

Effect of Iron Ore Tailing on the Properties of Concrete

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Abstract
Experiments were conducted to determine the suitability of iron ore tailing (IOT) as fine aggregate replacement of sand (RS) for concrete used for rigid pavement. The use of iron ore tailing (IOT) from Itakpe mines near Okene in north-central Kogi state of Nigeria will ensure economy in concrete production as well as a better way of disposing the tailing. Mix design was carried out for concrete of grade 35 using standard practice for selecting proportions for normal weight, and mass concrete [ACI 211.1-91, 1997]. The constituent materials were batched by weight. The mix with only sand as fine aggregate served as the control mix, while sand was replaced in the other mixes by 20%, 40%, 60%, 80% and 100% iron ore tailing (IOT). Consistency and Strength test were conducted on both concrete specimens. It was observed that concrete workability reduced with increase in the percentage of iron ore tailing in the mix. Twenty-eight (28) days compressive strength and indirect tensile strength values of 43.67N/mm^2 and 2.69N/mm^2 respectively, were obtained for concrete when 20% iron ore tailing (IOT) was used, Values comparable to 28days compressive strength and indirect tensile strength values of 45.02N/mm^2 and 2.64N/mm^2 respectively, obtained using only sand as fine aggregate.
Keywords: concrete; sand (RS); iron ore tailing (IOT); compressive and tensile strength.

1. Introduction

Concrete is a composite construction material made primarily with Cement, fine aggregates, water and coarse aggregates, and may contain chemical admixtures. It contains some amount of entrapped air and may also contain purposely entrained air obtained by use of an admixture or air entraining cement (ACI 211, 1997). The mixture of the materials results in a chemical reaction called hydration. The worldwide consumption of sand as fine aggregate in concrete production is very high, and several developing countries have encountered some difficulty in the supply of natural sand in order to meet the increasing needs of infrastructural development in recent years, A situation that is responsible for increase in the price of sand, and the cost of concrete (Raman et al 2007). Expensive and scarcity of river sand (RS) which is one of the constituent material used in the production of conventional concrete was reported in India (Ilangovan and Nagamani 2007).

To overcome the stress and demand for river sand, researchers and practitioners in the construction industries have identified some alternatives namely fly ash, slag, limestone powder and siliceous stone powder (Siddique 2003).

Nan Su *et al*. (2001) examined the feasibility of reusing spent zeolite catalyst, after fluidized catalytic cracking, as a substitute for fine aggregate (sand) in cement mortars. The tested result shows that spent catalyst can replace up to 10% of fine aggregate without decreasing the mortar strength. In fact, the substituted mortars show higher compressive strength than the control samples. The workability of the fresh mortars decreases with increasing substitution level and the mortars incorporated with spent catalyst show less bleeding. In the hardened state, the water absorption of the resulting mortar increases with longer curing age, higher substitution level and smaller water-to-cement (W/C) ratio. Toxicity characteristic leaching procedure (TCLP) analysis confirmed that the spent catalyst meets the standard, and thus should be classified as general non-hazardous industrial waste.

Waste glass creates serious environmental problems, mainly due to the inconsistency of waste glass streams. With increasing environmental pressure to reduce solid waste and to recycle as much as possible, the concrete industry has adopted a number of methods to achieve this goal. Ismail and Al-Hashimi (2008) investigated the properties of concrete containing waste glass as fine aggregate. The strength properties and expansivity were analyzed in terms of waste glass content. An overall quantity of 80 kg of crushed waste glass was used as a partial replacement for sand at 10%, 15%, and 20% with 900kg of concrete mixes. The flexural strength and compressive strength of specimens with 20% waste glass content were 10.99% and 4.23% higher than those of the control specimen at 28 days. The mortar bar tests demonstrated that the finely crushed waste glass helped reduce expansion by 66% as compared with the control mix.

Adedayo and Onitiri (2001) carried out research on Tensile Properties of Iron Ore Tailings Filled Epoxy Composites. They stated that the 30 % volume content of 300 μm particle size of iron ore tailings is the better combination that can be added to epoxy to give maximum Young's modulus. Though tensile strength for ITR-ECs produced is lower when compared with pure epoxy, better tensile strength with increased particle size was recorded for all % volume content considered. On the other hand, better yield strength was recorded at reduced particle size and increasing the % volume content.

