SUSTAINABLE CEMENTITIOUS MATERIALS: EVALUATING ALCCOFINE AND LIME SLUDGE FOR ECO-FRIENDLY CONCRETE PRODUCTION

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Abstract - *Cement production, a cornerstone of global construction and infrastructure, is among the largest contributors to carbon emissions, accounting for approximately 8% of global CO_2 output. Each stage of its production generates significant greenhouse gases, underscoring the need for sustainable practices to mitigate its environmental impact. This study explores the potential of supplementary cementitious materials (SCMs) such as alccofine and lime sludge to partially replace traditional cement and reduce its carbon footprint. Lime sludge is a residual substance came from the paper sector. Initially, alccofine was incorporated at replacement levels of 10%, 20%, and 30% by weight of cement to determine the optimal proportion. Subsequently, using the optimal alccofine percentage lime sludge was replaced at varying replacement levels 5%, 10%, and 15%. The mechanical properties of these concrete mixtures, including workability, compressive strength, split tensile strength, and flexural strength, were systematically assessedand compared with conventional concrete, highlighting the viability of these SCMs in sustainable concrete production. Results indicate that mix consisting 20% alccofine and 10% lime sludge performed better when compared to conventional concrete.*

***Key Words*: Alccofine,Lime Sludge**

1.INTRODUCTION

The construction industry had long relied on cement as a fundamental material in the development of infrastructure such as buildings, roads, and bridges. However, cement production had become a significant environmental concern due to its high energy consumption and substantial carbon dioxide (CO_2) emissions. It had been estimated that the cement industry contributed nearly 8% of global CO_2 emissions, making it one of the largest industrial sources of greenhouse gases.

To address this issue, various strategies had been explored to make concrete more sustainable. One effective approach involved the use of supplementary cementitiousmaterials (SCMs), which are industrial by-products capable of partially replacing cement in concrete. These materials helped reduce the carbon footprint of concrete while also improving or maintaining its performance.

In this study, two SCMs were selected for investigation: alccofine, a highly reactive, finely ground slag-based material known for enhancing strength and durability; and lime sludge, a waste product generated by the paper industry. The use of lime sludge aimed to reduce cement consumption and promote the recycling of industrial waste, contributing to sustainable construction practices.

The experimental work was conducted in two phases. Initially, alccofine was used to replace cement at 10%, 20%, and 30% by weight to determine the optimal proportion based on mechanical performance. After identifying the best-performing alccofine percentage, lime sludge was added to the mix at 5%, 10%, and 15% replacement levels. The resulting concrete specimens were tested for mechanical properties such as workability, compressive strength, split tensile strength, and flexural strength. Furthermore, This project aimed to demonstrate the potential of alccofine and lime sludge as effective and sustainable alternatives to traditional cement, with the goal of reducing environmental impact while maintaining the quality and strength of concrete.

1.1 Literature review

[1]P. R. K. Chakravarthy and R. Rathan raj, (2017) analyzed the compressive strength of concrete by partial replacement of cement with alccofine. They replaced cement with alccofine at a percentage 0%, 4%, 8%, 16%, 25%, 50%, 75%, 100%.They conducted tests such as setting time , split tensile strength , flexural strength, impact test, compressive strength. They concluded that 16% replacement of alccofine can give maximum compressive strength and resistance against chloride attacks.

[2]R.Balamurali Krishnan & J. Saravanan, (2021) investigated that replacement for cement to enhance environmental sustainability and improve the mechanical properties of concrete. Several industrial by-products, including fly ash, silica fume, GGBS, metakaolin, and quartz powder, have been widely studied. The focus is on Alccofine-1203, an ultrafine material derived from glass waste, which has shown promising results in improving the compressive strength of cement mortar cubes. Studies indicate that a 10% replacement of cement with alccofine provides optimal strength gains, making it a viable supplementary cementitious material.

[3]R. Pranamika& S. Thirugnanasambandam, (2024) investigated the potential of Alccofine 1203 as a cement replacement in concrete to enhance strength, durability, and sustainability. Researchers explored how varying

proportions of Alccofine (ranging from 0% to 50%) affected the mechanical properties of M20-grade concrete. They conducted tests such as compressive strength, modulus of elasticity, flexural strength. They concluded that addition of alccofine exhibits higher compressive strength compared to conventional concrete.

