

EXPERIMENTAL STUDIES ON INFLUENCE OF SCMS AND WASTE FOUNDRY SAND ON THE MECHANICAL BEHAVIOUR OF HIGH- PERFORMANCE CONCRETE

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Abstract

Concrete is the most widely used structural material, primarily consisting of cement, aggregate, and water. Rapid industrialization has led to the generation of vast quantities of industrial waste, while population growth has accelerated the consumption of natural resources like river sand. This study explores the sustainable production of High-Performance Concrete (HPC) by utilizing industrial by-products. Supplementary Cementitious Materials (SCMS)—fly ash and Alccofine—were used to partially replace cement, and Waste Foundry Sand (WFS) was used to replace natural fine aggregate. Fly ash and Alccofine enhance concrete durability and mechanical properties through pozzolanic activity, while WFS provides an economical and eco-friendly alternative to natural sand. An experimental investigation was conducted on M40 grade concrete by partially replacing cement with 20% fly ash and 10% Alccofine, and replacing fine aggregate with WFS at varying levels (0%, 10%, 20%, 30%, and 40%). The mechanical properties—compressive strength, split tensile strength, and flexural strength—were evaluated at 7, 14, and 28 days. The results indicate that the optimal mix, containing 20% WFS along with SCMS (20% fly ash and 10% Alccofine), produced the highest mechanical strengths, outperforming the conventional control concrete. This approach demonstrates a viable sustainable solution for developing high-performance concrete incorporating industrial wastes.

Keywords: High-Performance Concrete, Supplementary Cementitious Materials (SCMS), Fly Ash, Alccofine, Waste Foundry Sand (WFS).

1. Introduction

Concrete is the most prevalent building material globally due to its strength, adaptability, and availability. The escalating demand for construction, driven by population growth, is depleting natural resources such as river sand at an alarming

rate, causing significant environmental harm. Concurrently, rapid industrialization generates substantial industrial waste, the improper disposal of which poses a serious environmental threat. A promising sustainable approach is to utilize these

waste by-products in the production of High-Performance Concrete (HPC).

Supplementary Cementitious Materials (SCMS) like fly ash and Alccofine can effectively replace a portion of cement, enhancing the concrete's microstructure and durability. Fly ash, a pozzolan, reacts with calcium hydroxide from cement hydration to form additional calcium silicate hydrate (C-S-H) gel, improving long-term strength and reducing heat of hydration. Alccofine 1203, an ultra-fine SCM, significantly reduces permeability, improves pore structure, and accelerates early strength development, offering superior resistance to sulfate and chloride attack.

Furthermore, Waste Foundry Sand (WFS), a by-product from metal casting industries, presents an economical and environmentally responsible alternative to natural river sand as a fine aggregate. Its granulometry is similar to natural sand, making it a technically feasible substitute that can alleviate the pressure on quarry resources.

While previous studies have often examined these materials in isolation, this experimental study focuses on their combined influence on the mechanical behaviour of High-Performance Concrete. This research investigates the partial replacement of cement with a blend of SCMS (20% fly ash and 10% Alccofine) and the replacement of fine aggregate with WFS at various levels (10%, 20%, 30%, 40%). The mechanical properties—compressive strength, split tensile strength, and flexural strength—of M40 grade concrete are evaluated and compared to a conventional control mix. The objective is to identify an optimal replacement level that yields superior mechanical performance, thereby

contributing to the development of a more sustainable and high-performing concrete composite.

MATERIALS

Cement: The principal binding agent used in this investigation was 53-grade Ordinary Portland Cement (OPC), conforming to IS 12269:2013. This grade was selected for its dependable performance in structural applications, rapid strength development, and outstanding compressive strength. The physical properties of the cement, which critically influence the hydration process, workability, and ultimate durability of the concrete, were characterized. The cement exhibited a standard consistency of 33%. Its setting times were measured at 33 minutes (initial) and 550 minutes (final), indicating a normal setting behaviour. The material had a grey colour and a specific gravity of 3.11. Its particle size distribution was confirmed by two fineness tests: it retained 7.5% on a 90 μm sieve and possessed a Blaine's fineness of 378 m^2/kg .

