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UTILIZATION OF IRON ORE TAILING AS PARTIAL SUBSTITUTION TO FINE AGGREGATE FOR A SUSTAINABLE AND DURABLE HIGH-STRENGTH CONCRETE

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Abstract

Viable management of iron ore tailings is of paramount importance for iron ore mining stakeholders. This research aims to increase the value of tailings by investigating their potential application as a substitute for fine particles in high-strength concrete. With a W/B ratio of 0.32, a 60 MPa concrete mixture was prepared in the lab. The curing periods for the concrete were 28 & 56 days, respectively. Concrete parameters such as workability, compressive strength, tensile strength, flexural strength, young's modulus, permeability, Sorptivity, chloride ion diffusion, and resistance to acid attack were evaluated. The experimental results reveal that using iron ore tailings in concrete enhances its workability & physical attributes such as compressive strength, tensile strength, modulus of elasticity, and modulus of rigidity. Furthermore, with higher percentages of IoT, chloride penetration, permeability, and adsorption rate decrease, and it performs better in acidic environments.

Keywords: Control Concrete (CC), IoT, Compressive strength, Tensile strength, Flexural Strength, Modulus of Elasticity (MOE)

1. INTRODUCTION

Due to its numerous benefits in terms of accessibility, availability, and cost-effectiveness, concrete is widely used across the building sector. The yearly global usage of concrete is around 25 billion tonnes (WBCSD). The recent rise in environmental consciousness has compelled civil engineers to develop a new approach that is both economically and environmentally sound. This was obvious from the numerous publications that regularly mentioned natural resource depletion and the significance of feasible development. However, viable growth in the construction industry can only be accomplished by a plethora of different methods, such as selecting pertinent materials, innovative mechanisms for recyclable processes, & reusing waste resources. According to research [3,4,5,6], harnessing industrial by-products may considerably enhance green and sustainable construction.

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About 70 % of the entire volume of concrete is composed of aggregates, which are essential components of the matrix. In the concrete matrix, fine particles make up around 25% of the total volume. However, over the past few decades, the natural sources of obtaining raw materials have become increasingly scarce due to the massive usage of concrete. Due to rapidly dwindling natural deposits, as well as a slew of issues linked with the mining of natural sand from riverbeds, authorities in numerous nations throughout the world have imposed limitations on sand extraction [8]. Increasing globalization and industrialization have contributed to an exponential rise in consumerism over the past several decades, eventually leading to an increase in waste generation. The time has come to appropriately handle these waste products, which have recently become a global concern. From previous research, it is clear that there are ways to eliminate the waste, i.e., by lowering waste generation and reusing or recycling waste for other intent [9]. During the past several decades, the scientific community has been actively involved in this field, & various by-products of industries have been evaluated for their viability as an alternative to sand.

India is bestowed with a substantial iron ore deposit. For many years, according to the World Steel Association (WSA) 2014 study, India has been Asia's third-largest producer of crude steel. Enduring extensive mining of iron ore in India has resulted in the build-up of vast volumes of IoT that must be managed, disposed of, and monitored appropriately. The inability to manage these tailings in a sustainable manner might have negative repercussions on the habitat. One of the prevalent ecological issues related to these tailings is the cause of surface and groundwater contamination [10].In addition to this, the tailings take up a significant amount of land that would otherwise be put to better use and also diminish the natural beauty of the locations in which they are located [11]. Furthermore, these tailings dump threaten the surrounding ecosystem because of the possibility of erosion [12]. Most of these tailings are either amassed in the natural habitat or stored in a tailings dam.

Exploring the use of mine tailings as a potential application in the building sector which is one area that might help mitigate the difficulties caused by mine tailings, as there is a higher possibility in this industry for considering industrial by-products as building materials. If mine tailings are regarded as a fractional substitute for regular aggregates in concrete, almost all of these tailings can be reclaimed and utilized responsibly by converting them into a usable resource and offering cheaper options for manufacturing concrete [14]. As a result, it will be optional to mine raw resources like concrete aggregates. Therefore, it is possible to handle the tailings in a sustainable manner while also conserving limited resources. Furthermore, because of how the iron ore beneficiation process works, the tailings are made up of particles ranging in size from fine to coarse [15].

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2. LITERATURE REVIEW

Although it is clear from the literature that several researchers have already attempted to use waste materials, particularly as aggregates. The effects of using low CaO steel slag as a substitute for sand in concrete were evaluated. When steel slag was used in place of sand, it was found that both compressive strength and tensile strength rose. The maximum increase in compressive strength was seen between 15.0 and 30.0 percent of replacement. Although tensile strength rose for all % of substitution, a replacement of roughly 50% showed the most remarkable improvement [17]. BFS utilized as the fine aggregate in SCC exhibits increased autogenous shrinkage, higher self-desiccation produced by the hydration of slag, and chemical shrinkage brought on by slag reactivity [18]. The compressive strength of concrete containing BFS as the filler material is lower at early ages than concrete produced with sand, but it increases after 91 days [19,20]. BFS was used as filler material in concrete. The findings indicated that the BFS/sand ratio is the regulating criterion for the impacts on strength and durability [21]. Laboratory research was carried out on the use of oxidizing EAF slag as fine and coarse material to produce concrete with desirable qualities. The durability features of the concrete, including its strength, leaching test, and accelerated aging test, were evaluated. It was determined that the endurance of EAF slag concrete was satisfactory, particularly where its application was proposed when winter temperatures seldom drop below 32 F (0 ° Celsius) [22].

Laboratory research was conducted on the use of Lightweight aggregates as substitution levels of F.A increase, the compressive strength of alkali-activated mortar fell sequentially regardless of the water-binder ratio [23]. Recycling steel mills as filler material in cement mortars was explored where the compressive strength was raised by 40% when fine aggregate was substituted for 40% of the steel mill scale & drying shrinkage was reduced when the steel mill scale was used [24]. Foundry entailment was used in the production of concrete. Although foundry slag was used in place of the typical coarse aggregate in the concrete, the strength was still adequate for structural concrete [25]. The resilience of HPC with industrial waste was investigated. According to their findings, chloride ion penetration in concrete reduced when 30% GGBS & 100% copper slag were substituted for cement and F.A. [26]. According to Kayali [27], lightweight concrete using fly ash as aggregate exhibits little chloride ion penetration and low carbonation.

