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Enhancing Compressive Strength in M45 Grade Concrete: A Comparative Evaluation of Micro-silica and Alccofine as Partial Cement Replacements

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Abstract

This study investigates the compressive strength and durability of M45 grade concrete using Micro-silica and Alccofine as partial replacements for cement. Experimental results indicate that Alccofine-based concrete achieves 28-day compressive strengths of up to 60.6 MPa at 10% replacement, outperforming Micro-silica-based mixes by 55.2 MPa. Alccofine also enhances workability, with slump values peaking at 144 mm and 135 mm for Micro-silica. The optimal replacement level for both materials is 10% by cement volume, where Alccofine's dual pozzolanic-cementitious reactivity improves microstructure densification, reducing permeability and enhancing durability. These findings position Alccofine as a superior additive for high-strength concrete applications, offering significant mechanical and durability advantages.

Keywords: Concrete, Compressive Strength, Micro silica, Alccofine, M45 Grade Concrete, Cement Replacement, Workability

1. Introduction

Concrete remains the backbone of modern infrastructure, with high-strength variants increasingly demanded for critical structures. Supplementary cementitious materials (SCMs) like Microsilica and Alccofine are pivotal in enhancing concrete performance by reducing cement content and improving workability and durability. While Micro-silica is well-established, Alccofine, an ultrafine, high-reactivity SCM, offers unique advantages, including reduced water demand and enhanced early-age strength (Narender Reddy et al., 2018). However, comparative studies on their efficacy in M_{45}-grade concrete remain limited, particularly at varying replacement levels. The concrete composition is of coarse aggregates, fine aggregates, cement, and water. Additives such as plasticizers, fly ash, Alccofine, and Microsilica are commonly used to enhance the strength and durability of high-performance concrete. In this research, standard grade concrete from the Seti River basin coarse and fine aggregate is studied, potentially including crusher plant materials from the Kaski district.

This study was carried out to identify optimal replacement levels for both SCMs and compare the compressive strength of Alccofine- and Microsilica-based M45 concrete. Existing studies focus on individual SCMs, leaving a gap in direct comparisons between Alccofine and Microsilica in high-strength mixes. This study addresses this gap by evaluating their compressive strength, workability, and microstructural interactions.

In most cases, fine and coarse aggregate adjustment is necessary to supplement the grading by adding respective size fractions, which may be deficient in the aggregate as found in the gradation analysis (M L Gambhir, 2006). The cement replacement by 10% of Alccofine gives higher values for all other mixes. Alccofine incorporated mortar cubes almost 15% to 20 % higher than the conventional cement concrete (Balamuralikrishnan and Saravanan, 2021). A study comparing the effects of various SCMs found that blends of Alccofine and Micro silica resulted in superior compressive strength and reduced permeability, indicating their effectiveness in improving concrete performance (Abrahimi and Bhikshma, 2024).

1.1. Alccofine-1203

Alccofine-1203 is a specially treated product based on high glass content with high reactivity obtained through controlled granulation. The raw materials are composed of low-calcium silicates—the processing with other selected ingredients results in controlled particle size distribution (PSD). The computed blain value based on PSD is around 12000 cm^2/gm and is ultra-fine. Due to its unique chemistry and ultrafine particle size, Alccofine-1203 provides reduced water demand for given workability, even up to 70% replacement level as per the requirement of concrete performance. Alccofine 1203 can also be used as a high-range water reducer to improve compressive strength or as a super workability aid to improve flow.

1.2. Micro-silica Fume

Silica Fume is generally proposed as the appropriate cement extender where high strength, low permeability are the prime requirements. Though silica fume is known to improve durability, its addition in concrete is often negated by the increase water and/or admixture dosage required to improve the workability and handling properties of the fresh concrete.

Alccofine is a new pozzolanic material bringing a technical revolution to the construction industry. The survey found that the alccofine can achieve high strength when it is replaced by cement at 0%-20 % compared to the traditional concrete (Reddy and Thiruvadi, 2017). Results have shown that adding Al and nano-silica (Ns) to concrete decreased weight and compressive strength. The increase in temperature above 600ºC affected the compressive strength of the Al + Ns mixes more than the control mixes. At 1000ºC, excessive micro-cracking is also observed. Increased fire duration substantially increased concrete degradation (Ashwini and Srinivasa Rao, 2021). The present study is the influence of Alccofine on cement mortar cubes by replacing the cement by Alccofine with various proportions like 5%, 10%, 15%, 20% were cast and tested in the laboratory as per Indian Standard 4301-1988 (Part-6) and the results were analysed and presented in the form of charts and graphs. It is observed that the early age strength is obtained for all the combinations, but 10 per cent of Alccofine yields more strength than other dosages (Balamuralikrishnan and Saravanan, 2021). These materials are easy to mix and can be mixed directly with cement; ultrafine particles provide a better and smoother surface finish. The results of these materials were found to significantly increase their strength (Reddy, Mounika and Moulika, 2018).As the temperature rises above 600ºC, control mixes performed better than the concrete mixes using nanosilica and alccofine (Ashwini and Srinivasa Rao, 2021).

