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EFFECTS OF USING PULVERIZED TERMITE MOUND (PTM) AS PARTIAL REPLACEMENT OF FINE AGGREGATE ON THE DURABILITY PROPERTIES AND MICROSTRUCTURE OF CONCRETE

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ARTICLE INFO	Abstract
	The unrestrained use of non-renewable natural resources used in the production of structural concrete raises sustainability concerns. The use of appropriate waste and non-conventional materials is encouraged to address some of these concerns. Understanding the relationship between the durability properties and microstructure of such a material will increase innovation in its use and mitigate some of the environmental issues associated with concrete production. This paper presents the results of a study conducted to evaluate the durability and investigate the microstructure of concrete with fine aggregate partially replaced by pulverized termite mound (PTM). Durability was evaluated by sorptivity and water absorption coefficient tests. Scanning electron microscopy (SEM) was used to study the microstructure of the concrete specimens after 28 days of curing. The results show (i) that the durability of the PTM concrete specimens, as measured by the water absorption coefficient, improves progressively with PTM content, (ii) that the durability of the PTM specimens, as evaluated by sorptivity, improves up to a PTM content of 70%, and (iii) that the microstructure of the concrete specimens has smaller pores compared to the control, which follows the trend of the sorptivity results. Therefore, for practical purposes, the use of PTM mounds as a substitute for fine aggregate in the production of structural concrete should be limited to 70 %.

1 Introduction

Every concrete structure must continue to perform its intended function, i.e. the required strength and serviceability, during its specified or traditionally expected service life [1, 2]. A concrete is said to be durable if it is capable of resisting all the wear processes to which it is expected to be subjected. The types of stresses to which concrete may be subjected are classified and enumerated in Table 1. Until recently, developments in cement and concrete technology have been directed towards achieving ever higher strengths. This was based on the assumption that strong concrete is also durable concrete. It is now becoming clear that for many exposure conditions of concrete structures, both strength and durability need to be explicitly considered at the design stage [1]. However, closely related to durability is the microstructure of concrete. According to [2 - 4], microstructure, which controls porosity and permeability, is an important property that affects the durability of concrete.

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Table 1. Agents of Deterioration in Concrete [1].

	Agents of Deterioration	Examples
1	Chemical	1. Alkali-aggregate reaction 2. Alkali-carbonate reaction 3. Chloride attack 4. Sulfate attack 5. Natural/Industrial Liquid 6. Natural/Industrial Gases
2	Mechanical	1. Impact, 2. Abrasion 3. Cavitation 4. Erosion
3	Physical	1. Effects of High Temperatures 2. Difference in thermal expansion of aggregate 3. Differences in thermal expansion of hardened cement paste 4. Alternating freezing and thawing of concrete. 5. Effects of de-icing salts

With the exception of mechanical damage (Table 1), all adverse effects on durability are associated with the transport of fluids through the concrete. According to [1], this transport depends mainly on the structure of the hydrated cement paste. In addition, there is a growing awareness to limit the environmental impact of concrete industry practices by using non-conventional materials in the production of structural concrete. These materials include waste (industrial or agricultural) and any material found suitable on site.

These include: Rice husk ash (RHA), palm oil fuel ash (POFA), palm kernel (PK), silica fume, (SF), granulated blast furnace slag (GGBS), fly ash (FA), pulverized termite mound (PTM), etc. They are used as partial substitutes for cement or aggregates in the production of structural concrete. Undoubtedly, the use of any of these materials on a large scale in the production of concrete will have a positive impact on the environment.

This requires that not only the mechanical properties (such as density, compressive strength, tensile strength, etc.), but also the long-term behavior and microstructure are recorded. Recently, Fapohunda and Daramola [5] investigated the possibility of using powdered termite mold (PTM) as a partial substitute for fine aggregate in the production of structural concrete. The PTM replacement was limited to 50 wt% of the fine aggregate. Although improved performance of concrete with PTM was reported at all replacement levels, the work was limited to mechanical properties such as workability, density, compressive strength, and tensile strength. Durability and microstructural aspects were not addressed.

Therefore, the objective of the present work is to investigate the durability and microstructure of concrete with PTM as a partial replacement of fine aggregate. Specific objectives are: (i) the determination of durability properties by water absorption coefficients and sorption tests and (ii) microstructural investigations by the use of scanning electron microscopy (SEM). The authors' choice of water-based assessment of durability properties is consistent with established sources [1, 6] that water is often the cause or a contributing factor to the deterioration of buildings and infrastructure.

