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Performance of Calcined Termite Mound and Metakaolin in Geopolymer Concrete. A Comprehensive Review

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ABSTRACT*:* Geopolymer concrete is an innovative construction material produced by the chemical action of inorganic molecules. The material that is rich in silica and alumina will react with an alkaline solution to produce an aluminosilicate gel that acts as the binding material for the concrete. Geopolymer concrete (GPC) is a type of concrete that fully replaces cement as a binder in concrete. Recently, researchers have found geopolymer as a worthy replacement for cement as a result of its distinct properties. It is eco-friendly by eliminating the emission of harmful gasses (NO_2 and CO_2 gases) from cement production and it does not pose any danger to the environment. It has also gained popularity due to its improved strength and durability. The review focused on the use of Metakaolin and Calcined Termite Mound in the production of geopolymer concrete. The review explored the economic and environmental benefits of using GPC, and also the potential drawbacks that may be encountered when using these materials in concrete production. The review also considered the various methods of curing GPC and techniques for using abundant waste material in GPC production. Overall, the result of the review suggests that the use of CTM and MK has advantages in terms of eliminating the carbon footprint released during the production of cement. However, further research is needed to assess the efficacy of these materials in concrete production, and the various techniques for incorporating these materials into concrete mixes should be assessed.

KEYWORDS: Geopolymer Concrete, Metakaolin, Calcined Termite Mound, Compressive strength, Tensile strength.

I. INTRODUCTION

Geopolymer cement is an advanced innovative material produced from a low-cost, ecologically friendly material that fully replaces Portland cement in concrete production. Geopolymer concrete is made without any Portland cement in its production. The difference between geopolymer concrete and Portland cement concrete is the composition of the binder. The aluminium and silicon oxides in the metakaolin or low-calcium fly ash react with the alkaline liquid to form a geopolymer paste. The paste binds the coarse aggregates, fine aggregates, and other unreactive materials together to form the geopolymer concrete. Geopolymer cement is formed from chemical reactions between aluminosilicate and alkali polysialate in a highly alkaline medium. The use of metakaolin in concrete production helps to reduce the environmental impact resulting from the production of Portland cement which is a main concern in the world today and it also improves the structural and engineering performance of concrete.

II. LITERATURE REVIEW

2.1 Geopolymer Concrete.

GPC is an excellent alternative construction material to the existing conventional cement concrete. The use of available waste materials in concrete production will reduce the cost of production of concrete, minimize environmental pollution and provide an eco-friendly environment for people. Most research over the last decade shows that pulverized fly ash (PFA) and metakaolin (MK) are the most preferable aluminosilicates for the production of either Ca-free or low-calcium-content geopolymers (Duxson *et al.,* 2007). Fernandez-Jimenez *et al.,* (2007) said that a low calcium oxide content allows the development of both high mechanical strength and excellent durability of concrete. Metakaolin (MK) is a pozzolanic substance that is made from kaolin clay that has been burned at temperatures ranging from 650 to 800 ^{0}C. MK is rich in silica and alumina and will react with an alkaline solution to produce aluminosilicate gel that acts as the binding material for the concrete.

Rangan (2008) revealed the superior properties of GPC over conventional concrete. He listed the properties as

(i) setting at room temperature.
(ii) non-toxic and no bleeding.
(iii) It has a long working life before stiffening
(iv) very impermeable when exposed to salt and harsh chemicals
(v) resistance to heat and resistance to all inorganic solvents
(vi) It gives high compressive strength to concrete.

2.2 Curing of Geopolymer Concrete

Hardijito and Rangan (2004) revealed that an increase in curing temperature from the range of 30 to 90 °C helps to increase the compressive strength of geopolymer concrete. Tests conducted by Lloyd and Rangan (2008) showed that the inclusion of 24 hours before curing helped to increase the compressive strength of GPC. Curing at ambient conditions will produce low early strength concrete but a significant strength improvement was observed on using high temperature. Nurrudeen (2018) noted that extended curing time enhanced the geopolymerization mechanism and consequently the strength but a longer duration of curing at an elevated temperature will lead to the failure of the concrete.

Joseph and Mathew (2012) indicated 100^{0}C as the best temperature. The optimum time of curing at 60^{0}C observed by Chindaprasirt et al. (2007) was 3h. Most of the researchers found that the optimum curing temperature is 75 ^{0}C and the reaction was completed at 7 days to obtain the maximum strength. Görhan and Kürklü (2014) investigated the duration of heat curing and found that there is an increase in compressive strength when heat curing (65^{0}C and 85^{0}C) increased from 5 to 24 h. Curing time above 24 h was found to have no appreciable effect on the strength (Joseph and Mathew, 2012).

