Characteristics of Concrete Containing Iron Ore Tailings as Partial Replacement of Sand

Akilu, M. A[1].; Oritola, S.F[2].; Abbas, B. A[3].
Department of Civil Engineering, Federal University of Technology, PMB 65 Minna, Niger State, Nigeria.
Corresponding email: kizzy01@gmail.com

Abstract
*Natural sand has been the conventional fine aggregate in concrete production for many decades. However, there has been extensive research into alternative materials suitable to replace sand in concrete. In this research Itakpe Iron Ore Tailings (IIOT) was used as partial replacement of fine aggregate in concrete production. The IIOT was obtained from different locations at the tailings dump sites of National Iron Ore Mining Company (NIOMCO) in Itakpe, Kogi State, Nigeria. Sieve analysis, Specific gravity, Bulk density, Moisture content, AIV and ACV tests were carried out on the aggregate. Three concrete specimens were prepared from a mix of designed strength 25N/mm^2. IIOT was used to replace fine aggregates from 0% to 20% in steps of 5%. Concrete cubes measuring 150 x 150 x 150mm were cast and theirdensities and compressive strengths evaluated at 3, 7, 14, 21 and 28 days. The result showed IIOT concrete had high densities than control due to the Iron (Fe) content while that of 5% IIOT has the highest compressive strength of concrete at 28days and 15% and 20% were very close to 5%. The findings of this research showed there is a potential towards utilization of IIOT in construction applications and can serve as a normal aggregate alternative for future use. Tailings promote the preparation of eco-friendly IIOT concrete and provide a new way to use waste resource*s.

Keywords: Concrete, Iron ore tailings, Itakpe, Compressive strength, Sand replacement

Introduction

Concrete is the basic material in all construction works. Concrete is a solid mass made by the use of a cementing medium, generally the ingredient consists of cement(binder), fine aggregate(sand), coarse aggregate (gravel) and water. Concrete is a construction and structural material consisting of hard, chemically inert particles substance known as aggregate such as sand and gravel, that is bonded together by cement and water (Abdullahi, 2006).

Natural sand has been the conventional fine aggregate in concrete production for many decades. However, there has been extensive research into alternative materials suitable to replace sand in concrete. The need to find replacement for sand stems from the fact that in most parts of the world, there is growing concern about the depletion of sand deposits, environmental and socio-economic threats associated with extraction of sand from river banks, coastal areas and farm lands (Aditya and Lakshmayya, 2016). Some alternative materials which have been studied for use as partial replacement for sand include fly ash, slag limestone, silica stone, furnace bottom ash and recycled fine aggregate (Siddique, 2003).

Ugama *et al.* (2014); Uchechukwu and Ezekiel (2014) examined the feasibility of reusing Iron Ore Tailings (IOT) after conducting, physical, compressive and tensile tests, as a substitute for fine aggregate (sand). The presence of heavy metals concentration in Iron rich soil for Iron ore in the following order of trend Fe > Pd > Mn > Zn > Cr > Ni > Cu > Cd were found within the neighbouring farm lands of Itakpe Iron Ore mines, Kogi State(Itodo *et al.*, 2017).

Itakpe iron-ore deposit has an orereserve of about 200 million tonnes with an average of36% Fe content with a conservative mine life at 25 years under average productionrate of 8 million tonnes per year(Audu *et al.*, 2013; Oladeji *et al.*, 2015). The Itakpe iron ore deposit in Nigeria which has a total estimated reserve of about 182.5 million metric tonnes consists mainly of quartzite with magnetite and hematite (Soframines, 1987). The Itakpe project was designed to treat a minimum of 24,000 tons of ore per day and operate 300 days per year. For a plant of production capacity of 24,000 tons per day, an average ore grade of 36%, 64% gangue, 20% iron mineral content in waste and at an average concentrate price of ($1,200 per ton of concentrate)(Soframines, 1987; Ajaka, 2009).