[4]B. Venkatesan et al., (2020) studied the use of supplementary materials to improve concrete. Materials like fly ash, silica fume, and GGBS were commonly used, but Alccofine, a newer material, showed better performance in terms of strength and workability. It had very fine particles and reacted well with cement, which helped increase early and long-term strength. Some studies also looked at using waste materials like iron powder from steel industries as a partial replacement for sand. Replacing fine aggregates with iron powder improved the density and strength of concrete. It also helped concrete resist damage from harmful chemicals like acids and sulphates. A few researchers combined both Alccofine and iron powder in concrete. They found that this mix improved both strength and durability compared to normal concrete. Tests like compressive and split tensile strength were done after 7, 14, and 28 days of curing, and the concrete was also tested in chemical solutions to check its durability.

[5]B.L.N. Sai Srinath et al., (2021) studied that Concrete production had heavily relied on cement, which contributed significantly to greenhouse gas emissions due to the release of CO_2 during the clinkering process. To reduce this environmental impact, researchers had explored various Supplementary Cementitious Materials (SCMs) such as fly ash, Ground Granulated Blast Furnace Slag (GGBS), rice husk ash, silica fume, phosphogypsum, and metakaolin. These materials had shown pozzolanic properties that enhanced the performance of concrete. Alccofine 1203, a newer microfine SCM, had recently gained attention for its ability to improve the fresh, mechanical, and durability properties of concrete when used as a partial replacement for cement. Several studies had reported improved strength, better workability, and higher resistance to chemical attack in concrete mixtures containing alccofine. However, its effects on microstructure and fire resistance had not been widely studied.

[6]Ansari U.S et al.,(2020) studied that Fly ash had been widely used for many years as a partial replacement for cement in concrete, typically in low replacement levels ranging from 10% to 20%. It had been recognized for its pozzolanic properties, contributing to improved workability and long-term strength. However, its effectiveness in high-performance concrete (HPC) was often limited when used alone at low dosages.Recent studies had introduced the use of alccofine, a microfine material with high reactivity, as a supplementary cementitious material. Researchers had explored its combined use with fly ash to enhance the mechanical properties of high-grade concrete mixes. When applied to higher-strength concrete, such as M70 grade, the inclusion of alccofine had shown significant improvements in compressive strength.

Comparative studies had indicated that concrete mixes incorporating both alccofine and fly ash exhibited better performance than ordinary Portland cement (OPC) concrete. In particular, a 20% increase in compressive strength had been observed when alccofine partially replaced cement.

[7]N. Raghavendra et al., (2019) examined the influence of alccofine 1203 as a supplementary cementitious material on the performance of concrete. The study involved replacing cement with alccofine in varying proportions (5%, 10%, 15%) in M30 grade concrete. Test results showed that the addition of alccofine significantly improved workability, compressive strength, and resistance to sulphate and chloride attack. The ultrafine particle size of alccofine was credited for enhancing particle packing and reducing porosity. The study concluded that alccofine was an effective high-performance SCM for improving concrete strength and durability.

2. MATERIALS, METHODS AND MIX PROPORTIONS

2.1 Cement

Cement is a fine, gray powder that acts as a binding material when mixed with water. It is one of the most important components in construction and plays a key role in making concrete and mortar. When water is added to cement, a chemical reaction called hydration occurs, causing the mixture to harden and gain strength over time .

2.2 Alccofine

Alccofine 1203 is a high-performance, ultrafine mineral admixture primarily composed of granulated blast furnace slag. It is processed through a controlled grinding technique to achieve a very fine particle size, even smaller than that of silica fume. Alccofine 1203 is used in high-performance concrete (HPC) to enhance strength, durability, and workability. It is particularly effective in improving early strength development and reducing permeability, making it suitable for critical infrastructure and precast elements.’

Fig -1: Alccofine

The presence of calcium (CaO) and silica (SiO_2) in alccofine-1203 improved the mechanical and durability properties of concrete better than the other SCMs. From the literature review, the optimum dosage of alccofine-1203 is obtained between 8% to 12%, and at these percentages, the improvement in mechanical and durability properties of the concrete is highest. The table.2.1 shows the physical properties of alccofine.

