Potential of Calcined and Uncalcined Termite Mounds as Pozzolans in Concrete Mix

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ORIGINAL RESEARCH

Abstract- The high cost of construction materials especially concrete and steel coupled with environmental unfriendliness of cement pose a great problem in building and construction industries. This makes a case for increased advocacy for affordable and environmentally friendly materials. One of the envisaged solutions to this impending problem is the use of termite's mound as pozzolan. Termite's mound as pozzolan can be utilized in calcined or uncalcined form. The potential of utilizing these two forms of termite's mounds in concrete mix design has been exploited in this research work. The compressive strength as well the elemental composition of the various mixes was employed in conjunction with statistical packages to assess the potentials of utilizing termite mound for construction purposes. The compressive strengths were obtained with the aid of universal testing machine of 1000.0kN capacity, the elemental compositions were obtained using Atomic Absorption Spectrophotometer and models were also generated for predicting the compressive strength of either form of the termite's mound using statistical package for social sciences. The results showed that the calcined form of termite's mound has a compressive strength of 12.3 N/ mm2 and 12.6 N/mm2 for 5% and 10% percentage replacement respectively these values are comparable to the control mix compressive strength of 15.7 N/ mm2; This is an indication that calcined termites' mound has a good potential of being used for concrete works in terms of compressive strength. The uncalcined form of termite's mound has a compressive strength range of 6.9 N/mm2 to 6.0 N/mm2 for 5% and 10% respectively, this shows that its potential of being used for concrete work is very low and could therefore be recommended for making termite mound blocks. The greater compressive strength obtained in calcined termite mounds can be traced to the changes observed in the chemical composition of the calcined and uncalcined termites' mounds.

Keywords- Calcined termite mound, Compressive Strength, Pozzolans, Uncalcined termite Mound.

1 Introduction

Affordability of a comfortable housing has since become a lingering problem in developing countries especially in Africa. Report showed that in Nigeria about 70% of the population (Makinde, 2013; UN Habitat, 2001) and in Namibia about 70% cannot afford a comfortable house (Randa, 2016); they live in tenement rooms. This problem cuts across a larger percentage of every nation because housing is one of the basic necessities of life. It also plays a vital role in the development of any nation as well as the wellbeing and productivity of every individual. For so many decades now, there has been shortage of housing and construction amenities in Nigeria. This has been traced to high cost of building materials among others. It has been reported that 65% of housing cost centres on the cost of building materials and 60% of these materials are being imported (Makinde, 2013). Cement is one of the basic ingredients used in Civil Engineering and building construction industries. Its high cost of production coupled with the environmental unfriendliness of the productions process is presently a big problem to the world at large. Researchers are working assiduously towards the possibility of eliminating cement or reducing its use to the barest minimum.

Different postulations have been put forward to achieve this aim, some of which are; recycling of concrete, replacing the constituents of concrete with cheap and locally available materials, using supplementary cementitious materials such as pozzolanic materials (Arum, Ikumapayi, and Aralepo; Ikumapayi, 2018; Ikumapayi, Arum and Alaneme, 2020). In concrete, partial replacement of cement with pozzolanic materials has demonstrated to be more favorable in terms of concrete strength and durability (Ikumapayi and Taiwo, 2022; Adegun and Adedeji 2017). Various benefits like reduced cost, enhanced strength, mitigation of thermal effect from cements, reduced thermal conductivity, improved chloride ion resistance (Ikumapayi, Arum and Oguntunde, 2019) and prevention of chemical attack have all been traced to pozzolanic cement usage if the optimum replacement level is not compromised (Ikumapayi and Taiwo, 2022; Anvanite *et al*., 2015).

Pozzolans are defined as siliceous or alumino siliceous materials, which have no or minute cementitious property but in a fine form and with the existence of favourable humidity will react chemically with calcium hydroxide at room temperatures to produce compounds with cementitious properties (ASTM C618 – 22, 2022). Past research records show replacement level of pozzolans to range between 5 and 30 percent for various pozzolans like kaolin clay (Hailu *et al.*, 2021), fly ash (Kumar *et al*., 2015; Salmia *et al.*, 2020), Rice husk ash, (Singh, Singh and Singh, 2016; Joel, 2020), Groundnut shell ash, (Kawade 2013; Ikumapayi *et al.*, 2018), Sugarcane bagasse ash (Hussein *et al*., 2014).

