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Performance Evaluation of Self-Compacting Concrete by Incorporating Iron Ore Tailings and Ggbs

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Abstract

Due to its comparatively large content of cement and fine aggregates, SCC has become remarkably expensive. Alternative materials for cement and fine aggregate are considered in order to achieve environmental sustainability as well as cost effectiveness. As a replacement for cement in concrete, according to the various studies it has been established that ground granulated blast furnace slag can be replaced with 5% of all cementitious materials. Hence, in this study 5% of ground granulated blast furnace slag is considered and Iron Ore Tailings as a replacement for fine aggregate content of 10% is considered. Since the iron ore tailings have very high-water absorption capacity than manufactured sand the study is continued by considering 1.5 % of superplasticizer content. The fresh properties of SCC such as slump flow, V- funnel and L- box test is checked according to IS code specification. The hardened properties such as compression strength test, Split-tensile strength test and Flexural- strength test was conducted. The results showed that as the SP dosage is increased the fresh behavior of SCC is improved up to certain dosage for each mix further addition leads to the segregation of concrete was observed. The optimum IOT content arrived at 10% replacement mix having 1.5% of SP dosage.

Introduction

The advancement of a nation's infrastructure depends significantly on the availability of adequate housing, transportation, and construction facilities, with concrete serving as a cornerstone material globally. Over decades, concrete has been the backbone of infrastructure development due to its versatility and durability.

Self-compacting concrete (SCC), a specialized form of concrete, has emerged as a revolutionary material, capable of flowing under its own weight and achieving complete compaction without external vibration. Its ability to fill intricate formwork and navigate heavily reinforced spaces without segregation offers significant advantages over traditional concrete. However, the production of SCC is inherently more expensive due to its high cementitious material content and reliance on finer aggregates, both of which are subject to rising costs and dwindling natural supply. Strategic optimization of SCC mix design can help reduce these costs while maintaining its superior properties.

Fig 1.1 – Self-Compacting Concrete

Given the increasing emphasis on sustainable construction practices, exploring environmentally friendly materials has become essential. Recycling industrial by-products for concrete production presents a promising approach to sustainability. This study focuses on replacing conventional cement and fine aggregates in SCC with alternative and waste-derived materials.

Mineral admixtures, such as fly ash, ground granulated blast-furnace slag (GGBS), silica fume, rice husk ash, and metakaolin, are commonly employed as partial substitutes for cement. These materials not only enhance concrete properties but also address environmental concerns associated with their disposal. Among the potential substitutes, industrial solid waste, such as iron ore tailings (IOT), offers a dual benefit of waste mitigation and resource conservation.

Iron ore tailings, a by-product of mineral extraction in the steel industry, represent a significant waste stream with increasing volumes due to lower-grade ore processing. Utilizing IOT as a partial replacement for fine aggregates in SCC addresses pressing environmental and resource challenges. Previous research highlights the viability of IOT as a sustainable alternative in concrete production, making it a key focus of this study.

This research aims to evaluate the performance of SCC incorporating GGBS as a partial cement replacement and IOT as a fine aggregate substitute, contributing to cost-effective and sustainable construction practices.

2.1 Literature Review on Self-Compacting Concrete (SCC)

Okokpujie, I.P. (2023):

With the growing emphasis on sustainability in construction, integrating waste materials into self-compacting concrete (SCC) presents a promising solution for reducing environmental impacts. This study explored the incorporation of calcium carbide waste (CCW), crumb rubber (CR), and fly ash (FA) into SCC. It analyzed their effects on workability, setting time, and mechanical properties such as compressive, tensile, and flexural strengths. Findings indicate that CCW is a viable substitute for cement, with FA and CR improving SCC consistency. The study suggests utilizing up to 50% FA to achieve high-volume fly ash SCC, emphasizing its potential for sustainable waste management and eco-friendly construction practices.

