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High-Performance, Eco-Friendly Blocks from Iron Ore Tailings: A Solution for Sustainable Construction

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ABSTRACT

Goa's iron ore mining industry has generated over 7.7 million tonnes of iron ore tailings (IOTs) in the past two decades. These IOTs pose a significant environmental threat due to heavy metal contamination, dust generation, and acid mine drainage. While some IOTs are used for backfilling, the majority are stored in tailings storage facilities (TSFs), posing long-term risks to surrounding water resources, ecosystems, and land use. Large-scale utilization technologies are crucial for sustainable IOT management. This study investigates the feasibility of incorporating IOTs in construction block production, aiming for high-volume waste consumption and improved resource efficiency. This approach offers a potential pathway to remediate the environmental impact of IOTs. The proposed method replaces 85% of the cement content with a cementitious material comprising 65% Ground Granulated Blast Furnace Slag (GGBS), 10% Fly Ash, and 10% Lime. It also utilizes IOTs entirely as a substitute for sand, with ceramic waste partially replacing coarse aggregates. While partial substitution of coarse aggregates with ceramic waste was attempted, it decreased workability. The optimal mix design, achieving the highest compressive strength, utilizes 15% cement, 65% GGBS, 10% Fly Ash and Lime, and 100% IOTs as fine aggregate with 100% basaltic aggregates. This formulation successfully demonstrates the potential use of IOTs in manufacturing construction blocks that reach compressive strengths of 10.91 $N.mm^{-2}$ and 15.92 $N.mm^{-2}$ at 7 and 28 days, respectively, satisfying the IS 2185-Part 1 (2005) code requirement. The block density was 2.20 $g.cm^{-3}$. This research demonstrates the potential to convert a significant environmental challenge into a sustainable solution. By utilizing IOTs in construction block production, we can effectively achieve waste remediation; and create resource-efficient and eco-friendly building materials, offering substantial dual benefits for Goa's environment and construction sector.

INTRODUCTION

Mineral extraction, which involves the extraction of raw materials from the Earth's crust, encompasses the entire mining value chain comprehensively. This chain traverses the initial exploration and discovery stage through exploitation and processing, culminating in post-closure land use planning. Across all sub-processes, advances in geoscientific prospecting, extraction methodologies, beneficiation techniques, material characterization, safety protocols, and environmental mitigation strategies contribute significantly to improving efficiency and sustainability within the mining sector (Das et al. 2023). The mining sector plays a crucial role in driving socioeconomic advancement for nations endowed with economically viable mineral deposits (Mouih et al. 2023). Iron, being the second most plentiful metal in the Earth's crust, significantly impacts this dynamic. However, the very extraction of these vital resources, while driving economies, generates a significant waste stream, predominantly tailings and overburden (Tayebi et al. 2019, Gou et al. 2019). Iron ore beneficiation, crucial for the refining of iron ore, inadvertently generates IOTs as a by-product. However, the rising global demand for iron and steel products has led to the exploitation of lower-grade ores, resulting in a dramatic increase in IOT production, which poses significant environmental challenges (Zhang et al. 2021).

Surging population growth and accelerated industrialization in recent years have driven a substantial increase in resource consumption, particularly of finite natural materials. These conventional construction materials, employed in the dominant paradigm, often bear a significant environmental footprint. Consequently, within the imperative of sustainable development, there is a critical need to shift toward alternative elements for building material production (Mouih et al. 2023). India faces the challenge of unutilized iron ore reserves, which constitute 10 to 15% of its mined ore, a consequence of the economic infeasibility of extracting valuable iron from low-grade deposits (Lamani et al. 2015). The large-scale accumulation of IOTs within confined impoundment structures (tailing dams) presents significant challenges. Beyond direct land footprint encroachment, substantial capital expenditures associated with both construction and ongoing maintenance of these extensive containment facilities are incurred (Zhang et al. 2021).

