Flexural Strength of Revibrated Concrete Using Iron Ore Tailings (IOT) as Partial Replacement for River Sand

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Abstract

River sand is one of the major concrete constituents. Sand mining from rivers results in several environmental problems which leads to destruction of river banks among others. The use of IOT as a substitute for river sand is capable of addressing this problem. The effect of partial replacement of river sand with IOT on the flexural strength of revibrated concrete was studied in this paper. Sieve analysis, bulk density specific gravity and water absorption tests were conducted on the IOT, river sand and crushed granite to ascertain their suitability for use in concrete. A mix ratio of 1:2.1:2.7 and water-cement ratio of 0.5 was used to prepare concrete mixes with 0%, 10%, 20%, 30%, 40%, 50%, and 100% IOT as sand replacement. A total of 63 prisms of size 100 x 100 x 500 mm were cast and revibrated 30s for 3 minutes within 1 hour to provide samples to be tested for flexural strength at 7, 14 and 28 days curing age. Results revealed that the workability of concrete decreased with increase in percentage of IOT. Highest flexural strength was noted with concrete containing 100% IOT at all curing ages. Flexural strength model was proposed as a function of % IOT at 28 days curing age. It was recommended that IOT can be used as either partial or total replacement for river sand in concrete.

Keywords

Concrete; flexural strength; revibrated; IOT; river sand

1. Introduction

Natural river sand is the conventional fine aggregate recommended for use in the production of concrete. Concrete is a composite material made of aggregates (fine and coarse), cement and water (Neville, 2011; Shetty, 2004;

Gambir, 2001). The global demand for river sand as fine aggregate for construction activities continue to increase. In Nigeria particularly, the prices of all construction materials year in year out continue to escalate (Felix *el al.*, 2014). This results in high cost of construction of buildings and various types of infrastructure. Furthermore, river sand is obtained by mining sand from rivers. This implies that sourcing river sand for construction purposes will in the nearest future constitute environmental problems such as destruction of river embankment, lowering of water table due to increased bed depth, destruction of aquatic life ecosystem as well as causing salinity (Anooja *et al.*, 2011; Padmalal and Maya, 2014). It is therefore necessary to sought alternative sources of fine aggregate that can be used as either partial replacement for river sand or can be used to totally substitute river sand in concrete.

Iron Ore Tailing (IOT) has been identified as a viable alternative to river sand in concrete (Umar and Elinwa, 2005; Michibi, 2010; Ugama *et al*, 2014). IOT is a waste product generated from the processing and mining of iron from its ore. Mining of iron sites are located at Itakpe and Aklaja in Kogi and Delta State of Nigeria respectively, where iron ore is in abundance in several million metric tons. Itakpe which was designed to process 24,000 tons of iron ore in 24 hours produce IOT in excess of 3000 tons as waste per day (Ajaka, 2004; Elinwa and Maichibi, 2014). The produced waste (tailings) are deposited as unwanted materials in landfill and rivers which possess a serious environmental problem such as the extinction of aquatic life and pollution.

Since IOT possess environmental risks coupled with the fact that cost of fine aggregate is on the rise, researchers have sought to use IOT as alternative to river sand in concrete. Liu *et al* (2011) used up to 100% IOT as replacement for river sand in the preparation of sprayed concrete. The study reported 28-day strength of 23.4 N/mm^2. According to Zhao *et al*, (2014), 100% replacement of sand with IOT considerably reduces the slump and compressive strength of ultra-high-performance concrete. However, Elinwa and Machibi, (2014) presented a contrary claim. The study asserted that increase in IOT either as sand or cement replacement resulted in an increase in compressive strength. Proportions of 5 % up to 30 % IOT was used in the study and the workability and compressive strength increased with increase in IOT content. Ugama *et al*, (2014) used IOT to replace sand from 20 % to 100 % in steps of 20%. It was concluded that at 20% replacement, IOT performed better than the control mix containing only river sand. In similar vein, Chaithanya (2015) used IOT replacement of 0%, 15%,17.5%, 20%, 22.5%, 25%, 27.5% and 30% in the production of normal concrete. A compressive strength increases of about 40 % was reported but the flexural strength of reinforced concrete beams did not show any significant increase in strength. Flexural behavior of concrete made using 5%, 10%, 15% and 20% iron ore tailing was studied by Shivam *et al*, (2017). Mixes with 5%, 10% and 15% IOT recorded flexural strength greater than the control. Ali *et al,* (2018) used 25%, 50%, 75% and 100% sand to IOT replacement to produce concrete mixes. All the replacement levels were reported to record lower slump that the control mix and highest compressive and flexural was reported at 50 % IOT replacement.

