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AN EVALUATION OF THE PROPERTIES OF CONCRETE INCORPORATING TERMITE HILL MOUNDS AS A SUPPLEMENTARY CEMENTITIOUS MATERIAL

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ABSTRACT

Concrete composite is the universal principal rich building material, but cement production contributes to CO_2 emissions. This necessitates alternatives, such as supplementary cementitious materials (SCMs), to partly replace cement while preserving its mechanical performance. The SCMs like fly ash are costly and not abundant in Nigeria. Termite hill mounds (THMs) are naturally occurring potential pozzolanic materials. This study intended to assess the mechanical performance of concrete with THM as SCM to mitigate cement dependence and SCMs cost and scarcity. THM samples were collected from five locations to study if there is a significant variation, then characterized via energy-dispersive X-ray fluorescence (EDXRF), results indicated that the material is pozzolanic; therefore, the samples were mixed together, since no significant difference observed. The concrete mixes of Grade M15, 1:2:4 ratio, 0.5 w/c ratio were prepared with THM replacements of 0% to 50% at 5% intervals. The workability was measured using the slump test as per (BS EN 12350-2:2009). Result indicated the workability peaked at 15% replacement (36 mm slump). The compressive strength performance was tested at day 7, 14, and 28 as per (BS EN 12390-2:2000). 5% replacement produced a 4.93 N/mm² increase in day 28 compressive strength performance of (18.65 N/mm² versus 16.97 N/mm² control), with a strength activity index (SAI) of 119% exceeding ASTM C618-05 requirements. Microstructure was analyzed using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX). The 5% mix appeared denser indicating calcium silicate hydrate (C-S-H) formation. In conclusion, THM can enhance concrete mechanical performance at low replacement levels.

KEYWORDS*:* *Compressive Strength, Microstructure, Pozzolanic Reaction, Supplementary Cementitious Material, Termite Hill Mound, Workability*

INTRODUCTION

Concrete is indispensable in modern buildings, with worldwide production exceeds 4.1 billion metric tons yearly (Statista, 2024). This is due to it mechanical performance which can also be limited due to some challenges that include emotion of approximately 0.9 tons of CO_2 per ton in the process of production, contributing roughly 8% of global anthropogenic CO_2 emissions (IEA, 2023; Andrew, 2019). Supplementary cementitious materials (SCMs) like fly ash and slag have been in use to reduce cement consumption while maintaining or enhancing mechanical properties, but their availability is limited in developing countries like Nigeria. Termite hill mounds (THMs) are biogenic structures with pozzolanic properties, rich in silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), offer a locally available substitute to cement in sub-Saharan Africa, where termites construct over 1.8 billion mounds (Sileshi *et al.,* 2010). This research focuses on unveiling of the potential of Sabon Gari area THM because no similar work found in the area. It is hypothesised that THM replacement from 5% to 10% will improve compressive strength and 10% to 15% will increase workability.

LITERATURE REVIEW

Supplementary Cementitious Materials

According to Malhotra & Mehta (2017) supplementary cementitious materials (SCMs) improve concrete by chemically reacting with calcium hydroxide ($Ca(OH)_2$) to form additional cementitious compounds, with improved strength and durability. Pozzolans as per ASTM C618-05 are siliceous or aluminous materials forming cementitious compounds when they react with lime. Examples include natural pozzolans (e.g., volcanic ash) and artificial pozzolans (e.g., fly ash). Termite Hill Mounds (THM) are materials composed of clay, sand, and termite secretions, exhibiting pozzolanic reactivity due to high SiO_2 (60-70%) content (Muhammad, 2006). Empirical research shows THM improves soil stabilization (Kaschuk *et al.,* 2006) and concrete properties. Guyo *et al.,* (2019) reported 10% calcined THM replacement increased 28-day strength by 15% in C-25 concrete, attributing gains to finer particles filling voids. Olatunji *et al.,* (2023) found that 15% THM enhanced workability, flexural and compressive strengths. Assia *et al.,* (2018) highlighted THM's bio-cementation, increasing fracture toughness. Scrivener *et al.,* (2018) theoretically stated that pozzolanic reactions convert portlandite (CH) to C-S-H, leading to densification of microstructure.

