e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-12, Issue-4 (August 2022)
https://doi.org/10.31033/ijemr.12.4.10

Iron Ore Tailings as Partial Replacement for Fine Aggregate in Concrete Production – Review

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ABSTRACT

Normal River sand is one of the major components of concrete, generally termed fine aggregate. A large volume of sand is needed annually for construction work globally. Mining or extraction of sand from the river bed, ocean beds, beaches, and inland dunes is accompanied by several problems such as; lowering of the water table, sinking of bridge piers and erosion of river bed and instability of river bed on the environment, etc. To decrease these environmental impacts and the cost of conventional fine aggregates, alternative materials like mining waste have been studied by several researchers to replace partially fine aggregates in concrete production. Iron ore tailings (IOT) are one of the mining wastes obtained from the beneficiation process of iron ore concentrates. This paper presents an overview of the work carried out on the use of IOT as a partial replacement of fine aggregate in concrete and its effects on the workability, mechanical, and durability properties of concrete.

Keywords-- Normal River Sand, Iron Ore Tailings, Beneficiation, Mining Waste, Concrete

I. INTRODUCTION

Essentially, concrete is a composite material of cement, fine aggregate, coarse aggregate, water and sometimes admixture [1]. The increase in construction activities all over the world has caused a corresponding increase in the demand and cost of materials such as natural river sand owing to the method or processes for obtaining it [2]. According to [3], [4] a conservative estimate of the global consumption or extraction of aggregates annually is between 32 and 50 billion tonnes. The demand for sand due to various construction activities will continue to increase and it will have consequential effects on the environment and other sectors of national life such as tourism, fishery, insurance etc [4]. The amount or volume of sand extracted from either a pit, river bed, lake, or sea bed, results in loss of land through river or coastal erosion, lowering of the water table, decreases in the amount of sediment supply, increase in flood frequency and intensity, and exacerbating drought occurrence, greenhouse gas increase, Extinction of species, etc.[5],[3],[6][4]

To mitigate the effects of sand exploration on the environment and as well as to address the scarcity and cost of fine aggregate, and have sustainable mining of river sand, there is a need to research materials that can be used as a partial replacement for normal river sand in concrete production. Iron ore tailings (IOTs) are a form of solid waste produced during the beneficiation process of iron ore concentrate [7], and have been used by many researchers as a replacement for fine aggregate in concrete production [8][9][10][11], [12][13]–[16] This paper is about the review of various research works on the nature of IOT and its effects on the properties of concrete as a partial replacement for fine aggregate in the production of concrete.

II. IRON ORE AND IRON ORE TAILINGS

Iron ores as shown in Fig 1 are rocks and minerals from which metallic iron can be economically extracted. The iron is usually found in the form of magnetite (Fe_3O_4, 72.4% Fe), hematite ($Fe_2 0_3$, 69.9% Fe), goethite ($FeO(OH)$, 62.9% Fe), limonite ($FeO(OH).n(H_2O)$, 55% Fe) or siderite ($FeCO_3$, 48.2% Fe) [17]. It was reported that iron ore is one of the most common metallic minerals in Nigeria and is found in various locations in the north-western, north-central, south-western, and south-eastern parts of the country and more than thirty iron ore deposits have been reported in the country with estimated reserves of over one (1) billion tons of iron ore comprised of 800 million tons of confirmed reserves and 500 million of likely reserves located in the following states; Enugu, Niger, Zamfara, Kaduna, Oyo and Anambra [18]

Figure 1: Iron Ore

e-ISSN: 2250-0758 | p-ISSN: 2394-6962
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https://doi.org/10.31033/ijemr.12.4.10

Table I: Physical Properties of Iron Ore Tailings

Researchers	Mine location	Colour	Fineness modulus	Particle size	Specific gravity	Bulk density
[15]	Itakpe, Nigeria.	---	2.53	---	2.85	1594
[19]	Kudremukh Lakya valley, India	---	2.545	---	3.33	---
[20]	Perenjori, West Australia	---	3.85	0.13-2.67	2.65	1860
[21]	Nigeria	---	---	---	3.49	3180
[22]	Bellary mining area	---	1.8	$< 150\mu m$	2.34	---
[23]	Johor, Malaysia.		1.05		2.6	1270
[24]	Kudremukha, Karnataka, India		2.69		3.27	1816
[25]	Kudremukh Lakya valley, India	---	2.545		3.33	
[26]	Hargrah, India	Dark Tan (brown)	---	---	3.10	1440
[13]	Kudremukh Lakya valley, India	---	2.54	---	2.67	---

