© APR 2023 | IRE Journals | Volume 6 Issue 10 | ISSN: 2456-8880

Durability of UHPFRC Using Nanosilica as Partial Replacement for Cement in a Magnesium Sulphate Prone Environment

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Abstract- This study focused on durability behaviour of hardened state properties of Ultra High-Performance concrete reinforced with alkaline glass fibers at varying percentages (0.5, 1.0, 1.5 %). Increasing strength, reducing cost and shrinkages resulting from cement volume, can be achieved with the partial replacement of cement with a cementitious material called Nano-silica. In order to reduce void, the Particle Packing Method of mix design was adopted for the design of specimens. The durability of the hardened state concrete after curing in percentages of MgSO4, compressive strength tests were carried out on the specimens to ascertain concrete exposure to sulphate attack. Magnesium sulphate attack showed insignificant loss of compressive strength at 4%, 8% and 12% concentration for 56 and 90 days in the Ultra-High Performance Fiber Reinforced Concrete. Results shows that the possibility to produce Ultra-High Performance Fiber Reinforced concrete using locally available materials if they are carefully selected to achieve a minimum compressive strength of 150Mpa at the age of 28 days. Concrete durability decreases as the concentration of magnesium sulphate increases over a prolonged period of time

Indexed Terms- UHPFRC, Nano-silica, Compressive Strength and Durability

I. INTRODUCTION

In developing societies, infrastructural development is essential to the measure of growth of the economy. Particularly, those infrastructural elements made with reinforced concrete, have undergone serious degradation due to extreme environmental conditions and its associated factors. A major challenge facing civil engineers is the development of durable and sustainable infrastructures to replace the fast-deteriorating methods and adopting a cost-effective repair of the existing concrete structures. Strict adherence to formulated strategies on implementation of newly developed methods and cost-effective remedial procedures are needed to prolong the design life of the Reinforced Concrete Structures (Emmons 1993, Emmons and Vaysburd 1994, Green et al. 2000). Unexpected deterioration of concrete structures is a major concern to both Civil Engineers and the developing society because it amounts to unsafe conditions of reinforced concrete structures and increased remedial cost. To reduce the time and cost of remedy while retaining the use of the structures, the problem must be reduced to the bearable level. (Denarié 2005)

With the focus on cost effectiveness and sustainability of concrete structures, researchers developed a concrete commonly called Ultra High-Performance Concrete (UHPC). UHPC is a cement-based composite which shows improved mechanical and durable properties exhibiting a high compressive strength of not less than 150 MPa Although, UHPC has several advantages over normal strength concrete (NSC) and high strength concrete (HSC) and commercially available, but its application is restricted due to the limited design codes. The influence of the curing type also plays a vital role in the overall performance of UHPC. (Sido dikromo et al. 2019).

The use of UHPC to remedy existing old concrete structures is increasing because the material can be replaced with ease on-site. In general, UHPC has extremely low porosity which results to an extremely low permeability and high durability, making it potentially suitable for rehabilitation and retrofitting reinforced concrete structures or for use as a new construction material (Alaee & Karihaloo2003, Farhat et al. 2007, Farhat et al. 2010).

1.2 AIM and OBJECTIVES

i. Propose a mix design for the production of UHPFRC at the selected water/cement ratio within the range of 150MPa and above.
ii. Study the effects of Nano-silica on the compressive strength of UHPFRC at varying water/cement ratios of 0.2 and 0.22.
iii. Investigate the influence of glass fiber in the comprehensive strength of UHPFRC.
iv. Evaluate the durability properties such as mass lost and deterioration of UHPFRC specimen at different concentration of magnesium sulphate.

II. LITERATURE REVIEW

In this literature review, the historical development of UHPFRC up to date, the mix compositions, principles and production methods are discussed. Also, the improved mechanical and durability properties and how they depend on the mix composition as well as curing are presented. Large scale application from structural to architectural designs around the world are highlighted. The advantage and limitation of using UHPFRC are also included.

Sobolev and Gutiérrez (2005) in their study of the nanotechnology revealed that the next industrial revolution will be nanotechnology. Nanotechnology which was first introduced in the famous lecture of Nobel Laureate Richard P. Feynman, "There's Plenty of Room at the Bottom," given in 1959 at the California Institute of Technology, deals with the production and application of physical, chemical and biological systems at scales ranging from a few nanometers to submicron dimensions. It also involves the investigation of matter to individual atoms integration of the resulting nanostructures into larger systems, was Nanotechnology.