In India the use of quarry dust to replace river sand was reported by (Ilangovan and Nagamani 2007). The use of rock dust as an alternative to natural sand was also reported by (Nagaraj and Banu, 1996). The use of up to 20% quarry waste fine as a partial replacement for natural sand in the production of concrete, in Malaysia was also reported (Safiuddin et al, 2007). Use of crushed granite fines or crushed rock fines as an alternative to sand in concrete production was also reported (Murdock et al, 1991). 20% Use of crushed granite Fines or crushed rock fines as partial replacement for sand in concrete production for rigid pavement was also reported (Manasseh, 2010).

This research is interested in the use of iron ore tailing as sand in concrete and mortar. The global demand to reduce the increasingly high cost of waste disposal and conserve raw material has led to intense global research towards economic utilization of waste for engineering purposes. The successful utilization of iron ore tailing (IOT) as fine aggregate would turn this waste material into valuable resources, reduction in the strain on the supply of natural sand, and economy in concrete production.

World production averages one billion metric tons of raw ore annually. The sea borne trade in iron ore, that is, iron ore to be shipped to other countries was 849 metric tons in 2004 (Lasisi, et al 2010)

According to SRK consulting engineers and scientists (2010) Tailings are the materials left over after the process of separating the valuable fraction from the worthless fraction of an ore. The composition of tailings is directly dependent on the composition of the ore and the process of mineral extraction used on the ore. The physical and the chemical characteristic of the processing waste varies accordingly to the mineralogy and the geochemistry of the treated resource, type of processing technology, particle size of the crushed material and the type of process chemicals. The particle of the processing waste can range in size from colloidal size to fairly coarse, gravel size particles (Kachhap, 2010). Itakpe iron ore deposit has a reserve of about 200 million tonnes with an average iron ore content of 36%. This has to be beneficiated at a rate of 8 million tonnes per year to produce 64% Fe concentrate as sinter material for the Ajaoukuta blast furnace and 68% Fe concentrate as pellet feed for the direct reduction plant at Aladja, in Nigeria. At this production rate, large quantities of tailings are obtained as waste product of the beneficiated iron ore. It is estimated that the stripping ratio (waste/ore ratio) of the deposit would amount to approximately 28 million tons (Umar and Elinwa, 2005). Tailings must be managed to optimize human safety and environmental protection.

In recent decades, intensive research and development efforts have been directed towards finding cost-effective and eco-compatible solutions for minimizing and utilizing the waste produced in iron-ore mining operations (Bandopadhyay et al, 2002; Johnson et al, 1992.

Ruiyingbai et al, (2011), stated that the fine particles less than 75µm in iron ore tailing sand are beneficial to the reduction of expansion induced by alkali- silica reaction(ASR) in concrete and mortar. According to (Ayrton and Adriana, 2010), IOT is described to be innocuous based on the quantity of dissolved silica and reduction in alkalinity of the mix.

This research is aimed at investigating the strength characteristics of control concrete and concrete made with iron ore tailing and determining the optimum content of sand and iron ore tailing combination suitable for use as fine aggregate for concrete used for rigid pavement.

2. Materials and Methods

2.1 Materials

2.1.1 Cement

Ordinary Portland cement conforming to ASTM 150 specification was used. Table 1 shows the physical properties of cement used compared with code specification.

Table 1 Comparison of results of Cement tests with Code specifications

S/No.	Parameter	Value	Code Specifications ASTM C 150-00
01	Fineness	0.05	0.01 – 0.06
02	Consistency	31%	26-30%
03	Initial Setting time	80 minutes	≥ 45 minutes
04	Final Setting time	170 minutes	≤ 375 minutes
05	Soundness	1.0 mm	≤ 10 mm
06	Mortar Cube Compressive Strength (7 days)	21.53 N/mm^2	≥ 16 N/mm^2

(Each is an average of three test result)

2.1.2 Sand

River sand having bulk density 1352 kg/m3 and fineness modulus 2.78 was used. The specific gravity was found to be 2.63. The particle size distribution is plotted as shown in fig 1. The gradation of sand used, is within limits specified in ASTM C 31. And it's suitable for concrete works.

