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Research Article

# Assessment of iron tailings as replacement for fine aggregate in engineering applications

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## ABSTRACT

This study evaluated the suitability of iron tailings as fine aggregate replacements for engineering applications. This is necessary to find economic usage for the enormous amount of waste from Itakpe mines. The physical properties of specific gravity, bulk density, moisture content, particle size, fineness modulus, and mechanical properties in terms of compressive strength, compaction factor, flexural strength, and relative density of the concrete made with iron tailings were determined. World Health Organization (WHO) standard methods for examining water and wastewater were used to analyze water used for curing the concrete cubes and beams to ascertain toxicity. The result shows the workability of concrete made with 50% iron tailings within the standard limit. The compressive strength at 28 days for 0% to 100% percentage replacement increases from 10.1N/mm$^2$ to 15.3N/mm$^2$. Therefore, replacing sand with the iron filling will improve the compressive strength of any concrete. The flexural strength analysis shows that the iron tailings concrete beam increases the flexural strength from 15N/mm$^2$ to 16.9N/mm$^2$ from 0 to 100% at 28-day curing. There is also a linear relationship between the flexural strength and the density of the iron tailing concrete. The pH and Alkalinity tests of the water used to cure the iron tailing concrete indicate that the curing water's alkalinity was high (20.883 to 40.75) with a pH range of 12.1-12.4. This shows that using iron tailing will not harm the durability of the resulting concrete. The iron tailings are suitable for acceptable aggregate replacement up to 75% without negatively altering the mechanical properties of such concrete.

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## INTRODUCTION

Mining activities involve the separation of valuable minerals from the surrounding waste rocks, which often litter the vicinity of the mine, where they remain unsightly features in the natural landscape [1]. Iron-ore tailings are waste materials obtained in the Iron ore mine after the extraction of Iron from the ore. The Iron tailings are alkaline in nature with a pH value of 7.0-8.5, unfit for farming and making the land barren. It is, therefore, necessary to permanently dispose-off unwant-

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ed or unused materials or find an alternative usage for these wastes. The disposal of the mine tailings continues to burden the mining industries and the general public regarding economic and environmental health, respectively. Pollution concern is also one of the main issues for the mining industry. Therefore, the need to get environmentally friendly and sustainable disposal methods. After successful disposal of the tailings, there is also the need to monitor and manage the tailings site [2]; prevention of erosion, development of acid mine drainage (AMD), and dam failures must be ensured [3, 4]. They can also release toxic and heavy metals into the environment. The industries are therefore confronted with mine and post-disposal costs, which deplete substantial profit from their production. There are pretty several iron ore mining sites in Nigeria and worldwide. Concrete, on the other hand, is a construction material that is valuable and widely acceptable. One of concrete's significant constituents is fine aggregates that have recently experienced cost escalation. This, in turn, has increased the cost of concrete and made the cost unfriendly to the construction industries and other stakeholders. There is, therefore, a dire need to source for an alternative. Waste rocks such as tailings are abundant and can be utilized for this purpose. This will reduce groundwater pollution caused by leachates from the heaps of iron ore tailings and reduce the overall cost of concrete production. Tiwari et al. [5] predicted that the advancement in concrete technology could reduce the consumption of natural resources and energy sources and lessen the burden of pollutants on the environment if wisely utilized. They considered the feasibility of using Iron Ore Tailing (IOT) as a partial replacement for sand (or Fine Aggregate). This research has assessed the possibility of partially replacing fine aggregates with iron ore tailings.

## MATERIALS AND METHODOLOGY

The primary materials employed in this research were iron tailings, sharp sand, 19 mm granite aggregates, water, and cement. Samples of iron tailings were collected from the final tailings dump in the beneficiation section of the National Iron Ore Mining Company (NIOMCO) in Itakpe, Kogi State, Nigeria. In contrast, 19 mm granite aggregates were collected from Zibo Quarry in Ijare Ondo State, and sharp sand was collected from the Bonvick block industry in Akure Ondo State. Samples of sharp sand were replaced with 15%, 25%, 50%, 75%, and 100% of IOT denoted as T15, T25, T50, T75, and T100, respectively, while the control sample (100% sharp sand) was denoted as T0. The samples were subjected to various tests, as highlighted below.

