IRON ORE TAILING AS FINE AGGREGATE IN MORTAR USED FOR MASONRY

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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 mortar used for masonry. The use of iron ore tailing (IOT) from Itakpe mines near Okene in Kogi state of Nigeria will ensure economy in mortar production as well as a better way of disposing the tailing. Mix design was carried out for mortar using absolute volume method. The mix for the mortar specimen is one part cement and three part fine aggregate (1:3). The constituent materials were batched by weight. The mix with only river sand (RS) 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). It was observed that the Iron or tailing contain more fines passing BS number 200 sieve than the river sand used. Twenty-eight (28) days compressive strength, indirect tensile and flexural strength values of 34.67N/mm2, 1.82N/mm2 and 7.04N/mm2 respectively were obtained for mortar when 20% iron ore tailing (IOT) was used. These values are comparable to 28days compressive strength, indirect tensile and flexural strength values of 36.95N/mm2, 1.76N/mm2 and 5.73N/mm2 respectively obtained for the mortar control mix. The optimum combination of iron ore tailing (IOT) and sand (RS) is therefore 20% IOT and 80% RS.

KEYWORDS: *Masonry mortar, sand (RS), iron ore tailing (IOT), compressive, tensile and flexural strength.*

I. INTRODUCTION

Mortar is a plastic mixture of approved cementitious materials (Lime, Cement, etc), fine aggregates and water used to bond masonry or other structural units. It is the material that bonds units and accessories together and compensates for dimensional variations of the units. Both the plastic and hardened properties of mortar are important for strong, durable, water-tight construction. Industrialization has resulted in generation of large quantities waste, e.g. Iron ore tailing (IOT). Most of the wastes do not find any effective use and create environmental problems apart from occupying large tracts of land. It has been observed that some of these wastes have high potential and can be gainfully utilized as fine aggregates for concrete and mortar production. The utilization of the iron ore tailing (IOT) in mortar production will not only help in solving the environmental pollution problems associated with the disposal of these wastes but also help in conservation of natural resources (sand) which are over utilized. The high cost of concrete used in building construction stems from the cost of the constituent materials, e.g. cement, sand and coarse aggregates [1a]. Therefore effort has been ongoing to obtain cheaper aggregates that can be used as substitutes for conventional mortar aggregate.

Nan Su *et al*. [2] 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 [3] 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.

In India the use of quarry dust to replace river sand was reported by [4]. The use of rock dust as an alternative to natural sand was also reported by [5]. 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 [6]. Use of crushed granite fines or crushed rock fines as an alternative to sand in concrete production was also reported [7]. 20% Use of crushed granite Fines or crushed rock fines as partial replacement for sand in concrete production for rigid pavement was also reported [1b].

According to SRK consulting engineers and scientists [8] 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 [9]. 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, all in Nigeria. At this production rate, large quantities of tailings are obtained as waste product of the beneficiated iron ore. Tailings must be managed to optimize human safety and environmental protection.

Ruiyingbai et al, [10], 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 [11], IOT is described to be innocuous based on the quantity of dissolved silica and reduction in alkalinity of the mix.The effectiveness and the economy of this research would make available, abundant materials for mortar production. This research is aimed at investigating the strength characteristics of control mortar as well as mortar made with iron ore tailing and determining the optimum content of sand and iron ore tailing combination suitable for use as fine aggregate for masonry mortar production.

II. MATERIALS AND METHODS

2.1. Cement

Ordinary Portland cement conforming to BS EN 197-1[12a] 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 BS EN 197-1[6b]
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 value is an average of three)

2.2. 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 figure 1.

