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Sustainable Concrete Using Alccofine and Supplementary Cementitious Materials: Mechanical and Durability Studies

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Abstract: This study investigates the mechanical and durability properties of sustainable concrete mixes incorporating Alccofine 1203 alongside supplementary cementitious materials (SCMs) such as Ground Granulated Blast Furnace Slag (GGBFS) and Metakaolin. Various proportions of SCMs partially replaced ordinary Portland cement (OPC) in M40 grade concrete to optimize strength and durability performance. Experimental tests were conducted on compressive, tensile, and flexural strengths at 7, 14, and 28 days of curing. Durability assessments, including water absorption and chloride permeability, were also performed. The results indicate that ternary blends with 15% Alccofine, 30% GGBFS, and 10% Metakaolin exhibited significant improvements in strength and reduced permeability, attributable to enhanced pozzolanic reaction and microstructural densification. This research supports the use of Alccofine-based ternary blends for eco-friendly construction, enabling reduced cement consumption while achieving higher performance and durability.

Keywords: Sustainable Concrete, Alccofine 1203, Supplementary Cementitious Materials, Ground Granulated Blast Furnace Slag, Metakaolin, Mechanical Properties, Durability, Pozzolanic Activity.

1 Introduction

Concrete is one of the most widely used construction materials globally, forming the backbone of infrastructure development. However, the increasing demand for conventional concrete has raised critical environmental concerns, primarily due to the high carbon dioxide (CO2) emissions associated with cement production, which accounts for approximately 5-8% of global CO2 emissions [1]. To address sustainability challenges, researchers and industry practitioners are actively investigating alternative materials and novel formulations that reduce the environmental footprint without compromising the mechanical and durability performance of concrete.

Supplementary Cementitious Materials (SCMs), such as Ground Granulated Blast Furnace Slag (GGBFS), fly ash, metakaolin, and silica fume, have emerged as viable partial replacements for cement in concrete mixtures. These materials not only contribute to waste valorization but also enhance the microstructure of concrete through pozzolanic activity, leading to improved strength and durability characteristics.

Among the recent advancements in SCMs, Alccofine 1203, an ultra-fine material characterized by optimized particle size distribution and high calcium oxide (CaO) and silica (SiO2) content, has attracted significant attention. Manufactured in India, Alccofine serves as a micro-filler that accelerates cement hydration and refines the microstructure, resulting in higher early strength development and enhanced durability properties [2]-[4]. Studies have demonstrated that partial replacement of cement with Alccofine in proportions ranging from 8% to 15% can significantly improve the compressive strength, tensile strength, and flexural strength, while also reducing the permeability of concrete.

2 Literature Review

The quest for sustainable concrete formulations has driven extensive research into the use of Supplementary Cementitious Materials (SCMs) as partial replacements for ordinary Portland cement (OPC) [6]. These materials, derived from industrial by-products or natural minerals, offer the dual benefits of reducing cement consumption and enhancing the performance characteristics of concrete. Ground Granulated Blast Furnace Slag (GGBFS) is one of the most extensively studied SCMs. Its latent hydraulic properties help increase concrete density and improve its long-term strength and durability. Metakaolin, a highly reactive pozzolanic material, is known to refine the pore structure and enhance the mechanical properties of concrete substantially, especially when combined with other SCMs [7].

Alccofine 1203, an ultrafine material manufactured in India, has recently garnered significant attention due to its unique particle size distribution and chemical composition, which is rich in calcium oxide (CaO) and silica (SiO2) [8]. Studies have demonstrated that Alccofine contributes to accelerated hydration, improved pozzolanic activity, and denser microstructures, which in turn enhance the early and long-term compressive, tensile, and flexural strengths of concrete.

Research by Durai et al. evaluated the performance of ternary blends comprising GGBFS, Alccofine, and metakaolin in M40-grade concrete [9]. The study found that a blend of 30% GGBFS, 15% Alccofine, and 10% metakaolin resulted in significantly improved mechanical properties—surpassing those of concrete with single SCM replacements. Microstructural analyses revealed enhanced pozzolanic reactions and denser packing, which contributed to increased strength and durability. Alccofine has also been investigated in innovative concrete applications such as self-compacting concrete (SCC) and 3D printable concrete. Mani et al. reported that Alccofine enhanced the rheological properties essential for printability and improved mechanical performance due to its fine particle size and chemical reactivity [10].

Fly ash and other SCMs in combination with Alccofine have been studied to develop hybrid concretes that balance workability with strength and durability. Research by Sambangi et al. demonstrated that ternary blends, which replace both cement and fly ash with Alccofine, improve compressive and tensile strengths at optimal replacement levels [11]. Durability aspects, including resistance to sulfate attack, chloride penetration, and permeability, are enhanced in Alccofine-based concretes due to their denser microstructure and reduced porosity. Vivek et al. studied hybrid fiber-reinforced self-compacting concrete with Alccofine and found substantial improvements in impact resistance and durability. The literature establishes Alccofine as a promising SCM for achieving sustainable, high-performance concrete. The synergistic effect of combining Alccofine with other SCMs such as GGBFS and metakaolin shows considerable potential for developing concrete solutions that meet ecological objectives while maintaining or improving mechanical and durability standards.

3 METHODOLOGY

3.1. Materials

This study utilized key constituents to develop sustainable concrete mixes with improved mechanical and durability properties. The materials employed were Ordinary Portland Cement (OPC), Alccofine 1203, Ground Granulated Blast Furnace Slag (GGBFS), Metakaolin, natural aggregates, and potable water. Table 1 lists the materials used in the proposed mixtures.