Albidah et al. (2021) experimented on metakaolin-based geopolymer concrete. Specimens that were cured for 7 days of ageing and tested. They have achieved 89.1–95.3% of the compressive strength obtained at 28 days. Kriven (2017) stated 24 hours as the optimum strength gain time of geopolymer mortar. Duxson et al. (2007) observed a minimal change in the compressive strength of metakaolin-based geopolymer concrete specimens between the ages of 7 and 28 days of curing.

2.2.1 Heat/oven curing

In the geopolymerization process, water is given out during the chemical reaction and tends to vaporize as the specimens are subjected to heat during the curing process (Hardjito and Rangan, 2005). Similarly, the drying shrinkage becomes negligible due to the small quantity of water in the pores of the rigid specimens. Kumaravel (2014) reported that the compressive strength of concrete cured in an oven is better than that of ambient cured concrete at 60°C for a day. Curing temperature is essential for achieving higher strength in geopolymer concrete, specimens subjected to higher curing temperature exhibited higher mechanical strength compared to those of lower temperature (Singh et al., 2015 and Nurudding et al., 2018). They also observed that a longer duration of curing gives better strength but the increase of strength is negligible when curing time was extended beyond 24 hours. Curing for a shorter period in the oven didn't yield real changes in strength development, but extended curing time to at least 20 hours gives rapid early strength gain. However, elevated temperature at an early stage leads to the growth of larger pores in the concrete specimen which will influence its mechanical strength.

Yewale et al. (2016) reported the result of an experimental investigation on the evaluation of an efficient type of curing geopolymer concrete. In their research work, concrete cube specimens of 150 mm were cast and cured by four different methods using oven, steam, water and room temperature curing respectively. In oven curing, the curing temperature was varied at an interval of 20°C starting from 40°C up to 140°C for 24 hours and tested on 7 and 28 days after demoulding. Steam curing was done by placing specimens in a steam at 60° to 110°C for 18 hours and tested on 7 and 28 days respectively. Specimens were cured in water as per the conventional method and at room temperature. The experimental evidence reveals that concrete cubes improved at higher temperatures, the optimum strength was found to be 60°C oven curing.

2.2.2 Steam curing

Yewale et al. (2016) found that the strength of geopolymer concrete improves at higher temperatures and the optimum strength was found to be 80°C for steam curing while for water curing, the strength obtained at 28 days was less than the characteristic strength due to the low development of strength at lower temperature.

Yunsheng et al. (2007) revealed that the condition of curing has a significant influence on the strength of slag-based geopolymer concrete. Slag-based geopolymer exhibited lower strength development at ambient temperature compared to the steam-cured specimens. During the first 2 hours of steam curing at 80°C, compressive strength of 9.4 MPa was achieved which is 19.14% higher than 3 days of ambient curing. As the curing time was prolonged to 4 and 8 hours, the concrete strengths improved by 46.03% and 53.16% respectively with maximum compressive and flexural strengths of slag-based geopolymer of 75.2 MPa and 10.1 MPa.

2.2.3 Ambient curing

Yewale et al. (2016) reported that the result of mechanical strength result of geopolymer concrete cured at room temperature is promising compared to the water curing method. Also, Kumaravel (2014) conducted research on various curing conditions of geopolymer concrete for cast-in-place applications. Concrete specimens were subjected to three modes of curing and found that the rate of strength development for ambient cured geopolymer concrete resembles that of OPC Concrete and therefore recommended to be used for onsite constructions.

Perera et al. (2007) studied the curing of metakaolin-based geopolymers at ambient temperature and reported that it yields positive strength which is almost the same as that of oven curing but heat-cured specimens developed strength rapidly within a day. The report showed that humidity influences the curing process whereby the result is favourable at low humidity. Heah et al. (2011) studied metakaolin-based geopolymer concrete, it was reported that ambient curing of metakaolin-based geopolymers gives a very low strength at an early stage as compared to oven curing, they suggested a temperature within the range of 40°C to 100°C for rapid strength development. Lastly, early curing of geopolymer concrete at advanced elevated temperature for a prolonged period may cause the deterioration of the specimens due to the thermo-analysis of silicate –Si–O–Al–O– bond.

2.3 Engineering Properties of Geopolymer Concrete.

The engineering properties exhibited by geopolymers such as high compressive strength, better acid, thermal resistance, low carbon emissions, low energy requirements for processing etc. have justified their acceptability as a sustainable construction material in comparison with conventional cementitious materials like cement and lime.

