Comparative Sulphate Resistance of Pozzolanic Cement Mortars

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Abstract**—**This is report on experiment out to compare the sulphate resistance of sand mortar made with five different pozzolanic cement. The pozzolanic cement were prepared by blending powered burnt bricks from the Adamawa, Makurdi, Kano, Kaduna and Niger bricks factories with ordinary Portland cement in the ratio 1:4. Sand –pozzolanic cement mortars of mix ratio 1:6 and 1:3 with water-cement ratio of 0.65 and 0.40 respectively were used to prepare cubes and bars specimens. 150 mortar cubes of size 70mm x 70mm x 70mm and 35 mortar bars of 15mm x 15mm x 100mm dimensions were cast and cured for 28 days. The cured specimens then immersed in the solutions of K_2SO_4, $(NH_4)_2SO_4$ and water for 28 days and then tested. The compressive strengths of cubes in water increased by 34% while those in the sulphate solutions decreased. Strength decreases of the cubes, cracking and warping of bars immersed in K_2SO_4 were less than those in $(NH_4)_2SO_4$. Specimens made with Niger and Makurdi pulverized burnt bricks experienced less effect of the sulphates and can therefore be used as pozzolan in mortar and concrete to resist sulphate.

Keywords**—**Burnt bricks powder, comparative, pozzolanic cement, sulphates.

I. Introduction

ORDINARY Portland cement products such as concrete, mortars, plasters are designed, prepared, placed, treated and sometimes protected so that they will perform satisfactorily during their service life [8]. With an appropriate degree of safety, they should; carry on all the loads and deformations that act in service, have satisfactory durability, have a sufficient resistance to effects of injurious agents of all nature, aggressive chemicals inclusive. That is, the concretes, mortars and plasters just like other building materials should be durable. Thus, the durability of ordinary Portland cement product can be defined as its resistance to deterioration resulting from internal and external causes [5]. Chemical attack from the environment is among the external causes of deterioration.

Chemical aggression has been known to produce devastating effect on concrete [4]. Subjection of concrete to sulphuric acid, nitric acid, hydrochloric acid, carbonic acid and sulphate salt among other chemicals impair the satisfactory performance of the concrete. According to [2], two major sources of chemical aggression are; the natural source such as sea water, river water and soils rich in sulphate, nitrates, chlorides and carbonates and the artificial source such as chemical manufacturing industries, textile industries, sale and usage of industrial chemical outlets, catchment areas for effluents from animal rearing units and sewage tanks. Sulphates, nitrates, and chlorides when present in the environment of the Portland cement product could lead to reduction in the strength of the product due to their adverse effects.

Reference [6] opined that Portland cement product attacked by sulfate has a characteristic whitish appearance, damage usually starting at the edges and corners and followed by cracking and spalling of the concrete. The reason of this appearance is that the essence of sulfate attack is the formation of calcium sulfate ($CaSO_4$) i.e., gypsum and calcium sulphoaluminate (ettringite), both products occupying a greater volume than the compounds which they replace so that expansion and disruption of hardened mortar or concrete takes place.

Reference [3] reported that the extent of sulfate attack depends on its concentration and on the permeability of the concrete, i.e., on the ease with which sulfate can travel through the pore system. Thus, if the concrete is permeable such that water can percolate right through its thickness, $Ca(OH)_2$ will be leached out. Extensive leaching of $Ca(OH)_2$ will increase porosity so that concrete becomes weaker and prone to chemical attack. Since it is C_3A that is attacked by sulfates, the vulnerability of concrete to sulphate can be reduced by the use of cement low in C_3A, by using sulfate–resisting cement. According to [1], improved resistance is obtained also by the use of Portland blast–furnace cement, and of Portland pozzolan cement. [3] Suggested the use of mixtures of powdered burnt bricks and ordinary Portland cement to produce concrete and mortar with improved resistance to sulphate. This paper is the report of research carried out with the aim of finding the suitability of different samples of powdered burnt brick manufacturing in Nigeria as materials for improving the sulphate resistance of cement-sand mortar.

II. Methodology

A. Materials

Ordinary Portland cement (Dangote brand), five different sample of powdered and sieved (to cement fineness) burnt bricks from burnt bricks factories located Makurdi, Kano, Kaduna, Niger and Adamawa (these bricks had earlier been found by [7] to be pozzolanic), naturally occurring clean sharp river sand and portable water, potassium sulphate (K_2SO_4) and ammonium sulphate ($(NH_4)_2SO_4$) solutions were used for the research work. Broken burnt bricks samples obtained were

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crushed manually into fine powdered form and sieved with a 75µm BS sieve.

