Physico–Chemical Properties of Fine Aggregates in Ilesha, Southwestern Nigeria for Building Construction

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Abstract-In this paper, series of experimental programmes were carried out to determine both the physical and chemical properties of the fine aggregates used in construction work in the study area. Fine aggregates were sampled from 10 different construction sites in Ilesha-West Local Government Area of Osun State in Nigeria. The soil samples were labelled A - J. The physical and chemical properties of the samples were analyzed. The tests performed revealed that the specific gravities of the soil samples were found to be between 2.00 and 3.3, while the bulk compacted densities of aggregates were between 1750 kg/m3 and 2180 kg/m3, and the un-compacted densities were between 1690 kg/m3 and 2160 kg/m3. From the results, sample C had the highest moisture content, all the samples had silt content greater than the required 8% except sample F, which had the closest value of 11%. The soil samples A, C, D, E, F, H, I, and J were all medium-graded sandy soil while samples B and G were fine-graded sandy soil. The chemical tests showed that only sample A would be prone to sulphate attack. All the samples had low content of chloride ions. It was also noted that sample B had high carbonation vulnerability due to its comparatively higher organic carbon content. The investigation has provided cautionary measures against early structural damage when sourcing for fine aggregates for reinforced concrete (RC) structures in the study area.

Keywords — Physico-chemical analysis, Fine aggregates, concrete, Sulphate, carbonation, corrosion

I. INTRODUCTION

Reinforced concrete (RC) has been the most economic and versatile material that is widely utilized in the construction industry [1], [2]. Concrete on its own provides the compressive strength while the embedded reinforcement provides the tensile strength required. Over the years, reinforced concrete has suffered deterioration in its strength especially in structures constructed in areas subjected to harsh environmental challenges and chemical conditions.

It is well established that the compressive strength of concrete depends on some essential factors such as water to cement ratio (w/c), degree of compaction, the ratio of cement to aggregate, the ratio of fine aggregate to coarse aggregate, the bond between mortar and aggregate, and grading [3], shape, strength, and size of the aggregate [4]. For instance, to have a concrete mix, knowing the water content of its constituent part is important in that higher initial water content could lead to further average spacing between the cement grains [5]. In addition, when an initial w/c ratio is high, the resultant pores within the cement hydrates can be interconnected to each other, which results in lower strength, higher penetrability and lower durability of the hardened concretes [6].

The cost-effectiveness, as well as the performance of concrete, is largely affected by aggregate characteristics since approximately 80 percent of the total volume of concrete consists of aggregates (fine and coarse aggregates) [4]. The characteristics of aggregates in terms of shape, texture, and grading can influence workability, bleeding, degree of being pumpable, finishing, and segregation of fresh concrete, which can subsequently affect strength, stiffness, shrinkage, creep, density, permeability, and durability of hardened concrete. Hence, proper mixture, proportioning, and variation on grading is necessary to avoid construction and durability problems as reported [7].

It has been reported that the properties possessed by fine aggregates are also pivotal in determining if a structure would fail before reaching the serviceability or the ultimate design years [8]–[11]. It is therefore imperative to have a technical understanding of the properties of the fine aggregates to be used for construction purposes [12], [13]. Series of tests should be carried out to ascertain both the physical and the chemical characteristics of the soil. For instance, clay has been reported to be very plastic while silt is slightly plastic with sand and gravel showing no plasticity. Due to different management options, soil aggregate stability is widely used to measure the change in soil structure [14], [15] which will later determine the failure pattern when it is subjected to loading.

Generally, sand contains particles measuring about 0.0025 in - 0.08 in (0.063 mm - 20 mm) in diameter. Particles smaller than this are classified as silt while those which are larger than the normal size of sand are referred to as granular or gravel, depending on their sizes. In the construction business, all aggregates with particles greater than 0.25 in (64 mm) and up to 6.0 in (15.2 cm) are classified as coarse aggregates. It has been reported that the density of sand which ranges from 0.063 mm - 20 mm in diameter varies substantially due to the trapped water content [16], [17]. Iffat [18] reported that the density of concrete is directly proportional to its mechanical properties and inversely proportional to the dead weight of the concrete.

One of the major causes of RC deterioration is corrosion of the embedded steel rebar in the concrete which usually leads to the high cost of repair or the structure not living up to the service year. When steel is embedded in concrete, it becomes passive due to the formation of a thin, but protective oxide layer (about 10 nm thick). This layer is very stable in the alkaline pH ranges typical of the concrete pores (pH around 12.5). At this region, the pH is high enough to aid the formation of the protective film [19]. This protective film which acts as a shield can be damaged due to chloride attack [20]-[22] or due to concrete carbonation, these attacks lead to a reduction in the pH of the pore electrolyte and undermine the stability of the passive film[23]. Although the concrete protects the rebar against aggressive chemical agents externally, when water, oxygen along with chlorides or carbon dioxide within the RC reaches the surface of steel reinforcements, the protective film gets depassivated and damaged due to the reduction in the pH level (around 9), leading to the corrosion of reinforcements[22], [24] by the formation of expansive corrosion products which accumulate in the interface reinforcements and concrete and between in consequence causes cracks of concrete cover[25].