There is an estimated reserve of about 200 million metric tonnes of iron ore deposits with an average iron ore content of 36%, at a site near National Iron Ore Mining Company (NIOMCO), Itakpe in Kogi state [8], [15]. The iron ore has to be beneficiated at the rate of eight (8) million tonnes per year by NIOMCO to supply 2.15 million tons of 63 % to 64 % grade concentrate of iron (Fe) per year to Ajaokuta Steel Company Nigerian Limited and 68% Fe concentrate as pellet feed for the direct reduction plant at Aladja, in Nigeria [27].

Iron ore tailings (IOTs) as shown in Fig 2, are a form of solid waste produced during the beneficiation process of iron ore concentrate [7]. At the expected production rate, large quantities of tailings are obtained as waste products of the beneficiated iron ore and the estimated stripping ratio (waste/ore ratio) of the deposit would amount to approximately 28 million tons [27]

Figure 2: Iron Ore Tailings[28]

According to [29], IOT is a class of cast-off mineral processing and composite mineral raw material; in addition to containing a small number of metals, its main mineral components are gangue minerals such as quartz, pyroxene, feldspar, garnet, hornblende, and alteration minerals.

II.a Physical Properties of IOT

Table I shows some of the physical properties of IOT used in various researches from different locations. From the table, the specific gravity ranges from 2.34 to 3.49. The specific gravity of aggregates normally used in construction ranges from about 2.5 to 3.0 with an average value of about 2.68 [30]. Some IOTs are heavier than normal river sand as evident by their specific gravity. Generally, the sand having a fineness modulus of more than 3.2 is not used for making good concrete [31] and from the table, IOT satisfies the requirement that the fineness modulus must not be greater than 3.2 except for iron ore tailings from Perenjori, West Australia. The iron ore tailings generated depend on the type, geological location and the treatment method being used.

II.b Chemical Properties of IOT

Chemical properties of IOT from previous studies are presented in Table II. The main components of iron ore tailings are the same as natural sand, and the high silica content in the iron ore tailings indicates that they can be used to prepare concrete is considered.

II.c Microstructure of IOT

According to the study by [32], the XRD pattern of IOT as shown in Fig 3 shows that there is a presence of kaolinite and calcite in addition to the crystalline phase of hematite.

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https://doi.org/10.31033/ijemr.12.4.10

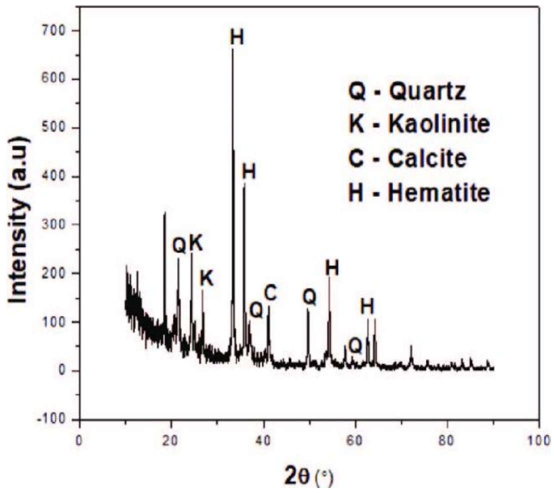

Figure 3: XRD pattern of IOT[32]

Table II: Chemical Composition of IOT

Researchers/Oxide Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	MnO_2	TiO_2	Cl^-	$Loss$
[33]	70.32	5.10	10.93	4.710	4.510	1.14	1.3	0.26			0.016	1.1
[29]	68.44	8.27	7.46	4.460	3.040	1.90	2.29	0.35	---	---	---	2.73
[23]	56.00	10.00	8.30	4.300	1.700	1.50	---	---			---	3.3
[15]	45.64	3.26	47.70	0.607	0.393	---	---	---		0.24	---	---
[22]	9.02	9.56	66.56	1.960	2.120	---	---	---	1.15	0.66	---	---
[21]	66.00	3.80	15.00	1.800	1.000	---	---	0.80	---	---	---	---
[34]	57.31	9.58	25.13	0.030	0.080	0.04	0.04	0.16	---	0.61	---	6.67
[24]	62.05	3.08	28.59	0.073	0.017	---	---	---	---	---	---	2.32
[35]	67.29	8.49	8.95	3.63	4.800		2.90	0.45	---	---	---	2.39