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Termite hills belongs to the group of earth-based materials. They are abundantly available in Nigeria but presently do not serve any vital commercial purpose, and are therefore often demolished. Termites' mounds are complex and robust products arising from the mixture of termite secretion (saliva) and soil (Mahamat and Azeko, 2021). Termite mounds have been considered for stabilization, in road surfacing (Assam, Okafor and Umoh, 2016), making of mortar and concrete matrix for construction purposes (Udoeyo, Cassidy and Jajere, 2000), constructing bricks (Legese *et al.*, Legese, Kenate and Feyessa, 2021) and making pottery (Davies and Richards, 1977). Some researchers have explored the possible use of termite mound as pozzolans (Mahamat *et al*., 2021).

Omobowale *et al.* (2016) explored the usage of termites' mound clay as silos in humid tropics. Elinwa *et al* (2006) employed the use of calcined mound clay and cement mortar as pozzolanic material. Mujinya *et al., (*2013) reported also that termite mounds possess some good properties like better impermeability and resistance to abrasion as well as erosion resistance when compared to ordinary clay. Its ability to maintain permanent shape after molding and good resistance to cracking than most other types of clay has also been reported. It has also been reported that it is a promising material in cold weather concreting and for early formwork removal. Although, a reduction in strength was experienced, the recorded strength can still be used for structural construction works (Ikponmwosa, Salau and Mustapha, 2011).

Otieno, Kabubo and Gariy (2015) reported that the compressive strength and chemical composition of uncalcined termite mound is adequate and suitable as pozzolan and concluded that their use as partial replacement for cement up to 10% is profitable. Moreover, the usage of termite mound which is an earth-based material will reduce the CO_2 emission that is associated with cement production, which accounts for 70 percent volume of global CO_2 emission (Daudon *et al.*, 2014; Adegun and Adedeji, 2017; Mahamat *et al*., 2022). It will also offer a better performance in the area of thermal conductivity coupled with the green concept (Lamrani *et al*, 2019). Hence the aim of this research is to consider the possibility of using calcined and uncalcined termite mounds as pozzolans in cement production.

2 Materials and Method

The termite mound soil used in this research work was gathered from Akure metropolis. The sample collection was done at a depth greater than 20cm and it was taken to the laboratory and calcined at a temperature of 650oC for one hour in a muffle furnace. It was then made to cool for approximately 6hrs, before grinding to the precise fineness with use of manual grinder. The termite soil was sieved with the use of a sieve size of 150μm and the powder taken to the laboratory to analyse the chemical composition. Both calcined termite mound (CTM) and uncalcined termite Mound (UTM) were characterized using Atomic Absorption Spectrophotometer (AAS). Other test materials include Dangote ordinary Portland cement (grade 42.5N), fine aggregates (river sand), coarse aggregate (granite) with maximum size of 19mm gotten from a quarry site plant located in Akure, and potable water.

2.1 Quality Control Tests of the Other Concrete Constituents

The quality tests of the other concrete constituents were obtained through laboratory experiments. Consistency of the cement was determined in agreement with ASTM C187 (2016) specification and the setting time in accordance with ASTMC191 (2021) as well as the fineness of OPC using ASTM C204 (2019) gradations. The unit weight, specific gravity, natural moisture contents and silt contents of the aggregates were carried out as specified in ASTM C33/C33M – 18 (2018) for fine aggregates and the method specified in ASTMC127-15 (2015) for coarse aggregates. Potability of mix water was also examined in line with the standard specification (ASTM C1602M-22, 2022).

2.2 Concrete Preparation and Mix Proportioning

The concrete samples were prepared using the cementitious mix proportion shown in Table 1. and a cement, sand, coarse aggregates mix ratio of 1:3:6 (C10).

