

Sustainable High-Strength Concrete: A Study on M60 Mixes with Alccofine as a Supplementary Cementitious Material

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Abstract

Concrete, which combines cement, water, aggregates, and admixtures to create a flexible material that solidifies into stone-like strength, is the foundation of contemporary building. Because of its versatility, it can be used for anything from pavements to skyscrapers, but typical mixes require large amounts of cement, which increases manufacturing costs and CO₂ emissions. This study investigates the use of alccofine-1203, a powder made from ultrafine slag, as a partial substitute for cement in M60 high-strength concrete at 0%, 5%, 10%, 15%, and 20% levels. The experiments used Ordinary Portland Cement (OPC) 53 cement, river sand, crushed stone (20 mm maximum size), and superplasticizer for ideal flow, all in accordance with IS 10262–2009 mix design. Important tests included flexural (9.6 MPa max), split tensile strength, compressive strength on cubes (peaking at 74.48 MPa for 10% mix at 28 days), and workability (slump up to 118 mm, compaction factor 0.99). Results demonstrate that 10% alccofine improves workability and reduces cement consumption for greener projects while increasing early and long-term strength by 27% over control mixes through tighter packing and pozzolanic reactions. With research supporting 8–15% for peak performance, this dose is ideal for demanding applications like bridges and towers.

Keywords: Alccofine 1203, compressive strength, flexural strength, M60 concrete, pozzolanic reaction, split tensile strength

INTRODUCTION

Concrete, the most widely used building material, serves as the structural foundation for pavements, buildings, bridges, and other infrastructure. Cement, water, fine, and coarse aggregates, and occasionally chemical or mineral admixtures, are combined to create a new mix that may be applied, compacted, and solidified into a long-lasting mass. The quest for more sustainable alternatives is prompted by the fact that conventional Portland cement concrete, despite its dependable strength, is linked to high cement consumption, huge energy demand, and significant carbon dioxide emissions during cement manufacture [1].

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Supplementary cementitious materials are being used more often to partially replace cement and enhance sustainability and performance to solve these issues. Alccofine 1203, a highly reactive ultrafine slag-based material, has attracted interest because of its extremely tiny particle size, which improves particle packing, speeds up hydration, and refines the pore structure of hardened concrete. In particular, for high-strength grades, these qualities can enhance workability in the fresh state and boost tensile, flexural, and compressive strengths, as well as durability in the hardened state [2].

The current study focuses on M60 high-strength concrete and investigates the effects of substituting varying amounts of alccofine-1203 for cement while maintaining the same amounts of OPC 53 cement, natural sand, and crushed coarse aggregate. The goal of the work is to determine the ideal replacement percentage for more sustainable structural concrete that strikes a balance between strength increase, durability, and cement consumption reduction by assessing workability characteristics and mechanical qualities at different curing ages [3].

LITERATURE REVIEW

Overview of Prior Work

Alccofine 1203 has been thoroughly studied by researchers as an additional cementitious ingredient to improve concrete strength, workability, and durability. According to several studies, compared with traditional mixes, its ultrafine, slag-based composition enhances particle packing, refines the pore structure, and speeds up the development of extra calcium–silicate–hydrate gel. Alccofine is often used to replace cement at a rate of 5–20%. Depending on the grade and mix design, most studies have shown an ideal range of 10–15% [4].

Studies in Mechanical Properties

Early research on high-grade concretes (M50–M100) revealed that the compressive strength increased significantly at all ages when cement was partially replaced with alccofine, with the most improvements occurring at dosages of 8–15%. Due to the increased packing density and pozzolanic activity, Rajesh Kumar et al. found that 10% alccofine in high-grade concrete yielded the best cube strength at 3, 7, 14, and 28 days. Similar patterns were identified by Deepa and Hasan, who found that alccofine enhanced the residual strength at high temperatures and increased the compressive, flexural, and split tensile strengths when combined with fly ash. The most significant increase in compressive and tensile strengths occurred at 10–15% replacement, after which the strength decreased, according to more recent research on ordinary and standard grades (M20–M40) [5].