The morphology of IOT was also studied through the Scanning Electron Micrography and the IOT surface showed a random distribution of irregular particles, as seen in Fig 4

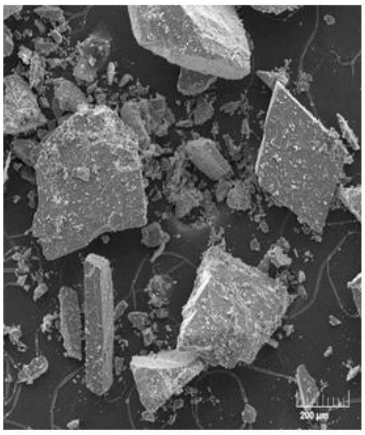

Figure 4: SEM of IOT [32]

[23] carried out the X-ray diffraction (XRD) and Field Emission Scanning Electron Microscopy (FESEM) analysis on IOT. The XRD as shown in Fig 5 indicated that the main crystalline phases were quartz (SiO_2), gibbsite, hematite (Fe_2O_3), and chamosite ($(Fe^{2+}, Mg)_5Al_2Si_3O_{10}(OH)_8$. It was reported that traces of calcite ($CaCO_3$) in the spectrum are attributed to the high loss of ignition observed in the chemical composition. SEM analysis showed that IOT was made up of porous and irregular-shaped particles which were well dispersed. The conclusion from the study shows that the irregular-shaped particles coupled with the loose ones are responsible for the high surface area and water demand.

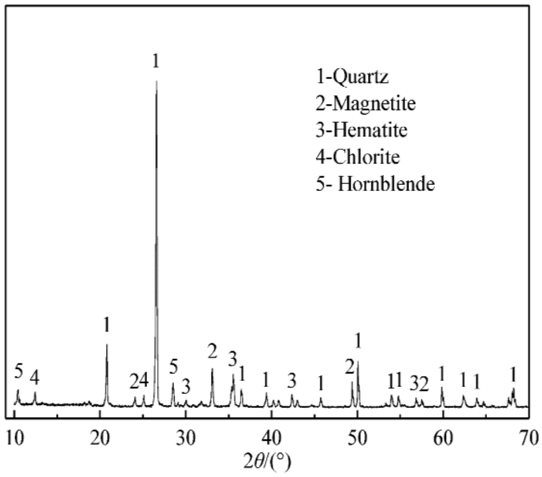

Figure 5. XRD pattern [36]

According to [35], the iron tailing powder's X-ray diffraction (XRD) pattern, the primary mineral phase of the iron tailing powder is quartz. SEM analysis of the morphology of iron tailings powder revealed that after mechanical grinding, there are many small particles as well as some coarse particles with irregular shapes.

III. EFFECTS OF IRON ORE TAILINGS AS FINE AGGREGATE IN CONCRETE PRODUCTION

III.a Workability of IOT Concrete

The workability of IOT concrete decreases as the percentage of fine aggregate replaced with IOT increases, which could be owing to the fineness and large specific surface area of the IOT, which necessitates a substantial amount of water to wet all particles in the mix. Several studies such as [37][14], [15], [36], [38] have reported the reduction in the workability of IOT concrete as the percentage replacement fine aggregate with IOT increases. In the same vein,[16] found that adding IOT to the mix increased water demand while lowering the flowability of the fresh material due to the IOT's high specific surface area and rough surface. [39] concluded that superplasticizers should be used for enhanced workability, which is also in agreement with [28].

III.b Compressive strength of IOT Concrete

Many researchers have carried out investigations on the compressive strength of IOT concrete and few of the studies are reported in this section.

[39] investigated the effect of replacing sand with iron ore tailings on concrete compressive strength and reinforced concrete beam flexural strength. The percentage replacement of fine aggregate by IOT were 0, 10, 20, 30, 40, 60, 80, and 100% for cast cubes of 150mm sides and reinforced concrete beams of 1000 x 100 x 100 mm. According to the study, an increase in compressive strength of the cubes and beams was achieved by replacing the fine aggregate with IOT at 40% optimal replacement.