2. Materials and Methods

The methodology involved conducting laboratory tests according to the IS code standards. The data were analysed and compared with the standard provisions outlined in the IS codes. Both primary and secondary test results were analysed qualitatively and quantitatively, compared with standard IS code provisions.

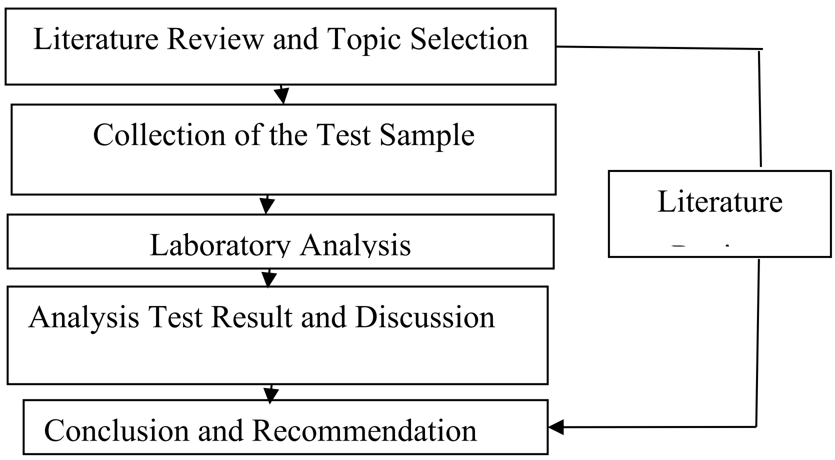

Figure 1: Research Frameworks

Research was carried out within the Pokhara Metropolitan City of the Seti River basin, on crushed aggregate; most of the concrete material in the Seti basin was produced for ethical research and the secrecy of crusher plant material test results obtained from the laboratory testing. The researcher team only identifies which crusher plant has the test results.

Experimental data were studied and related to Indian Standard Code provisions, and test procedures were carried out using IS 383:2016 (Bureau of Indian Standards, 1970). Three samples were collected from the crusher plant by slicing, and sample screening was done to test the physical and mechanical properties of the crusher plant, whose material is used for constructing infrastructure within the Kaski district of Nepal. The average value obtained from the three samples was calculated and compared with the standard value in the code IS 383:2016 (Bureau of Indian Standards, 1970). All the laboratory tests were conducted in Barahi Technical Solutions Pvt Ltd., which was certified and calibrated by the Government of Nepal, Nepal Bureau of Standards for material testing. The methodological flow chart applied in this study is shown in Figure 1.

The research was based on the IS code provision of standard concrete with grades of M_{45} using Nepal Standard OPC cement and IS standard Alccofine and Silica fume. The specified laboratory test was conducted under normal laboratory temperature and pressure, and seasonal variation on the sample's properties and the geological properties of the aggregate sample was not considered. The physical and mechanical properties of coarse and fine aggregates are presented in Table 1, while the chemical properties of Alccofine and silica fume are provided in Table 2. The Los Angeles abrasion value, Aggregate Impact Value (AIV), and Aggregate Crushing Value (ACV) for the coarse aggregate were found to be 33%, 21%, and 26%, respectively.

Table 1: Physical and Mechanical Properties of Coarse and Fine Aggregate

Sample Name	Gradation	Sp Gravity	Water Absorption (%)	Particles Finer than 75 microns (%)	FI and EI (%)
Fine Aggregate	Zone II	2.62	1.78	2.3	-
Coarse Aggregate	Single size 20 down	2.69	1.01	0.6	15 and 17

Table 1 confirms that both physical properties of the research source satisfy the specification declared by the code provision.

According to IS 383:2016 (Bureau of Indian Standards, 1970), aggregates with particles smaller than 4.75 mm are classified as fine aggregates (commonly known as sand), while those with particles larger than 4.75 mm are classified as coarse aggregates. The specific gravity test is a key indicator of aggregates' density and water absorption properties. It helps identify the suitability of stones for construction purposes. Aggregates with high water absorption are generally more porous. They are often deemed unsuitable for construction unless their strength, impact resistance, and hardness are proven adequate through additional testing. Fine particles smaller than 75 microns, as determined by the IS sieve, exhibit unique characteristics. When mixed with water, these particles behave like emulsions, displaying slight plasticity or non-plasticity regardless of moisture content. When air-dried, such particles typically show little to no strength, making them less desirable for construction applications. The shape of aggregate particles, particularly the presence of flaky and elongated particles, plays a significant role in determining the quality of the aggregate. In applications such as base courses, bituminous concrete, and cement concrete, flaky and elongated particles are generally undesirable. Their presence can lead to inherent weaknesses, increasing the likelihood of structural failure under heavy loads. The mechanical properties of the coarse aggregates used in this study comply with the specifications outlined in IS 383:2016, ensuring their suitability for construction purposes.