Paulo et al., (2016) studied the effect of Rice Husk Ash Addition to Metakaolin-Based Geopolymers and revealed that the properties such as water absorption, apparent porosity and dry density do not significantly alter the properties of geopolymer concrete if the RHA addition is limited to 40%. MK-RHA geopolymers contained micropores (10 microns) as a result of the high water content employed and also large voids considered to be entrapped air (order of 500 microns). Compressive strength is one of the most important engineering properties of concrete. Different factors that affect the value of compressive strength of Geopolymer concretes are curing temperature, mixing ratio and the molarity of the alkaline activator. Many researchers have concluded that Geopolymer concrete has a very high tendency to develop high strength at an earlier age under high curing temperatures (Guo et al. 2010; Hardjito et al. 2004, 2005; Yost et al. 2013) and also gains target 28day strength under ambient condition (Kumar et al. 2010; Manjunath and Giridhar 2011). The improvement in physical properties is a result of intrinsic structure developed by geopolymerization (Kumar & Kumar 2011).

Ammar (2020) conducted a test to determine the compressive strength of geopolymer mortar containing rice husk ash (RHA) and metakaolin (MK). Sodium Silicate in powder form was used as an activator. The water to binder ratio was kept constant at 0.5 for each sample. Two percent superplasticizer by weight of binder was added to the mortar mix. Tests were conducted on the strengths of geopolymer mortar samples with different RHA/MK mass ratios at 7, 14, and 28 days. The samples were placed in an oven at 70°C for the first 24 hours and then at ambient temperature of 19°C for the other days. The compressive strength of the RHA/MK mass ratio of 10/90 is the highest among all the mixes. It was clearly shown in the result of the test that RHA more than 10 percent resulted in reduced compressive strength.

Yost et al., (2013) said that curing at 60^0 C for 24 hours produces very rapid strength gain which gives a compressive strength at one day ranging between 47 and 53 MPa. This important property makes geopolymer concrete suitable for precast applications.

Hardijito and Rangan (2004) revealed that a higher concentration of sodium hydroxide (molar) leads to a higher compressive strength of geopolymer concrete. The higher the ratio of sodium silicate-to-sodium hydroxide liquid ratio by mass, the higher the compressive strength of geopolymer concrete.

Geopolymer concrete has higher tensile strength than the OPC. Olivia and Nikraz (2012) reported that the tensile strength of GPC is about 8 - 12 % greater than that of conventional concrete. Also, the flexural strength of related samples is 1.4 times higher than that of OPC. This is a result of the aluminosilicate network associated with the polymerization process (Nuruddin et al. 2011). Various studies have shown that the splitting tensile strength and flexural strength of geopolymer concrete are functions of compressive strength (Hardjito et al. 2005).

2.4 Termite and Termite Mound.

A termite is a group of social insects that eat wood and other cellulose–rich vegetable matter. They are mostly found in the tropical rain forest (Claudius & Duna, 2017). Termite mounds are readily available in African countries including Nigeria and Ghana (Mahamat and Azeko, 2018). They are found between latitude 45°N and 45°S where they are restricted by a combination of extreme aridity and lack of vegetation. (Badejo, 2002). Termites live in organized colonies comprising hundreds to millions of individuals inside a nest system which could be arboreal, epigeal or subterranean. A colony is morphologically and functionally distinct and consists of several castes. Their major role is biodegrading fallen and dead wood in the environment. Termites live in nests, which could either be on the earth's surface or below the earth's surface and are also known as Mound (termitaria) (Ndaliman, 2006). Nests are structures made by termites from a combination of soil, mud, saliva, chewed wood/cellulose and faeces and they are often located near trees, stumps, wood piles and other cellulosic materials. Termites feed on wood and wood products e.g. wood, boxes, cardboard and wooden door and window frames and cabinets (Aguwa, 2009).

Table 1: Chemical Composition of Termite Mound

Composition	Percentages (%) Ndaliman, 2006	Percentages (%) Fapounda et al., (2020)	Percentages (%) Cladius et al., (2023)
SiO	58.06	70.01	67.74
Al_2O_3	27.72	15.98	14.23
K_2O	2.59	2.40	4.12
Fe_2O_3	1.46	15.98	5.15
TiO_2	0.87	0.96	1.05
CaO	0.20	1.29	1.79
MgO	0.36	0.73	0.59
Na_2O	0.30	0.40	0.23

2.4.1 Suitability of Using Termite Mound in Concrete Production.

Claudius and Duna, (2017) reported that Calcined Termite Mound is pozzolanic and can be used to replace cement in concrete at 10%. They also reported that CTM concrete requires more water content to attain a standard consistency, which means the material has an affinity for water.