B. Method

To assess the sulphate resistance of five ''pozzolanic cements'', the pozzolanic cement were first prepared by blending each of powdered burnt brick (PBB) with ordinary Portland cement in the ratio of 20%:80% by weight. Five different mortars were then produced with the five pozzolanic cements. Specimens, which were used to assess to suitability of the pozzolanic cement as sulphate resistant were then cast and cured with moist jute bags for 28 days. The following specimens were prepared and tested.

a. Thirty mortar cubes were cast for each of the five pozzolanic cement using pozzolanic cement –sand mortar nix ratio of 1:6 and water-cement ratio of 0.65
b. Third two bars cast for each of the five pozzolanic cement using pozzolanic cement-sand mortar mix ratio of 1:3 and a lower water-cement ratio of 0.40.

The mortar cubes specimens of size 70mmx70mmx70mm were cast using well-oiled timber moulds. The mortar mix for the cubes was cast into the moulds in three approximately equal layers and each of the layers were tamped 25 times using a standard rammer of 25mm diameter. The bar specimens were cast in the same way as the cubes but their moulds was of 15mm x 15mm x 100mm dimension. Tables I and II show the quantities of materials per the respective volume of specimen as computed using the absolute volume method.

TABLE I
QUANTITIES OF MATERIALS PER CUBIC METER FOR MORTAR CUBES W/C RATIO = 0.65

Materials	Control Mix Neat Cement (Kg)	Pozzolanic Cement 20% Replacement(kg)
Sand	4.3062	4.3062
Water	0.4334	0.4334
Cement	0.6668	0.5334
PBB	0	0.1334

TABLE II
QUANTITIES OF MATERIALS PER CUBIC METER FOR MORTAR BARS W/C RATIO =0.40

Materials	Control Mix Neat Cement (Kg)	Pozzolanic Cement 20% Replacement(kg)
Sand	0.2702	0.2702
Water	0.0335	0.0335*
Cement	0.0837	0.0669
PBB	0	0.0167

*0.08kg of water was used to achieve reasonable workability

The mortar cubes and bar specimens were cured by covering them with moist jute bags for 28days. Set A, consisting of ten mortar cubes from each of the five mortars were immersed in clean water (control set), set B consisting of ten mortar cubes from each of the five mortars were immersed one-mole solution of K_2SO and set C, also consisting of ten mortar cubes from each of the five mortars were immersed in one-mole solution of $(NH_4)_2SO_4$ solutions. The sets A, B and C were left in water and Salts solutions for another period of 28days. A set, of five bars from each of the mortars was also completely immersed in water and the two sulphate solutions of the same concentration. At the end of the immersion period, the specimens were brought out, dried, examined and tested. The cubes were tested for compressive strength using compression testing machine of 1100kN capacity. The bars were observed for any corrosion and cracking or warping. The bars were also tested for expansion by checking their dimensions using a measuring ruler. All the tests were carried out in the laboratories of the Departments of Building and Chemistry of the Ahmadu Bello University, Zaria.

III. MATH

A. Compressive Strength Test

The 150 cubes were crushed at the end of 28 days of second period of immersion to find their compressive strengths. The average compressive strength and density at the age of 28 days for cubes immersed in water, K_2SO_4 and $(NH_4)_2SO_4$ are presented in Tables III, IV, and V, respectively.

TABLE III
AVERAGE 28 DAYS COMPRESSIVE STRENGTH AND DENSITY FOR CUBES IMMERSED IN WATER (CONTROL CUBES)

Identification Number	Average Density (kg/m^3)	Average Crushing Strength (N/mm^2)
C_{AD}	2033.6	6.63
C_{MK}	2078.7	7.65
C_{KN}	2053.9	5.95
C_{KD}	2090.4	6.63
C_{NG}	2349.9	7.65

TABLE IV
AVERAGE 28 DAYS COMPRESSIVE STRENGTH AND DENSITY FOR CUBES IMMERSED IN $(NH_4)_2$ SO_4 SOLUTION

Identification Number	Average Density (kg/m^3)	Average Crushing Strength (N/mm^2)
C_{AD}	2151.6	3.27
C_{MK}	2139.9	2.86
C_{KN}	2204.1	3.78
C_{KD}	2123.9	5.10
C_{NG}	2370.3	6.12

TABLE V
AVERAGE 28 DAYS COMPRESSIVE STRENGTH AND DENSITY FOR CUBES IMMERSED IN K_2 SO_4 SOLUTION

Identification Number	Average Density (kg/m^3)	Average Crushing Strength (N/mm^2)
C_{AD}	2158.9	4.39
C_{MK}	2135.6	4.59
C_{KN}	2188.1	4.39
C_{KD}	2155.9	4.49
C_{NG}	2437.3	5.10

