American Journal of Civil Engineering and Architecture, 2019, Vol. 7, No. 3, 128-134
Available online at http://pubs.sciepub.com/ajcea/7/3/2
Published by Science and Education Publishing
DOI:10.12691/ajcea-7-3-2

Calcined Termite Hill Clay Powder: As Partial Cement Replacement in Production of C-25 Grade Concrete

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Received January 19, 2019; Revised March 11, 2019; Accepted May 04, 2019

Abstract Cement is one of the components of concrete plays a great role in the construction industry. Nevertheless, it is the most expensive and environmentally unfriendly material. Therefore, requirements for economical and more environmentally-friendly cementing materials have extended interest in other cementing materials that can be used as partial replacement of the ordinary Portland cement. This research was, conducted to examine the suitability of calcined termite hill clay powder as a cement replacing material in the production of C-25 grade concrete as a relief for this problem. The Termite Hill Clay sample was collected from Bokuluboma vicinity. The sample was calcined at the temperature of 650°C using muffle furnace, ground to the fineness of 150 µm and its chemical composition was investigated. Normal consistency and setting time of the paste having Ordinary Portland Cement and calcined termite hill clay powder from 0% to 40% replacement in 5% increment percentage investigated. The compressive strength of eight different concrete mixes with the CTHCP replacing the ordinary Portland cement prepared for 22MPa and 34MPa (i.e., for 7^{th} and 28^{th} days targeted compressive strength) concrete with water - cement ratio of 0.5 and 360kg/m^3 cement content. The properties of the mixture assessed both at the fresh and hardened state. Results revealed that calcined termite hill clay powder found pozzolanic and can partially replace cement. It has shown that up to 11.3% replacement of the ordinary Portland cement by CTHCP, the cubes achieved a target mean compressive strength of C-25 grade concrete at 28^{th} day 34Mpa. Although, the replacement percentage greater than 11.3% of the cement of calcined termite hill clay powder in the concrete has shown a slightly lower compressive strength. Moreover, the mix indicated workable up to 25% replacement percentage and also the setting time of the paste containing calcined termite hill clay powder found faster than that of the control mix. Hence, it is concluded that CTHCP was suitable to replace cement partially with 11.3% replacement of cement by calcined termite hill clay powder as the optimal percentage of the production of C-25 grade concrete. The fresh concrete mix was workable up to 25% replacement, and the mineral admixture served as an accelerator which is suitable for cold weather concreting works.

Keywords: *concrete grade C-25, partial replacement, calcined termite hill clay powder, workability, compressive strength, initial and final setting time.*

Cite This Article: Guyo Konso Danbala, Emer Tucay Quezon, and Getachew Kebede, "Calcined Termite Hill Clay Powder: As Partial Cement Replacement in Production of C-25 Grade Concrete." *American Journal of Civil Engineering and Architecture*, vol. 7, no. 3 (2019): 128-134. doi: 10.12691/ajcea-7-3-2.

1. Introduction

Concrete is probably the most commonly used construction material in the world [1]. For desired characteristics of concrete, many research and modifications have been made in concrete as there is always a requirement for concrete with high durability and strength is the case. To this requirement, blended cement concrete has been introduced in which cement is partially replaced by other pozzolanic material [2]. On the other hand, as the use of cement in concrete is increasing with time. However, it has been criticized by some researchers on green environment grounds. This criticism was leveled based on the production of Portland cement which caused greenhouse emission: a phenomenon which contributes to global warming. According to some researchers, the production of a tonne of Portland cement generates about one tonne of carbon dioxide (CO_2) to the atmosphere, and it is about 5% of global CO_2 emission [3]. Therefore, There is always pressure on the construction industry to reduce the consumption of cement because each ton of cement produces approximately 1 ton of CO_2, mainly from the burning of fossil fuels and from the de-carbonation of limestone [4]. According to this researcher, gas emission is directly proportional to the quantity of cement produced. Thus, In a developing country like Ethiopia, due to rapid urbanization and infrastructure projects, there is the vast expansion of cement industries which releasing this pollutant to the surrounding. Apart from these environmental concerns regarding CO_2 emission during cement manufacturing, consumption of natural resources also makes cement expensive when compared with aggregates and water in the production of concrete. Consequently, As the relief to this problem requirements for economical and more environmentally-friendly cementing materials have extended interest in other cementing materials that can be used as partial replacement of the ordinary Portland cement [5]. These are supplementary cement replacing materials that have become a new era for construction industry sectors due to their pozzolanic properties. Out of this Blast furnace slag, silica fume, fly ash and rice husk can be cited as the example [6]. Termite hill clay (Figure 1) has also been found to have such pozzolanic property. These hills also populated a Southernmost Borena lowland of Ethiopia in very high densities. This termite builds the hill from clay materials necessary to use in construction.