2 Materials and Method

2.1 Materials

The materials used for this study are cement, fine aggregate, coarse aggregate, powdered termite mound (PTM) and water. Portland limestone cement (PLC) classified as CEM II by [7] was used as cement. The fine aggregate used was river sand obtained from FUOYE river, a river that flows through Federal University, Oye-Ekiti, Nigeria. The sand was dried and all harmful substances were removed. The coarse aggregate was obtained from a quarry in Ikole town where the Engineering Faculty of the university is

located. The PTM was obtained from one of the many termite mounds in the vicinity of the Federal University, Oye-Ekiti, Nigeria.

It was pulverized and subjected to sieve analysis. The material that passed sieve size 4.75 mm but retained sieve size 2.36 mm was collected and stored in a cool place. Portable water was used for this study. The concrete mix design method adopted from BS EN 206 [8] and supplemented by the recommendations of the Council for the regulation of Engineering in Nigeria COREN [9] was used for the control mix with a mix ratio of 1:2:4 and a water-cement ratio of 0.5. In accordance with the specifications of [10], a maximum aggregate size of 20 mm and a slump of 30 - 60 mm were used.

The target mean 28-day cube compressive strength was 25 N/mm2. The fine aggregate in the concrete was replaced at intervals of 25% up to 50% and at intervals of 10% thereafter. The mixing ratio is shown in Table 2. The concrete ingredients were batched by weight, mixed thoroughly and poured into cube molds (100 x 100 x 100 mm). The cubes were demoulded after 24 hours and wet cured up to the day of testing after 28 and 90 days.

Table 2. Mix design for the investigation in this study.

%PTM in the Mix	Cement (kg/m^3)	Fine aggregate (kg/m^3)		Coarse aggregates (kg/m^3)	Water (kg/m^3)
		Sand	PTM		
0	343	686	0	1372	172
25	343	515	172	1372	172
50	343	343	343	1372	172
60	343	275	411	1372	172
70	343	206	480	1372	172
80	343	137	549	1372	172
90	343	68	618	1372	172
100	343	0	686	1372	172

2.2 Methods

2.2.1 Characterization of Materials

Preliminary investigation was carried out to characterized the materials used by determining some of their properties. Physical properties like: specific gravity, moisture content, water absorption, dry density, bulk density and sieve analysis, were carried out on the aggregates and the pulverized termite mound (PTM). Chemical analysis of PTM was also carried out to determine its oxide composition.

2.2.2 Durability Assessment through the Rate of Water Absorption Test

The water absorption coefficient is proposed as a measure of the permeability of water [11]. It is measured by the rate of water absorption of dry PTM concrete specimens in a 1 h period. 48 100 x 100 x 100 mm cubes, cured and tested after 28 and 90 days, were used to evaluate the water absorption of PTM concrete.

The concrete specimens were preconditioned by drying them in an oven at 105 0C for three days until they reached a constant weight and then allowed to cool in a sealed container for three days. The sides of the concrete specimens were coated with silicone to allow flow in one direction. Then, the specimens were held in a vertical position with one end partially immersed to a depth of 5 mm while the rest of the pieces were exposed to laboratory air. This configuration for assessing the rate of water absorption is shown in Figure 1.
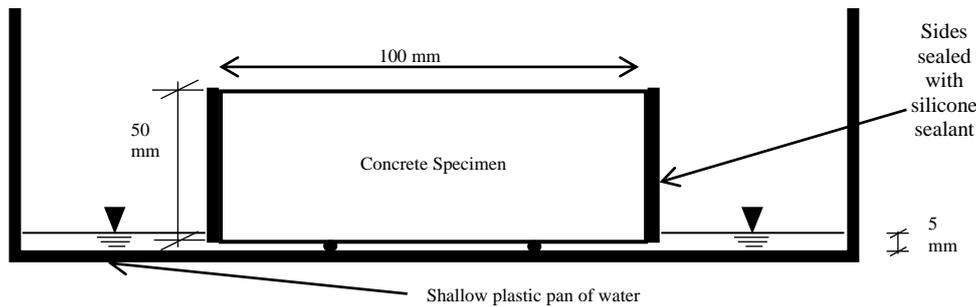
Figure 1. Arrangement for Coefficient of Absorption and Sorptivity Tests (adaptation from 12, 13].