In the coastal Indian state of Goa, iron and manganese extraction employs the open pit mining technique, necessitating the pre-stripping of overburden to access the underlying ore bodies. This approach currently covers approximately 30,325 hectares, representing approximately 8% of the total landmass of the state, and the target mineral deposits occupy geological formations beneath the surface material removed (Sebastian et al. 2017). The process of extracting iron ore may present significant challenges during the removal of the overlying material, impacting storage, handling, and subsequent land reclamation efforts. The abundance of iron ore deposits within the banded iron formations of Goa, coupled with their flexibility for beneficiation, has resulted in the setting up of multiple iron ore processing plants. Surface mining operations in Goa exhibit a high stripping ratio (waste-to-ore ratio) compared to the national average. During the 2017-2018 fiscal year, a total of 86 operational mines in Goa produced 10,279 tonnes of iron ore (MoM-GoI 2022). Considering the prevailing waste-to-ore ratio (stripping ratio) for open-pit mining practices in Goa, which typically ranges from 3:1 to 5:1 due to site-specific geological considerations (TERI 2001, Yellishetty et al. 2009, Sebastian et al. 2017, Jakati 2021), we can anticipate related waste generation due to ore processing. In India, tailings generation is about 10% to 25% by weight of total iron ore mine production (Zhang et al. 2021), and in the last two decades, Goa's IOTs generation has been 7.7 million tons. Extensive IOT generation, if not managed, presents a significant environmental and public health risk within the region. A primary concern among these tailing-related risks is the potential for acid mine drainage (AMD). Groundwater contamination, dust pollution, and land desertification are serious environmental threats in the vicinity of IOTs dams.

Apart from environmental devastation, the tailing dams pose a direct and alarming hazard to the well-being and safety of nearby inhabitants. Tailing dams represent a higher risk of collapse than reservoir dams due to their specific mechanical properties and operating style (Zhang et al. 2021). Fuelled by a growing global demand for recycled and environmentally friendly materials, the construction sector presents a perfect opportunity to address the challenge of managing Iron Ore Tailings. The granulometry and chemical composition of IOTs make them suitable for various construction applications (Franco et al. 2022). Through strategic repurposing of mine tailings into geopolymers, aggregates, and composite blocks, we can simultaneously realize a triple bottom line: environmental mitigation through reduced waste generation and cleaner production (Kuranchie et al. 2015), resource creation with novel sustainable construction materials and economic advantages through cost savings and market diversification (Haibin & Zhenling 2010, Thejas et al. 2022). This approach presents a potentially viable long-term solution to tailings management while simultaneously conserving precious resources. Implementing comprehensive tailings reuse strategies can empower Goa's iron ore mining industry not only to remediate the environmental burdens inherent in its operations but also to propel it towards a sustainable and economically tough future.

Integration of waste materials into construction materials has ignited a growing research interest, particularly in the pursuit of Fly Ash, slag, and silica fume as robust alternatives to traditional materials. These efforts have produced encouraging results, propelling the advancement of novel and innovative construction materials. Driven by the pursuit of economic and environmental sustainability, researchers have revealed an overabundance of novel construction materials that incorporate waste materials such as IOTs, as demonstrated by Thejas et al. (2022) and Elahi et al. (2021). These advances offer the construction industry not only cost-effective alternatives but also a strategic avenue to reduce its environmental footprint and enter a lucrative circular economy, promoting resource efficiency and economic diversification.

This paper examines the utilization of iron ore tailings (IOT) in manufacturing construction blocks. It explores the potential of replacing sand and cement with cementitious binders to evaluate their suitability as an eco-friendly and sustainable solution for the construction industry.

MATERIALS AND METHODS

Material Collection and Characterization

To manufacture the construction block, the sample of Iron

a) Cement b) GGBS c) Fly Ash d) Lime e) Iron Ore Tailings f) Aggregate

Fig. 1: Materials used to cast construction blocks

Ore Tailings (IOTs) was collected from a specified mine within Dharbandora Taluka, South Goa district, India (15.3366411°N, 74.24727°E). Ground Granulated Blast Slag (GGBS) and Fly Ash for this study were sourced from JSW Cement Ltd. Cement, Lime, and basaltic aggregate were purchased from local vendors. To comprehensively assess their physicochemical properties, the IOTs, GGBS, Fly Ash, and ceramic waste were subjected to rigorous analyses using standardized protocols. X-ray fluorescence (XRF) spectroscopy provided a comprehensive elemental analysis of all materials, revealing their key oxide compositions. These data are crucial for determining the reactivity, potential pozzolanic activity, and suitability. Fig. 1 shows the different materials used to cast construction blocks.