Fly Ash: Class F fly ash, procured as a waste product from a nearby thermal power plant, was used as a supplementary cementitious material to partially replace cement. Its high content of reactive silica and alumina classifies it as an outstanding pozzolanic material. The incorporation of fly ash facilitates the pozzolanic reaction, where it reacts with calcium hydroxide to form additional calcium silicate hydrate (C-S-H) gel. This process enhances the concrete's long-term strength, improves workability, and reduces the heat of hydration. Physically, the fly ash had a slightly higher standard consistency of 34% and a blackish-grey colour. It demonstrated a lower specific gravity of 2.26 compared to cement. The fineness tests showed a retention of 7.86% on a 90 μm sieve and a

Blaine's fineness of 323 m²/kg, indicating a marginally coarser particle size distribution than the cement. The initial setting time was recorded at 45 minutes.

Alccofine 1203: Alccofine 1203, a proprietary ultra-fine supplementary cementitious material, was utilized in this study. It is produced through a controlled granulation process of ground granulated blast furnace slag (GGBS), resulting in a highly reactive material with superior fineness. Its primary function is to enhance the microstructure and durability properties of concrete. It is predominantly composed of silica (SiO₂: 35.30%), calcium oxide (CaO: 32.20%), and alumina (Al₂O₃: 21.40%). In terms of physical properties, Alccofine 1203 exhibits a bulk density of 680 kg/m³ and a specific gravity of 2.70, which indicates it is lighter than Ordinary Portland Cement. Its specific surface area of 1200 m²/kg. This balanced composition, characterized by a significant content of calcium and aluminosilicates, imparts strong pozzolanic and latent hydraulic reactivity. This promotes the formation of additional calcium silicate hydrate (C-S-H) gel, which is critical for enhanced strength development and long-term durability.

Fine Aggregate: Natural river sand conforming to IS 383:2016 (Zone II) was employed as the primary fine aggregate. Its physical properties, which are crucial for workability and mix design, are summarized in Table 4. The sand's fineness modulus of 2.79 and its well-graded particle size distribution (Zone II) contributed to a dense granular packing, resulting in excellent workability and reduced shrinkage in the fresh concrete. It exhibited a specific gravity of 2.64 and a water absorption of 0.85%.

Waste Foundry Sand (WFS): To promote sustainability and reduce the reliance on natural resources, Waste Foundry Sand (WFS) was used as a partial replacement (10%, 20%, 30%, and 40%) for natural river sand. The WFS was sourced from local ferrous and non-ferrous metal casting industries and processed by passing through a 4.75 mm IS sieve to remove oversize particles. WFS possesses a granulometry similar to natural sand, with a fineness modulus of 2.66, classifying it as a well-graded Zone-II material. Its specific gravity (2.3) is slightly lower, and its water absorption (1.2%) is higher than that of natural sand, factors that were accounted for in the mix proportioning. The primary advantage of incorporating WFS is the diversion of industrial waste from landfills, thereby reducing the environmental footprint of the concrete.



Figure 1 Waste Foundry Sand

Coarse Aggregate: Crushed angular granite aggregates with a nominal maximum size of 20 mm, conforming to IS 383:2016, were used. The key physical properties are presented in Table 4. The aggregates had a specific gravity of 2.66, a fineness modulus of 6.72, and low water absorption (0.4%). Their angular shape and rough texture enhanced the mechanical interlocking within the concrete matrix, significantly contributing to the higher

compressive and flexural strengths of the hardened concrete.

