Assessment of Fine Aggregates from Different Sources in Ibadan and Environs for Concrete Production

W. O. Ajagbe[1], M. A. Tijani[2*], I. S. Arohunfegbe[1], M. T. Akinleye[2]
[1]Department of Civil Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria.
[2]Department of Civil Engineering, Faculty of Engineering, Adeleke University, P.M.B. 250, Ede, Nigeria.

ABSTRACT: Assessment of natural sand being used as fine aggregate for concrete production in Ibadan and its environs was carried out. Ten sources (F1 – F10) were selected for the study; four (F5, F6, F7, F8) were river sand sources while six (F1, F2, F3, F4, F9, F10) were burrow pit sand sources. Samples from each source were subjected to sieve analysis, atterberg limit, bulk density, specific gravity, water absorption, sand equivalent, clay lumps and friable particles, amount of materials passing 75µm and organic impurities adopting ASTM standard procedures. Results revealed that sand from river sources met all the criteria for concrete production stated in ASTM standard while sand from burrow pits deviated from limits of the standard in some respects. F10 had water absorption of 2.6% which exceeded maximum 2% specified, F9 was not free from clay lumps and friable particles with a significant value of 6% as against 3% maximum specification. F1, F2, F3, F4, F9 and F10 have more amounts of materials passing the 75µm sieve ranging from 10.8% for F9 to 20.1% for F10 than maximum of 5% in standard specification while F1, F9 and F10 showed an indication of having organic impurities. It is recommended that performance test be conducted on concrete made from burrow pits sand before use for concrete production. The knowledge of this study can be used as a prospecting tool for selecting suitable sand for the production of quality concrete.

KEYWORDS: Aggregate, burrow pit sand, concrete, organic impurities, river sand.

[Received May 22 2017; Revised December 5 2017; Accepted December 13 2017]

I. INTRODUCTION

It is germane to note that concrete will only become a quality material for construction when its constituents are properly sourced. The quality of fine aggregate can vary significantly due to the geographic location and environmental condition. According to Oke (2011), poor quality of materials has accounted for more than 50% of causes of building collapse in Nigeria. Ayininuola and Olalusi (2004) and Ede (2011) stated that the use of substandard materials for concrete is the leading cause of building collapse in Nigeria. Provision of necessary information to local concrete industry and practitioners regarding the application of aggregates from different sources will prevent selection of substandard aggregates for concrete (Ajagbe *et al.*, 2017). Bosede and Sunday (2014) as well as Fakere *et al.* (2012) reiterated that poor materials do not make good concrete. Cement, sand and stone must all have the attributes and qualities stated in the standard specifications. Gollu *et al.* (2016) mentioned unsuitable materials, unsound aggregate, reactive aggregate, contaminated aggregate as among the sources of concrete failure in buildings.

ASTM C33-03 specifies that a fine aggregate shall consist of natural sand, manufactured sand, or a combination thereof and ASTM C125-03 defines fine aggregate based on the particle size as an aggregate passing the 9.5mm (3/8in.) sieve and almost entirely passing the 4.75mm (No. 4) sieve and predominantly retained on the 75µm (No. 200) sieve; or that portion of an aggregate passing the 4.75mm (No. 4) sieve and retained on the 75µm (No. 200) sieve. Generally, fine aggregates for concrete construction purposes are normally sourced locally and are available in natural deposits at various locations and along the shores of rivers.

It exists abundantly as a surface deposit along the courses of rivers, on the shores of lakes and the sea, and in arid regions (Neville, 2011). In Ibadan, rivers and burrow pits sand are majorly used as fine aggregate materials for concrete production because of the presence of many rivers and natural deposits of sand. Fine aggregates have great influence on the workability and cost of concrete. Very coarse sands produce harsh and unworkable concrete mixtures, and very fine sands increase the water requirement and are uneconomical. Aggregates that do not have a large deficiency or excess of any particular size produce the most workable and economical concrete mixture (TTTI, 2005 and Neville, 2011).

