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Evaluation of the iron ore tailings from Itakpe in Nigeria as concrete material

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Abstract: An evaluation of the Itakpe iron ore tailings (IOT) for concrete production has been carried out using the material to replace sand and cement, in proportions of 5 % up to 30 %, and curing for periods 90 days in water. Characterization of the material showed that it has pozzolanic properties, and can be used as a retarder for hot-weather concreting. Other characteristics of the IOT, as sand and cement replacements materials in concrete production exhibited improved workability and higher compressive strengths over the control strength with approximately 10 % and 38 % for sand and cement respectively. The linear regression models that were developed on the experimental data showed that they are significant and could be used to predict relationships of IOT-OPC concrete.

Keywords: Iron Ore Tailings, Pozzolana, Compressive Strength, Workability, Regression Models

1. Introduction

Nigeria is a fast developing nation blessed with abundant mineral resources. With major economic developments in the country, more minerals are in demand and thereby, increasing the mining activities. Itakpe iron ore deposits in Ajaokuta, Kogi State, Nigeria, is where such mining activities are going on, and has a total estimated reserve of about 182.5 million metric tonnes. It designed to treat a minimum of 24000 tonnes of ore per day while operating for 300 days per year. The waste material from the processing is approximately 64 % which translates into 3,072 tonnes/day [1]. This Project was established in 1971 and was designed to supply 2.15 million tones of 63 % to 64 % grade concentrate of iron (Fe) per year to Ajaokuta Steel Company Nigerian Limited. The iron ore is ferruginous quartzite deposit of geological reserve amounting to 200 million tonnes [2, 3].

While the output of these tailings are on the increase, proper disposal of these wastes are an important component in reducing the environmental nuisance of these wastes and also, maintaining a healthy environment. Apart from using it as secondary source and landfills, it can be gainfully used as supplementary material in the cement and concrete industries.

Recent research works have been geared towards effective utilization of this material in the production of cement and concrete works. Prahallada and Shanthappa [4] studied the suitability of using copper ore tailing (COT) as admixture in the preparation of concrete specimens.

Cement was replaced in proportions of 0 % to 50 % by weight of COT. Their results showed that COT improved the properties of the concrete and, the water absorption was only decreased at 20 % replacement. They also showed in their work that the strength of the concrete decreased as the replacement levels increased.

Kiran et al [5] investigated the use of red mud and IOT for the production of self compacting concrete (SCC). The cementitious material in the mixture was replaced with red mud at 1 % to 4 %, and for each replacement level, 10 % to 40 % of the fine aggregate was replaced with IOT. Their results showed that the compressive, flexural and splitting tensile strengths increased as the replacement levels increased, and that, the optimum strength for every test was achieved at 2 % red mud for every IOT replacement level.

Iron ore by-products have also been used with cement to produce interlocking bricks and paving blocks, respectively [6, 7 & 8]. Carrasco et al [6] used 75 % of coarse tailings and 25 % of fine tailings with Portland cement at 10 % cement content to produce interlocking tiles that were tested as load bearing walls. Their results were favorable. In the same realm, Ravi et al [7] did a comparative study on the strengths of different mixes with IOT in different proportions to produce interlocking paving blocks that were tested for compressive strengths and water absorptions. Their results also showed good performance. Kumar et al [8] used iron ore tailings in the proportions of 10 % up to 50 %, to replace fine aggregate by mass. The specimens were cured for periods of 56 days and the effects on workability, compressive and flexural strengths were studied. Their results showed that workability and flexural strength decreased as the replacement levels are increased while; the reverse was the case for compressive strength.

In the present research work, IOT is used to replace sand and cement respectively, in proportions of 5 % to 30 %, and its effect evaluated on the compressive strengths and water absorption of concrete specimens. Relations on these were derived using the regression package in the Minitab Software.

2. Materials

Table 1. *Physical Properties of IOT and Cement*

Parameter	IOT	Cement
Specific gravity	3.51	3.15
Loose bulk density (kg/m^3)	1650	3150
Loss of ignition (%)	-	1.0
Specific surface (m^2/g)	-	2.30
Soundness (mm)	-	8.0
Moisture Content (%)	0.22	-
pH	13.11	-

Table 2. *Chemical Properties of IOT and Cement*

Oxide	Percentage by mass	
	IOT	Cement
SiO_2	71.00	19.90
FeO_3	15.00	2.90
Al_2O_3	2.62	5.60
CaO	1.20	63.70
MgO	0.30	1.50
Na_2O	1.20	0.21
TiO_2	0.20	-
K_2O	0.08	0.71
SO_3	0.03	2.30