MATERIAL AND METHODS

This study adopted a laboratory-based quantitative experimental research design, involving the collection of raw materials, physical properties assessments, laboratory characterization, concrete batching, and destructive mechanical testing.

Materials

Samples of termite hill mounds (THM) were collected from five locations in Sabon Gari Local Government Area, Kaduna State, Nigeria, to account for variations in soil mineralogy: Figure 1 Basawa (7.68° N, 11.17° E), Figure 2 Bomo (7.37° N, 11.18° E), Figure 3 Hanwa (7.63° N, 11.10° E), Figure 4 Samaru (7.66° N, 11.14° E) and Figure 5 Jama'a (7.68° N, 11.17° E). The THM was harvested using a hoe and iron parker, air-dried to remove moisture, ground into fine powder, and sieved through an 80 micron ASTM C29/C29M-17a standard sieve to ensure sufficient surface area for reactivity per ASTM C618. Equal portions from each site were mixed to create a homogeneous composite material. Other Materials include; Cement cement served as the primary binder, fine aggregate**:** clean river sand, coarse aggregate: crushed gravel, water: tap water from the Department of Building, Ahmadu Bello University (ABU) Zaria, used for mixing and curing under room temperature.

Methods

Material Characterisation

The physical properties of the fine aggregate, coarse aggregate, and THM composite powder were characterised according to the following standard procedures: Bulk density was measured by compacting material in a standard metal container in three layers, each tamped 25 times (ASTM C29 / BS EN 1097-3). Specific gravity was determined for aggregates by weighing samples in air (saturated-surface-dry condition) and then submerged after 24 h of soaking (ASTM C127 for coarse aggregate, ASTM C128 for fine aggregate); for the THM powder, a pycnometer (density bottle) was used (BS EN 1097-6). Moisture content was determined by evaluating samples before and after oven-drying at 110 ± 5 °C for 24 h until constant mass (ASTM C566). Water absorption was calculated as the percentage gain in weight of saturated-surface-dry aggregates relative to their oven-dry mass (ASTM C127 / C128). The THM composite recorded a specific gravity of 3.05 and zero moisture content, confirming it was properly air-dried and suitable as a dry supplementary cementitious material. Fresh concrete workability was assessed using the slump test (BS EN 12350-2).

Concrete Mix Design

The concrete mix design followed the absolute volume method (IS 10262:2009), with a nominal mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) by volume adopted for Grade M15 concrete (characteristic compressive strength of 15 N/mm² at 28 days). The water-cement ratio of 0.5 was used. For the control mix (0% THM), the cement content was 330 kg/m³. For THM-blended mixes, cement was replaced by THM powder at 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50% by weight. The fine aggregate (river sand) had a fineness modulus of 2.86, and the coarse aggregate (crushed gravel, 20 mm nominal maximum size) had a fineness modulus of 6.72. The THM powder passed an 80-µm sieve and had a fineness modulus of 3.05. Mixing was performed using a tilting drum concrete mixer for 3 minutes to ensure homogeneity. Compaction was achieved by rodding each of two layers 25 times using a 16 mm diameter steel rod, followed by vibration on a table vibrator for 10 seconds per layer, in accordance with BS EN 12390-2:2000. 100 x 100mm concrete cubes were casted and three were crushed from each replacement mix at 7, 14 and 28 days of curing.

