link

American Society for Testing and Materials Standards - ASTM C 39. (2001). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. *ASTM International*, *04*(02), 1–5. link

American Society for Testing and Materials Standards - ASTM C150/C150M. (2012). Standard Specification for Portland Cement. *ASTM International*, 1–9. link

American Society for Testing and Materials Standards - ASTM C1585. (2013). Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes. *ASTM International*, *41*(147), 1–6. link

American Society for Testing and Materials Standards - ASTM C618. (2019). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use in Concrete. *ASTM International*, 3–6. link

British Standards - BS 1881-103. (1993). Method for determination of compacting factor. *BSI Standards Institute*. link

British Standards - BS 882. (1992). Specification for Aggregates from natural sources for concrete. In *British Standards*. British Standards Institute. link

BS EN, 1008. (1997). Mixing water for concrete: *British Standard*. link

Bumanis G, Vitola L, Stipniece L, Locs J, Korjakins A., and Bajare D. (2020). Evaluation of Industrial by-products as pozzolans: A road map for use in concrete production. *Case Studies in Construction Materials*, *13*, 424. https://doi.org/10.1016/j.cscm.2020.e00424

Dembovska L, Bajare D, Pundiene I, and Vitola L. (2017).

Effect of Pozzolanic Additives on the Strength Development of High Performance Concrete. *Procedia Engineering*, *172*, 202–210. https://doi.org/10.1016/j.proeng.2017.02.050

Elinwa AU (2006). Experimental characterization of Portland cement-calcined soldier-ant mound clay cement mortar and concrete. *Construction and Building Materials*, *20*(9), 754–760. https://doi.org/10.1016/j.conbuildmat.2005.01.053

Fapohunda CA, and Daramola DD (2019). Experimental study of some structural properties of concrete with fine aggregates replaced partially by pulverized termite mound (PTM). *Journal of King Saud University - Engineering Sciences*. https://doi.org/10.1016/j.jksues.2019.05.005

Guyo KD, Emer TQ, and Getachew K. (2019). Calcined Termite Hill Clay Powder: As Partial Cement Replacement in Production of C-25 Grade Concrete. *American Journal of Civil Engineering and Architecture*, *7*(3), 128–134. DOI: 10.12691/ajcea-7-3-2

Ikponmwosa E, Salau M, and Mustapha S. (2019). Strength Characteristics of Concrete Beams with Cement Partially Replaced by Uncalcined Soldier-Ant Mound Clay. *Second International Conference on Advances in Engineering and Technology*, 402–408. http://ir.unilag.edu.ng:8080/xmlui/handle/123456789/792

Ikumapayi CM, Arum C, Olaseinde OA, Omotayo OO, and Oniwide EO (2023). Potential of Calcined and Uncalcined Termite Mounds as Pozzolans in Concrete Mix. *FUOYE Journal of Engineering and Technology*, *8*(3), 371–376. https://doi.org/10.46792/fuoyejet.v8i3.996

Khan MI and Alhozaimy AM (2011). Properties of natural pozzolan and its potential utilization in environmental friendly concrete. *Canadian Journal of Civil Engineering*, *38*(1), 71–78. https://doi.org/10.1139/L10-112

Mohan M, Apurva A, Kumar N, and Ojha A (2020). *A Review on Use of Crushed Brick Powder as a Supplementary Cementitious Material*. https://doi.org/10.1088/1757-899X/936/1/012001

Ohwofasa JO, Ikumapayi CM, and Arum C (2023). Effects of Fly Ash on Compressive Strength and Durability Properties of Lean Concrete. *Journal of Applied Sciences and Environmental Management*, *27*(11), 2597–2610. https://doi.org/10.4314/jasem.v27i11.32

Olaniyi A and Umoh AA (2014). Influence of Curing Media on the Compressive Strength of Termite Mound-Lime Blended Cement Mortar. *Malaysian Journal of Civil Engineering*, *26*(3), 349–365. https://doi.org/10.11113/mjce.v26.15896

Olanrewaju SB, Akinpelu S and Olaniyi A (2019). Durability of Termite Mound Lime-Blended Cement Mortar Mixtures. *International Journal of Engineering and Innovative Technology*, *9*(6), 10–16. DOI:10.17605/OSF.IO/CM9AT

Sapal SS, and Wegner LD (2017). Effectiveness of a natural pozzolan from southern Saskatchewan for cement replacement in concrete. *6th International Conference on Engineering Mechanics and Materials 2017*, *1*, 385–392. link