Figure 1. Particle size curve (RS)

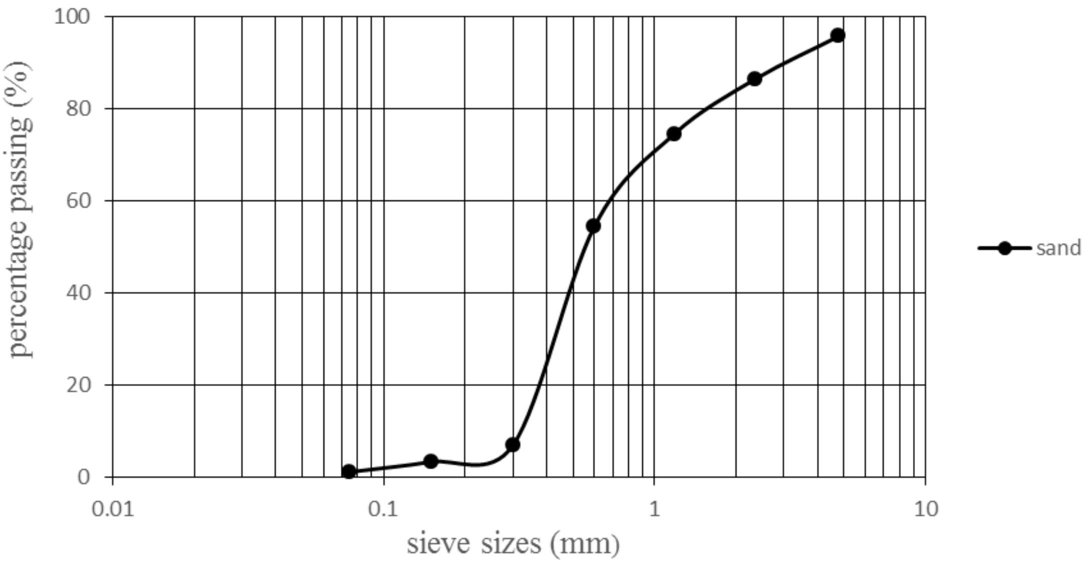

Figure 1. Particle size curve (RS)

2.1.3 Iron ore tailing

Iron ore tailing having bulk density 1594 kg/m3 and fineness modulus 2.53. The specific gravity was found to be 2.85.The particle size distribution is plotted as shown in fig 2. The gradation of tailing used, is partly within limits specified in ASTM C 31. Hence suitability analysis has to be carried out to determine its possible use as fine aggregate.

Table 2 Chemical Composition of Itakpe Iron Ore tailing (IOT)

Mineral	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	TiO_2
Composition (%)	47.70	45.64	0.607	3.26	0.393	0.240

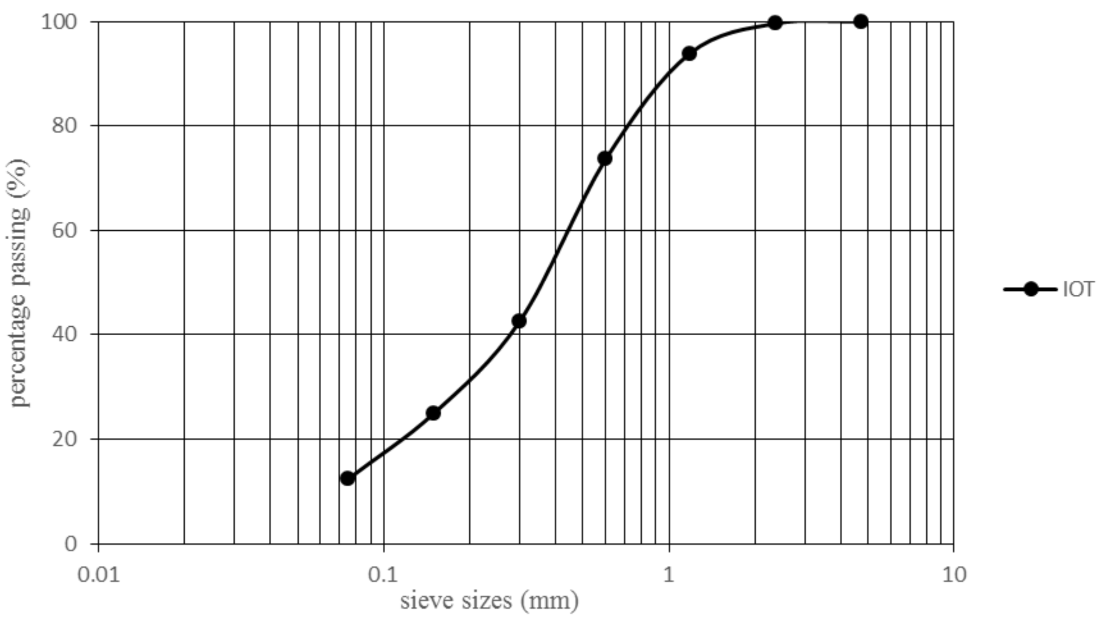

Figure 2. Particle size curve (IOT)

2.1.4 Coarse aggregates

Natural gravel aggregates having bulk density of 1600kg/m3. The specific gravity of coarse aggregate is 2.85.