The sieve analysis for particle size distribution, specific gravity for density determination, and loss-on-ignition (LOI) for residual organic content were carried out on IOTs. GGBS and Fly Ash were analyzed for specific gravity, LOI, Moisture Content, Fineness, and residue on the sieve. Ceramic waste and basalt aggregate were analyzed for specific gravity and sieve analysis.

Mix Proportions

Based on the substantial demand and requirements for building materials within the construction sector, a novel approach that uses IOTs in construction units was explored. This involved the development of four distinct mix design trials: a baseline mix with 10mm aggregate and three experimental mixes that combined 10 mm and 4.75 mm ceramic waste in varying ratios. Table 1 presents the detailed aggregate proportions for each mix design. The process of determining the optimal concrete mix design involves a series of interrelated steps. It begins with the calculation of the target strength, which is derived by adding 1.65 times the standard deviation (as specified in Table 1 of IS 10262 (2019) to the characteristic compressive strength (f_{ck}). Subsequently, the water-cement ratio is carefully selected, guided by the values outlined in Table 5 of IS 456 (2000) *(Reaffirmed Year: 2021)*.

Table 1: Percentage breakdown of aggregates in the mix.

Trial	10 mm aggregate in %	Ceramic waste in %
1	100	-
2	90	10
3	80	20
4	70	30

The maximum water content is then determined from Table 2 of IS 10262 (2019), taking into account the nominal maximum size of the aggregate. With these parameters established, the Cement content is determined. Proceeding further, the proportion of coarse aggregate is estimated based on the recommendations in Table 3 of IS 10262 (2019). This paves the way for the crucial step of accurately estimating the quantities of each mixed ingredient. In particular, adjustments may be necessary to account for the moisture content of the aggregates. The culmination of this meticulous process involves the preparation of concrete trial mixes that serve to validate and refine the proportions of the designed mix.

Cube Casting

The fractions of material were mixed according to the percentage stated in Table 2 to cast the cubes to decide the optimal mix.

Table 2: Percentage of material used in test cubes.

Trial	Percentage of Cementitious Material				Percentage of IOTs in replacement of sand	Percentage of Coarse Aggregate	Percentage of Ceramic Waste
	Cement	GGBS	Fly Ash	Lime			
1	15.00	65.00	10.00	10.00	100.00	100.00	--
2	15.00	65.00	10.00	10.00	100.00	90.00	10.00
3	15.00	65.00	10.00	10.00	100.00	80.00	20.00
4	15.00	65.00	10.00	10.00	100.00	70.00	30.00

A controlled water addition rule yielded a homogeneous cohesive paste without air voids. Standardized mixing parameters optimize workability and uniformity. Pre-treatment with a mold release agent facilitated smooth specimen extraction. Optimal filling and compaction were achieved through standardized procedures. Controlled vibration further enhanced the internal packing density, promoting optimal strength development. Standardized surface finishing techniques ensured both aesthetic appeal and test precision. A controlled humidity environment followed by immersion in water facilitated optimal curing conditions. The precise positioning of the specimen and the controlled loading rate within the testing apparatus ensured accurate and reliable compressive strength data. These meticulously controlled procedures guaranteed the creation of robust and reliable concrete samples suitable for their designated structural applications.

Test Methods

To identify the optimal concrete mixture, in each trial, 6 cubes were cast and cured at ambient temperature. The cubes were tested for compressive strength at 7 and 28 days. The tests were conducted in accordance with IS Code IS 516 (1959) *(Reaffirmed Year: 2018)*. During compression testing, the cubes were placed sideways, nestled between the sturdy steel plates of a 200-ton machine of Venus make.

The load was applied gradually, without shock, and continuously increased at a rate of approximately 140 $kg.cm^{2-}.min^{-1}$ until the sample's resistance broke down and it could no longer sustain a higher load. This relentless pressure continued until the resistance of the cube was crushed, and its capacity to bear the burden was finally exhausted. In simpler terms, the steadily increasing pressure eventually overpowered the cube, revealing its breaking point. When these concrete cubes were subjected to this controlled trial, the researchers could analyze their individual strengths and weaknesses, ultimately paving the way for the selection of the most robust and reliable concrete mix for the intended application.

Casting of Block

After identifying the optimal concrete mix based on the compressive strength of the test cube, block production commenced at an industrial facility situated within the Kakoda Industrial Estate in Goa, India. At this location, the necessary ingredients were mixed and subsequently transformed into robust building blocks.

