American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-11, pp-93-101
www.ajer.org
Research Paper Open Access

Performance Evaluation of Laterite Rock Concrete in Aggressive Environment

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ABSTRACT: *In this study, the effects of sulfuric acid was investigated on various grades of concrete: M25, M30 and M40, for a period of 90 days exposure to the acid. Each grade comprised of three mixes: laterite rock concrete, superplasticized laterite rock concrete and granite or conventional concrete. The concrete cubes were first cast and cured in water for 28 days before being exposed to 2% concentration of sulphuric acid. The tests were carried out to simulate the deterioration processes of concrete exposed to acidic environment as seen in sewers, foundations, industrial structures etc. The deterioration parameters observed were physical deterioration, mass loss and compressive strength loss. Results showed that the deterioration process increased as the immersion period in acid increased.Physical deterioration as seen from spalling and scaling ranged from mild to severe whereas,mass loss and strength deterioration factors averaging 4.54% and 26.77% were observed respectively for all mixes. Results also show that, the addition of superplasticizers to laterite concrete improved its performance and durability under acid attack, comparative to granite concrete.*
KEYWORDS:*Laterite Rock Concrete, Physical Deterioration, Mass Loss, Strength Deterioration factor, Durability*

Date Of Submission:02-11-2018 Date Of Acceptance: 16-11-2018

I. INTRODUCTION

The use of laterite Rock Concrete (LRC) in Nigeria, India, Malaysia, Brazil and other tropical regions of the earth is necessitated by availability, cost and the unsustainable mining of granite (Kasthurba, Reddy, & Reddy, 2015). Laterite Rock Concrete is concrete produced using laterite, a ubiquitous metamorphic rock in the tropics, as coarse aggregate(Ephraim , Adoga , & Rowland-Lato, 2016). In the quest to meet infrastructural deficit, LRC has been used for decades often as coarse aggregate in the construction of buildings, road sub grades and pavements, drainages etc.This is in tandem with BS 8500-2 (2006) and ACI 318 (2008) which support the use of alternative materials for concrete production provided sufficient information is gathered on them. However, there is paucity of data on the durability performance of LRC under different exposure condition. Particular mention must be made of the Niger Delta region of Nigeria where oil and gas exploration have polluted the environment giving rise to acid rain. (Joorabchian, 2010)reported that the burning of fossil fuel and natural gashas increased the atmospheric sulphur content which can produce sulphuric acid with a pH of 3 by the oxidation of sulphur dioxide. Other scenario where sulphuric acid attack on concrete is prominent include concrete sewers, manholes, junction chambers and so on where sulphuric acid is synthesized by bacteria in a process known as Microbial Induced Corrosion MIC(Joorabchian, 2010). Furthermore, sulphuric acid may be produced in groundwater and soil by the oxidation of iron sulphide minerals in the form of pyrites or marcasite(Richardson, 2002). This can attack concrete foundations which is the case for the Niger Delta region where high ground water is prevalent. To this end, it is imperative to study the possibility of using LRC for these structures where acid attack is prevalent. Furthermore, this study will also provide an insight on the structural health of existing LRC structures under sulphuric acid attack.

It is worthy of note that previous studies on acid resistance of LRC have been limited to concrete involving partial replacement of laterite as coarse aggregate. (Muthusamya,, Kamaruzzamana, Zubir, Hussin, Mohd Sam, & Budiea, 2015)and(Muthusamy, Kamaruzaman, Ismail, & Budiea, 2015)reported that the performance of 20% laterite rock as partial replacement for granite coarse aggregate was comparable to conventional granite concrete when exposed to Magnesium Sulphate and hydrochloric acid respectively. Other durability studies on acid attack had focused on the use of laterite fines as replacement for sand in concrete otherwise known as laterized concrete (Olusola & Joshua, 2012) and (Olusola & Olugbenga, 2014).This study will however focus on the use of laterite aggregate wholly (100%) as coarse aggregate in concrete. An attempt will be made at improving LRC performance using superplasticizer.