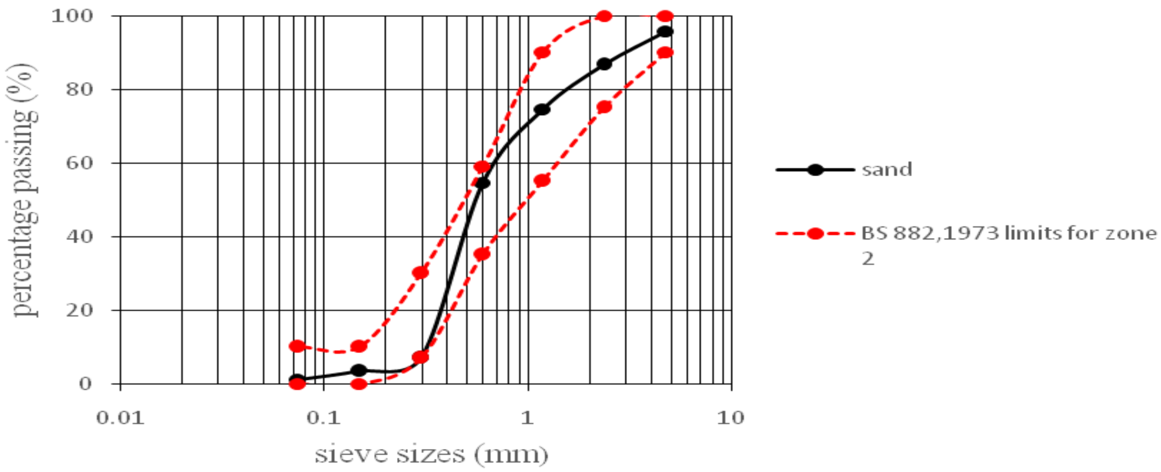

Figure 1. Sand within fine aggregate limits specified by BS 882, [7b] for zone 2

The graph shows that the gradation of sand, is within zone grading No. 2.The gradation of the used particles falls within the fine aggregates specified gradation limits in BS 882 [13a], Neville [14a] as shown in figure 1.1

2.3. Iron Ore Tailing

Iron ore tailing having bulk density 1594 kg/m3 and fineness modulus 2.53 was used. The specific gravity was found to be 2.85**.** The particle size distribution is plotted as shown in figure 2. The graph shows that the gradation of iron ore tailing (IOT) is within zone grading No. 3. And it's suitable for concrete works. The gradation of the used particles falls within the fine aggregates specified gradation limits in BS 882 [13c], Neville, [14b] for zone 3 as shown in figure 2. The chemical composition of iron ore tailing is presented in table 2.

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

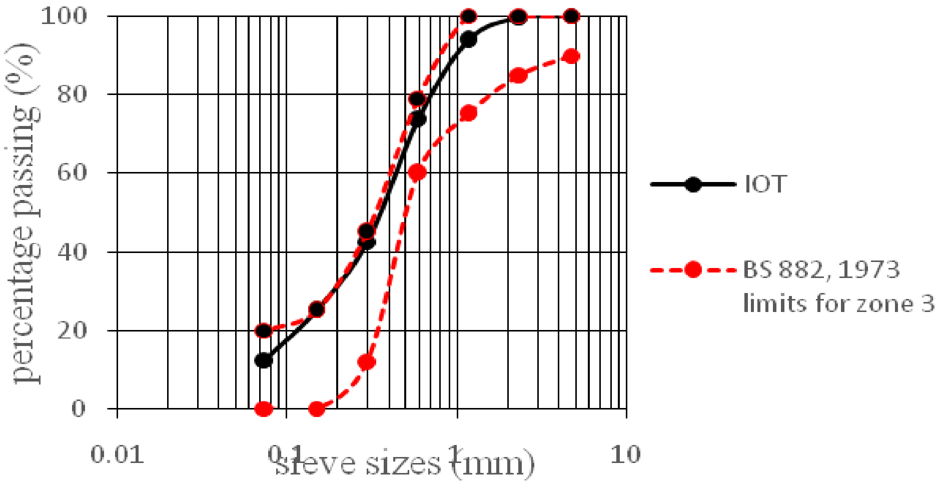

Figure 2. Iron ore tailing shown within fine aggregate limits specified by BS 882, for zone3

2.4. Water

Pure and clean tap water fit for drinking was used.