According to the literature study, the primary attempts at utilizing IoT as a partial substitute for F.A. in concrete have mostly focused on evaluating the rheological and mechanical qualities of concretes. There have been very few investigations on the durability characteristics of waste replacement concrete. The study's goal is to assess the feasibility of replacing fine aggregate in high-strength concrete with IoT based on the results of numerous tests ranging from rheological, physical, persistent, and micro-level examinations. This study aims to outline the characteristics and possible percentage replacements of IoT in high-strength concrete.

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3. Experimental details

3.1. Materials

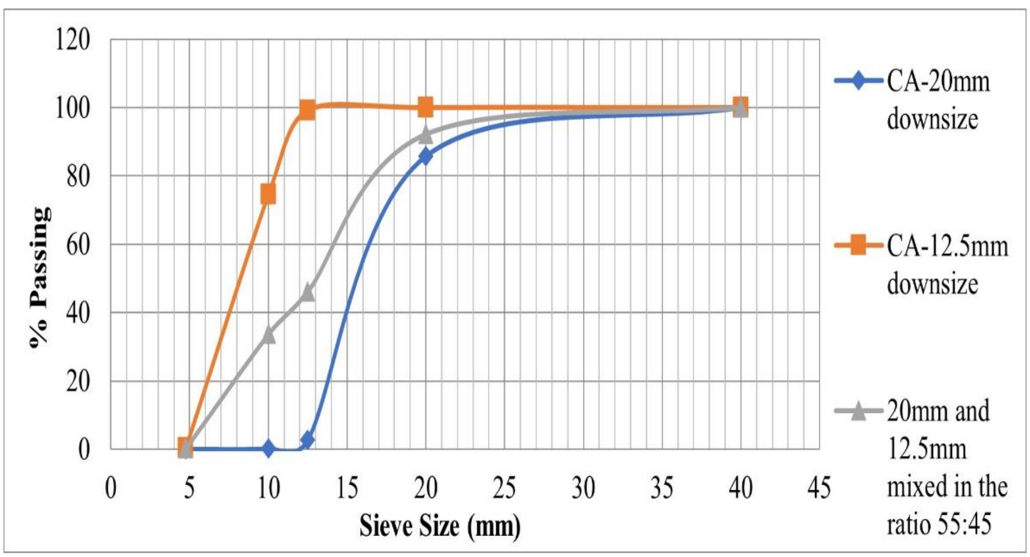
3.1.1 Cement

For this investigation, a PPC of 43 grade, according to BIS: 1489 -1-2015 [33], with a fineness of 346 M^2/kg, a standard consistency of 28.5%, and a specific gravity of 2.9, was utilized. The initial and final setting times were reported as 166 & 260 minutes.

3.1.2 Coarse Aggregate

For this study, coarse aggregates with down sizes of 20 mm & 12.5 mm in angular shapes that meet the requirements of BIS standards 383- 1970[36] were used, and properties were tested according to I.S.: 2386, Part-I [35], Part-III [34]. Specific gravity is found to be 2.54 and 2.5, water absorption is 0.4%, and the Fineness modulus is 5.04.

Fig.1: Particle Size Distribution of Coarse aggregates



3.1.3 Fine Aggregates

M sand, were utilized. They were obtained from local sources. The specific gravity and the fineness modulus of M sand were determined to be 2.57 and 2.67. The sand utilized for HSC was compliant with the specifications for grading zone II of BIS:383-1970[36].

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3.1.4 Iron ore tailings

Iron ore tailings were sourced from the Jindal iron industry in Karnataka. The principal chemical components in IoT are Fe_2O_3 (0.12%), SiO_2 (34.65%), Al_2O_3 (28.65%), CaO (28.42%), MgO (5.7%), Na_2O (0.441%), and k_2O (0.249%). The table-01 shows the physical properties of blast furnace slag pertaining to IS 2836 Parts 1 and 3[34][35]. SEM analysis of IoT is shown in the figure 3. From SEM analysis, It was clear that the particles were irregular to angular in form; this might be because of The production of granulated slag using an atomization technique, Where water jets were used to immediately cool the liquid slag as it flowed out of the blast furnace. Because of the expeditious cooling of the liquid slag, the particle morphology is uneven, angular, and glassy. EDS elemental analysis was performed for IoT, as shown in the figure 4. For IoT, silicon, calcium, magnesium, iron, oxygen, and Aluminum were found to be the most prevalent components. These elemental tests were consistent with the slags' initial chemical composition.