Table 3. *Sieve Analysis of the Fine Aggregate and IOT*

BS Sieve Sizes	Percentage Passing (%)	
	Fine Aggregate	Iron Ore Tailings
2.36 mm	99.7	-
1.18 mm	89.12	-
425μm	59.12	-
212 μm	17.30	99.9
150 μm	-	83.8
106 μm	1.07	73.3
75 μm	0.42	66.5
63 μm	0.17	12.4
Pan		0.00

The iron ore tailing (IOT) used for this work was sourced from Itakpe Iron Ore processing plant in Ajaokuta, Kogi State, Nigeria, and was designed to supply 2.15 million tones of 63 % to 64 % grade concentrate of iron (Fe) per year, to Ajaokuta Steel Company, Nigeria. The iron ore is ferruginous quartzite deposit of geological reserve amounting to 200 million tones and the tailings are the by-product from the manufacture of iron ore.

The cement used is the Ashaka Portland cement, which conforms to BS 1881 [9]. The physical and chemical compositions of both the iron ore tailing and Ashaka Portland cement are shown in Tables 1 and 2.

The fine aggregate is river sand with a specific gravity of 2.61, moisture content of 0.46 % and a bulk density of 1547 kg/m^3 and falls in zone 2 in the classification table in accordance with BS 882 [10]. Table 3 shows the sieve analysis for the fine aggregate and IOT. The coarse aggregate was a nominal weight aggregate with a normal size of 20 mm and has an average specific gravity of 3.15, bulk density of 1280 kg/m^3 and an aggregate crushing value and impact value of 10.30 and 7.23 respectively. Both fine and coarse aggregates conform to the British standard Specifications.

3. Mix Proportions

The mix used in this work had a total cement content of 380 kg/m3, fine aggregate content of 812 kg/m3, coarse aggregate of 1856 kg/m3 and a water content of 190 kg/m3. Fine aggregate replacement levels were 5 %, 10 %, 20 %, and 30 %, by mass of IOT and cement replacement levels were 5 %, 10 %, and 20 % by mass of IOT. The concrete was tested in the fresh and hardened conditions.

Tests on the IOT/OPC pastes were carried out to ascertain the setting time of the mixes. The results are shown in Table 4. Table 5 shows the workability of IOT/OPC cement mixes.

Table 4. *Setting time of IOT/OPC Paste*

Mix No	Initial (Min)	Final (Min)
S-0	30	245
S-5	22	228
S-10	10	210
S-20	5	200

Table 5. *Workability of Concrete with IOT*

IOT (%)	Slump (mm)	
	Cement replacement	Fine Aggregate replacement
0	50	50
5	56	55
10	60	60
20	70	60

The hardened concrete was tested for compressive strength. For this purpose, a total of 75cube specimens, 150 mm in size, were cast and cured in water for periods of up to 90 days. Sixty (60) cube specimens of the same size and days of curing were also prepared for the cement replacement levels. Three specimens were crushed at the end of each curing period and the average recorded as compressive strength. Results are shown in Table 6.

Table 6. *Compressive strength for concrete mixes with IOT*

Replacement type	IOT (%)	Compressive Strength (kN/m^2)				
		3 days	7 days	28 days	60 days	90 days
Aggregate	0	12.5	16.0	21.2	25.3	26.1
	5	13.0	16.8	21.7	25.6	26.2
	10	14.1	17.2	22.0	26.4	27.0
	20	15.6	18.8	23.1	27.2	28.8
	30	18.8	23.4	24.2	28.0	30.0
Cement	5	16.5	18.2	23.1	24.0	28.1
	10	20.4	22.5	29.8	34.7	35.2
	20	23.1	26.7	30.2	35.2	36.1

4. Analysis of Results and Discussion

Tables 1 and 2 show the physical and chemical characteristics of the IOT. The average moisture content of bulk IOT is 0.22 %. The total percentage of SiO_2 + Al_2O_3 + Fe_2O_3 is 88.62 % which is greater than the minimum (70 %) specified in ASTM C-618 [11]. Preliminary tests carried out on the IOT/OPC mixture to determine the pozzolanic activity as per British Standard Specifications gave a pozzolanic activity index of 75 %.