It has also been recognized that the chemical composition and cementitious binders of the constituents in concrete mix are crucial factors that determine the microstructure of concrete and hydration products and therefore play an indispensable role in the corrosion behavior of reinforcements [26].

The presence of sulphides in the pore solution of concrete is another major factor that can initiate the corrosion of reinforcement in concrete because it can significantly reduce the redox potential of the pore solution [27]. Redox potential measurement is simply a reflection of oxidation and reduction activities [28], [29]. The decrement in the redox potential is a result of the increment of the reduction atmosphere, which would protect the embedded steel from its oxidation to a certain extent to reduce the corrosion rate of the steel. Besides, the oxidation of chemically reduced sulphides

would form elemental Sulphur which is deposited in the pores of the damaged passive film allowing the corroded steel to regain a bit of passivation [30]. However, Shoesmith et al. [31]] suggested that sulphides also play a role in the breakdown of the passive film on the surface of steel which then exposes the steel to corrosion.

This paper reports an investigation of the physicochemical properties of fine aggregates obtained from Ilesha-West Local Government Area of Osun State in Nigeria. The investigation aimed at providing control in the selecting of sites for sourcing fine aggregates for concreting to avert early deterioration of reinforced concrete structures in the study area.

II. MATERIALS AND METHOD

- A. Materials
- a) Sampling points

The materials used for this research work were fine aggregates obtained from 10 different sites in the llesha-West Local Government Area of Osun State in Nigeria. The fine aggregates, which were intended for moulding of blocks and construction, were carefully collected. The fine aggregates with varying sizes fall between 150µm and 4.75mm. Some of the fine aggregates gotten from the sites were used as constituents for concrete mixture for construction of residential buildings whilst the other fine aggregates were to be used for moulding of blocks (either Sandcrete block or Concrete blocks).

The fine aggregates were categorized as shown in table 1 based on the sample size, spatial distribution, grading, particle shape and surface texture, unit weight, voids, moisture content, and so on.

S/N	SHARPSAND	BUILDERSAND
1.	Sample A	Sample C
2.	Sample B	Sample I
3.	Sample D	Sample G
4.	Sample E	Sample H
5.	Sample F	Sample J

Table I. Classification of Samples

b) Overview of the Site.

All the samples were obtained from the llesha-West Local Government Area of Osun State. As depicted in Figure 1. Osun is an inland state which falls in the Western region of Nigeria. Its capital is Osogbo. It is bounded in the north by Kwara State, in the east partly by Ekiti State and partly by Ondo State, in the South by Ogun State, and in the West by Oyo State. Much of the Ilesha land lies around the upper reach of the rivers Oni, Shasha, and Osun. The Ijesha county sits on land rising from about 800ft in the forests along the Oni valley of about 1700ft in the hills around Imesi IIe to the North and close to about 2,000ft in the Eastern boundaries with Ekiti State [32]. The typical soil found in this area is largely red laterite with heavy rainfall during the rainy season which lasts from late March to early November. Underneath the laterite soil is the Precambrian basement complex largely of folded politic schists, older granites, quartzite, gneisses, and sporadic amphibolite bodies. The occurrence of gold, schist, and amphibolite belt is found in the Ilesha. Ilesha is located in the deciduous rainforest zone of Nigeria.



Fig. 1: Sample point at Ilesha-West L.G.A, Osun State Nigeria.

B. Methods

a) Moisture Content

The weight of the empty container was recorded and noted as W1 after which a sizeable amount of the fine aggregate was placed in the empty container. Both were weighed, and the new weight was noted as well as w2. The sample with the container was then oven dried for about 24 hours. After drying, the ovendried sample was allowed to cool off for some minutes before the new weight is measured and recorded (w3). The moisture content (%) was determined using the formula:

Moisture Content (%)
$$= \frac{W_2 - W_3}{W_3 - W_1} \times 100$$
 (1)

The test was carried out following the ASTM C566 standard [33].

b) Organic Matter

The dry combustion test was followed to determine the total Organic Carbon in the fine aggregate sample, which was a direct measure of the total carbon as a percentage. The container used for this TOC sample processing were combusted at 400°C for at least 4 hours. Then the samples remain frozen at -20° C until processing. Sediment samples were thawed and homogenized.

