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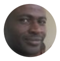

Ezekiel Babatunde Ogunbode
Federal University of Technology Minna

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Ogunbode E.B.[1], Akanmu W.P.[1], Moses D.W.[2], Akaleme M.C.[2], and Idris H[1].
[1]Department of Building, Federal University of Technology Minna, Niger State, Nigeria
[2]Department of Building Technology, Federal Polytechnic Bida. Niger State, Nigeria
Corresponding author e-mail: onbodmail@yahoo.com

Abstract

The deterioration of concrete structures owing to the existence of sulphate in soils, groundwater and marine environments is an eminent observable fact. The use of blended cements incorporating supplementary cementing materials is becoming regular in such aggressive environments. This paper presents the results of an research on the performance of 36 Fly ash (FA)/ordinary Portland cement (OPC) blended cement Laterized concrete (LATCON) mixtures with immersion period of 28 and 90 days in environments characterized by the presence of magnesium sulphate (2%, 4% and 8%). The concrete mixtures comprise a combination of 20% FA substitute to OPC and 10%, 20%, 30% content of laterite replacement to sand as fine aggregate and granite stone as coarse aggregate with water-to-binder ratio of 0.55. Background experiments like strength and fresh properties, pozzolanic activity were conducted. Deterioration of concrete due to sulphate attack was evaluated by assessing concrete weight loss at 28 and 90 days immersion period. The results show that, as the $MgSO_4$ *concentration increases, the compression strength decreases.*

Keywords: blended cement, deterioration, fly ash (FA), laterized concrete (LATCON), sulphate attack

1. Introduction

The existence of sulphate ion is the basis of deterioration of concrete structural components exposed to groundwater and soils contaminated with sulphate salts or marine environments.

Research on concrete deterioration due to the presence of sulphate ions had been continued for decades. Sulphate attack on concrete is a complex process and many factors such as cement type, Sulphate cation type, sulphate concentration and exposure period may affect the sulphate resistance (Neville, 2004; Cohen & Mather, 1991). Mehta,(1973) and Frigione & Sersale, (1989) explained that sulfate ions react with C_3A and $Ca(OH)_2$, to produce expansive and/or softening types of deterioration, so the sulphate attack in marine environment gives rise to expansive ettringite, gypsum, and brucite and sometimes is associated with calcite formation.

The sulphate resistance or opposition of concrete structures can be enhanced by controlling sulphate infiltration into concrete and the sulphate attack can be vetoed either by changing cement from ASTM Type I to Type II or Type Or by introducing pozzolans such as fly ash, blast furnace slag, volcanic ash (VA) and finely ground volcanic pumice (VP) in concrete

(Hossain,1999; Kalousek, et al,1972; Al-Amoudi, et al,1994; Naik, et al,1996;Wong & Poole, 1987; Dikeon,1975).

The use of blended cement made with supplementary cementitious materials (such as: fly ash, silica fume, and blast furnace slag) is, therefore recommended in sulphate environments (Frigione & Sersale,1989; Amoudi et al, 1994; Naik et al, 1996).

The sulphate resistance of such blended cement concretes depends on the composition and physical properties of concrete as well as type and concentration of sulphate ion. The improvement in sulphate resistance for fly ash and silica fume based blended cement concretes is reported. This is attributed to the pore refining and pore refinement effect occurring due to pozzolanic reaction where calcium hydroxide becomes bound by fly ash or silica fume converting it into secondary C–S–H gel. However, with additional cementitious materials, the complexity of sulphate attack becomes even greater (Hossain, & Lachemi M. 2006).