[36] examined the Evaluation of iron ore tailings as a replacement for fine aggregate in concrete. Concrete mixtures containing 25, 50, 75, and 100% IOT as river sand replacement with a 0.5 water-to-cement ratio (W/C) were cast, compressive and splitting tensile strengths, modulus of elasticity, and durability tests (drying-shrinkage, water absorption, chloride penetration, and carbonation effects) were carried out on the concrete containing IOTs. According to the results, the compressive strength was higher than the normal concrete at all levels of replacement and curing periods. Factors suspected to be responsible for the higher strength are the fineness of the IOT, higher iron content, and a possible secondary reaction between excess $Ca(OH)_2$ and IOT to produce more C-H-S. However, it was also observed that the strength of the concrete with IOT was decreased as the percentage of IOT was increased and concluded that the optimum replacement of sand with IOT is 25%.

[37] carried out an experimental study on iron ore tailings and bottom ash as fine aggregates in concrete. They replaced fine aggregate with 10%, 20%, 30%, 40%, and 50% iron ore tailings and with 10, 20, 30, 40, and 50% bottom ash for concrete cubes. The compressive strength of 30% IOT increased by 5.32% from the control mix. However, for 10, 20, 40, and 50% IOT, the compressive strength of the mix reduced from that of the control mix by 20.17, 16.51, 10.61, and 11.5% respectively. According to the investigation, 30 % optimum replacement of fine aggregate by IOT was obtained.

[40] experimented to determine the suitability of iron ore tailings (IOT) as a fine aggregate replacement of sand (RS) for concrete used for rigid pavement. The iron ore tailings (IOT) used were obtained from Itakpe mines near Okene in the north-central Kogi state of Nigeria. Mix design was carried out for concrete of grade 35 using the standard practice for selecting proportions for normal weight and mass concrete [41]. The constituent materials were batched by weight. The mix without IOT served as the control mix, while sand was replaced in the other mixes by 20, 40, 60, 80, and 100% iron ore tailing (IOT). 28 days compressive strength value of 43.67N/mm^2, was obtained for concrete containing 20% iron ore tailing (IOT), Value comparable to 28 days compressive strength of 45.02 N/mm^2 was obtained using only sand as fine aggregate.

[14] investigated the effect of partial replacement of sand by iron ore tailings on the compressive strength of concrete. In their work, iron ore tailings were used as partial replacement to fine aggregates at levels of 0, 5, 10,15, and 20% and they studied the basic material properties and strength parameters. An experimental investigation was done using an M25 mix and tests were carried out as per recommended procedures by relevant codes. The mix

proportions used for concrete are 1: 1.484: 2.698. The compressive strength of concrete increases gradually with the addition of iron ore tailings from 0% to 15% and after that the strength of concrete decreases. Hence concluded that 15% replacement of sand with IOT gives the best result for the compressive strength of concrete.

[38] examined experimentally the properties of concrete mixed with IOT. Fine aggregate was replaced by 0, 25, 35, and 45% of IOT. The workability and mechanical properties of concrete specimens with different amounts of iron ore tailings as a replacement were tested. Results show that 35% replacement of natural aggregates by iron ore tailings is optimal. The performed tests on permeability, frost resistance, and carbonation resistance for the concrete specimens with an optimal amount of iron ore tailings, and the mechanical performance of the specimens were assessed, the change in the mechanical properties of the specimens was obtained after seepage, freezing-thawing, and carbonation. It was concluded that the performance of the concrete with 35% replacement of iron ore tailings is equivalent to that of natural sand concrete. Hence, it can be utilized in engineering applications.

[20] investigated the utilization of iron ore tailings as a replacement for aggregates in concrete. A concrete mix of grade 40 MPa was prepared in the laboratory with a water-cement ratio of 0.5. The concrete was cured for 1, 2, 3, 7, 14, and 28 days. They performed tests on the properties of concrete such as workability, durability, density, compressive strength, and indirect tensile strength. The iron ore tailings aggregate concrete exhibited a good compressive strength, with an increment of 11.56% over plain or normal concrete. This improved strength of IOT concrete may be due to the high content of iron oxide present in the IOT, which has the ability to accelerate cement hydration as reported by [42].