Table 2.1: Physical Properties of Alccofine

S.No	Properties	Value
1	Particle Size	5 micron
2	Specific Surface Area	12000 cm^2/g
3	Specific Gravity	2.85
4	Colour	Gery White
5	Form	Powder

2.3 Lime Sludge

Lime sludge is a by-product generated mainly from industries such as paper mills, sugar mills, water treatment plants, and chemical plants. It is primarily composed of calcium carbonate ($CaCO_3$) along with some impurities like lime (CaO), silica, alumina, and magnesium. Lime sludge is produced when lime is used in processes like water softening or chemical recovery. Over time, the lime reacts with impurities and settles as sludge.

2.4 Fine Aggregate

Fine aggregate is a key component of concrete and mortar, providing bulk, strength, and resistance to wear. It consists of naturally occurring or manufactured mineral particles that are smaller than 4.75 mm in diameter. Common sources include river sand, crushed stone sand, and manufactured sand. Fine aggregates fill the voids between coarse aggregates and contribute to the overall density and workability of the mix. They influence important properties like setting time, strength, shrinkage, and durability of concrete or mortar. Proper grading of fine aggregate ensures better compaction and minimizes voids, leading to improved mechanical performance of the final product.

2.5 Coarse Aggregate

Coarse aggregate is a key ingredient in concrete and construction materials, consisting of naturally occurring or artificially crushed stones such as gravel or crushed rock. These aggregates are typically retained on a 4.75 mm sieve and range in size up to 80 mm. Their primary function is to provide bulk, strength, and stability to the concrete mix. Coarse aggregates can be either angular, which come from **crushed rocks and offer better interlocking properties, or** rounded, which are smoother and easier to mix but may reduce the overall strength of concrete.

2.6 Water

Water is a crucial component in construction, especially in concrete and mortar production. It plays a vital role in the hydration of cement, workability of mixes, and overall strength and durability of concrete. The quality of water used in construction significantly affects the performance of the final structure.

2.7 Testing Methods

1.Workability

This is the most widely adopted method due to its simplicity and quick results. The test is conducted using a metallic slump cone, which is 300 mm high with a diameter of 100 mm at the top and 200 mm at the base. The cone is placed on a non-absorbent, flat surface and filled with fresh concrete in three equal layers. Each layer is compacted by tamping it 25 times with a standard tamping rod to eliminate air pockets and ensure consistency. Once the cone is filled and leveled at the top, it is carefully lifted vertically, allowing the concrete to subside or "slump." The vertical distance between the top of the cone and the highest point of the slumped concrete is measured, which is referred to as the slump value.

2.Compressive Strength

The compressive strength test is one of the most fundamental and widely used tests to assess the quality and performance of concrete. It measures the ability of concrete to withstand axial loads and provides critical information about its structural integrity. The test is typically conducted on concrete cubes or cylinders that have been cured for specific durations, most commonly at 7, 14, and 28 days. In India, the standard size used is a cube of 150 mm × 150 mm × 150 mm, while cylinders of 150 mm diameter and 300 mm height are more common in some other countries like the U.S. The specimens are cast and compacted properly, then cured in water at controlled temperatures. On the day of testing, the concrete specimen is removed from the curing tank, surface dried, and placed in a compression testing machine (CTM). The load is applied gradually and uniformly at a specific rate, usually around 140 kg/cm^2 per minute, until the specimen fails. The maximum load carried by the specimen before failure is recorded, and the compressive strength is calculated by dividing this load by the cross-sectional area of the specimen.

3.Split Tensile Strength

The split tensile strength test is conducted to determine the tensile strength of concrete, which is an important property affecting the cracking behavior and overall durability of concrete structures. Since concrete is relatively weak in tension, this test provides valuable insight into its resistance

to tensile stresses. The test is typically performed on a cylindrical concrete specimen, usually of 150 mm diameter and 300 mm height, after curing for standard periods such as 7, 14, or 28 days. In this method, the cylinder is placed horizontally between the platens of a compression testing machine, and a compressive load is applied along its vertical diameter. As the load is applied, it induces a tensile stress along the horizontal plane of the cylinder, ultimately causing the specimen to split vertically. The maximum load at failure is recorded, and the split tensile strength is calculated using formula:
$T = 2P / (\pi DL)$,

where *P* is the maximum applied load,

D is the diameter, and *L* is the length of the cylinder.

