Secant Modulus of Concrete Containing Itakpe Iron ore tailings as Partial Replacement for Sand

*S. F. Oritola[1], M. A. Akilu[2], B. A. Abass[3]
[1,2,3]Department of Civil Engineering, Federal University of Technology, Minna, Nigeria, *sfaoritola@futminna.edu.ng

Abstract

Natural sand is the conventional fine aggregate material in concrete production. Due to depletion of the environment, more and more plants are removed (erosion), this leads to gradual reduction in natural sand. Also there is increasing demand for sand due to huge consumption of concrete worldwide. There is therefore, a need for alternative materials suitable to replace sand in concrete. This study, looks into the possibility of using Itakpe Iron Ore Tailings (IIOT) to partially replace sand in concrete production. The IIOT was obtained from different locations at the tailings dump sites of National iron ore mining company in Itakpe, Kogi State, Nigeria. Sieve analysis, specific gravity, bulk density, moisture content, aggregate impact value and aggregate crushing value tests were carried out on the fine and coarse aggregate. Based on the British research establishment method, a normal weight concrete mix was designed with a target strength of 25 N/mm^2. IIOT was used to replace sand at intervals of 5% ranging from 0% to 20%, resulting in one control sample and four others containing IIOT. Concrete cubes measuring 150 x 150 x 150mm were cast and their density and compressive strengths evaluated at 3, 7, 14, 21 and 28 days. The result of this study shows that all the concrete samples containing IIOT recorded higher density and compressive strength values than the control concrete sample. The concrete sample which contain 20 % tailings recorded the highest value of elastic modulus (19.6 GPa) this value is higher than that of the control sample by 17.4 %. The outcome of this study shows that, concrete mix produced according to this sample, can be used as eco-friendly material in the production of concrete.

Keywords

Secant modulus, Normal weight concrete, Fine aggregate, Iron ore tailings, Density

1. Introduction and Concept

Some studies have been carried out to find out the constituents of iron ore tailings (Oritola *et al.*, 2019), to determine the effect of iron ore tailings on the properties of concrete, produced using fly ash cement (Oritola, 2018) and to evaluate the structural application of iron ore tailings obtained from tailings dumps in Malaysia (Oritola, 2018). Concrete is a composite matrix made by the use of a cementing medium. Concrete can also be described as 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 paste (Abdullahi, 2006).

Natural sand is 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 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) as a partial substitute for sand in concrete, physical properties of the materials were determined and compressive as well as tensile strengths of concrete were also examined. The presence of heavy metals concentration such as iron, zinc, copper and manganese were found in soils within the neighbouring farm lands of Itakpe iron ore mines, Kogi State (Itodo *et al.*, 2017). Itakpe iron-ore deposit has an ore reserve of about 200 million tonnes with an average of 36% iron content with a conservative mine life of 25 years under average production rate of 8 million tonnes per year (Audu *et al.*, 2003; 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 for 300 days per year (Soframines, 1987; Ajaka, 2009).

The level of utilization stems from sustained research work carried out regarding increasing application of IOT as fine aggregate. Studies into properties of hardened concrete have shown there is decrease in drying shrinkage when iron ore tailings is used in the production of concrete. The decrease in drying shrinkage can be attributed to the uniform distribution of particles in the IOT and also the rough texture of the tailing particles (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. Kankam *et al.* (2017), also studied the characteristics of replacing fine aggregate with quarry dust, which has similar texture with iron ore tailings, on the stress-strain relationship of the concrete produced. Similarly, Ilangovan and Nagamani (2007), investigated into the durability of quarry dust concrete, showing that the dust, improved both the strength and durability properties of the concrete. Gonzalez *et al.*, (2020), studied the replacement of iron ore tailings as a substitute for natural aggregates for production in Ultra-High-Performance Fibre-Reinforced Concrete (UHPFRC). The results obtained indicated variations in the properties of consistency, compressive strength, modulus of elasticity and tensile strength, which 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 iron ore tailings improved the workability, strength and toughness of UHPC. Although some researches have been carried out on the suitability of using Itakpe iron ore tailings in concrete, the stress-strain relationship of concrete produced has not been reported. The stress-strain relationship of concrete produced, using Itakpe iron ore tailings as partial replacement for sand forms the main focus of this study.

