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The Physico-Chemical Properties of Some Fine Aggregates in Lokoja, Nigeria

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A B S T R A C T

Fine aggregates, as one of the major components of concrete, play a major role in determining the quality of concrete to be produced, hence the need to know its physical and chemical properties. Disturbed soil samples were obtained from ten different construction sites in Lokoja, Nigeria. The samples were analysed for their physical properties such as moisture content, silt and clay content, organic content, density, specific gravity and particle size distribution, and their chemical properties. The results obtained showed that samples 3, 4, 5 and 9 had the highest specific gravity of 2.63 while samples 1, 2 and 7 had the least specific gravity of 2.83. However, the silt and clay contents were also significantly high for samples 1, 2, 5, 9 and 10 which have their values greater than 7% indicating that the samples need to be washed before use for adequate integrity of the concrete as stipulated by ASTM C33 of 1994. It was also observed from the analysis that almost all the samples were poorly graded, with samples 5, 9 and 10 having significantly better gradation than the others. On the basis of the values of porosity, void ratio and unit weight, majority of the samples could be classified as uniform fine sand or coarse sand. Meanwhile, the result of the chemical analysis showed that sample 4 has the highest composition of Ca2+ (356 mg/kg) while sample 3 has the highest composition of Cl-1 (1.6 mg/kg). However, majority of the samples could be susceptible to alkali-aggregate reactions when used in concrete production hence the need for alkali-silica reaction suppressants such as fly-ash, silica fumes and lithium compounds.

1. Introduction

Concrete is a mixture of cement, aggregates and water. Aggregates are the major component of concrete and constitute 60 to 80% of its total volume (Rached et. al., 2009). This makes their selection very important for any kind of construction. Abdullahi (2006) noted that the particles that make up aggregates should have adequate strength and resistance to exposure conditions and should not contain materials that will cause deterioration of the concrete.

Aggregate can be classified as fine or coarse. Coarse aggregates have large sizes, usually greater than 4.75mm (retained on a number 4 sieve), while fine aggregate particles have sizes between 4.75 mm and 0.75mm (passing the number 4 sieve but retained on sieve number 200). The geologic origin and mineralogy of the source of aggregates, and its subsequent weathering or alteration usually defines the physical and chemical properties of the aggregate (Langer & Knepper, 1995). The physical properties of aggregates include shape and texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight. For mixture proportioning and general quality control and assurance, physical characteristics of aggregates, such as gradation, absorption, and specific gravity are important properties to be considered. They can also be essential to durability of the concrete in several ways. For example, for some aggregate types, absorption and specific gravity values can serve as useful indices for frost susceptibility (Page & Page, 2007).

In addition, these properties along with the water/cement ratio determine the strength, workability, durability and performance of concrete. Hyodo et. al. (2013) also noted that the presence of aggregates reduces the concrete shrinkage because of restraining the paste shrinkage. Although, aggregates were once thought to be inert, it is now known that all aggregates are chemically reactive. While enhanced bond is one of the beneficial effects of the chemical reactions between the aggregates and the cement paste, there are other effects that can be deleterious to the durability of the concrete (Schuman et. al., 1988).

Concrete aggregates have been relatively widely studied in the past decades, though most of the research has been done on

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the coarse aggregate and limited only to one or few quality characteristics at a time. In order to optimize the aggregate-concrete chain, one has to know the aggregate quality characteristics that dominate different concrete properties, and how basic changes in the concrete mix design affect their influences. The need for knowledge is increasing as conventional concrete aggregate supplies are becoming depleted, and environmental challenges prevent the use of existing sources.

Fine aggregate prevents shrinkage of cement. When surrounded by cement, it gains mobility to enter the voids in coarse aggregates and binding of ingredients takes place. It adds density to concrete, since it fills the voids. The denser the concrete is, the stronger it is. Their specific gravity, particle size distribution, shape and surface texture influence markedly the properties of mortars and concrete in the fresh state. On the other hand, the mineralogical composition, toughness, elastic modulus and degree of alteration of aggregates are generally found to affect the properties of mortars and concrete in the hardened state. It is therefore imperative to ensure that the right type and quality of fine aggregates are used in construction and this is why the focus of this study is to determine the physical and chemical properties of fine aggregates in selected sites in Lokoja, Nigeria.