II. MATERIALS

Materials used for this study includes Ordinary Limestone Cement (OLC) Grade 42.5 produced by Dangote Cement Company and conforming to NIS 444-1:2003. Sharp river sand from a local supplier was used. Crushed laterite rock obtained from Nnewi, Nigeria and granite obtained from Uturu, Nigeria were also used as coarse aggregate. All aggregates conform to BS EN 12620. Auracast 200, a Polycarboxylate Ether superplasticizer complying with EN 934-2was also used for this work. A dosage of 1litre for every 100kg binder was adopted.Portable water from Rivers State University mains was used in this research.

III. EXPERIMENTAL PROGRAMME

3.0.1 Method

Tests carried out on aggregates in preparation for mixing include: specific gravity test, particle size distribution, water absorption and Los Angeles Abrasion(See Table 1 and Fig. 1).

Three grades of concrete were designed for to achieve a minimum of grade 25 after 28 days. Each grade of concrete had 3 mixes comprising of granite or normal concrete NC as control, laterite rock concrete LRC and laterite rock concrete plus superplasticizer LRC + S. In all, a total of 9 mixes were developed(See Table 2). Thereafter, mixing was done in accordance with BS 5328: 1997 using a 50litre capacity rotary mixer.

Slump test was done in compliance with BS EN 12350-2:2009 to ascertain the workability of the fresh concrete. The concrete was cast in150mm cubes, compacted and allowed to set. After 24 hours, they were demoulded and then cured for a period of 28 days. After which, compressive strength test complying with BS EN 12390-3-2009 was carried out and results recorded.

3.0.2 Acid Resistance Test

Cube specimens were air dried, weighed and compressive strength measured before being immersed in 2% concentration of sulfuric acid (H_2SO_4).This is done in conformity with ASTM C 267- 2001 to measure the acid resistance of laterite rock concrete. The following parameters are then determined after exposure of the concrete to the acid medium:

i. Physical Appearance

ii. Mass Loss

$$\text{Mass Loss Factor MLF} = \frac{M_1 - M_2}{M_1} \qquad 1$$

Where, M_1 = Mass of specimen before immersion in acid

M_2 = Mass of specimen at the end of immersion period

iii. Compressive strength loss

$$\text{Strength Deterioration Factor SDF} = \frac{f_{cu\,28} - f_{cu}}{f_{cu\,28}} \times 100\% \qquad 2$$

Where; fcu_{28} = water cured 28 day compressive strength (N/mm^2)

fcu = compressive strength at end of exposure period in acid (N/mm^2)

RESULTS

Table 1: Physical properties of laterite and granite aggregates

Physical Properties	Laterite	Granite
Specific gravity	2.74	2.60
Water absorption (%)	4.60	0.71
Los Angeles abrasion (%)	24.90	15.40