Elinwa (2006) calcined termite mound and grounded it into fine form. The grounded fine form was used to partially replace cement and the results showed that it produced concrete with compressive strength greater than the reference mix.

Fapounda et al., (2020) investigated the microstructure of concrete with fine aggregate partially replaced by pulverized termite mound (PTM). A water absorption test was carried out and Durability was evaluated by sorptivity. The microstructure of the concrete specimens after 28 days of curing was studied using scanning electron microscopy (SEM). The results show improvement in the durability of the PTM concrete specimens and the microstructure of the concrete specimens has smaller pores compared to the control which follows the trend of the sorptivity results. Finally, it was recommended that the use of PTM mounds as a substitute for fine aggregate in the production of conventional concrete should be limited to 70%.

Table 2. Physical Properties of PTM and Sand (Fapounda et al., 2020).

Physical Property	PTM	Sand
Specific Gravity	2.17	2.63
Moisture Content	1.50%	0.00%
Density (Kg/m^3)	1370.00	1540.00

Olanrewaju et al., (2019) replaced cement with termite mound and lime. Specimens were produced for testing. Compressive strength, water absorption and its performance in the magnesium sulphate environment of blended cement mortar were all studied. Specimens were cured in magnesium sulphate concentration (2%). The maximum compressive strength of 7.46N/mm^2 and 6.80N/mm^2 were obtained for 1:4 and 1:6 at 25% replacement. The study recommended a 25% replacement of termite mound and lime for the replacement of cement in mortar.

Gitu et al., (2020) investigated and compared the equivalent strength replacement of manually compacted blocks by replacing sand with termitarium silty fine ranging from 0, 6, 12, 18, 24, 30 and 36%. A mix ratio of 1:6:0.55 was adopted via batching by weighing was adopted. 450 x 255 x 150 mm hollow block mould was used in moulding the blocks manually. A total of fifty-six blocks of samples moulded were cured manually through spraying of water for 7, 14, 21 and 28 days respectively. The result showed that at the 28th-day compressive strength test of the block in N/mm^2 was 2.07 and the lowest strength of the individual block on the 28th day's compressive strength test in N/mm^2 was 1.41 N/mm^2. The result indicates that the termitarium silty fine can partially replace sand satisfactorily up to 10%.

2.5 Kaolin and Metakaolin

Kaolin is a clay material containing 10 to 95% of the mineral kaolinite (Kambai, 2014). It is commonly called China clay. The name was derived from the word ''Kau-Ling'' named after a hill near Jau-Chau Fu, China, where kaolin was first mined. Metakaolin (MK) is a material produced from burnt kaolin clay at temperatures ranging from 650 to 800^{0}C. Kaolin can be calcined in Muffle furnace. MK is a natural pozzolanic material that can be used in concrete production as a supplementary cementitious material (SCM). Marvila et al., (2021) said when compared to other ingredients for producing concrete, metakaolin gives better strength development of the interfacial transition zone. Metakaolin has been used commercially in construction as a building material for decades (Marvila et al., 2021).

Most of the research that was conducted on metakaolin-based geopolymer concrete shows a significant improvement in the hardened qualities of concrete. Alumina, an important material for making geopolymers can be sourced from metakaolin obtained from the calcination of kaolin at a temperature of about 750°C. Metakaolin demonstrates high pozzolanic reactivity, and filling effects, and is also responsible for the enhanced mechanical properties and durability of geopolymer (Nuaklong et al., 2018).

Ikponmwosa et al., (2014) revealed that concrete allows for innovations and creativity in its production. It can be achieved by altering its composition during mix designs, or by the addition of chemical or mineral additives etc. This has led to the development of many types of concrete with different properties and for different applications or uses.