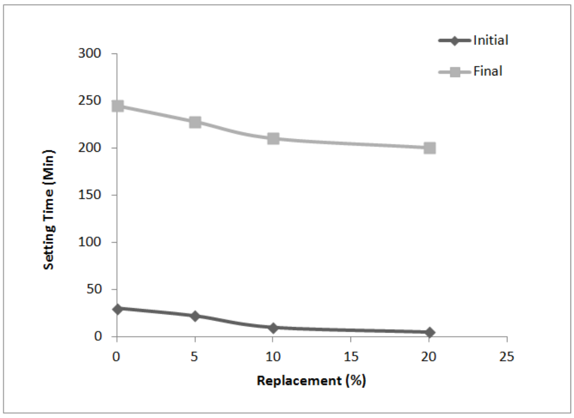

Figure 1. *Settng Times of IOT/OPC Paste*

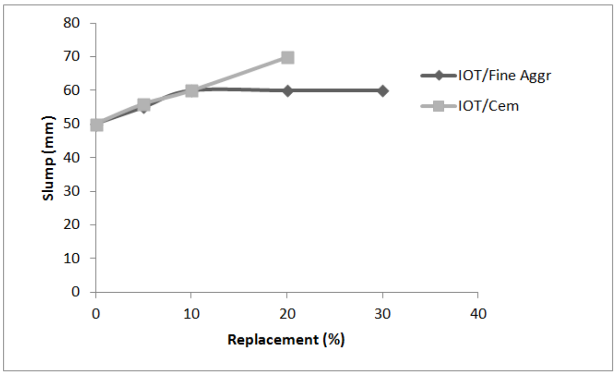

Figure 2. *Slump of IOT/OPC Concrete (mm)*

The setting time of IOT/OPC is important for practical applications of the material. This was determined using the Vicat method [9] and shown in Fig. 1.This shows that IOT/OPC paste conforms to specifications for setting times for similar materials and that IOT could be classified as a accelerator. Also, the workability of the concrete increases for all replacement of IOT with fine aggregate, and remained constant, after 10 % when IOT replaces cement (Fig.2).

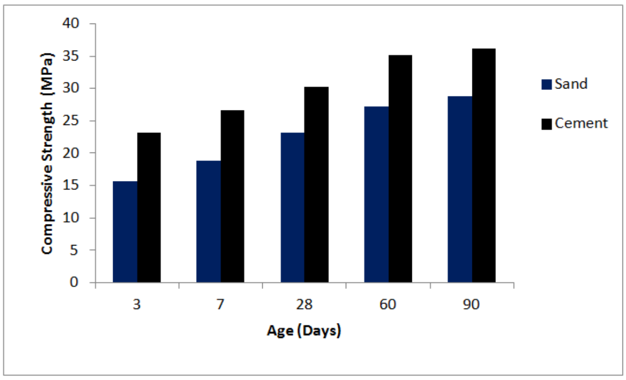

Figure 3. *Compressive strength of Sand and Cement Compared – 20 % Replacement*

Table 6 shows the compressive strengths of IOT/OPC concretes. The table shows similar characteristic behavior when IOT is used to replace either fine aggregate or cement. The compressive strengths increase as IOT replaces either fine aggregate or cement and at 90 days of curing and at replacement level of 20 %, the strengths are 10 % and 38 % higher than the control, for fine aggregate and cement replacements, respectively. The design strength of 20 kN/m^2 is achieved at all replacement levels. Although, the material could be used as both cement and sand replacement the results however show that the use of IOT to replace cement is more beneficial. At 20 % replacement, the difference in strengths between the sand and cement are approximately 48 %, 42 %, 31 %, 29 % and 25 % , respectively, for 3, 7, 28, 60 and 90 days of curing (Fig.3). This singular behavior rests on the reactivity of the material (IOT). As curing proceeded, there was progressive increase in the compressive strengths and thus a confirmation of the pozzolanic nature of IOT. The excess Ca $(OH)_2$ in cement hydration goes into secondary reaction with the IOT to produce C-S-H, which imparts strength to the concrete.