Fig.2: Particle Size Distribution of M-sand and IOT

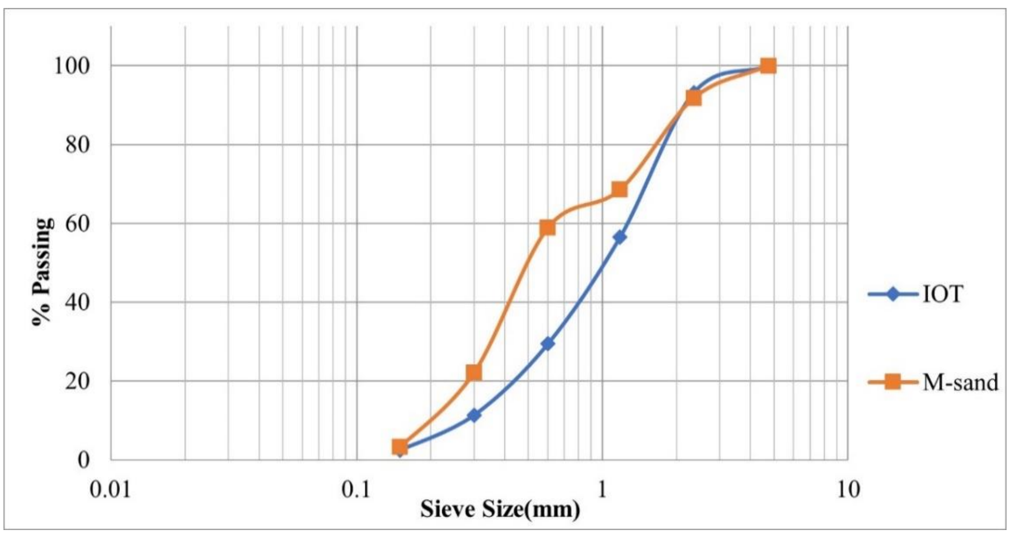

Table 01: Physical Properties of IoT

1	**Specific Gravity**	**2.57**
2	Water absorption	0.6%
3	Fineness Modulus	2.98

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Fig. 3: SEM images of IoT

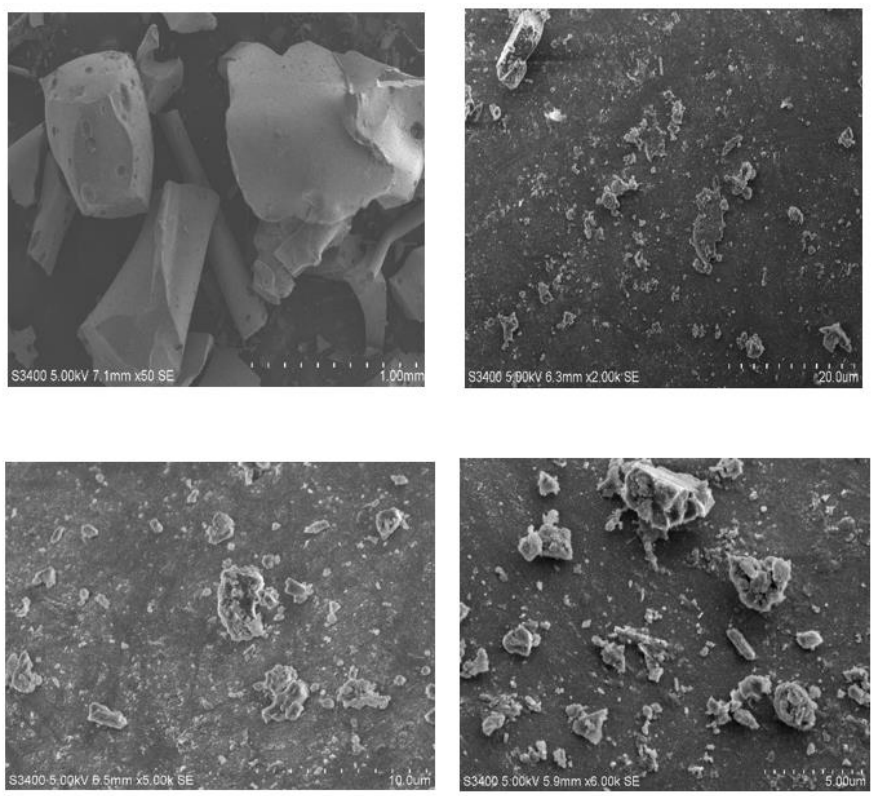
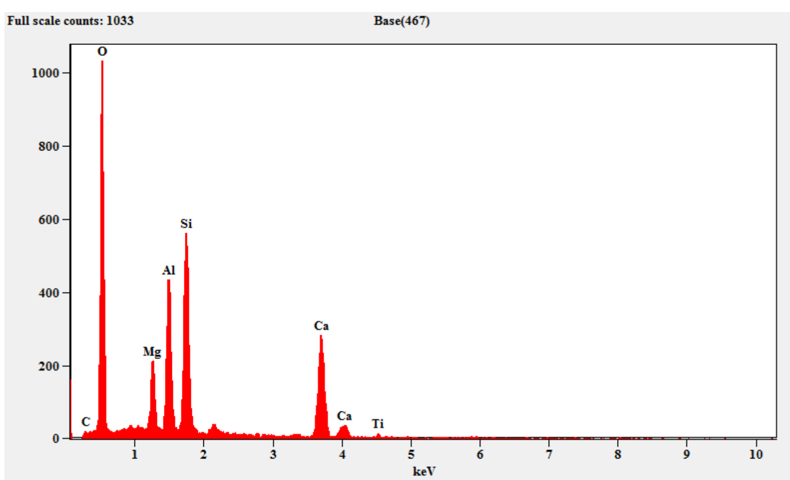


Fig. 4: EDS of IoT



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3.1.5 Micro Silica

Micro silica is a waste product of the ferrosilicon and silicon alloy manufacturing processes. Its ultra-fine particle size and a high percentage of glassy SiO2 make it a highly reactive pozzolanic material. The mineral admixture was a dry densified micro silica with a specific gravity of 2.46 and a specific surface area of 20.9 M^2/gm, was used.

3.1.6 Admixture

For this study, a Polycarboxylic ether-based superplasticizer, which complies with ASTM C494 type F [43] and IS 9103-1999 [44], is used. The addition of S.P. reduces the interparticle friction, which directly influences the workability of concrete by improving the concrete cohesiveness. Master Glenium SKY 8233 SP, having a specific gravity of 1.08, is used.

4. MIX DESIGN

Table 02: Design Mix for M-60 Grade concrete with IoT replacement

	CC	**I10**	**I20**	**I30**	**I40**	**I50**
CEMENT (PPC) in kg/m³	500	500	500	500	500	500
M.S. in kg/m³	47	47	47	47	47	47
C.A. in kg/m³	970.5	970.5	970.5	970.5	970.5	970.5
F.A in kg/m³	724.5	652	579.6	507.1	434.7	362.25
IOT in kg/m³	0.0	72.5	144.9	217.4	286.8	362.25
Superplasticizer in kg/m³	2.725	2.725	2.725	2.725	2.725	2.725
Water in kg/m³	174.5	174.5	174.5	174.5	174.5	174.5

Table 02 depicts the mix proportions proposed by [P.D. Kumbhar and P.B. Mural] in line with I.S. standard specifications for M-60 grade concrete. The 20mm down size was used for the coarse aggregate. The specified W/B ratio for all combinations was 0.32. The slump ranged from 100 to 150 mm. In all of the mixes, 0.5% superplasticizer was utilized as an additive. To investigate how waste substitution affects the peculiarities of high-strength concrete, concrete mixes with varying quantities of IoT were utilized as a partial replacement for F.A. The % of IoT replaced was 10%to50% by wt. of F.A.