The quantity of water absorbed during the first 60 min by the PTM concrete samples was calculated. Coefficient of water absorption values of PTM blended concrete specimens after 28 and 90 days of moisture curing were determined using equation 1 [13]

$$Ka = [\frac{Q}{A}]^2 \times \frac{1}{t} \tag{1}$$

where Ka is the coefficient of water absorption (m^2/s), Q is the quantity of water absorbed (m^3) by the oven dry specimen in time (t), t is 3600 s and A is the surface area (m^2) of concrete specimen through which water penetrates.

2.2.3 Durability Assessment through Sorptivity Test

Sorptivity is a material property that characterizes the tendency of a porous material to absorb and transmit water by capillarity. It is assumed that the cumulative water absorption (per unit area of incident surface) increases with the square root of the elapsed time (t).

The arrangement for the determination of sorptivity, the cube samples used, and the sample preparation were similar to those used for the determination of the absorption coefficient, as shown in Figure 1, but in this case the tests were performed at selected times 0, 2, 4, 8, 10, 20, 30, 60, 90, and 120 minutes.

At the selected times, the samples were removed from the water, excess water was blotted off with a damp paper towel, and then the sample was weighed. It was then placed back in the water for the selected time period. The increase in mass per unit area over the density of the water was plotted against the square root of the elapsed time. The slope of the straight line of the best fit of these points was taken as the sorption value. The sorption values of PTM-mixed concrete specimens after 28- and 90-day moisture curing were calculated using the following formula (Equation 2) proposed by [14].

$$I = St^{0.5} \tag{2}$$

where *I* is the cumulative water absorption per unit area of inflow surface (m^3/m^2), S is the sorptivity ($m/s^{0.5}$) and t is the time elapsed (s). A total number of forty-eight (48) 100 x 100 x 100 cube specimens cured for both 28 and 90 days were used. This test was performed according to [12].

2.2.4 Microstructure Studies

JEOL Scanning electron microscopy (SEM) equipment with energy dispersive spectrometry features was used for the microstructural study, which is shown in Figure 2. The SEM studies, in backscattered electron (BSE) mode, were performed on fractured samples of concrete specimens after 28 days of curing to investigate their morphological structures. The samples were taken from the innermost core of the concrete cubes after breaking.

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Figure 2. The SEM Equipment used for Microstructural Investigation of Samples.

All the samples are then prepared into appropriate size that fit into the specimen chamber of the SEM equipment. Samples were freeze-dried, cut and polished and examined with SEM equipment set at the backscattered electron (BSE) mode. The range of scale used in SEM analysis was 5μm with the resolution of x 10000.

3   Results and Discussion

3.1 Materials Characterization

The results of the preliminary investigations in relation to some physical properties of sand and PTM are presented in Table 3 and the particle size distribution are shown in Figure 3.

Table 3. Summary of the physical properties of PTM and Sand.

Physical Property	PTM	Sand
Specific Gravity	2.17	2.63
Moisture Content	1.50%	0.00%
Uniformity Coefficient (C_u)	5.60	3.29
Coefficient of Curvature (C_c)	1.28	1.00
Density (Kg/m^3)	1370.00	1540.00

It can be seen from Table 3 that the observed values of weight parameters like density and specific gravity of sand is higher than those of PTM, which is an indication that, the inclusion of PTM in concrete will result in lighter product. The values of the coefficient of uniformity and coefficient of curvature computed from the result of the sieve analysis conducted for the PTM and sand are 5.60 and 3.29; 1.28 and 1.00, respectively. In choosing fine aggregate for structural concrete, wide range of grading is permitted. However, the values obtained in this work fall within the ranges permitted by [15] for fine aggregate to be used for producing concrete. From Figure 3, it can be observed that gradings of both PTM and the sand are similar. Thus, the PTM is comparable to the replaced fine aggregate.
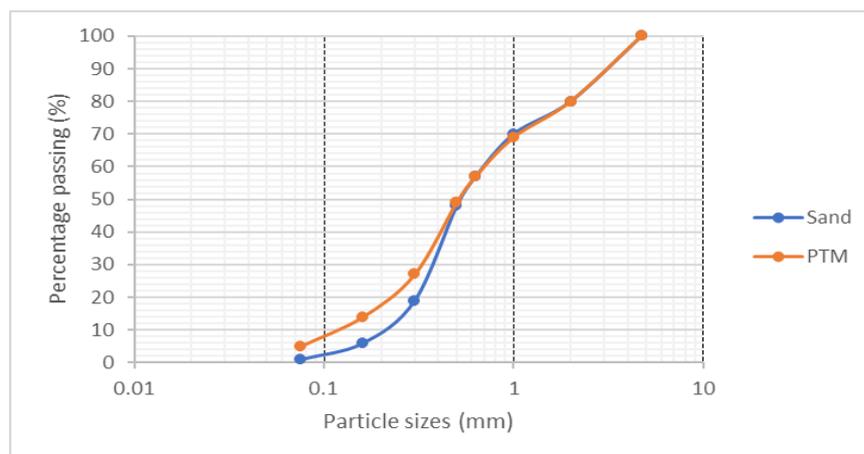
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Figure 3. Grain size distribution curve for PTM and Sand.