The level of utilization stems from sustained research work carried out regarding increasing application of IOT fine aggregate.Studies into properties of hardened concrete have shown there is decrease in drying shrinkage with Itakpe IOT in concrete. The decrease in drying shrinkage is mostly attributed to high percentage of fines if the IIOT and also the rough texture of the tailing particles(S. F. Oritola *et al.*, 2017).Uchechukwu and Ezekiel (2014) evaluated the properties of IIOT which showed that it has pozzolanic properties, and can be used as a retarder for hot-weather concreting.

Adebimpe and Fatoye (2021) characterised IIOT as fine medium sand with low porosity, permeability, high specific gravity, having mainly crystalline phases of quartz (SiO2), Hornblende, Amphibole, Haematite, Magnetite, Calcite and Plagioclase. Similarly, Alabi *et al.* (2019) studied the chemical composition of IIOT consisting of C, Ti, Al, Mn, Cu, and O within the mineral matrix; such that iron, titanium, and silicon are the major elemental constituents.Radiological impacts of IIOTcannot constitute external radiological problems to its workers and the public in general(Audu *et al.*, 2013).

IOT used as fine aggregate replacement in cement concre was suitable for low grade concrete pavement in rural areas due to its high density, high axial compression and low deformation due to external loads(Costa and Adriana, 2010; Che *et al.*, 2019).Kankam *et al.* (2017) studied the characteristics of replacing fine aggregate with Quarry dust on the stress-strain curve (SSC). Similarly, Ilangovan and Nagamani (2007) investigated into the durability of quarry dust concrete showing it had improved both the strength and durability properties of the concrete.

Gonzalez *et al.*, (2020)studied the replacement of IOT as a substitute for natural aggregates for production in Ultra-High-Performance Fibre-Reinforced Concrete (UHPFRC) at 50%, 70% and 100% by volume of 0–0.5 mm natural silica sand. The results obtained indicated the variations in the properties of consistency, compressive strength, modulus of elasticity and tensile strength, were acceptable for substitutions of up to 70%. Similarly, (Jiang *et al.*, 2019) observed that the sand replacement in eco-friendly Ultra-High Performance Concrete (UHPC) containing aeolian sand improved the workability,strength and toughness of UHPC but the aeolian sand accessibility proved to be a challenge yet resolved.

Experimental Work

Materials

Ordinary Portland limestone cement as the binding agent, river sand and ItakpeIron Ore Tailings (IIOT) both of 5 mm maximum size as fine aggregate, and 20 mm crushed rock coarse aggregate were used for the concrete. The iron ore tailings used for the experiment was obtained from Itakpe mines, located in Okehi LGA, Kogi State, Nigeria. Portable water, obtained within the structurallaboratory of Kaduna Polytechnic, Tudunwada, Kaduna State, was used for the concrete production. Both sand and granite used were also obtained from kabala junction, western by-pass, in Kaduna State. The physical properties of the fine and coarse aggregates are shown in Table 1. The fine and coarse aggregates satisfied the BS 882 (1992) specification.

Table 1: Physical Properties of Aggregates

Aggregates	Un-compacted Bulk Density (kg/m^3)	Compacted Bulk Density (kg/m^3)	Fineness Modulus	Moisture Content (%)	Specific Gravity	Crushing Value (%)	Impact Value (%)
River sand	1537.44	1688.68	3.29	2.41	2.65	-	-
Itakpe Iron Ore Tailings	1660.06	1924.53	4.43	5.74	3.12	-	-
Coarse Aggregate	1641.18	1783.02	-	6.97	2.74	7.10	7.97

Method

Based on the British Standard specifications, materials used for concrete production (sand, crushed granite, and iron ore tailings) were tested before using them. Sieve analysis test BS 812: part 103 (1985), determination of moisture content and specific gravity test were conducted in order to arrive at a viable concrete mix design

Concrete Design

The Building Research Establishment (BRE) design of normal concrete mixes was adopted in this study for the selection of the proportions of constituents for concrete, to make the most economical use of available materials and to produce concrete of the required properties for adequate mix. The mix proportion was designed for characteristics strength of 25N/mm^2 maximum aggregate size of 20mm, slump 50mm, based on the procedure of the concrete mix design and using the appropriate design tables and figures. The normal weight concrete design for the production of one metre cube of concrete is presented in Table 2.