FarhadAslani (2015) reviewed the development of nanotechnology as delivery materials with new properties which can be incorporated as nanoparticles (NPs) in concrete technology in order to enhance properties and produce concrete with improved performance. The advantages of incorporation of NPs in SCC mixes decreases flowability, improve the consistency of SCC mixes, less bleeding and segregation were observed in SCC mixes containing NPs. The inclusion of NPs increased the V-funnel times of SCC mixes, SCC mixes with NPs have higher air content than SCC mixes without NPs. In SCC mixes with fly ash or GGBFS filler, the compressive, split tensile and flexural strengths increased with the addition of silicon dioxide, titanium dioxide, zinc peroxide or copper oxide NPs up to 4.0 weight% replacements but later decreased. However, adding 5.0 weight% NPs still produced specimens with much higher strengths than SCC mixes without NPs. The study of durability and sustainability of concrete is of essence for the construction industry. Mainly, self-compacting concrete (SCC) has gained increasing importance in recent years because of the advantages it offers. SCC is a concrete that can be placed and compacted under its own weight with little or no vibration and without segregation or bleeding. It is used to facilitate and ensure proper filling and thus good structural performance of restricted areas and heavily reinforced structural members.

Anandaraj et al (2019) investigated the structural distress in glass-reinforced foamed concrete made with marble and granite dusts under various loading and aggressive environment conditions. Marble and granite dust were used as partial substitute for fine aggregate at varying percentages. Mechanical and durability tests were carried out on the concrete mixtures. The workability of concrete made with either marble or granite were observed to be similar. The workability of the concrete was reduced through reduction in slump of concrete when glass fibers are added.

The strengths of the concrete were improved with 20% of marble of granite dust as fine aggregate. Addition of 1% of glass fiber produced higher strength. Also, the strength performance of the concrete modified with marble or granite dust and glass fiber were observed to be better under aggressive condition.

Attia et al (2019) examined the flexural behavior of concrete slabs reinforced with basalt fiber and glass fiber through experimental and analytical approach. under four-point loading configuration, twelve one-way concrete slab strips were prepared and tested to failure. Four volume fractions of fibers were used (0, 0.5, 1.0 and 2.0%).

The following observations were made from the study;

i. The mechanical properties of the concrete reinforced with basalt fiber were enhanced. At 2.0% volume fraction of macro basalt fiber, the compressive strength and modulus of rupture of the concrete slabs observed to have increased by 10 and 37% respectively. Also, there were gains in cracking loads of concrete slabs reinforced with the fibers. The gains were in range of 46 to 93% depending on the reinforcement ratio.
ii. The mode of failure of the concrete slabs were not altered by the incorporation of the fibers. The concrete was observed to have failed without degradation of the fibers. Concrete with high volume of fibers were subjected to more ductile failure than plain concretes.
iii. The post-cracking stiffness and flexural strength of the concrete slab strips were slightly improved or had no improvement on 0.5% addition of basalt macro fiber. When the content was improved to 2.0% about 41% and 33% gain in flexural strength of basalt fiber reinforced slab strips and glass fiber reinforced slab strips respectively were achieved.

Kazmi et al (2019) examined the axial stress-strain behaviour of macro-synthetic fiber reinforced recycled aggregate concrete. The concretes prepared were tested under axial compression. Three different replacement ratios (0, 50% and 100%) of recycled aggregate were used with three dosage of macro-polypropylene fibers (0,0.5 and 1.0%) of volume of recycled aggregate concrete.

From the study:

i. On increasing content of fiber, the peak stress, ductility and energy dissipation of normal aggregate concrete and recycled aggregate concrete were improved. Also, increasing the dosage of macro-polypropylene fibers reduced the adverse effect of increasing the replacement ratio of recycled aggregate.
ii. The peak strain of unreinforced concrete containing 0% recycled aggregate were observed to be larger than the unreinforced concrete with 50% and 100% recycled aggregate.
iii. The recycled aggregate reduced the elastic modulus of concrete not reinforced with the fiber. Also, all the reinforced concrete showed further reduction in elastic modulus of concrete