3.2 Chemical Analysis

The oxide compositions of the pulverized termite mound (PTM) are presented in Table 4.

Table 4. Oxides Composition of Pulverized Termite Mound (PTM).

Oxides	%
CaO	1.29
SiO_2	70.01
F_2O_3	4.56
MgO	0.73
Al_2O_3	15.98
SO_3	0.23
Na_2O	0.40
K_2O	2.40
T_1O_2	0.69
LOI	2.67
Insoluble Residue	1.08

It can be observed from Table 4 that the sum of SiO_2 + Al_2O_3 + Fe_2O_3 is 90.55%. which exceeds 70%. This clearly indicates that the finer grains of PTM are in the same category with the Class F fly ash [16]; which is the category for materials with high pozzolanic characteristics. Also, this result agrees well with earlier results obtained by [17 – 19, 5].

3.3 Durability Assessment of PTM Samples

The durability of concrete specimens containing pulverized termite mound (PTM) as a partial replacement of fine aggregate was evaluated by water absorption coefficient and sorptivity. The results are discussed below

3.3.1 Coefficient of Water Absorption

The water absorption coefficient is proposed as a measure of the permeability of water. The results of water absorption coefficient are shown in Table 5. It can be seen from Table 5 that the values of water absorption coefficient of the specimens decrease with increasing PTM after 28 days of curing. These values are also lower than the control specimens. The fact that the control values are higher is an indication of lower permeability of the specimens with PTM compared to the control specimens.

Table 5. Coefficient of Water Absorption for the PTM Concrete Specimens.

PTM in the Mix %	Ka (m^2/s) x 10^{-8}	
	28 days	90 days
0	84.03	56.25
25	51.00	25.00
50	34.03	26.56
60	14.00	12.17
70	12.92	16.56
80	8.03	5.06
90	7.93	2.25
100	5.06	4.25

In the work of [5] on concrete with PTM as a partial replacement of fine aggregate, it was observed that the compressive strength (the measure of the quality of the concrete) of the specimens studied increased significantly with the increase of PTM content up to a replacement level of 50%. Considering the reduced permeability of the specimens with PTM from the results of water absorption coefficient, the assertion that a strong concrete gives a durable concrete is confirmed. This is because the higher the strength of the hardened cement paste, the lower its permeability - a condition that is to be expected because strength is a function of the relative volume of gel in the space available to it [1]. Obviously, the additional C-S-H gel produced by pozzolanic activities in concrete specimens leads to pore refinement, and the result is reduced permeability [3, 13, 20]. This phenomenon is known as the filler effect of pozzolans [21 - 22]. Table 4 also shows that, with the exception of the samples with 70% PTM replacement, the values of water absorption coefficient after 90 days of curing are generally lower than those obtained after 28 days of curing. This indicates that prolonged curing of concrete specimens with PTM leads to a reduction in permeable voids. Also, the fact that the value obtained for the control is higher than the values obtained for the specimens with PTM indicates improved performance of the specimens at higher curing age.

3.3.2 Durability Assessment of PTM Samples through sorptivity

Such a test measures water absorption by capillary suction of unsaturated concrete in contact with water; no water column exists [1, 23, 24]. The calculated sorption values for concrete specimens with PTM after 28 and 90 days of curing are also shown in Table 6.

Table 6. Sorptivity of the PTM Concrete Specimens.