Plate I: Itakpe Iron Ore Tailings

Plate II: River sand

Proportioning of Concrete Materials

Five different types of concrete samples (C_0, C_1, C_2, C_3, and C_4) were considered, with the percentage of tailings used to replace sand as fine aggregate ranging from 0 to 20%. The reference sample is taken as C_0 with no tailings and the four others, containing tailings at 5% intervals. The reference mix adopted is that, which contain sand as the only fine aggregate. The quantities of cement, water and the coarse aggregate were kept constant for all the mix samples, the only variant are the materials used as fine aggregate (sand and iron ore tailings). The five different types of concrete samples produced and the details of the concrete mix proportioning of materials, based on water-cement ratio of 0.58, determined from Tables in BRE design of normal concrete mixes, is shown in Table 3.

Testing of Concrete

The concrete Samples produced for hardened concrete cubes were also tested for density and compressive strength using the average of three samples each and cured for 3, 7, 14, 21 and 28 days respectively based on British Standard (BS) guidelines BS 1881 Part 108 (1983) and BS 1881 Part 116 (1983) respectively

Table 2: Materials Requirements to Produce 1m^3 of normal weight concrete

Materials	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)

Quantity (kg/m^3)	362.06	668.88	1189.12	210.0
Ratio	1.00	1.85	3.28	0.58
1 Bag of Cement (kg)	50.0	92.5	164.0	29.0

Table 3: Mix Proportions of Concrete Mixes.

Constituent Materials for 0.30375m^3					
Concrete Samples	Water (kg)	Cement (kg)	Fine Aggregate mass (kg)	Itakpe Iron Ore Tailings (kg)	Coarse Aggregate (kg)
C_0	63.79	109.98	203.17	0.00	361.20
C_1	63.79	109.98	193.01	10.16	361.20
C_2	63.79	109.98	182.86	20.32	361.20
C_3	63.79	109.98	172.70	30.48	361.20
C_4	63.79	109.98	162.54	40.63	361.20
Total	318.94	549.88	914.28	101.59	1805.98

Results and Discussions

Particle Size Distribution

The Particle size distribution curve for sand, iron ore tailings and crushed granite are shown in Figure 1. The result indicates that the Iron ore tailings are very similar with the sand and the crushed granite are uniformly graded. Uniformly graded aggregate, indicates aggregate containing particles of almost the same size,with this type of grading, aggregates are not well packed, and resulting concrete will require lot of paste to make the workable concrete.