III. MATERIALS AND METHODS

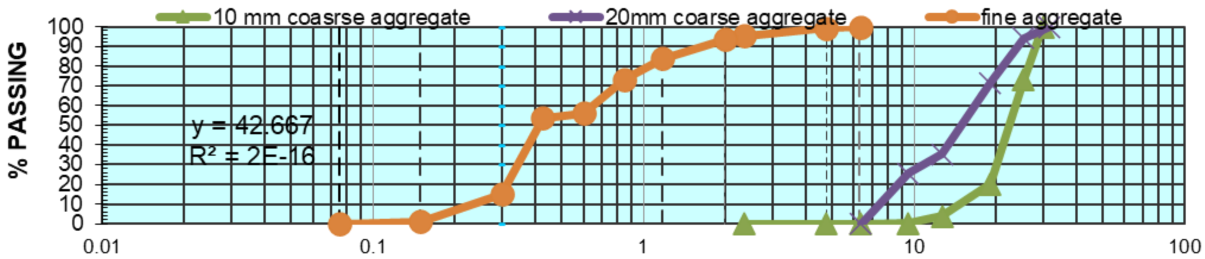
3.1 Materials

The following materials were used in carrying out this research.

i. Cement: Portland Limestone Cement grade 42.5R produced by Dangote Group of Company PLC conforming to NIS 444- 1:2003, obtained from Mile 3 Market Diobu Port-Harcourt.
ii. Crushed granite stones of maximum size 20mm from quarry in Akamkpa, Cross Rivers State obtained from the Mile 3 MarketDiobu dump were used as the coarse aggregate.
iii. Fine aggregate (River Sand) conforming to EN 12620 was used and was obtained from the river bed in Choba, Obio/Akpor Local Government Area of Rivers State.
iv. Water used for this study was obtained from the RSU water mains obtained in the Civil Engineering Laboratory.
v. Nano-silica used for this study was obtained from Lagos State
vi. Alkali resistant glass fiber in compliance with EN 15422 was used.
vii. Super plasticizer used was Fosroc Auracast 200 obtained at Aba, Abia State.
viii. Magnesium sulphate was obtained at mile 3 market.

PARTICLE SIZE DISTRIBUTION (PSD)

The results of the sieve analysis test carried out on the aggregates are presented in Figure 3. 1



CLAY	SILT			SAND			GRAVEL		
	FINE	MED	COARSE	FINE	MED	COARSE	FINE	MED	COARSE

Figure 3.1: Particle Size Distribution

3.2 MIX DESIGN METHOD

3.2.1 PARTICLE PACKING METHOD.

In the Particle Packing Method (PPM) the optimal combination of aggregate is determined experimentally. In this study, the different sized coarse aggregates are selected; their gradation in different size zones from coarser to finer, such as $CA_{1,}$ CA_2 and CA_3 was carried out. The compacted bulk density and specific gravity of aggregates are determined separately for each size category.

The basic concept of the packing density is to minimize the void content. The objective of PPM is to obtain maximum possible packing density which leads to the minimization of voids.

We do have two important steps involved in the PPM design:

(a) Determination of aggregate fractions and packing density

(b) Determination of paste content

In each mixture, the bulk density is determined experimentally and packing density (PD) and void content (CV) are calculated using Eqn (1) and Eqn (2) accordingly to EN1097-3:1998

Packing density $= \frac{BulkDensity x Weight fraction}{Specific Gravity}$ 3.1

Void Content $= 1 - \frac{BulkDensity x Weight fraction}{Specific Gravity}$ 3.2

3.2.2 DETERMINATION of PASTE CONTENT

The total packing density (PD) determined by mixing different sized coarse aggregates and fine aggregate is used to determine the void content (VC) of the mixture using Eqn (3.3)

Void content (VC) $= 1 - PD$ 3.3

3.2.3 AGGREGATE FRACTIONS and PACKING DENSITY

The present study incorporates 20mm, 10mm sized with zone 2 fine aggregate to optimize the combination of aggregates. To achieve maximum packing density, the proportion of aggregates used is 40:60 for fine and coarse aggregates respectively and 70:30 for 10mm and 20mm coarse aggregate respectively, making the final proportion 18:42:40 for fine, 10mm coarse and 20mm coarse aggregates respectively. Various aggregate combinations were examined and the aggregate combination that gives the maximum packing density was selected. Bulk Density

(a) Bulk density of combined coarse aggregate 20mm, 10mm in the proportion 18:40,

Bulk density $= \frac{W_1 - W_2}{Volume of mould}$

Where, W_1 = Empty weight of mould

W_2 = Weight of mould + aggregate filled

(b) Bulk density of three aggregates i.e. 20mm coarse aggregate, 10mm coarse aggregate and fine aggregate calculated are 1744 kg/m^3, 1524 kg/m^3 and 1940 kg/m^3.