Figure 1: Basawa

Figure 2: Bomo

Figure 3: Hanwa

Figure 4: Samaru

Figure 5: Jama’a

Figure 6: THM Composite

RESULTS AND DISCUSSION

Table 1: Physical properties of materials

S/No	Property	Coarse Aggregate	Fine Aggregate	THM Composite
1	Bulk Density (kg/m^3)	1537	1732	837.03
2	Specific Gravity	2.63	1.86	3.05
3	Moisture Content (%)	0.60	3.95	0
4	Water Absorption (%)	1.6	1.83	N?A

Table 1 presents the physical properties of the used materials. The coarse and fine aggregates have normal bulk densities (1537 and 1732 kg/m^3) and moderate water absorption (1.6% and 1.83%), while the THM composite has a much lower bulk density (837 kg/m^3) and zero moisture content, confirming it was properly oven-dried for accurate water-cement ratio control. The specific gravity of THM (3.05) is close to that of ordinary Portland cement (≈3.15), allowing direct mass-based replacement without substantial volume adjustment, and its water absorption is listed as N/A because powdered pozzolans are not typically tested for this property. These findings are consistent with observations by Okonkwo *et al.,* (2022), who reported similar specific gravity values for termite mound materials from northern Nigeria. The THM in this research behaves as a fine, dry powder with cement-compatible specific gravity, making it a viable supplementary cementitious material for partial replacement.

Chemical Analysis

Table 2: Chemical compositions of the termite hill mound from various sources (%)

S/No	Elemental Components	Jama'a	Samaru	Bomo	Basawa	Hanwa
1	SiO_2	64.675	63.184	64.44	70.89	64.94
2	Al_2O_3	16.44	26.103	25.90	21.48	25.26
3	Fe_2O_3	3.789	5.973	6.14	4.03	6.000
4	K_2O	1.8180	1.714	1.509	1.694	1.689
5	SO_3	0.1150	0.389	0.000	0.000	0.056
6	TiO_2	0.7770	1.356	1.81	1.35	1.35
7	CaO	0.1707	0.744	0.04	0.59	0.43
8	MgO	2.79	0.000	0.000	0.000	0.000
9	ZrO_2	0.4147	0.09	0.191	0.19	0.14
10	PO_5	0.1837	0.000	0.000	0.000	0.000
11	MnO	0.0354	0.061	0.059	0.040	0.044
12	PbO	0.00754	0.000	0.000	0.000	0.000
13	Cr_2O_3	0.00706	0.041	0.031	0.050	0.039
14	Cl	0.10	0.00	0.00	0.00	0.00
15	NiO	0.0079	0.00	0.00	0.000	0.004

Table 2 present the elemental oxide composition of the THM powder which was determined using Electron Dispersive X-ray Fluorescence (EDXRF). This technique quantified oxides such as SiO_2, Al_2O_3 and Fe_2O_3, and others to assess compliance with ASTM C618 pozzolanic requirement

Table 3: Chemical composition of termite hill mound meeting the requirements of ASTM C618 (%)

Oxides	Jama'a	Samaru	Bomo	Basawa	Hanwa
SiO_2	64.68	63.184	64.44	70.89	64.94
Al_2O_3	16.44	26.103	25.90	21.48	25.26
Fe_2O_3	3.78	5.973	6.14	4.03	6.00
∑(S+A+F)	84.88	95.5	96.48	96.40	96.00

Table 2 present the summary of primary oxides $\sum(SiO_2+Al_2O_3+Fe_2O_3)$ averaging 93.85%, exceeding the 70% least for Class F pozzolans per ASTM C618. This high combined oxide content indicates robust pozzolanic potential, similar to values reported by Guyo *et al.,* (2019) for Kenyan termite mounds (87-92%) and by Adeyemi and Borode (2024) for Nigerian deposits (89-94%). The consistently high silica content (>64%) across all five locations confirms that THM from Sabon Gari is a reliable natural pozzolan. THM from Basawa was utilised because it has the highest silica contents (96.4%).