Figure 1. Termite hill material

Meshack et al., (2015) [7], were published the paper on the production of roofing tiles from uncalcined termite soil blended cement concrete for small housing schemes in Kenya and reported that, this supplementary cementitious material found to improve some of the properties of the paste, mortar and concrete like compressive strength in specific replacement percentages and fineness. The loose soil that had been brought to the surface and piled on the ground by termites during an excavation of their nests weighed approximately 40 tons [8]. Therefore a colony could approximately produce 40tons of soil which is an excellent potential when replaced cement. To use this as cement replacing the material in mortar and concrete production, American Society for Testing and Materials (ASTM) set a minimum value of 70% for the sum of silica, alumina, and iron oxide of the total compounds making up the pozzolanic material with sulfur dioxide less than 4% and loss of ignition of less than 10% [9]. Moreover, Mortar and concrete, which contain pozzolanic materials like termite hill clay, exhibit considerable enhancement in durability properties [10]. Other researchers also came up with promising results; According to Eugene *et al.*, 2014, [11] the presence of admixtures like fly ash, limestone, slag and pozzolana in Portland cement influences the rate and degree of cement hydration as well as the phase composition of hydrated cement paste. Termite hill clay was also acting as a pozzolanic material when added to cement because of its silica (SiO_2) content which reacts with free lime released during the hydration of the cement and forms additional calcium silicate hydrate (CSH) as a new hydration product [12]. This additional C-S-H improves the mechanical strength of the cement mortar and concrete. This makes the termite hill clay more viable for use as a partial replacement for cement. But, In all these little or no literature has been documented on the activated (calcined termite hill clay) to replace cement partially. The study, therefore, sought to investigate the suitability of calcined termite hill clay powder as partial cement replacement in the production of C-25 grade concrete.

2. Materials and Method

2.1. Materials

2.1.1. Calcined Termite Hill Clay Powder

The Termite hill clay powder used in this study was obtained from the southern part of Ethiopia, Oromia regional states, Borena Zone, Miyo Woreda, Bokuluboma town (Figure 2). In the study area composed of arid and semi-arid nature of the environment, of which Termite hill clays are abundant.

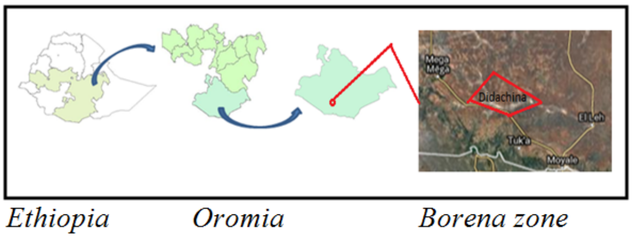

Figure 2. Study area

2.1.2. Cement

Dangote ordinary Portland cement (grade 42.5N) used in this research was purchased from the market. This cement complies with the requirements of Standards, ASTM Standard [13].

2.1.3. Aggregates

The fine aggregate used was river sand obtained from Moyale sand quarry. It is free of harmful materials. Laboratory tests were carried out to check the quality of the aggregate before has taken to mix proportioning. And similarly, the coarse aggregate was obtained from a JMC project crusher plant located at Bokuluboma. The maximum aggregate size of 19 mm was used in all the concrete tests [14].

2.1.4. Water

The water used for concreting was collected from bore well at Bokuluboma town. It is potable drinking water as per the standard [15].