Shen, W., et al. (2022):

To address the environmental and cost challenges of traditional SCC, a sustainable mix design incorporating higher proportions of fly ash and coarse aggregates was developed. The study examined the influence of aggregate and fly ash content on shrinkage and permeability, achieving an optimal mix with 30% fly ash and a 0.6 coarse aggregate packing ratio. This formulation reduced porosity and shrinkage while enhancing compressive and flexural strengths, offering a cost-effective and eco-friendly SCC alternative.

Kumar, M.A., et al. (2022):

Investigating marble waste as a partial replacement for fine aggregates, this study evaluated three mix ratios—20%, 30%, and 40%—with added polypropylene fibers. The 20% replacement mix exhibited superior compressive strength, while 40% replacement demonstrated adequate fresh properties. Polypropylene fibers enhanced flexural and tensile strengths, highlighting the potential of marble waste as a sustainable SCC component.

Mim, N.J., et al. (2023):

Banana leaf ash (BLA) was evaluated as a partial cement replacement in SCC, with substitution levels up to 20%. The BLA20 mix maintained properties within EFNARC guidelines, achieving durability and mechanical performance comparable to conventional SCC. Chloride ion penetration tests confirmed improved durability, while global warming potential (GWP) was reduced by 19.41%, underscoring its environmental benefits.

Kanagaraj, B., et al. (2023):

This study developed self-compacting lightweight concrete using expanded clay aggregate (ECA) as a coarse aggregate replacement. The addition of ECA improved fresh concrete properties and met international standards. Up to 50% replacement maintained strength properties, demonstrating ECA's effectiveness in lightweight SCC applications.

2.2 Literature Review on Iron Ore Tailings (IOT) in Concrete

Shettima, A.U., et al. (2016):

Iron ore tailings (IOT) were evaluated as a fine aggregate replacement in concrete, with substitution levels of 25%, 50%, 75%, and 100%. The 25% IOT mix showed significant improvements in compressive and tensile strengths compared to standard concrete. This approach highlights the dual benefits of waste management and resource conservation.

Yunhong, C., et al. (2020):

Mechano-chemically activated siliceous IOT was tested as a partial cement replacement (10%, 20%, and 30%). The 30% replacement mix exhibited improved impermeability and frost resistance. However, increased IOT content reduced carbonation resistance, suggesting the need for optimized replacement ratios to balance durability and environmental benefits.

Yang, M., et al. (2020):

Iron tailings powder (ITP) was explored as a cement additive, with activity optimized at a specific surface area of 469 m^2/kg. The study found that replacing up to 30% of cement with ITP enhanced strength and reduced costs, presenting a sustainable alternative to traditional binders.

Chen, Z., et al. (2022):

Rice husk ash (RHA) and IOT were used as partial replacements for sand in SCC, with optimal replacement levels identified as 10% RHA and 40% IOT. The resulting concrete exhibited enhanced frost resistance, compressive strength, and flexural performance, emphasizing the synergy between agricultural and industrial waste utilization.

Lv, Z., et al. (2022):

This research combined diatomite (cement substitute) and IOT (sand substitute) in SCC, achieving optimal mechanical properties at 10% diatomite and 25% IOT. The study leveraged machine learning models to optimize mix designs for environmental efficiency, advancing sustainable concrete production.

3.0 OBJECTIVES

- To get the design mix for M40 grade self-compacting concrete. The cement be partially replaced by GGBS and sand is replaced by manufactured sand.
- To use alternative materials like GGBS and iron ore tailings as replacement for cement and M sand respectively.
- To determine and study the fresh properties as well as Hardened properties of Self Compacting Concrete by incorporating Iron Ore Tailings and GGBS.
- To obtain the Optimum percentage replacement of Sand by IOT & superplasticizer content that satisfies fresh & hardened properties of considered M40 grade of SCC.
- To provide efficient disposal of iron ore tailings.
- To minimize the utilization of natural fine aggregate. in the preparation of SCC by partially replacing with iron ore tailings.

Raw Materials Used

4.0 Overview

This study focuses on developing a mix proportion for self-compacting concrete (SCC) of Grade M40, adhering to the guidelines of IS 10262:2019. The objective is to compare conventional SCC with a mix incorporating Iron Ore Tailings (IOT) as a sustainable alternative. The fresh and hardened properties of these mixes are evaluated to assess their feasibility.