The sample was dried in an oven at 40°C after which an aliquot of dried homogenized sample was conveyed via an aluminum-weighing pan and dried in an oven calibrated at 105°C. The procedure and computation of the TOC were carried out following B&B Laboratories Inc. [34]

c) Specific Gravity

A clean, dry pycnometer was taken, and its weight was determined and recorded as W1, then about 500g of clean sample was taken into the pycnometer and weighed as W2. The pycnometer with the measured sample was filled with water at a temperature of 270C immerse the sample. After immersion, the to entrapped air was removed from the sample by shaking the pycnometer thoroughly with a finger placed on the hole at the top of the sealed pycnometer. After ensuring all entrapped air has been displaced, the pycnometer was filled with water to the brim and carefully weighed. The weight of the saturated aggregates was recorded as W3. The contents of the pycnometer are discharged and properly cleansed according to standard [35]. Afterward, the pycnometer was filled with water to its brim and then weighed without any entrapped air and recorded as W4.

The Specific Gravity was calculated using the formula:

Specific Gravity =
$$\frac{W_2 - W_1}{[(W_4 - W_1) - (W_3 - W_2)]}$$
 (2)

d) Silt and Clay Content

First, a 50ml solution of 1% salt and water was prepared in the measuring cylinder. Owing to the fact that the addition of salt increases the settlement time of silt. A measured quantity of the sample to be tested was then added to the cylinder until it reached 100ml. The 50ml of the solution of salt and water was again added to the measuring cylinder. Afterward, the cylinder was shaken thoroughly after closing the open end and later allowed to settle adequately for about 4 hours. Layers of clay, silt, and sand were formed in the cylinder, noted, and recorded accordingly.

e) Bulk and Loose Densities

Bulk Density

The volume of the cylindrical metal was measured by pouring water into the metal and measured and recorded as 'V' in liter. The cylindrical metal was then filled to about one-third full of fine aggregates and tamped 25 times using the tamping bar. Another onethird of the sample was added and tamped 25 times again. Finally, the cylindrical metal was filled to overflowing and tamped 25 times with the surplus content trimmed off using a straightedge. The weight of the aggregate was measured and recorded as "W" in kg.

Loose Density

The volume of the cylindrical metal was measured by pouring water into the metal and measured and recorded as 'V' in liter. The cylindrical metal was then filled with the aid of a shovel or scoop until it filled up the cylindrical metal and trimmed with a straightedge. The weight of the aggregate was measured and recorded as "W" in kg.

Both the loose and bulk densities were computed using the formula:

Density =
$$\frac{Weight of Aggregate(W)}{Volume(V)}$$
 (3)

f) Particle Size Distribution

The gradation of the soil was used for classification and the curve was used to determine the coefficient of uniformity. The particle size distribution test was carried out according to the ASTM C136 / C136M – 19 standards [36].

g) Determination of Chloride ion (Cl⁻)

The test for chloride ions described was based on the precipitation of an insoluble chloride salt. The procedure involved the addition of a few drops of silver nitrate solution to a slightly acidic aqueous solution that contained chloride ions, which formed a white precipitate of silver chloride. The amount of precipitate formed was used to estimate the concentration of chloride ions available in the sample. The solution formed was compared with a standard solution with known chloride ion concentration. This test was carried out according to the procedure outlined by the Canadian Conservation Institute (CCI) [37].

The chloride ion concentration available in the fine aggregates was given as parts per million and estimated using:

Parts per million $= \frac{Parts \text{ per million}}{2aParts \text{ per million}}$ (4)

h) Determination of Sulphate (SO4²⁻)

The soil sample required for the analysis was taken in a state in which it could be crushed. The sample was oven-dried between 1050 0C and 1100 0C. The lumps were broken in a mortar with a rubber-covered pebble. The sample was mixed thoroughly and subdivided by quartering.

Then 10 g of soil from the sample was measured into a 250 ml bottle, the bottle was filled with 100 ml of distilled water. Afterward, the solution was shaken occasionally for about 2 hours with a mechanical shaker. The soil was allowed to stand overnight. About 0.5 to 1.0 g of pure potassium nitrate is added to flocculate the particles. The solute was filtered off and then 25 ml of filtrate/solvent was measured into a beaker. Concentrated hydrochloric acid was added to the filtrate to neutralize the solution, and 4 ml of hydrochloric acid was further added to make the solution acidic.