Table 3: Location of kaolin deposits in Nigeria

	State	Location		Exploration
1.	Abia	Nnochi, Umuahia, Ikwuano, Isiukwato.		Small scale exploitation.
2.	Akwa-ibom	Ikot, Ibiaku,ntok okpo,mbiafum, Ekwere .etc		
3.	Anambra	Aguata, Ozubulu, Ukporo, Ekwusigo, Nnewi, Ihiala, Njikoka, Anambra etc		Partial exploration is being carried out
4.	Bauchi	Alkaleri, Dambam, Ganjuwa, Darzo, Misua, Kirfi.	million tones	Commercial exploration
5.	Benue	Apa, Vandikya, Ogbadibo, Okpokwu.		
6.	Borno	Maiduguri[gongulon]bui,damboa		
7.	Crossriver	Alege, Betikwe, Mba, Bbuabong		More investigation required
8.	Delta	Aniocha, Ndokwu	Large	Yet to be exploited
9.	Edo	All part of the state	Large	Yet to be exploited
10.	Enugu	Udi, Uzo Uwani, Nsukka south,River oji Enugu		Small scale mining activities at Nsukka.
11.	Ekiti	Isan-ekiti, Omi-Alfia, Ikere Ekiti		
12.	FCT	Kwali,Dongara		
13.	Imo	Orlu, Ehime, Mboano, ahiazu mbaise,Ngor-okpalla, okigwe,Oru		Small scale mining in some of the sites.
14.	Kaduna	Kachia Manaraba-Rido	5.5 million tons	Partial exploration
15.	Kano	Gwarzo, Rabo,Bichi,Tsanyawa,dawakin Tofa.	Not available	Not available
16.	Katsina	Kankara, Batsari, Dustsenma, Safana, Ingawa, Musawa, Malumfashi	million tones	Exploitation by RMRDC/
17.	Kebbi	Danko, Zuru, Giru, Dakin gari, Illo, Kaoje	Not yet quantified	
18.	Kogi	Abgaja		

19.	Nasawara	Keffi, Awe.	45,000 metric tones	
20.	Niger	Bida, Lavun gbako, Patigi, Kpaki		
21.	Ogun	Ibeshe, Abeokuta, Bamojo, Onibode.	Not yet qualified	Exploitation at small scale level
22.	Ondo	Abusoro, Okitipupa, Ifora Ewi Ode-aya, Omifun-fun		Partial exploitation is carried out
23.	Osun	Iwo, Irewole, Ile-ife, Ede, Odo otin, Ilesa.		Partial exploitation
24.	Oyo	Tede, Ado-awaye	Not yet quantified	
25.	Plateau	Major Porter Nahute, Mangu, Barkin-ladi, Kanam	million tones	Commercial exploration
26	Yobe	Fika (Turmi)		

Source: RMRDC survey report, 2003.

2.5.1 Composition of Metakaolin

Table 4: Oxides composition of metakaolin.

Chemical composition Of Metakaolin	P. Dinakar et al., (2013) Metakaolin (%)	Rasheed et al., (2021) Metakaolin (%)
Silica (SiO_2)	54.3	50.10
Alumina (Al_2O_3)	38.3	19.2
Ferric oxide (Fe_2O_3)	4.28	1.74
Calcium oxide (CaO)	0.39	4.42
Magnesium oxide (MgO)	0.08	4.61
Sodium oxide (Na_2O)	0.12	0.15
Potassium oxide (K_2O)	0.50	0.45
Sulphuric anhydride (SO_3)	0.22	0.96
Loss on ignition (LOI)	0.68	

Table 5: Physical Properties of Metakaolin (Kumar and Ramesh, 2017).

Constituents	Property
Colour	Pink / Off-white
Pozzolan Reactivity Mg Ca $(OH)_2$ / gm	900
Average Particle size	1.4 micron
Brightness (ISO)	75 ± 2
Bulk Density (Gms / Ltr)	320 to 370
Specific Gravity	2.5

2.5.2 Recent Developments on Metakaolin-based Geopolymer Concrete

Olugbenga et al., (2017) produce a metakaolin-based geopolymer as a sustainable alternative to Portland cement. Kaolin clay was sourced from Kankara in Katsina State Nigeria and calcined at 700^0C for 2 hours to produce MK geopolymers. Specimens were prepared and cast in a 50mmx50x50mm mould. The samples were tested for compressive strengths after curing at temperatures of 40^0C and 60^0C for 7 and 28 days. The result showed the highest recorded compressive strength value as 17.10MPa. The study also revealed that metakaolin-based geopolymers can serve as a potential sustainable construction material for the Nigerian construction industry.

Wu et al., (2022) investigated the performance of metakaolin (MK) based geopolymer blended with rice husk ash (RHA) and silica fume (SF). Samples were cast and subjected to compressive strength and fluidity tests. X-ray diffraction (XRD) and Scanning electron microscope (SEM) were employed to detail the phase composition and microstructural properties of geopolymers. The information about the molecular bonding of the geopolymer was provided by Fourier transform infrared spectroscopy (FTIR). Mercury intrusion porosimeter (MIP) was used to analyse the porosity of geopolymer concrete. The results showed that the properties of preventing morphology cracking and compressive strength were improved.