METHODOLOGY

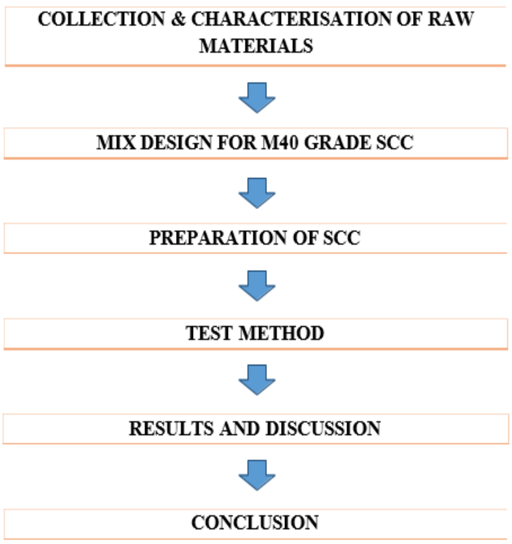

Fig 4.1 – Flow chart of Methodolog

4.1 Cement

Cement serves as the primary binding agent in concrete, providing strength and durability. In this study, **Ordinary Portland Cement (OPC) 53 Grade** is utilized due to its high strength and suitability for SCC. Basic tests, such as specific gravity and fineness, confirmed the quality of the cement.

- **Fineness**: 7%
- **Specific Gravity**: 3.10

Fig 4.2 - 53 Grade Ordinary Portland Cement

4.2 Fine Aggregate

Fine aggregates are essential for the strength and workability of concrete. This study employs **Manufactured Sand (M-Sand)** instead of natural river sand to enhance particle size control and bonding.

- **Specific Gravity**: 2.63
- **Fineness Modulus**: 2.75

Sieve Analysis for M-Sand

Sieve analysis classified the M-Sand as **Zone II**, meeting the requirements of IS 383:1970.

Fig 4.3 - Manufactured Sand

4.2.1 Iron Ore Tailings (IOT)

IOT is a byproduct of the steel industry and an environmental pollutant. By processing and activating IOT, this study evaluates its use as a partial fine aggregate replacement in SCC.

- **Specific Gravity**: 3.13
- **Fineness Modulus**: 2.713
- Sieve analysis confirmed its classification as **Zone II**, making it suitable for fine aggregate replacement.