The maximum bulk density is selected.

The void content in percentage volume of aggregate of mixture of three aggregate is determined from its bulk density from the following relations.

Void content in percentage volume $= \frac{Specific\ Gravity - Bulk\ Density}{Specific Gravity}$

Packing Density (max) $= \frac{BulkDensity x Weight Fraction}{Specific Gravity}$

Bulk density of 20 mm CA = 1744 kg/m^3

Bulk density of 10 mm CA = 1524 kg/m^3

Bulk density of FA = 1940 kg/m^3

Weight of 20mm Aggregate = $\frac{0.6399}{0.3851}$ x 0.42 x 1000 = 697.89 kg/m^3

Weight of 10mm Aggregate = $\frac{0.6399}{0.3851} x\ 0.18\ x\ 1000$ = 697.89 kg/m^3

Weight of Fine Aggregate = $\frac{0.6399}{0.3851} x\ 0.40\ x\ 1000$ = 664.66 kg/m^3

Weight of 20mm Aggregate = $\frac{0.6449}{0.3851} x\ 0.42\ x\ 1000$ = 708.79 kg/m^3

Weight of 10mm Aggregate = $\frac{0.6449}{0.3851} x\ 0.18\ x\ 1000$= 303.77 kg/m^3

Weight of Fine Aggregate = $\frac{0.6449}{0.3851} x\ 0.40\ x\ 1000$ = 675.05 kg/m^3

Weight of 20mmAggregate= $\frac{0.6399}{0.3851}$ x 0.42 x 1000 = 697.89 kg/m

Weight of 10mm Aggregate =$\frac{0.6399}{0.3851} x\ 0.18\ x\ 1000$ = 697.89 kg/m^3

Weight of Fine Aggregate = $\frac{0.6399}{0.3851} x\ 0.40\ x\ 1000$ = 664.66 kg/m^3

TABLE 3.1: MIX DESIGN PROPORTION

% NS	% GF	20mm CA (kg/m^3)	10mm CA (kg/m^3)	FA (kg/m3)	CEMENT Content (kg/m^3)	NS	GF Content (kg/m^3)
0	0	714.25	306.11	680.21	648.20	0	0
	0.5	708.79	303.77	675.05	648.20	0	12
	1.0	703.35	301.43	669.85	648.20	0	24
	1.5	697.89	299.10	664.66	648.20	0	36
5	0	714.25	306.11	680.24	615.79	32.41	0
	0.5	708.79	303.77	675.05	615.79	32.41	12
	1.0	703.35	301.43	669.85	615.79	32.41	24
	1.5	697.89	299.10	664.66	615.79	32.41	36
10	0	714.25	306.11	680.24	583.38	64.82	0
	0.5	708.79	303.77	675.05	583.38	64.82	12
	1.0	703.35	301.43	669.85	583.38	64.82	24
	1.5	697.89	299.10	664.66	583.38	64.82	36
15	0	714.25	306.11	680.24	550.97	97.23	0
	0.5	708.79	303.77	675.05	550.97	97.23	12
	1.0	703.35	301.43	669.85	550.97	97.23	24
	1.5	697.89	299.10	664.66	550.97	97.23	36
	1.0	703.35	301.43	669.85	615.79	32.41	24
	1.5	697.89	299.10	664.66	615.79	32.41	36

3.3 DURABILITY

Haseeb Jamal (2017) states that durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired Engineering properties.

3.3.1 SULPHATE ATTACK

It will interest you to know that the expansion or mass loss of concrete strength is because of the pressure arising from the growth of trisulfoaluminate crystals that are formed by the interaction of the sulphate ions that diffused into the concrete structure and calcium aluminate hydrate in the hydrated cement paste.

3.3.2 REDUCTION OF SULPHATE ATTACK

One of the most effective ways to protect concrete from the damaging effects of sulphate attacks is to reduce permeability of concrete by using various mineral additives to reduce the amount of calcium hydroxide formed during the hydration of cement.