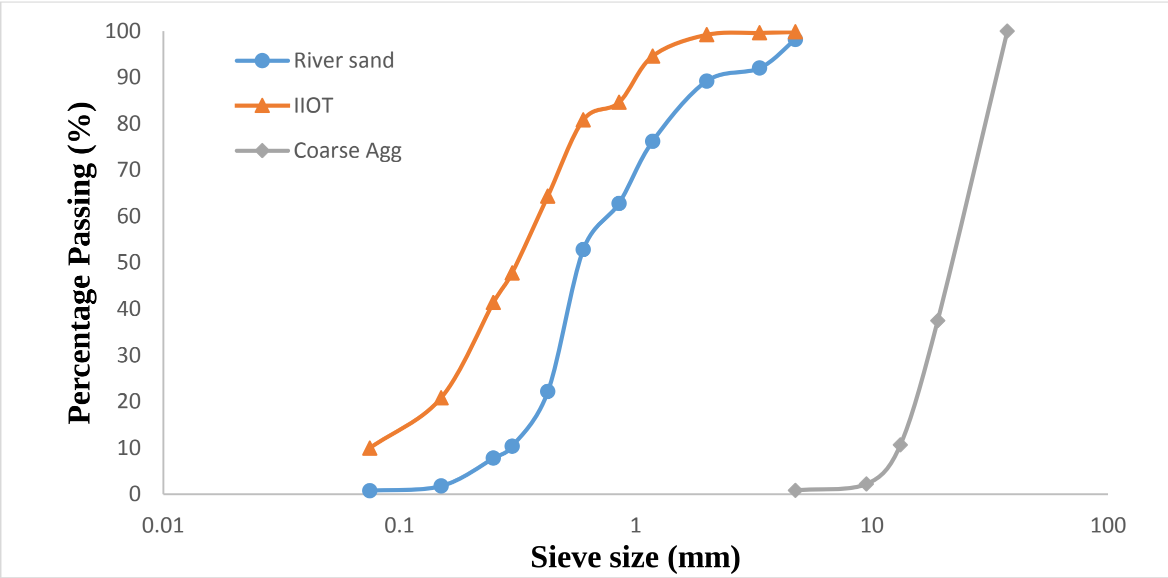

Figure 1: Sieve Analysis of Aggregates; Sand, IIOT and Coarse Aggregate

The Effect of ItakpeIron Ore Tailings on Compressive Strength of Concrete

Variation of density and compressive strength withcuring age are presented in Figure 2 and Figure 3 respectively. The density of the produced concrete cubes samples falls within the range 2400kg/m^{3}to 2553.09kg/m^3 at 28 days which makes it a heavy aggregate. The densities followed a steady increase in similar pattern with C_0 having 2553.09kg/m^3 of C_2 as the highest. The increase in densities of IIOT concrete was due to the high Iron (Fe) content. The compressive strength values range from 25.96N/mm^2 to 30.20N/mm^2 at 28days. The compressive strength increases with the increase in tailings content up to 20% replacement level. The compressive strength of all sand replacement, C_0, C_1, C_2, C_3, and C_4 at 28 days hydration period all met the desired design strength of 25N/mm^2. These are comparable with the values obtained by other researchers (S. Oritola *et al.*, 2015; Kuranchie *et al.*, 2015; Krikar and Hawkar, 2018). The results indicated that replacing 5% of the fine aggregates with IIOT yielded the highest strength, 30.47N/mm^2; this value is approximately 17.4% higher than that of the control mixture C_0but the density decreases for 5% but was close to C_0 at 28 days, which had the lowest strength, approximately 25.96N/mm^2. The strength development for IIOT percentage mix is faster up to 28 days hydration period where as the control mix containing 0% IIOT is lower.

This is due to the angular and rough texture of Itakpe Iron ore Tailings which improves the bond between cement and aggregate interface, the presence of Iron, Fe in reasonable quantity resulting in higher compressive strength.