Table 2: Chemical Properties of Cement, Alccofine and Micro-silica Fume (Anisur Rahman, 2017)

Sample Name	Calcium oxide (CaO)	Silicon dioxide (SiO_2)	Alumina (Al_2O_3)	Magnesium oxide (MgO)
Alccofine 1203	43.92	27.53	16.26	5.82
Silica Fume	0.86	86.25	1.52	1.32

The work is to design the mix portion for Alccofine 1203, partially replacing the conventional cement in various percentages such as 2%,4 %, 6%, 8%, 10%, 12%, and 14%, and the compressive strength of the partially replaced Alccofine 1203 and Micro-silica fume in standard concrete grade of M_{45} as per IS 456:2000 (IS 456, 2000).

Table 3: Various Ingredient Uses for Concrete Preparation

Sample Name	Fine Aggregate	Coarse Aggregate	Water	Admixture	Cement
Concrete Grade M45	712	1097	161.7	3.43	485

The experimental investigations were planned to study concrete partially when added with cement replacement material (CRM). Different mix proportions are designed and standardised. The study aims to determine the compressive strength and workability of various mix proportions organised for testing. Six cubes of each percentage, 42 cubes for Alccofine and 42 cubes of Micro silica, were prepared for the concrete mix proportions and cured under controlled conditions until they were ready for testing. The compressive strength of the designed concrete was carried out as per the IS code at 7 and 28 days of cement, with cement replacement material by micro silica and Alccofine and compared with the target strength.

3. Results and Discussion

The test specimens were cast, cured, and tested, and the results are presented in this section. The M45 design mix was prepared and cast into cube specimens to achieve high-performance concrete. The primary objective of this study was to determine the compressive strength of concrete, and to this end, the properties of the constituent materials were evaluated through standard laboratory tests.

The compressive strength of the concrete cubes was measured for mixes incorporating varying percentages of silica fume and Alccofine. The results for both 7-day and 28-day compressive strengths are tabulated below, providing a comparative analysis of the performance of the different mixes. Alccofine's peak strength was at 10% replacement (60.6 MPa at 28 days), declining thereafter. Micro-silica's maximum strength was at 8% (55.2 MPa), with earlier strength gain but lower ultimate performance.

Table 3: Compressive Strength of 7 and 28 Days

Sample Name	2%	4%	6%	8%	10%	12%	14%
			7 Days Compressive Strength				
Alccofine 1203	40.4	56.4	55.3	51.1	47.4	46.2	44.1
Silica Fume	33.2	48.5	49.3	50.4	49.2	45.7	42.15
			28 Days Compressive Strength				
Alccofine 1203	47.2	60.4	60.6	58.2	57.2	52.4	51.9
Silica Fume	41.3	54.3	54.7	55.2	54.3	52.1	51.85

The slump value of the concrete was measured for mixes incorporating varying percentages of silica fume and Alccofine. The results for both additives are tabulated below, Alccofine use slump increases steadily from 80 mm (2%) to 144 mm (10%), then declines at higher replacements (135 mm at 12%, 129 mm at 14%), micro silica use slump rises from 70 mm

(2%) to 135 mm (10%), then decreases to 124 mm (14%), providing a comparative analysis of the performance of the different mixes. Alccofine mixes showed superior slumps of 144 mm and 135 mm for Micro-silica at 10%, attributed to its ultrafine particles reducing inter-particle friction.

Table 4: Alccofine and Micro Silica Slump Value at Various Percentage Use

Sample Name	2%	4%	6%	8%	10%	12%	14%
				Slump Value (mm)			
Alccofine 1203	80	100	125	131	144	135	129
Silica Fume	70	95	115	128	135	130	124

4. Conclusions

The experimental findings depict that the appropriate substitution level of Alccofine and Micro-silica in M45 Grade Concrete is 10% by volume of cement. Curing ages of concrete at seven and twenty-eight days were carried out and compared results between Alccofine-based concrete and Micro silica-based concrete, at this replacement level, Alccofine-based concrete strengthened was 60.6 MPa, while Micro silica-based concrete had 55.2 MPa, which is 9.78% more.

Workability using Alcocofine at a 10% dose is 144mm, and that of Micro silica is 135mm, which shows that Alcocofine enhances the slump by 6.7% at the optimal dosage. The key aspect responsible for this benefit is Alcocofine's dual nature, which allows it to participate in pozzolanic and cementitious reactions. The dual reactivity of Alcocofine reduces pore size, improving impermeability and chemical resistance.

Recommendations:

- Alccofine is preferred for M45 concrete in load-bearing structures.
- Further studies on long-term durability (e.g., chloride ingress, carbonation) are warranted.

Declaration of Competing Interest

The authors assert that they have no known competing financial interests or personal relationships that could have appeared to compel the work reported in this paper.

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