Compressive strength of concrete is the most desired property of concrete when designing reinforced concrete elements. Flexural strength is important when estimating response of flexural members in the serviceability limit state. Majority of the research efforts reviewed have established the compressive strength of concrete using IOT. Some notable efforts were also made in estimating the flexural strength of IOT based concrete. This study is therefore focused on studying the effect of reviberation on the flexural strength of concrete using IOT as partial replacement for river sand.

Revibration of concrete refers to a delayed vibration of concrete that has already been placed and compacted (Ismail, 2007). Auta *et al,* (2015a) and Auta *et al,* (2015b) stated that flexural strength of Rice Husk Ash (RHA) concrete increases when reviberated from 0-30 minutes but reduces afterwards for almost all replacement levels of RHA. Although it has been found that reviberation of concrete and cement mortar significantly increases the strength of concrete so far, the concrete is still in the plastic state (Suresh, 1970). Information on the assessment of the flexural strength of reviberated concrete using IOT is however scarce in literature. This study attempts to solve this problem to better understand the valuable effects of reviberation on the flexural strength of concrete containing various percentage of IOT.

3. Materials and Methods

3.1 Materials

<u>Iron Ore Tailing (IOT)</u>: The IOT used was obtained from Itakpe Iron Ore processing plant in Ajaokuta, Kogi State, Nigeria. The IOT satisfied the grading limits specified by BS 882 (1992) and recorded specific gravity of 3.14, finess modulus of 2.03 and water absorption of 4.2 %.

<u>Fine Aggregate:</u> Fine river sand obtained from Lapai Gwari area of Minna, Niger State was used as fine aggregate. The sand satisfied grading limits

specified by BS 882 (1992) and recorded specific gravity of 2.70, water absorption of 3.5% and finess modulus of 2.60.

Cement: Ordinary Portland Cement of grade 42.5R obtained from local retailers was used in the preparation of all mixes. The cement conforms to BS EN 197- 1 (2000) with a specific gravity of 3.17.

Coarse Aggregate: Crushed granite of nominal size of 20mm obtained from quarry site long Zungeru Road in Niger State was used as coarse aggregate. The granite recorded an average SG of 2.90 and satisfied the grading limits of BS 882 (1992).

3.2 Mix Design

The Department of Environment (DOE) method of mix design was used in the selection of appropriate mix ingredients for M30 designated concrete grade at 28 days of curing with a water-cement ratio of 0.5. A mix ratio of 1:2.1:2.7 was obtained and the required quantity of mix ingredients in 1m^3 was calculated using absolute volume method as shown in table 1.

Table 1: Mix composition for 1m^3 of concrete

Ingredients	Cement	River Sand	Crushed Granite	Water
Quantity kg/m^3	394	840	1061	197
Ratio	1	2.1	2.7	0.5

3.3 Experimental Procedure

The required quantity of material was measured and mixing was thoroughly executed until the mix was homogenous. Concrete mixes were prepared with 0%, 10%, 20%, 30%, 40%, 50%, and 100% IOT as sand replacement. 0 % serving as the control mix. The slump of the freshly prepared concrete mix was determined for each of the replacement levels in compliance with BS 1881: Part 102 (1983). The fresh concrete was cast and reviberated for 3 minutes at an interval of 30 seconds using a vibrating table. For each replacement level and curing age (7, 14 and 28 days), a total of 63 prisms of size 100 x 100 x 500 mm were cast based on guidelines of BS 1881: Part 108 (1983). After 24 hours of casting, the concrete prisms were demoulded and cured in a water curing tank by full immersion according to BS 1881: Part 111 (1983). The specimens were tested for flexural strength using the centre point loading method as shown in Figure 1 for 7, 14 and 28 days based on guidelines of BS1881, Part 118 (1983).