2.2. Method

The investigation involved replacing cement with various percentages (0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%) of the Calcined termite hill clay powder in both the cement mortar and concrete.

2.1.1. Clinicians' and Chemical Composition of Termite Hill Clay Soils

The Termite hill clay soil was collected once, after the outer part of the hill was removed up to 20cm to get undisturbed weather soil. Then, the sample was taken to Bule Hora University chemistry laboratory to calcine at the temperature of 650°C, since the best calcination temperature was between 600°C - 800°C using muffle furnace for an hour [16]. And finally, it was allowed to cool for about 6hr before ground to the desired fineness using a manual grinder. Sieve analysis was carried out, and materials are passing sieve 150µm was used in this research. The powder is then taken to the Geological Survey laboratory of Ethiopia for the complete silicate analysis. Chemical characteristics of the CTHCP were determined using Atomic Absorption Spectrophotometer (AAS).

2.1.2. Quality Tests of Other Concrete Ingredients

The quality tests of ingredient materials were obtained through laboratory experiments; Consistency as per [17], setting time as per [18] and fineness of OPC as per [19], gradation, specific gravity, unit weight, silt contents and natural moisture contents of the aggregates as stipulated by [20] for fine and [21] for coarse and potability of mix water as per [15]. And finally, Unit weight, workability and compressive strength of concrete tested at both 7th and 28th days curing period.

3. Results and Discussion

3.1. Chemical Composition of CTHCP Used as Partial Replacement of Cement in the Production of C-25 Grade Concrete

Table 1. Chemical composition of Termite hill clay powder

S.No.	Chemical composition of CTHCP	Quantity in percentages (%)
1	SiO_2	38.82
2	Al_2O_3	23.98
3	Fe_2O_3	11.68
4	CaO	19.22
5	MgO	12.64
6	Na_2O	0.24
7	K_2O	0.28
8	MnO	0.01
9	TiO_2	0.05
10	P_2O_5	0.16
11	H_2O	0.77
12	LOI	21.06

As shown in Table 1, the main components of CTHCP are SiO_2 (38.82%), Fe_2O_3 (11.68%), (Al_2O_3 23.98%). The sum of SiO_2, Fe_2O_3 and Al_2O_3 also exceeded the minimum limit of 70% (i.e. $SiO_2 + Al_2O_3 + Fe_2O_3 = 74.48 > 70\%$) prescribed by ASTM C 618 for the Pozzolana samples. Therefore, the material was found to be chemically suitable as a pozzolanic material of Class N Pozzolana and can be used to replace cement partially. The loss on ignition (LOI) value for the calcined termite hill clay powder was found to be 21.06 which is higher than that specified by the ASTM standard (10%). The sulfur trioxide amount was found negligible value (i.e., Far less than zero) and discarded from the table during the analysis. The ASTM recommends a value of less than 4%. Moreover, the calcined termite hill clay powder was found to have almost less alkali content like K_2O (0.28%) implying less contribution for the alkali-silica reaction when used in concrete with active aggregates. The summation of oxides: silica, alumina, and iron were found to be greater than the seventy percent (70%). This implies that, as indicated above under the table, calcined termite hill clay powder can be classified as class N Pozzolana.

3.2. The fineness of Dangote OPC and CTHCP

As shown in Table 2. Calcined termite hill clay powder has a lower surface area (Blaine surface area, 293.4m^2/kg) as compared to Dangote OPC. According to the Ethiopian standard ordinary Portland cement shall have a specific surface area of not less than 225 m^2/kg, whereas the ASTM C 204 standard recommends a minimum of 260m^2/Kg with no maximum value. Therefore, both cement and calcined termite hill clay powder complied with the ASTM C 204 requirement for the fineness.