**Uniaxial Compressive Strength:** This was carried out to know the maximum compressive strength capacity of iron tailings at 0, 15, 25, 50, 75, and 100% as an acceptable aggregate replacement, which could sustain under a gradually applied load of compressive stress without fracture. The compressive strength test used a concrete cube of 100 X 100 X 100mm. The concrete cube was made and cured in water for seven days, 14 days, 21 days, and 28 days. They were removed after the specified time for crushing. Compressive strength was calculated by dividing the maximum load by the original cross-sectional area of a specimen by the provision of ASTM [6]. The mixed proportioning of the materials used for the compressive strength test is shown in Table 1.

**Flexural Strength:** This was carried out to know the maximum bending stress capacity of iron tailings at 0, 15, 25, 50, 75, and 100% as acceptable aggregate replacement. The flexural strength test was conducted using a concrete cube of 500 X 100 X 100 mm. The concrete cube was made and cured in water for seven days, 14 days, 21 days, and 28 days. They were removed after the specified time for testing. Flexural strength was calculated by dividing the maximum load by the original cross-sectional area of a specimen by the provision of ASTM [7].

The mix proportioning of the materials used for the flexural strength test is shown in Table 2.

**Toxicity Test:** This was done on the curing water from day seven till day twenty-eight by carrying out Alkalinity, pH, and Hardness tests in order to ascertain no seepage of heavy metals in the iron tailings concrete cubes and beams when it is used in water structures like reservoir and well rings which was done relatively to WHO [8].

**Table 1.** Mix proportioning by mass of materials used for the compressive strength test

| S/N | Percentage Replacement (%) | Cement | Sand | IT | Granite |
|---|---|---|---|---|---|
| 1. | 0 | 9.63 | 19.30 | 0 | 38.52 |
| 2. | 15 | 9.63 | 16.40 | 2.90 | 38.52 |
| 3. | 25 | 9.63 | 14.47 | 4.83 | 38.52 |
| 4. | 50 | 9.63 | 9.60 | 9.70 | 38.52 |
| 5. | 75 | 9.63 | 4.80 | 14.50 | 38.52 |
| 6. | 100 | 9.63 | 0 | 19.30 | 38.52 |

Key: IT means Iron tailings.

**Table 2.** Mix proportioning by mass of materials used for the flexural strength test

| S/N | Percentage Replacement (%) | Cement | Sand | IT | Granite |
|---|---|---|---|---|---|
| 1. | 0 | 20.8 | 41.60 | 0 | 83.20 |
| 2. | 15 | 20.8 | 35.36 | 6.24 | 83.20 |
| 3. | 25 | 20.8 | 31.20 | 10.40 | 83.20 |
| 4. | 50 | 20.8 | 20.80 | 20.80 | 83.20 |
| 5. | 75 | 20.8 | 10.40 | 31.20. | 83.20 |
| 6. | 10% | 20.8 | 0 | 41.60 | 83.20 |

Key: IT means Iron tailings.

## PROPERTIES OF THE RESEARCH MATERIALS

### Characterization and Chemical Analysis of the Iron Ore Tailings

**Sample Digestion:** Samples of iron tailings were digested by adding 1g with 10 ml mixture of $HNO_3$ and HCl. The mixture was after that heated for 15mins by the open-air method. A color change from blackish-grey to pale yellow was noted. On cooling, decantation was done (to separate the filtrate from the residue) then the filtrate was added to aqua reagent solution ($HNO_3$ and HCl). Distilled water was diluted to the required volume of 100 ml by ASTM [9].

**X-ray Fluorescence Analysis:** It involves the emission of characteristic secondary X-rays from a material that has been excited by being bombarding it with High-Energy gamma rays, commonly designated an electric lamp-like device emitting ultraviolet radiations or black light. The concentration of heavy metals in the iron tailings, including Pb, Ni, Cd, and Ti, was examined to ensure that the materials were non-hazardous per ASTM [10].

## RESULTS AND DISCUSSION

**Bulk Density and Specific Gravity Tests:** The bulk density of iron tailings (2121.9 kg/m$^3$) is higher than that of the sharp sand (2118.3 kg/m$^3$). Samples of iron tailings used have an average specific gravity of 4.13 compared to the specific gravity of sharp sand (2.97). This high specific gravity can be traced to iron content since its density is more significant than sand. Therefore, concrete cubes and beams made with the tailings are expected to have high specific gravity with high strength and less possibility of deformation resulting from external loads [11].