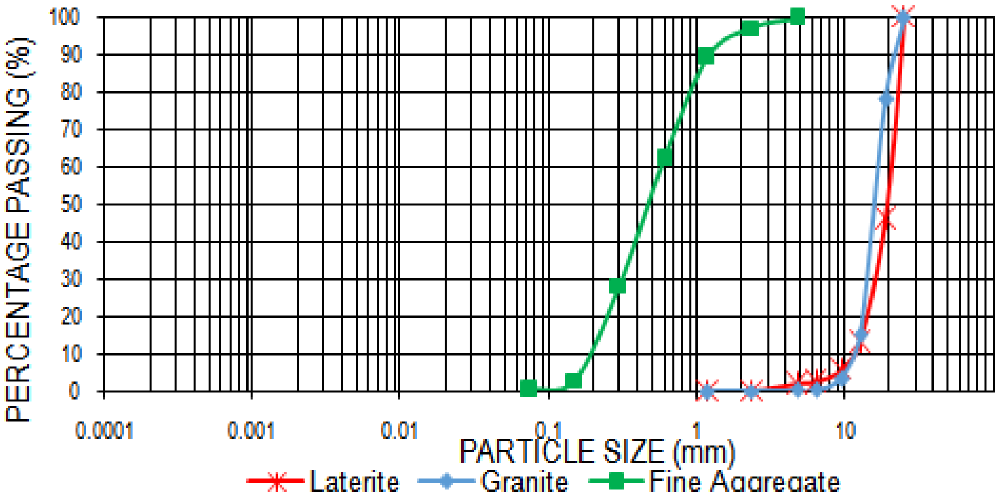

Figure 1 Particle size distribution curve of different aggregate

Table 2: Mix Ratios for Different Concrete Grades for Different Mixes

Grade	Mix Ratio	w/c	Mix
M25	1: 1.8 :2.5	0.5	LRC
			LRC + S
			NC
M30	1: 1.5 : 2.0	0.5	LRC
			LRC + S
			NC
M40	1:1.2 : 1.5	0.45	LRC
			LRC + S
			NC
LRC = Laterite Rock Concrete			
LRC + S = Laterite rock concrete plus superplasticizer			
NC = Normal (granite) concrete			