Table 2. The fineness of OPC and CTHPC

S. No.	Materials	Fineness in (M^2/Kg)
1	Dangote OPC	334.4
2	CTHCP	293.1

3.3. Normal Consistency of Blended Pastes

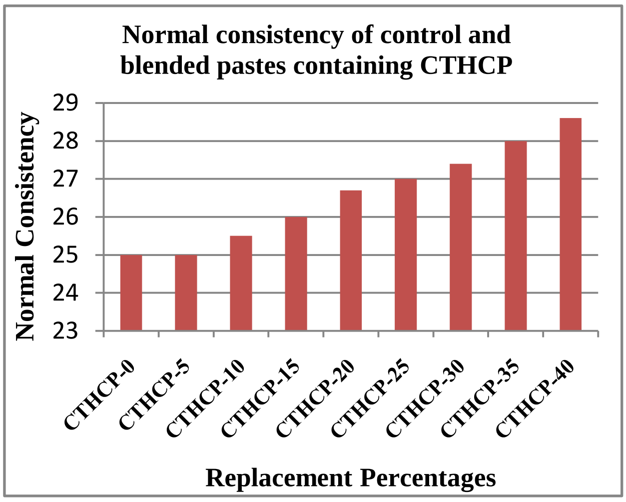

Figure 3. Normal consistency of control and blended paste

Figure 3 showed that the blended pastes containing calcined termite hill clay powder need more water than that of control paste of having 25%. The percentage increase in water requirement of this blended paste is probably due to the higher porosity of calcined termite hill clay powder as compared to cement. The usual range of water to cement ratio for normal consistency is between 25% and 33% [21]. The pastes with replacing up to 10%

showed a consistency very close to that of the control paste, however, after 10% replacement the results showed slightly higher values, even though it is within the standard ranges.

3.4. Setting Time of Control and Blended Pastes

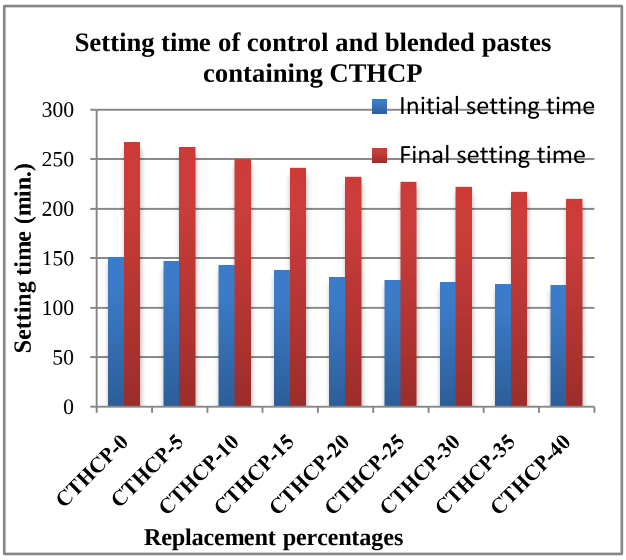

Figure 4. Setting time of control and blended pastes

As is indicated in Figure 4 above, the addition of calcined termite hill clay powder accelerates the initial setting and final setting time of the concrete mix. The ASTM C191 standard limits the initial setting time of hydraulic cement prescribed not less than 45 minutes, while the final setting time not to exceed 375min. As the calcined termite hill clay powder content increases, the setting time has also shown a trend of decrements despite some laboratory uncertainty. The researcher called A.U.Elinwa, (2005) [22] had also confirmed to the decrease in setting time of cement-calcined termite hill clay powder blended pastes of similar supplementary cementitious materials. The Calcined termite hill clay powder particles here act as sites of nucleation and have prompted the hydration mechanism to speed up. The setting of cement paste is recognized to be caused by the increasing volume of hydration products and leads to a decrease in the distance between individual particles until the plastic flow is restricted by cohesive forces [23].

3.5. Fine Aggregates Quality Tests

3.5.1. Summary Tests Results of Fine Aggregates

Table 3. Summary tests results of fine aggregates

S.No.	Tests description	Results obtained
1	Silts contents	0.35%
2	Natural moisture	1.245%
3	Unit weights	1.425g/cm^3
4	Water absorption	1.052%
5	Bulk (SSD)	2.677
6	Bulk	2.650
7	Apparent	2.725
8	Fineness modulus	3.20