The process started with the IOTs poured into a pan mixer. This was followed by the addition of GGBS, Fly Ash, Cement, and Lime in precise proportions determined by laboratory tests. For nearly two minutes, the mixer agitated, ensuring a uniform blend of the finer ingredients. This homogeneous mix is crucial to creating strong and consistent blocks. Once the finer materials were well combined, a 10mm basaltic aggregate was added to the mix. These small stones provide additional strength and structure to the blocks. Water was carefully added until the mixture reached a perfect consistency for block manufacturing. Imagine a doughy texture, not too wet and not too dry. The prepared mixture was then transferred to the block-making machine. Here, a powerful hydraulic press applied 80 tons of pressure, compacting the mixture into sturdy blocks. The newly formed blocks were then carefully cured. This process helps the concrete harden properly and reach its full strength. To ensure the quality of the blocks, various tests were performed. These included dimension test, compressive strength and bulk density, water absorption, and efflorescence. Each test provides valuable information on the suitability of the block for construction.

The following paragraphs describe the various procedures adopted for testing.

Dimension Test

Block dimension verification must adhere to the established guidelines outlined in IS 2185-Part 1 (2005). This procedure involves the random selection of twenty or more blocks, followed by their orderly arrangement in rows. Subsequently, a precise measurement of their respective dimensions is conducted to the nearest millimeters. The total lengths of the aligned blocks are meticulously determined using calibrated steel tape. This ensures a consistent and accurate assessment of the longitudinal dimension throughout the row. Similar to length measurement, the width and depth of the arranged blocks are meticulously assessed. This involves using a standardized technique that uses a straight-line reference along each dimension.

Compressive Strength and Dry Bulk Density

A digital compression testing machine was used to conduct compression testing following the procedure outlined in IS 2185-Part 1 (2005). This test apparatus applies an axial load with a consistent rate of 14 $N.mm^{2-}$ per minute, incrementally increasing the pressure until the specimen exhibits definitive failure. Subsequently, the compressive strength quantified in $N.mm^{2-}$ was determined using Equation (1).

Compressive strength ($N.mm^{-2}$) =

$$\frac{Maximum\ Load\ (N)}{Leng\quad (mm) X\ Bread\quad (mm)} \qquad \ldots(1)$$

The bulk density of each sample was evaluated according to the established protocol described in IS 2185-Part 1

(2005). Before measurement, the three blocks were dried in a controlled oven environment. They were kept at a constant temperature of 100°C for 24 hours to ensure complete moisture removal. After the drying period, the samples were cooled to ambient temperature and subsequently weighed using a calibrated balance. To determine the volume of the sample, precise measurements of length, width, and thickness were made at three different locations for each dimension. The average values were calculated for each dimension to account for possible minor variations within the block. Using Equation (2), the bulk density of each sample was subsequently calculated.

Density by volume ($kg.m^{-3}$) =

$$\frac{Weigh\ \ of\ block\ (kg)}{(length\ (m) \times width\ (m) \times thickness\ (m))} \quad \ldots(2)$$

Water Absorption

The experiment involved submerging the test samples entirely in water at ambient temperature for a duration of 24 hours. This ensured a thorough saturation of the material. After the immersion period, the samples were weighed while suspended in water using a fine metal wire, eliminating any buoyancy effects. To standardize surface water removal, samples were gently drained for one minute on a 10mm or larger wire mesh. Before conducting the initial submerged weight measurement (M2), any remaining visible superficial water was carefully removed using a moist cloth. To obtain the saturated mass, all samples were subsequently subjected to oven drying at a temperature of 100°C to 115°C under controlled conditions for a minimum of 24 h and weighed (M1). This rigorous procedure, which employs standardized immersion, drainage, and drying protocols, ensures an accurate and reproducible measurement of water absorption capacity, a crucial parameter for evaluating the durability and performance of construction materials. Subsequently, water absorption, expressed as a percentage of mass, was calculated by applying the formula provided in Equation (3), which provides a quantitative measure of the ability of the blocks to absorb and retain water.

$$\text{Water absorption (\%)} = \frac{M2-M1}{M1} \quad \ldots(3)$$

Efflorescence

The efflorescence assessment of the block samples adhered to the procedures outlined in IS 3495- Part 3: 1992 (Reaffirmed Year: 2016). Each sample was placed in a shallow plate, with one end submerged in water to a predetermined depth of 25 mm. This immersion continued until the water was completely absorbed by the sample and the subsequent evaporation of excess water from the dish. Following this initial drying cycle, a repeat step of adding water was performed. Finally, an examination of the blocks after the second evaporation identified any potential efflorescence manifested as discernible deposits on the surface.