ASTM C 33-03 requires that "aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion except that if such materials are present in injurious amounts, the aggregate may be used with a cement containing less than 0.6 percent alkalies or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction". According to Neville (2011), the presence of a significant amount of

doi: http://dx.doi.org/10.4314/njtd.v15i1.2

organic impurities such as decayed vegetable matter in the form of organic loam or humus in aggregate can lead to concrete setting and hardening problems. Materials with excessive amount of fines increase the overall surface area and consequently bring about increase in the amount of water required to wet all the particles in the mix, posing workability problems (Neville, 2011). It was noted in BS 882 that materials having lower or higher values could be used if an evidence of satisfactory performance in use or a valid result of trial mixes exists to justify their adoption.

Mehta and Monteiro (2001) stated that aggregates exercise a significant influence on strength, dimensional stability, and durability of concrete and in addition to these important properties of hardened concrete, aggregates also affect greatly the cost and workability of concrete mixtures. Chen and Liu (2004) as well as Rao and Prasad (2002) viewed aggregates as the skeleton of concrete and consequently persuaded that all forms of coatings should be avoided in order to achieve a good concrete.

Occurrences of building collapse linked to poor quality concrete are many in Nigeria nowadays. Specifically in Ibadan, the collapse of two-storey building under construction that occurred at Ologuneru in Ido Local Government area of Ibadan city was associated with bad concrete. The building was reported to collapse the same day they concluded casting of the concrete first floor slab. The report of the committee that investigated the collapse revealed that poor quality of aggregates materials were used for the production of concrete. A building being used as Nursery/primary School at Olomi area Ibadan collapsed in March 2008 due to the use of substandard materials for concrete and took the lives of 13 pupils. In July 2011, the two-storey building which collapsed at Oleyo area, Odo-Ona Elewe in Oluyole Local Government Area is another example of bad concrete practice among others.

The incidence took live of about five workers and left four others injured. In another episode, a two-storey building under construction at Kobiowu Crescent, Iyanganku GRA in Ibadan also collapsed leaving one person dead with nine others sustaining serious injuries in March 2017. In the various ways concrete is used, it is exposed to a variety of stresses, and the response of the structure in which it is used will largely depend on the properties of the aggregate (Egesi and Tse, 2012).

This study aims to provide important information on the geotechnical and physical properties of fine aggregates found from different sources in Ibadan and environs. The study outcome will provide local concrete industry and practitioners necessary information regarding the application of fine aggregates sourced from Ibadan for producing concrete. This will prevent them from making wrong choice of selecting unsuitable fine aggregate materials that may lead to concrete failure as well as collapse in buildings.

The results from this study will establish sources with the best fine aggregate materials for quality concrete production. The knowledge acquired from this study can be used as a prospecting tool for selecting suitable sand for production of quality concrete.

II. METHODOLOGY

Ten sources were selected for the study based on the results of questionnaire administered to consultants, contractors and suppliers of aggregates within the city of Ibadan. Four of the sources are river sand sources while the rest six are burrow pits sand sources. The questionnaire was designed to capture data on the sources/locations of fine aggregates in the study area. The sources and location of selected aggregates are shown in Table 1.

Table: 1 Description of the studied aggregates.

S/N	Name	Sample Code	Location
1.	Ikire burrow pit	F1	Mojeroku, Ikire (a neighbouring town to Ibadan), Ayedade Local Government Area, Osun State.
2.	Ogunmakin burrow pit	F2	Ogunmakin, another neighbouring town to Ibadan located in Ogun State. It is a few minutes' drive from New Garage in Ibadan
3.	Onigari burrow pit	F3	Onigari bus-stop along Lagos-Ibadan Expressway Ibadan, Oyo State.
4.	Ona-Ara burrow pit	F4	Ona-Ara Area, Ona-Ara Local Government Area, Ibadan, Oyo State.
5.	Ogunpa River	F5	Omitowoju area, Mokola, Ibadan North Local Government Area, Ibadan, Oyo State.
6.	Ajibode River	F6	Ajibode area, Sasa Road, Ibadan North Local Government Area, Ibadan, Oyo State.
7.	Moniya River	F7	Moniya area, Akinyele Local Government Area, Ibadan, Oyo State.
8.	Akinyele River	F8	Sasa area, Akinyele Local Government Area, Ibadan, Oyo State.
9.	Egbeda burrow pit	F9	Egbeda area, Egbeda Local Government Area, Ibadan, Oyo State.
10.	Iddo burrow pit	F10	Iddo Area, Iddo Local Government Area, Ibadan, Oyo State.