The solution was boiled, and after boiling, barium chloride solution was added to the boiled solution and constantly stirred till there was no precipitation with further addition. The beaker was then placed on a steam bath for a minimum of 4 hours to allow the precipitate to settle. The precipitate was filtered off through an ash-less filter paper which was free from chloride ions. Dry and ignite filtration was carried out through a pre-weighed sintered glass crucible. The precipitate was then ignited in a muffle furnace at about 6000 0C for half an hour. The desiccator was allowed to cool, then weighed and the residue noted which was the weight of the barium sulphate.

The corresponding weight of the sulphate was determined as follows:

a) Sulphate (SO₄) percent by mass = $41.15 W_1/W_2$

b) Sodium Sulphate (Na₂SO₄) percent by mass = 60.85 W_1/W_2

in which,

W1 = mass in g of the precipitate

 W_2 = Mass of g of the soil contained in the solution taken for precipitation.

III. RESULTS AND DISCUSSION

a. Moisture Content

In the conventional concrete mix proportion design, the lowest moisture content is desirable for a sufficient level of workability dependent on the project requirements. For most aggregates, the optimum moisture content is found within the range of 5% to 8%[38].



Fig. 2: Moisture content for all samples

Moisture in fine aggregates may be present as adsorbed moisture at internal surfaces and as capillary condensed water in small pores. For instance, in the areas with low relative humidity, the moisture in the fine aggregates consists mainly of adsorbed water. While in areas with higher relative humidity, the liquid water becomes more and more important, depending or not depending on the pore size which can also be an influence of volume [39]. From Figure 2 sample C has the highest moisture content which shows that it has the highest microfine than all the other samples and falls within the specified requirement. Sample D has the lowest, indicating it is sandier than all the other samples.

b. Soil Organic Matter

Organic matter influences the physical, chemical, and biological properties of fine aggregates. Compared to all other samples as shown in Table 2, sample A has the largest amount of organic matter, which depicts that when used for construction such as concrete, it might slightly affect the strength of the concrete. Fine aggregates with high soil organic matter (SOM) are reported to be prone to both carbonation and sulphate attack due to the presence of decomposable biological materials [40]. As rightly reported, SOM concentration in fine aggregates generally ranges from 1% to 6% of the total mass of topsoil for most upland soils. This thereby implies that all the samples gotten from Ileshawest LGA are all upland soils and are suitable for construction purposes since the SOM content falls within the allowable range [41].

Table 2.	Soil	Organic	Matter	content
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Sample	%	
	Content	
Α	2.9	
В	2.0	
С	1.3	
D	1.1	
Ε	1.7	
F	1.1	
G	1.6	
Н	1.8	
Ι	1.7	
J	0.7	

c. Specific Gravity of Soil Samples

From the result obtained which is displayed in Figure 3, the specific gravity of the soil samples ranges from 2.0 to 3.33. The permissible specific gravity is said to fall within the range of 2.6 to 2.9 [42] which thereby implies that samples B, E, F, H falls into the stipulated range. Samples D, G, I, J have values that are of close range to the permitted range while the other samples have values that exceed the required standards. Carrying out specific gravity tests on samples before their utilization for any construction work is very important because it's an indicator of the presence of impurities in the sand.



Fig. 3: Specific gravity for soil samples

Specific gravity is also a piece of important information for calculating air voids and voids in mineral aggregates. The specific gravity of any fine aggregates is inversely proportional to the number of impurities/voids present in that soil sample.

Soil samples with a high amount of organic matter or porous particles would have a specific gravity value that is lower than 2.6. From the result displayed above, sample C has the lowest specific gravity which shows that it has a higher content of impurities such as organic matters or voids when compared to other samples. Sample C when used for construction work would be prone to chemical attacks such as carbonation and sulphate attack.

d. Silt and Clay Content

The permits of silt contents are said to be within the range of 3 to 8 %. Silt is a material between $2\mu m$ and $60\mu m$.

All the samples as displayed in Table 3, and figure 4 have a silt content percentage to be higher than 8%. This shows that all the samples have high microfine. Fine aggregates samples with a silt content of less than 3 % have insufficient fines and will require more amount of cement and water for reasonable workability. If such soils are to be used for construction work, they have to be blended with suitable finer aggregates from other sources.

Fine aggregates samples with silt content between 3 to 8 % are quite suitable for construction purposes. This will require optimum water and cement content for reasonable workability.

Silt content of over 8 % is unsuitable as it increases the amount of water needed to wet the particles in the mix. This results in a mix with high slump, high dry shrinkage, and consequently weak and non-durable concrete. Also from Table 3, sample C has the highest percentage of silt and clay content which was also noted under the moisture content section. While sample F recorded the least silt and clay content.