Gambo et al., (2020) assessed the performance of Metakaolin Based Geopolymer Concrete at elevated temperatures. MKGPC cubes of grade 25 using a mix ratio of 1:1.58:3.71 were produced and placed in an electric oven at a temperature of 60^0C for 24 hours and later stored in the laboratory at ambient temperature for 28 days. The specimens were exposed to elevated temperatures of 200, 400, 600 and 800^0C and subjected to compressive strength, water absorption and abrasion resistance tests. Results from the findings show that at 600 and 800^0C, the metakaolin-based Geopolymer Concrete lost a compressive strength of 59.69% and 71.71% respectively. Lower water absorption and lower abrasion resistance were observed.

III. CONCLUSION

After reviewing all the research work done, the following conclusions are drawn.

(1) GPC is an environmentally friendly, innovative construction material.

(2) Metakaolin-based Geopolymer concrete has more resistance against both chloride and sulfate attacks.

(3) A rise in temperature leads to an increase in water absorption of metakaolin geopolymer concrete while abrasion resistance decreases.

(4) Nearly 90% of the total strength of GPC is achieved within the age of 7 days.

(5) Geopolymer concrete is an effective way to replace conventional concrete considering economic and eco-friendly considerations.

(6) The ratio of sodium silicates to sodium hydroxide of 2.5 gives a good result.

(7) Geopolymer mortars are more resistant to elevated temperatures up to 900^0C and have shown better acid-resistant properties.

(8) The chemical composition of GPC and the curing conditions play important roles in its mechanical properties. It exhibits a higher compressive strength and higher tensile strength compared to OPC concrete.

(9) GPC has excellent resistance to harsh conditions such as sulphate attack, fire and exposure to acids.

REFERENCES

1. Adejo Jacob, E.1, Ka'ase Ephraim, T , Marafa Muhammad (2020): Properties Of Metakaolin Based Geopolymer Concrete Made With Recycled Concrete Aggregate. International Journal Of Research And Innovation In Applied Science (Ijrias) | Volume V, Issue Ix, September 2020|Issn 2454-6194
2. Aguwa, J. I. 2009. Study Of Compressive Strength Of Laterite - Cement Mixes As A Building Material; Austrialian Journal Of Technology; 13 (2): 114 – 120
3. Albidah, A., Alghannam, M., Abbas, H., Almusallam, T., & Al-Salloum Y. (2021). Characteristics Of Metakaolin-Based Geopolymer Concrete For Different Mix Design Parameters. Journal Of Materials Research And Technology, 10, 84–98.
4. Ammar Iqtidar, Muhammad Faisal Javed, Umer Khurshid, Jawad Ihsaan, Hadi Kamal (2020): One Part Geopolymer Using Rice Husk Ash And Metakaolin. 2nd Conference On Sustainability In Civil Engineering (Csce'20) Department Of Civil Engineering Capital University Of Science And Technology, Islamabad Pakistan. Page 1 Of 5
5. Assia A. Mahamat And Salifu T. Azeko (2018): Mechanical And Structural Properties Of Termite Soil As A Partial Replacement To Cement For Different Applications. Materials Science: Advanced Composite Materials Volume 2 Issue 2. Doi: 10.18063/Msacm.V2i2.681
6. Badejo, M. A. (2002). Termites And Man Who Wins, Entomological Society Of Nigeria, Vol. 3, No. 34. Pp. 92 – 99.
7. Chindaprasirt, P.; Chareerat, T.; Sirivivatnanon, V. Workability And Strength Of Coarse High Calcium Fly Ash Geopolymer. Cem. Concr. Compos. 2007, 29, 224–229. [Crossref]
8. Claudius K. And Duna S. (2017). Performance Evaluation Of Calcined Termite Mound (Ctm) Concrete With Sikament Nn As Superplasticizer And Water Reducing Agent. The International Journal Of Engineering And Science. 6(6), 40-48.
9. Claudius Konitufe, Abubakar Sabo Baba And Aliyu Abubakar (2023): Optimization Of Calcined Termite-Mound Material (Ctm) Mortar And Concrete Using Response Surfaces Methodology. Global Journal Of Engineering And Technology Advances, 2023, 14(02), 047–060. Doi: Https://Doi.Org/10.30574/Gjeta.2023.14.2.0020
10. Dinakar, Pradosh K. Sahoo, And G. Sriram (2013): Effect Of Metakaolin Content On The Properties Of High Strength Concrete. International Journal Of Concrete Structures And Materials, Vol.7, No.3, Pp.215–223, September 2013. Doi 10.1007/S40069-013-0045-0 Issn 1976-0485 / Eissn 2234-1315
11. Duxson P., Fernandez-Jimenez A., Provis J.L., Lukey G.C, Palomo A., And Van Deventer J.S., (2007): "Geopolymer Technology: The Current State Of The Art", J. Mater. Sci., Vol. 42, Pp. 2917-2933. Http://Dx.Doi.Org/10.1007/S10853-006-0637
12. Elinwa, A. U. (2006). Experimental Characterization Of Portland Cement-Calcined Soldier-Ant Mound Clay Cement Mortar And Concrete. Construction And Building Materials. 20(2006): 754-760. Doi: 10.1016/J.Conbuildmat.2005.01.053.