For field sample collection, procedures given in ASTM D75 were adopted as a guiding principle in the sampling procedure. ASTM C702 informed and guided the sampling procedure employed in reducing the field sample to obtain the required test portion for each of the tests performed.

Sand from each sources were subjected to series of laboratory experiments in accordance with ASTM standards. ASTM C136 was used for Particle size distribution analysis, ASTM C29 for bulk density, ASTM C128 for specific gravity and water absorption, ASTM D2419 for sand equivalent, ASTM C142 for clay lumps and friable particles, ASTM C117 for amount of materials passing 75µm, ASTM C40 for organic impurities and ASTM D4318 for atterberg limit.

The plasticity index (PI) was computed as the difference between the liquid limit (LL) and the plastic limit (PL). The samples were classified using the Unified Soil Classification System described in ASTM D 2487. The test results were compared with ASTM standard to determine aggregate suitability for concrete production.

III. Results and Discussion

A. Geotechnical Properties

The gradation chart obtained is presented in Figure 1. It shows that some fine aggregates fell within the lower and upper limits specified by ASTM standard while some deviated from the limits. Table 2 shows the percent fines (% fines), percent sand (% sand), percent gravel (% gravel), coefficient of uniformity (Cu), coefficient of curvature (Cc), fineness modulus (FM) and the plasticity index computed from the results of particle size distribution analysis and Atterberg limits tests. The result from Table 2 was used for samples classification according to the Unified Soil Classification System as presented in Table 3.

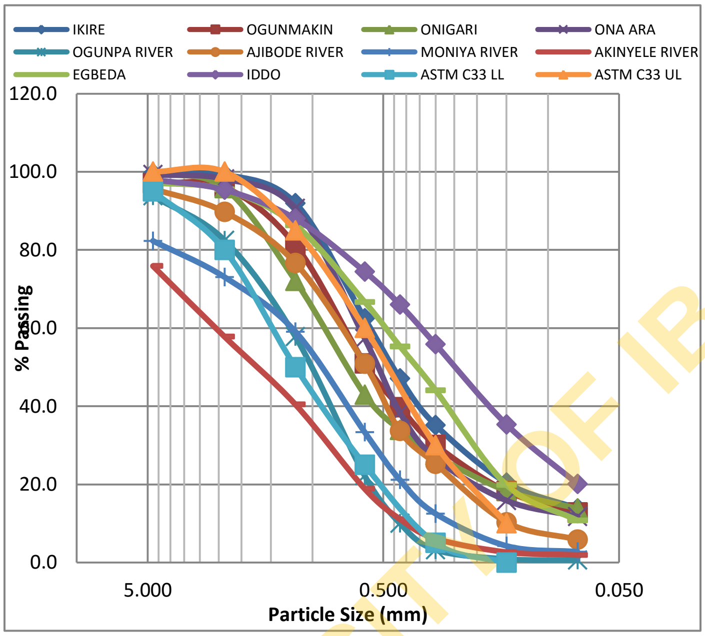

Figure 1: Particle size distribution for aggregates used in this study.

Table 3: Soil classification according to USCS.

S/N	Sample Code	Group Label	Group Name
1.	F1	SM	Silty Sand
2.	F2	SM	Silty Sand
3.	F3	SM	Silty Sand
4.	F4	SP-SM	Poorly Graded Sand With Silt
5.	F5	SP	Poorly Graded Sand
6.	F6	SP-SM	Poorly Graded Sand With Silt
7.	F7	SP	Poorly Graded Sand With Gravel
8.	F8	SP	Poorly Graded Sand With Gravel
9.	F9	SW-SM	Well Graded Sand With Silt
10.	F10	SM	Silty Sand

The classification results showed that most of the samples were poorly graded except F9 that was well graded but with silt of 10.77% fines that is greater than the maximum 5% allowed for pure sand classification. A given sample is well graded when Cu is equal or greater than 6 (Cu >= 6) and Cc is between 1 and 3 (1<=Cc<=3), otherwise it is poorly graded (Thomas, 2003). Furthermore, most of the samples have silt component due to the presence of considerable amount of fines (% fines greater than 5 %), only F5, F7 and F8 have fines less than 5%, but the latter two (F7and F8) have gravel content greater than 15%. The implication of this poor grading and % fines and gravel being on the high side is that concrete made from these materials might pose workability problems and necessary measure such as introduction of mineral admixture to curtail this problem should be envisaged (Ken, 1999 and Neville, 2011).