Workability and Fresh Concrete Behavior

The beneficial effects of alccofine on new concrete have been highlighted by several authors. Mixes containing alccofine exhibit greater slump, better flowability, and less segregation than those containing fly ash or silica fume alone because of its smooth ultrafine particles and high glass content. Suthar et al. [6] discovered that alccofine mixes consistently demonstrated higher slump values than silica fume mixes while still achieving stronger compressive strength for high-performance concrete. Additionally, other studies on M20–M35 concretes have reported that 10%–15% alccofine boosts slump and compaction factor without using more water, suggesting a lower water requirement for a given workability [7].

Durability and Microstructural Improvements

Durable testing revealed that alccofine enhances resistance to acid, sulfate, and chloride attacks and decreases permeability. In comparison with control specimens, Deepa et al. found that alccofine-based concretes exhibited better residual compressive strength and less mass loss following chemical exposure. In addition to achieving extremely high compressive strength, Sharma et al. demonstrated that a mixture of foundry slag and 15% alccofine considerably reduced permeability, suggesting its use in harsh situations. More thorough analyses have verified that alccofine-modified concrete typically has a finer microstructure and less porosity, which improves durability performance [6].

Combined Use with Other Supplementary Cementitious Material (SCMs) and Fibers

Several researchers have investigated hybrid systems in which fly ash, GGBS, metakaolin, microsilica, or steel fibers are combined with alccofine. Soni et al. achieved optimal strength with 8% alccofine and 16% fly ash in M80 concrete, demonstrating the advantageous synergy between the two mineral admixtures. According to Mohd. Hamraj, adding steel fibers together with approximately 15% alccofine, enhanced the strength and acid resistance of M50 concrete, showing the potential of fiber-

reinforced mixes that are binary or ternary mixed. Similar results from recent studies on sustainable concrete demonstrate that mixes that include alccofine with other SCMs can increase durability and mechanical performance while lowering cement content and environmental effects [8].

OBJECTIVES

This study aimed to investigate the effects of partially substituting alccofine 1203 for regular Portland cement on the behavior of M60 grade concrete in both its fresh and hardened phases. The specific goal of this research was to determine whether this microfine, slag-based material could improve performance while lowering cement usage and advancing more environmentally friendly building techniques [9].

Another goal was to assess the workability properties of alccofine-modified concrete using slump and compaction factor tests to determine the impact of various replacement amounts on cohesiveness, flowability, and placement ease without increasing the water–binder ratio. This helps determine whether alccofine can produce extremely workable blends that are appropriate for intricate formwork and thick reinforcement while preserving consistency [10].

Evaluating the mechanical characteristics of concrete mixes with different percentages of alccofine at specific curing ages, particularly compressive, flexural, and split tensile strengths, is another important goal. This study aims to determine the ideal replacement percentage that optimizes strength and overall structural performance by comparing the results with those of a control mix.

MATERIALS USED

A reactive high-reactivity mineral additive and locally accessible components suitable for M60 grade concrete were used in the experimental program. Each material was chosen and processed in accordance with the applicable Indian Standards requirements for structural concrete.

Cement

The main binder, regular Portland cement, was a 53-grade cement that complied with IS 12269 and had its specific gravity, standard consistency, and setting times checked before use. The effects of partial replacement with alccofine were assessed using cement as the reference material (Table 1).

Fine Aggregate

Clean, well-graded natural river sand was used. To guarantee appropriate workability and strength in the intended mixtures, their specific gravity and water absorption were calculated in accordance with the provisions of IS 2386 (Table 2).

Coarse Aggregate

To provide the concrete skeleton with sufficient strength, crushed angular coarse aggregate with a proper nominal maximum size was utilized. Standard tests, such as specific gravity, impact value, and crushing value, were conducted (Table 3) to verify that the aggregate satisfied the strength and durability standards for high-grade concrete.

