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NUMERICAL INVESTIGATION OF REINFORCED CONCRETE BEAM CONTAINING IRON ORE TAILINGS AS PARTIAL REPLACEMENT OF SAND

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Abstract

The production of industrial and agricultural residual byproducts can generate significant environmental impact. In response, incorporating supplementary materials made from agro-industrial wastes to create more sustainable concrete is being undertaken. However, testing the performance of these waste-based concrete mixtures can be time-consuming and expensive. To resolve this problem, this study utilized three-dimensional non-linear Finite Element simulation using the ABAQUS/Computer Aided Engineering software/ to predict the behavior of a reinforced concrete beam that incorporated 20% IOT as partial sand replacement. The ultimate load obtained from the 20% IOT concrete beam was compared with experimental results, which showed a 19% positive difference in terms of the load-carrying capacity. Hence, the simulated experiments successfully predicted the damage behavior of the 20% IOT concrete, indicating the potential of this modeling approach to accurately predict the performance of waste-based concrete mixtures in various designs.

Keywords: ***ABAQUS, Computer Aided Engineering, Iron Ore Tailings, Numerical Analysis, Rein-forced Concrete Beam.***

I. Introduction

Concrete is a popular construction material worldwide [1]. It is made up of a combination of coarse and fine aggregates, cement, water, and sometimes other components. The high demand for aggregates has led to a scarcity of their non-renewable natural sources and the search for more sustainable options [2]. On the other hand, the production of cement results in significant greenhouse gas emissions and air pollution [3]. Research has indicated that the ordinary Portland

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cement industry is responsible for approximately 7% of the world's CO_2 emissions, with the majority being released during concrete production [4]. It takes 1.6 tons of raw materials and emits 1 ton of CO_2 to produce just 1 ton of ordinary Portland cement [5]. To minimize the negative impact on the environment, there is a need to find alternatives to cement with a lower carbon footprint.

Iron ore tailings are a common waste product of the mining industry that is generated during the extraction and processing of iron ore. These tailings are typically composed of a mixture of crushed rock, water, and chemicals used in the beneficiation process, and they can be disposed of in a variety of ways, including in tailings storage facilities or backfilling into mining pits.

The disposal and management of iron ore tailings can pose significant environmental challenges. These tailings can release harmful chemicals and heavy metals into the environment, leading to soil and water contamination and potentially harmful effects on human health and ecosystems [6], [7]. In addition, the construction and maintenance of tailings storage facilities can be expensive and resource-intensive [8].

However, iron ore tailings also present opportunities for resource recovery and reuse. They can be used as a source of valuable metals and minerals, as well as for the production of construction materials such as concrete, bricks, and ceramics [9], [10]. The utilization of iron ore tailings as a substitute for natural aggregates in concrete has shown great potential in recent years, providing a sustainable solution to reduce the demand for virgin aggregates and waste accumulation [10], [11].

In related works, the contribution of the iron ore tailings material to the flexural behavior of the reinforced concrete beam elements is described in terms of load-concrete strain, load-steel strain, load-deflection relationships, cracking behavior, and the ultimate load at failure [12]. [13] investigate the replacement of natural quartz sand with an iron-rich mine tailing in PVA-reinforced AAM. [14] study geopolymer bricks using iron ore tailings, slag sand, ground granular blast furnace slag, and fly ash. Development of geopolymer binder-based bricks using fly ash and ground granulated blast furnace slag has been carried out. [15] aim to identify the influence of the incorporation of iron ore tailings (IOT) obtained from the Germano dam in Brazil in the substitution of sand fractions in concrete. 15%, 30%, 50%, and 70% iron tailings were used to

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replace the natural sand in concrete, and 1.5% steel fiber and 0-0.75% PVA fibers were added to the iron tailings concrete [16]. Other influential work includes [17]. However, while the usage of alternative materials in concrete mixes, such as IOT, has been considered a solution to the environmental and economic impacts of natural sand depletion, there is a lack of comprehensive understanding of the structural behavior of concrete containing these materials under long-term loading and environmental exposure.

This paper presents a numerical investigation of reinforced concrete beams containing iron ore tailings as a partial replacement for sand. The research aims to evaluate the mechanical and structural performance of reinforced concrete beams with 20 percent iron ore tailings replacement. The investigation focused on the flexural strength, crack pattern, and failure modes of the beams. The findings of this research will provide valuable insights into the potential of iron ore tailings as a sustainable and cost-effective alternative to natural sand in concrete production.

II. Finite Element Model

The study of the performance of concrete has been made possible by advances in finite elements and high-end computers. One of the computer software used to solve complex engineering problems and applicable across industrial disciplines such as mechanical engineering and civil engineering is ABAQUS. According to failure behavior criteria, a geometry model can be constructed [18]. The ABAQUS explicit dynamics finite element program is a mathematical technique used for integrating equations of motion through time. Previous research [19] and [20] have shown that predicted load defection curves, the linear law, even though slightly neglected the initial stiffness, and the test peak curve for plain concrete (though steep for triangular mesh) were in good agreement with the corresponding standard experimental values.