RESULTS AND DISCUSSION

Before optimizing the material combination for maximum compressive strength, a comprehensive characterization of GGBS, Fly Ash, and IOTs was conducted. Table 3 presents the physical and chemical properties of the material. Chemical analyses for IOTs, GGBS, and Fly Ash included SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, and ignition loss. Specific gravity was determined for GGBS, Fly Ash, and IOTs, while fineness and residue on the sieve were determined for GGBS and Fly Ash (Kakodkar & Sawaiker 2023).

To obtain an optimal concrete mix design that balances high performance and economic feasibility, following the established guidelines outlined in IS 10262 (2019), the cubes were cast. Table 4 shows the amount of material and the proportions of constituents implemented in the mix design while Table 5 presents the compressive strength obtained on cubes. The compressive strength of the molded cubes, evaluated after 7 and 28 days, is shown graphically in Fig. 2.

Trial 1 achieved a compressive strength of 7.76 $N.mm^{-2}$ at 7 days and 8.53 $N.mm^{-2}$ at 28 days. Given the importance of compressive strength as a measure of resistance to forces (Castillo et al. 2021), masonry blocks were considered a suitable alternative due to their adhesion to IS codes and the significant demand in construction.

Tests on Blocks

Dimension test: The blocks were arranged lengthwise, and their dimensions were measured. This step was repeated

Table 3: Physical and Chemical Properties of a Material used to cast Construction Blocks.

Property	Raw Material			
	IOTs	GGBS	Fly Ash	Ceramic Waste
Specific Gravity	3.255	2.91	2.30	2.25
Fineness $M^2.kg^{-1}$	--	379	325	--
Residue on Sieve [%]	--	4.80	23.1	--
SiO_2 [%]	17.90	34.81	56.61	60.30
Al_2O_3 [%]	5.80	17.92	27.54	17.60
Fe_2O_3 [%]	63.09	1.36	4.80	4.00
CaO [%]	0.018	37.63	5.00	2.40
MgO [%]	0.135	7.83	0.60	4.20
LOI [%]	11.66	0.18	3.10	1.80

Table 4: Material used for mix design along with proportion.

Trial	Cementitious Material in kg				IOTs in kg	Coarse Aggregate in kg	Ceramic Waste in kg	Remarks
	GGBS	Fly Ash	Cement	Lime				
1	300.95	46.3	69.45	46.3	678.96	934.95	--	100%
2	300.95	46.3	69.45	46.3	678.96	826.20	84.51	90%+10%
3	300.95	46.3	69.45	46.3	678.96	712.72	164.04	80%+20%
4	300.95	46.3	69.45	46.3	678.96	618.96	244.18	70%+30%

Table 5: Compressive strength obtained on cubes.

Trial	T1(N/mm^2)		T2(N/mm^2)		T3(N/mm^2)		T4(N/mm^2)	
	7days	28 days	7days	28 days	7days	28 days	7days	28 days
1	7.73	8.50	7.25	7.97	7.32	8.05	7.40	8.14
2	7.82	8.59	7.20	7.92	7.29	8.02	7.42	8.15
3	7.75	8.52	7.17	7.88	7.35	8.08	7.46	8.20
Average	7.76	8.53	7.20	7.92	7.32	8.05	7.43	8.16