3.5.2. Moyale Sand Gradation Tests

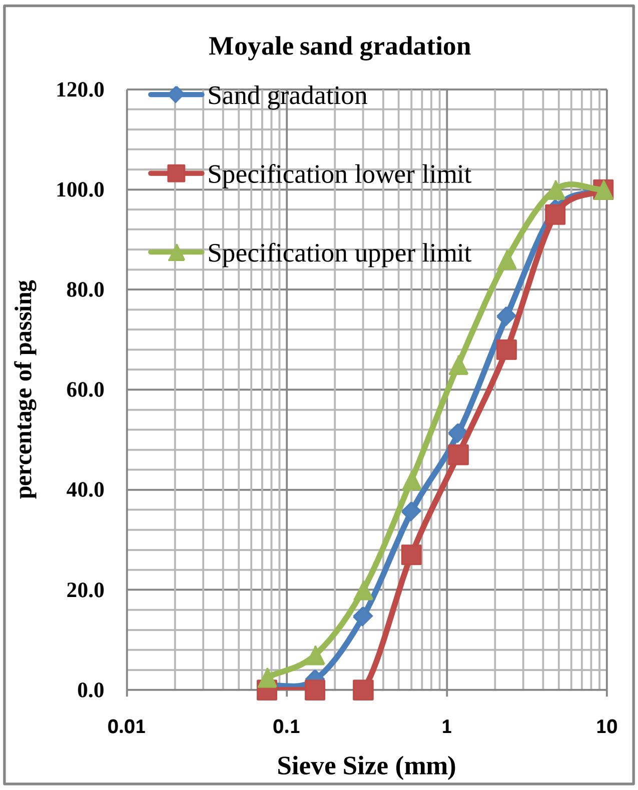

Figure 5. Moyale sand gradation curve

According to ASTM C 136 to have fine quality aggregates the gradation of the aggregate should not be out of the lower and upper limit set. From Figure 5 above The gradation of Moyale sand was within the specification range. Therefore, the sample sand used in this research was met the grading requirement (ASTM 136) and used for the mix directly.

3.6. Coarse Aggregates Quality Tests

3.6.1. Summary Tests Results of Coarse Aggregates

Table 4. Summary tests results of coarse aggregates

S.No.	Tests description	Obtained results
1	Maximum aggregate size	19mm
2	Natural moisture	0.194%
3	Dry rodded Units weights	1.590g/cm^3
4	Loose unit weights	1.475 g/cm^3
	Water absorption	0.49%
5	Bulk (SSD)	2.652
6	Bulk	2.640
7	Apparent	2.674

ASTM C 33 (“Standard Specifications for Concrete Aggregates”) limits the range of physical properties of normal weight aggregates. Nominal maximum size 9.5mm-37.5mm, absorption 0.5%-4%, bulk specific gravity 2.30-2.90, dry rodded bulk unit weight, 1280kg/m^3-1920kg/m^3 and moisture contents 0-2%. All results found within the standard limits.