Summarily, out of the applicable six grading limits specified in ASTM C 33-03 for materials proposed for use in fine aggregate (Table 2), F6 closely satisfied all the six limits, F2 and F3 satisfied five, F4 and F7 satisfied four, F5 satisfied three while F1, F8, F9 and F10 satisfied two out of the six specified limits. However, the ASTM permits the use of aggregate material failing to meet the specified grading requirements if it can be demonstrated that concrete of the class specified made with such aggregate have an acceptable performance record in similar concrete construction.

Table 2: Sieve Analysis and Atterberg Limits Results.

S/N	Sample Code	% Fines	% Sand	% Gravel	Cu	Cc	FM	LL	PL	PI
1.	F1	13.82	85.71	0.47	13.02	2.20	1.9	14	NP	NP
2.	F2	12.81	84.21	2.98	14.04	2.37	2.3	NP	NP	NP
3.	F3	13.83	85.91	0.26	21.95	3.32	2.4	15	NP	NP
4.	F4	11.78	87.49	0.73	11.92	3.59	2.1	15	NP	NP
5.	F5	0.62	93.24	6.14	2.94	0.92	3.4	NP	NP	NP
6.	F6	5.88	89.78	4.34	4.93	1.23	2.5	NP	NP	NP
7.	F7	2.76	79.56	17.68	4.84	1.00	3.5	NP	NP	NP
8.	F8	1.95	73.93	24.12	6.25	0.74	4.0	NP	NP	NP
9.	F9	10.77	86.44	2.79	7.00	1.29	1.9	NP	NP	NP
10.	F10	20.09	77.9	2.01	7.02	0.93	1.5	17	NP	NP

*C

Theoretically, liquid limit will normally range from around 20% for silts to 100% and above for high-plasticity clays and plasticity index from near 0% (i.e. a non-plastic soil) for silts to over 50% for high-plasticity clays (Michael, 2011).

The standard specifies that soil be reported as non-plastic in the event where the liquid limit or the plastic limit could not be determined or where the result of the plasticity index is negative (plastic limit greater than liquid limit). Atterberg limits results in Table 2 showed that all the sampled aggregate materials were non-plastic due to the inability to determine the plastic limit or both the plastic limit and the liquid limit. It implies that all the sampled fine aggregate materials have a plasticity index of 0 % and that the fine grained portion composed mainly of silt particles. Both the plastic and the liquid limit could not be determined for all the rivers sand (F5, F6, F7 and F8) and two (F2 and F9) burrow pits sand. The liquid limit results for F1, F3, F4 and F10 as shown in Table 2 ranges from 14% to 17%, which confirmed that the fine grained portions of the samples are composed of silt particles by having a liquid limit value less than 20%.

On the basis of the fineness modulus (FM), only F2, F3 and F6 have fineness modulus within the range of 2.3 - 3.1 given in the ASTM standard. Others have fineness modulus values outside this range on either side of the extremes with F10 having the lowest fineness modulus of 1.5 and F8 having the highest fineness modulus of 4.0 as shown in Table 2. Generally, samples with fineness modulus outside the specified range of 2.3 – 3.1 will pose workability problems and supplementing them with mineral admixture in areas of their deficiency to make them workable may therefore be necessary (Kosmatka *et al.*, 2003; Neville, 2011). Specifically, the coarser materials having little or no fines (like F7 and F8) will likely produce fresh concrete bleeding excessively, proving difficult to be pumped (ASTM C 33), not easily compacted and hardened concrete having honeycomb and voids that would otherwise have been filled up with fines (Obla, 2011).

Furthermore, this class of materials will tend to produce concrete that is not homogenous (segregation) and that is resistant to surface finish attempts leading to hardened concrete that is porous, less dense and having rough surface (TTTI, 2005). On the other hand, sampled aggregate materials with excess amount of fines will affect the amount of water and cement required to achieve a workable concrete and satisfy water cement ratio requirement owing to an increase in the surface area to be wet by the water (Ken, 1999).

B. *Physical Properties*

1) Bulk density

Bulk density is the weight of aggregate required to fill a container of unit volume. It is used in mix design calculations for concrete. Both compacted and loose bulk density tests were performed on the samples and were recorded for both rivers and burrow pits sand. The results of loose bulk density ranges from 1320kg/m^3 - 1550 kg/m^3 while compacted bulk density ranges from 1440 kg/m^3 - 1660 kg/m^3 as shown in Table 4.