5. Regression Analysis

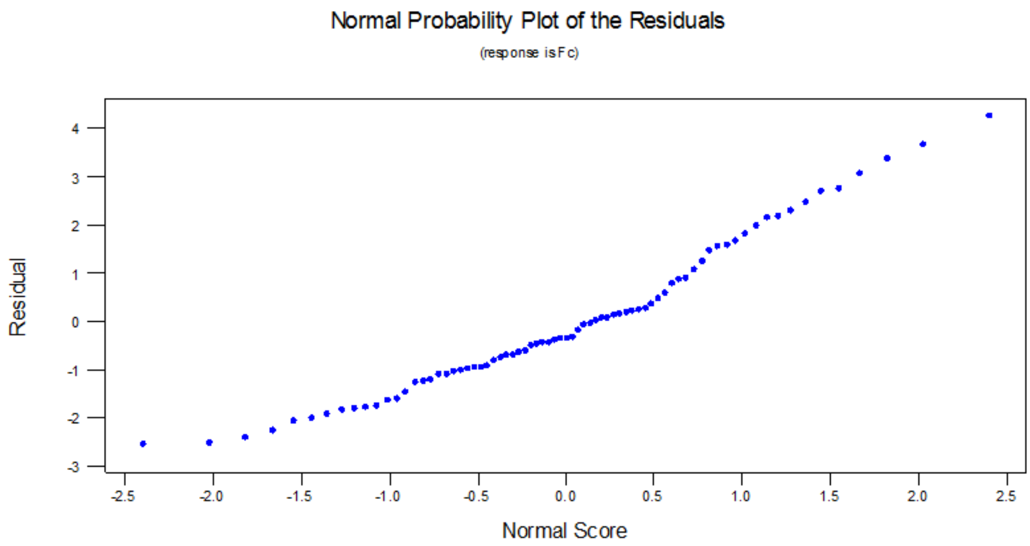

Figure 4. *Normal Probability Plot - IOT/Fine Aggregate*

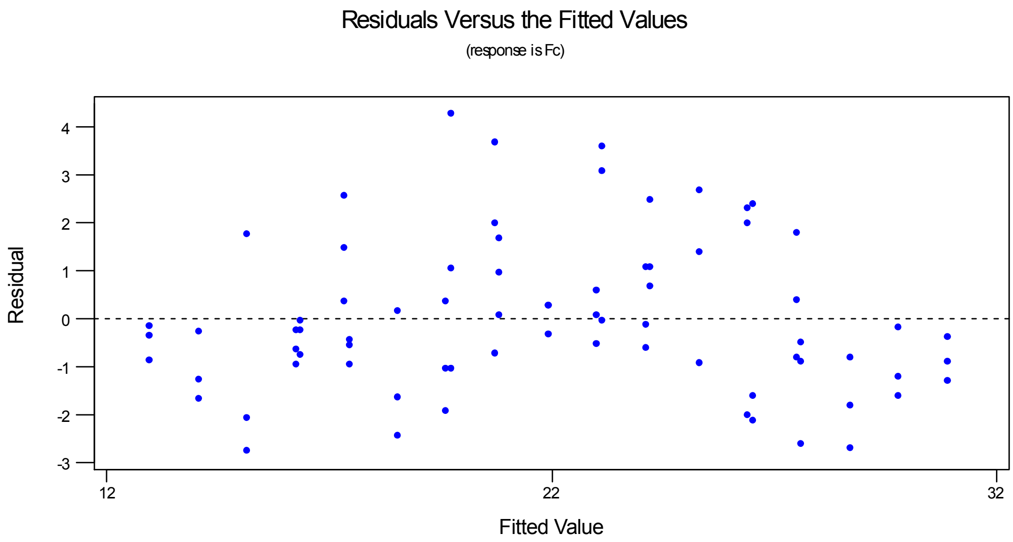

Figure 5. *Residual versus the Fitted Values - IOT/Fine Aggregate*

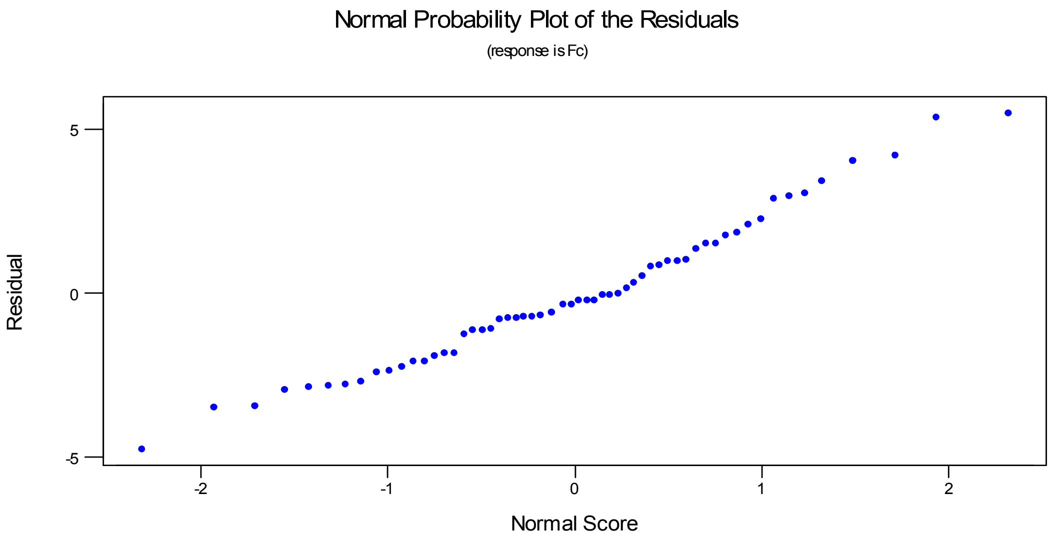

Figure 6. *Normal Probability Plot - IOT/Cement*

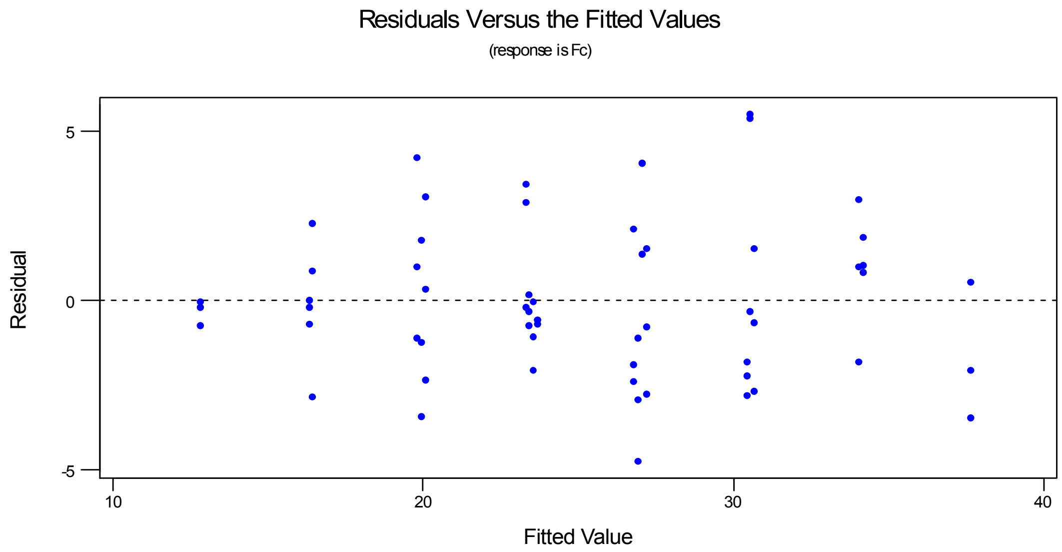

Figure 7. *Residuals versus the Fitted Values - IOT/Cement*

The sensitivity analyses of the experimental data in Table 4 were carried out using the Minitab Statistical Software. For data on the replacement of fine aggregate, the linear regression equation on the compressive strength is given as:

$$y = 8.48 + 1.09\,x + 3.39\,x_1 \quad (1)$$

Where, x an x_1 are the replacement levels and the age of the concrete respectively. The analysis shows that x and x_1 are significant, since $P = 0.000 < 0.05$. The correlation factor (r^2) is 91.1 % and shows good correlation between the various mixes and the age of the concrete, and these contributed to the compressive strength gains. The standard deviation $(\sigma) = 1.608.$ The analysis of variance shows that the linear regression model is significant and adequate. The normal probability and residual plots are shown in Figs. 4 and 5, confirming the adequacy of the data of the experiment and the model chosen.

The same could be said of the data on replacement of cement by IOT. The regression equation on the data is given as:

$$y = 5.71 + 3.62\,x + 3.49\,x_1 \quad (2)$$

Where x and x_1 are defined as the replacement level and age respectively, with a correlation factor of 89 %. The probability and residual plots are also given in Figs. 6 and 7, respectively.

6. Conclusions

The following conclusions can be drawn from this work:

1. That IOT has pozzolanic property and from the setting time result, it can be used as a retarder for hot weather concreting.
2. Using IOT improved the workability of the sand for all replacement levels and workability can only be improved up to 10 % replacement when is cement is replaced; signifying that the need to use admixtures may be necessary for improved performance.
3. The use of IOT increased the compressive strengths of concrete either as sand or cement replacement but better performance was recorded for cement replacement.
4. The increase in strength was up to 10 % and 38 % respectively, when used as sand and cement, at 20 % replacement and cured for 90 days; comparing sand performance and cement, showed increase of 48 % to 25 % by cement over sand for periods of curing from 3 to 90 days.
5. The behavior of IOT-OPC concretes can be represented adequately by linear regression models.

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