Water and Admixtures: Implementing the rules of IS 456:2000, mixing and curing must be carried out using potable water. Using a polycarboxylate ether (PCE) superplasticizer that complies with IS 9103:1999 requirements, the required workability (slump: 75-100 mm) was achieved without raising the water-cement ratio. To reach the requisite M40 grade strength, all mixes were made using a water-cement ratio of 0.35. A 0.5% by weight binding agent dose is included in all of the concrete formulations used in this experiment.

Mix Design

Mix Design: Concrete mix designs were made based on IS 10262:2019 for M40 grade concrete. The conventional mix served as the control, and experimental mixes included partial replacements as described:

- Cement replacement by flyash (20%) and Alccofine (10%).
- Fine aggregate replacement by 3.025WFS: 10%, 20%, 30%, and 40%
- Mix proportion:
- 1:1.625:3.025:0.35

Table:01 Mix Proportion	
Material	Quantity
Cement	400 kg/m ³
Fine aggregate	650 kg/m ³
Coarse aggregate	1210 kg/m ³
Water	140 lit/m ³
Super Plasticizer	2.0 kg/m ³
W/C ratio	0.35

EXPERIMENTAL INVESTIGATION

The experimental program was designed to develop and evaluate M40 grade concrete in line with the provisions of IS 10262:2019. Ordinary Portland Cement (OPC, 53 grade) served as the primary binding material. To promote sustainability and enhance performance, 20% of the cement was replaced with fly ash and 10% with Alccofine, both known for their pozzolanic and micro-filling properties. Additionally, natural river sand, used as the fine aggregate, was partially substituted with waste foundry sand (WFS) at four levels: 10%, 20%, 30%, and 40% by weight, reducing reliance on natural resources. Crushed angular coarse aggregates (20 mm nominal size) and potable water were employed throughout the study. A polycarboxylate ether-based superplasticizer was incorporated to achieve the required workability (slump 75–100 mm) while maintaining a low water-cement ratio of 0.35. All dry constituents were carefully weighed and homogenized before introducing water and the superplasticizer to ensure uniform mixing. The fresh concrete was cast into standard moulds—cubes (150 × 150 × 150 mm), cylinders (150 × 300 mm), and beams (100 × 100 × 500 mm)—and compacted using vibration to minimize voids. Specimens were covered for 24 hours, then demolded and subjected to water curing under ambient conditions for 7, 14, and 28 days. After curing, the samples were tested to assess different mechanical properties of M40 grade concrete are determined. The compressive strength and split tensile strength of concrete were determined using a compression testing machine (CTM). 3. The flexural strength was determined using two-point load test.



Figure 2 Casting of Cubes

Mix Trails Details

Table: 02 Mix Composition					
Nomenclature Of Mixes					
Mix	Cement	Flyash	Alccofine	Fine Aggregate	Waste Foundry Sand (Wfs)
M1	100%	0%	0%	100%	0%
M2	70%	20%	10%	90%	10%
M3	70%	20%	10%	80%	20%
M4	70%	20%	10%	70%	30%
M5	70%	20%	10%	60%	40%

RESULTS AND DISCUSSIONS

Workability:

The workability of fresh concrete, measured via the slump test as per IS 1199:1959, is a critical parameter that dictates its ease of placement, compaction, and finish ability. The results for all mixes (M1 to M5) are presented in Table 3 and graphically depicted in Figure 3.

Table: 03 Workability of Concrete	
Mix	Workability (mm)
M1	100
M2	96
M3	94
M4	91
M5	87

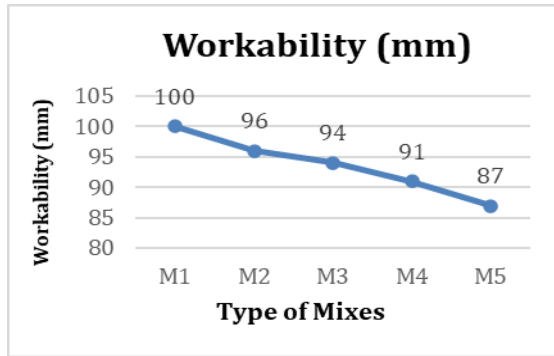


Figure 3 Workability Results

As illustrated in Figure 4, a clear inverse relationship exists between the Waste Foundry Sand (WFS) content and the slump value. The workability exhibits a gradual but consistent decline from 100 mm in the control mix (M1) to 87 mm in mix M5 (40% WFS replacement).