The flakiness and elongation indices are 13.38 and 14.87% respectively, Aggregate impact and crushing values of 26.0 and 20.5% respectively. Sieve analysis results are shown in Table 3.

Table 3 Particle size distribution of coarse aggregate compared with ASTM C 33-78 limits.

Sieve size (mm)	Cumulative percentage passing (%)	ASTM C 33-78 limits (%)
50	100	100
38.1	100	95 – 100
25.4	92.8	-
19.05	47.8	35 – 70
12.7	4.3	-
9.52	0.17	10 – 30
6.35	0.13	-
Pan	0	-

2.1.5 Water
Pure and clean tap water fit for drinking was used.

2.2 Methods
2.2.1 Concrete mix proportion
Using American concrete institute code which is a standard practice for selecting proportions for normal heavyweight, and mass concrete (ACI 211.1-91) reapproved in 1997, the mix proportion was designed for grade 35 concrete, and the various weight of ingredients are as given in Table 4. The sand is replaced by iron ore tailing in the following percentages; 0, 20, 40, 60, 80, and 100 percent. The mix of the various iron ore tailing concrete were labeled as follows; TM-1, TM-2, TM-3…, TM-6 Where TM-1 implies concrete mix for zero percent of tailing, TM-2, implies concrete mix where 20 percent of sand is replaced by tailing, TM-3 implies concrete mix where 40 percent of sand is replaced by tailing, and so on.

Table 4. Weight of ingredient per m^3 of concrete

S/NO	INGREDIENTS	WEIGHT (KG)	CUMULATIVE WEIGHT (KG)
1	Cement	472	472
2	Fine aggregate	655	1127
3	Coarse aggregates	1072	2199
4	water	184	2383

2.2.2 Test specimens and test procedure
90 concrete cylinders of 150mm diameter and 300mm length (ASTM C 39), 18 cylinders of size 150mm diameter and 300mm length (ASTM C 496) were used as test specimens to determine the compressive strength of concrete and split tensile strength of concrete for both cases i.e. normal concrete and modified concrete. The ingredients of concrete were thoroughly mixed till uniform consistency was achieved. The cylinders were compacted on a vibrating table. The properties of fresh concrete were measured according to ASTM C 143.

3. Results and Discussions
3.1 Concrete Slump
Changes in concrete workability are presented fig 3. It is observed that concrete workability reduced with increase in the percentage of IOT in the mix. This may be due to the fineness and therefore large surface area of the IOT which resulted in the need for large amount of water necessary to wet all the particles in the mix.

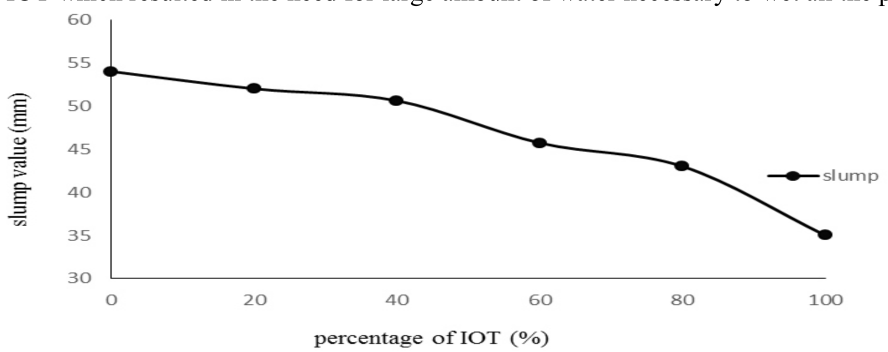

Figure 3. Variations in concrete workability with percentage replacement of RS with IOT

3.2 Compressive Strength of Concrete

It is observed from fig 5, that all tested specimens and load cases for different percentages of iron ore tailing (IOT) showed increases in load bearing capacities as curing age increased. Also, with increase in content of iron ore tailing (IOT), compressive strengths of specimens reduced almost linearly.