B. Density

From the result in Tables III, IV, and V, respectively, it was observed that the average densities of mortar cube samples that were immersed in water varied. Mortar mix with pozzolanic cement that was made with the powdered burnt brick from Adamawa state had the least density, just 2033.6kg/m^3, while the mortar prepared with the powdered burnt bricks from Niger state had the highest at 2349.9kg/m^3. When immersed in $(NH_4)_2SO_4$ solution the densities still varied but the least dense became the mortar made with the powdered burnt brick from Kaduna state (2123.9kg/m^3) instead of the made from Adamawa state. The heaviest mortar was that made with the Niger burnt brick (2370.3kg/m^3). These increase in density could either be due to the crystallization of salt in the pores and capillaries of the mortar samples or the absorption of dense fluids by the cubes. This implies that the cube samples that had the highest increase in density, i.e. the cubes made with the Niger burnt brick could either had been less compacted and thus providing pores and capillaries for the crystals or dense fluids or the Niger burnt is a very good or poor pozzolan because it allowed the formation of this products which could be cementitious. The average density of cubes samples immersed in K_2SO_4 varied. Densities of 2158.9kg/m^3, 2135.6kg/m^3, 2188.1kg/m^3, 2155.9kg/m^3 and 2437.3kg/m^3 were obtained for cubes made with Adamawa, Makurdi, Kano, Kaduna, and Niger powdered burnt bricks respectively. Based on these values of the density, it can be seen as the average density of test samples immersed in K_2SO_4 and $(NH_4)_2SO_4$ are higher than the value of cubes immersed in water and the cubes of samples immersed in $(NH_4)_2$ SO_4 solution are denser than those immersed in the K_2SO_4 solution.

C. Compressive Strength

The average compressive strength of test samples made with Adamawa. Makurdi, Kaduna, Kano, and Niger powdered burnt brick immersed in water were 6.63N/mm^2, 7.65N/mm^2, 5.95N/mm^2, 6.63N/mm^2 and 7.65N/mm^2 respectively. The average compressive strength of test samples made with Adamawa, Makurdi, Kaduna, Kano, and Niger powdered burnt brick immersed in K_2SO_4 solution were 4.39N/mm^2, 4.59N/mm^2, 4.39N/mm^2, 4.49N/mm^2 and 5.10N/mm^2 respectively. The average compressive strength of test samples made with Adamawa. Makurdi, Kaduna, Kano, and Niger powdered burnt brick immersed in $(NH_4)_2SO_4$ solution were 3.27N/mm^2, 2.86N/mm^2, 3.78N/mm^2, 5.10N/mm^2 and 6.12N/mm^2 respectively.

It was observed that the average strength of cubes immersed in water (i.e. the control specimens) is higher than the strength of the cubes immersed in both K_2SO_4 and $(NH_4)_2SO_4$ solution. Also the strength of cubes immersed in $(NH_4)_2SO$ is lower than the average strength of cubes immersed in K_2SO_4 which shows that K_2SO_4 is less aggressive than $(NH_4)_2SO_4$. Cubes made with Niger powdered burnt brick immersed in K_2SO_4 and $(NH_4)_2SO_4$ had higher strength than the cubes made with Adamawa, Kaduna, Kano, and Makurdi powdered burnt bricks in the same exposure condition, which indicates that Niger burnt brick is more resistance to sulphates than the other powdered burnt bricks. After the cubes were removed from the chemicals, it was observed that there were cracks on cubes made with Adamawa, Kaduna, Kano and Maiduguri powdered burnt bricks immersed in the two sulphate solutions but there was no crack noticed on cubes made with Niger powdered burnt bricks. Thus, this further indicate that Niger powdered burnt brick is more resistant to K_2SO_4 and $(NH_4)_2SO_4$ than the other powdered burnt bricks. In general, and based on the experiments done, mortar made with the Niger and Makurdi powdered burnt bricks are more resistant to sulphates.

D. Mortar Bar Test

The data on the 32 mortar bars were generated by measuring the change in length and weight of the sample immersed in the K_2SO_4 and $(NH_2)_2SO_4$ solutions. The values are as given in Tables VI and VII, respectively.