These results showed that the samples satisfactorily fit into the description of normal weight aggregate given in ASTM C 125 as aggregate having bulk density ranging from 1120 – 1920 kg/m^3 and as such can be used as aggregate for normal weight concrete addressed by ASTM C 33-03.

Table 4: Physical properties of fine aggregate from different sources.

S/N	**Sample Code**	**Bulk Density (kg/m^3)**		**Specific Gravity (kg/m^3)**		
		Loose	Compacted	OD	SSD	Apparent
1	F1	1420	1550	2.54	2.59	2.66
2	F2	1420	1550	2.54	2.59	2.66
3	F3	1360	1470	2.48	2.54	2.65
4	F4	1320	1440	2.51	2.56	2.64
5	F5	1470	1590	2.62	2.64	2.67
	F6	1480	1600	2.58	2.61	2.67
7	F7	1550	1660	2.57	2.62	2.69
8	F8	1530	1620	2.55	2.6	2.68
9	F9	1430	1570	2.56	2.59	2.65
10	F10	1480	1660	2.55	2.57	2.6
	ASTM Limits	1120 - 1920		2.40 – 3.00		

S/N	**Sample Code**	**Water Absorption (%)**	**Materials Finer than 75µm (%)**	**Clay Lump & Friable Particles (%)**	**Sand Equivalent (%)**
1	F1	1.8	13.8	1.99	50
2	F2	1.7	12.8	1.34	34
3	F3	2.6	13.8	0.18	31
4	F4	2	11.8	5.96	37
5	F5	0.7	0.6	0.4	81
6	F6	1.2	5	0.32	67
7	F7	1.7	2.8	0.7	77
8	F8	1.8	2	0.16	86
9	F9	1.3	10.8	0.96	59
10	F10	0.8	20.1	1.33	38
		Max 2%	Max 5%	Max 3%	-

OD = oven-dry, SSD = saturated-surface-dry

2) Specific Gravity

The specific gravity of all the samples tested is within the standard range (Table 4). It was found to vary from a minimum of 2.48 (OD) for F3 to a maximum of 2.67 (Apparent) for F2. Specifically, the oven-dry specific gravity results range from 2.48 – 2.62, the saturated-surface-dry specific gravity ranges from 2.54 – 2.64 and the apparent specific gravity ranges from 2.64 – 2.69. As expected, the relation OD < SSD < Apparent, holds for the entire sampled fine aggregate material. According to Kosmatka et al. (2003), relative densities for most natural aggregates fall between 2.4 and 2.9. ASTM C33 specifies specific gravity range of 2.40 – 3.00 for normal weight aggregates.

3) Water Absorption

Water absorption controls the concrete quality (water-cement ratio). The rates of water absorption for all the samples tested are below 2% specified in ASTM C33 except for F3 with a value of 2.6% slightly higher than specification. F5 has the least affinity for water with absorption rate of 0.7%. This implies that F5 has the least amount of pore spaces and relatively the most sound while F3 has the highest amount of pore spaces and the least on the soundness scale. In concrete mix proportioning, for a given water cement ratio (w/c), the aggregates with considerable absorption will require additional water and cement to meet the w/c requirement and make the fresh concrete workable (Neville, 2011).

4) Materials Finer than 75µm sieve

The amount of materials finer than 75µm sieve ranges from 0.6% - 5% for river sand and 10.8% - 20.1% for sand from burrow pits. ASTM C33-03 specifies maximum value of 3% for concrete subjected to abrasion and 5% for all other concrete uses. BS 882 specifies 4% for gravel sand for all concrete uses. This shows that all river sand fell within the limit specification of ASTM while the burrow pits sand violated the limits. Gaynor and Meininger (1983) reported that increased 75-µm (No. 200) sieve size material in fine aggregate material requires an increased dosage of air entraining admixture to obtain required air content.

5) Clay Lump & Friable Particles

The results of clay lump and friable particles show that all aggregate samples have values less than maximum 3% specified in ASTM except for F4 with a high value of 5.96%. The presence of clay lumps in considerable amount will result in popouts near the concrete surface. Friable particles are easily broken down into smaller particles.