3.3.3 NANO-PARTICLE EFFECT ON SULPHATE ATTACK

Nano-silica (NS) is an effective mineral admixture for reducing the negative effects of sulphate attacks. it expedites the nucleation process that occurs during early age hydration reactions of cement. NS creates exceptionally large reactive surfaces, enabling the formation of many nucleation points. Reactivity potential of nano-particles with the components of cement paste is very high.

3.3.4 DURABILITY TEST PROCEDURE:

1. Weigh the sample before submerging or soaking in Magnesium Sulphate (MgSO4) solution
2. After 56 and 90 days respectively of curing, remove the samples from MgSO4 solution.
3. Oven or Air dry the cube sample to dry off the moisture retained in the sample pores
4. Weigh the dried sample to obtain your value.

3.3.5 ACID RESISTANCE

PHYSICAL DETERIORATION

Mass Losses or Mass Deterioration Factor MDF

$$\text{MDF} = \frac{M_1 - M_2}{M_1} \times 100\%$$

Compressive strength losses or Strength Deterioration Factor

$$\text{SDF} = \frac{f_{cu28} - f_{cu}}{f_{cu28}} \times 100\%$$

where: MI = Mass of Specimen before immersion

M2 = Mass of Specimen after immersion in days

Fcu28 = average compressive strength of cured concrete cubes at first 28days

fcu = average compressive strength of concrete cubes immersed in the acid solutions.

Magnesium sulphate attack for 56 days

The percentage magnesium sulphate attack used in curing the concrete the deterioration is measure in 4%, 8% and 12% for 56.

Mass Deterioration for 56 days

$$\text{MDF} = \frac{2.6 - 2.54}{2.6} \times 100\% = 2.31\%$$

$$\text{MDF} = \frac{2.55 - 2.48}{2.55} \times 100\% = 2.75\%$$

$$\text{MDF} = \frac{2.55 - 2.40}{2.55} \times 100\% = 5.88\%$$

Strength Deterioration for 56 days

$$\text{SDF} = \frac{152.3 - 147.7}{152.3} \times 100\% = 2.6\%$$

$$\text{SDF} = \frac{152.3 - 145.3}{152.3} \times 100\% = 4.6\%$$

$$\text{SDF} = \frac{152.3 - 142.2}{152.3} \times 100\% = 6.6\%$$

Magnesium sulphate attack for 90 days

The percentage magnesium sulphate attack used in curing the concrete the deterioration is measure in 4%, 8% and 12% for 90 days.

Mass Deterioration for 90 days

$$\text{MDF} = \frac{2.6 - 2.535}{2.6} \times 100\% = 2.5\%$$

$$\text{MDF} = \frac{2.55 - 2.488}{2.55} \times 100\% = 2.43\%$$

$$\text{MDF} = \frac{2.55 - 2.49}{2.55} \times 100\% = 2.34\%$$

Strength Deterioration for 90 days

$$\text{SDF} = \frac{152.3 - 140.2}{152.3} \times 100\% = 7.9\%$$

$$\text{SDF} = \frac{152.3 - 137.3}{152.3} \times 100\% = 9.8\%$$

$$\text{SDF} = \frac{152.3 - 131.2}{152.3} \times 100\% = 13.8\%$$

Resistance of UHPFRC concrete to attack by varying magnesium sulphate acid concentrations (4%, 8% and 12%) showed:

Reduced physical deterioration of UHPFRC

The compressive strength reduced slightly as the period of immersion increased

The compressive strength generally reduced as the acid concentration increased.

The Strength Deterioration Factor (SDF) increased with increasing acid concentration

IV. RESULTS AND DISCUSSIONS

In this chapter, the results obtained from the experimental investigations are presented and discussed in details. The results from physical, fresh and hardened state of the concrete are presented in tables and plots.

The results of the particle size distribution test for fine aggregate, 10mm coarse aggregate and 20mm coarse aggregate and graphical analysis is presented in Figure 3.1.