3.6.2. Coarse Aggregate Gradation Tests

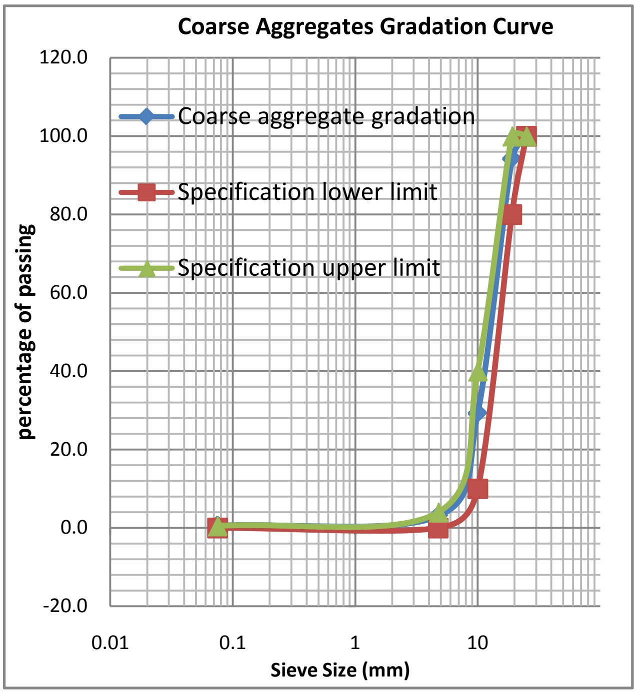

Figure 6. Coarse aggregates gradation curve

3.7. Mix water quality tests

Table 5. Water quality tests

Test conducted	Test results		WHO Max. Allowable *(mg/l)*
	Sample 1	Sample 2	
PH	7.40	7.41	6.5-8.5
Electrical conductivity (µS/cm)	784.00	715.00	-
Dissolved solids 105°C (mg/l)	522.00	474.00	1000.0
Alkalinity (mg/l $CaCO_3$)	237.50	212.80	-
Carbonates (mg/l CO_3^{2-})	Nil	Nil	-
Bicarbonate (mg/l HCO_3^{2-})	289.75	259.62	-
Chloride (mg/l Cl^-)	86.53	77.18	250.0
Sulphate (mg/l SO^{2-}_4)	52.88	53.81	400.0

In the case of doubt about the suitability of water, particularly in remote areas, where water is derived from sources of normally utilized for the domestic purpose, water should be tested. ASTM C 1602-06 limits the impurities in the mix water for chlorides, sulfates, and alkali. For chloride ions 1000mg/l, sulfate ion 3000mg/l and 600mg/l of alkalinity. From Table 5 concentration value of chloride, sulfate and alkalinity indicated less than that of the standard for both samples.

3.8. Concrete at Fresh State

3.8.1. Slump Tests

From Figure 7, the slumps of the concrete containing calcined termite hill clay powder have shown a moderate reduction as the CTHCP content increases when calcined termite hill clay powder contents reach 30% of replacements the slumps have started to be out of the range fixed by a targeted slump which is 25mm-75mm.

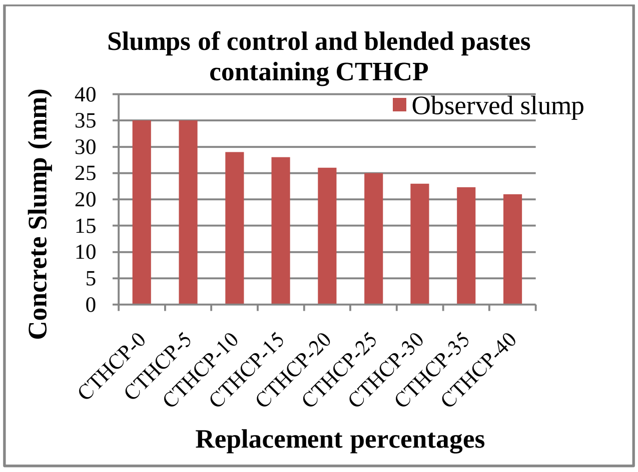

Figure 7. Slump tests

3.9. Concrete at Hardened State

3.9.1. Unit Weight

Since the volume of the cubes molds was already known (i.e., 150mmx150mmx150mm), the weight of concrete cubes measured just before crushing the sample. These tests were conducted at 7 and 28 days. The reduction in a unit weight of the concrete cubes observed as a percentage of replacement increases.