Although significant progress has been made on the understanding of the mechanism of sulphate attack in concrete, our knowledge and understanding remains inadequate (Neville, 2004). Still the role of C_3A, cement content, water to binder ratio, and the role of pozzolanic materials remains controversial. Research had been conducted over the last few years on the use of FA and laterite in cement and concrete production (Ogunbode, 2010). The meaningful use of Fly ash wastes can transform them into natural resources and can, not only provide low cost cement and concrete but can, also help to decrease environmental hazard. In addition to economic and ecological benefits, the use of Fly Ash in concrete improves its workability, reduces segregation, bleeding, heat evolution and permeability, inhibits alkali-aggregate reaction, and enhances sulphate resistance. According to Varghese [12] Fly Ash obtained from lignite is superior to that obtained from coals, Fly Ash can be used to replace cement or fine aggregate, he also put it that Up to 20 per cent Fly ash replacement of cement and 30 per cent replacement of fine aggregates has been reported, and it is on this premise that the research work adopted a replacement of 20% fly ash by weight of cement. Even though the use of Fly Ash in concrete has increased in the last 20 years, less than 20% of the Fly Ash collected was used in the cement and concrete industries (Helmuth, 1987).

Laterite has been identified as a possible material for partial replacement of sand in concrete to produce what has been called laterized concrete (LATCON), while studies have been carried out on effects of laterite incorporation in strength and serviceability properties of fresh and hardened concrete (Ogunbode & Olawuyi, 2008; Adepegba, 1975; Balogun & Adepegba, 1982; Lasisi & Ogunjimi, 1984; Falade, 1991; Ata, 2007; Olusola, 2005). Laterite or laterized concrete on the other hand has attracted the attention of many authors and researchers. Gidigasu (1976) as cited in Olusola (2005) defined laterite as a term used to describe all the reddish residual and non-residual tropically weathered soils, which generally form a chain of materials ranging from decomposed rock through clay to sesquioxide (Al_2O_3 + Fe_2O_3) - rich crusts, generally known as carapace. Laterized concrete is defined as concrete in which stable laterite fines replace sand wholly or partially whole replacement is also referred to as terracrete (Olusola, 2005)

Lasisi et al. (1990) reported the result of short-term studies on the durability of laterized concrete. On a short-term basis, the resistance of laterized concrete specimen to chemical attack, like that from magnesium sulphate solution, was found to be good and produces no detrimental effect on the compressive strength of laterized concrete.

Durability of concrete is one of its most important properties and it is essential that the concrete made with FA/OPC (cement) and Laterite/sand (fine aggregate) should be capable of preserving its durability throughout the life of structures. ACI 318-813-1999 and BS 8110-1985 and other codes of practices provide guidelines on the quality of concrete and the type of cement to be used for varying sulphate concentrations. However, these guidelines do not specifically cover the sulphate resistance of FA/OPC based blended cement concrete.

Preceding investigations on sulphate attack are performed largely by using sodium, magnesium and calcium sulphate solutions (Neville, 2004; Lawrence, 1990). However, due to limited solubility of calcium sulphate in water at normal temperatures (about 1400 mg/l SO4), higher concentrations of sulphate ions in ground waters are generally due to the presence of magnesium and sodium sulphates. Both of these salts are abundant in many parts of the world including Arabian Gulf coast (known as saline sabkha soils), coastal areas of Papua New Guinea and coastal areas of Lagos in Nigeria. It is important to study the performance of concretes in such mixed sulphate environment. Far-reaching studies has been conducted by researchers on the durability of cement mortar and concrete made with pozzolanic materials and alternative aggregates exposed to sulphate and sulphate bearing environments (Hossain and Lachemi, 2005). Therefore, this article presents the outcome of the research perform to evaluate deterioration resistance of 36 concrete mixtures in triplicate which invariably gave a total of 108 cubes, which comprised a combination of FA and Portland cements (FA/OPC) and Three levels (10%, 20%, 30%) of laterite replacement with sand as fine aggregate with common water-to-binder ratios, exposed to sulphate solution for a period of 28 and 90 days. This study is of significant practical interest and can be helpful in the selection of FA and laterite based concrete for structures subjected to sulphate environments characterized by the presence of Magnesium (i.e. magnesium sulphate) as exists in many parts of the world.

2. Materials and Methods

2.1 Materials:

2.1.1 Cement: Ordinary Portland cement brand manufactured by Burham plc was used in the experiment. Generally, care was taken in both material procurement and experimental procedure to ensure test reliability.