4.1 DENSITY OF CONCRETE

Table 4.1 Density of Concrete Samples

REPLACEMENT WITH NS-INCLUSION OF GF DENSITY (kg/m^3)				
%	%	7 Days	14 Days	28 Days
0	0.0	2368.14	2316.71	2323.17
	0.5	2205.23	2170.82	2172.39
	1.0	2070.72	2046.43	2050.43
	1.5	1960.12	1950.99	1950.54
5	0.0	2305.09	2250.25	2258.62
	0.5	2161.14	2118.46	2100.52
	1.0	2031.73	1986.23	1958.43
	1.5	1891.54	1836.73	1850.93
10	0.0	2254.83	2205.53	2205.63
	0.5	2111.72	2005.73	2048.63
	1.0	1967.24	1856.37	1894.32
	1.5	1850.25	1725.64	1815.26
15	0.0	2150.25	2111.45	2102.35
	0.5	2004.53	1947.84	1950.73
	1.0	1900.45	1810.29	1826.62
	15	1772.94	1648.19	1729.59

The maximum density value from Table 4.1 above is observed for concrete without Nanosilica and glass fiber. The inclusion of Nanosilica and glass fiber is observed to reduce the density of the concrete. This is as a result of the reduction of aggregate content for the incorporation of glass fiber and the replacement of cement with Nan silica

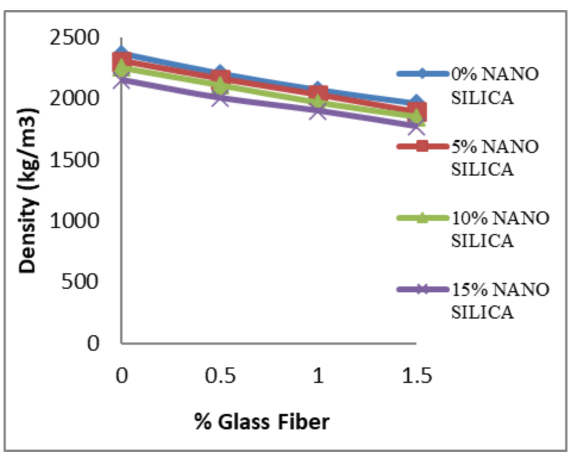


Figure 4.1: DENSITY OF CONCRETE AFTER 7 DAYS CURING

From Figure 4.1 the density of the concrete is observed to decrease almost linearly with an average of 0.5 % on increase in glass fiber content for all amount of Nanosilica. It is due to the reduction of aggregate volume for the incorporation of glass fiber that made the density to decrease. At 0 % inclusion of glass fiber without Nanosilica replacement, we had a density of 2368.14kg/m^3 and at 1.5 % inclusion of fiber without nanosilica replacement, the density reduced to 1960.12kg/m^3. At 0 % inclusion of glass fiber with 5 % nanosilica replacement, we had a density of 2305.09kg/m^3 and at 1.5 % inclusion of glass fiber, the density reduced to 1960.12kg/m^3. At 0 % inclusion of glass fiber with 10 % nanosilica replacement, we had a density of 2254.83kg/m^3 and at 1.5 % inclusion of glass fiber, the density reduced to 1850.25kg/m^3. At 0 % inclusion of glass fiber with 15 % nano-silica replacement, we had a density of 2150.25kg/m^3 and at 1.5 % inclusion of glass fiber, the density dropped to 1772.94kg/m^3.