2.5. Mortar mix proportion

Type M mortar [15a], of mix ratio 1:3 was used for the experiment. i.e. 1 part of cement and 3 parts of fine aggregate respectively. Given the water cement ratio to be 0.39 and the aggregate cement ratio to be 3, and using the method of absolute volume the mix proportion, i.e. the weight of various ingredients were obtained as shown in table 3.

Table 3. Weight of ingredient per m^3 of mortar

S/NO	INGREDIENTS	WEIGHT (KG)	CUMULATIVE WEIGHT (KG)
1	cement	493.6	493.6
2	Fine aggregate	1480.8	1974.4
3	Water	192.5	2166.9

The mix with only river sand as fine aggregate served as the control mix. While in the other mixes, sand was replaced by 20%, 40%, 60%, 80%, 100% iron ore tailing. The various percentage of iron ore tailing in the mortar are labeled MTM-1, MTM-2, MTM-3…, MTM-6. Where MTM-1 implies mortar mix for zero percent of tailing, MTM-2, implies mortar mix where 20 percent of sand is replaced by tailing, MTM-3 implies mortar mix where 40 percent of sand is replaced by tailing, and so on.

2.6. Test specimens and test procedure

90 mortar cubes of 70.7mm X 70.7mm X 70.7mm [16], 18 briquette specimen after curing for 28 days in accordance with [17] and 18 mortar prism specimens of 160mm X 40mm X 40mm dimension after curing for 28 days in accordance with [18] were used as test specimens to determine the compressive strength of mortar, tensile strength and flexural strength of masonry mortar. For each cases i.e. normal mortar and modified mortar. The ingredients of mortar were thoroughly mixed till uniform consistency was achieved. The specimens were compacted on a vibrating table.

III. Results And Discussions

3.1. Compressive strength of mortar

All tested specimens and load cases for different percentages of IOT showed increases in load bearing capacities as curing age increased. Also, with increase in percentage content of IOT, compressive strengths of specimens reduced almost linearly as shown in Fig.3 and 4. All the mixes have compressive strength greater than the minimum compressive strength specified in ASTM C 270 [15b] for class M mortar. Fig. 5.shows the variation, to have a linear relationship as expressed in Eq. (1):

$$f_{cu} = -0.158R + 37.62 \qquad (R^2 = 0.988) \qquad (1)$$

Where f_{cu} and R denote the 28-day compressive strength and IOT replacement, expressed in N/mm^2 and % respectively

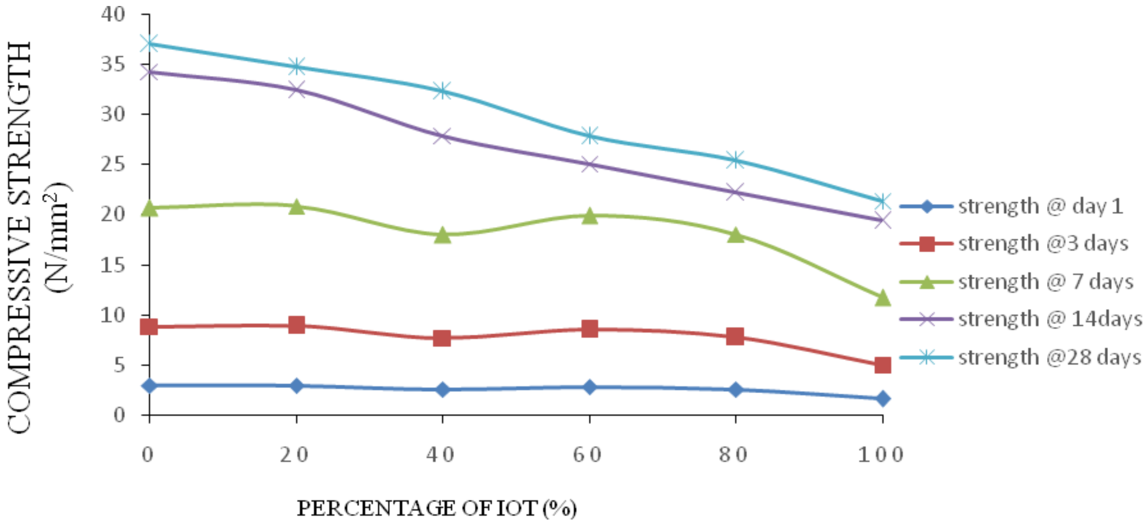

Figure 3. Variation of compressive strength of mortar with quantity of iron ore tailing