A. Description of the FE Model

To model reinforcement in ABAQUS, a truss element called T3D2, which is a 3D element with 2 nodes, is used. For simulating the behavior of concrete, a 3D general-purpose linear brick element, C3D8I, with 8 nodes and 1 integration point is employed. An elastic-perfectly plastic model is utilized to simulate the material behavior of the longitudinal and transverse reinforcement in ABAQUS. This model ensures that the reinforcement is embedded in the same degree of freedom

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as the concrete, ensuring perfect bonding between the two materials. Tables 1 and 2 present the concrete properties and the concrete damage parameters used for modeling the concrete in ABAQUS.

Table I: Materials Properties Parameter for Concrete Containing 20 % Iot

Dilation Angle	Eccentricity (mm)	Initial biaxial/uniaxial ratio	K	Density (kg/m^3)	Young's Modulus ($x10^{-6}$ MPa)	Poisson ratio
40^0	1.0	1.16	0.667	2430	26,530	0.26

Table II: Concrete Damage Plasticity Parameters

Compression Behavior			Tension Behavior		
Yield Stress (Mpa)	Inelastic Strain	Damage Parameter	Yield Stress (Mpa)	Cracking Strain	Damage Parameter
12.87000	0.00000	2.41370	0.00000	0.00000	0.00000
13.01573	0.00000	2.33619	0.54410	0.00420	0.03211
15.44780	0.00001	1.78654	0.61722	0.00496	0.25983
17.77072	0.00002	1.37712	0.67193	0.00569	0.42946
19.96187	0.00003	1.11500	0.71392	0.00641	0.53805
22.00059	0.00006	0.93943	0.74694	0.00712	0.61079
23.86922	0.00008	0.81500	0.77346	0.00782	0.66234
25.55379	0.00012	0.72249	0.79516	0.00851	0.70067
27.04457	0.00016	0.65104	0.81320	0.00920	0.73027
28.33630	0.00021	0.59415	0.82841	0.00989	0.75384
29.42813	0.00027	0.54773	0.84140	0.01057	0.77308
30.32330	0.00034	0.50907	0.85261	0.01125	0.78909
31.02866	0.00041	0.47634	0.86237	0.01193	0.80265
31.55409	0.00049	0.44823	0.87094	0.01261	0.81430
31.91175	0.00057	0.42381	0.87853	0.01328	0.82441
32.11546	0.00067	0.40237	0.88529	0.01396	0.83330
32.18000	0.00076	0.38337	0.89134	0.01463	0.84117
32.06651	0.00087	0.36641	0.89680	0.01531	0.84820
27.79177	0.00170	0.35116	0.90175	0.01598	0.85452

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22.27407	0.00258	0.33736	0.90624	0.01665	0.86023
17.88359	0.00341	0.32481	0.91035	0.01732	0.86543
14.67073	0.00420	0.31335	0.91412	0.01799	0.87018
12.31800	0.00496	0.30282	0.91758	0.01866	0.87454
10.55733	0.00569	0.29311	0.92078	0.01934	0.87856
9.20590	0.00641	0.28413	0.92374	0.02001	0.88229
8.14341	0.00712	0.27579	0.92649	0.02068	0.88574
7.29007	0.00782	0.26802	0.92906	0.02135	0.88896

III. Experimental Set-Up

Previous research has shown that the ultimate replacement level for IOT in concrete is 20 %. Thus, on this basis, concrete grade 25 was designed using the DoE method and incorporating OPC. The quantities obtained are presented in Table 3. Testing of the beam specimen was conducted after 28-day curing in water to determine the flexural behavior of the beam in terms of cracking pattern, failure mode, and load vs deflection.

Table III: Constituent Materials for A Cubic Meter of Concrete

Concrete Samples	Constituent Materials (Kg/m^3)				
	Water	Cement	Fine Aggregate	Iron Ore Tailings	Coarse Aggregate
0% IOT	210	362.06	668.88	0.0	1189.12
20% IOT	210	362.06	535.10	133.78	1189.12

For this study, six beam specimens were cast and tested: three for the control group and three with a 20% IOT sand replacement level. The length of each beam was 1500mm with a cross-sectional area of 200mm depth and 100mm width. The beams were double reinforced using 2Y8 high tensile bars and R4 mild steel round bar stirrups. Testing was conducted following BS EN12390-5:2009, using a four-point load to measure the ultimate failure load after 28 days of curing. Fig. 1 illustrates the experimental setup of the beam.