Table 3. Silt and Clay content

SAMPLES	Overall Height of sample (cm)	Percentage content of clay and silt (%)	Percentage content of Sand (%)
Sample A	7.2	12.5	87.5
Sample B	6.8	14.7	85.3
Sample C	5.1	19.6	80.4
Sample D	5.7	14	86
Sample E	6.6	15.2	84.8
Sample F	6.3	11.1	88.9
Sample G	6.1	13.1	86.9
Sample H	6.9	14.5	85.5
Sample I	7.0	15.7	84.3
Sample J	6.1	13.1	86.9





e. Bulk and Loose Density

The uncompacted (loose) densities of the aggregates are between 1690 kg/m3 and 2160 kg/m3. The bulk densities obtained for the fine aggregate ranges from 1750 kg/m3 to 2180 kg/m3. The permitted range for the bulk densities is said to be between 1538 kg/m3 and 1842 kg/m3 [18]. From the results obtained in figure 5 all other samples fall within the range except for C, F, G, H, J. It's been reported that the mechanical properties of concrete are influenced by its density [18]. Fine aggregates with higher bulk density imply it is denser and will yield higher strength with fewer number of voids and porosity. The lesser the voids in the aggregate, the less permeable to water and soluble elements. The water absorption will also be less and the concrete such aggregates are used for would be more durable. The bulk density must not be higher than the required range because it would lead to an increase in the dead weight of the concrete.



Fig. 5: Bulk and loose densities

f. Particle Size Distribution

The results obtained for the sieve analysis are shown in Figure 6

From the result obtained in the charts (Figure 6), It can be deduced that all the samples complied with BS 882[43] standard for Sieves 5.0mm, 4.0mm, 2.36mm, 1.70mm, 600 μ m, 500 μ m, 425 μ m, and 212 μ m. It was discovered that when it got to sieve 150 μ m that only Sample D and E met with the required percentage pass which ranges from 0 – 20%. This, therefore, implies that only Sample D and E have the required distribution of Silt and Sand composition. It is therefore regarded as the most suitable material for construction purposes. Also from the particle size distribution graph, it was deduced that samples B and G were fine-graded sandy soil while samples A, C, D, E, F, H, I, and J were all medium graded sandy soil.



Fig. 6: Sieve analysis of all Soil Samples

g. Chemical Analysis of Fine Aggregate

From the results in Table 4 below, it could be deduced that all the values for the (Total Organic Carbon) are of closer range except that of samples A, B, and C. Samples with high organic carbon content would be prone to carbonation which is due to its high organic matter [20], [22], [44]. Carbonation is said to be a process in which the pH of the soil is reduced (making it to be acidic) and thereby making the reinforcement coating to be passive. The presence of soil organic matter in samples A, B, and C is a major factor for the high T.O.C in the soil samples. This thereby implies that when these samples (A, B, and C) are used for construction work, the construction edifice would be prone to carbonation.

Table 4. Chemical parameters and concentration of metals in soil samples

Soil	Percentage Composition of Mineral Elements in Soil Samples				
Samples	Calcium (ppm)	Magnessi um (ppm)	Chloride (%)	Sulphate	Total Organic Carbon (TOC)
Sample A	0.381	0.172	7.3	129.03	10.936
Sample B	0.271	0.158	6.25	56.45	8.764
Sample C	0.465	0.2	8.6	120	8.1
Sample D	0.257	0.16	4	20	5.2
Sample E	0.301	0.167	6.15	8.06	0.702
Sample F	0.278	0.158	5.1	21.5	1.2
Sample H	0.294	0.161	4.525	38.71	0.858
Sample I	0.272	0.159	6.5	22.58	0.78
Sample J	0.051	0.054	5.45	85.48	0.702

Furthermore, also from Table 4, we could see that all the samples have differing sulphate content. With sample A having the highest content followed by samples C, J, and B in descending order. According to Latif et al [45], this might be due to the many sources from the environment where the samples are derived from such as aerosol spray, sewer system and also burning activity. This shows that samples A, C, J, and B would be susceptible to sulphate attack while all the other Samples are less vulnerable to sulphate attack [27]–[31].

In addition, the presence of chloride ions in fine aggregates will be of deleterious effect on the embedded reinforcement through the process of depassivation of the protective film around the reinforcement. The lower the chloride content within the samples the better it is for the samples [20]–[25] and from the result displayed in Table 4, all the samples have a lower range of Chloride content embedded in the soil samples. Sample C recorded the highest Chloride content when compared to all the other samples. This thereby implies that sample C would be more susceptible to corrosion

All the samples have a low range of heavy metal content (Calcium and Magnesium) because the fine aggregates are obtained from sites that are free of metallic particles such as iron fillings. Due to the low content of calcium and magnesium, when these samples are used for RC concrete works the compressive strength of the concrete might be affected. It was reported that the presence of a Ca(OH)2-rich layer that adheres to the steel protects the steel [46]–[48] [45]–[47].