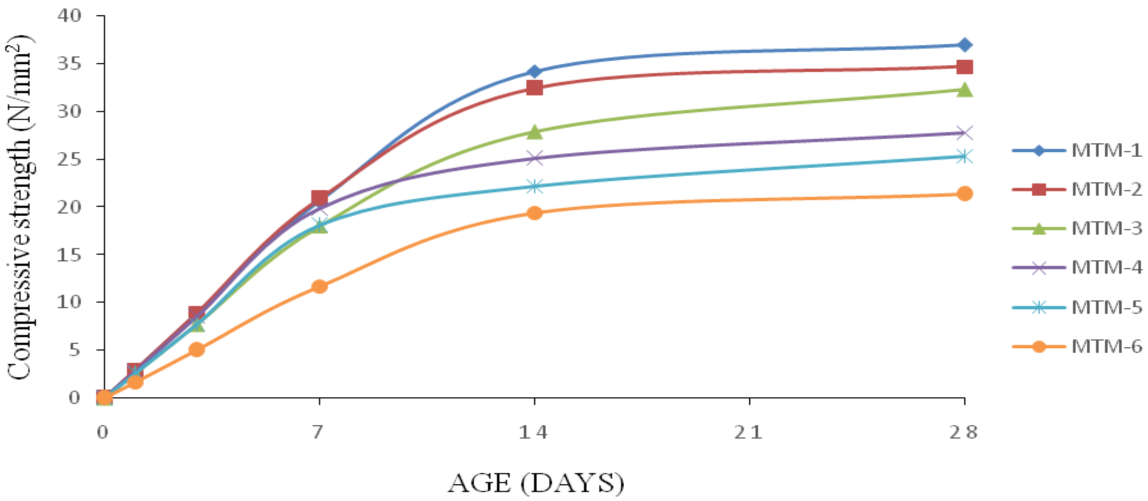

Figure 4. Variation of compressive strength of mortar with curing age

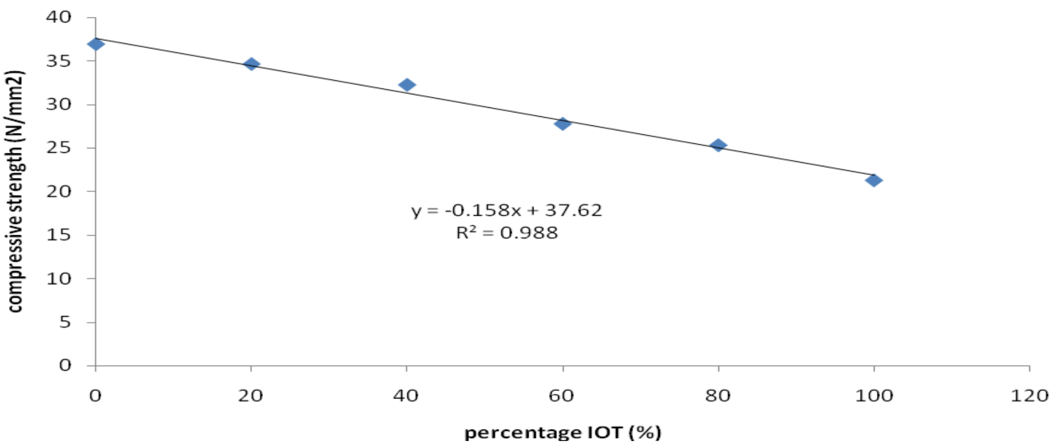

Figure 5. Relationship between compressive strength and percentage IOT

3.2. Tensile strength of mortar

The tensile strength of control mortar (MTM-1) and mortar with 20% IOT (MTM-2) are 1.76 N/mm^2 and 1.82 N/mm^2 respectively The results of tensile strength evaluation for the control mortar and mortar with river sand replaced by iron ore tailing is shown in figure 6 below.