4.1 Sample preparation.

For every concrete combination, 150 mm cubes, cylinders of 150 by 300 mm, & prisms of 150 by 150 by 700 mm were cast. Cubes were utilized for compressive strength and permeability testing, while cylinders were employed for tensile strength, modulus of elasticity, RCPT, Sorptivity testing, and prisms for Flexural strength. All samples were cured for 56 days in water while being periodically inspected.

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4.2 Testing procedure.

4.2.1 Investigation on Fresh Concrete

Slump tests were done as per IS-1199–1959 [39] on both CC and the mix in which IoT is a replacement for fine aggregates. The slump was measured with a standard slump cone; concrete was filled in 3 layers and was tamped 25 times each with a metal rod to make sure it was well packed. Then, carefully, the concrete was taken out of the cone. The cone was then turned over and put close to the concrete. The difference in height between the cone and the concrete was used to measure the slump with a ruler.

4.2.2 Hardened properties of concrete

Since concrete's primary purpose is to endure compression, this property of concrete has received the most attention among the several concrete strengths. Split tensile strength was performed to evaluate tensile strength. Compressive & tensile strengths were measured using a CTM of 300 tones capacity according to IS 516-1959 [41].

Flexural tensile strength must be determined for the Prediction of the load at which concrete members may crack. Since it's impossible to establish concrete's tensile strength via direct tension, it's computed through flexure. Thus, the modulus of rupture is calculated. The computation of the modulus of rupture assumes linear material behaviour up to failure. The flexural test is conducted on a 28-day cured prism specimen in conjunction with IS -516 1959[41].

Modulus of elasticity was measured throughout the middle 2/3 of a cylindrical specimen, to which a longitudinal compressometer was attached to estimate the compressive strain during loading. Four cycles of loading and unloading were repeated until the difference between the two cycles was less than 5%, and Deformation was recorded.

4.2.3 Tests on Durability

4.2.3.1 Water penetration under pressure

The permeability of concretes was determined using the DIN 1048-5 1991[46] test technique. After 56 days of curing, the surface of the cube was cleaned using a brush and then exposed to 5 bar water pressure on the same surface. Water pressure was released after 72 hours of exposure, and the specimens were divided in half perpendicular to the pressure surface to estimate the amount of infused water in the concrete. The results are represented as the depth of the water that entered the concrete in millimeters.

4.2.3.2 Chloride Penetration test

Assembly for the RCPT comprises a two-compartment cell. Between the two-compartment cell assembly, a 50 mm thick specimen disc is mounted and verified for air

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& water tightness. The cathode cell contains a 3% solution of Na-Cl, while the anode cell contains a 0.3 N solution of Na-OH. The cells are then impressed with 60V from a D.C. supply b/w the cathode & anode. The current is measured for a specific period of six hours at intervals of thirty minutes in accordance with ASTM C1202[47]. The penetrability of chloride ions is insignificant if the charge passed is less than 100, very low if it is between 100 and 1000, low if it is between 1000 and 2000, moderate if it is between 2000 and 4000, and high if it is over 4000.

4.2.3.3 Sorptivity test

The concrete disc of height 50 mm and diameter of 150 mm was used to explore the capillary water absorption capabilities of concrete, which can define water movement in concrete capillary pores. Concrete specimens were dried at 60 degrees Celsius for 48 hours before being placed at ambient temperature for 12 hours. The disc had one side surface in touch with water, while the remaining sides were sealed with a silicone coating. The samples were submerged to a depth of 5mm in water, and the adsorption coefficient of concrete was estimated by quantifying the change in mass of the specimens over time.

4.2.3.4 Acid Attack Test

150 mm concrete cubes were prepared and cured in water for 56 days and then placed in a solution of 5% diluted sulfuric acid. Prior to immersion, the cube specimen was dried at an Ambient temperature, cleaned &weighed. The solution was replaced due to the loss in concentration. Mass loss & loss in compressive strength tests were conducted, and the strength loss factor was calculated accordingly.

5. RESULTS AND DISCUSSIONS

5.1 Workability

Figure 5 illustrates how IOT replacement enhanced the fresh properties of concrete. When replacing 50% IOT with concrete, the slump increases by 13.3%. Compared to control concrete. The fact that it is non-absorbent and glassy also contributes to increased water availability in the system compared to control concrete. There is a one-to-one relationship between the fineness modulus of the aggregates used in making concrete and its workability [28]. Hou [29] claims that when the fineness modulus rises, concrete's workability rises because of the decreased total appearance area.

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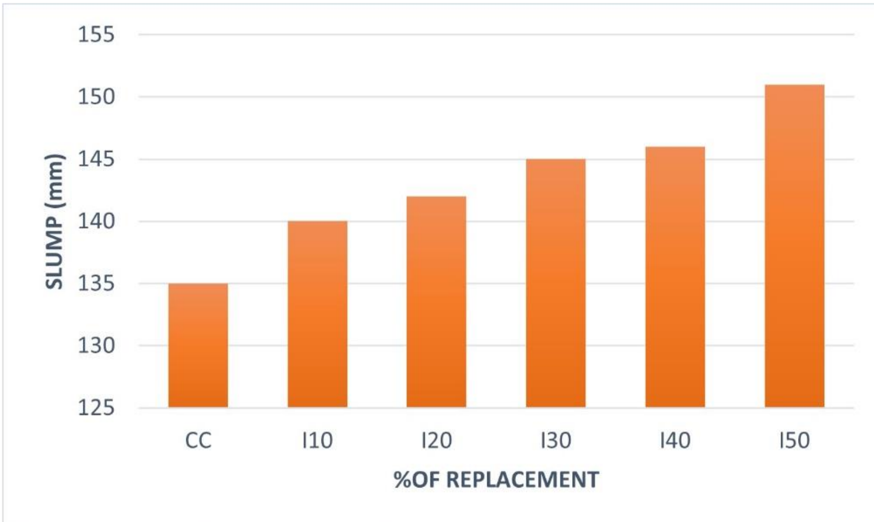
Fig-5: Comparison of Slump values of concrete



5.2 Compressive Strength

Figure 6 depicts that the IOT concrete samples consistently exhibited greater compressive strength than CC counterparts across all curing durations. The 56-day increase in strength relative to CC was 4.0% for I20, 6.3% & 6.43 % for I30, I40, and 1.0% for I50. Because of the superior particle gradation in concrete comprising IoT, which allows for better compaction in the mould during casting, and its rough and angular form, it enhances the interface between cement and aggregates [29]. Another theory is that the additional calcium hydroxide created during the process of hydration may cause the auxiliary reaction between IoT because it contains more CaO [30].