2. Materials and Methods

In this study, disturbed soil samples were obtained from ten various construction sites in Lokoja Local Government Area of Kogi State, Nigeria. Physical analysis of these soil samples were carried out in the Structural and the Geotechnical Laboratories, Department of Civil Engineering, while the chemical analysis were carried out at the at the Central Research Laboratory, both in The Federal University of Technology, Akure, Ondo State. For the physical analysis, the following tests were carried out: moisture content (in accordance with ASTM D 2216), silt and clay content (in accordance with ASTM C117-03), organic content (in accordance with ASTM D 2974), bulk density, dry density and loose packing density (in accordance with ASTM D 2937-00), specific gravity (in accordance with ASTM D 854-00) and sieve analysis (in accordance with ASTM D 422).

However, for the chemical analysis, three equipment were used, which include the PFP7 flame photometer (Plate 1), UV/VIS spectrometer, and atomic absorption spectrometer. The flame photometer was used in determining the sodium, potassium, calcium as well as barium and lithium concentrations. The UV/VIS spectrometer provided the sulphur and phosphorus content while the concentration of elements such as Fe, Ca, Mg and other metals was measured with the atomic absorption spectrometer.

Plate 1: PFP7 Flame Photometer (Camlab, 2017)

3. Results and Discussion

3.1 Moisture Content

The moisture content obtained for each sample analysed is summarized in Table 1. Sample 9 has the largest percentage moisture content of 8.90% while sample 8 has the least percentage moisture content of 0.34%. The consistency of a fine-grained soil largely depends on its water content. The water content is also used to express the phase relationships of air, water, and solids in a given volume of soil. It is important to note that some of the samples were not collected at their natural moisture content, some having been air dried while some have been sun dried at their storage points. These conditions will have to be considered in the mix design of concrete.

Hover (2013) noted that since the mix design typically is based on dry aggregate, so any water in the aggregate has to be subtracted from the water to be used in batching the concrete. This, on its own, may take too much time. Therefore, in reality, moisture corrections often are based on average moisture conditions over the course of a day or a week of operation.

3.2 Silt and Clay Content

The silt and clay content for each sample is presented in Table 1. Kosmatka et. al. (2002) highlighted that materials finer than the 75-µm (No. 200) sieve, especially silt and clay, may be present as loose dust and form a coating on the aggregate particles. This can be harmful because they are capable of forming a bond between the cement paste and aggregate. On this note, samples having the silt and clay content greater than 7% will require washing before they can be used as concrete material (ASTM C33, 1994). Therefore, from the results obtained, Samples 1, 2, 5, 9 and 10 need to be washed so as to maintain their integrity as concrete materials.

3.3 Specific Gravity

From Table 1, samples 3, 4, 5 and 9 had the highest specific gravity of 2.63, while Samples 1, 2 and 7 had the least specific gravity of 2.38. Neville (2011) noted that the specific gravity of aggregate is used in the calculation of quantities; however, the actual value of the specific gravity of aggregate is not a measure of its quality.

3.4 Organic Content

Sample 3 from Table 1 has the highest organic content (6.11%) while samples 1 and 6 have the least organic content (0.56%). Organic impurities can affect setting and hardening of concrete which may cause deterioration (Kosmatka et. al., 2002).

3.5 Bulk Density, Dry Density and Loose Packing Density

Judging from Table 1, the reduction in the density of samples, relating the packing density with the bulk density is evidenced that there will be tendency of shrinkage in concrete. The results show that the value of the dry packing density and bulk density were the same for Samples 1, 5 and 9.