13. Fapohunda Christopher, Oluwatosin Oladipupo And Luke B. Ajayi (2020): Effects Of Using Pulverized Termite Mound (Ptm) As Partial Replacement Of Fine Aggregate On The Durability Properties And Microstructure Of Concrete. Engineering Review, Doi: 10.30765/Er.1665
14. Fapohunda Christopher, Oluwatosin Oladipupo And Luke B. Ajayi (2020): Effects Of Using Pulverized Termite Mound (Ptm) As Partial Replacement Of Fine Aggregate On The Durability Properties And Microstructure Of Concrete. Engineering Review, Doi: 10.30765/Er.1665
15. Fernandez-Jimenez A., García-Lodeiro I., And Palomo A.,(2007): Durability Of Alkali-Activated Fly Ash Cementitious Materials, J. Mater. Sci., Vol. 42, No. 9, Pp. 3055-3065. Http://Dx.Doi.Org/10.1007/S10853-006-0584-8.
16. Gambo, K. Ibrahim, A. Aliyu, A. G. Ibrahim And H. Abdulsalam (2020): Performance Of Metakaolin Based Geopolymer Concrete At Elevated Temperature. Nigerian Journal Of Technology (Nijotech) Vol. 39, No. 3, July 2020, Pp. 732 – 737.
17. Gitu I. Bassey, Jerome G. Egbe And Stanley E. Ubi (2020): Evaluation Of Compressive Strength Of Sandcrete Blocks Containing Termitarium Clay. Journal Of Civil Engineering And Construction Technology. Issn: 2141-2634.
18. Gorhan, G.; Kurklu, G. (2014). The Influence Of The Naoh Solution On The Properties Of The Fly Ash-Based Geopolymer Mortar Cured At Different Temperatures. Compos. Part B Eng. 2014, 58, 371–377. [Crossref]
19. Guo, X, Shi, H & Dick, Wa (2010) 'Compressive Strength And Microstructural Characteristics Of Class C Fly Ash Geopolymer', Cement And Concrete Composites, Vol. 32, No. 2, Pp. 142-7.
20. Hardjito, D, Wallah, Se, Sumajouw, Dm & Rangan, Bv (2004), 'On The Development Of Fly Ash-Based Geopolymer Concrete', Aci Materials Journal-American Concrete Institute, Vol. 101, No. 6, Pp. 467-72.
21. Heah Cy, Kamarudin H, Al Bakri Am, Binhussain M, Luqman M, Nizar Ik, And Liew Ym (2011). Effect Of Curing Profile On Kaolin-Based Geopolymers. Physics Procedia, 22: 305-311.
22. Ikponmwosa, E., Falade F. And Fapohunda C. (2014). A Review And Investigation Of Some Properties Of Foamed Aerated Concrete. Nigeria Journal Of Technology (Nijotech), 33(1), Pp. 1 – 9.
23. Joseph, B.; Mathew, G. (2012): Influence Of Aggregate Content On The Behavior Of Fly Ash Based Geopolymer Concrete. Sci. Iran. Trans. A Civ. Eng. 2012, 19, 1188–1194. [Crossref]
24. Kambai, L. (2014). Kinetic Study of the Novel Dealumination Approach of Kaolin Using High
25. Acid Strength. Ahmadu Bello University.
26. Kriven, W. (2017). The Geopolymer Route To High Tech Ceramic. Www.Youtube.Com/Watch?V=9kqap9xrgwu
27. Kumar, S And Kumar, R (2011), 'Mechanical Activation Of Fly Ash: Effect On Reaction, Structure And Properties Of Resulting Geopolymer', Ceramics International, Vol. 37, No. 2, Pp. 533-41.
28. Kumer Sarath Chandra And K. Ramesh (2017): Experimental Study On Metakaolin And Ggbs Based Geopolymer Concrete. International Journal Of Engineering And Technology (Ijet). Vol 9 No 2 Apr-May 2017
29. Manjunath, G & Giridhar, C (2011), 'Compressive Strength Development In Ambient Cured Geopolymer Mortar', International Journal Of Earth Sciences And Engineering, Vol. 4, No. 6, Pp. 830- 4
30. Marvila M.T, Azevedo, A.R.G., Vieira C.M (2021): Reaction Mechanisms Of Alkali-Activated Materials, Rev. Ibracon Estrut. Mater. 14 (3).
31. Ndaliman, M. B. 2006. Refractory Properties Of Termite Hills Under Varied Proportions Of Additives. Leonardo Electronic Journal Of Practices And Technologies; 9 (4):161-166.
32. Nuaklong, P., Sata, V., Chindaprasirt, P., 2018. Properties Of Metakaolin-High Calcium Fly Ash Geopolymer Concrete Containing Recycled Aggregate From Crushed Concrete Specimens. Constr. Build. Mater. 161, 365–373.
33. Nurruddin, M.F.; Sani, H.; Mohammed, B.S.; Shaaban, I. (2018): Methods Of Curing Geopolymer Concrete: A Review. Int. J. Adv. Appl. Sci. 2018, 5, 31–36. [Crossref]