This trend is linear and predictable, which is highly beneficial for practical mix proportioning. The reduction, while consistent, is not drastic. All five mixes successfully achieved the target slump range of 75–100 mm specified for the experimental program, indicating adequate workability for standard placement and compaction techniques. Yes, all mixes are suitable for structural concrete applications.

The observed decline in workability with increasing WFS content is primarily attributed to the physical and chemical properties of the constituent materials. WFS has a significantly higher water absorption (1.2%) compared to natural river sand (0.85%). This increased porosity means that a portion of the mix water is absorbed by the WFS particles, thereby reducing the amount of water available for lubricating the mix and decreasing fluidity. Fly ash particles are typically fine, hard, and spherical. These "ball bearings" act as a lubricant in the concrete mix, reducing internal friction and improving workability.

This effect partially counteracts the negative impact of WFS, which is why the reduction in slump is gradual and not sudden. With an exceptionally high specific surface area (1200 m²/kg), Alccofine has a high-water demand. However, its extreme fineness also contributes to a denser particle packing. In the presence of a superplasticizer, this can lead to a more lubricated paste, but its net effect on workability in this system is likely neutral to slightly negative when compared to cement alone.

The polycarboxylate ether (PCE)-based superplasticizer was instrumental in maintaining workability. PCE superplasticizers work by dispersing cement and other fine particles through electrostatic and steric repulsion, freeing up trapped water and thus increasing fluidity without adding extra water. This allowed the mix to maintain its low water-cement ratio (0.35) while achieving the necessary slump, even with the water-thirsty WFS.

The maintained workability within the desired range confirms that the partial replacements of cement with fly ash and Alccofine, and fine aggregate with WFS, are practically viable. The use of a superplasticizer was effective in mitigating the stiffer consistency of the mixes containing WFS, ensuring they remained workable and could be easily handled without segregation or bleeding.

Compressive Strength of Concrete Test

The compressive strength of concrete is a fundamental property that defines its ability to withstand axial loads. The results for all mixes at 7, 14, and 28 days are presented in Table 4 and graphically depicted in Figure 5.