3.5 Fineness Modulus

Fineness Modulus (FM) is an index of the fineness of an aggregate—the higher the FM, the coarser the aggregate. A very small number indicates fine sand; a large number indicates coarse sand. For mix proportioning, the fine sand would require more cement and a greater tendency to develop cracks. A coarse sand will produce a concrete mixture that is harsh and difficult to finish and will cause segregation. Degradation of fine aggregate due to friction and abrasion will decrease the FM and increase the amount of materials finer than the 75 μm (No. 200) sieve (Kosmatka et al., 2002).

Comparing the values of the fineness modulus for the ten samples with the ASTM C33 standard Table 1, Samples 1, 2, 5, 8, and 10 fulfil the satisfactory requirements for the fineness modulus, while samples 3, 4, 6 and 9 did not conform to the recommended gradation.

3.6 Coefficient of uniformity and Coefficient of curvature

The results are also contained in Table 1. ASTM D2487 (2006) specifies the procedure for classification of coarse grained soils. If less than 5% of the test specimen passes the No. 200 (75-μm) sieve, the soil can be classified as well-graded gravel (GW), or well-graded sand (SW), if Cu is greater than or equal to 4.0 for gravel or greater than 6.0 for sand, and Cc is at least 1.0 but not more than 3.0. Otherwise it is classified as poorly graded.

The results of coefficient of uniformity (Cu) fall below standard for all the ten samples with sample 5 having the highest Cu value (5.47) and sample 6 having the least Cu value (1.85). On the other hand, only samples 1, 2, 3, 7 and 8 had unsatisfactory coefficient of curvature (Cc) values. These results suggest that almost all the samples are poorly graded, with samples 5, 9 and 10 having significantly better gradation than others.

The porosity, void ratio and unit weight of each of the samples was also used in predicting the soil types in accordance with the standard presented by Garg (2005).

3.7 Chemical Analysis

The results of the chemical analysis of the samples are presented in Figure 1. The results of the chemical analysis of the samples are presented in Figure 1. The results show tremendously high presence of Calcium (Ca) in all the samples with samples 1, 2, 4, 5 and 7 having the highest values. The presence of Potassium (K), Magnesium (Mg), and Carbon (C) were also relatively high for all the samples, with samples 1, 4, 8, 9 and 10 having the highest contents of Potassium (K) and Magnesium (Mg). These results suggest that the oxides of these metals are relatively high in the soils.

However, the presence of Iron (Fe), Sulphur (S), Chlorine (Cl) and Carbon (C) were comparatively equal for all the soil samples and lower than the others. It is significant to note that sample 3 had the least chemical constituents relative to the nine other samples, which suggests that it is the least reactive. Chemical constituents in concrete such as alkali, calcium, silica and water can cause alkali-aggregate reaction (AAR) and can be potentially harmful causing significant expansion and consequently deterioration of concrete (Xu, 1987; Schuman et. al., 1988). It is believed that the necessary condition for concrete deterioration to take place is the presence of reactive silica, as well as sodium, potassium and calcium ions (Owsiak & Zapała-Sławeta, 2013).

This suggests that the concrete produced by the samples, especially samples 1, 4, 5, 8, 9, and 10 are susceptible to alkali-aggregate reactions. It is advised that these reactions should be limited by using additives such as fly-ash, silica fumes, natural pozzolanas and lithium compounds (Farny & Kerkhoff, 1997).

4. Conclusions

The study has evaluated some physical and chemical properties of fine aggregates in selected sites in Lokoja, Nigeria. It was observed from the analysis that almost all the samples were poorly graded, with samples 5, 9 and 10 having significantly better gradation than others. On the basis of the values of porosity, void ratio and unit weight, majority of the samples can be classified as uniform fine sand or coarse sand. The silt and clay contents were also significantly high for samples 1, 2, 5, 9 and 10, indicating a need for these samples to be washed before use for adequate integrity of the concrete.

Meanwhile, the result of the chemical analysis shows that majority of the samples could be susceptible to alkali-aggregate reactions when used in concrete hence the need for alkali-silica reaction suppressants such as fly-ash, silica fumes and lithium compounds should be considered in production of concrete from these aggregates, as noted by Farny & Kerkhoff (2007) and Lane (2002).