2.1.2 Fly Ash (FA): The Fly Ash used was obtained as an ash (fine particles) from the waste dump at Thermal Electric Power Station in Oji River, Enugu State, Nigeria. The physical properties of Fly Ash used are presented in Table 1.

2.1.3 Aggregates: The fine aggregate used in this research is in two categories. (1) River Sand and (2) Laterite. The initial is naturally occurring clean sand obtained at Sarkin pawa in shiroro local government in Niger state, while the later is obtained from Gidan kwano village in Minna. The coarse aggregate was made of machine crushed granite stone obtained from a quary site in Lapai, Lapai Local Government Area, Niger state. The aggregates were supplied to the Department of Building, Federal University of Technology, Minna, Nigeria for experimental purposes. The aggregates were ensured to be free from deleterious substances. Sieve Analyses were conducted on the aggregates in accordance to BS 812, [4]. The results of the analyses are shown in Figure 1, 2 and 3. The properties of the aggregates were presented in Table 1.

Table: 1 Physical Properties of the concrete Constituent.

Parameter	Fly ash	Sand	Laterite	Granite
Bulk Density(kg/m^3)				
Uncompacted	1306	1417	1412	1260
Compacted	1414	1533	2112	1483
% Void	17.12	9.67	8.02	25.22
Specific Gravity	2.20	2.70	2.90	2.70
Moisture Content (%)		10.06	29.00	21.00
Sieve Analysis				
Fineness Modulus		2.32	2.79	
Coefficient of Uniformity		5.90	9.11	4.16
Coefficient of Curvature		1.06	1.22	1.11

2.1.4 Water: Deionized water was used for the concrete mixes, $MgSO_4$ solutions at different concentrations for preparation and curing of sample.

2.1.5 Magnesium Sulphate Media: The magnesium sulphate used was obtained at keteren gwari area of Minna and the properties of the chemicals are presented in Table 2. Magnesium sulphate was used in different concentrations in order to study sulphate attack on reference and test specimens. The media were prepared into three concentrations of 2%, 4% and 8%. The water spiked with magnesium sulphate at different concentrations is to represent groundwater and soils contaminated with sulphate salts or the marine environments.

Table 2: Compositions of magnesium sulphate chemical (MgSO47H2O)

Content	Magnitude
Mol. Wt (g)	246.47
Minimum Assay (ex Mg) %	99
Maximum limits of impurities	
Chloride (Cl) %	0.02
Iron (Fe) %	0.01
Heavy metals as Lead (Pb) %	0.0005
Zinc (Zn) %	0.001
Loss on Drying %	48-52 at $400^0{}_C$

2.2 Methods:

2.2.1 Concrete mix Details

The Laterized concrete (LATCON) mixtures made up of 20% of Fly ash (FA) replacements and four levels of laterite replacement ranging from 0 to 30% samples produced in triplicate (i.e. a total of 108 cubes) were tested. The control mixture was proportioned for a target concrete strength of 25 N/mm^2 for 28 day strength, adopting the British Mix Design (D.O.E) method been the required minimum strength for structural concrete in accordance to BS8110[26]. The laterized concrete cubes produced were of size 100mmx100mmx100mm. The mix had a cementitious material content of 292 kg/m^3, fine aggregate content of 680 kg/m^3, coarse aggregate content of 1158 kg/m^3, and water cementitious materials ratio of 0.55 giving a free water content of 190 kg/m^3.

2.2.2 Concrete Compression Test:

The filling of the mould was in three layers and were manually compacted using 16mm diameter metal rod at minimum strokes of 35. The compacted specimens in mould were maintained at a controlled temperature of 27 ± 2° for 24 hour by keeping the moulds under gunny bags wetted by the deioned water and then demolded. After 28 days curing, the specimens were immersed in four plastic curing tanks. Magnesium sulphate concentrations maintained in the curing tanks were 0, 2, 4 and 8% respectively. These concentrations represent very severe sulphate exposure conditions according to ACI 318-99, that are widely prevalent in many parts of the world (Al-Amoudi et al., 1992, 1994).