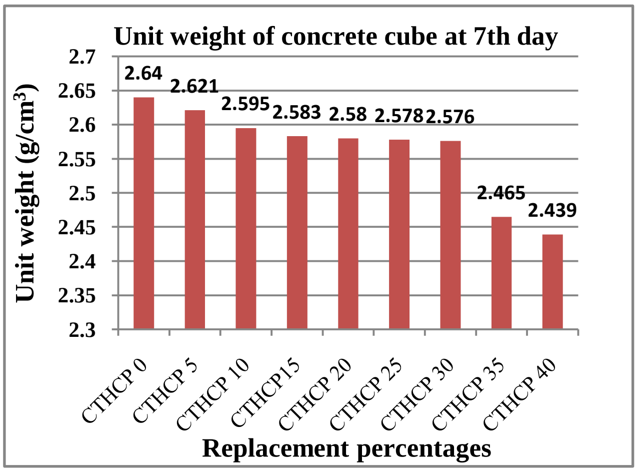

Figure 8. Unit weight of concrete cubes on the 7th day

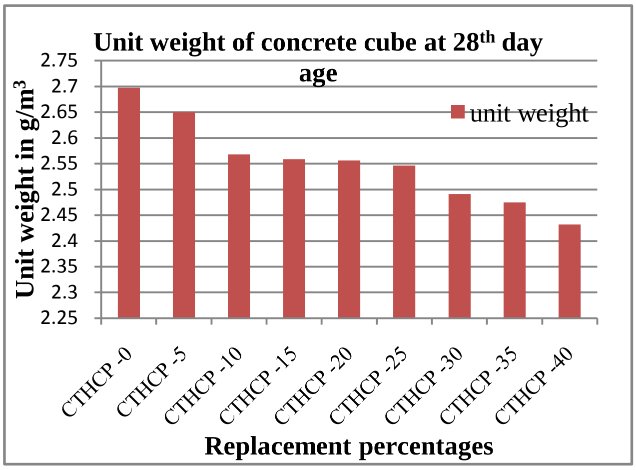

Figure 9. Unit weight of concrete cubes at 28th day

3.9.2. Compressive Strength of the Concrete Cubes

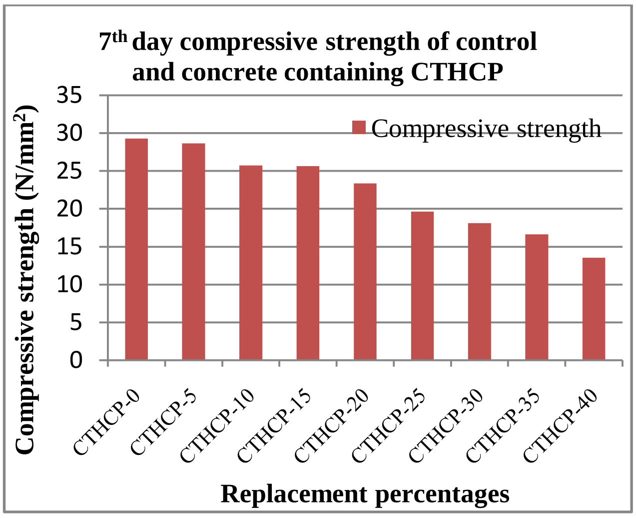

Figure 10. Compressive strength of concrete cubes on the 7th day

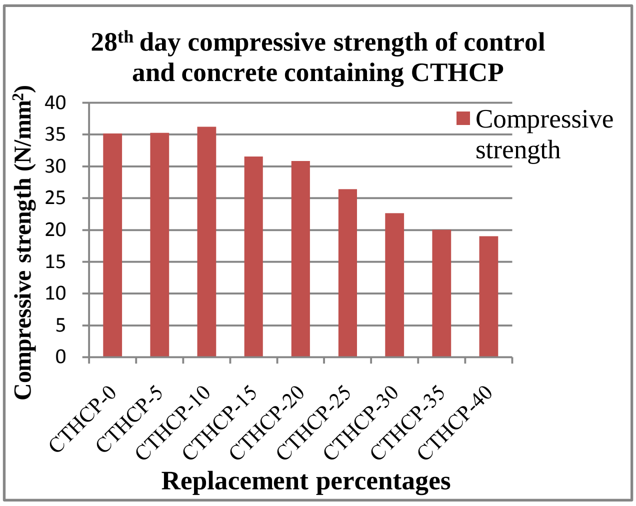

Figure 11. Compressive Strength of Concrete Cubes on 28th Day

According to [ACI-318 M, 02], the 7th days' compressive strength of concrete is 67% of the targeted mean strength of the cubes after 28th days. It implies that the compressive strength of cubes at 7th should be higher than 22MPa (i.e., 0.67*34MPa=22.78MPa).