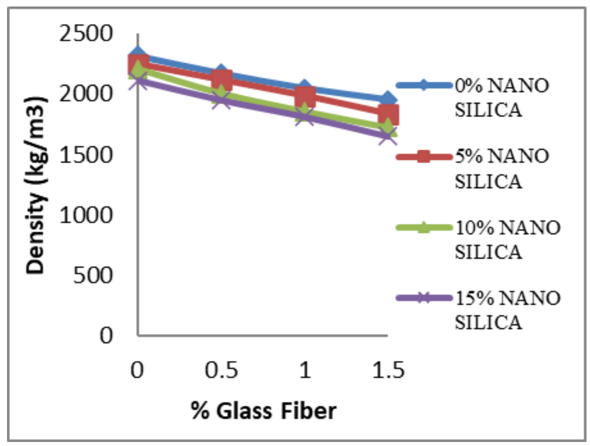


Figure 4.2: DENSITY OF CONCRETE AFTER 14 DAYS CURING

From Figure 4.2 the density of the concrete is observed to decrease almost linearly with an average of 0.5 % on increase in glass fiber content for all amount of Nanosilica. It is due to the reduction of aggregate volume for the incorporation of glass fiber that made the density to decrease. At 0 % inclusion of glass fiber without nano-silica replacement, we had a density of 2316.71kg/m^3 and at 1.5 % inclusion of fiber without nanosilica replacement, the density reduced to 1950.99kg/m^3. At 0 % inclusion of glass fiber with 5 % nanosilica replacement, we had a density of 2118.46kg/m^3 and at 1.5 % inclusion of glass fiber, the density reduced to 1836.73kg/m^3. At 0 % inclusion of glass fiber with 10 % nanosilica replacement, we had a density of 2205.53kg/m^3 and at 1.5 % inclusion of glass fiber, the density reduced to 1725.64kg/m^3. At 0 % inclusion of glass fiber with 15 % nanosilica replacement, we had a density of 2111.45kg/m^3 and at 1.5 % inclusion of glass fiber, the density dropped to 1648.19kg/m^3.

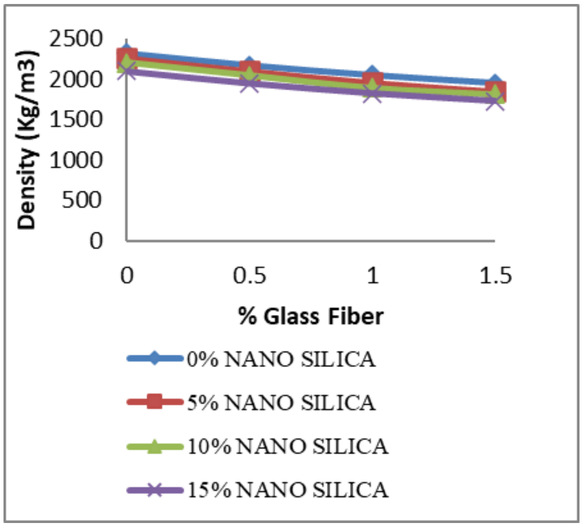


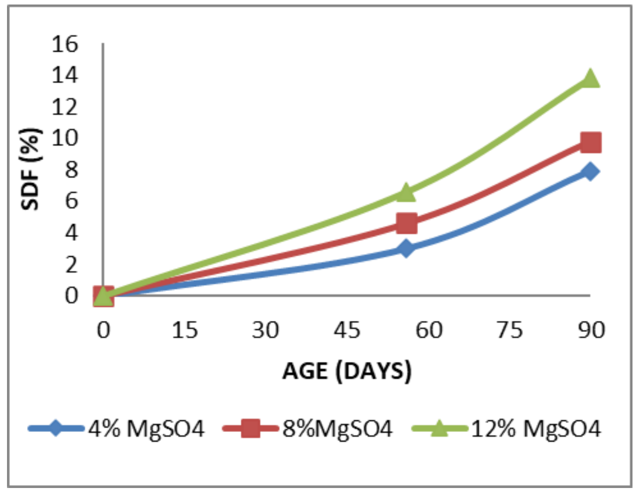
Figure 4.3: DENSITY OF CONCRETE AFTER 28 DAYS CURING

From Figure 4.5 the density of the concrete is observed to decrease almost linearly with an average of 0.5 % on increase in glass fiber content for all amount of Nano-silica. It is due to the reduction of aggregate volume for the incorporation of glass fiber that made the density to decrease. At 0 % inclusion of glass fiber without nano-silica replacement, we had a density of 2323.17kg/m^3 and at 1.5 % inclusion of fiber without nano-silica replacement, the density reduced to 1950.54kg/m^3. At 0 % inclusion of glass fiber with 5 % nano-silica replacement, we had a density of 2258.62kg/m^3 and at 1.5 % inclusion of glass fiber, the density reduced to 11850.93kg/m^3. At 0 % inclusion of glass fiber with 10 % nano-silica replacement, we had a density of 2205.63kg/m^3 and at 1.5 % inclusion of glass fiber, the density reduced to 1815.26kg/m^3. At 0 % inclusion of glass fiber with 15 % nano-silica replacement, we had a density of 2102.35kg/m^3 and at 1.5 % inclusion of glass fiber, the density dropped to 1729.59kg/m^3.