PTM in the Mix (%)	Sorptivity x 10^{-2} $(mm/t^{0.5})$	
	28 days	90 days
0	5.29	4.86
25	3.34	3.24
50	3.19	3.14
60	3.04	2.73
70	3.02	2.73
80	9.53	13.88
90	10.73	10.58
100	14.49	14.71

From Table 6, the sorptivity after 28 days of curing decreases with increasing PTM content up to 70%. Moreover, the sorptivity values up to 70% PTM are lower than the control samples. This indicates lower water absorption at PTM content up to 70% compared to the control specimens, possibly due to refinement of pores. This obviously implies better durability of the concrete specimens up to 70%. The sorption values of the concrete specimens after 90 days also show two obvious patterns. First, the sorptivity values decreased

up to 70% of the PTM replacement compared to the control. Second, the sorptivity values of the specimens are lower than the values obtained after 28 days of curing.

That is, the rate of water absorption by capillary suction progressively decreased up to 70% sand replacement with PTM. This can only mean that concrete with PTM up to 70% has the potential to prevent water ingress. However, beyond 70%, an increase in sorption values was observed; the values were higher than those of the control. This indicates a potential deterioration of the concrete when PTM is used in replacement of more than 70% by weight of fine aggregate.

There are many reasons for this. According to [1], there is a sharp increase in permeability at water-cement ratios above about 0.40. Near this water-cement ratio, segmentation of capillaries occurs, so there is a significant difference in permeability between mature cement pastes with a water-cement ratio below 0.4 and those with higher water-cement ratios.

The fact that the water-cement ratio adopted for this study is 0.50 could explain the observed increase in sorption values beyond 70% PTM content. Moreover, it can be seen from Table 3 that PTM has a higher water content (1.5%) than the sand it replaces. Therefore, the observed increase in sorption values at PTM content above 70% may be due to the cumulative effects of higher water content of PTM in the samples at high replacement values.

3.3.3 Practical implications of results of durability tests

From a consideration of the results of the water absorption coefficient and the sorptivity, it is clear that the sorptivity takes precedence over the water absorption coefficient in the design. Therefore, for practical reasons, the use of powdered termite mound as a substitute for fine aggregate in the production of structural concrete should be limited to 70%.

3.4 Microstructure Investigations

The results of scanning electron microscopy (SEM) for the control specimen and the specimens with PTM at 25%, 50%, and 80% replacement levels after 28 days of curing are shown in Figure 4. Following the interpretation pattern of Feldman and Sereda [25, 26], the SEM image of the control sample (without PTM) shows white crystals of calcium hydroxide Ca (OH)2 platelets covering the anhydrous calcium silicate grains. The image appears to be loosely packed and thus porous.

On the other hand, the SEM images of samples containing 25% and 50% PTM have few calcium hydroxide Ca (OH)2 platelets and the pores are smaller and appear denser compared to the control. The reduction in Ca (OH)2 may be attributed to the pozzolanic effect involving the consumption of calcium hydroxide Ca (OH)2 to produce the secondary C-S-H gel. Moreover, the secondary pozzolanic reactions are known to lead to reduced pore crosslinking (Jung et al., 2018).