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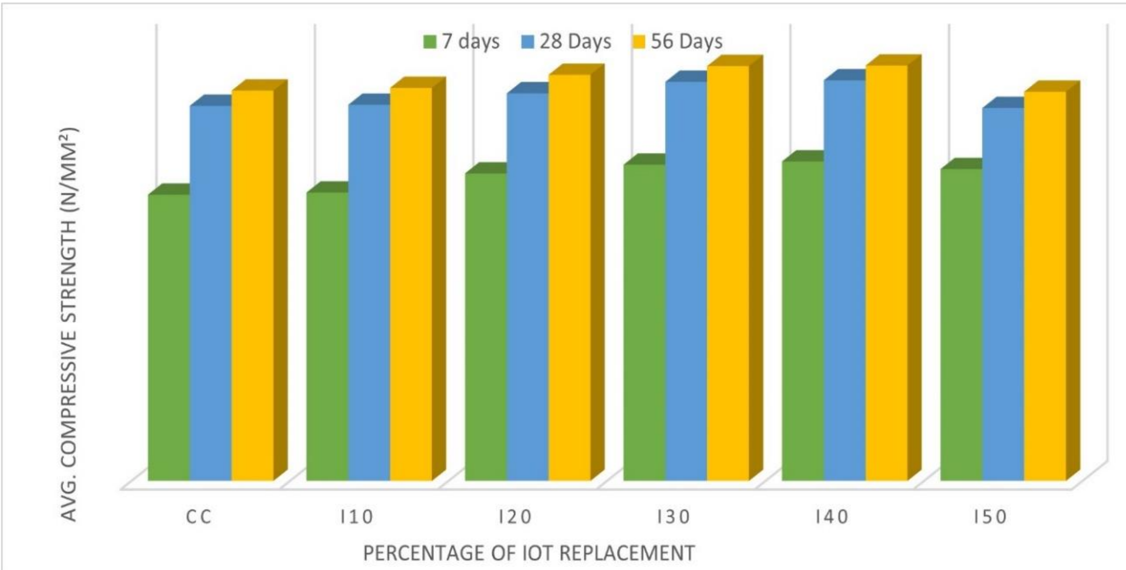
Fig-6: Comparison of compressive strength of concrete with & without IoT



5.3 Tensile strength

Figure 7 illustrates the tensile strength outcomes. Specimens with 30% & 40% of IOT substitute showed significant increases in tensile strength; however, beyond 40%, the substitution of IoT entailed a fall in tensile strength but nevertheless remained greater than CC. However. At 56 days, the tensile strength was enhanced by 6.73%, 11.89%, 14.77%, and 8.68%, respectively. The increased strength over CC can be imputed to the better link between the aggregates & cement paste formed by smaller tailings particles. The optimal percentage of IoT to fine aggregate replacement for achieving tensile strength was determined to be 40%.

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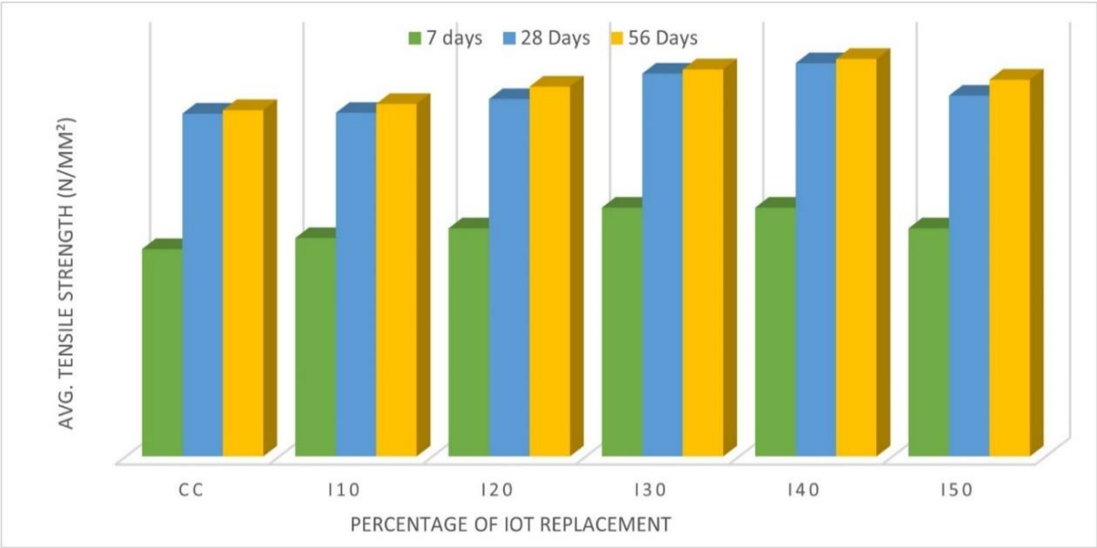
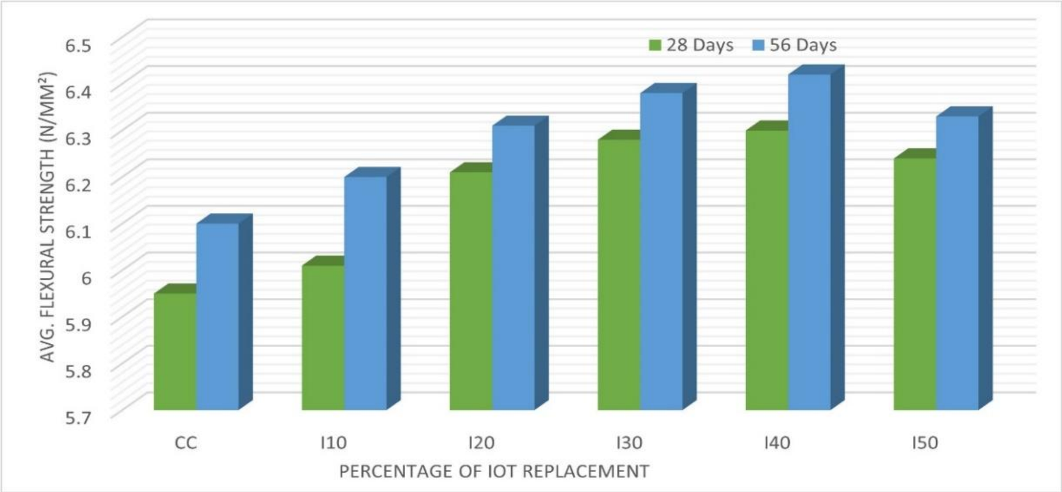
Fig 7: Comparison of tensile strength of concrete with & without IoT