4.2. Assessment of Workability

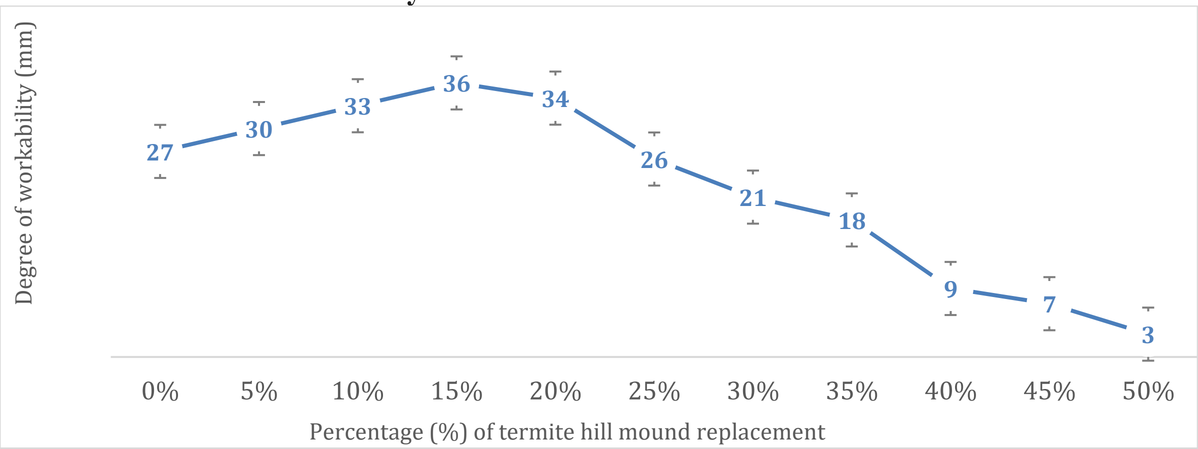

Figure 7: The slump of the concrete mix design A and B

Workability (slope of slumped concrete) and compressive strength do not follow a direct relationship as presented in Figure 7. In this study, slump increased with THM content up to 15% (giving a shallower slope, higher workability), but strength peaked at only 5% THM. Beyond 5%, strength declined and may be due to dilution of the cementitious matrix, despite better workability. Thus, a shallower slope indicates higher workability but not necessarily higher strength. Strength depends mainly on binder concentration and pozzolanic reactivity. These results agree with

Olatunji *et al.,* (2023), who also observed peak in workability at 15-20% THM without a corresponding strength gain. Also, Muntohar (2021) noted that improved THM content improves particle dispersion up to a peak, after which excess fines increase water demand and reduce slump.

Mechanical Strength Development

Table 4: Average compressive strength at 28-day (N/mm^2)