Alccofine 1203

Alccofine 1203, an ultrafine slag-based supplemental cementitious material, was used to partially replace cement at varying percentages by weight of binder. Its high glass content and fineness were designed to increase the pozzolanic reactivity and packing density, which would improve the mechanical performance and workability (Table 4).

Superplasticizer and Water

To achieve the required workability at a low water–binder ratio, a high-range water-reducing admixture (superplasticizer) suitable for the binder system was utilized. All specimens were mixed and cured using potable water that was free of harmful contaminants.

Table 1. Physical properties of cement.

Property	Value
Specific gravity	3.10
Fineness (retained on 90 μm)	2%
Standard consistency	32%
Initial setting time	43 min
Final setting time	420 min
28-day compressive strength	≥ 53 MPa

Table 2. Properties of fine aggregates.

Property	Typical value/description
Specific gravity	2.65
Water absorption	1%
Fineness modulus	2.71 (Zone II)
Maximum size	Passing a 4.75 mm IS sieve.
Silt and clay content	3%

Table 3. Properties of coarse aggregates.

Property	Value
Specific gravity	2.73
Water absorption	0.60%
Aggregate crushing value	37.53%
Aggregate impact value	34.44%
Los Angeles abrasion	45.8%
Flakiness index	6.13%

Table 4. Properties of alccofine 1203.

Property	Value
Type	Ultrafine slag-based SCM
Specific gravity	2.90
Fineness (Blaine)	12000 cm^2/g
Bulk density	800 kg/m^3
d10 (particle size)	1.5 μm
d50 (particle size)	5.0 μm
d90 (particle size)	9.0 μm

Experimental Setup

The main purpose of the experimental program was to assess the behavior of M60 concrete containing varying amounts of alccofine 1203 in a laboratory setting. To directly compare the results with traditional design practices, all specimens were fabricated, cured, and tested in accordance with applicable Indian Standard protocols.

Concrete was combined in a tilting drum laboratory mixer using the previously established proportions for the control and alccofine-modified mixes. To create a homogeneous and workable mixture, the dry materials (cement or cement–alccofine blend, fine aggregate, and coarse aggregate) were first blended to achieve homogeneity. Water was then added progressively, along with the calculated dose of superplasticizer.