**Particle Sizing:** The particle size analysis of the iron tailings samples is shown in Figure 1. The iron ore tailings sample is of a high coarse and high medium grains size and 30% fines in terms of its structure in granular form. This is responsible for the increased compacting density of the iron tailing obtained. Figure 2 also shows the particle size analysis of the sharp sand samples. Similarly, the sharp sand is of a high coarse and high medium grains size and 27% fines in its structure in granular form resulting in its high compacting. The two figures indicate iron tailing to be well-graded while the sand is uniformly graded.

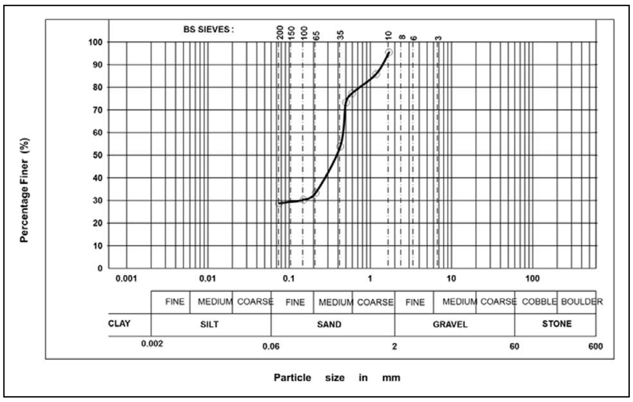


**Figure 1**. Particle Size and Texture of Iron Tailings.

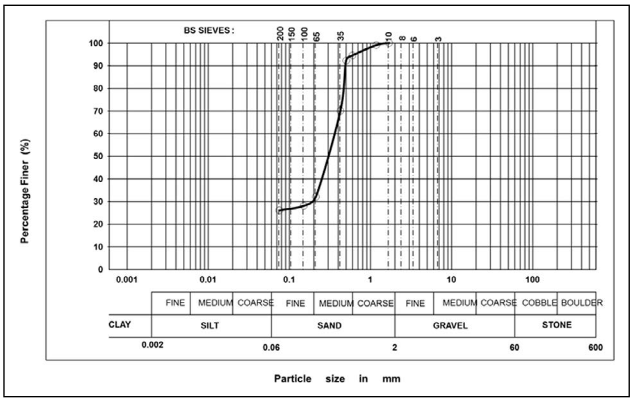


**Figure 2**. Particle size and Texture of Sharp Sand.

**Fineness Modulus:** The fineness modulus of the iron tailings is shown in Table 3. This result shows that the material used lies within fine and medium sand grains suitable for making satisfactory concrete cubes and beams in accordance with ASTM [12].

**Coarse Aggregates:** The aggregate impact value (AIV) and specific gravity of granite used in this study are 19.1 % and 2.73, respectively. This makes the granite aggregate competent as an Aggregate Impact Value of 19-21% is desired [12].

**Table 3.** Fineness Modulus for Aggregates of different Sieves Sizes

| Aperture size | Sharp sand | Iron Tailings | 15% | 25% | 50% | 75% |
|---|---|---|---|---|---|---|
| 1.8 mm | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.7 mm | 0.02 | 22.8 | 3.44 | 5.72 | 11.41 | 17.11 |
| 1.18 mm | 4.5 | 47.7 | 10.98 | 15.3 | 26.1 | 36.9 |
| 600 microns | 22.8 | 42.2 | 25.71 | 27.65 | 32.5 | 37.35 |
| 500 microns | 11.2 | 20.6 | 12.61 | 13.55 | 15.9 | 18.25 |
| 425 microns | 111 | 97.7 | 109.01 | 107.68 | 104.35 | 101.03 |
| 212 microns | 189.8 | 102.4 | 176.69 | 167.95 | 146.1 | 124.25 |
| 150 microns | 20.2 | 15.3 | 19.47 | 18.98 | 17.75 | 16.53 |
| 75 microns | 10 | 7.5 | 9.63 | 9.375 | 8.75 | 8.125 |
| pan | 130.48 | 143.8 | 132.48 | 133.81 | 137.14 | 140.47 |
| | 500 | 500 | 500 | 500 | 500 | 500 |

**Curing Water:** The potency of hydrogen ion concentration, an average of total alkalinity test, and hardness test of the water sample used for curing every seven days of crushing test done by WHO's Drinking water standards (2008) is presented in Table 4. The results show an increase in the alkalinity of the curing water from 20.883 to 40.75mg/l and hardness from 209.023 to 297.025mg/l. This implies that the reaction releases hydrogen iron as the end product when iron tailing partially replaces sand. This benefits concrete durability [13].