34. Nurruddin, M.F.; Sani, H.; Mohammed, B.S.; Shaaban, I. (2018): Methods Of Curing Geopolymer Concrete: A Review. Int. J. Adv. Appl. Sci. 2018, 5, 31–36. [Crossref]
35. Nuruddin Mf, Malkawi Ab, Fauzi A, Mohammed Bs, And Al-Mattarneh Hm (2016). Effects Of Alkaline Solution On The Microstructure Of Hcfa Geopolymers. In The 3rd International Conference On Civil, Offshore And Environmental Engineering (Iccoee'16), Crc Press, Malaysia: 501-505.
36. Nuruddin, Mf, Qazi, Sa, Kusbiantoro, A & Shafiq, N (2011), 'Utilisation Of Waste Material In Geopolymeric Concrete', Proceedings Of The Ice-Construction Materials, Vol. 164, No. 6, Pp. 315-27.
37. Olanrewaju Sharafadeen Babatunde O., Akinpelu Samuel O., Alake Olaniyi (2019): Durability Of Termite Mound Lime-Blended Cement Mortar Mixtures. International Journal Of Engineering And Innovative Technology (Ijeit) Volume 9, Issue 6, December 2019 Doi:10.17605/Osf.Io/Cm9at
38. Olugbenga Ayeni (2017): Performance Of A Nigerian Metakaolin-Based Geopolymer As A Sustainable Building Material. A Thesis Presented To The Department Of Materials Science And Engineering African University Of Science And Technology, Abuja.
39. Olivia, M & Nikraz, H (2012), 'Properties Of Fly Ash Geopolymer Concrete Designed By Taguchi Method', Materials & Design, Vol. 36, Pp. 191-8.
40. Paulo H. R. Borges, Vitor A. Nunes, Tulio H. Panzera, Giorgio Schileo And Antonio Feteira (2016). The Influence Of Rice Husk Ash Addition On The Properties Of Metakaolin-Based Geopolymers. The Open Construction And Building Technology Journal, 2016, 10, (Suppl 3: M4) 406-417
41. Perera Ds, Uchida O, Vance E, And Finnie K (2007). Influence Of Curing Schedule On The Integrity Of Geopolymers. Journal Of Materials Science, 42(9): 3099-3106.
42. Rangan, B.V. (2008). Low-Calcium Fly Ash-Based Geopolymer Concrete.In Nawy, E.G. (Ed), Concrete Construction Engineering Handbook. Crc Press, New York.
43. Rasheed Abdulwahab, Samson Olalekan Odeyemi, Habeeb Temitope Alao, Toyyib Adeyinka Salaudeen (2021). Effects Of Metakaolin And Treated Rice Husk Ash On The Compressive Strength Of Concrete. Research On Engineering Structures And Materials · January 2021 Doi: 10.17515/Resm2020.223ma1014
44. RMRDC. (2013). Unlocking the potentials of Nigeria's non-oil sector (Series 13.2 ed.). (I. O.A.P Onwualu, Ed.) Abuja, Nigeria: Raw Materials Research and Development Council (RMRDC).
45. Yewale Vv, Shirsath Mn, And Hake Sl (2016). Evaluation Of Efficient Type Of Curing For Geopolymer Concrete. Evaluation, 3(8): 10-14.
46. Yost J.R, Radlinsca, A and Salera M (2013): Structural Behaviour Of Alkali Activated Flyash Concrete. Part 1: Mixture Design, Material Properties And Sample Fabrication', Materials And Structures, Vol. 46, Pp. 435 47.
47. Yunsheng Z, Wei S, Qianli C, And Lin C (2007). Synthesis and Heavy Metal Immobilization Behaviors Of Slag Based Geopolymer. Journal of Hazardous Materials, 143(1): 206-213.

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