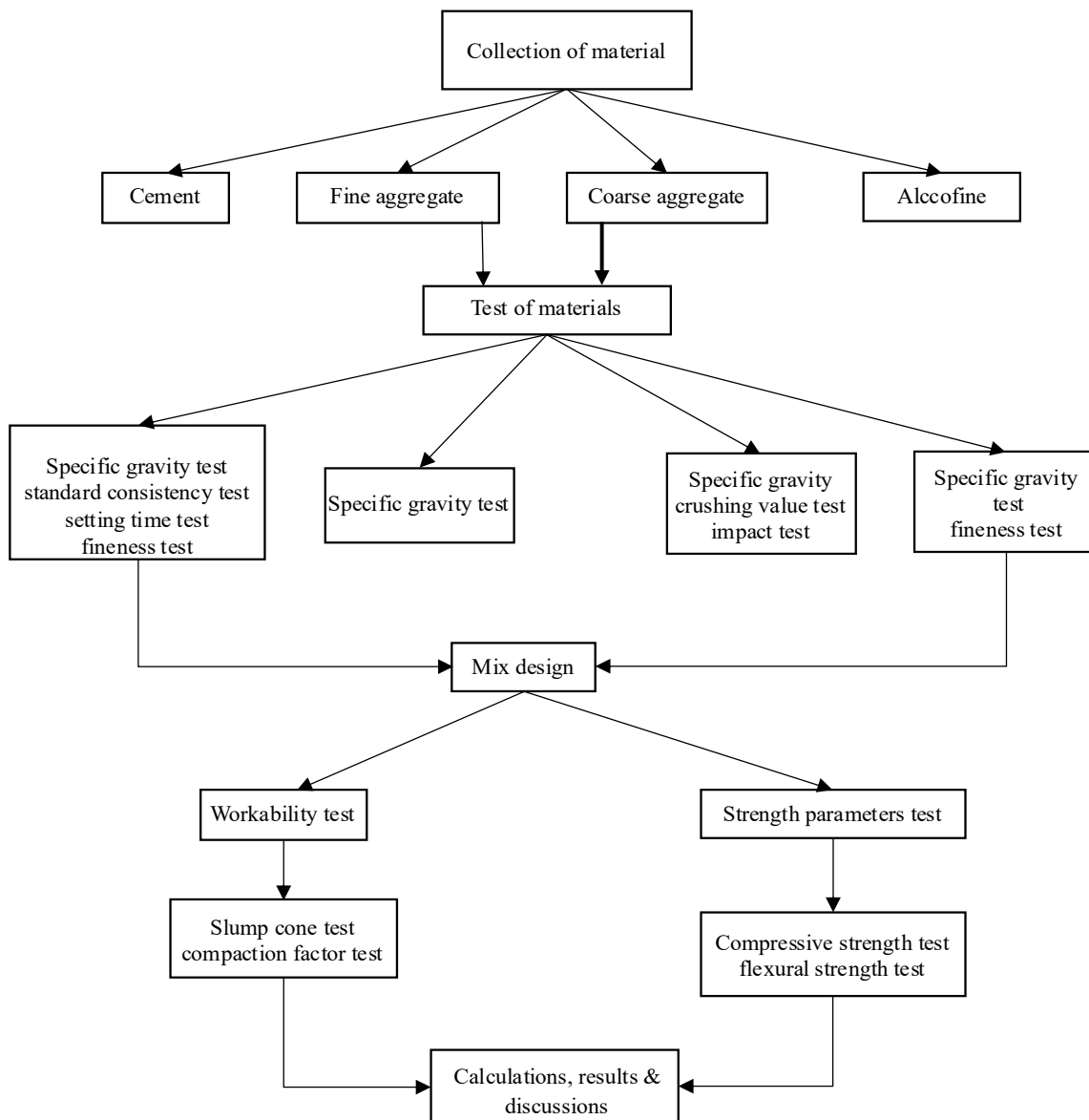


Figure 1. Methodology.

Immediately following mixing, the workability of each mix was evaluated using a slump test, and if necessary, a compaction factor test was performed using standard equipment on a clean, non-absorbent surface. Beam and cylinder molds were similarly prepared for flexural and split tensile strength testing, while 150 mm cube molds were filled in stages and compressed using a tamping rod or vibration to prevent honeycombing.

After casting, all specimens were covered to prevent moisture loss, demolded after 24 h, and subsequently placed in a curing tank with clean water at approximately 27°C until the designated test ages. Split tensile, flexural, and compressive strength tests were conducted on cylinders, beams, and cubes, respectively, using calibrated testing equipment at certain curing times with a force applied uniformly, in accordance with the relevant IS regulations (Figure 1).

Mix Design

The mix design table illustrates how, although other ingredients remain mostly unchanged, the binder composition varies throughout all M60 mixes.

Table 5. Mix proportions of M60 concrete with varying alccofine content.

S.N.	Mix name	Cement (kg/m ³)	FA (kg/m ³)	CA (kg/m ³)	WB (L/m ³)	AF (kg/m ³)	SP (L/m ³)
1	Normal concrete (A0)	483.33	586	1297.39	145	0.00	5.19
2	A5	458.2	586	1297.39	145	21.73	5.19
3	A10	434.32	586	1297.39	145	44.05	5.19
4	A15	410.44	586	1297.39	145	65.78	5.19
5	A20	386.56	586	1297.39	145	87.51	5.19

**Figure 2.** Batching of cement, alccofine, fine aggregate, and coarse aggregate for M60 concrete mix.

The amounts of cement, alccofine-1203, fine, and coarse aggregates, water, and superplasticizer are listed per cubic meter. OPC makes up 100% of the binder in the control mix, whereas alccofine replaces 5%, 10%, 15%, and 20% of the cement mass in the modified mixes. As a result, the water–binder ratio and aggregate contents stay constant while the cement content gradually drops as alccofine rises. This graphic explicitly connects each percentage set to the observed workability and strength values, simplifying the batching in Table 5 and Figure 2.