The filling effect of pozzolans is well known [21, 22]. Thus, partial replacement of fine aggregate by PTM resulted not only in densification of the matrix but also in reduced permeability of the microstructure. Therefore, the SEM images are in agreement with the absorption coefficient and sorptivity results obtained in this study, where the addition of PTM up to 70% leads to a concrete with better permeability compared to the control. The SEM image of the specimens with 80% PTM content shows a porous microstructure. This can be understood from the perspective of the water/cement ratio (0.50) used for this study.
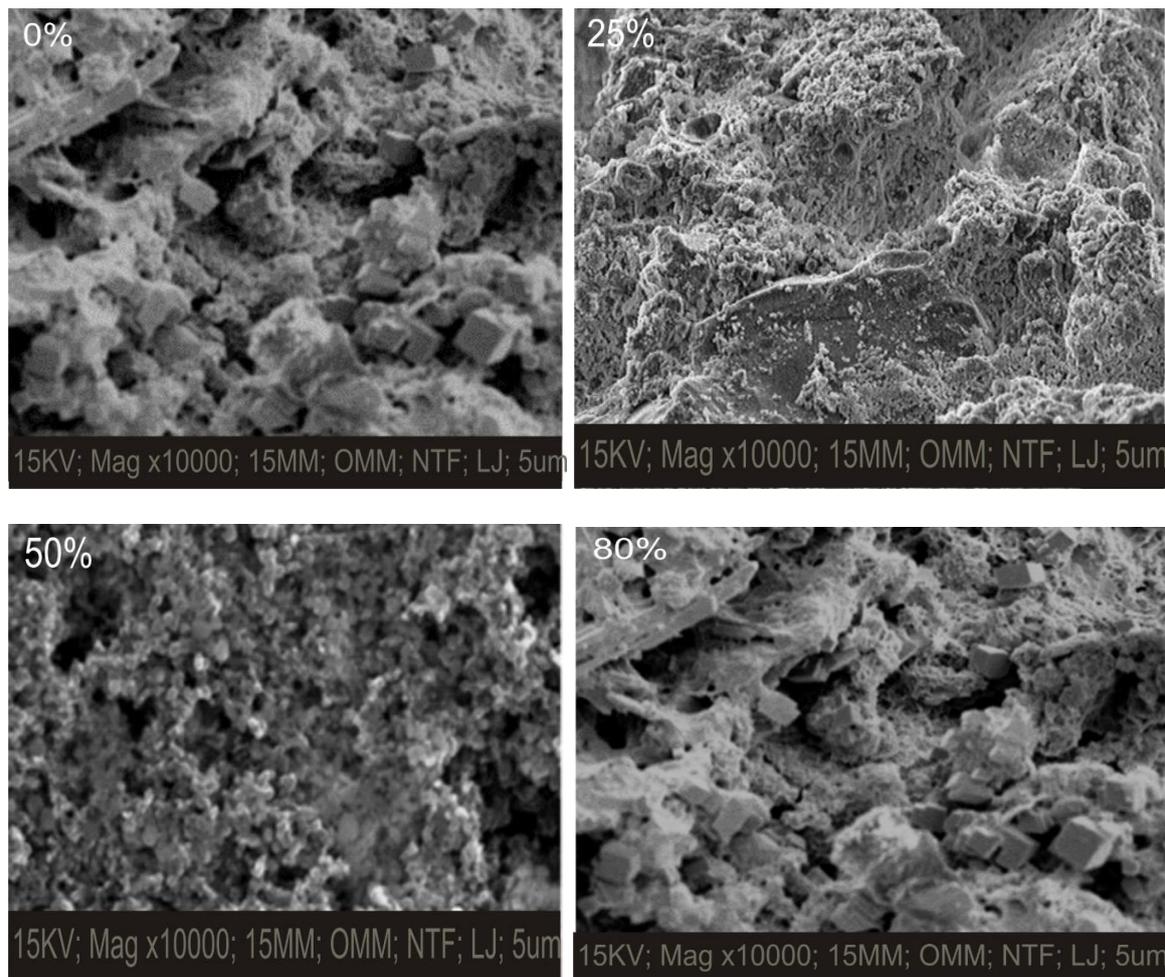
Figure 4. SEM images of concrete samples with PTM.

According to [1], higher water content increases the w/c ratio; and the w/c ratio in turn determines the porosity of the cement paste. At higher w/c ratio (more than 0.38), the formation of capillary pores increases. It is these capillary pores that are responsible for the permeability of the cement paste. It was also observed in Table 3 that the moisture content of PTM is higher than that of the replaced fine aggregate. So, the cumulative effect is higher water at higher PTM replacement values resulting in increased porosity. The SEM image at 80% PTM showing a porous microstructure is consistent with this.

4 Conclusions and Recommendations

4.1 Conclusions

From the results of this investigation the following conclusions may be drawn:
1. The durability of PTM concrete specimens, measured by absorption coefficient, improves progressively with PTM content.
2. the durability of PTM specimens, measured by sorptivity, improves up to a PTM contentof 70% 3. the microstructure of concrete specimens with PTM shows smaller pores compared to the control, which follows the trend of sorptivity results.For practical purposes, it can be concluded that the use of powdered termite mound (PTM) as a substitute for fine aggregate in the production of structural concrete could be limited to 70% for durability reasons.

4.2 Recommendations

Table 1 lists some of the causes of deterioration of structural concrete. With the exception of mechanical deterioration, all of the adverse effects on durability relate to the transport of fluids through the concrete.

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A limited number of them have been studied in this paper. Others such as sulphate attack, chloride intrusion, alkali aggregate reactions among others of concrete containing PTM are still awaiting investigation. These are therefore presented and recommended for investigation.

Acknowledgement

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