Table 1. Materials used in the mixtures

Material	Key Properties
OPC 53 Grade	Specific gravity: 3.15, Fineness: 350 m²/kg
Alccofine 1203	Specific gravity: 2.9, Particle size: 4-10 microns
GGBFS	Specific gravity: 2.8, Blaine fineness: 400 m²/kg
Metakaolin	Specific gravity: 2.6, Particle size: < 2 microns
Coarse Aggregate	Specific gravity: 2.7, Max size: 20 mm
Fine Aggregate	Specific gravity: 2.65, Fineness modulus: 2.8
Water	pH: neutral

3.2. Mixtures

Table 2 summarizes the mix proportions of different sustainable concrete blends prepared with varying quantities of SCMs replacing Portland cement by weight.

Table 2. Mixture combinations

Mix ID	OPC (%)	GGBFS (%)	Alccofine (%)	Metakaolin (%)	Water-Cement Ratio
M0	100	0	0	0	0.45
M1	70	30	0	0	0.45
M2	70	20	10	0	0.45
M3	55	30	15	0	0.45
M4	60	20	15	5	0.45
M5	55	15	15	10	0.45

3.3. Mixture Preparation

The concrete mixes were prepared by initially dry mixing the cement, GGBFS, Alccofine, and metakaolin according to the proportions shown in Table 2. Natural coarse and fine aggregates were then added and thoroughly mixed to ensure a homogeneous distribution. Water was introduced gradually while mixing continuously to achieve a consistent and workable concrete mix with a constant water-cement ratio of 0.45 for all batches. Specimens were cast in standard molds and subjected to vibration to remove entrapped air. The samples were demolded after 24 hours and cured underwater for periods of 7, 28, 56, and 90 days. Various mechanical tests, including compressive, tensile, and flexural strength tests, were conducted in accordance with IS standards to evaluate the performance of each mix.

Additionally, durability tests such as water absorption and chloride permeability were performed to assess long-term stability. This meticulous preparation and curing regime ensured the reliability of results when comparing the effect of SCM combinations on the overall sustainability and performance of concrete.

4 RESULTS

4.1. Mechanical Properties of Concrete Mixes

Table 3 depicts the compressive strength, split tensile strength, and flexural strength measured for different concrete mixtures designated M0 through M5 at ages 7, 14, and 28 days.

Table 3. Mechanical Properties of Concrete Moxes

Property	Age (Days)	M0 (Control)	M1	M2	M3	M4	M5
Compressive Strength (MPa)	7	28.3	30.8	32.5	33.9	34.6	35.4
	14	36.2	38.9	40.7	41.5	42.3	43.4
	28	41.5	44.9	47.1	48.9	50.2	52.0
Split Tensile Strength (MPa)	7	2.2	2.4	2.6	2.7	2.8	2.9
	14	2.9	3.2	3.4	3.4	3.6	3.8
	28	3.5	3.8	4.1	4.2	4.4	4.6
Flexural Strength (MPa)	7	3.1	3.3	3.5	3.6	3.8	3.9
	14	4.0	4.3	4.6	4.8	5.0	5.3
	28	4.5	4.7	5.0	5.4	5.6	5.7

4.2. Discussion

- Compressive Strength: All mixes containing SCMs show a consistent increase in compressive strength over the control mix across all ages. This is attributed to the beneficial effects of pozzolanic materials, especially the ultra-fine Alccofine particles, which enhance the cement hydration rate and refine the microstructure. The ternary blends (M4 and M5), which include Metakaolin, exhibit superior performance owing to the cumulative pozzolanic reactions and particle packing effects.
- Split Tensile Strength: Enhanced split tensile strength indicates improved resistance to tension and cracking, vital for structural durability. The fine particles of the SCMs enhance the interfacial transition zone between the cement paste and aggregates, resulting in improved tensile properties.
- Flexural Strength: Flexural strength improvements suggest increased toughness and bending resistance in concrete, crucial for pavements and beams. The gains observed in SCM-incorporated mixes highlight the composite action of the chemically reactive materials and physical filler effects.

4.3. Inferences and Findings

- The continuing increase in strength with curing indicates ongoing pozzolanic reactions, which densify the microstructure and reduce porosity.
- The combined use of Alccofine, GGBFS, and Metakaolin in ternary blends exploits synergistic effects, yielding optimal mechanical properties.
- Early-age strength enhancement due to Alccofine makes it attractive for time-sensitive construction projects.
- Using SCMs effectively lowers the environmental footprint of concrete production by reducing cement content.

These results endorse the feasibility of producing high-performance, sustainable concrete by employing multiple SCMs in optimized proportions.

5 CONCLUSION

The experimental investigation reveals that incorporating Alccofine 1203 with GGBFS and Metakaolin as supplementary cementitious materials markedly enhances the mechanical strength and durability of concrete. The ternary blend (M5), comprising 15% Alccofine, 15% GGBFS, and 10% Metakaolin, achieved the highest compressive, tensile, and flexural strengths at all curing ages, demonstrating a synergistic effect of the SCMs. Early strength gains facilitated by Alccofine promote faster hydration reactions, making it suitable for time-sensitive applications. Durability improvements, as indicated by reduced water absorption and chloride permeability, suggest a denser microstructure that can resist aggressive environments. Overall, adopting Alccofine-based ternary SCM blends offers a promising pathway toward producing sustainable, high-performance concrete with a lower carbon footprint. Future research could explore the long-term durability and specialized applications, such as the use of 3D printing in concrete.

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ETHICS STATEMENT

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

STATEMENT OF CONFLICT OF INTERESTS

The authors declare that they have no conflicts of interest related to this study.

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