The fines content in the mix with 20% IOT are moderate hence it fulfils 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. This explains why MTM-2 has a greater tensile strength value compared to MTM-1 and the drop in tensile strength with increase in IOT content.

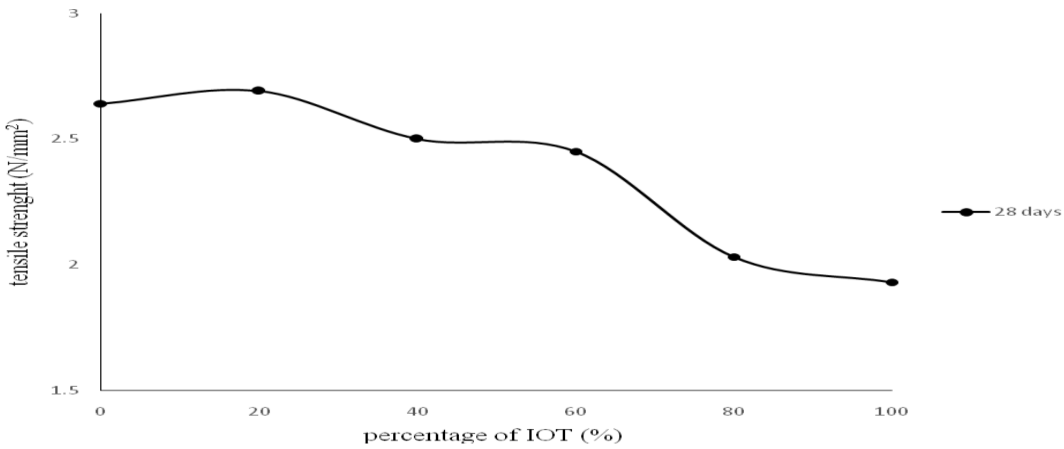

Figure 6. variations in tensile strength of mortar at 28 days

3.3. Flexural strength of mortar

The flexural strength of control mortar (MTM-1) and mortar with 20% IOT (MTM-2) are 5.73 N/mm^2 and 7.04 N/mm^2 respectively. The results of flexural strength evaluation for the control mortar and mortar with river sand replaced by iron ore tailing are plotted as shown in figure 7.

The flexural strength of the other mixes with 40, 60, 80 and 100 percent iron ore tailing content reduced due to excess fines content as a result of increase in percentage of IOT in the mixes. Excess fines content increases the need for water and cement needed for effective interfacial bond. A good bond is essential for improving strength of mortar. The iron ore tailing contains more fines content compared to river sand used. This provides larger area of contact between binder and aggregates giving rise to increase in the interfacial bond. These agrees with the findings of Wakchaure, *et al*, [20] while investigating the effect of types of fine aggregate on mechanical properties of cement concrete.