The targeted 7th-day compressive strength of the control mix was 22.78MPa. From Figure 10, up to 20%, partial replacement of cement by calcined termite hill clay powder the compressive strength of the concrete has shown a strength increase over the targeted strength. Similarly, the 28th day's targeted mean strength of concrete should be 34MPa for the concrete to have compressive strength 25MPa. As indicated in Figure 11. The 28th compressive strength of control cubes was found to be 35.19N/mm^2. Up 10% replacement, the compressive strength of the concrete cubes shows significant increments. The optimal percentage of a mix of partial replacement is the percentage at which cube strength is greater than mean targeted strength at 28th day. In determining the following line graph was used to determine the percentage of replacement in which compressive is greater than or equal to the targeted mean strength of C-25 grade concrete.

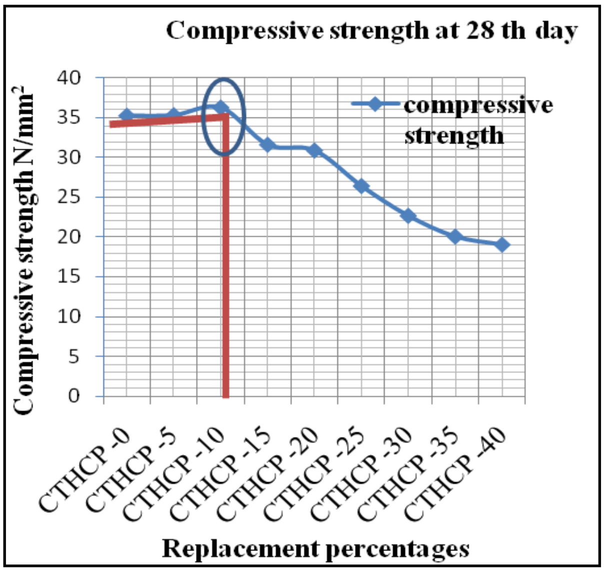

Figure 12. Optimum mix of CTHCP to produce C-25 grade concrete

From the graph above at 11.3% of partial replacement of cement by CTHCP, the compressive strength of the blended cube is equal to 34Mpa.

4. Conclusion

Based on the results of the study, the following conclusions are drawn:

i. The chemical properties of calcined termite hill clay powder include the fact that the material is pozzolanic with the sum of SiO_2 (38.82%), Al_2O_3 (23.98%), and Fe_2O_3 (11.68%) constituting 74.48% of the material, leading to the conclusion that termite hill clay powder calcined at the temperature of 650°C satisfied the requirement of ASTM C618, a minimum of 70%. Hence, the results classified as natural Pozzolana class N.

ii. The calcined termite hill powder had displayed pozzolanic property and classified under class N Pozzolana. It means, the material can produce the cementitious compound that has binding property upon reaction with calcium hydroxide gained from the hydration of cement. Therefore, calcined termite hill clay powder found suitable to replace cement in the production of concrete partially.

iii. The quality of control materials; cement, mixing water, fine aggregates and coarse aggregate had shown compliance with the set standard criteria, thus leading to the conclusion that any significant effect on the tests having calcined termite hill clay powder as partial cement replacement was from CTHCP itself.

iv. The workability of concrete containing calcined termite hill clay powder decreases, slightly as the calcined termite hill clay powder content increases, especially, at 30% (23mm), 35% (22.3mm) and 40% (21mm) of partial replacement the slump found to be out of the targeted slump 25mm-75mm for C-25 grade concrete. Therefore, the concrete is not workable at a replacement percentage higher than 25% of calcined termite hill clay powder with cement.

v. Up to 11.3% partial replacement of cement with calcined termite hill clay powder, it can be possible to produce C-25 grade concrete during its normal curing aging since the compressive strength of these replacement percentages exceeds the targeted mean strength of the control mix.

vi. The setting times of the cement paste decreased. The initial and final setting time of the control mix is 151minute and 267minutes respectively. As replacement percentage increases, both initial and final setting time of the blended pastes had shown significant reduction and finally, at the far ends, which is a 40 % replacement it was found to be 123minute for initial and 210minute for that of final setting time. This implies that calcined termite hill clay powder is a set accelerator and is suitable for cold weather concreting where early removal of formwork is needed.

Abbreviation

ASTM - American Standards for Testing of Materials
CTHCP - Calcined termite hill clay powder
OPC - Ordinary Portland Cement

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