Fig 4.4 – Mine tailing, Sandur

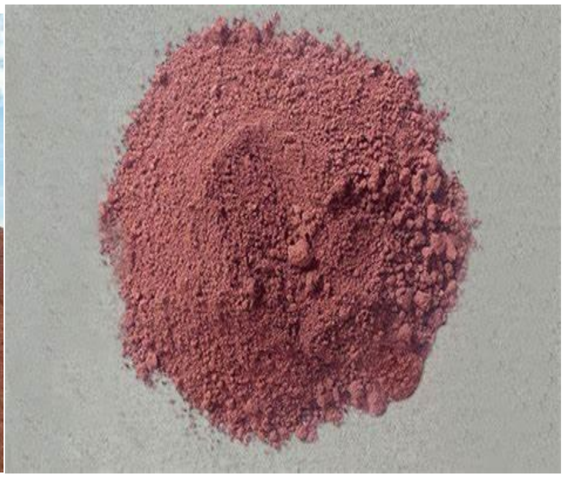

Fig 4.5 – Iron Ore Tailing

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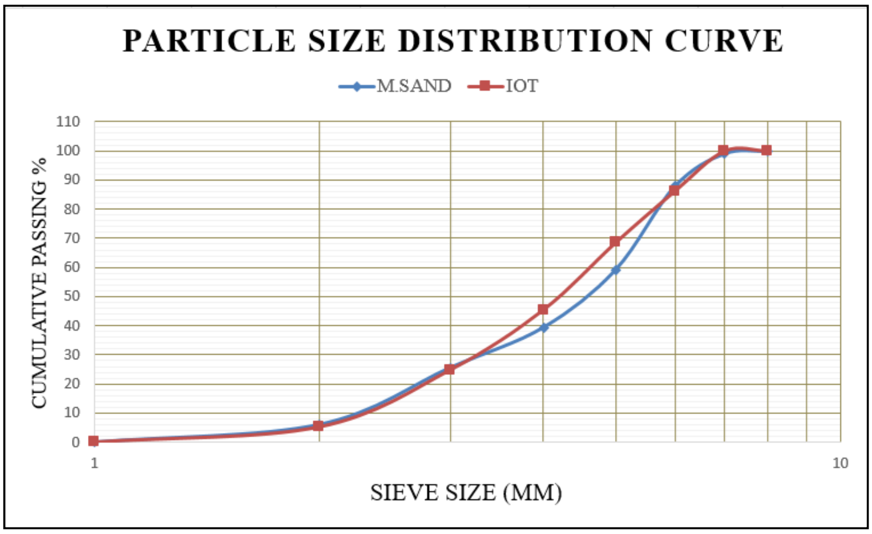

Fig. 4.6 Comparative particle size distribution of M.Sand and IOT

4.3 Coarse Aggregate

Coarse aggregates provide structural integrity to concrete. This study utilizes **12.5mm downsize coarse aggregates** for both conventional and IOT-based SCC.

- **Specific Gravity**: 2.65
- **Water Absorption**: 0.3%

Fig 4.7 – Coarse aggregate (12.5mm down size)

4.4 Water

Potable water free from impurities, sourced locally, is used in the concrete mixes.

4.5 Mineral Admixture

Ground Granulated Blast Furnace Slag (GGBS) is employed as a supplementary cementitious material, replacing 5% of cement. Its pozzolanic and hydraulic properties enhance concrete strength and durability.

- **Specific Gravity**: 2.74
- **Fineness**: 15%

Fig 4.8 – GGBS

4.6 Chemical Admixture

Auramix 400 Superplasticizer, a polycarboxylic ether-based admixture, is used to improve SCC workability.

- **Dosage**: Based on 0.5% increments of cement weight.

Mix Design for M40 Grade SCC

Mix Proportioning

The mix design targets Grade M40 SCC, using IS 10262:2019 guidelines.

4.0 Mix Design for 10% iron ore tailings incorporated M40 grade SCC

Fine aggregate manufactured sand is, replaced with IOT at 10% mass of manufactured sand.

a) At 10% replacement:

Manufactured sand = 0.9 × 898.56 = 808.704 kg/m3Iron Ore Tailing = 0.1 × 898.56 = 89.856 kg/m3

Mix proportions for M40 Grade Normal Conventional SCC

Water	= 190	Lit.
Total binder content	= 482	kg/m3
Cement	= 457.19	kg/m3
GGBS	= 24.06	kg/m3
Fine aggregate	= 898.56	kg/m3
Coarse aggregate	= 792.35	kg/m3
Super plasticizer	= 4.82	kg/m3

Incorporating IOT

For a mix replacing 10% of M-Sand with IOT:

- **M-Sand**: 808.7 kg/m³
- **IOT**: 89.86 kg/m³

Experimental Investigation (Rewritten and Condensed)

Objective

Develop a sustainable SCC by partially replacing conventional materials with GGBS and IOT, evaluating fresh and hardened properties in line with IS 10262:2019 and EFNARC guidelines.

5.1 Mix Procedure

5.1.1 Mixing

The materials—cement, GGBS, water, M-Sand, coarse aggregate, and superplasticizer—are batched and mixed sequentially. Adjustments in superplasticizer dosage ensure desired flowability.

Fig 5.1 – Concrete mixing

5.1.2 Casting

Concrete is poured into molds for cubes, cylinders, and prisms without external compaction, ensuring homogeneity and minimizing air voids.

Fig 5.2 – Casting of Normal Cubes, prisms and cylinders

5.1.3 Curing

Specimens are cured in water at ambient temperature for 7, 14, and 28 days. IOT-based SCC specimens with higher superplasticizer content require extended demolding times.