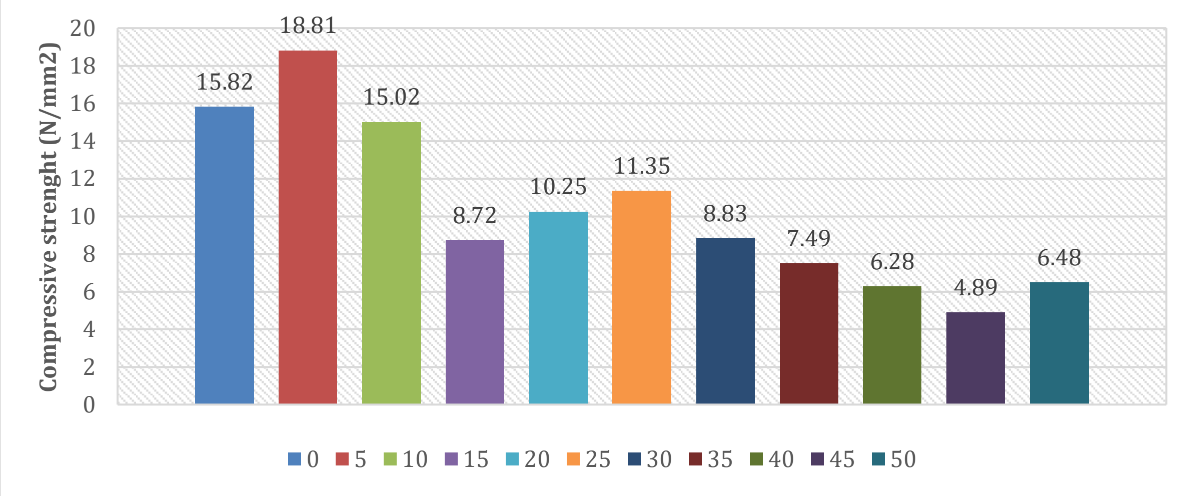

Figure 8: Average compressive strength at day 28

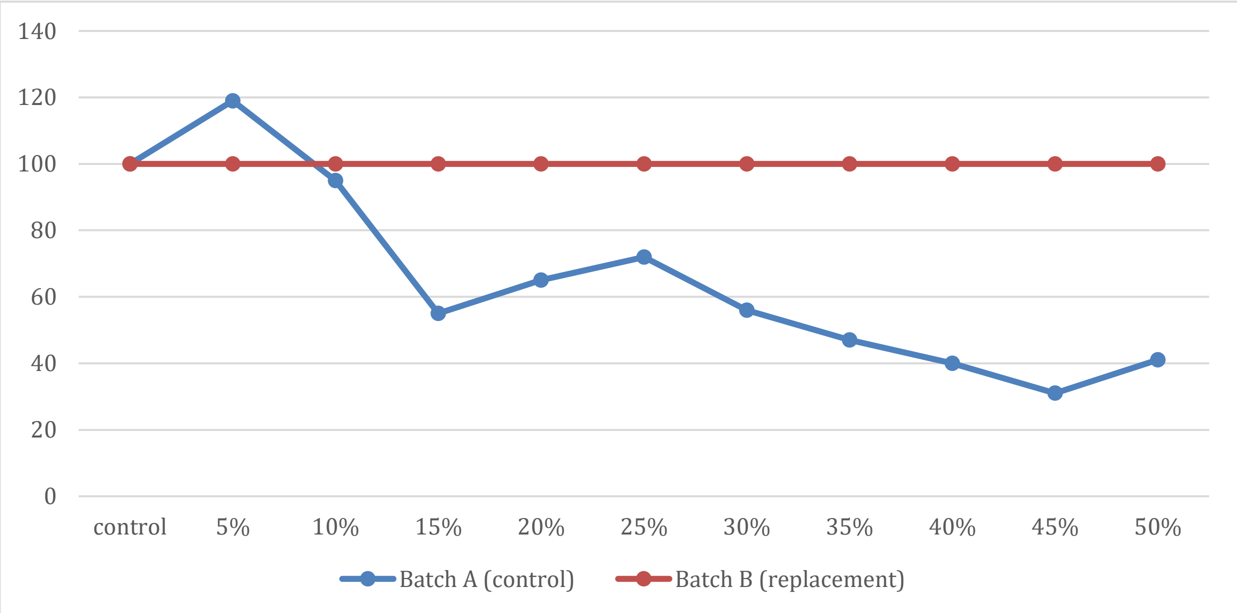

Figure 9: SAI of the average compressive strength batch A and B at 28-day (SAI) %

Table 4 and Figure 8 present the compressive strength performance and strength activity index (SAI) of concrete containing termite hill mounds (THM) as a partial cement replacement were evaluated at 28 days for replacement levels from 0% to 50% by weight of cement. The results indicated maximum strength at 5% THM replacement, with a 28-day compressive strength of 18.81 N/mm² and an SAI of 119% representing a 19% increase over the control (15.82 N/mm², SAI 100%). Beyond 5%**,** strength declined progressively. At 10% replacement, strength fell to 15.02 N/mm² (SAI 95%), slightly below the control. Substantial strength loss occurred above 15% replacement. The lowest values were recorded at 45% replacement (4.89 N/mm², SAI 31%) and 40% replacement (6.28 N/mm², SAI 40%). A minor recovery was observed at 50% (6.48 N/mm², SAI 41%), but this remained far below the control. The Strength Activity Index (SAI) quantifies the pozzolanic effectiveness of THM relative to plain cement. According to ASTM C618, an SAI ≥ 75% is required for a material to be considered a valid pozzolan. In this study: At 5% THM, SAI = 119% indicating that THM actively contributes to strength gain, exceeding the minimum requirement. These findings are consistent with results by Guyo *et al.,* (2019) and Okonkwo *et al.,* (2022), who reported SAI values of 110-125% for low-level THM replacements. The progressive decline beyond 10% is consistent with the dilution effect described by Neville (2011) and more lately by Adeyemi and Borode (2024), where insufficient cement remains to bind the additional fines and maintain hydration products. Damtie Yehualaw *et al.,* (2025), stated a 9.5% strength development at the same 5% replacement level with Termite Hill Soil, further supporting the use of termite-based materials at low dosages