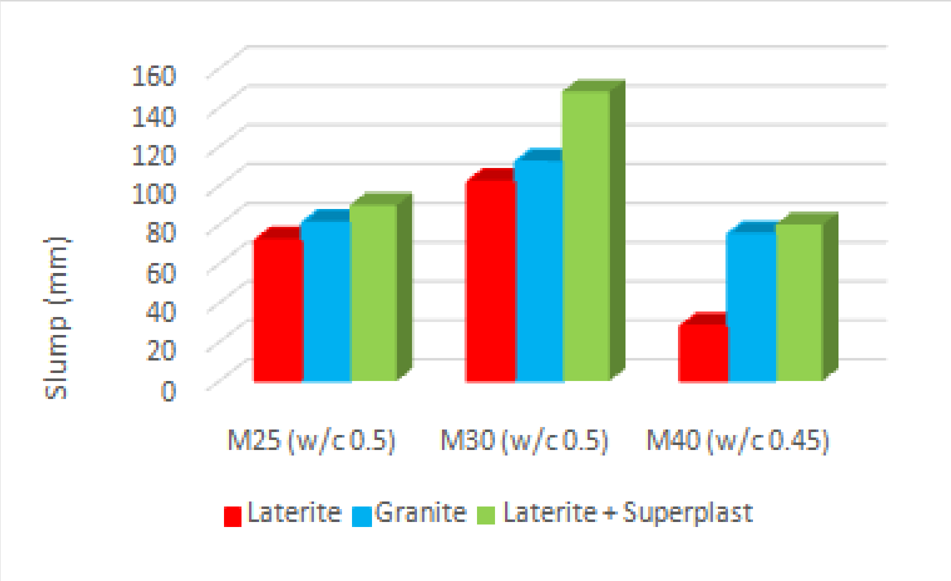

Fig. 2: Slump Test Results for Various Mixes

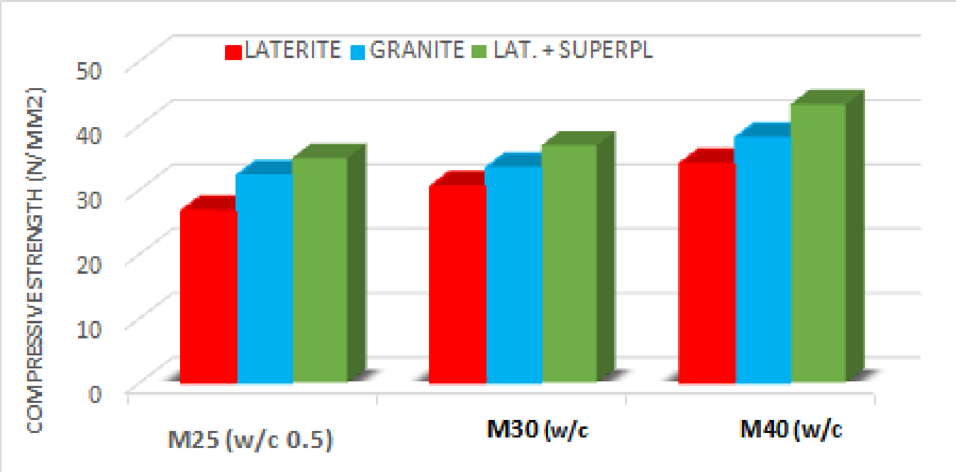

Fig. 3: 28 Day Compressive Strength Result

Fig. 4: Deterioration for M25 concrete at 90 days

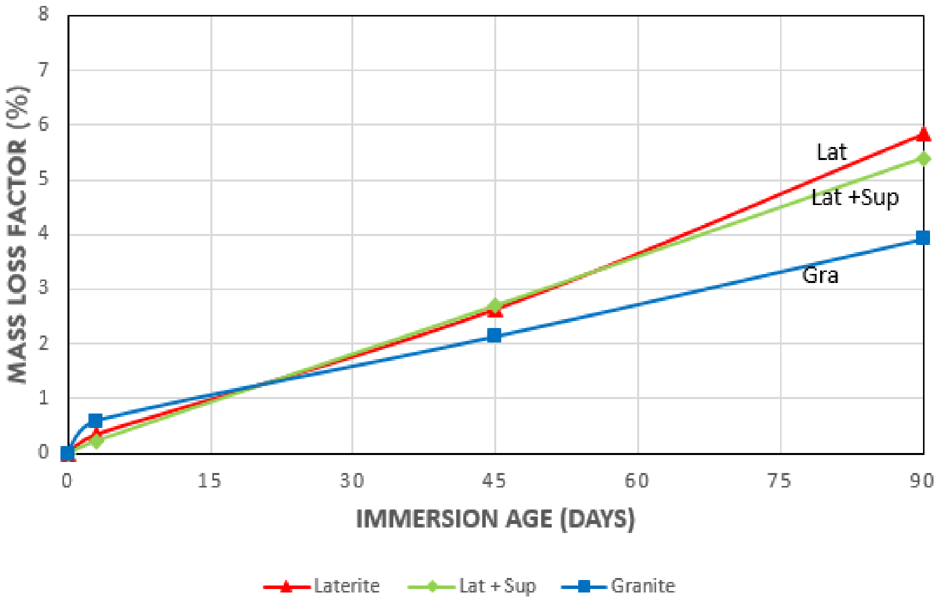

Fig. 5: Mass Loss for M25 Mixes

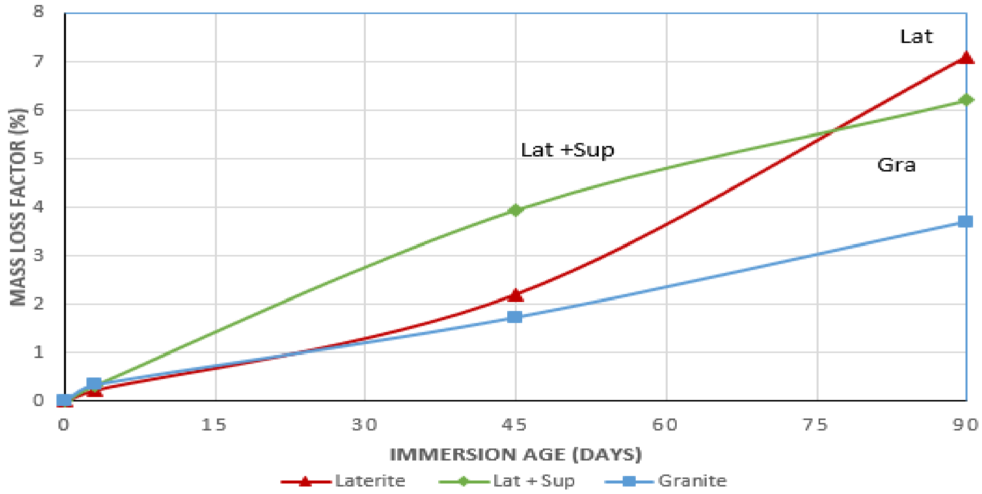

Fig. 6: Mass Loss for M30 mixes

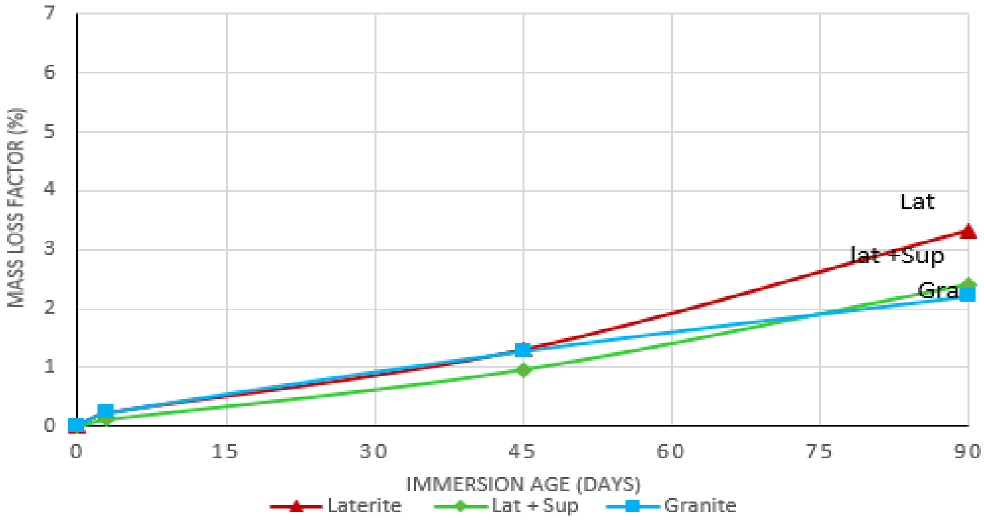

Fig. 7: Mass Loss for M40 mixes

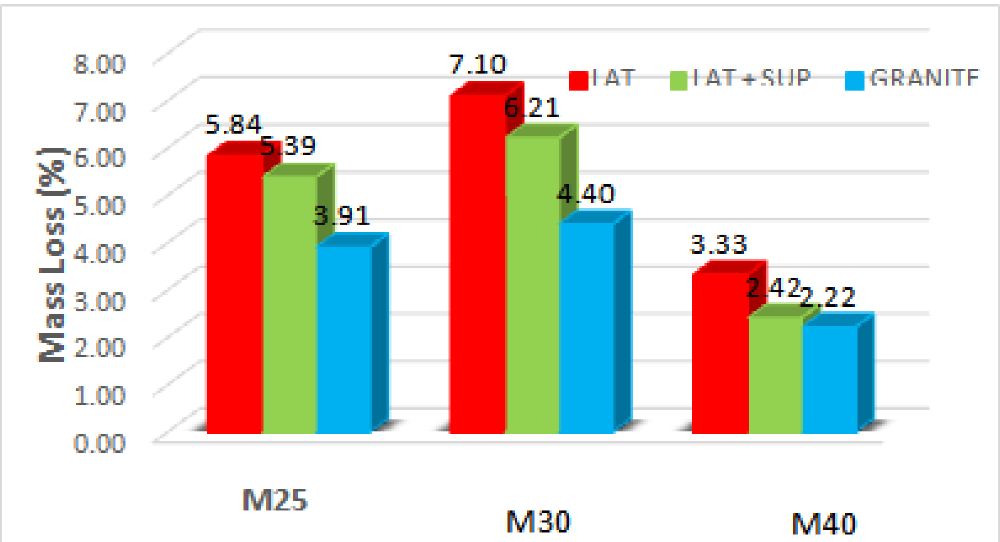

Fig.8: Mass Loss Factor (MLF) for all mixes at 90 Days

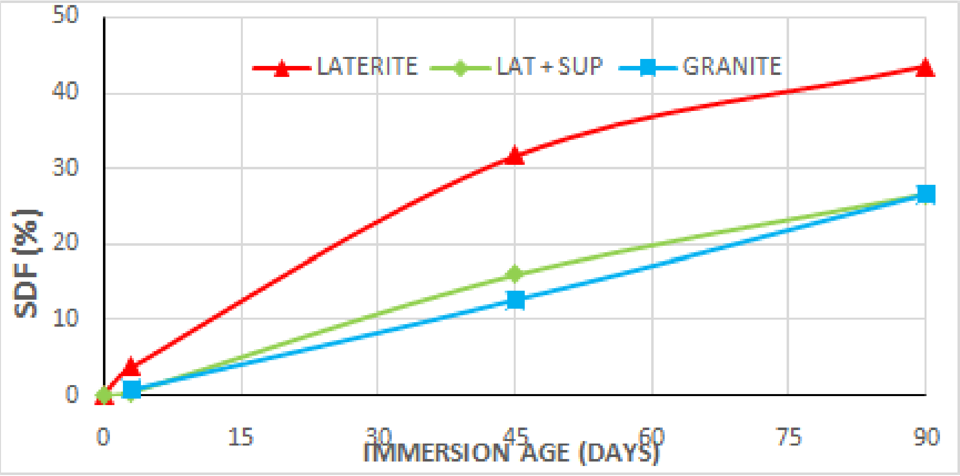

Fig. 9: Strength Deterioration Factor (SDF) for M25 mixes

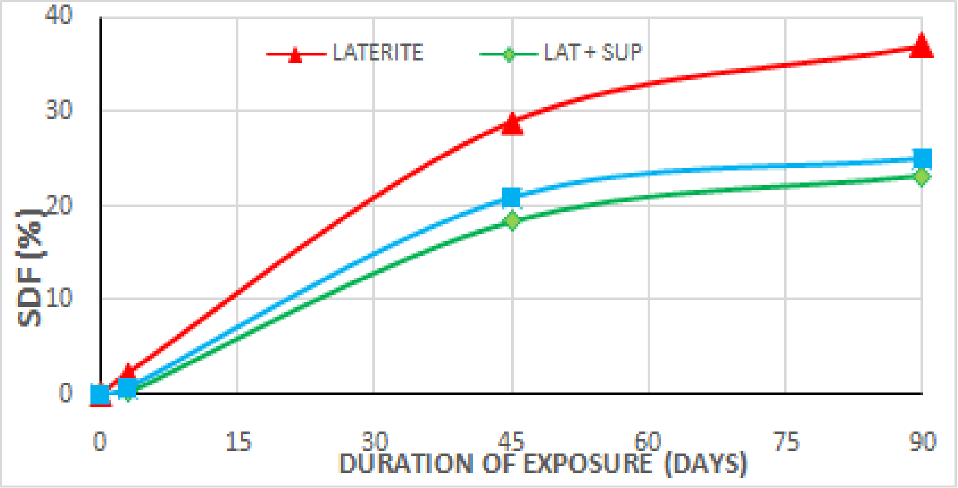

Fig. 10: Strength Deterioration Factor (SDF) for M30 mixes

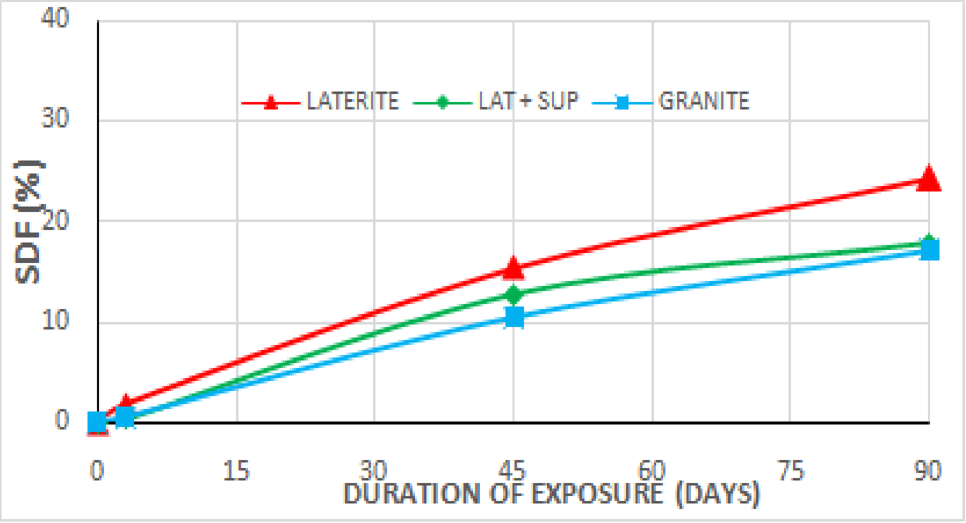

Fig. 11: Strength Deterioration Factor (SDF) for M40 mixes

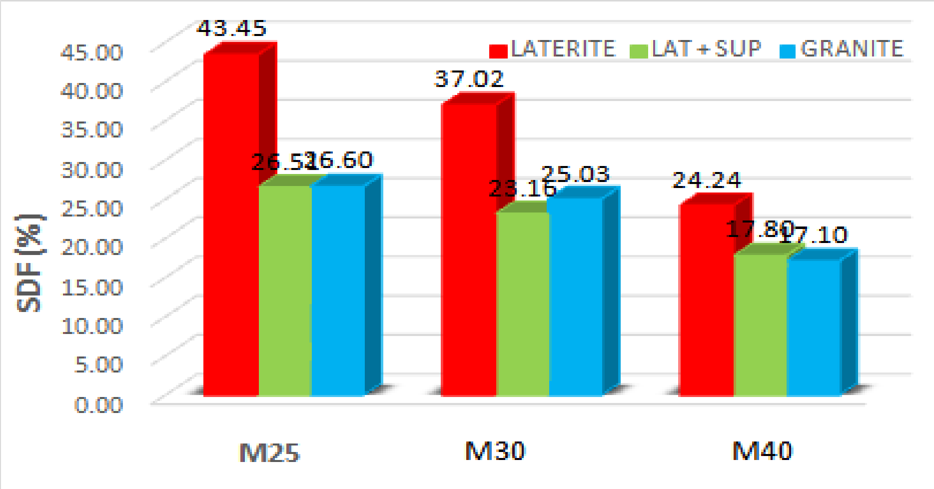

Fig.12: Strength Deterioration Factor (SDF) for all mixes at 90 Days

IV. DISCUSSION

4.1. Workability