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Fig. 1: Experimental set-up

A. Flexural Strength of the Beam

The flexural strength test result is presented in Table 4. It is observed that the flexural strength gains of the concrete containing IOT was superior to control specimens. It is observed that the flexural strength of concrete containing 20% IOT for M25 at the age of 28 days was found to develop a higher flexural strength of 19.4% above that of the control concrete beam. In general, concrete containing IOT showed higher rates of flexural strength development throughout the curing period.

Table IV: Flexural Strength of 20% IOTs Concrete Beam

Type of Concrete Mix	Age (days)	Flexural Strength (MPa)	% difference
Control mix	28	7.2	
20% IOT mix	28	8.6	19.4

B. Cracking Pattern in the Beam

From Fig. 2, both control (0% IOT) and 20% IOT concrete beams can be observed to have primary cracking patterns at the middle region which propagates diagonally towards flexural failure. However, minimal failure concentration in the FE model is shown in Figure 3 while in the experimental beam, multiple cracks were visible. However, it can be said in general terms that cracking patterns in both the experimental beam and ABAQUS model have a good agreement and compare well.

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Fig.2(a). Experimental Cracking Pattern in Control Beam

Fig. 2(b). Experimental Cracking pattern in 20%

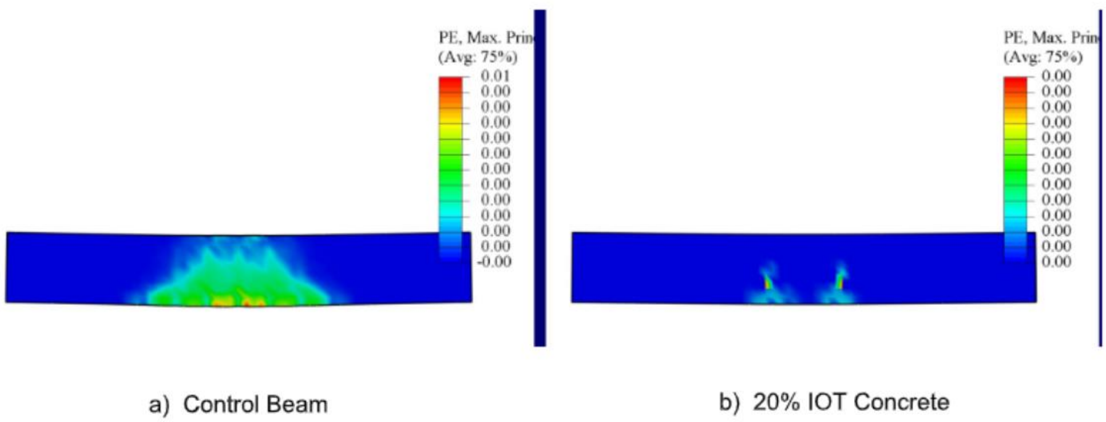

Fig.3. FE Model Cracking Pattern

C. Axial Load Vs Displacement

During the ABAQUS analysis, the history output request was utilized to examine the vertical load versus displacement for a beam model in FEA. Fig. 4 and 5 show the load against the corresponding displacement of the beam model for both control and 20% IOT concrete respectively. The results reveal that the 20% IOT concrete has a greater load-bearing capacity in both the experimental and FE models. The load increment trends against displacement were also similar between the experimental beam specimen and the simulation model, indicating that the FE model can accurately predict the behavior of the IOT concrete beam.

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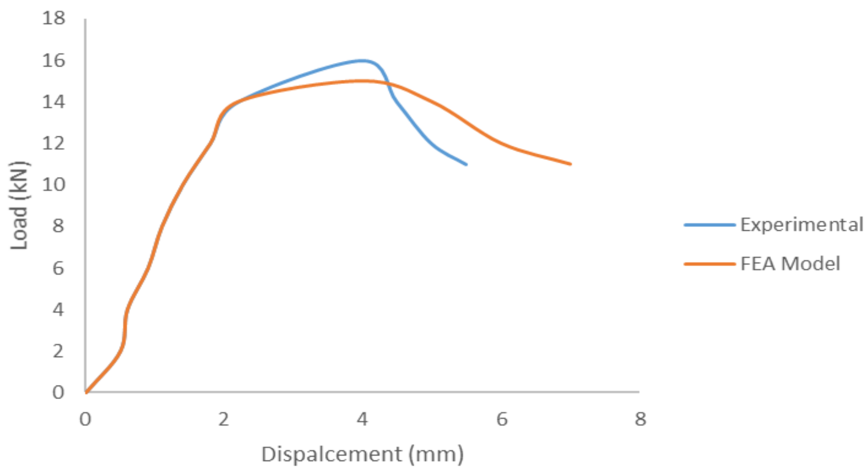