(a) (b)

Figure 1: (a) Test specimens (b) Flexural Strength machine (Centre point method)

Source: Authors Laboratory Experiment

3.4 Model Development

Flexural strength results and percentage IOT were analysed using version 2017 of Minitab Software by following the procedure in Figure 2. Fitted line plot regression analysis was used to perform ANOVA. The model gives the relationship between the predictor (% IOT) and the response (Flexural Strength at 28 days curing age). The model is shown in equation 1 and graphical plots in Figures 5 and 6. Model statistics were obtained and employed to explain the performance of the regression model. The regression analysis was done at 95% confidence interval and significance level of 0.05.

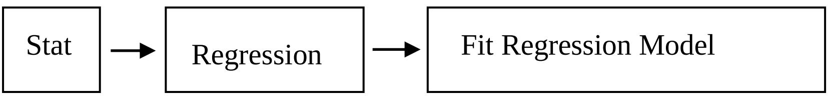


Figure 2: Procedure for regression analysis in Minitab package

4. Results and Discussion

4.1 Workability Result:

Slump test was conducted on the fresh concrete. The results obtained as shown in Figure 3 were between 25 - 38 mm corresponding to a low slump (10 - 40 mm) range according to BS EN 206 - 1 (2000). The control mix with 0% IOT recorded a slump of 32mm. A decrease in slump was however recorded as the percentage of IOT increased from 10 to 100% (38 - 25 mm). This was because the IOT recorded high water absorption capacity than the river sand which will reduce the amount of water required to aid the coating and lubrication of aggregates surfaces thereby reducing the workability of the concrete.

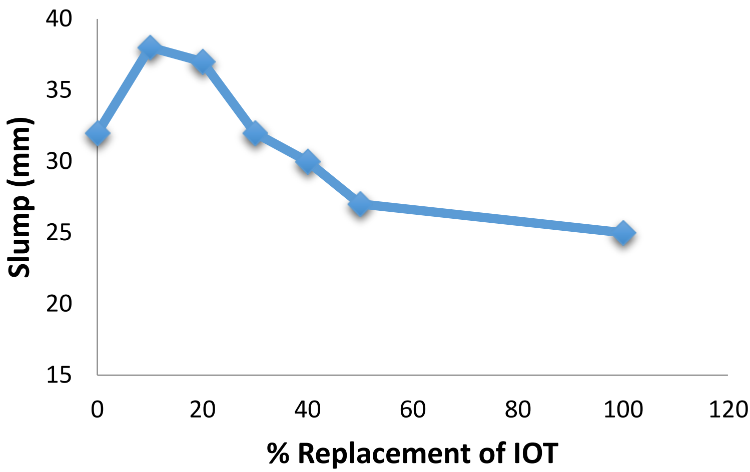


Figure 3: Result of slump for different percentage of IOT

4.2 Flexural Test Result:

The flexural strength result at different curing ages are given in Figure 4. Flexural strength increased with increase in percentage of IOT (10.88 - 19.13 N/mm^2) with 100% IOT content recording the highest flexural strength at 28 days of curing. This was about 40% in excess of the flexural strength recorded by the specimen containing 0% IOT and 15% more that the flexural strength of the concrete made with 50% IOT. There was steady increase in flexural strength as the curing age increased as shown in Figure 4.