Results show that the workability of the laterite concrete was consistently lower than that of the granite concrete for all mixes (Fig. 2). This can generally be attributed to the higher porosity and high water absorption values of the laterite rock aggregate thereby requiring more water for mixing (Muthusamy & Kamaruzaman, 2012). However, the introduction of superplasticizer to the laterite concrete resulted in significant slump increase values for all grades: 25% increase for M25, 45.10% for M30 and 185% for M40. This increase in workability could be attributed to the polarizing effects superplasticizers have on cement particles thereby causing dispersion of the cement particles so that they can readily mix with water and aggregates hence leading to improved workability (Drainsfield, 2003)(Amadi & Amadi-Oparaeli, 2018)(Ramachandran, 1996). It was also observed that slump values dropped significantly for M40 mixes owing to the reduction of w/c to 0.45, this implies that less water is available for mixing especially for the porous laterite aggregate-cum-concrete.

4.2. Compressive Strength

The 28 day compressive strength of LRC was lower in magnitude than that of granite aggregate concrete in all the gradesinvestigated (Fig. 3). The addition of superplasticizer, however resulted in a significant increase of compressive strength for the LRC mixes. An increase of 30.81%, 20.81% and 27.09% was observed between laterite concrete and superplasticized laterite concrete for M25, M30 and M40 respectively. Again, the superplasticizer higher cement dispersion ability may have provided greater interaction between the cement and other concrete constituents, thus more hydration reactions giving rise to higher strength(Drainsfield, 2003)(Amadi & Amadi-Oparaeli, 2018)(Ramachandran, 1996).

It can also be seen that M40 mixes with w/c of 0.45 reported the highest compressive strength.This is a consequence of pore and void reduction occasioned by low w/c, leading to a reduction of evaporable water, thereby giving rise to denser concrete with more hydrated CSH products and aggregates taking up void spaces(Drainsfield, 2003)(Naik, 1997).

4.3. Physical Appearance

Various levels of deterioration were observed, ranging from mild to severe. The degree of deterioration generally increased with increase in duration of immersion in acid. The most severe deterioration was observed for laterite rock concrete M25 specimens with w/c of 0.5 (See Fig. 4). The mixes containing superplasticizer also showed some moderate level of deterioration.The deterioration process occurred in the form of wear on the surfaces and edges of the concrete cubes which, according to (Lorente , Cubaynes , & Auger, 2011), could be as a result of development of more quantum of gypsum and decalcification of calcium silicate hydroxide (CSH) gel in the concrete matrix on exposure to aggressive environment. This leads to softening, loss of cementitious structure and disintegration of specimens.