2. Experimental Work

2.1 Materials

Dangote 3x ordinary Portland limestone cement was used as binder, river sand and Itakpe Iron ore tailings (IIOT) both of 5 mm maximum size as fine aggregate, 20 mm single size crushed rock coarse aggregate and portable water were used for producing 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 structural laboratory 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. Figure 1, shows the photographic images of the natural sand and that of Itakpe iron ore tailings. The physical properties of the fine and coarse aggregates materials used in this study, as determined experimentally, are shown in Table 1. The fine and coarse aggregates satisfied the BS 882 (1992) specification requirements for aggregates that can be used in concrete production.

Natural sand Itakpe iron ore tailings

Figure 1 Images of natural sand and Itakpe iron ore tailings

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 (%)
Natural sand	1537.4	1688.7	3.29	2.41	2.65	-	-
Itakpe Iron Ore Tailings	1660.1	1924.5	2.43	5.74	3.12	-	-
Coarse Aggregate	1641.2	1783.0	-	6.97	2.74	7.10	7.97

2.2 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 according to 812: part 103 (1985), determination of moisture content (BS 812, 1990) and specific gravity test (BS 882, 1992) were conducted in order to arrive at a viable concrete mix design

2.2.1 Design of Concrete Mix

The Building Research Establishment (BRE) method, for the design of normal concrete mixes was adopted in this study for the selection of the proportions of ingredients 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, a normal weight concrete with water content 210kg/m^3, cement content 362 kg/m^3, fine aggregate content 669 kg/m^3 and coarse aggregate content of 1189 kg/m^3 was designed using water-cement ratio of 0.58.

2.2.2 Proportioning of concrete materials

Five different types of concrete samples (C_0, C_1, C_2, C_3, and C_4) were prepared, 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% replacement intervals. The reference mix adopted is that, which contain sand as the only fine aggregate. The description of these concrete samples is shown in Table 2. 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, is shown in Table 3.

Table 2 - Description of concrete samples

Concrete sample	Description	Fine Aggregate content (%)	
		Sand	IIOTs
C_0	Control concrete sample with 0 % tailings	100	0
C_1	Concrete containing 5 % tailings	95	5
C_2	Concrete containing 10 % tailings	90	10
C_3	Concrete containing 15 % tailings	85	15
C_4	Concrete containing 20 % tailings	80	20

Table 3 - Mix proportions of concrete samples

Constituent materials to produce 0.304 m^3 concrete

Concrete Samples	Water (kg)	Cement (kg)	Natural Sand (kg)	Itakpe Iron Ore Tailings (kg)	Coarse Aggregate (kg)
C_0	63.9	110.0	203.4	0.00	361.5
C_1	63.9	110.0	193.2	10.2	361.5
C_2	63.9	110.0	183.0	20.3	361.5
C_3	63.9	110.0	172.8	30.5	361.5
C_4	63.9	110.0	162.6	40.7	361.5

2.2.3 Testing of concrete

The hardened concrete samples were tested for density and compressive strength using the average of three cubes results, after curing the concrete cubes 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. The static modulus of elasticity, was determined experimentally, directly from the stress–strain relationship of the concrete cylindrical samples following the procedure described in BS EN 12390-13 (2021).

3. Results and Discussions

3.1 Materials used for producing the concrete

Figure 2, shows the particle size distribution curve for sand, iron ore tailings and crushed granite. The result indicates that, Itakpe Iron ore tailings have similar grading characteristics with natural sand and the crushed granite are uniformly graded. Uniformly graded aggregate, indicates aggregate containing particles of almost the same size. Uniformly graded aggregates will require lot of paste to produce workable concrete. Based on the outcome of the concrete mix design for this study, the paste constitutes 23.5 % of the entire concrete while the fine aggregate is 27.5 %.