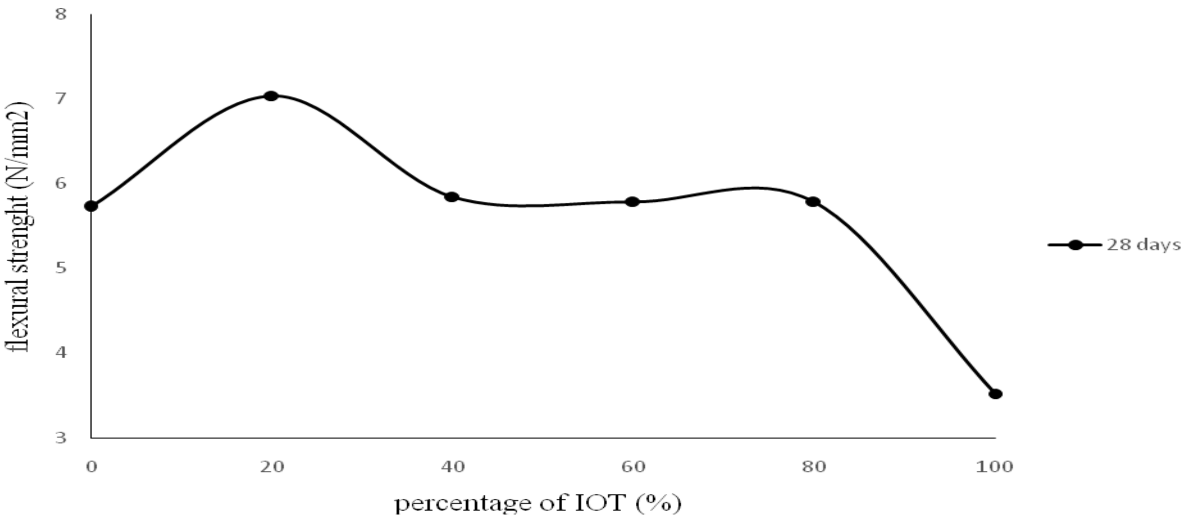

Figure 7. Variations in flexural strength of mortar at 28 days

3.4. Relationship between Flexural and Compressive strength

In order to establish a potential relationship between flexural and compressive strength in this study, Eq.(2) was obtained from the test data as shown in Fig.8:

$$f_s = 0.289 f_{cu}^{0.872} \quad (R^2 = 0.608) \quad (2)$$

Where f_s and f_{cu} denote the flexural strength and compressive strength respectively expressed in N/mm^2. The coefficient of determination, R^2 was obtained between the test data and the regression equation. When R^2 is unity, all data points lies exactly or closely on the regression equation, and value of zero signifies no correlation between data points and regression equation. Therefore, statistically, there is a moderate correlation between flexural and compressive strength of mortar containing IOT.

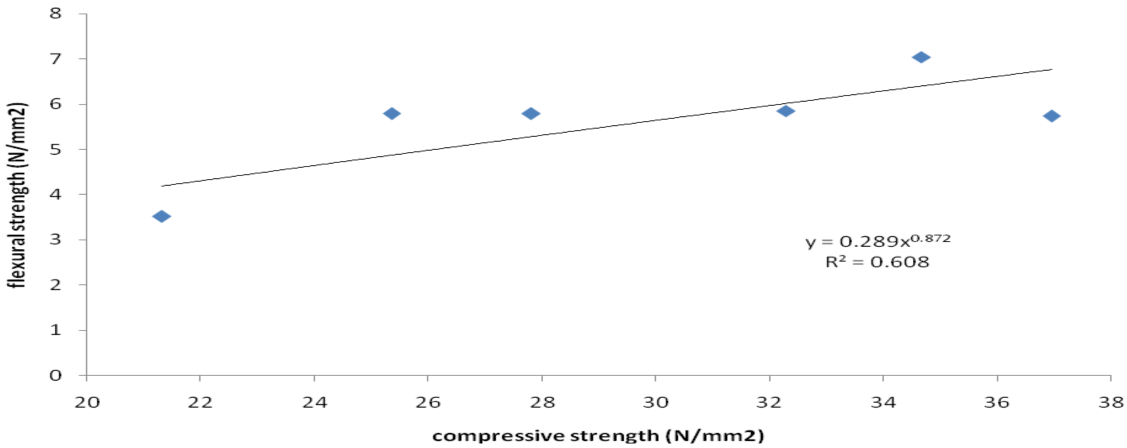

Figure 8. Relationship between flexural and compressive strength

3.5. Relationship between Splitting tensile strength and Compressive strength

Figure.9. shows a relationship between splitting tensile strength and compressive strength using regression analysis. There is therefore a high linear relationship between the compressive and tensile strength.