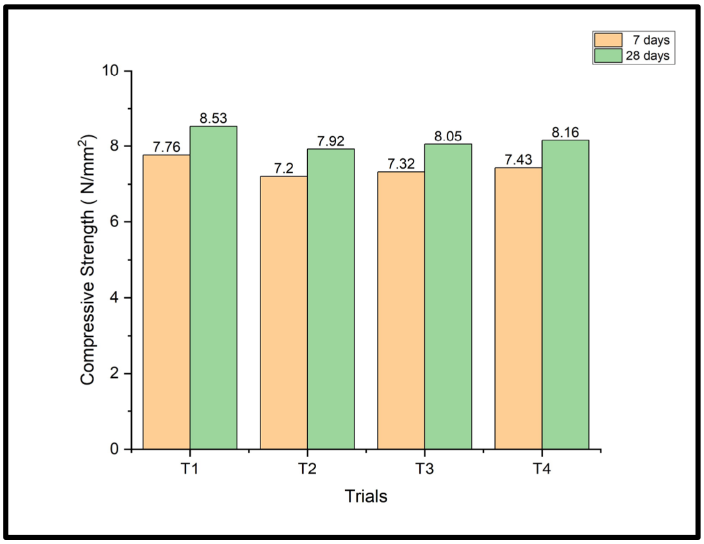

Fig. 2: 7 and 28 days Compressive strength obtained by Trials.

thrice by rearranging the blocks, and the average length was recorded. A similar process was carried out for width and thickness. Table 6 presents the Dimension Test on blocks.

Compressive Strength and Density of the Cast Block

Masonry material exhibits strong behavior under compression but is vulnerable under tension. Consequently, when choosing blocks for load-bearing structures, understanding their capacity for compressive stress is vital. In this research, the average compressive strength was 10.91 $N.mm^{-2}$ for 7 days and 15.92 $N.mm^{-2}$ for 28 days when 65% of GGBS and 15% of Fly Ash were used in addition to 100% IOTs as fine aggregate and 10mm basaltic aggregate. Thejas and Hossiney (2022) performed five different block trials and found the maximum average compressive strength of 7.7 $N.mm^{-2}$ in one of the trials wherein 42% IOTs and 44% GGBS were used. Such enhancements can be credited to the intricate reaction mechanisms of GGBS and Lime with IOTs. The complex

Table 6: Dimension Test on Construction Blocks.

Dimensions	No. of units	Dimensions [mm]	Average Dimensions [mm]	Code recommendations [mm]	
L	20	290	295	5680	5920
B		190	192	3720	3880
H		140	142	2740	2860

reaction mechanisms between GGBS, Lime, and IOTs play an important role. The GGBS and Lime interact with the IOTs through two primary mechanisms: an exothermic reaction and quick ion exchange, as well as a gradual, slower chemical reaction between calcium hydroxide and pozzolanic materials. Furthermore, the extended chemical reaction between calcium and the silica-alumina compounds in IOTs results in highly stable silicates and aluminates, providing a stronger bond and an ability to resist deterioration over time. These findings align with those of Oti et al. (2009), who observed similar reactions of GGBS and Lime to improve soil properties for construction applications. Elahi et al. (2021) reported an average compressive stress capacity of 4.4 $N.mm^{-2}$ when 21% Fly Ash was used along with soil and Cement. Nagaraj and Shreyasvi (2017) used Cement, quarry dust, and Lime along with mining waste materials and observed that at 40% replacement with mining waste material, the compressive stress capacity was 3.5 $N.mm^{-2}$. Sekhar and Nayak(2018) manufactured blocks using 75% fine-grained sedimentary rock along with 25% GGBS and 12% Cement and witnessed a compressive stress capacity of 5.5 $N.mm^{-2}$ at 28 days. Table 7 presents the compressive strength obtained by block at 7 and 28 days.

The influence of IOTs on block density, a crucial parameter in the design of masonry, was investigated.

The incorporation of IOTs resulted in a marginally higher density ranging between 2.09 to 2.28 $g.cm^{-3}$ across different block samples, with an average of 2.20 $g.cm^{-3}$. This is consistent with the observations of Abdulrahman (2015), who reported an increase in density in the Sand Crete Blocks (SCB) due to the IOTs replacing sand (ranging from 10% to 30%) in a Cement-to-sand mix of 1 6. The denser nature of the IOTs compared to that of sand was cited as a contributing factor. Similarly, James et al. (2016) observed a bulk density of 1.85 $g.cm^{-3}$ when using IOTs. The observed density enhancements in this study may be linked to the tighter arrangement of fine IOT particles and their marginally greater specific gravity in contrast to conventional earthen blocks, which usually demonstrate densities ranging between 1.8 and 1.9 $g.cm^{-3}$. Table 8 summarizes the block densities of the investigated samples.

Table 7: Compressive Strength of Construction Blocks.