Deterioration of friable particles may result in freeze-thaw damage of the concrete (Lamond and Pielert, 2006). According to Mehta and Monteiro (2001) and Neville (2011), clay lump and friable particles exist as surface adherent coatings or lumps in aggregate and when present in an undesirable amount they may interfere and seriously affect bond development between aggregate particles and the cement paste and subsequently affecting strength and durability of the concrete.

6) Sand Equivalent

The measure of amount of silt or clay contamination in the fine aggregate called sand equivalent was recorded. The results range from a minimum of 31% for F3 to 86% for F8. Fine dust and plastic fines are undesirable in cement concrete and as such the use of those with extremely low (less than 30%) sand equivalent values should be discouraged. It can be deduced from the results shown in Table 4 that the four river sand samples gave better sand equivalent values when compared to burrow pits sand. This might be because of the washing effect of water on these samples that has purified them from fine dust contamination.

A low sand equivalent value suggests more clay-like or plastic fines and therefore the water demand and fresh properties of concrete can be affected (Gaynor and Meininger, 1983).

7) Presence of Organic Impurities

Table 5 shows the result of test performed to determine the presence of organic impurities by colour comparison using potassium dichromate standard colour solution. It was observed that five samples: F2, F3, F4, F5 and F7 have colours lighter than the standard colour solution. Two samples (F6 and F8) have colours equal to the standard colour solution and the remaining three burrow pits sand samples F1, F9 and F10 have colours darker than the standard colour solution. ASTM C 33-03 requires that materials proposed for use as fine aggregate be free of injurious amount of organic impurities.

A material is deemed to contain organic impurity if it produces a colour darker than the standard. Hence, F1, F9 and F10 contain organic impurities while others are free from it. F5 with the least amount of materials finer than 75µm sieve (0.6%) had the lightest colour while F10 with the highest amount of materials finer than 75µm sieve (20.1%) had the darkest colour compared to the standard colour solution.

Table 5: Test for the Presence of Organic Impurities

S/N	Sample Code	Result	Interpretation
1.	F1	Darker	Organic Impurities Present
2.	F2	Lighter	Organic Impurities Not Present
3.	F3	Lighter	Organic Impurities Not Present
4.	F4	Lighter	Organic Impurities Not Present
5.	F5	Lighter	Organic Impurities Not Present
6.	F6	Equal	Organic Impurities Not Present
7.	F7	Lighter	Organic Impurities Not Present
8.	F8	Equal	Organic Impurities Not Present
9.	F9	Darker	Organic Impurities Present
10.	F10	Darker	Organic Impurities Present

IV. CONCLUSION

A practical approach has been presented for the assessment of fine aggregate from different sources in Ibadan and environs in order to determine their suitability for concrete production. The comprehensive assessment used in this study revealed that fine aggregates from river sources fell within the ASTM limit of standard specifications of the physical properties of aggregates while those from burrow pits were found to deviate from limits in certain respect. F10 had water absorption of 2.6% which exceeded maximum 2% specified, F9 was not free from clay lumps and friable particles with a significant value of 6% as against 3% maximum specification. F1, F2, F3, F4, F9 and F10 have more amounts of materials passing the 75µm sieve ranging from 10.8% for F9 to 20.1% for F10 than maximum of 5% in standard specification while F1, F9 and F10 showed an indication of having organic impurities.

It is concluded that only fine aggregate from river sources can make quality concrete because of their compliance with the requirement of the standard. It is recommended that performance test be conducted on concrete made from burrow pits sand to ascertain the level of interference of deleterious substances in them on chemical reaction of cement hydration, bond development between aggregate and cement paste as well as strength and durability of concrete before being used in concrete construction.

REFERENCES

Ajagbe W. O.; Tijani, M. A. and Oyediran, I. A. (2017). Engineering and geological evaluation of rocks for Concrete Production. LAUTECH Journal of Engineering and Technology, 9 (2): 67 – 79.

ASTM (American Society for Testing and Materials). (1997). Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate. C29/C29M. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (1997). Standard Test Method for Clay Lumps and Friable Particles in Aggregates. C142. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (1998). Standard Practice for Reducing Samples of Aggregate to Testing Size. C702. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2000). Standard Practice for Classification of Soils for Engineering Purposes (USCS). D2487. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2000). Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. D4318. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2001). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. C136. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2001). Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate. C128. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2002). Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate. D2419. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2003). Standard Specification for Concrete Aggregates. C33. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2003). Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing. C117. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2003). Standard Terminology Relating to Concrete and Concrete Aggregates. C125. West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2003). Standard for Sampling Aggregates. D75.West Conshohocken, PA, USA.