The 28-day test cylinders had an average compressive strength of 43.67 N/mm^2 for TM-2 (concrete with 20% IOT), but less than the compressive strength of the TM-1 (control concrete) of45.02N/mm^2. Since there is little difference in strength values of TM-1 and TM-2, replacement of sand with iron ore tailing should be limited to 20%.

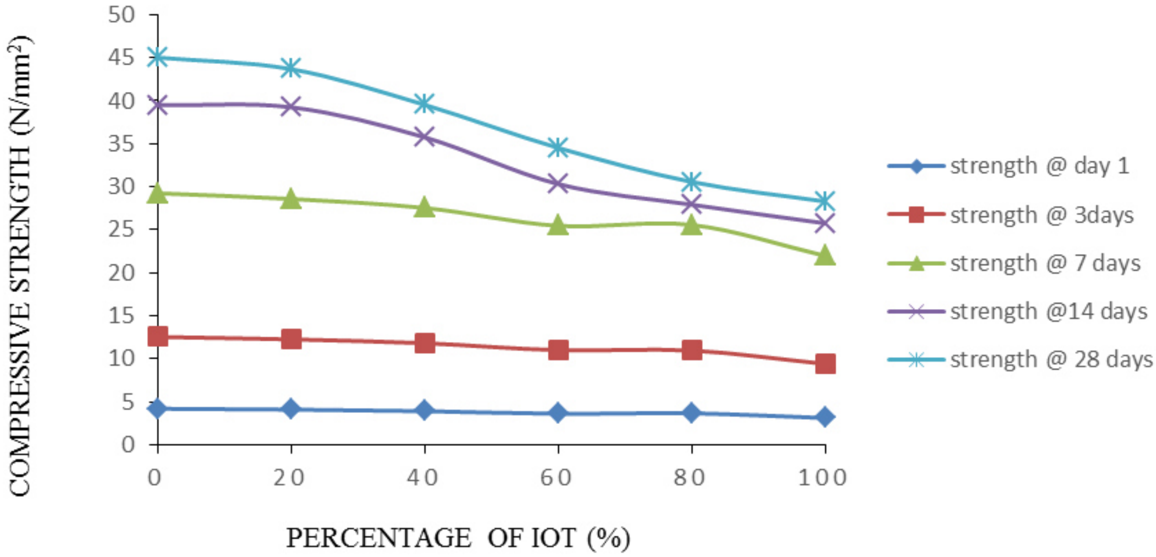

Figure 4. Variation of compressive strength with proportion of IOT at 7, 14, and 28 days