**Chemical Analysis of Iron Tailings**

Table 5 shows the chemical analysis of iron ore tailings. Metals that are toxic when in contact with environmental media, such as lead, nickel, cadmium, and titanium, were analyzed but were found below the detection limit, which differs entirely from the chemical composition analysis carried out by (Shettima et al., [14], other elements like copper were analyzed. They were not detected in the iron tailings. This makes the tailings environmentally friendly when partially replaced or entirely replaced in construction works as there cannot be fear of seepage of toxic heavy metals, which are inimical to healthy living into the ecosystem due to its usage.

**Table 4.** The pH, total alkalinity, and hardness of the water sample for curing every seven days of crushing test

| Water Sample @ | pH | Total Alkalinity (mg/l) | Hardness (mg/l) |
|---|---|---|---|
| 7 Days | 12.1 | 20.833 | 209.023 |
| 14 Days | 12.3 | 21.85 | 219.145 |
| 21 Days | 12.3 | 29.84 | 229.231 |
| 28 Days | 12.4 | 40.75 | 297.025 |

**Cement Test**

**Fineness and Soundness Test:** The cement used had a fineness percentage of 9.89 and a soundness value of 5.6. These value (fineness and soundness) shows that the cement used is not adulterated, as adulterated cement will have a fineness and soundness percentage that will exceed ten percent (10%). This is the ability of a hardened cement paste to retain its volume after setting to assert if it has not been subjected to delayed destructive expansion due to the presence of excessive free lime or magnesia.

**Consistency, Initial and Final Setting Time Test Result:** The Setting time of a Lafarge cement used in this study was done by the ASTM [15].

**Workability Test:** Table 6 shows the workability tests (compaction and slump tests) results for fresh concrete made with different aggregate replacement mixtures. The workability decreases with an increase in Iron tailings which is very different from the research done by Owolabi [1] because of the post-beneficiation tailings used in this study.

The compressive strength replacement for the various concrete mixes made from the partial replacement of the fine aggregates with iron tailing is shown in Figure 3. The compressive strength at 28 days for 0% to 100% percentage replacement increases from 10.1N/mm$^2$ to 15.3N/mm$^2$. The same trend of increment in the compressive strength was also observed for all the remaining curing days. There is an improvement in the compressive strength for all the

**Table 5.** Chemical analysis of iron tailings (ppm)

| Element | Fe | Mn | Zn | Ca | Na | K | Ni | Pb | Al | Si |
|---|---|---|---|---|---|---|---|---|---|---|
| Amount | 622 | 1.92 | 0.39 | 1.59 | 5.66 | 0.66 | 0.01 | 0.21 | 0.0008 | 0.0014 |

**Table 6.** Workability classification

| Replacement with IOT | Compaction Factor | Slump (mm) | Workability Classification |
|---|---|---|---|
| 0% | 0.96 | 98.0 | Medium |
| 15% | 0.97 | 70.0 | Medium |
| 25% | 0.92 | 90.0 | Medium |
| 50% | 0.94 | 85.0 | High |
| 75% | 0.94 | 80.0 | Medium |
| 100% | 0.87 | 85.0 | Medium |

curing days considered and the percentage of iron tailing (IOT) replacement considered. The sharp increase at 75% replacement of sharp sand with iron tailings could be because iron tailings are more resistant to compressive force than sharp sand. After all, the result was consistent on all the days. This indicates that fine aggregates can be replaced with IOT without impairing the compressive strength of such concrete. This was also similar to the result obtained by Arum and Owolabi [13].

Figure 4 shows the flexural strength of cast beams. The results follow the same trends for all the curing days. A reduction is noticed at seven days and 14 days of curing, while at 21 days and 28 days of curing, the flexural strength at 75% replacement of the IOT shows comparable results. The higher flexural strength obtained at 75% indicates that iron tailings are more resistant to bending than sharp sand. This is in line with the fundamentals of reinforced concrete properties. However, for flexural strength stability, the percentage replacement of the fine aggregates with the IOT should not exceed 75%.

The result of the density of the Beams used for Flexural strength is presented in Figure 5. The result is similar to the flexural strength obtained in Figure 4. This is an indication that there is a linear relationship between the flexural strength of any concrete and its density. The flexural strength depends on the concrete's density, as Figure 6 shows that the higher the density, the higher the bending stress of the casted beams and satisfies the null hypothesis.