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Table 1: Physical Properties of the Selected Samples from all the sites

Physical Properties	Samples									
	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*	*Sample 8*	*Sample 9*	*Sample 10*
Fineness Modulus	2.78	2.32	4.23	3.72	2.6	3.34	3.1	2.55	2.25	2.43
Coefficient of uniformity (C_u)	2.43	2.43	2.94	2.32	5.47	1.85	2.42	1.9	5.27	5.27
Coefficient of curvature (C_c)	0.94	0.94	0.82	1.22	1.57	1.19	0.96	0.933	1.25	1.12
***Classification according to Unified Soil Classification System (USCS)* (ASTM D2487, 2006)**	Uniform fine sand	Coarse sand, Medium sand	Uniform fine sand	Uniform fine sand	Uniform fine sand	Coarse sand, Medium sand	Coarse sand, Medium sand	Coarse sand, Medium sand	Uniform fine sand	Uniform fine sand
Moisture Content (%)	4.57	7.36	1.48	2.64	2.02	0.54	0.43	0.34	8.7	7.97
Porosity (%)	36	27	36	34	34	41	45	26	36	29
Void ratio	0.56	0.36	0.56	0.52	0.52	0.69	0.82	0.35	0.56	0.4
Specific Gravity (G_s)	2.38	2.38	2.63	2.63	2.63	2.5	2.5	2.38	2.63	2.5
Loose packing density(g/cm^3)	1.42	1.27	1.6	1.56	1.46	1.38	1.56	1.53	1.53	1.31
Dry packing density (g/cm^3)	1.71	1.67	1.67	1.78	1.75	1.82	1.78	1.67	1.71	1.82
Bulk density (g/cm^3)	1.71	1.93	1.71	1.75	1.75	1.56	1.46	1.96	1.71	1.89
Natural Unit weight, γ (kN/m^3)	16.77	18.91	16.77	17.12	17.12	15.34	14.27	19.26	16.77	18.55
Dry Unit Weight, γ_d (kN/m^3)	14.97	17.17	16.38	16.97	16.97	14.5	13.47	17.3	16.55	17.52
Saturated Unit Weight, γ_{sat} (kN/m^3)	18.49	19.84	20.06	20.33	20.34	18.52	17.9	19.84	20.06	20.32
Buoyant or submerged, γ_{sub} (kN/m^3)	8.68	10.03	7.36	10.52	10.53	8.71	8.09	10.03	10.25	10.51
Silt and Clay Content (%)	6.2	25	1.6	1.2	9.8	2.1	3.1	4.3	17.6	18.5
Organic Content(%)	0.56	2.37	6.11	0.95	1.43	0.56	0.79	0.72	1.11	1.36

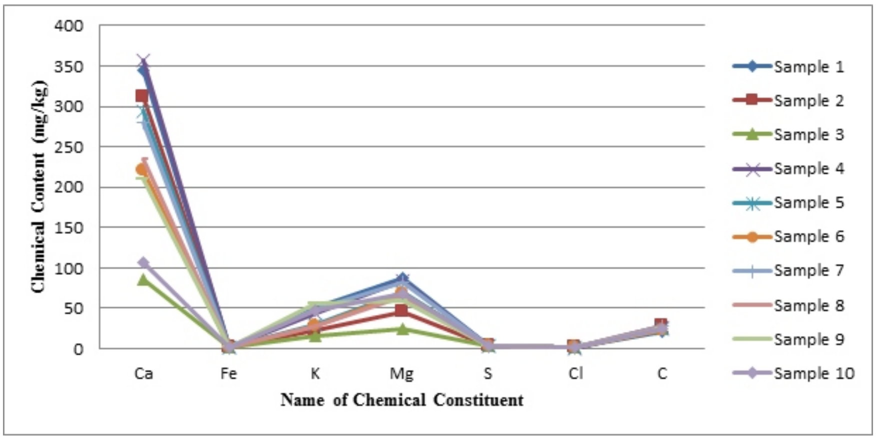

Figure 1. Chemical Composition of the Samples