Microstructural Analysis Mechanisms

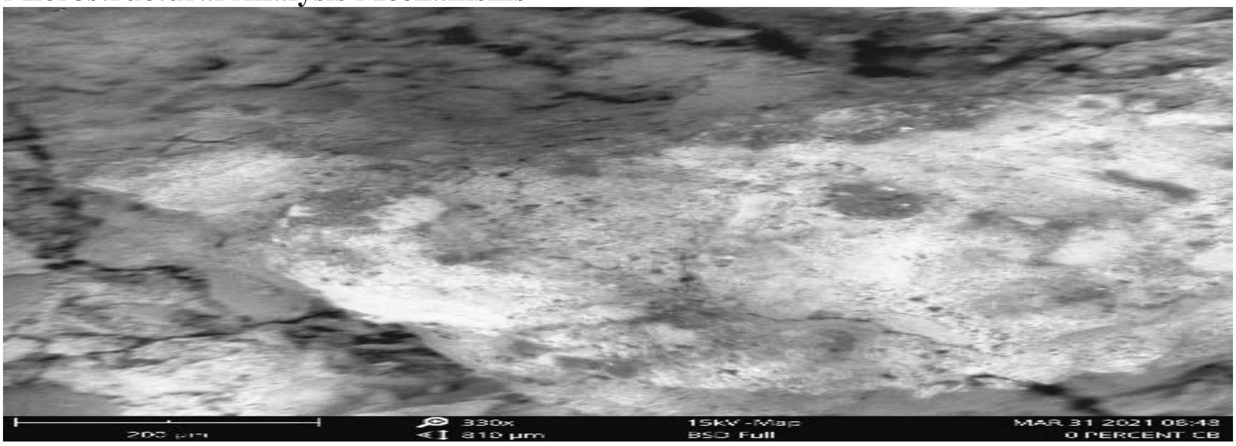

Figure 10: (810µm) X330 SEM

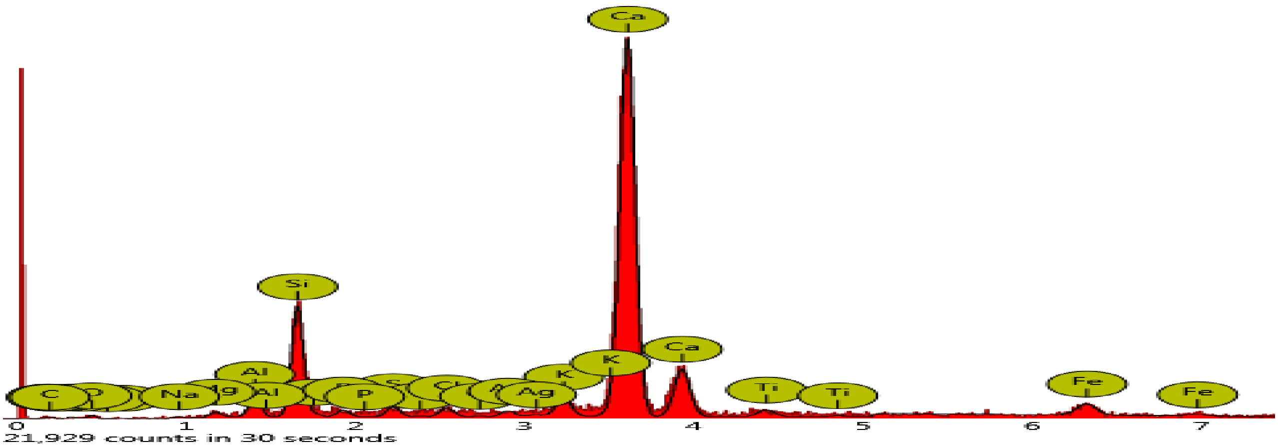

Figure 11: SEM-EDX

Figure10 presents the microstructure of the 0% replacement concrete showed a heterogeneous matrix with visible capillary pores and distinct crystals of CH (Portlandite), lowering bond strength and cleavage planes that facilitate crack propagation. The presence of C-S-H gel intermixed with significant amounts of CH crystals and visible pores (appearing as dark regions).

The presence of excess portlandite indicates that hydration was proceeding normally, but regions of weakness (pores and cleavage planes in crystals) were evident. Figure 11 present pozzolanic properties of THM (high SiO_2 and Al_2O_3 for reactions forming C-S-H and C-A-H gels), but the porous nature of the control mix explains its lower compressive strength performance compared to the 5% THM replacement mix