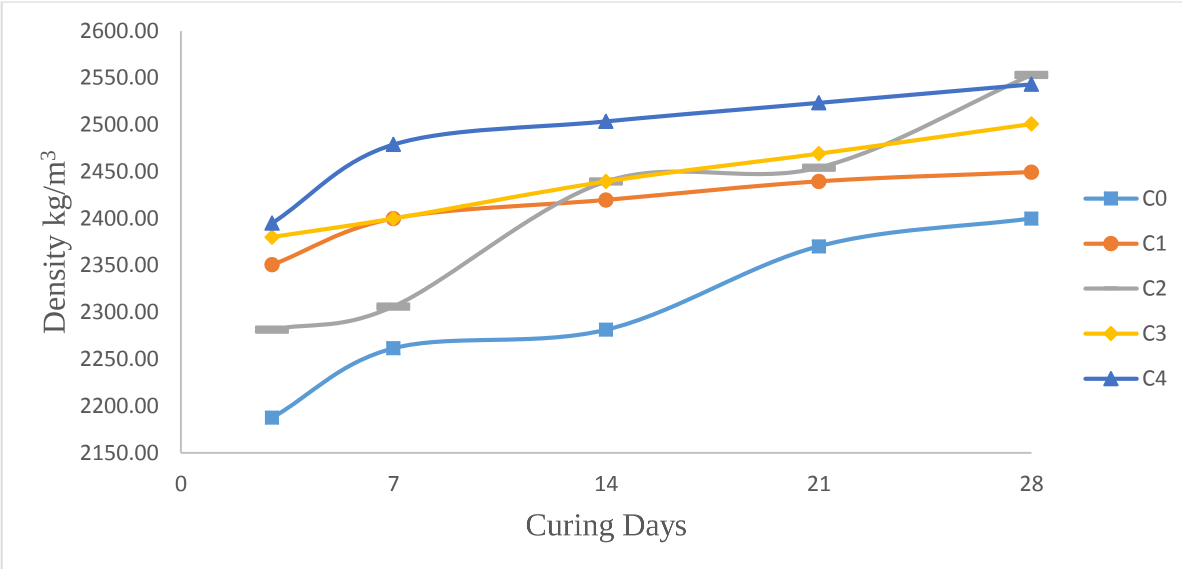

Figure 2: Variation of Density with Curing Age of Concrete

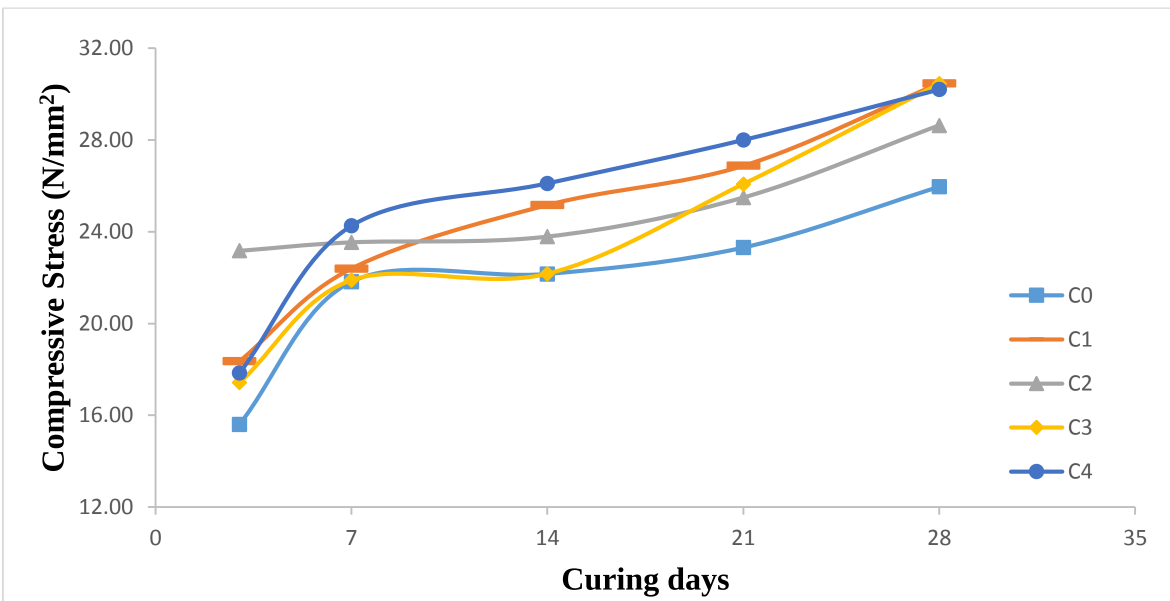

Figure 3: Variation of Compressive Strength with Curing Age of Concrete

Conclusion

From the outcome of this study, the following conclusions were drawn:

1. Properties of concrete containing iron ore tailings obtained from Itakpe, owned by Nigerian Iron Ore Mining Company(NIOMCO) Okehi LGA, Kogi Sate, Nigeria, have been determined. The hardened properties of concrete evaluated are density and compressive strengthin accordance to British Standards.