[39] studied the utilization of IOT as a replacement for fine aggregates in concrete. IOT was used as a partial replacement for fine aggregates at levels of 10, 20,30,40, and, and 50%. The basic material properties and strength parameters were studied. It was discovered that at 40% replacement level, during the 28 days the compressive strength is more than that of the control mix and other replacement percentage mixes. The overall test result showed that IOT replaced concrete can be used for pavements and is recommended for village road traffic load.

[11] performed experimental work by replacing sand partially or completely with IOT and observed about a 40% increase in compressive strength of concrete produced by IOT as a fine aggregate replacement compared to the control mix.

III.c Split Tensile and Flexural Strength of IOT Concrete

Split Tensile strength and flexural strength of IOT concrete are the indirect methods for evaluating the tensile strength of concrete. The tensile strength of concrete is an important consideration in the design of concrete roads and airport runways, it is used in distributing the concentrated loads over a wider area of road pavement and helps to determine the resistance of concrete members to tensile stresses resulting from any restraint to contraction due to drying or temperature variation [1], [43], [44].

[26] carried out an experimental study on the feasibility of using IOT as a partial replacement for fine aggregate. In this research, iron ore tailings (IOT) from Eurobond industries, Hargrah near Sihora in Jabalpur district were used. Mix design was carried out for concrete of grade M25. 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 with 5, 10, 15, and 20% of iron ore tailings (IOT). A flexural strength test was conducted on the concrete beam specimens of size 150mm x 150mm x 700mm. 28 days flexural strength value of 16.96N/mm2 was obtained for concrete when 15% iron ore tailings (IOT) were used as a partial replacement for sand.

[9] stated that the splitting tensile strength exhibited by the concrete with tailings aggregates was 2.82 MPa at 28 days and this is slightly lower than concrete with conventional aggregates by 16% due to the higher quantity of fines in the iron ore tailings as compared with the natural sand in the control mix. It was reported, however, that the tensile strength improved favourably with age and there was an improvement of 4.8% on the tensile strength as compared with similar research carried on where the conventional fine aggregate was partially replaced by 20% with iron ore tailings.

[11] also reported that the flexural strength of the reinforced concrete beams was in no way weakened by the replacement of sand with IOT.

In research carried out by [45], it was concluded that the Split tensile strength of 10, 20, 30, 40, and 50% IOT mix decreased by 1.38, 2.79, 14.10, 33.9, and 42.03% respectively from that of the control mix and that the flexural strength of 10, 20, 30, 40 and 50% IOT replacements for fine aggregate decreases by 21.14, 24.95, 26.19, 30.95, and 32.86% respectively from control mix.

According to [36] the splitting tensile strength of IOT concrete mixes has higher splitting tensile strength values than that of the corresponding control concrete as clearly shown in Fig 6

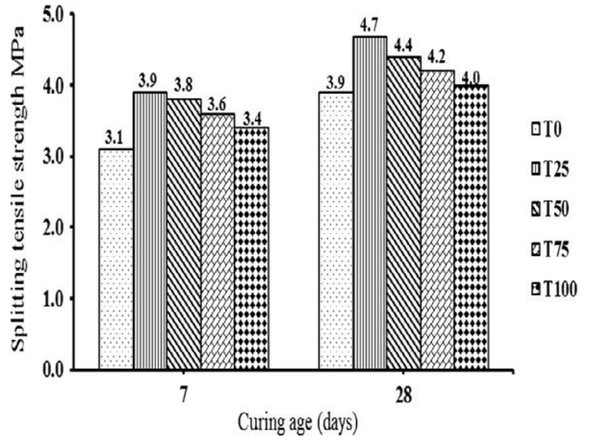

Figure 6: Splitting tensile strength of concrete with and without IOT [36]

From Fig 6, the splitting tensile strength increased sharply in concrete specimens containing 25% but decreased both at 7 and 28 days of curing when IOT increased but was higher than the control concrete. The increase in tensile strength observed in IOT concrete could be due to the enhanced bonding between aggregates and the cement paste engendered by the smaller particles of the tailings [46]

[47] concluded that the mix with 20% IOT has a higher splitting tensile strength in concrete than that of the control mix, and they concluded that 20% IOT can be used to replace normal river sand in structural elements.