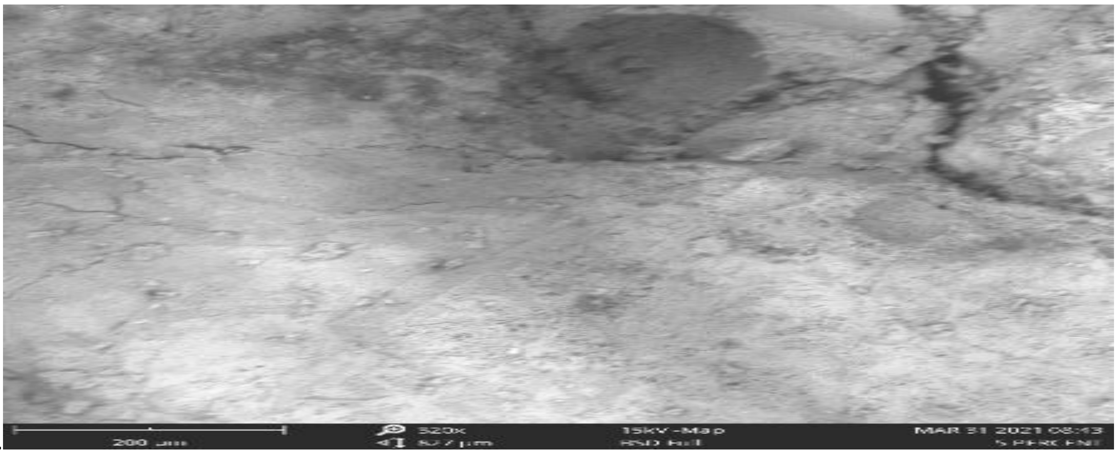

Figure 12: (810µm) X330 SEM

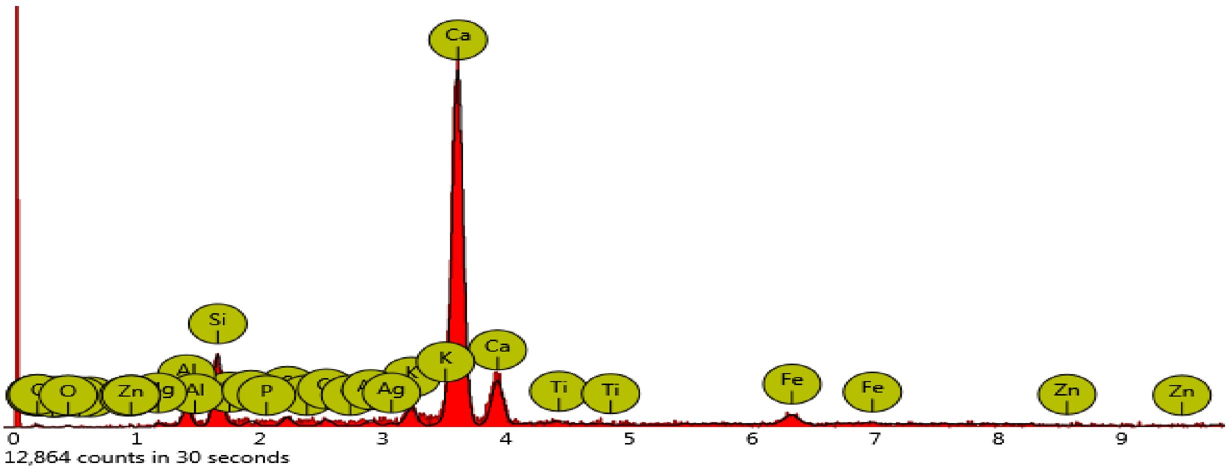

Figure 13: SEM-EDX

Figure 12 present the 5% THM concrete revealed a markedly different structure that appeared significantly denser and more compacted than the control indicating an improved mechanical performance. The large pores seen in the control were largely absent, closing the Interfacial Transition Zone (ITZ) through the pozzolanic reaction by hydration products. The dark portions were less interconnected, indicating a refinement of the pore network. Figure 13 aligns with Termite Hill Mound (THM) as a pozzolanic material, with high Ca and Si suggesting silicates/oxides for reactions like C-S-H formation (per ASTM C618). Elements like Fe, Ti indicate clay minerals from soil; no major contaminants visible. These microstructural explanations are consistent with Scrivener *et al.,* (2018) and Olatunji *et al.,* (2023), who reported similar densification and ITZ refinement at optimal SCM replacement levels. Muntohar (2021) also noted that 5-10% THM creates additional nucleation sites for C-S-H growth, reducing porosity and enhancing mechanical interlocking.

CONCLUSION AND RECOMMENDATION

Conclusion

Based on the results of this research, it was concluded that: The chemical quality of THM from Sabon Gari is a high-quality Class F pozzolan, with combined oxides (SiO_2+Al_2O_3+Fe_2O_3) averaging 93.85%, far above ASTM C618 requirements. The optimal mechanical performance 28-days was achieved at 5% THM replacement of 18.81 N/mm² (19% higher than control) and SAI of 119%. The workability versus strength: Workability increased up to 15% THM, but strength peaked at 5%. Higher workability does not guarantee higher strength. Strength