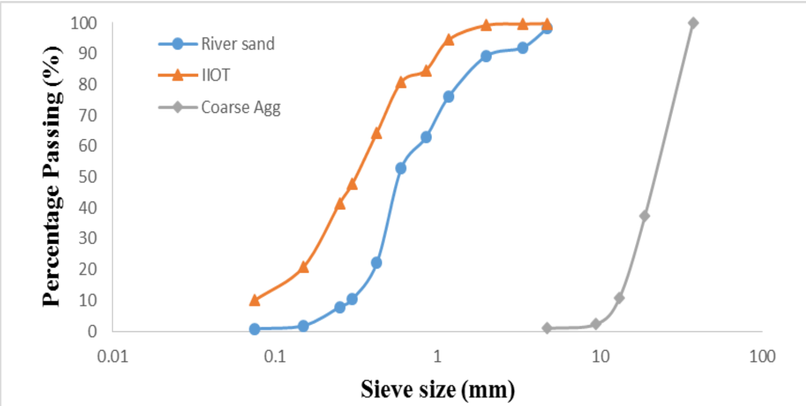


Figure 2 Particle size distribution of sand, IIOT and crushed granite

3.2 The effect of Itakpe Iron ore tailings on the mechanical properties of concrete

Variation of density and compressive strength with curing age are presented in Figure 3 and Figure 4 respectively. The density of the produced concrete cubes samples falls within the range 2187.7 kg/m^3 to 2553.1 kg/m^3. The compressive strength values range from 26.0 N/mm^2 to 30.2 N/mm^2 at 28 days. The compressive strength increases with the increase in tailings content up to 20% replacement level. The compressive strength of all the concrete samples, C_0, C_1, C_2, C_3, and C_4 at 28 days hydration period all met the desired design strength of 25 N/mm^2. The trend of the compressive strength results obtained in this study, are similar and comparable with the values obtained by other researchers (Oritola *et al.*, 2015; Kuranchie *et al.*, 2015; Krikar and Hawkar, 2018).

The compressive strength test results shows that replacing 20% of the sand with IIOT yielded the highest strength of 30.2 N/mm^2 at 28 days, this value is approximately 16.2 % higher than that of the control concrete sample C_0, which recorded the least strength value of 25.7 N/mm^2. The compressive strength of the control mix C_0, ranges from 15.6 N/mm^2 at 3 days to 25.7 N/mm^2 at 28 days, while that of IIOT concrete sample with the highest compressive strength C_4, ranges from 17.8 N/mm^2 at 3 days to 30.2 N/mm^2 at 28 days. After 3 days hydration period, the control concrete recorded 60.7 % of the 28 days compressive strength while the IIOT concrete C_4 recorded 58.9 % of its 28 days strength

.

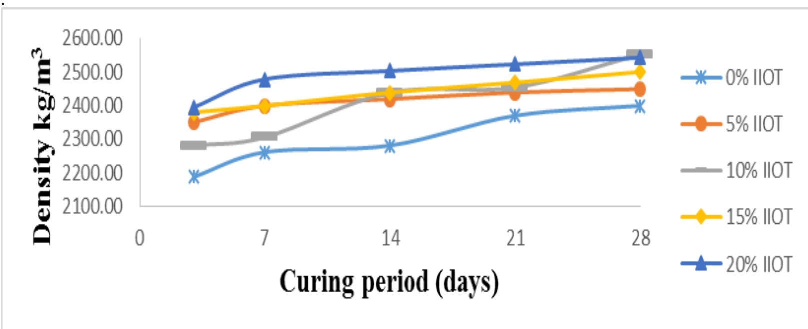


Figure 3 Variation of density with curing age of concrete

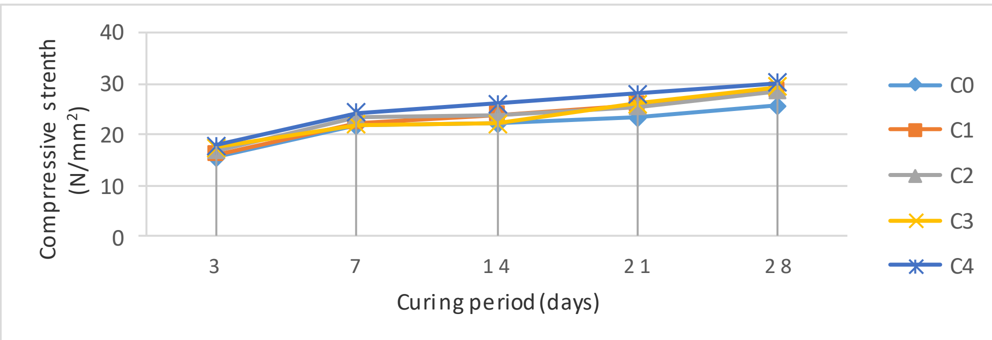
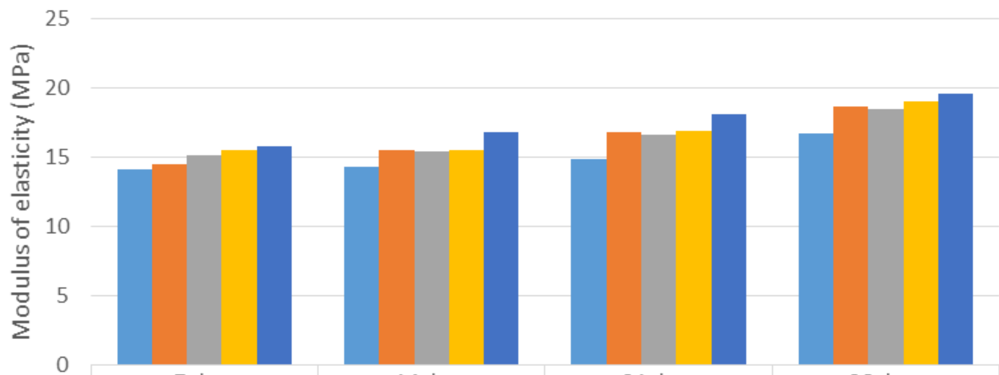