The concentration of the solution was checked periodically and the solution was changed every 14 days. Compression test was carried out on the concrete cube specimens in accordance to EN197-1 specifications using the compressive testing machine of 2000KN capacity and at constant rate of 15KN/s load application.

The effect of magnesium sulphate concentrations on the performance of reference and test specimens was evaluated by measuring the reduction in compressive strength. The reduction in compressive strength of reference and test specimens immersed in magnesium sulphate solutions were compared with that of reference specimens cured in deionised water.

3. Results and Discussion

3.1. Preliminary and *Fresh properties of FA/OPC based Laterized concrete mixtures.*

Table 6 presents the result of the chemical analysis of Fly ash and this shows that the total content of Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3) was 71.75% which is slightly above the minimum of 70% specified in ASTM C 618, which made it fit as a good pozzolan. Fly ash (FA) has cementitious compounds like calcium oxide, alumina and iron oxide (total about 15%). The amount of oxides of sodium and potassium known as ‘alkalis’ in FA is found to be 0.35% which is within the range (0.2-1.3) given by Neville (2006) and 0.6% maximum specified in ASTM C150 for OPC and also a maximum of 1.5% specified in ASTM C-618 for Fly ash in Cement and concrete. Higher alkali presence in the Fly ash may have deleterious effects leading to disintegration of concrete due to reaction with some aggregate and affect the rate of gain in strength of cement. Table 1 however shows the specific gravity of the FA sample as 2.20, a value less than that of cement (3.12) as provided by Neville (2006).

Table 3: Chemical composition of FA and Laterite (% by mass)

Chemical composition	**Fe_2O_3**	**SiO_2**	**Al_2O_3**	**CaO**	**MgO**	**TiO_2**	**LOI**	***$Sio_2+Al_2O_3+Fe_2O_3$***	***Sesquioxide $SiO_2/Al_2O_3+Fe_2O_3$***
Fly Ash	6.57	60.20	4.98	4.24	5.14	-	0.2	71.75	-
Laterite	33.50	29.10	20.30	-0.65	-0.64	1.3	-	-	0.54

3.2. Deterioration of concrete exposed to mixed sulphate environment based on weight loss

The weight loss of various concrete specimens exposed to sulphate solution with immersion period of 28 and 90 days are presented in Table 4. Results exhibited initially a marginally negative weight loss/gain in weight which is more pronounced in OPC (0%FA/0%Lat) concrete mixtures. This phenomenon is attributable to the filling up of pores by the expansive reaction products, thereby densifying the hardened mortar mix and increasing the weight and strength (Montemor, et al, 2000). Subsequently, the disruption of the hydrated cementitious matrix by these expansive reaction products resulted in a decrease in the weight of specimens, thus increasing the weight loss with immersion period. The overall weight loss is higher in FA/OPC blended laterized concrete compared with control concrete.

Table 4: Average Weight (Kg) of Blended FA/OPC laterized concrete specimens at 28 and 90 days hydration in 2%, 4% and 8% $MgSO_4$ curing media.

Sulphate Conc.	**28Days**	**28Days**	**28Days**	**28Days**	**28Days**	**90 Days**	**90 Days**	**90 Days**	**90 Days**
Mix Prop.	0%FA/ 0%lat	20%FA/ 0%lat	20%FA/ 10%lat	20%FA/ 20%lat	20%FA/ 30%lat.	20%FA /0%lat	20%FA/ 10%lat	20%FA/ 20%lat	20%FA/ 30%lat
					Weight of cubes (Kg)				
0%	2.32	2.66	2.74	2.81	2.95	2.46	2.76	2.99	3.18
2%	2.49	2.58	2.63	2.54	2.33	2.61	2.53	2.63	2.54
4%	2.41	2.50	2.45	2.51	2.44	2.57	2.52	2.47	2.28
8%	2.32	2.57	2.61	2.55	2.33	2.65	2.62	2.54	2.39

3.3. Strength and durability characteristics of concrete mixtures

Effect on strength of OPC concrete

Average compressive strength of cubes prepared with different concentrations of $MgSO_4$ is compared with that of similar specimens prepared with deionised water. If the difference in the strength is less than 10%, it is considered to be insignificant and if it is greater than 10% it is considered to be significant. This 10% is taken as reference for the discussion.