RESULTS AND DISCUSSIONS

Slump Cone Test

The results of the slump cone test demonstrated that the workability of M60 concrete increased progressively with the addition of alccofine-1203 in comparison to the control mix without a mineral additive. The slump values increased with the replacement level at a constant water–binder ratio, suggesting that the fresh concrete became easier to place and more flowable while remaining cohesive and free from obvious bleeding or segregation. This behavior may be explained by the ultrafine particle size and smooth texture of alccofine, which promotes lubrication within the mix, fills in spaces between cement and aggregate grains, and increases the mix's deformability under self-weight without the need for additional water (Table 6 and Figure 3).

Table 6. Slump values of M60 concrete mixes with varying alccofine content.

S.N.	Mix design	Slump in mm
1	A0	92
2	A5	101
3	A10	108
4	A15	114
5	A20	118

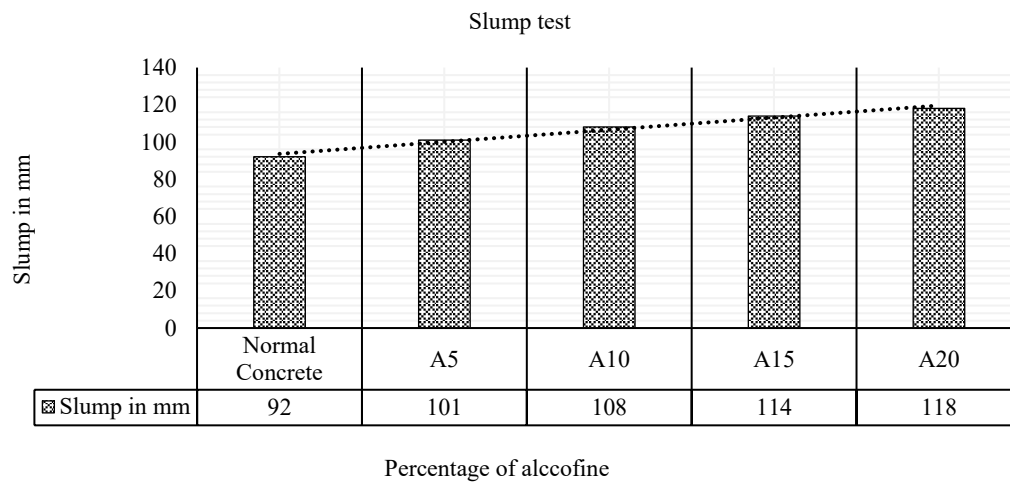


Figure 3. Variation of slump with percentage of alccofine in M60 concrete.

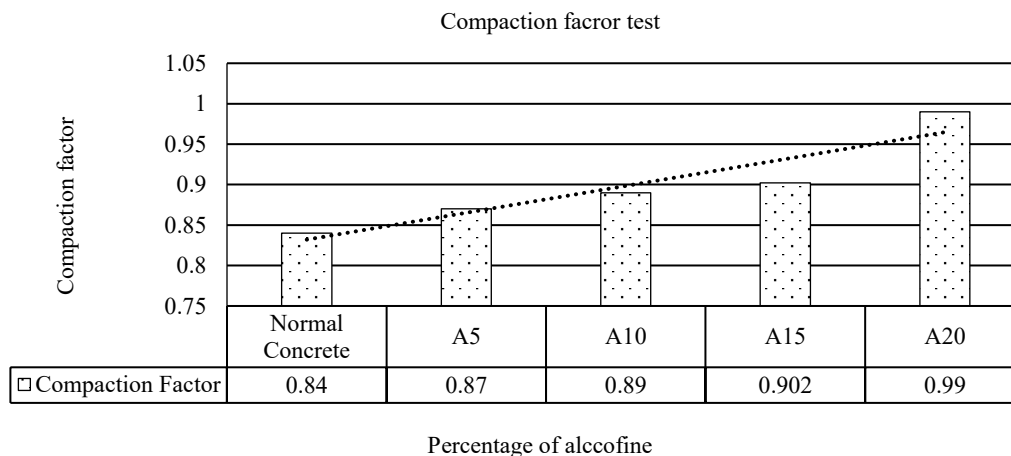


Figure 4. Variation of compaction factor with percentage of alccofine in M60 concrete.