IV. CONCLUSION

Soils for construction works should be analyzed for their Physical and Chemical properties before they are used for construction purposes. This will enable the users to prepare an accurate mix to ensure workability, minimum dry shrinkage, durability, and high strength. The specific gravities of the soil samples were found to be between 2.00 and 3.3 from which only sample B, E, F, and H has the required value. The bulk compacted densities of aggregates were between 1750 kg/m3 and 2180 kg/m3 and the un-compacted (loose) bulk densities are between 1690 Kg/m3 to 2160 Kg/m3. Sample C yielded the highest moisture content, showing that it has the largest amount of microfine. Also, all the samples have silt content greater than the required 8% of which only sample F has the closest value of 11%. The soil samples A, C, D, E, F, H, I, and J were all medium-graded sandy soil while samples B and G were fine-graded sandy soil.

The chemical tests showed that only sample A would be prone to sulphate attack, though all the samples had low content of chloride ions. Sample B had high carbonation vulnerability due to its comparatively higher organic carbon content. The results of this investigation have provided support for sourcing fine aggregates to avert chemical attacks on reinforced concrete structures in the study area.

REFERENCES

[1] M. F. Montemor, A. M. P. Simões, and M. G. S. Ferreira, "Chloride-induced corrosion on reinforcing steel: from the fundamentals to the monitoring techniques," Cem. Concr. Compos., vol. 25, no. 4, pp. 491–502, 2003, doi: https://doi.org/10.1016/S0958-9465(02)00089-6.

[2] R. G. Duarte, A. S. Castela, R. Neves, L. Freire, and M. F. Montemor, "Corrosion Behavior of Stainless Steel Rebars Embedded in Concrete: an Electrochemical Impedance Spectroscopy Study," Electrochim. Acta, vol. 124, pp. 218–224, 2014, doi: https://doi.org/10.1016/j.electacta.2013.11.154.

[3] M. S. Meddah, S. Zitouni, and S. Belâabes, "Effect of content and particle size distribution of coarse aggregate on the compressive strength of concrete," Constr. Build. Mater., vol. 24, no. 4, pp. 505–512, 2010, doi: https://doi.org/10.1016/j.conbuildmat.2009.10.009.

[4] C. G. Rocco and M. Elices, "Effect of aggregate shape on the mechanical properties of a simple concrete," Eng. Fract. Mech., vol. 76, no. 2, pp. 286–298, 2009, doi: https://doi.org/10.1016/j.engfracmech.2008.10.010.

[5] T. A. Harrison, "Early-Age Thermal Crack Control in Concrete," in Construction Industry Research and Information Association, Illustrate., Construction Industry Research & Information Association, 1981, 1981, p. 48 pages.

[6] S. Apebo, A. Shiwua, A. Agbo, J. Ezeokonkwo, and A. Paul, "Effect of Water-Cement Ratio on the Compressive Strength of gravel – crushed over burnt bricks concrete," Civ. Environ. Res., vol. 3, Apr. 2013.

[7] J. L. Lafrenz, "Improving Constructability of Concrete Pavements by Assuring Consistency of Mixes.," 1997.

[8] E. T. A. Omotoso, A. Oladele, J. O. Ojo, and T. E. Adetolaju, "Engineering properties of lateritic soils around Dall quarry in Sango Area, Ilorin, Nigeria.," Earth Sci. Res., vol. 1, no. 2, p. 71, 2012.

[9] C. N. Akujieze and S. O. Ogunlade, "Evaluation of Some Lateritic Soils of Basement Complex Rocks from Ado Ekiti and Environs, Southwestern Nigeria for Road Construction," J. Min. Geol., vol. 56, no. 1, pp. 125–131, 2020.

[10] O.S. Osuji and J.T. Akinwamide, "Physico-Chemical Properties of Lateritic Soils in Ado-Ekiti, South Western Nigeria.," Univers. J. Environ. Res. Technol., vol. 7, no. 1, pp. 10–18, 2018, [Online]. Available: www.environmentaljournal.org.

[11] O. E. Eze, O. S. Osuji, and T. J. Akinwamide, "Evaluation of Index Properties of Lateritic Soils in Ado Ekiti Metropolis South Western, Nigeria," Electron. J. Geotech. Eng., vol. 22, no. 07, pp. 4261–4270, 2017.