ASTM (American Society for Testing and Materials). (2004). Standard Test Method for Organic Impurities in Fine Aggregates for Concrete. C40.West Conshohocken, PA, USA.

Ayininuola, G. M. and Olalusi, O. O. (2004). Assessment of Building Failures in Nigeria: Lagos and Ibadan Case Study. Africa Journal of Science and Technology, 5 (1): 73 – 78.

Bosede, A. F. and Sunday, G. M. (2014). An Investigation on the Causes of Building Collapse in Nigeria. Journal of Environmental Sciences and Resources Management, 6 (1): 12 – 22.

BSI (British Standard Institution). (1992). Specification for Aggregates from Natural Sources for Concrete. BS882. London, UK.

Chen, B. and Liu, J. (2004). Effect of Aggregate on the Fracture Behaviour of High Performance Concrete. Construction and Building Materials, 18 (8): 585 – 590.

Ede, A. N. (2011). Measures to Reduce the High Incidence of Structural Failures in Nigeria. Journal of Sustainable Development in Africa, 13 (1): 153 – 161.

Egesi, N. and Tse, A. C. (2012). Engineering–Geological Evaluation of Rock Materials from Bansara, Bamenda Massif Southeastern Nigeria, as Aggregates for Pavement Construction. Geosciences, 2 (5): 107 – 111.

Fakere, A. A.; G. Fadairo and R. A. Fakere. (2012). Assessment of Building Collapse in Nigeria: A Case of Naval Building, Abuja, Nigeria. International Journal of Engineering and Technology, 2 (4): 584 – 591.

Gollu, V. K.; D. Allam and S. Erla. (2016). Causes of Concrete Failure. International Journal of Advanced Technology in Engineering and Science, 4 (4): 198 – 206.

Ken W. D. (1999). Concrete Mix Design, Quality Control and Specification. (2nd ed.), E & FN Spon, London.

Kosmatka, S. H.; B. Kerkhoff and W. C. Panarese. (2003). Design and Control of Concrete Mixtures. (14th ed.), Portland Cement Association, Skokie, Illinois, USA.

Lamond, J. F. and Pielert, J. H. (2006). Significance of Tests and Properties of Concrete and Concrete-Making Materials. Journal of ASTM International, Volume 169, Part 4 of STP / ASTM International.

Mehta, P. K. and Monteiro, P. J. M. (2001). Concrete Microstructure, Properties and Materials. (2nd ed.), Mc Graw-Hill Professional, New York.

Michael, E. K. (2011). Soil Mechanics Lab Manual. (2nd ed.), John Wiley & Sons, Inc. USA.

Neville, A. M. (2011). Properties of Concrete. (5th ed.), Pearson Education Limited, England.

Obla, K. H. (2011). Variation in Concrete Performance Due to Aggregates. Concrete InFocus, 10 (5): 9 – 14.

Oke, A. (2011). An Examination of the Causes and Effects of Building Collapse in Nigeria. Journal of Design and Built Environment, 9: 37 – 47.

Rao, G. A. and Prasad, B. K. R. (2002). Fracture Energy and Softening Behaviour of High-Strength Concrete. Cement and Concrete Research, 32: 247 – 252.

Technical Teachers' Training Institute, TTTI, Chandigarh. (2005). Civil engineering materials. Tata Mc Graw-Hill, New Delhi.

Thomas, F. W. (2003). Soil Relationships and Classification. In W. F. Chan and J. Y. Richard (Eds.), the civil engineering handbook (776–794). USA: CRC Press (Taylor and Francis Group).

Vanguard, 2 March, 2017. NEWS headline, "One dead, 9 injured in Ibadan as building collapses". Retrived from https://www.vanguardngr.com/2017/03/one-dead-9-injured-ibadan-building-collapses/. Assessed on 1/12/2017

Vanguard, 3 May, 2014. NEWS headline, "Building collapses in Ibadan, one feared dead" https://www.vanguardngr.com/2014/05/building-collapses-ibadan-one-feared-dead/. Assessed on 1/12/2017