The effect of $MgSO_4$ concentration on the compressive strength and tensile strength of concrete of ordinary Portland cement concrete is presented in Table 5. Decrease in compressive strength of ordinary Portland cement concrete specimens prepared with $MgSO_4$ solution is observed as the magnesium sulphate concentration increases, the maximum concentration being 8%. There is significant decrease in the compressive strength of all the concrete cubes of at 28 and 90 days curing except 20%FA0%Lat. at concentration of 0% (See Table 5 and 6). For all the $MgSO_4$ concentration, the decrease in compressive strength is more than 10% for all the concrete mix type at 28 and 90 days curing when compared with the cubes prepared with the deionised water at 0%FA/0%Lat. (control sample). See Table 6.

Table 5: Average compressive strength (N/mm$_2$) of Blended FA/OPC laterized concrete specimens at 28 and 90 days hydration in 2%, 4% and 8% $MgSO_4$ curing media.

Sulphate Conc.	**28Days**	**28Days**	**28Days**	**28Days**	**28Days**	**90 Days**	**90 Days**	**90 Days**	**90 Days**
Mix Prop.	0%FA/ 0%lat	20%FA/ 0%lat	20%FA/ 10%lat	20%FA/ 20%lat	20%FA/ 30%lat.	20%FA /0%lat	20%FA/ 10%lat	20%FA/ 20%lat	20%FA/ 30%lat
Compressive Strength (N/mm^2)									
0%	35.09	21.94	21.91	19.88	15.02	35.38	26.72	29.22	19.65
2%	31.20	20.72	19.55	23.13	12.57	30.43	24.25	25.69	15.03
4%	23.94	22.26	16.08	22.12	16.36	27.14	20.19	22.63	15.90
8%	18.89	18.63	21.19	20.11	11.48	24.02	24.13	22.40	13.06

Table 6: Compressive Strength in Percentage of 28 Day Strength.

Sulphate Conc.	**28Days**	**28Days**	**28Days**	**28Days**	**28Days**	**90 Days**	**90 Days**	**90 Days**	**90 Days**
Mix Prop.	0%FA/ 0%lat	20%FA/ 0%lat	20%FA/ 10%lat	20%FA/ 20%lat	20%FA/ 30%lat.	20%FA /0%lat	20%FA/ 10%lat	20%FA/ 20%lat	20%FA/ 30%lat
Compressive Strength in Percentage of 28 Day Strength (%)									
0%	100.00	62.52	62.44	56.65	42.80	100.83	76.15	83.27	56.00
2%	88.91	59.05	55.71	65.92	35.82	86.72	69.11	73.21	42.83
4%	68.22	63.44	45.83	63.04	46.62	77.34	57.54	64.49	45.31
8%	53.83	53.09	60.39	57.31	32.72	68.45	68.77	63.84	37.22

4. Conclusion

The deterioration resistance of FA/OPC blended cement Laterized concretes in magnesium sulphate environment for an immersion period of 28 and 90 days are evaluated through physico-chemical deterioration of concrete. The influence of FA/OPC blended cements, Laterite/sand replacement and water-to-binder ratio on sulphate resistance is also studied. The following conclusions are drawn from the study:

1. FA/OPC blended cement concrete mixtures exhibited stage of deterioration (poor performance) when compared to plain cement (OPC) concrete (control) mixtures after 28 and 90 days of immersion in mixed sulphate environment at varying concentration. This can be

attributed to the consumption of portlandite by the pozzolanic reaction in FA/OPC blended cements that causes Mg^{2+} cations to react directly with C–S–H gel converting it to cohensionless, porous, reticulated M–S–H gel.