[12] C. George Hoff, Guide for the use of lowdensity concrete in civil works projects. Geotechnical and Structures Laboratory (U.S.) Engineer Research and Development Center (U.S.). [13] R. Purushothama, "Soil Mechanics & Foundation Engineering." p. 278, 2008, [Online]. Available:

http://books.google.com.ec/books?id=j9MhMcsGcOUC &pg=PA578&dq=restitution+coefficient+concrete+and +iron&hl=es&sa=X&ei=N-_IUPPvI-

Lu0gHBsIDAAg&ved=0CDAQ6AEwAA#v=onepage&q =restitution coefficient concrete and iron&f=false.

[14] J. M. Lynch and E. Bragg, "Microorganisms and Soil Aggregate Stability.," Adv. Soil Sci., vol. vol 2, no. 978-1-4612-9558–7, pp. 133–171, 1985, doi: https://doi.org/10.1007/978-1-4612-5088-3_3.

[15] S. A. Aziz and S. M. Karim., "The Effect of Some Soil Physical and Chemical Properties on Soil Aggregate Stability in Different Locations in Sulaimani and Halabja Governorate," Open J. Soil Sci., vol. 6, pp. 81–88, 2016, doi: 10.4236/ojss.2016.64009.

[16] J. Hussein, M. A. Adey, and H. A. Elwell, "Irrigation and dryland cultivation effects on the surface properties and erodibility of a Zimbabwe vertisol," Soil Use Manag., vol. 8, no. 2, pp. 97–102, Jun. 1992, doi: https://doi.org/10.1111/j.1475-2743.1992.tb00901.x.

[17] H. Beshr, A. A. Almusallam, and M. Maslehuddin, "Effect of coarse aggregate quality on the mechanical properties of high strength concrete," Constr. Build. Mater., vol. 17, no. 2, pp. 97–103, 2003, doi: https://doi.org/10.1016/S0950-0618(02)00097-1.

[18] S. Iffat, "Relation Between Density and Compressive Strength of Hardened Concrete," Concr. Res. Lett., vol. 6, pp. 182–189, Jan. 2016.

[19] Y. Morozov, A. S. Castela, A. P. S. Dias, and M. F. Montemor, "Chloride-induced corrosion behavior of reinforcing steel in spent fluid cracking catalyst modified mortars," Cem. Concr. Res., vol. 47, pp. 1–7, 2013, doi:

https://doi.org/10.1016/j.cemconres.2013.01.011.

[20] I. Ustabas, "The effect of capillarity on chloride transport and the prediction of the accumulation region of chloride in concretes with reinforcement corrosion," Constr. Build. Mater., vol. 28, no. 1, pp. 640–647, 2012, doi:

https://doi.org/10.1016/j.conbuildmat.2011.10.043.

[21] C. Li, Q. Chen, R. Wang, M. Wu, and Z. Jiang, "Corrosion assessment of reinforced concrete structures exposed to chloride environments in underground tunnels: Theoretical insights and practical data interpretations," Cem. Concr. Compos., vol. 112, p. 103652, 2020, doi: https://doi.org/10.1016/j.cemconcomp.2020.103652.

[22] Y. Cao, C. Gehlen, U. Angst, L. Wang, Z. Wang, and Y. Yao, "Critical chloride content in reinforced concrete — An updated review considering Chinese experience," Cem. Concr. Res., vol. 117, pp. 58–68, 2019, doi: https://doi.org/10.1016/j.cemconres.2018.11.020.

[23] F. Pacheco Torgal, S. Miraldo, J. A. Labrincha, and J. De Brito, "An overview on concrete carbonation in the context of eco-efficient construction: Evaluation, use of SCMs and/or RAC," Constr. Build. Mater., vol. 36, pp. 141–150, 2012, doi: https://doi.org/10.1016/j.conbuildmat.2012.04.066.

[24] U. Angst, B. Elsener, C. K. Larsen, and Ø. Vennesland, "Critical chloride content in reinforced concrete — A review," Cem. Concr. Res., vol. 39, no. 12, pp. 1122–1138, 2009, doi: https://doi.org/10.1016/j.cemconres.2009.08.006.

[25] X. Yuan, X. Wang, Y. Cao, and H. Yang, "Natural passivation behavior and its influence on chloride-induced corrosion resistance of stainless steel in simulated concrete pore solution," J. Mater. Res. Technol., vol. 9, no. 6, pp. 12378–12390, 2020, doi: https://doi.org/10.1016/j.jmrt.2020.08.056.

[26] C. Monticelli et al., "Corrosion behavior of steel in alkali-activated fly ash mortars in the light of their microstructural, mechanical and chemical characterization," Cem. Concr. Res., vol. 80, pp. 60– 68, 2016, doi: https://doi.org/10.1016/j.cemconres.2015.11.001.

[27] Q. Ma, S. V Nanukuttan, P. A. M. Basheer, Y. Bai, and C. Yang, "Chloride transport and the resulting corrosion of steel bars in alkali activated slag concretes," Mater. Struct., vol. 49, no. 9, pp. 3663–3677, 2016, doi: 10.1617/s11527-015-0747-7.