decline at replacements >10% causing strength loss as at 45% THM recorded the lowest strength (4.89 N/mm²), due to dilution of the cementitious matrix with THM. The Microstructure at 5% THM, SEM showed a denser matrix with refined pores and additional C-S-H gel, explaining the strength gain.

Recommendation

Based on the findings of this research, the following are recommendations was made: For structural concrete (where strength is critical), adopt 5% THM replacement by weight of cement to maximize compressive strength and carbon savings. For non-structural applications (e.g., plastering, flooring, mass concrete where workability is desired), replacement levels up to 15% may be used without increasing water content. Regulatory bodies (Standards Organization of Nigeria, SON; Council for the Regulation of Engineering in Nigeria, COREN) should recognize processed Termite Hill Mound soil as a standard SCM and develop guidelines for its processing, quality control, and field application. Long-term durability studies (90, 180, and 365 days) should be conducted to assess resistance to acid attack, sulfate attack, carbonation, and chloride ingress. Future work should explore calcination of the THM in order to transform the crystalline clay minerals like kaolinite into an amorphous, reactive phase metakaolin, so that it can increase the content of soluble silica and alumina, which readily react with calcium hydroxide (portlandite) from cement hydration to form additional calcium silicate hydrate (C-S-H) gel to potentially increase the pozzolanic activity, improve compressive strength, and better microstructural density allowing higher THM replacement levels without compromising mechanical performance.

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