2. The fine aggregates samples were characterised to be medium grading. The IIOT was very similar to the fine aggregate but had coarse but finely graded particles than the river sand, making it compatible for replacement of fine aggregate.
3. The IIOT concrete had high densities aggregate due to the high Iron (Fe) content. The densities of C_1, C_2, C_3 and C_4 all increased 2449.38, 2553.09, 2543.21 and 2553.09kg/m^3 respectivelyat a similar pattern with C_0 at 28 days.
4. The compressive strength of IIOT concrete is much higher than the control and there is a continuous strength development comparable with that of the control. The optimum level of IIOT replacement is 5% having attained 121.88% of the design strength at 28 days but both 15% and 20% were close at 121.80% and 120.80% respectively.

References

Building Research Establishment laboratory, (1988). Note on Mix Design method, Department of Environment (DOE), London, UK.

BS 882 (1992). Specification for Aggregates from Natural Sources for Concrete. British Standards Institution, Her Majesty Stationary Office London

BS 812: Part 1 (1990). Method for Determination and Particle Size and Shape. British Standards Institution, Her Majesty Stationary Office London

BS 12 (1996). Specification for Portland Cement. British Standards Institution, Her Majesty Stationary Office London

BS 812: Part 2 (1990). Physical Properties of Aggregate. British Standards Institution, Her Majesty Stationary Office London

BS 812: Part 109 (1990). Method for Determination of Moisture Content. British Standards Institution, Her Majesty Stationary Office London

BS 1881: Part 108 (1983). Methods for Determination of Slump. British Standards Institution, Her Majesty Stationary Office London

BS 1881: Part 116 (1983). Method for Determination of Compressive Strength of Concrete Cubes. British Standards Institution, Her Majesty Stationary Office London

BS 3148 (1980). Specification for Concrete Water. British Standards Institution, Her Majesty Stationary Office London

Abdullahi, M. (2006). Characteristics of Wood ASH/OPC Concrete. *Leonardo Electronic Journal of Practices and Technologies*(8), 9-16.

Adebimpe, R. A., and Fatoye, A. O. (2021). Characterisation of Tailings from Itakpe Iron Ore Mine, Itakpe, Nigeria. *Sustainable Geoscience and Geotourism, 4,* 1-8. doi: 10.18052/www.scipress.com/SGG.4.1

Aditya, G., and Lakshmayya, M. T. S. (2016). Effective utilization of various industrial wastes in concrete for rigid pavement construction. *International Journal for Innovative Research in Science & Technology, IJIRST, 3*(3), 65-73.

Ajaka, E. O. (2009). Recovering fine iron minerals from Itakpe iron ore process tailing. *ARPN Journal of Engineering and Applied Sciences, 4*(9), 17-28.

Alabi, O. O., Gbadamosi, Y., Olatunji, A. T., and Ola-Omole, O. O. (2019). Chemical and Mineralogical Characterization of Itakpe Iron Ore Mine Wastes (Tailings). *Journal of raw material research development council, 14*(2).

Audu, D. A., Zakari, Y. I., and Ibeanu, I. G. E. (2013). Radiological Effects of Iron-Ore Mining and Processing at Itakpe, Kogi State. *Journal of Natural Sciences Research, 3*(15), 92-98.

Che, T. K., Pan, B. F., Sha, D., and Lu, J. L. (2019). *Utilization of iron tailings as fine aggregates in low-grade cement concrete pavement*. Paper presented at the IOP Conference Series: Materials Science and Engineering, The 3rd International Conference on New Material and Chemical Industry.