2. Use of OPC cements reduced the deterioration of FA based concrete specimens compared with those of FA/OPC . However, FA/OPC based blended Laterized concrete specimens exhibited weight loss which was more than the 2.5% failure criterion.

3. FA/OPC based blended Laterized concrete mixtures showed inferior performance compared with OPC plain cements Laterized concrete in term of strength and weight loss.

The results presented in this study will provide assistance to the readers in understanding the performance of FA/OPC based blended Laterized concretes in sulfate environment.

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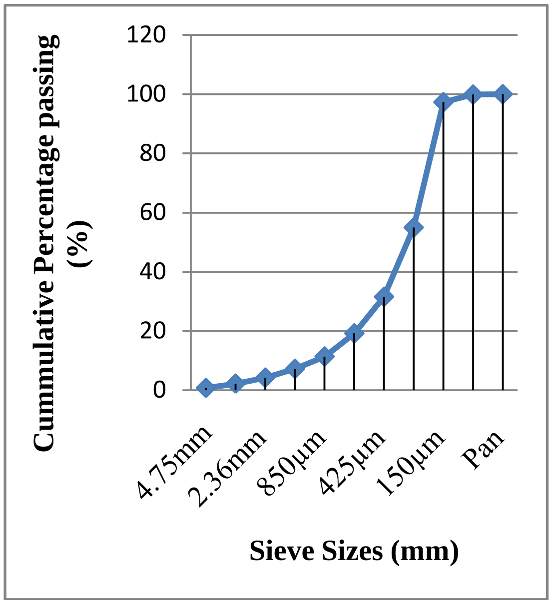

Figure 1: Particle size distribution curve for sand.

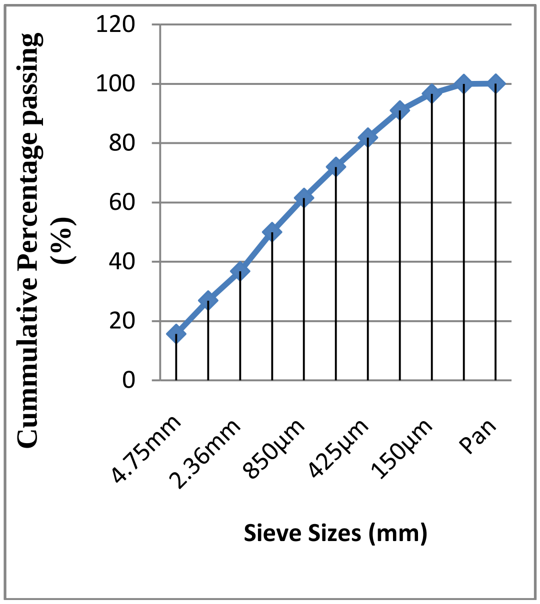

Figure 2: Particle size distribution curve for Laterite

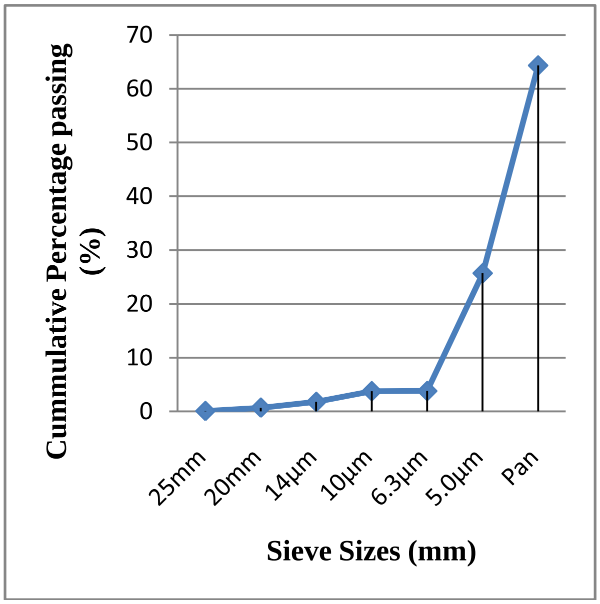

Figure 3: Particle size distribution curve for Coarse Aggregate

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