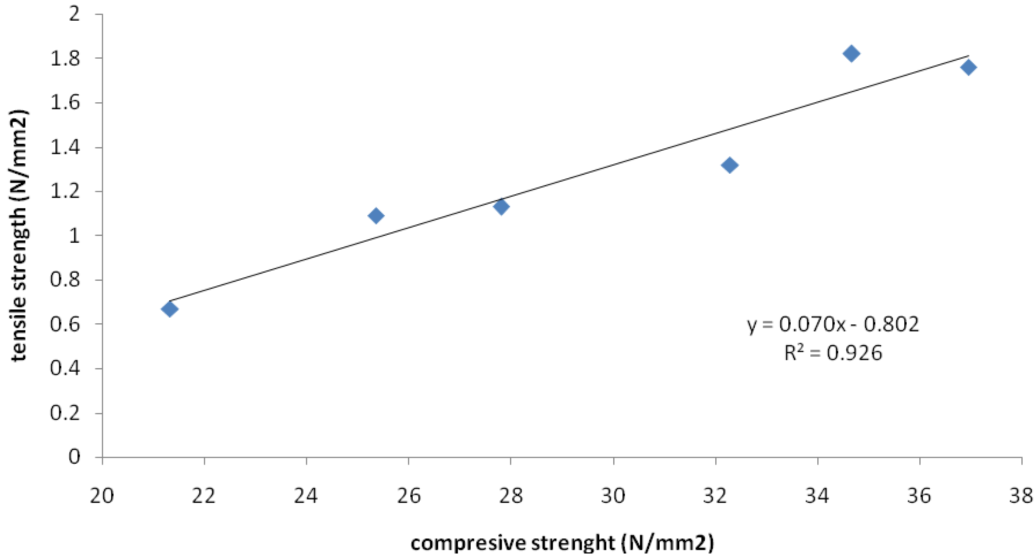

Figure 9. Relationship between compressive strength and tensile strength

IV. CONCLUSIONS

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

1. The sieve analysis of iron ore tailing (IOT) shows that it is within zone 3. The specific gravity and fineness modulus were determined to be 2.85 and 2.53 respectively. The gradation of the used particles falls within the fine aggregates specified gradation limits in [13c][14c]. The IOT was adjudged to be good for concrete work.
2. The compressive strength decreases with Iron ore tailing (IOT) content with 20% replacement level being the optimum level at 28 days.
3. All the mixes have compressive strength greater than the minimum compressive strength specified in ASTM C 270 [15c] for class M mortar. Hence Iron ore tailing can be used for masonry work. However, Twenty-eight (28) days compressive strength, tensile and flexural strength values of 34.67N/mm^2, 1.82N/mm^2 and 7.04N/mm^2 respectively was obtained for mortar when 20% iron ore tailing (IOT) was used. Values comparable to 28days compressive strength, indirect tensile and flexural strength values of 36.95N/mm^2, 1.76N/mm^2 and 5.73N/mm^2 respectively, obtained using only sand (RS) as fine aggregate.
4. IOT improved the tensile and flexural strength of concrete. The mix with 20% IOT performed better in terms of tensile and flexural strength with values 3.4% and 22.86% higher than the tensile and flexural strength of the control mix respectively.
5. The optimum replacement level for IOT content in masonry mortar production is about 20%.
6. There is a high linear relationship between the compressive and tensile strength and a high linear correlation between the percentage of iron ore tailing in the mix and the compressive strength of the mix.

V. RECOMMENDATIONS

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

1. Further research on iron ore tailing mortar is imperative in other to further optimize and improve on the strength of such composite materials with addition of admixtures, other pre-treatment methods, vary water-cement ratio, mix design etc.
2. Mortar durability test as well as alkali silica reactivity (ASR) test should be carried out to see the effect of Iron Ore Tailing (IOT) on mortar expansion due to ASR.

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