Table 1. Cementitious Mix Proportion

Constituents' material	Percentage Constituents (%)				
Cement	100	95	90	85	80
CTM	0	5	10	15	20
UTM	0	0	0	0	0
Cement	95	90	85	80	
CTM	0	0	0	0	
UTM	5	10	15	20	

2.3 Tests on Concrete Specimens

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2.4 Compressive Strength Test

The compressive strength test of the concrete samples 150 x 150 x 150 mm3 was carried out with the use of universal testing machine of 1000.0kN capacity located in the concrete laboratory of Federal University of Technology, Akure. This was done to find the load bearing ability of such concrete before the appearance of any deformation. The concrete mix was poured into the prepared steel mould and compacted to avoid any form of void. The concrete samples were demoulded after 24 hours and the concrete samples were buried in water for curing at a temperature range of 27±2^{o}C. The concrete samples were thereafter taken out in triplicate for test after each of the specified periods of 7, 28 and 56 days (Ikumapayi and Alamu, 2022). The test was done using a universal testing machine. Load was gradually applied on the concrete samples one after the other at 140N/mm2 per minute until the concrete cracked and crushed into pieces. The compressive strength was obtained as the load at failure divided by the area of the specimen as mathematically shown in Equation 1.

$$Compressive\ Strength\ (N/mm^2) = \frac{Load\ (N)}{Area(\ mm^2)} \quad (1)$$

3 Results and Discussion

Results of the index tests, workability test, setting time test, compressive strength test, comparison analysis, statistical analysis and elemental composition of the CTM and UTM are presented in this section. The result of the index tests specifying the quality and the properties of the materials used are also presented in Table 2. The tests results indicate the suitability of the sand and the aggregates used in the research. The result of the fresh concrete workability presented in Table 3 for both CTM and UTM shows that replacement of cement partially with either CTM or UTM between the range of 0% to 20 % will keep the workability of the fresh concrete within the acceptable range. The results of setting time of fresh CTM concrete shown in Table 4 and for fresh UTM concrete shown in Table 5 increase as the percentage of the replacement increases. The fineness and soundness of the cement increase with increase in the CTM or UTM percentage but all within the acceptable limit of the standard.

Table 2. Result of the index tests

Index test	Sand	Coarse Aggregates
Density	1610.00kg/m^3	-
Silt clay content	16.15%	-
Moisture content	15.16%	-
Specific gravity	2.6	-
Aggregates crushing value (ACV)	-	29.09%
Aggregate impact value (AIV)	-	18.90%
Specific gravity	-	2.7

Table 3. Fresh concrete workability

% Replacement	Slump values for CTM (mm)	Slump values for UTM (mm)	Degree of workability
0	50	50	Medium
5	60	60	Medium
10	50	52	Medium
15	50	55	Medium
20	50	50	Medium

3.1 Effect of CTM and UTM on the Concrete Compressive Strength

The concrete samples compressive strength results are shown in Figures 1 to 5. The result in Figures 1 and 2 show that the compressive strength of CTM concrete is least at 7 days for all the replacement levels. At 28 and 56 days, the compressive strengths for both CTM and UTM showed similar behaviour as that of 7-day compressive strength. This is an indication that fractional replacement of cement with termite mounds either CTM or UTM has the ability of causing the compressive strength of the newly formed concrete to drop. This result is comparable to the outcome of the research carried out by Mahamat and Azeko (2018) which reported that 28-day compressive strength of termite mounds concrete decreases as the percentage level of replacement of the termite mound increases even up to 60%.

3.2 Comparison Analysis of the CTM and UTM Concrete Potential

Evaluating the compressive strength of the CTM concrete across 7, 28 and 56 days as presented in Figure 1. The result shows that the compressive strength of CTM concrete increases with age. The compressive strengths at all levels of percentage replacement of calcined mound at 7, 28 and 56 days are lower than the control. At 56 days the control samples have a compressive strength of 15.7 N/mm^2 while the CTM concrete has 12.3 N/mm^2, 12.6 N/mm^2, 10.0 N/mm^2 and 6 N/mm^2 for 5%, 10%, 15% and 20% percentage replacement respectively. The compressive strengths of 12.3 N/mm^2 and 12.6 N/mm^2 obtained at 5% and 10% respectively is comparable to the compressive strength of 15.7 N/mm^2 obtained for the control and therefore CTM has some degree of potential in partially replacing cement in concrete mix design. Considering the UTM concrete as shown in Figure 2, the compressive strength of 6.9 N/mm^2, 6.0 N/mm^2, 4.4 N/mm^2 and 5.1 N/mm^2 were obtained for 5%, 10%, 15% and 20% percentage replacement respectively. These values are at variance with the compressive strength of 15N/mm^2 required which makes potential of utilizing UTM in partial replacement of cement limited in application. UTM can be utilized in weak concrete or better in making lateritic blocks for low-cost housing.