5.4 Flexural strength

The 28 days and 56 days flexural strength in relation to the Control concrete was observed to have followed the trend of compressive and tensile strength values. The strength for IOT mixes increases from I10 to I50, which can be attributed to the stronger aggregate-cement bond. For the I50 mix, it was noticed that there was a diminution in strength compared to I40, but it was still on a higher value compared to CC. This may be by virtue of the lack of finer specks to permeate the pores. From the figure-8, it is inferred that the flexural strength of concrete samples with 30% & 40% IoT ameliorated drastically in comparison to CC.

Fig 8: Comparison of flexural strength of Concrete with &without IoT



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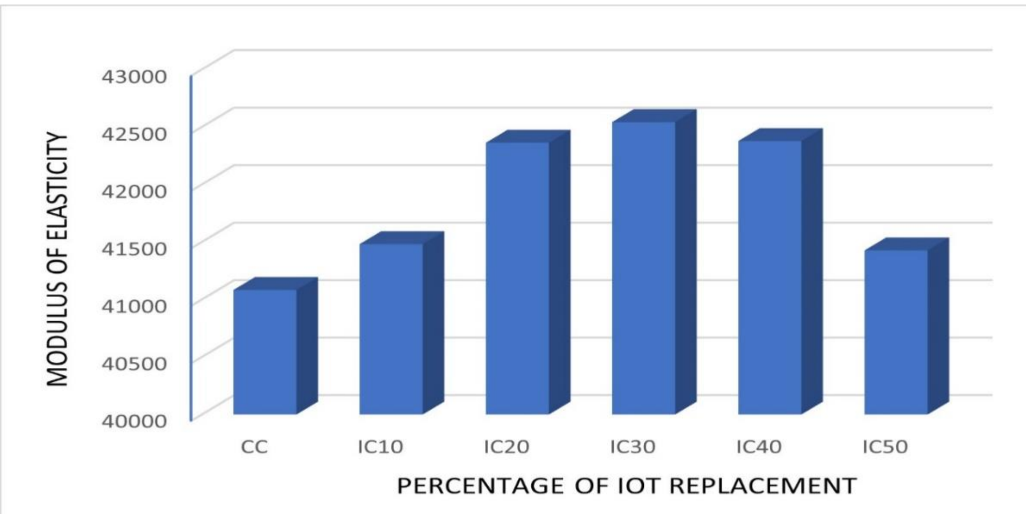
5.5 Modulus of elasticity [MOE]

Figure 9 depicts the findings of the MOE after 56 days of curing. All concretes containing IOT had a superior MOE than the control. The MOE of concrete enhanced by 3.02%, 3.52% &3.05% for I20, I30 & I40 when compared with CC. It was clear that adding IoT to concrete mixes increased the MOE. It might well be attributed to the compressive strength & adhesion b/w the aggregates and paste of the combinations [31].

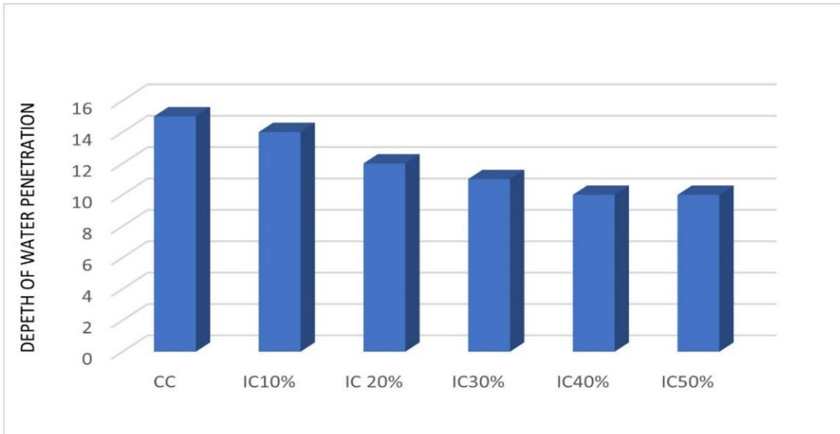
Fig 9: Modulus of elasticity at 56 days of curing



5.6 Water penetration under pressure

All samples showed no percolation when tested at the specified test pressure. However, the depth of penetration was evidently high in control concrete when compared to concrete containing IOT at all replacement levels. When the replacement of IoT is with Fine aggregates, the permeability of the concrete decreases but improves the quality of the concrete, this is because the aggregate and cement paste form a stronger interlacing bond. The combination of an increase in the extreme fineness of the binder and a low W/B ratio with IoT results in improved compaction and lower permeability.