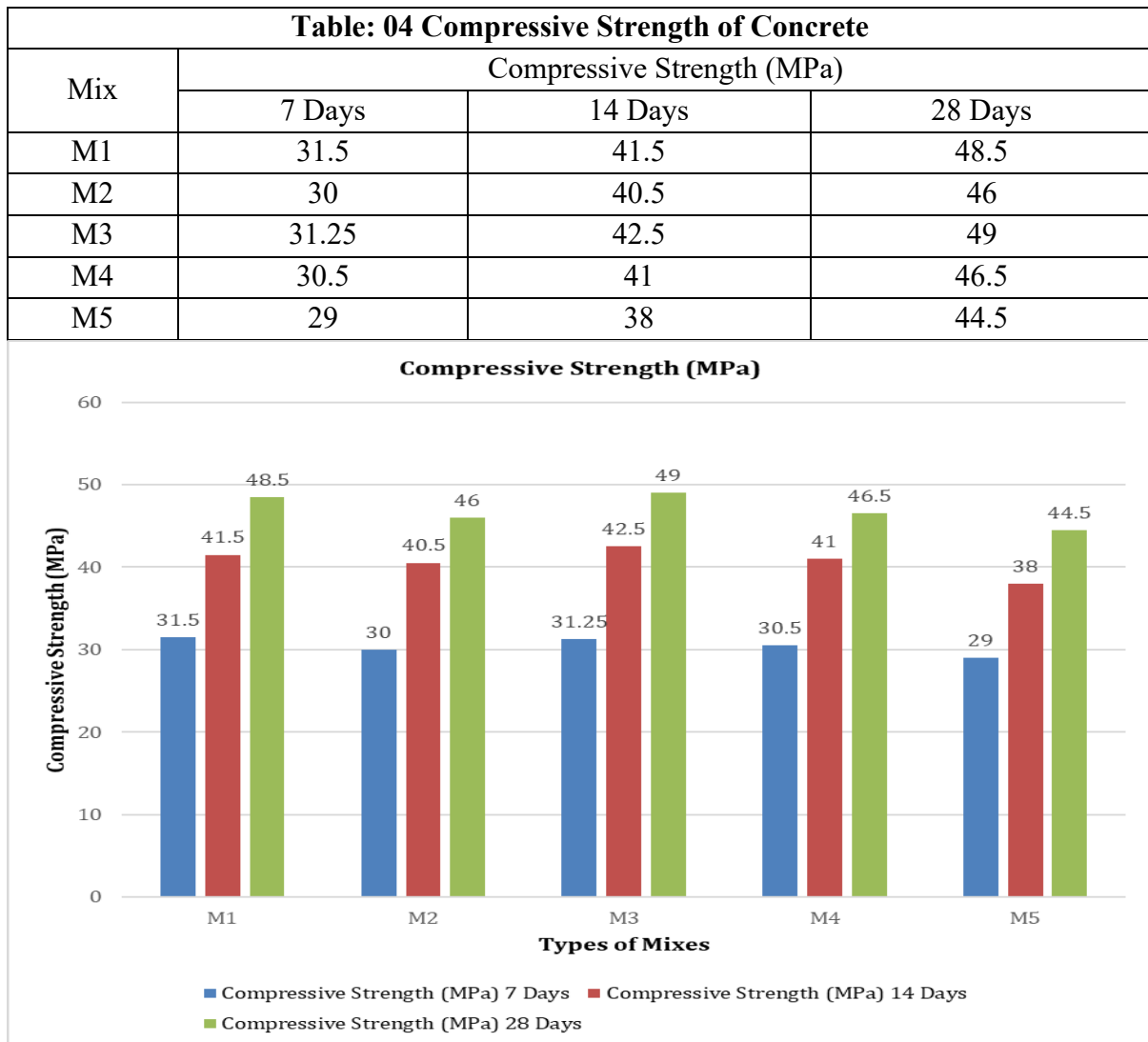


Figure 4 Compressive Strength Results

The 28-day compressive strength graph would show a distinct trend: a slight dip for M2 (46 MPa), a peak for M3 (49 MPa) exceeding the control (M1: 48.5 MPa), followed by a progressive decline for M4 (47.5 MPa) and M5 (45.5 MPa).

Mix M1 is the control mix which has attained 48.5Mpa strength at 28days. Wharse, as for mix M2 (10% WFS) a minor reduction in strength 46MPa compared to the control mix(M1). This is a common phenomenon where a small amount of a new material can slightly disrupt the established packing density and hydration kinetics before its benefits are realized. For mix M3(20% WFS) Peak

Performance has been achieved. This mix achieves the highest 28-day compressive strength of 49.0 MPa, exceeding the control mix M1 by approximately 1%. At 20% replacement, the well-graded WFS integrates effectively with the natural sand and the other fines in the mix. It contributes to a fuller particle size distribution, reducing interstitial spaces and creating a more cohesive and denser aggregate skeleton. The angularity of WFS particles also improves mechanical interlocking. Fly ash & Alccofine both materials are rich in reactive silica (SiO₂) and alumina (Al₂O₃). They react with the calcium hydroxide (Ca(OH)₂) produced during cement

hydration to form additional Calcium Silicate Hydrate (C-S-H) gel. This secondary reaction densifies the microstructure, reduces porosity, and is the primary driver for enhanced long-term strength and durability.