Table 4. Setting time and consistency of fresh CTM concrete

% Replacement	Fineness	Soundness (mm)	Consistency time (min)	Initial Setting time (min)	Final Setting Time (mm)
0	1.00	1.00	10.00	35	620
5	1.05	1.00	10.00	36	650
10	1.20	1.20	10.00	37	655
15	1.20	1.50	11.00	40	617
20	1.20	2.00	10.00	45	700

Table 5. Setting time and consistency of fresh UTM concrete

% Replacement	Fineness	Soundness (mm)	Consistency time	Initial Setting time (min)	Final Setting Time (min)
0	1.00	1.00	10.00	35	620
5	1.20	2.00	9.00	37	620
10	1.30	2.10	9.00	40	675
15	1.50	2.30	10.00	43	705
20	1.70	2.50	10.00	43	730

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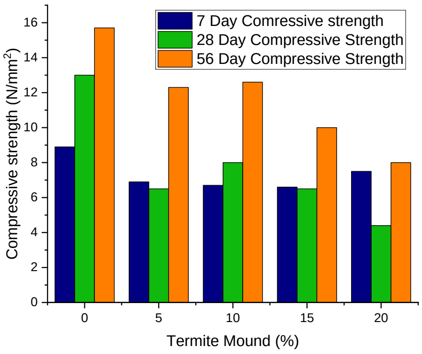

Fig. 1: Compressive strength of calcined termite mound concrete with variations in percentage replacement level and curing age

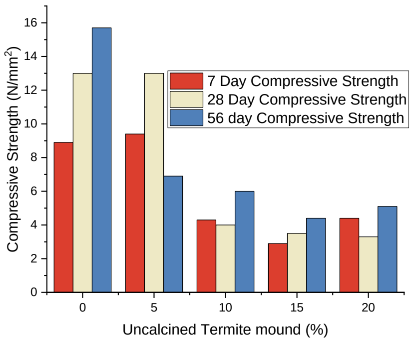

Fig. 2: Compressive strength of uncalcined termite mound concrete with variations in percentage replacement level and curing age

3.3 Effect of Calcination on the Compressive Strength of Termite Mound Concrete

The effect of calcinating termites' mound before its utilization in concrete mix design was explored and presented in Figures 3, 4 and 5 for 7, 28, and 56 days respectively. These results implies that calcined termites mound gives better performance in term of strength than when used uncalcined. This implies that calcination of termite's mound changes its chemical composition as indicated also in Table 3.

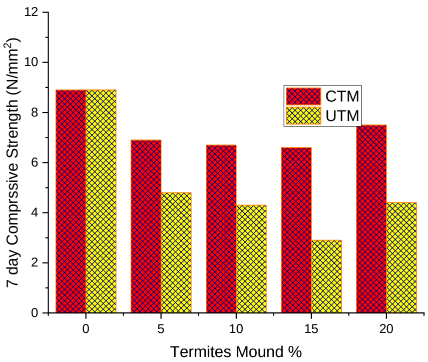

Fig. 3: Effect of calcination on the 7-day compressive strength of termite mound concrete

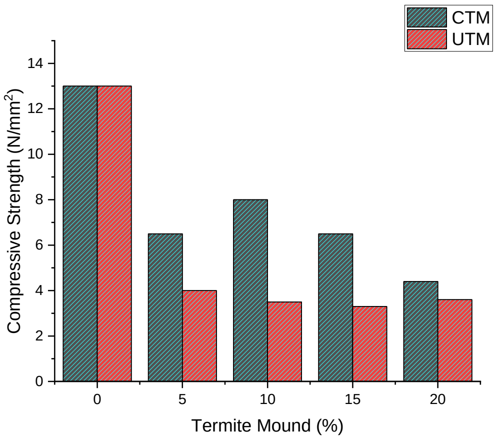

Fig. 4: Effect of calcination on the 28-day compressive strength of termite mound concrete