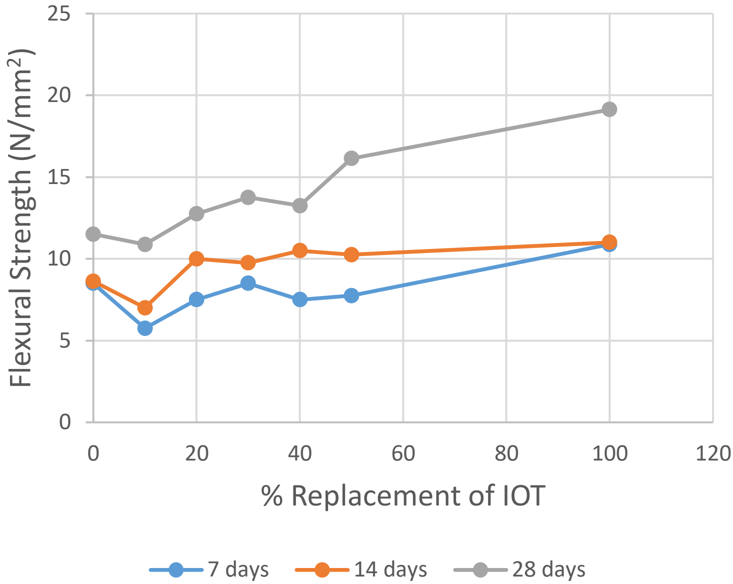


Figure 4: Flexural strength result at different curing ages

4.3 Developed Model

The regression equation fitted to the value is as presented in equation 1. The model for flexural strength (y) of concrete at 28 days curing age as a function of the % IOT (x) is shown in Figures 5 and 6. The regression output is presented in table 3. The coefficient of determination (R^2) was 0.932. An indication that 93.2% of the variability in flexural strength is accounted for by the model as stated by Abdullahi, 2012; Montgomery, Peck, and Vining 2001.

$$y = 10.89 + 0.08646x - 0.000031x^2 \qquad (1).$$

Table 3: Regression Output from Minitab Software (2017)

Source	DF	SS	MS	R^2	adj R^2	F	P
Regression	2	45.6358	22.8179	0.932	0.898	27.35	0.005

The p-value for the regression significance was 0.005 which is less than 0.05. Signifying that the parameters are not equal to zero and the terms contribute significantly to the model. The ANOVA analysis therefore recommends that the developed model is sufficient in explaining the data.

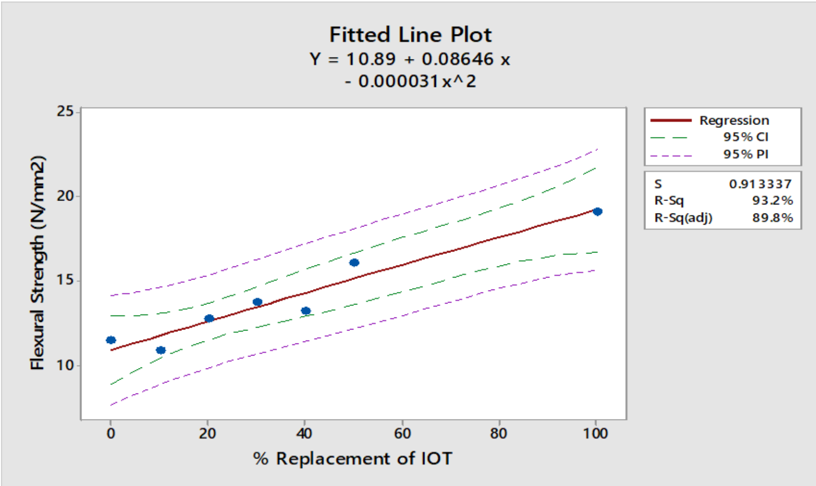
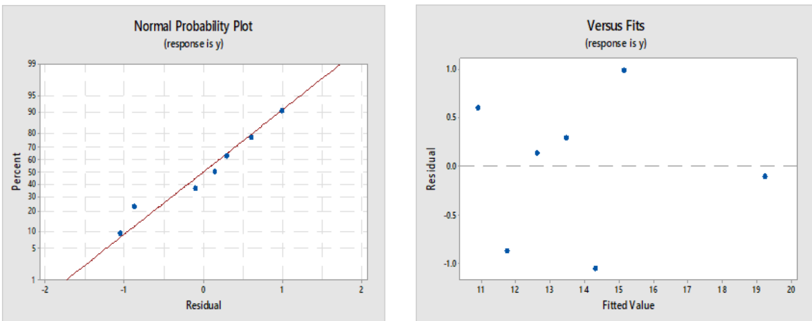


Figure 5: Flexural Fitted Line Plot of Regression Analysis



(a) (b)

Figure 6: (a) Normal Probability Plot of Response y
(b) Residual Plot of Response y

5. Conclusion

From the outcome of the study, it can be concluded that increase in the percentage of IOT leads to increase in flexural strength of reviberated concrete. Highest flexural strength of 19.13 N/mm^2 was obtained with 100%

IOT replacement for river sand at 28 days curing age. At 50% replacement level, a flexural strength of 16.13 N/mm^2 was obtained at 28 days curing period. Revibrated concrete with 20% IOT showed the least strength development at all curing ages considered. Quadratic polynomial model as a function of % IOT was sufficient for explaining the flexural strength data. It was proposed that IOT can be used as either partial or total replacement for river sand in the production of revibrated concrete.

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