This indicates that the combination of materials in M3 achieves a superior synergy. For mix M4 (30%) & M5(40%) there is gradual decline in strength compared to control mix M1. Beyond the 20% threshold, compressive strength shows a progressive decline. While Mix M4 (30% WFS) still performs respectably at 47.5 MPa, Mix M5 (40% WFS) shows a more noticeable reduction to 45.5 MPa. Replacing a significant portion (30-40%) of the fine aggregate introduces a large number of WFS particles. While they are inert, their surface may not bond as effectively with the cement paste as natural sand. This can create a higher population of weaker Interfacial Transition Zones

(ITZ), which are often the starting point for micro-cracks under load. The positive effects of fly ash and Alccofine are spread thinner and are insufficient to overcome this dilution effect.



Figure 5 Testing of Cubes

Split Tensile Strength Test

The split tensile strength of concrete is a crucial mechanical property that indicates its resistance to cracking under tensile forces. The results for all mixes at 7, 14, and 28 days are presented in Table 5 and graphically depicted in Figure 7.

Mix	Split Tensile Strength (Mpa)		
	7 Days	14Days	28 Days
M1	2.85	3.36	4.96
M2	2.78	3.4	4.85
M3	2.95	3.58	5.4
M4	2.7	3.3	4.75
M5	2.6	3.15	4.5

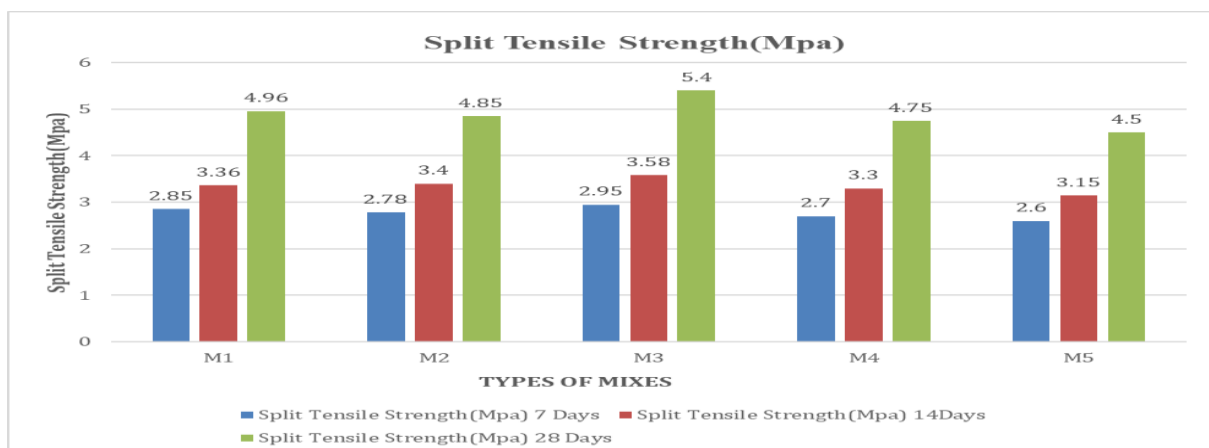


Figure 6 Split Tensile Test Results

Mix M1 is the control mix which has attained 4.96Mpa strength at 28days. Whereas mix M3 (20% WFS) Peak Performance has been achieved. This mix demonstrates superior tensile performance at all curing ages. It achieves the highest 28-day split tensile strength of 5.40 MPa, which is 8.9% higher than the control mix M1 (4.96 MPa). The consistent increase in strength from 7 to 28 days indicates robust and continuous strength development. The well-graded nature of WFS at the optimum 20% replacement level contributes to a denser particle packing. The rough surface texture of WFS particles, compared to natural sand, may provide a superior mechanical interlock with the surrounding cement paste, enhancing the bond strength and resistance to splitting forces.