TABLE VI
CHANGE IN LENGTH AND WEIGHT FOR MORTAR BARS IMMERSED IN $(NH_4)_2SO_4$

Identification Number	Average Change in Weight (g)	Average Change in Length (mm)
B_{MKO1}	+2	+0.50
B_{MKO2}	+2	+0.50
B_{MKO3}	+2	+0.50
B_{KDO1}	+2	+0.80
B_{KDO2}	+3	+0.80
B_{KDO3}	+3	+0.80
B_{KNO1}	-	+0.50
B_{KNO2}	-	+0.50
B_{KNO3}	-	+0.50
B_{ADO1}	+1	+0.50
B_{ADO2}	+1	+0.50
B_{ADO3}	+2	+0.50
B_{NGO1}	+1	-
B_{NGO2}	+2	-
B_{NGO3}	+1	-

TABLE VII
CHANGE IN LENGTH AND WEIGHT FOR MORTARS BARS IMMERSED IN K_2SO_4

Identification Number	Average Change in Weight (g)	Average Change in Length (mm)
B_{MKO1}	+3	-
B_{MKO2}	+3	-
B_{MKO3}	+2	-
B_{KDO1}	+4	+0.50
B_{KDO2}	+3	+0.50
B_{KDO3}	+3	+0.50
B_{KNO1}	+1	-
B_{KNO2}	+1	-
B_{KNO3}	+1	-
B_{ADO1}	+1	+0.50
B_{ADO2}	+1	+0.50
B_{ADO3}	+2	+0.50
B_{NGO1}	+1	-
B_{NGO2}	+2	-
B_{NGO3}	+1	-

The change in weight (measured in grams) for mortar bars immersed in $(NH_4)_2SO_4$ solution varied from 0 to +3, and the change in weight for bars immersed in K_2SO_4 solution varied from +1 to +4. The increase for bars made with Kaduna powdered burnt brick immersed in $(NH_4)_2SO_4$ was more than the other bars, while bars made with Kano powdered burnt brick, in the same exposure condition had no increase at all. For bars made with Makurdi powdered burnt brick, the increase was uniform i.e. +2 And for bars made with

Adamawa and Niger powdered burnt bricks in the same exposure condition the increase varied from +1 to +2.

The increase in the weight for bars made with Kaduna powdered burnt brick immersed in K_2SO_4 solution was more than the other bars, while bars made with Kano powdered burnt brick in the same exposure condition had a uniform increase of +1. For bars made with Makurdi powdered burnt brick, the increase varied from +2 to +3. Also, for bars made with Adamawa and Niger powdered burnt bricks in the same exposure condition had the same increase between the range of +1 to +2.

The change in length for mortar bars immersed in $(NH_4)_2SO_4$ solution varied from 0 to + 0.80, while the change in length for bars immersed in K_2SO_4 solution varied from 0 to +0.50. The increase in length for bars made with Kaduna powdered burnt brick immersed in $(NH_4)_2SO_4$ was higher than that of bars made with other powdered burnt brick samples, while bars made with Makurdi, Kano, and Adamawa had a uniform increase of +0.50. For bars made with Niger powdered burnt brick in the same exposure condition had no increase at all.

The increase in weight may mean that the specimen is been penetrated by a liquid which is denser than water and is been absorbed, and this adds more weight to the specimen. Increase in length might be due to the deposition of crystals on the surface of the specimen or the interior when there are cracks on the specimens. The cubes that had the least increase in length could imply resistance to attack by sulphate. Thus, Niger burnt bricks could be used to produce the best pozzolanic cement that is resistant to sulphates. The Makurdi, Kano, and Adamawa burnt bricks could also be used but they could be less effective than the Niger burnt bricks, it was also observed visually that there was warping on all specimen immerse in the two sulphate solutions.

IV. Conclusion and Recommendation

A. Conclusions

1. This highest average compressive strength of mortar cubes immersed in water was obtained from the pozzolanic cement made with Niger PBB(7.65N/mm2), after immersion in K2SO4 the strength became 5.10N/mm2 (strength loss of 34%).
2. The decreases in compressive strength of cubes immersed in K2SO4 solution were less than compressive strength of cubes immersed in (NH4)2SO4 solution.
3. Ammonium and potassium sulphate attacks on mortar are characterized by appeared of cracks on the surface.
4. Ammonium and potassium sulphate attacks on mortar are characterized by warping of the specimens.
5. Specimen made with Niger, Makurdi and Kano pulverized burnt brick experienced less effect of the sulphate (expansion of bars are between 0.0 and +0.50mm and average compressive strengths after immersion in sulphates is up to 6.12N/mm2 for the Niger mortar cubes) and therefore can be used as pozzolan in mortar and concrete to resist sulphate.

B. Recommendations

1. Ordinary Portland cement products in contact with sulphate based substances are not likely going to be durable. Therefore, for durability, excessive exposure to sulphate should be avoided
2. Pulverized burnt bricks can be used as pozzolanic cement to mitigate the harmful effects of sulphates. Preferably the pulverized burnt bricks made from Niger and Makurdi.

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