**Results of Toxicity Test**

The chemical composition of iron tailings is non-acidic, as the suspected harmful elements were analyzed and found beyond the detection limit. Also, the potency of hydrogen in the iron tailings had normal basicity, average hardness value, and World Health Organisation alkalinity standard for portable water achievable, making it portable for drinking. The negative toxicity result makes it highly environmentally friendly. Thus, suitable for industrial and commercial construction purposes.

Figure 7 shows the pH of the curing water used for curing the concrete at 7, 14, 21, and 28 days. Using IOT will reduce the pH of the concrete, as shown in Figure 7. The

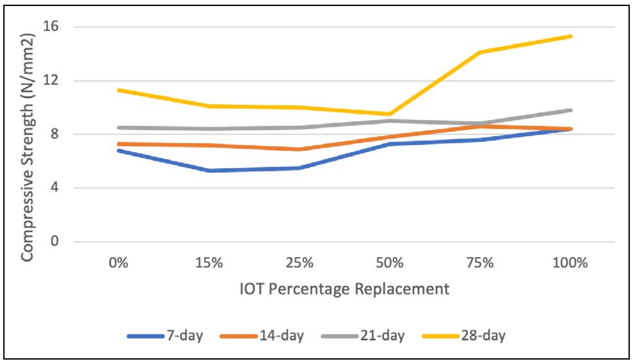


**Figure 3**. Compressive Strength of iron tailings concrete cubes.

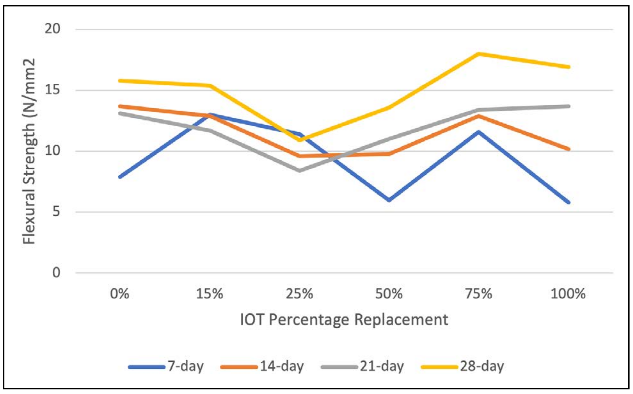


**Figure 4**. Flexural Strength of casted Beams.

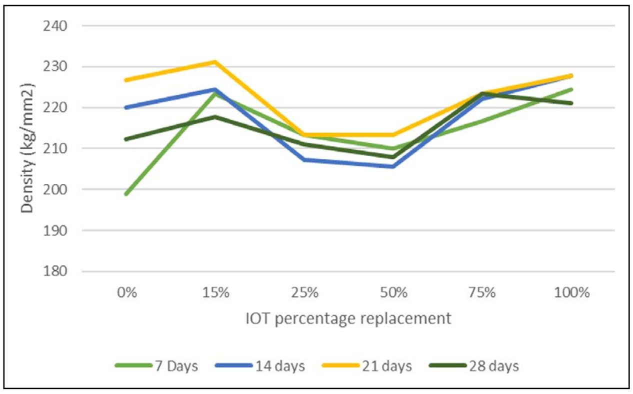


**Figure 5**. Density of the beams used for flexural strength.

pH of the curing water increases with age. This can be attributed to the reaction of the Iron tailing with the other constituents of the concrete.

Figure 8 shows the average alkalinity values of the iron tailings curing water sample casted cubes and beams at 7, 14, 21, and 28 days. The curing water at seven days has a normal alkalinity of 20.8 mg/l, while at 14, 21, and 28 days gives good normalized caustic bases values of 21.85, 29.84, and 40.75 mg/l, making the water drinkable as the normal drinkable water alkalinity should be between 20 – 200 mg/l. The alkalinity increases with curing days.