Whereas for mix M2 (10% WFS) 4.85MPa a slight reduction is observed compared to the control mix M1 at 28 days. This suggests that at 10% replacement, the positive effects of the supplementary materials are still integrating, and the slight increase in water demand from WFS may have a minor influence. For mixes M4 (30% WFS) & M5(40% WFS) a clear and progressive reduction in strength is evident with higher WFS content. Mix M4 (30% WFS) and M5 (40% WFS) show 28-day strengths of 4.75 MPa (4.2% reduction) and 4.50 MPa (9.3% reduction) respectively, compared to the control. The incorporation of a large volume of WFS particles (30-40%) introduces a vast number of new paste-aggregate interfaces. The higher water absorption of WFS (1.2%) creates a local zone of higher effective water-cement ratio around each particle during mixing. This leads to a more porous, weaker, and less durable Interfacial Transition Zone

(ITZ), which becomes the weak link and the preferred path for crack propagation under tensile load.



Figure 7 Cylinder Testing

Flexural Strength of Concrete Test

The flexural strength, or modulus of rupture, is a critical property that defines the ability of concrete to resist failure in bending. It is particularly important for structural elements like beams, slabs, and pavements. The results for all mixes at 7, 14, and 28 days are presented in Table 6 and graphically depicted in Figure 9.



Figure 8 Beams Testing

Table: 06 Flexural strength (MPa)			
Type of Mixes	Flexural strength (MPa)		
	7 Day	14 Day	28 Day
M1	2.49	3.72	4.92
M2	2.55	3.8	5
M3	2.65	4.25	5.5
M4	2.45	3.65	4.8
M5	2.35	3.5	4.6