Fig. 4. Load vs Displacement for FE Model and Experimental Beam

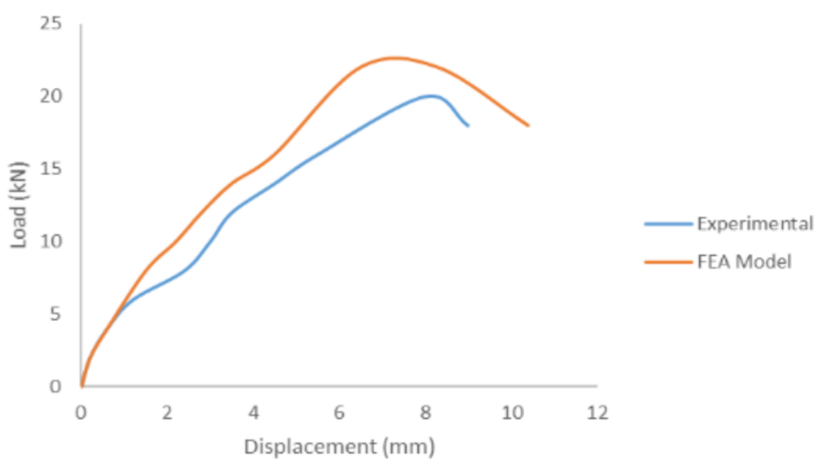

Fig 5. Load vs Displacement for FE Model and Experimental 20% IOT

D. Parametric Study

A study was conducted to analyze the failure mode of a beam model by varying its geometric parameters. This parametric study aimed to investigate the failure criterion across different cross-sectional dimensions and lengths that were not covered in previous experimental works.

In Fig. 6(a) and 6(b), the beam failure mode for a 450mm x 230mm beam with a 3m length, 10mm links, and 2Y16 and 3Y16 as top and bottom reinforcements, is shown. The stress pattern cracking mode for both the control and 20% IOT concrete beams showed similar behavior at 3m length. The red color indicates the locations of the concrete with large plastic strains, which correspond

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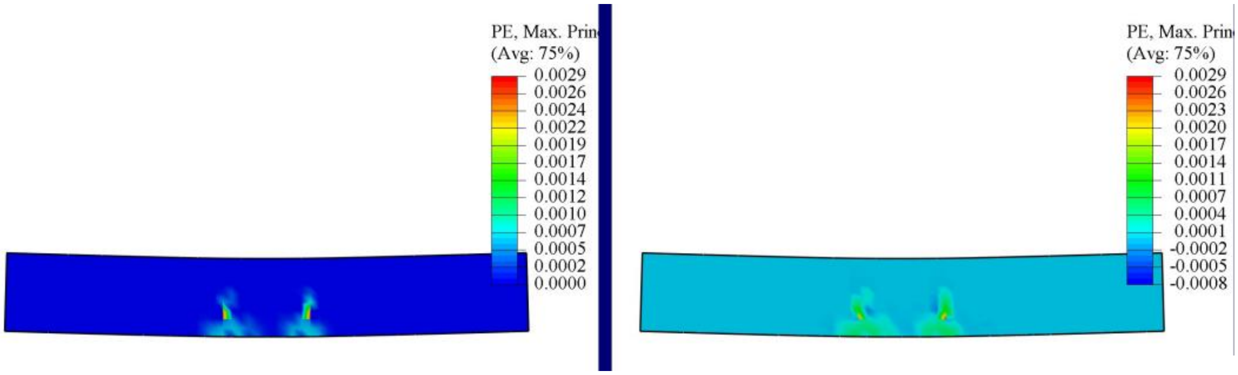
to the points with significant shear cracks. Meanwhile, the blue color represents points with low strain values.



a) 20% IOT Concrete Beam

b) 0% IOT Concrete Beam

Fig. 6. FE Model Cracking Pattern for a 3m Beam

IV. Conclusion and Recommendations

In conclusion, the study suggests that incorporating Iron Ore Tailings (IOT) as partial cement replacement has the potential to reduce the environmental damage caused by the waste. The focus was on analyzing the flexural strength and displacement of a 20% IOT concrete beam model, which performed better than the beam from a traditional concrete mixture. The ultimate load obtained from the 20% IOT concrete beam was compared with experimental results, which showed a 19% positive difference in terms of the load-carrying capacity. Additionally, a parametric study was conducted by varying the length, which showed a steady increase in the ultimate load capacity. However, the mode of failure remained the same, with more visible cracks.

It is recommended to incorporate IOT as a partial sand replacement of up to 20% in concrete to reduce the environmental damage caused by the waste. Further studies with different boundary conditions, beam model dimensions, and various material properties are suggested to overcome financial and time constraints. The concrete damage plasticity model can be used to effectively predict the failure behavior of the concrete. The use of IOT in concrete production can contribute to sustainable development efforts.

Overall, the study is a step toward sustainable development, and the hope is that the findings will be beneficial to researchers and practitioners in the field.

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