Figure 4 Variation of compressive strength with curing age of concrete

3.3 Modulus of elasticity of IIOT concrete

The static modulus of elasticity of the control concrete sample and those concrete which contains Itakpe iron ore tailings is depicted in Figure 5. The values of modulus of elasticity for the concrete samples shows similar trend compared with the compressive strength test results. The concrete sample which contains 20 % Itakpe iron ore tailings recorded the highest value of modulus of elasticity 19.6 GPa which is 17.4 % higher than that of the control concrete. Based on the analysis of the elastic modulus of concrete samples depicted in Table 4, an average of 81.2% of the 28 days elastic modulus was achieved after 7 days. It can also be deduced from the table that, the gain in modulus of elasticity of IIOT concrete samples over that of the control concrete is more pronounced at the age of 28 days.



	7 days	14 days	21 days	28 days
C0	14.1	14.3	14.9	16.7
C1	14.5	15.5	16.8	18.7
C2	15.2	15.4	16.6	18.5
C3	15.5	15.5	16.9	19.1
C4	15.8	16.8	18.1	19.6

Figure 5 Modulus of elasticity of concrete samples

Table 4 - Analysis of elastic modulus of concrete samples

Concrete sample	Elastic Modulus (GPa)			Relative gain in elastic modulus over control (%)	
	7 days MoE_7	28 days MoE_{28}	MoE_7 / MoE_{28}	7 days	28 days
C_0	14.1	16.7	0.84	0.0	0.0
C_1	14.5	18.7	0.78	2.8	12.0
C_2	15.2	18.5	0.82	7.8	10.8
C_3	15.5	19.1	0.81	9.9	14.4
C_4	15.8	19.6	0.81	12.1	17.4

4 Conclusion

From the outcome of this study, the following conclusions can be deduced:

1. The iron ore tailings obtained from Itakpe tailings dump site, has similar properties with natural sand and can be used to partially replace natural sand as fine aggregate in concrete.
2. Furthermore the Itakpe iron ore tailings samples were characterized to be medium grading based on the British standard data, thereby satisfying the requirements for overall grading limits for natural fine aggregates.
3. The findings from this research also revealed that, Itakpe iron ore tailings has the potential to be used in concrete for many practical construction applications.
4. The utilization of Itakpe iron ore tailings as aggregate in concrete will result in lower cost for concrete production. Presently, the Itakpe iron ore tailings is being discarded as a waste material. Utilization of the IIOT in concrete will provide a new way to use waste resources and the material can be regarded as eco-friendly.
5. The test results for density, compressive strength and modulus of elasticity of concrete containing Itakpe iron ore tailings reveals that this concrete can be used for structural applications, for concrete class C25.

References

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

BS EN 12390-13 (2021). Testing hardened concrete Determination of secant modulus of elasticity in compression.

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

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

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.

Audu, D. A., Zakari, Y. I., and Ibeanu, I. G. E. (2003). Radiological Effects of Iron-Ore Mining and Processing at Itakpe, Kogi State. Journal of Natural Sciences Research, 3(15), 92-98.

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. F. (2018). Properties of IOTs concrete produced using fly ash cement. Unilorin Science and Engineering Periodicals, Journal of Research Information in Civil Engineering. Vol. 15(2) pp. 2147-2158.

Oritola, S. F. (2019). Flexural behavior of reinforced iron ore tailings concrete (IOTC) beams. Nigerian Journal of Technological Research. Federal University of Technology, Minna.
Oritola, S. F., Saleh, A. L. and Mohd Sam, A. R. (2019). Characterization of

Iron ore tailings as Fine aggregate. Journal of American Concrete Institute (ACI) Materials Journal. (M-2019-095.R1).

Oritola, S. F., 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.

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.