Also [16] observed that the flexural strength of IOT concrete increased by up to 8% compared to the control mix

III.d Durability of IOT Concrete

[36] evaluated the durability of IOT concrete by carrying out the drying shrinkage, water absorption, rapid chloride penetration test (RCPT), carbonation depth, and acid resistance test on concrete mixes containing IOT as a replacement for fine aggregate. The study concluded that the drying shrinkage of concrete decreases with the increase of IOT, concrete with IOT indicates good resistance to carbonation compared to control concrete, water absorption rate and chloride penetration of the concrete increase as the IOT percentage replacement increases, and the weight of IOT decreases more than that of the control after exposure to acid solution.

A study on the durability of IOT concrete by [33], concluded that concrete with 35% replacement of natural aggregate by IOT, the permeability resistance of the concrete with IOT concrete is equal to that of the control concrete, and the frost resistance of the concrete decreased to 16.2% because of the iron tailings sand and its carbonation resistance is all most the same as that of the control mix.

[20] studied the pH of concrete produced using IOT as a replacement for fine aggregate. The results revealed that the solution of IOT concrete for various curing days has a high alkaline condition with pH between 11.8 to 12.5 as shown in Fig 7. It was finally concluded that the concrete with IOT as fine aggregates has high resistance to corrosion and a low potential for acid attack due to the high pH values of their resulting solution, hence an indication that IOT can be used to produce highly durable concrete.

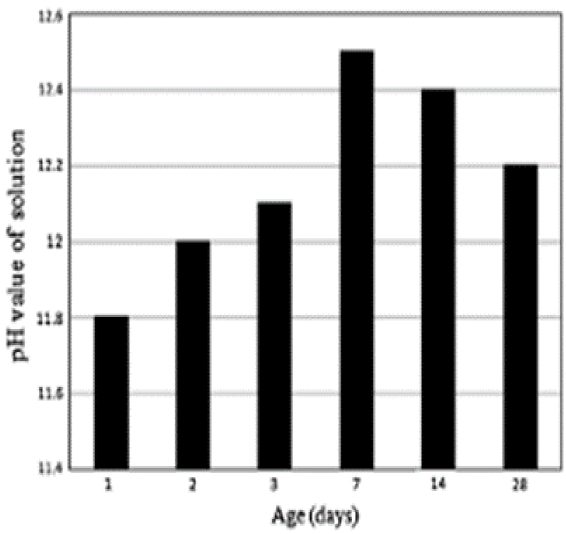

Figure 7: pH values showing the alkalinity of IOT concrete[48]

III.e Microstructure of IOT Concrete

The XRD carried out on the IOT concrete by [49] indicated that higher consumption of $Ca(OH)_2$ during hydration process leads to the formation of C-H-S which improves the compressive strength of the concrete.

IV. CONCLUSION

To produce environment-friendly and durable concrete products, the incorporation of IOT as a partial replacement of normal river sand in concrete has received attention. From the literature studied, some IOTs have oxide compositions with high content of silica and iron oxide. Researchers have carried out tests on IOT concrete containing IOT in comparison with control concrete by varying the replacement percentages of normal river sand with IOT. The use of IOTS as a partial replacement of fine aggregate in concrete production reduces the workability of concrete as the IOT replacement percentage in concrete increases. The utilization of IOT as a replacement for fine aggregate in concrete improves, the compressive strength of concrete increases, and so with other strength parameters with an optimal replacement not greater than 40% of the weight of sand in concrete. Concrete with IOT indicates good resistance to carbonation compared to control concrete, Water absorption rate and chloride penetration of the concrete increase as the IOT percentage replacement increases and the weight of IOT decreases more than that of the control after exposure to acid solution. The literature review shows that IOT has the potential to be used as a material in concrete production for the replacement of fine aggregates. The use of IOT will help in reducing the number of natural resources being depleted and help mining companies in the sustainable management of their waste disposal. From the studies made, there is a need to research into the long-term effects of IOT as a replacement for fine aggregate - normal river sand on the durability properties of concrete**.**

ACKNOWLEDGMENT

The authors would like to thank BUK, Nigeria, and Kogi State Polytechnic, Kogi State, Nigeria, for the support and assistance to achieve this paper.

COMPLIANCE WITH ETHICAL STANDARDS CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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