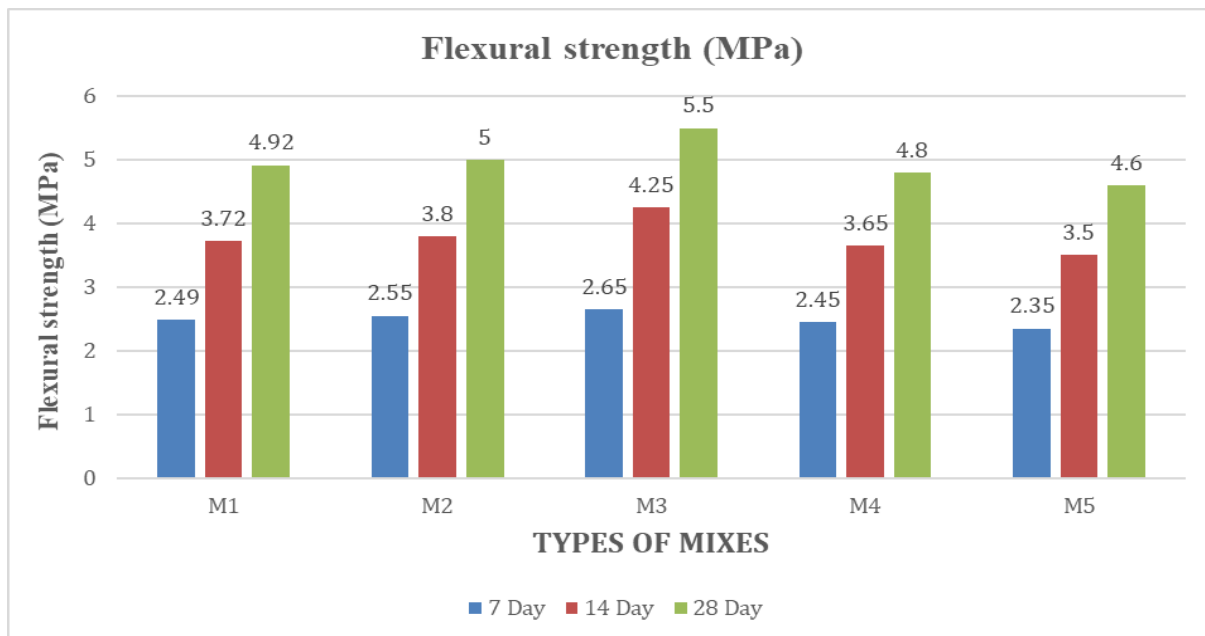


Figure 9 Flexural Strength Results

Mix M1 is the control mix which has attained 4.92Mpa strength at 28days. Whereas mix M3 (20% WFS) Peak Performance has been achieved. This mix demonstrates superior flexural performance, achieving a 28-day strength of 5.50 MPa. This represents a significant 11.8% improvement over the control mix (4.92 MPa). The dramatic increase between 7 and 14 days indicates very active pozzolanic reactions and rapid strength gain, which is highly desirable. The combination of well-graded WFS, spherical fly ash particles, and ultra-fine Alccofine

creates an optimal particle size distribution. This maximizes packing density and minimizes voids, resulting in a more homogeneous and defect-free composite material that can better distribute tensile stresses induced by bending.

Whereas mix M2 shows a consistent, though modest, improvement over the control at all ages, culminating in a 28-day strength of 5.00 MPa (a 1.6% increase). This suggests a positive but not yet optimal synergy at this replacement level. For mixes M4 & M5 (30-40% WFS) a clear and

progressive reduction in flexural strength is observed. Mix M4 (30% WFS) and M5 (40% WFS) show 28-day strengths of 4.80 MPa (2.4% reduction) and 4.60 MPa (6.5% reduction) respectively, compared to the control mix M1. The high volume of WFS particles introduces a vast number of aggregate-paste interfaces. The higher water absorption of WFS creates a local weaker and more porous ITZ around each particle. Under flexural load, these numerous weak zones become points of failure, allowing cracks to easily form and propagate, significantly reducing the overall flexural strength.

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CONCLUSIONS

Based on the experimental investigation into the mechanical behaviour of High-Performance Concrete incorporating Supplementary Cementitious Materials (SCMS) and Waste Foundry Sand (WFS), the following conclusions are drawn:

1. **Workability:** The combination of SCMS (fly ash and Alccofine) and WFS influences the fresh properties of HPC. While WFS increases water demand, its effect can be effectively mitigated with a superplasticizer. All designed mixes maintained adequate workability (75-100 mm slump), confirming their practicality for structural construction.
2. **Optimal Mix Design:** The mix **M3**, with 20% cement replaced by SCMS (20% fly ash + 10% Alccofine) and 20% of fine aggregate replaced by WFS, was identified as the optimal sustainable High-Performance Concrete composition. This mix demonstrated a superior synergy between its constituents, leading to enhanced mechanical properties.

3. **Compressive Strength:** Mix M3 achieved the highest 28-day compressive strength (49.0 MPa), marginally exceeding the conventional concrete. This is attributed to pozzolanic reactivity and improved particle packing density.
4. **Tensile Properties:** Mix M3 registered the highest split tensile (5.40 MPa) and flexural strengths (5.50 MPa), showing significant improvements of 8.9% and 11.8%, respectively, over the control mix. This indicates a superior resistance to cracking and bending failure.
5. **Influence of High WFS Content:** Mixes with 30% and 40% WFS replacement (M4 and M5) exhibited a gradual decline in all mechanical properties due to the increased number of weaker interfacial zones. However, they still met the minimum strength requirements for M40 grade concrete, suggesting their potential use in non-critical applications where the primary goal is waste utilization.
6. **Sustainable HPC Solution:** This study conclusively shows that the partial replacement of cement with SCMS and fine aggregate with WFS is not only feasible but also beneficial. The optimal mix produces an eco-friendly High-Performance Concrete that matches or exceeds the mechanical behaviour of conventional concrete, offering a technically sound and environmentally responsible solution for the construction industry.

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