Costa, A. V., and Adriana, G. G. (2010, June 28 - June 30, 2010). *Use of Sinter-Feed Tailings as Aggregate in Production of Concrete Paving Elements.* Paper presented at the Second International Conference on Sustainable Construction Materials and Technologies.

Gonzalez, J. S., Lopez Boadella, I., Lopez Gayarre, F., Lopez-Colina Perez, C., Serrano Lopez, M., and Stochino, F. (2020). Use of Mining Waste to Produce Ultra-High-Performance Fibre-Reinforced Concrete. *Materials (Basel), 13*(11). doi: 10.3390/ma13112457

Ilangovan, R., and Nagamani, K. (2007). Application of quarry dust in concrete construction. *High performance Concrete, Federal highway Administration, 4*, 1-3.

Itodo, A., Egbegbedia, L., Eneji, I., and Asan, A. (2017). Iron Ore Deposit and Its Tailing Impact on the Toxic Metal Level of Neighboring Agricultural Soils. *Asian Journal of Environment & Ecology, 2*(4), 1-16. doi: 10.9734/ajee/2017/32900

Jiang, J., Feng, T., Chu, H., Wu, Y., Wang, F., Zhou, W., and Wang, Z. (2019). Quasi-static and dynamic mechanical properties of eco-friendly ultra-high-performance concrete containing aeolian sand. *Cement and Concrete Composites, 97*, 369-378. doi: 10.1016/j.cemconcomp.2019.01.011

Kankam, C. K., Meisuh, B. K., Sossou, G., and Buabin, T. K. (2017). Stress-strain characteristics of concrete containing quarry rock dust as partial replacement of sand. *Case Studies in Construction Materials, 7*, 66-72. doi: 10.1016/j.cscm.2017.06.004

Krikar, M.-G. N., and Hawkar, H. I. (2018). Mechanical Properties of Concrete Using Iron Waste as a Partial Replacement of Sand. *Eurasian Journal of Science & Engineering, 3*(3). doi: 10.23918/eajse.v3i3p75

Kuranchie, F. A., Shukla, S. K., Habibi, D., Mohyeddin, A., and Puppala, A. J. (2015). Utilisation of iron ore tailings as aggregates in concrete. *Cogent Engineering, 2*(1). doi: 10.1080/23311916.2015.1083137

Oladeji, B. G., Olorunsogo, A. A., Ajibike, F. J., and Christopher, A. S. (2015). The Effects of Iron-Ore Tailings on Setting Times of Some Commercial Cement. *Scholars Journal of Engineering and Technology (SJET), 3*(1A), 14-20.

Oritola, S., Saleh, A. L., and Mohd Sam, A. R. (2015). Performance of Iron Ore Tailings as Partial Replacement for Sand in Concrete. *Applied Mechanics and Materials, 735*, 122-127. doi: 10.4028/www.scientific.net/AMM.735.122

Oritola, S. F., Saleh, A. L., Mohd Sam, A. R., Abubakar, M., and Alhaji, B. (2017). *Comparison of Drying Shrinkage Models of IOT Concrete*. Paper presented at the 2nd International Engineering Conference (IET), Federal University of Technology, Minna, Nigeria.

Siddique, R. (2003). Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete. *Cement and Concrete Research, 33*(4), 539-547. doi: 10.1016/s0008-8846(02)01000-1

Soframines (1987). [Evaluation of the National Iron ore mining project, Itakpe. National Steel Development Agency (NSDA) – personal communication].

Uchechukwu, E. A., and Ezekiel, M. J. (2014). Evaluation of the Iron Ore Tailings from Itakpe in Nigeria as Concrete Material. *Advances in Materials, 3*(4). doi: 10.11648/j.am.20140304.12

Ugama, T. I., Ejeh, S. P., and Amartey, D. Y. (2014). Effect of Iron Ore Tailing on the Properties of Concrete. *Civil and Environmental Research, 6*(10), 7-13.