Fig 5.4 – Curing of samples

Testing of SCC

5.2.1 Fresh Properties

(a) Slump Flow Test

Evaluates flowability, with results categorized into SF1, SF2, and SF3 classes per IS 10262:2019. Optimal flow ensures segregation resistance.

Fig 5.5 – Slump flow test

(b) L-Box Test

Measures passing ability through reinforcement. An H1/H2 ratio of 0.8–1.0 confirms adequate flow characteristics.

Fig 5.6 L – Box test

(c) V-Funnel Test

Assesses viscosity and segregation resistance. Flow time for V1 class should not exceed 8 seconds.

Fig 5.7 V – funnel test

5.2.2 Hardened Properties

(a) Compressive Strength

Cubes (100mm³) are tested after 7, 14, and 28 days using a 200-ton capacity machine. Results validate strength development across mixes.

Fig 5.8 – Cylinder testing in Compressive testing machine

(b) Split-Tensile Strength

Cylinders (200mm x 100mm) are tested under compression for indirect tensile strength, aiding in comparative analysis.

(c) Flexural Strength

Prisms (450mm x 75mm x 75mm) are subjected to two-point loading to evaluate bending resistance.

Fig 5.9 – Flexural-strength testing of prism

Results and Discussion

This section presents the fresh and hardened properties of self-compacting concrete (SCC), including its flow-ability, passing-ability, viscosity, and strength. Comparative evaluations were conducted between normal SCC (NSCC) and SCC with 10% fine aggregate replaced by Iron Ore Tailings (IOT), ensuring compliance with IS 10262:2019 and EFNAARC guidelines.

6.1 Fresh Properties of SCC

The fresh properties of SCC were assessed using the Slump Flow, L-Box, and V-Funnel tests. Results for normal SCC and SCC incorporating 10% IOT are summarized below:

Table 6.1 Comparative Fresh Properties of Normal SCC and 10% IOT-Based SCC

Method	Unit	NSCC	10% IOT
SP Dosage	%	1.5	1.5
Slump Flow	mm	700	690
T50	sec	4.5	4.7
V-Funnel	sec	7	8
L-Box	h2/h1	0.835	0.82

Fig 6.1 – Slump flow of normal SCC

Fig 6.2 – Slump flow of IOT based SCC with 1.5% SP dosage

Discussion

The results indicate that normal SCC achieved all fresh property criteria at a superplasticizer (SP) dosage of 1.5%, while the IOT-based SCC required the same dosage to reach comparable properties. The higher water absorption capacity of IOT (~10%) necessitated additional SP dosage to maintain adequate flowability and passing ability.

For SCC with 20% IOT replacement, fresh property criteria were achieved with an increased SP dosage of 2.5%, demonstrating the adaptability of IOT in SCC formulations with appropriate adjustments.

6.2 Hardened Properties of SCC

The hardened properties of SCC, including compressive strength, split-tensile strength, and flexural strength, were evaluated for NSCC and IOT-based SCC at 7, 14, and 28 da

6.2.1 Compressive Strength

Method: Six 100 mm³ cubes were tested for each mix using a universal testing machine. The compressive strength results for 7, 14, and 28 days are presented below:

Table 6.2 Compressive Strength of SCC at 7 Days

Type of Concrete	SP Dosage	7-Day Average Strength (N/mm²)
NSCC	1.5%	30.87
10% IOT-Based SCC	1.5%	34.33

Table 6.3 Compressive Strength of SCC at 14 Days

Type of Concrete	SP Dosage	14-Day Average Strength (N/mm²)
NSCC	1.5%	38.25
10% IOT-Based SCC	1.5%	51.45

Table 6.4 Compressive Strength of SCC at 28 Days

Type of Concrete	SP Dosage	28-Day Average Strength (N/mm²)
NSCC	1.5%	45.12
10% IOT-Based SCC	1.5%	56.30

Discussion

The compressive strength of SCC improved significantly with the inclusion of 10% IOT. At 28 days, the IOT-based SCC exhibited a 25% higher compressive strength compared to NSCC, highlighting its potential as a partial fine aggregate replacement

6.2.2 Split-Tensile Strength

Method: Cylindrical specimens (100 mm diameter, 200 mm height) were tested for split-tensile strength. Results are summarized below:

Table 6.5 Split-tensile strength of normal SCC and 10% fine aggregate replaced with IOTfor different SP dosages at 7 days.