4.2 DURABILITY

Table 4.2 STRENGTH DETERIORATION FACTOR

ACID CONCENTRATION %	SDF % 56 DAYS	SDF % 90 DAYS
4	3.0	7.9
8	4.6	9.8
12	6.6	13.8



4.4 GRAPH OF STRENGTH DETERIORATION FACTOR

Table 4.2 shows that acid concentration is a factor to reckon with in terms of durability. At 4% acid concentration, the compressive strength loss was insignificant at 56 days but for 90 days, slight strength loss was observed. At 8% acid concentration, compressive strength loss was still negligible compared to 90 days compressive strength loss of 9.8%. Finally at 12% acid concentration, 6.6% compressive strength loss was observed compared to the 13.8% for 90 days. This indicates that, as the acid concentration increases, the concrete compressive strength decreases over a prolonged period of time due to acid attack. The deterioration is as a result of the presence of Sulphate ions which attacks and weakens the Portland limestone cement, thereby leading to weak internal bonds of the concrete matrix, causing compressive strength loss.

The deterioration is as a result of Sulphate ions attack, which weakens the Portland limestone cement, thereby leading to weak internal bonds of the concrete matrix, causing compressive strength loss. Compressive strength loss generally increases with the immersion period due to prolonged acid attack. There are many factors affecting sulphate attack and steps to mitigate it. In general, three approaches are adopted: (a) preventing sulphates from penetrating into concrete; (b) consuming Ca(OH)2 as much as possible in hydrated cement matrix through the use of pozzolana such as; PFA and GGBS; and (c) using cement with low C3A. silica fume (Ganjian and Pouya, 2005).

MASS DETERIORATION FACTOR

ACID CONCENTRATION %	MDF% 56 DAYS	MDF % 90 DAYS
4	2.54	2.50
8	2.48	2.43
12	2.40	2.35

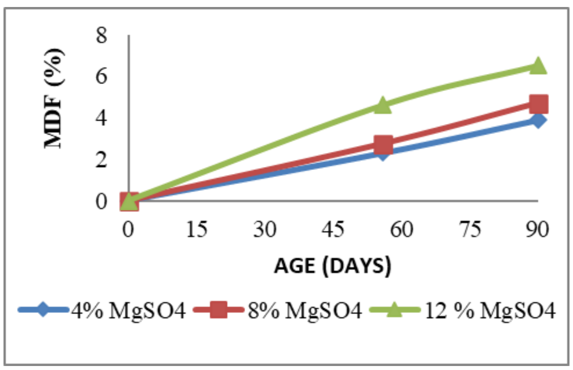


Figure 4.5: GRAPH OF MASS DETERIORATION FACTOR

Mass loss increases with period of immersion due to increased acid attack. At 4% concentration, the mass loss was 2.54% at 56 days and 2.5% for 90 days. At 8% concentration, the mass loss was 2.48 at 56 days and 2.43 at 90 days. At 12% concentration, the mass loss was 2.4% at 56 days and 2.35% for 90 days. This shows that the mass loss is almost negligible compared to the mass of the concrete before immersion.

Resistance of UHPFRC concrete to attack by varying magnesium sulphate acid concentrations (4%, 8% and 12%) showed: Reduced physical deterioration of UHPFRC. The compressive strength reduced as the period of immersion increased. The compressive strength generally reduced as the acid concentration increased. The Strength Deterioration Factor (SDF) increased with increasing acid concentration.

CONCLUSION

This study was aimed production of durable Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC) with the Particle Packing Method (PPM). The aim was achieved by harnessing the cementitious capability of Nano-silica, ductile capability of glass fiber and the exposure to. The salient findings are highlighted as follows;

1. The adopted Particle Parking Method (PPM) of mix design provided an acceptable result for the fresh and hardened state properties of the Ultra High-Performance Fiber-Reinforced concrete. Thus, this mix design method is proposed for the production of Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC) because the compressive strength above 150MPa, was recorded.
2. The replacement of cement with Nano-silica reduced voids in the concrete thereby achieving above the proposed compressive strength in the production of UHPFRC. Therefore, Nanosilica is recommended to be adopted as a replacement for cement in the production of UHPFRC to achieve the proposed strength of concrete.
3. The incorporation of glass fiber increased the ductility of UHPFRC and thereby increased the compressive strength of the concrete.
4. Sulphate ions attack and weakens the concrete. The sulphate ions may either come from the concrete itself, that is, when the sulfate content of the cement is excessively high or from external sources, when the environment in which the concrete is placed is rich in sulfates. In this study, the strength and mass losses were negligible. That is the high tensile strength will resist the concrete cracking.

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