In addition, some thick brownish gel-like paste was observed on the surface of the cubes. This may be as a result of the chemical reactions that may have occurred between the acid and the Fe^{2+} present in the laterite aggregate. According toAmerican Concrete Institute ACI, Committee 201(1992), this could also be due to the acid reaction with the calcium hydroxide of the hydrated Portland cement and formation of water-soluble calcium compounds, which are subsequently leached away by aqueous solutions.

Conversely, granite (NC) and superplasticized laterite concrete (LRC + SP) cubes with w/c of 0.45 showed a mild level of deterioration as observed by the little wear and change of colouration.This may be attributed to the reduced pores in these specimens, thereby leading to lower permeability and higher resistance to the acid ingress.

4.4. Mass Losses

Mass loss generally increased with increase in immersion period for all mixes (Fig. 5 to Fig. 7). (Muthusamya,, Kamaruzzamana, Zubir, Hussin, Mohd Sam, & Budiea, 2015)reported that with time, the sulphate ionsbegin to attack and weaken theportlandite thereby leading to loss of stability and weakening of the internal bonds in the concrete matrix .This paves the way for more and continuous sulphate penetration causingspalling and loss of weight. The formation of more quantum of gypsum as well as decalcification of CSH gel in the concrete could also contribute to weight loss(Lorente , Cubaynes , & Auger, 2011).

Results also show that mass loss was consistently highest in the laterite rock concrete at all ages of exposure in all the grades investigated (Fig 5 to Fig 8). This may be attributed to the higher porosity of the laterite aggregate(Muthusamy & Kamaruzaman, 2012) in comparison with granite, which when interconnected, can lead to increase in pathways (permeability) for the acid attack on the concrete.

It was observed that the superplasticizer consistently reduced the mass losses for laterite. 90 days result show a reduction of7.68%, 12.49% and 27.54% for M25, M30 and M40 mixes respectively. The higher dispersion ability of cement particles by the admixture during mixing, which results in pore blocking, may have been responsible, thus making it difficult for acid attack to progress(Drainsfield, 2003) and (Ramachandran, 1996).

4.5. Strength Deterioration Factor

Results show that compressive strength of all mixes decreases with time, in other words, strength deterioration factor increases as immersion period increases owing to the sustained acid attack (Fig. 9 to Fig 11). The sequence of event involves the reaction of sulphate ions which weakensportlandite thereby causing loss of stability and internal bonds in the matrix(Muthusamy, Kamaruzaman, Ismail, & Budiea, 2015).This is manifested by loss of stiffness, strength and adhesion(Ranjani & Ramamurthy, 2012).

Results also show that, as the concrete grade increased from M25 to M40, the SDF decreased at all ages for all mixes. At 90 days (Fig. 12), the average SDF for M25, M30 and M40 were 32.18%, 28.41% and 19.72% respectively. This trend could be ascribed to a decrease in aggregate/cement (A/C) ratio of mixesfrom M25 to M40 (Table 2) leading to stronger and cohesive concrete matrix which then translates to a higher acid resistance.

It was observed that, on addition of superplasticizers, the 90 days SDF of laterite rock concrete reduced by an average of 34.33% for the three grades. This decrease could be attributed to the higher pore blocking ability as well as the formation of more CSH products by the superplasticizer (Drainsfield, 2003).

V. CONCLUSION

From experimental results and discussions of this research, it can be concluded that:

- The performance of Laterite Rock Concrete LRC in a sulfuric acid mediumis not satisfactory due to its high porosity and permeability.
- However, on introduction of a poly carboxylate ether superplasticizer, the performance of LRC concrete in an acidic medium was increased considerably and comparable to conventional granite concrete.
- It is therefore recommended that LRC plus superplacticizer concrete can be used as replacement for granite concrete in areas where sulfuric acid attack is prevalent.

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Ephraim M. E."Performance Evaluation of Laterite Rock Concrete in Aggressive Environment"American Journal of Engineering Research (AJER), vol. 7, no. 11, 2018, pp. 93-101