Type of Concrete	SP dosage	7 Day Split-Tensile Strength				
		Sample 1		Sample 2		Average Split-Tensile Strength (N/mm2)
		Load (kg)	Strength (N/mm2)	Load (kg)	Strength (N/mm2)	
NSCC	1.5%	8	2.5	6.5	2.03	2.26
10% IOT based SCC	1.5%	8.5	2.65	8	2.5	2.57

Table 6.6 Split-tensile strength of normal SCC and 10% fine aggregate replaced withIOT for different SP dosages at 28 days.

Type of Concrete	SP dosage	28 Day Split-Tensile Strength				
		Sample 1		Sample 2		Average Split-Tensile Strength (N/mm2)
		Load (kg)	Strength (N/mm2)	Load (kg)	Strength (N/mm2)	
NSCC	1.5%	10.5	3.28	10	3.125	3.2
10% IOT based SCC	1.5%	10.5	3.28	11	3.434	3.35

Discussion

The split-tensile strength of SCC increased modestly with 10% IOT replacement. At 28 days, the IOT-based SCC achieved a 5% higher tensile strength compared to NSCC.

6.2.3 Flexural Strength

Method: Prism specimens (75 mm x 75 mm x 450 mm) were tested using a flexural testing machine. Results are summarized below:

Table 6.7 Flexural-strength of normal SCC and 10% fine aggregate replaced with IOT for different SP dosages at 28 days.

Type of concrete	SP Dosage	28 days Flexural-strength (N/mm2)						
		Sample 1			Sample 2			Average Flexural-strength
		Deflection (divisions)	Applied force (kN)	Flexural-strength (N/mm2)	Deflection (deviations)	Applied force	Flexural-strength	
NSCC	1.5 %	68	5.657	5.364	71	5.907	5.601	5.5
10% IOT based SCC	1.5 %	90	7.49	7.103	92	7.7	7.298	7.1

Discussion

The 28-day flexural strength of 10% IOT-based SCC showed a 29% improvement over NSCC. This enhancement in bending resistance highlights the structural advantages of incorporating IOT in SCC.

6.3 Overall Performance

The results demonstrate that incorporating 10% IOT as a partial fine aggregate replacement significantly enhances the mechanical properties of SCC. The adjusted SP dosage ensures compliance with fresh property criteria, making IOT-based SCC a viable and sustainable alternative for construction applications.

Conclusion

This experimental study evaluated the strength and behavior of self-compacting concrete (SCC) incorporating Iron Ore Tailings (IOT) as a partial replacement for fine aggregates, in comparison to normal SCC. Based on the experimental results, the following conclusions were drawn:

- The mix ratio for M40-grade SCC was successfully designed using IS 10262:2019 guidelines, ensuring compliance with relevant standards.
- Manufactured sand was found to be a suitable substitute for natural sand in SCC due to its favorable mechanical properties.
- An optimal replacement of 5% Ground Granulated Blast Furnace Slag (GGBS) for cement in M40-grade SCC provided enhanced strength. Increasing the GGBS content beyond this level resulted in a reduction in strength.
- Incorporating a superplasticizer (SP) in IOT-based SCC improved workability while maintaining a constant water-cement ratio.
- The inclusion of 10% IOT as a fine aggregate replacement significantly enhanced the long-term strength of SCC. At this level, the 28-day compressive strength reached 56.3 N/mm² at an SP dosage of 1.5%.
- The maximum compressive strength was achieved at an SP dosage of 1.5% for SCC with 10% IOT, making this the optimal mix for both fresh and hardened states.
- At an SP dosage of 1.5%, the split-tensile strength of 10% IOT-SCC at 28 days was 3.35 MPa, slightly higher than the 3.2 MPa observed in normal SCC.
- The maximum flexural strength of SCC with 10% IOT was 7.1 MPa, compared to 5.5 MPa for normal SCC, demonstrating a 29% improvement.
- SCC with 10% IOT content met all fresh property requirements per Indian standards and EFNAARC guidelines at a constant water-cement ratio and 1.5% SP dosage.