Block	Compressive strength [$N.mm^{-2}$]	
	7 Days	28 Days
1	10.59	15.55
2	10.78	15.86
3	11.45	16.32
4	10.67	15.76
5	11.08	16.13
Average	10.91	15.92

Table 8: Density of Construction Blocks.

Block	Block density [$g.cm^{-3}$]
1	2.09
2	2.28
3	2.21
4	2.18
5	2.25

Water Absorption

The water absorption of masonry units plays a crucial role in their durability, particularly in their resistance to freeze-thaw damage. Lower water absorption indicates a smaller pore volume within the unit, leading to enhanced frost resistance. Typically, standards recommend that the water absorption rate for clay bricks and blocks be below 20%. The present study uses 100% IOTs as fine aggregate, which constitutes 35% of the total volume of the mixture, resulting in a favorable water absorption rate of 4.64%. Furthermore, the incorporation of GGBS and Fly Ash improves pore filling via their fine particle size and reactive products formed during pozzolanic reactions, further reducing water absorption. Thejas & Hossiney (2022) reported optimal performance for 42I-44G blocks (42% IOTs, 44% GGBS) with water absorption of 13%, observing a correlation between an increase in IOTs content and an increase in water absorption. Table 9 presents the measured water absorption values. Nagaraj et al. (2014) studied compressed stabilized earth blocks (CSEB) that incorporate Lime and Cement, achieving minimum water absorption of 7% for a mixture of 92% soil, 4% Cement, and 4% Lime. Table 9 summarizes the water absorption data for these cast blocks. Kumar and Surendra (2020) reported water absorption below 18% in all of their tests with varying Cement percentages.

Efflorescence

Block efflorescence arises from the deposition of soluble

Table 9: Water Absorption of Construction Blocks.

Brick	Dry weight [kg]	Wet weight [kg]	Water Absorption [%]
1	19.05	20.04	5.19
2	19.18	19.94	3.96
3	19.48	20.41	4.77
4	18.98	19.81	4.37
5	20.15	21.14	4.91
Average			4.64

salts on the surface. This phenomenon occurs readily in the presence of three key elements: water-soluble salts, moisture, and a porous block medium. In particular, severe efflorescence can compromise wall plaster and paint adhesion and negatively impact aesthetics, even on unplastered surfaces. Consequently, efflorescence-free blocks are preferred. IS 3495 - Part 3: 1992 (Reaffirmed Year: 2016) establishes an efflorescence classification system based on the quantity of salt deposits on the surface of the block.

Thejas & Hossiney (2022) observed a correlation between increased IOT content and higher efflorescence, with their 82% IOT block showing significant salt deposition compared to their other trials without visible deposits. This suggests that a higher IOT content potentially facilitates salt migration. In contrast, incorporating GGBS and Fly Ash into blocks can elevate the alumina content, fostering stronger cross-linking within the binder phase and restricting the movement of alkali, thereby mitigating efflorescence. In our study, the use of IOT content did not result in efflorescence, possibly due to the aforementioned mechanisms.

CONCLUSIONS

The project addressed the significant environmental impact of iron ore tailings (IOTs) by exploring remediation strategies. It aimed to develop a sustainable composite construction block utilizing readily available IOTs from Goa's mines. This objective was achieved by testing various combinations of IOTs, Ground Granulated Blast Furnace Slag (GGBS), and Fly Ash. The optimal mix design, achieving the highest compressive strength, consisted of 15% cement, 65% GGBS, 10% fly ash, and lime and utilized 100% IOTs as fine aggregate along with 100% basaltic aggregates. The manufactured blocks met the dimensional criteria stipulated in IS 2185-Part 1 (2005). Their compressive strength even surpassed the code requirements, reaching 10.91 $N.mm^{2-}$ at 7 days and 15.92 $N.mm^{2-}$ at 28 days. While the block density of 2.20 g/cm^3 was slightly higher than standard blocks, the average water absorption of %4.64 remained within the limits of IS 2185-Part 1 (2005). Importantly, no efflorescence was observed on the blocks. This study successfully developed an eco-friendly composite block from mine waste, offering a potential pathway for remediating the environmental impact of iron ore tailings (IOTs). The blocks comply with relevant building code requirements, paving the way for sustainable waste management and resource utilization, particularly by utilizing IOTs as a viable construction material.

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