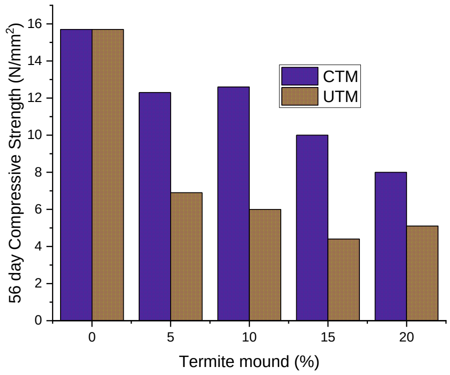

Fig. 5: Effect of calcination on the 56-day compressive strength of termite mound concrete

Results of the oxide composition from XRF (spectrometer) for the calcined and uncalcined termites mound shown in Table 6 indicates changes traceable to the calcination of the mounds. The concentration of Iron oxide in the calcined termites' mound is more than that of uncalcined. The oxide composition of Silica + Alumina + Iron Oxide obtained for CTM and UTM which are 88.375% and 93.305% respectively shows that CTM and UTM are pozzolans. According to ASTM C618 (2022) this sum must be > 50% for class C pozzolan and >70% for class N or F. Either form of Termite mound can be classified as class N or F.

3.4 Regression Analysis of the CTM and UTM Concrete Potential

The data obtained were analysed using regression analysis with compressive strength being the dependent variable while the independent variables were the percentage replacement of the termite mounds and the curing days. The analysis was carried out for both CTM and UTM. The multiple regression Equation for CTM concrete is as shown in Equation 2, with the results giving an overall significant of F= 0.00088 and individual significant p= 0.0051 for CTM percentage replacement and 0.0046 for curing day with the R square values of 0.722.

$$CS=8.79-0.26PR+0.09CD \qquad (2)$$

where CS is the compressive strength in N/mm^2; PR is the percentage replacement of CTM; CD is the curing days

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Table 6. Oxide composition of UTM and CTM

Oxide Composition	Concentration (CTM)	Concentration (UTM)
SiO_2	56.176	55.820
V_2O_5	0.177	0.147
Cr_2O_3	0.016	0.020
MnO	0.322	0.114
Fe_2O_3	13.079	13.325
Co_3O_4	0 .076	0.048
NiO	0.001	0.004
CuO	0.047	0.044
Nb_2O_3	0.017	0.016
WO_3	0.000	0.000
P_2O_3	0.441	0.687
SO_3	0.181	0.265
CaO	0.949	0.751
MgO	0.000	0.000
K_2O	3.101	0.720
BaO	0.281	0.000
Al_2O_3	19.490	24.160
Ta_2O_5	0.030	0.011
TiO_2	4.517	2.958
ZnO	0.011	0.009
Ag_2O	0.029	0.035
Cl	0.593	0.607
ZrO_2	0.425	0.235
SnO_2	0.000	0,000
Rb_2O	0.018	0.012
SrO	0.023	0.010
SiO_2+ Fe_2O_3 Al_2O_3	88.745	93.305

This further confirms that the CTM compressive strength is a function of CTM percentage replacement and that the Compressive strength reduces as the CTM content increases while the Compressive strength increases with increase in the curing days. Multiple regression analysis for UTM concrete shows the dependency of its compressive strength on curing days to be insignificant. The linear regression Equation for the UTM concrete is as shown in Equation 3. The results gave a significant of F and P = 0 for CTM percentage replacement with the R square values of 0.62.

$$CS=11.09-0.446PR \quad (3)$$

where CS is the Compressive Strength in N/mm2; PR is the percentage replacement of UTM

This shows that the compressive strength of the UTM concrete is a function of the UTM percentage replacement and that the Compressive strength reduces as the UTM content increases.

4 Conclusion and Recommendations

Following the outcomes of this research, it can be concluded that CTM and UTM both reduce the compressive strength of concrete if used to partially replaced cement in concrete mix. The degree of strength reduction is a function of the type of termites' mound adopted either CTM or UTM, the percentage replacement of the termites' mound and the curing days. CTM concrete mixes gave better strength than the UTM concrete mixes and therefore, CTM has higher potential in partially replacing cement than UTM.

CTM concrete is recommended for structural concrete works with optimal percentage of 10% while UTM is recommended for use in production of termite mound blocks.

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