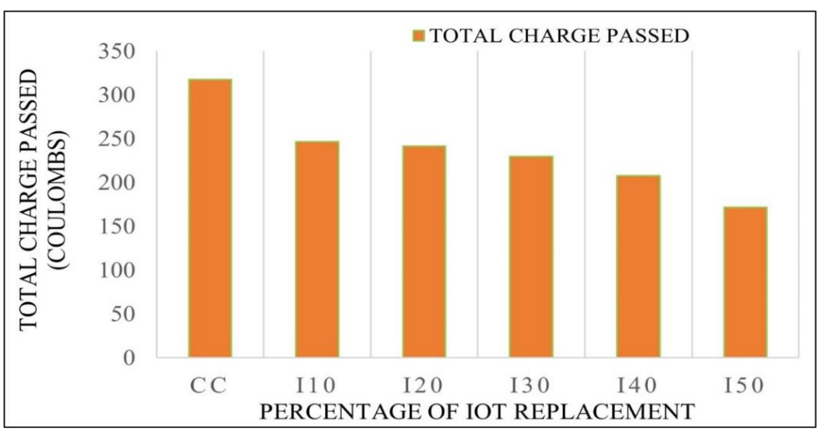
Fig 10: Permeability in concrete with and without IoT



5.7 Chloride Penetration test

From the figure-11, it can be observed that the amount of charge passed within the specimen measured in terms of coulombs is well in the range of 100-1000, which indicates that the chloride ion penetrability of the material is considerably low as per AASHTO T277 and ASTM C1202. Also, it can be observed that with the enhancement in the percentage of IoT replacement, the permeability decreases. Hence, all the replacement percentages of IOT yielded better permeability resistance to chloride ions. The rough texture and angular property of the material, enabling the concrete containing IOT to withstand the coerced perception of chloride ions, may be the cause of the lesser charge in IoT.

Fig 11:Chloride Ion Diffusion in concrete with and without IoT



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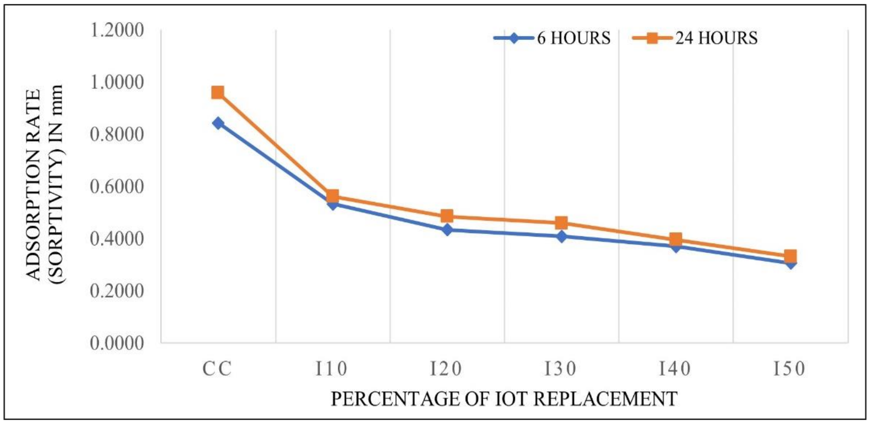
5.8 Sorptivity test

The Sorptivity test is used to asses the capillarity forces employed by the pore structure, causing fluids to be educed into the body of concrete. If the material has fewer pores, then the Sorptivity value becomes significantly less and vice-versa.

From the fig-12, it can be enunciated that as the % replacement of IoT increases, the Sorptivity rate declines indicating concrete made with IoT has fewer pores and occupies a very good position. The initial adsorption is lowest in the case of the I50 concrete specimen at the 6th hour, and at the 24th hour, very low adsorption is recorded for 50% replacement of IoT. This indicates good packing with fewer pores in it, and hence adsorption decreases.

Fig 12: Sorptivity of concrete with and without IoT



5.9 Acid Test

5.9.1 Mas loss

Figure 13 shows the repercussion of sulfuric acid on the mass of CC and IOT concrete specimens. All specimens are seen to display the same tendency (mass loss) throughout the immersion periods, which is the result of the acid's reaction with CA-OH, which weakens the cement gel binder of concrete [32], resulting in the formation of soft, and emulsifiable gypsum on the surface. During the duration of contact, the weight of the IoT concretes reduced more than that of the conventional concrete. A possible explanation for this is the direct bond-breaking attack on the aluminosilicate framework.

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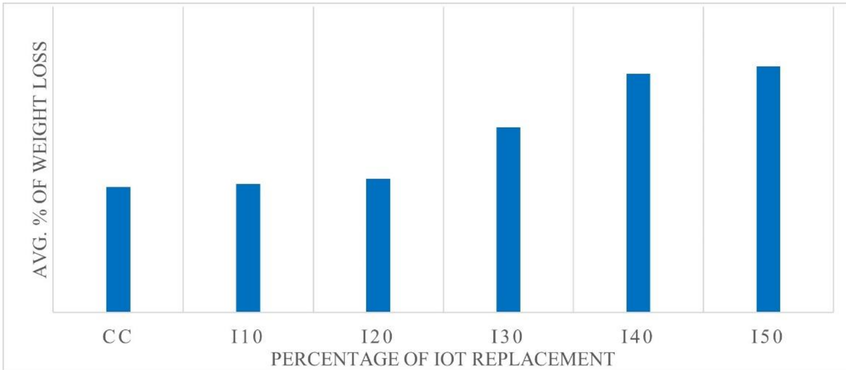
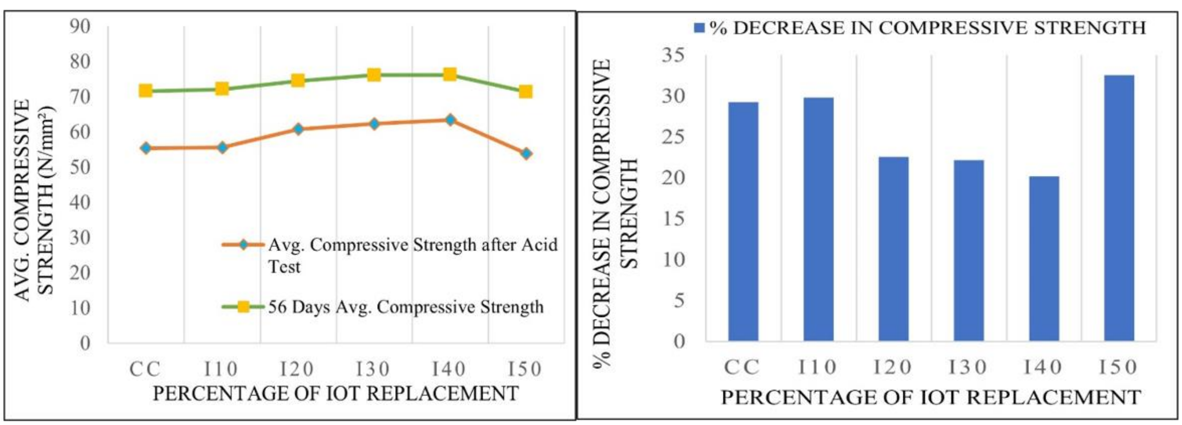
Fig 13: Weight Loss of concrete with and without IOT when Immersed in H_2SO_4