[28] P. A. Claisse, "Corrosion of steel in concrete – understanding, investigation and repair 2nd edn.," Broomf. J. P., Taylor Fr. London, vol. 978-0–4153, no. 3404–4, p. 296, 2008.

[29] J. Schuring, H. D. Schulz, J. Bottcher, and W. H. M. Duijnisveld., "Redox: Fundamentals, Processes and Applications," Illustrate., Springer Science & Business Media, 2013, p. 251 pages.

[30] J. Qu, H. Xie, Q. Song, Z. Ning, H. Zhao, and H. Yin, "Electrochemical desulfurization of solid copper sulfides in strongly alkaline solutions," Electrochem. commun., vol. 92, pp. 14–18, 2018, doi: https://doi.org/10.1016/j.elecom.2018.05.014.

[31] D. W. Shoesmith, P. Taylor, M. G. Bailey, and B. Ikeda, "Electrochemical behaviour of iron in alkaline sulphide solutions," Electrochim. Acta, vol. 23, no. 9, pp. 903–916, 1978, doi: https://doi.org/10.1016/0013-4686(78)87014-5.

[32] K. Omole, O. Julius Oluranti, and A. Olusa, "Towards Efficient Transport Connectivity for Sustainable Market Patronage in Nigeria," Int. J. Dev. Soc., vol. 1, pp. 88–96, Jun. 2012.

[33] ASTM C566-19, "Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying," West Conshohocken, PA, 2019. doi: 10.1520/C0566-19.

[34] B. B. Bernard, H. Bernard, and J. M. Brooks, "DETERMINATION OF TOTAL CARBON, TOTAL ORGANIC CARBON AND INORGANIC CARBON IN SEDIMENTS," Texas.

[35] B. Trishna, "How to determine the specific gravity of soils. Available Online." http://www.soilmanagementindia.com/soil/determinatio n-of-specific-gravity/how-to-determine-specific-gravityof-soils/13341 (accessed Nov. 10, 2018). [36] ASTM C136 /C136M-19, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates," West Conshohocken, PA, 2019. doi: 10.1520/C0136_C0136M-19.

[37] L. Selwyn, "How to Test for Chloride Ions in Iron Treatment Solutions Using Silver Nitrate," Can. Conserv. Inst., no. 1928–1455, 2016, [Online]. Available: https://www.canada.ca/en/conservationinstitute/services/conservation-preservationpublications/canadian-conservation-institutenotes/test-chloride-ions-iron-treatment-silvernitrate.html#a3.

[38] S. Tayabji, Designers's Guide for UFGS 32 13 16.16 Roller Compacted Concrete (RCC) Pavement. 2010.

[39] Wikipedia, "Water Content." https://en.wikipedia.org/wiki/Water_content.

[40] Wikipedia, "Soil organic matter." https://en.wikipedia.org/wiki/Soil_organic_matter.

[41] F. R. Troeh and L. M. Thompson, Soils and soil fertility. New York: Oxford University Press, 1993.

[42] H. Sood, "Specific gravity and water absorption of fine aggregates," 2015.

[43] BS 882, "Specification for Aggregates from Natural Sources for Concrete," Br. Stand. Institution, London, 1992.

[44] B. Li, S. Hou, Z. Duan, L. Li, and W. Guo, "Rheological behavior and compressive strength of concrete made with recycled fine aggregate of different size range," Constr. Build. Mater., p. 121172, 2020, doi:

https://doi.org/10.1016/j.conbuildmat.2020.121172.

[45] M. T. Latif, M. Othman, C. Kim, S. Murayadi, and K. Sahaimi, "Composition of Household Dust in Semi-Urban Areas in Malaysia," Indoor Built Environ. -INDOOR BUILT Env., vol. 18, pp. 155–161, Apr. 2009, doi: 10.1177/1420326X09103014.

[46] C. L. Page and K. W. J. Treadaway, "Aspects of the electrochemistry of steel in concrete," Nature, vol. 297, no. 5862, pp. 109–115, 1982, doi: 10.1038/297109a0.

[47] J. James, "Interface-durability correlations in concrete," Bull. Mater. Sci., vol. 14, no. 5, pp. 1183–1195, 1991, doi: 10.1007/BF02744611.

[48] J. Ožbolt, F. Oršanić, G. Balabanić, and M. Kušter, "Modeling damage in concrete caused by corrosion of reinforcement: coupled 3D FE model," Int. J. Fract., vol. 178, no. 1, pp. 233–244, 2012, doi: 10.1007/s10704-012-9774-3.