Table 7. Compactor factor values of M60 concrete mixes with varying alccofine content.

S.N.	Mix design	Compaction factor
1	A0	0.84
2	A5	0.87
3	A10	0.89
4	A15	0.902
5	A20	0.99

Compaction Factor Test

Improved workability at a fixed water–binder ratio was indicated by the compaction factor test, which demonstrated a consistent increase in the compaction factor with increasing alccofine concentration. With a compaction factor of approximately 0.99, the mix containing approximately 10% alccofine produced the densest and most readily compactable concrete, making it ideal for severely reinforced parts (Table 7 and Figure 4).

Compressive Strength Test

The data clearly indicate that alccofine-1203 favorably impacted the compressive strength up to the ideal replacement level. While mixtures containing alccofine showed steadily increasing strengths, the

control mix without alccofine generated the lowest strength at all ages. The 10% replacement mix produced the maximum 28-day cube strength, significantly exceeding the desired value for M60 concrete. The strengths of the 15% and 20% replacement mixtures somewhat declined after 10% replacement; however, they were still higher than those of the control. This suggests that while excessive replacement lowers the effective clinker concentration, modest alccofine addition improves hydration and matrix densification (Table 8 and Figure 5).

Flexural Strength Test

To investigate the impact of alccofine on the bending resistance of M60 concrete, the flexural strength was assessed using prism specimens. Similar to the compressive strength, the results revealed that mixes containing alccofine had greater flexural strength than the control, with the greatest modulus of rupture after 28 days occurring at the 10% replacement level. This enhancement suggests that alccofine helps create a denser, better-bonded matrix, allowing the concrete to sustain higher tensile stresses at the extreme fibers before cracking (Table 9 and Figure 6).

Table 8. Compressive strength of M60 concrete mixes with different alccofine contents at various curing ages.

S.N.	Mix name	3 Days (N/mm ²)	7 Days (N/mm ²)	14 Days (N/mm ²)	28 Days (N/mm ²)
1	A0	29.77	48.52	53.20	58.82
2	A5	42.46	55.16	57.46	59.11
3	A10	46.71	64.45	67.06	74.48
4	A15	54.48	58.27	60.15	65.27
5	A20	56.88	59.76	63.43	69.76