5.9.2 Strength loss

Submerging specimens in sulfuric acid solution results in a reduction of compressive strength, as seen in Figure 14. Sulfuric acid's effects are liable for the overall strength reduction in the samples. The results showed that after 60 days in acid, CC and I 50 lost 29% and 27% of their compressive strength, respectively, compared to water curing. The damaging effect of acid is caused by the interaction b/w calcium and aluminate in the compound, which results in the formation of the (3CaO.Al2O3.2H2O). This highly voluminous substance increases inward pressure, which leads to the progression of fissures & surface softening in concrete, which in turn causes the material to lose its mechanical strength.

Fig 14: Strength Loss of concrete with and without IOT when Immersed in H_2SO_4



5.9.3 Strength loss factor

The performance of IoT concrete may be expressed qualitatively by the strength loss factor, which is a quantifiable measure. Therefore, strength loss factor (SLF) measurements were used to analyze the degradation of concrete samples. Figure 15 shows the SLF for the 60 days of acid immersion, which expresses the decrease in

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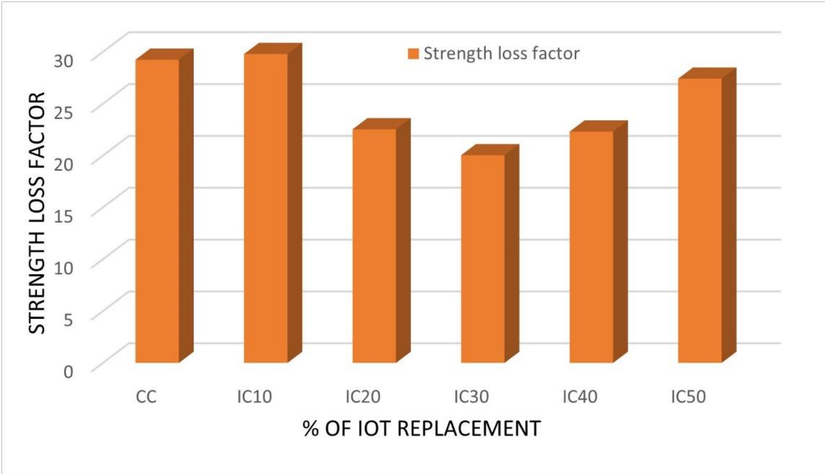
compressive strength of CC and the IoT owing to acid attack. In comparison to SLF recorded in IOT concrete specimens under the same situation, the CC was more severely impacted by the acid throughout the 60 days of immersion. It was evident that IOT's incorporation into the concrete sample resulted in a denser end product by removing some of the micro pores.

Fig. 15. Strength Loss Factor of concrete with and without IoT



6. CONCLUSIONS

- The fineness modulus of IoT is higher than that of M-Sand, which indicates that IoT is much coarser, which leads to superior workability of concrete comprising IOT pertaining to CC.
- The compressive strength of the concrete turned out to be highest for 30% and 40% IOT replacement than the CC mix. At these percentages, the strength increased by 6.40% and 6.83% at 28days of curing and by 6.3% and 6.43% at 56days of curing, respectively.
- The tensile strength of the concrete happened to be highest for 30% and 40% IOT replacement than the CC mix. At these percentages, the strength increased by 11.69% and 14.72% at 28days of curing and by 11.89% and 14.77% at 56days of curing, respectively.
- Using IoT as filler material in concrete improves both the compressive and tensile properties. Hence doing so would help mitigate a potential environmental impact on the steel industry.
- The concrete containing IOT showed better flexural strength when compared with CC. The flexural strength of the concrete turned out to be highest for 30% and 40% IOT replacement than the control concrete mix. At these percentages, the strength

increased by 5.55% and 5.88% at 28 days of curing and by 4.59% and 5.25% at 56 days of curing, respectively.

- With the substitution of M sand with IoT, the MOE of concrete mixes increased, which might be ascribed to improved interfacial behaviour of concrete due to the integration of IoT in concrete.
- The depth of water permeation which is a measurement for permeability declined with an increase in the percentage of IoT.
- As the portion of IoT increases in the concrete, the depth of chloride penetration in concrete significantly decreases, demonstrating superior defiance to chloride penetration correlated to reference mixes.
- The adsorption rate, which is a measure of Sorptivity, reduces with an increment in the % of IoT substitution at both the 6^{th} hour and 24^{th} hour, indicating the better performance of specimens with IOT-replaced concrete.
- At 60 days of acid susceptivity, the weight loss of IOT concrete specimens is much greater than that of conventional concrete.
- After being exposed to acid, concrete containing iron ore tailings has a greater residual compressive strength than the reference concrete. This demonstrates that IoT may be utilized as F.A. in concrete that is both sustainable and environmentally protective, even when exposed to acid.
- Under these conditions, the IoT does not require any special treatment and is a suitable aggregate component when combined with natural sand. Except for the slightly larger particle size, there appears to be no substantial difference between the usage of sand and IoT. Therefore, it is reasonable to expect that it is feasible to make concrete with a larger IoT content. Aside from the advantages of providing a more sustainable material than the original, cooperation with the concrete sector can assist the mining industry, which is responsible for tailings disposal.

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