Overall, the optimal composition for SCC was determined to be a mix with 10% replacement of fine aggregate by IOT, 5% GGBS replacement of cement, and a superplasticizer dosage of 1.5%. This mix achieved superior fresh and hardened properties, including compressive, split-tensile, and flexural strength, making it a sustainable and efficient alternative for construction applications.

References

[1] Imhade Princess Okokpujie. Review of Self-Compacting Concrete Incorporating Waste Materials

[2] Shen, W., Zhang, Z., Li, J., Li, Z., Wang, Z., Cao, L., ... & Zhao, Z. (2022). Experimental investigation on the high-volume fly ash ecological self-compacting concrete. *Journal of Building Engineering*, *60*, 105163.

[3] Kumar, M. A., Balaji, S., Selvapraveen, S., & Kulanthaivel, P. (2022). Laboratory study on mechanical properties of self compacting concrete using marble waste and polypropylene fiber. *Cleaner Materials*, *6*, 100156.

---

[4] Mim, N. J., Meraz, M. M., Islam, M. H., Farsangi, E. N., Mehedi, M. T., Arafin,

S. A. K., & Shrestha, R. K. (2023). Eco-friendly and cost-effective self- compacting concrete using waste banana leaf ash. *Journal of Building Engineering*, *64*, 105581.

[5] Kanagaraj, B., Anand, N., Praveen, B., Kandasami, S., Lubloy, E., & Naser, M. Z.(2023). Physical characteristics and mechanical properties of a sustainable lightweight geopolymer based self-compacting concrete with expanded clay aggregates. *Developments in the Built Environment*, *13*, 100115.

[6] Shettima, A. U., Hussin, M. W., Ahmad, Y., & Mirza, J. (2016). Evaluation of iron ore tailings as replacement for fine aggregate in concrete. *Construction and Building Materials*, *120*, 72-79.

[7] Cheng, Y., Huang, F., Qi, S., Li, W., Liu, R., & Li, G. (2020). Durability of concrete incorporated with siliceous iron tailings. *Construction and Building Materials*, *242*, 118147.

[8] Yang, M., Sun, J., Dun, C., Duan, Y., & Meng, Z. (2020). Cementitious activity optimization studies of iron tailings powder as a concrete admixture. *Constructionand Building Materials*, *265*, 120760.

[9] Chen, Z., Chen, S., Zhou, Y., Zhang, C., Meng, T., Jiang, S., ... & Hu, G. (2022). Effect of incorporation of rice husk ash and iron ore tailings on properties of concrete. *Construction and Building Materials*, *338*, 127584.

[10] Lv, Z., Jiang, A., & Liang, B. (2022). Development of eco-efficiency concrete containing diatomite and iron ore tailings: Mechanical properties and strength prediction using deep learning. *Construction and Building Materials*, *327*, 126930.

[11] Manisha jamgade, (2022) An experimental investigation on self-compacting concrete using Auramix 300 plus

[12] Uzma Rashid (2022)Experimental Analysis of Self Compacting Concrete by Replacing Sand with Stone Dust Uzma Rashid , and Ashish Kumar

[13] Alaka, H. A., Oyedele, L. O., & Toriola-Coker, O. L. (2016). Effect of excess dosages of superplasticizer on the properties of highly sustainable high-volume fly ash concrete. *International Journal of Sustainable Building Technology and Urban Development*, *7*(2), 73-86.

[14] Li, P. P., Yu, Q. L., & Brouwers, H. J. H. (2017). Effect of PCE-type superplasticizer on early-age behaviour of ultra-high performance concrete (UHPC). *Construction and Building Materials*, *153*, 740-750.