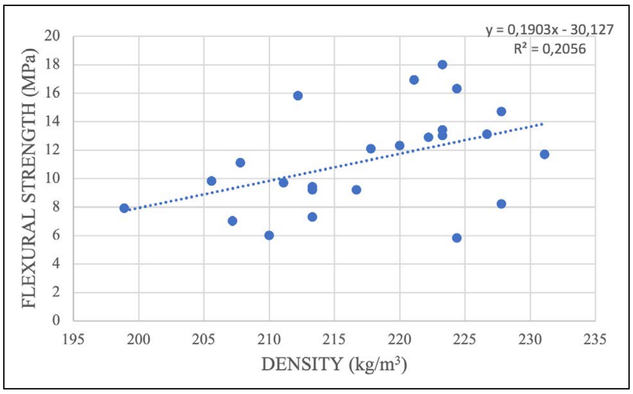


**Figure 6**. Relationship between density and the flexural strength of the casted Beams.

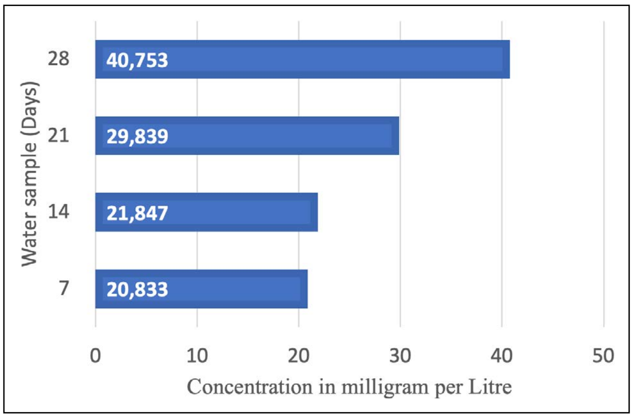


**Figure 8**. Alkalinity of the curing water at 7, 14, 21, and 28 days.

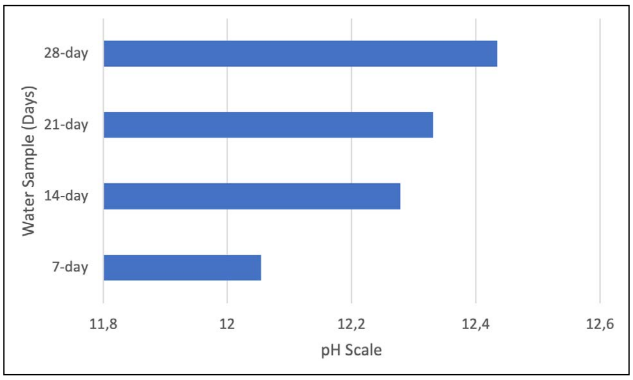


**Figure 7**. The pH of Curing Water on Different Days.

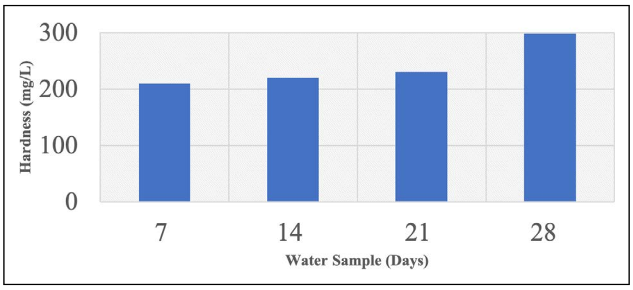


**Figure 9**. Hardness of curing water sample for seven, fourteen, twenty-one, and twenty-eight days.

Figure 9 shows the hardness values of the curing water sample of the iron tailings cast cubes and beams for 7, 14, 21, and 28 days. The hardness of the twenty-eight days curing water was higher at 297.03 mg/l than the twenty-one, fourteen- and seven-day water samples with 229.23, 219.15, and 209.02 mg/l, respectively. There is an increase in the alkalinity.

## CONCLUSION AND RECOMMENDATION

This research has shown that iron tailings can successfully replace river sand as fine aggregates without compromising the compressive strength and the flexural strength of such concrete when the iron tailings are available as waste without a reasonable means of disposal. It was indicated that when 75% of it is blended with 25% river sand, the resulting concrete can have a strength value of about 7% higher than the strength of concrete produced with 100% river sand fine aggregate. The research also showed that the highest strength with iron ore tailings resulted when 100% iron tailings were used as the acceptable aggregate content. This compressive strength value is 15.3N/mm$^2$ in this research. The alkalinity of the curing water shows that using the iron tailings will not impair the durability of such concrete if used in reinforced concrete. There is a relationship between the density and the flexural strength of concrete beams cast; thus, the higher the density, the higher its bending stress.

The iron tailings can be used to construct water structures like reservoirs and well rings without any fear of the seepage of toxic elements, making it environmentally friendly.

## ETHICS

There are no ethical issues with the publication of this manuscript.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

## PEER-REVIEW

Externally peer-reviewed.

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