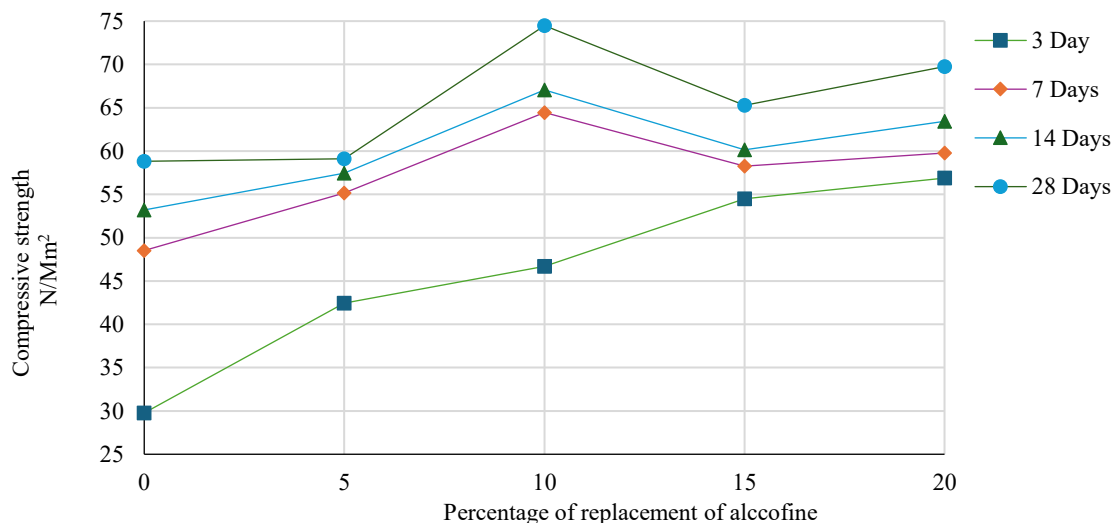


Figure 5. Compressive strength of M60 concrete at different ages for various alccofine replacement levels.

Table 9. Flexural strength of M60 concrete mixes with different alccofine contents at various curing ages.

S.N.	Mix name	7 Days (N/mm ²)	28 Days (N/mm ²)
1.	A0	6	7.1
2.	A5	4.6	5.8
3.	A10	7.2	9.6
4.	A15	4.4	5.2
5.	A20	5	6.3

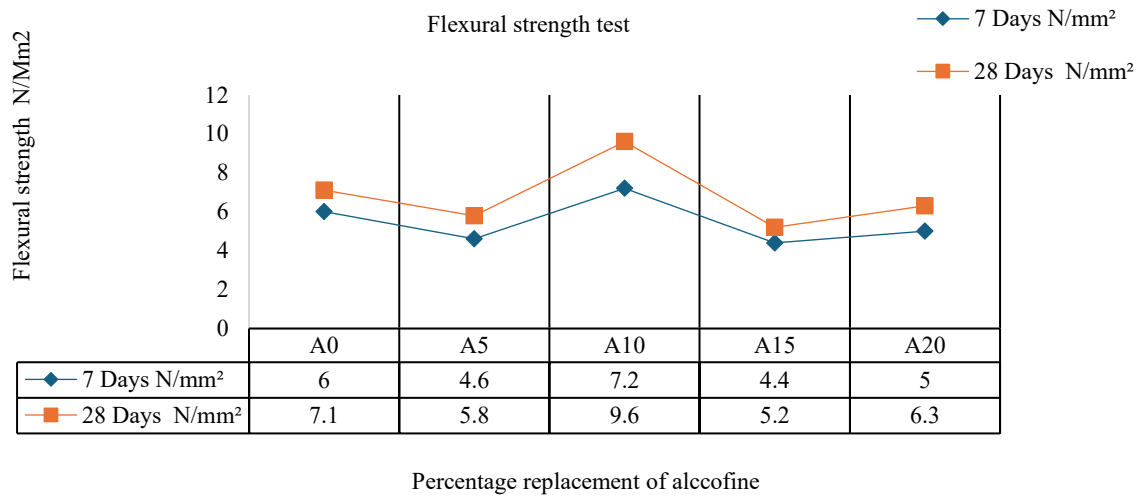


Figure 6. Variation of flexural strength with percentage of alccofine in M60 concrete.

CONCLUSION

The results indicate that using alccofine-1203 in place of some of the cement in M60 concrete produces definite benefits over traditional concrete without mineral addition. Alccofine mixtures exhibited superior behavior and easier compaction than the control mix in the fresh condition, as evidenced by the increased slump and compaction factor at the same water–binder ratio.

Alccofine mixes significantly outperformed ordinary concrete in the hardened state in terms of compressive, flexural, and split tensile strengths, with the highest values obtained at a 10% replacement level after 28 days. Because of the filler and pozzolanic actions of the ultrafine slag particles, the microstructure was denser, and the paste–aggregate bond was stronger. Therefore, the optimized alccofine mix provided better mechanical performance while lowering the clinker content when compared with regular M60 concrete. This resulted in less cement being used and a more sustainable high-strength concrete that is appropriate for strongly loaded structural applications.

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