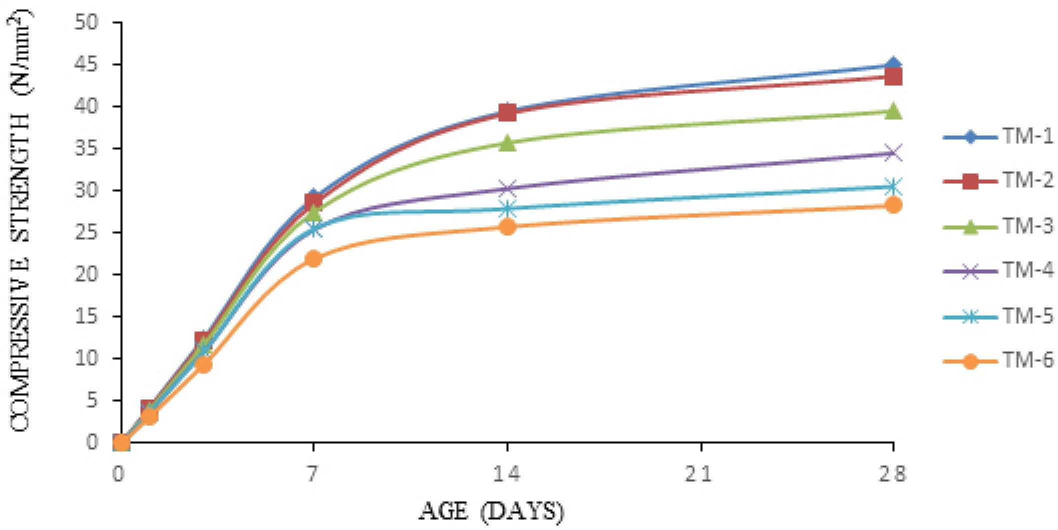

Figure 5. Variations in concrete compressive strength with curing age

3.3 Tensile Strength of Concrete

The tensile strength of TM-1 and TM-2 are 2.64 N/mm^2 and 2.69 N/mm^2 respectively. The low value of the tensile strength shows that the materials are weak in tension. The values are plotted as shown in the fig 6. It is observed that the value of TM-2 is higher than that of TM-1.Hence the replacement of RS with IOT should be limited to 20%. Therefore the fines content in the mix with 20% IOT are moderate hence it fulfills a void- filling role in the concrete matrix and aids cohesion and good finishing of concrete work. As the percentage of iron ore tailing increases in the subsequent mixes, the fines content also increases giving rise to increased water demand and reduced aggregate-cement paste bond. Hence the reduction in values of subsequent mixes tensile strength.

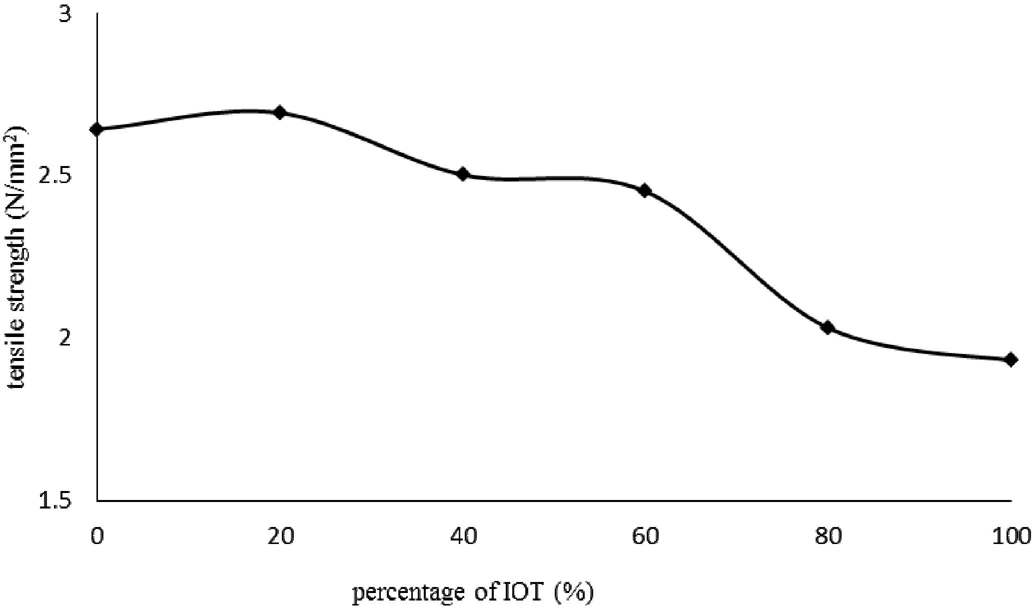

Figure 6. Variations in tensile strength at 28days

4. Conclusions

Based on the present and experimental investigation studies, the following conclusions can be drawn.

1. It was observed that concrete workability reduced with increase in the percentage of IOT in the mix. This may be due to the fineness and therefore large surface area of the IOT which resulted in the need for large amount of water necessary to wet all the particles in the mix.
2. The compressive strength of concrete for the control specimen were higher than that of the mix with various percentages of IOT replacing RS. However, the 28-day test specimens had an average compressive strength of 43.67 N/mm^2 for concrete with 20% IOT, value which is close to the compressive strength of the control concrete of 45.02N/mm^2. Hence the use of IOT to replace RS should be limited to 20%.
3. The mix with 20% IOT performed better in terms of splitting tensile strength in concrete than that of the control mix, thus 20% IOT can be used to replace river sand (RS) in structural elements such as beams.
4. The optimum replacement level for IOT content in concrete beam production is about 20%. With regard to density, the iron ore tailing was classified as a heavy aggregate and will therefore lead to concrete pieces of heavier weight. The high density of the waste is related principally with its high content of iron, which could not be separated by the magnetic separation process. However, as an aggregate in the production of concrete for paving elements applied directly on the ground, this waste would constitute paving with higher self-weight, less subject to deformation resulting from external loads.

5. Recommendation

From the findings of this research work, the following recommendation was hereby made:

Further research on iron ore tailing concrete is imperative in other to further optimize and improve on the strength of such composite materials with addition of admixtures, other pre-treatment method, vary water-cement ratio, mix design etc.

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