4.Flexural Strenth

The flexural strength test measures the ability of concrete to resist bending or flexural stress and is essential for structures like beams, pavements, and slabs. It is typically conducted on a concrete prism of size 100 mm × 100 mm × 500 mm using a three-point or two-point loading setup in a flexural testing machine. In the test, the specimen is placed on two support rollers, and load is applied at one or two points along the span until the beam fails. The maximum load applied before failure is recorded, and the flexural strength (also known as the modulus of rupture) is calculated using a specific formula depending on the loading method.

Mix Proportions

The table 2.2 presents various concrete mix proportions designed to evaluate the effects of incorporating alccofine and lime sludge as supplementary cementitious materials (SCMs) on concrete performance. All mixes maintain a constant water-to-cement ratio (W/C) of 0.45 and consistent quantities of fine aggregate, coarse aggregate, and water. The control mix (Mix 1) uses only traditional cement, while Mixes 2 to 4 progressively replace cement with 10%, 20%, and 30% alccofine by weight. Among these, Mix 3 (AF20) offers a balanced reduction in cement content (307.2 kg/m^3) with a notable increase in alccofine (76.8 kg/m^3), suggesting a potentially optimal blend for strength and sustainability.

Table 2.2 Mix Proportions

S.No	Mix	W/C Ratio	Cement Kg/m³	Alccofine Kg/m³	Lime Sludge Kg/m³	Fine Aggregate Kg/m³	Coarse Aggregate Kg/m³	Water Kg/m³
1	Control	0.45	384	0	0	667	1207	165
2	AF10	0.45	345.6	38.4	0	667	1207	165
3	AF20	0.45	307.2	76.8	0	667	1207	165
4	AF30	0.45	268.8	115.2	0	667	1207	165
5	AF20LS5	0.45	291.89	76.8	15.31	667	1207	165
6	AF20LS10	0.45	276.48	76.8	30.72	667	1207	165
7	AF20LS15	0.45	261.12	76.8	46.08	667	1207	165

3.RESULTS AND DISCUSSIONS

3.1 Workability

Figure 3.1 illustrates the results of the workability test conducted on various concrete mixes, measured in terms of slump values. The Control mix recorded a slump of 105 mm. With the inclusion of AF (assumed as Ash Fraction), the slump increased, indicating improved workability. Specifically, AF10 showed a 5.7% increase, AF20 showed the maximum increase of 8.6%, and AF30 resulted in a 2.9% increase compared to the Control mix. However, when lime sludge (LS) was incorporated with AF20 at varying dosages, the slump values began to decline. AF20LS5 exhibited a 1.9% increase, AF20LS10 had a 0.95% increase, while AF20LS15 showed a 0.95% decrease in slump relative to the Control mix. These results indicate that while the addition of AF enhances the workability of concrete, the inclusion of lime sludge reduces this effect progressively with higher dosages.

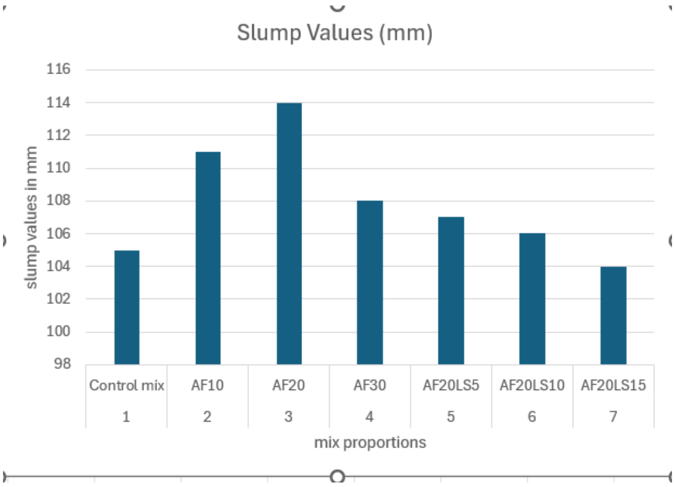

Fig.3.1 workability values

3.2 Compressive Strength

The compressive strength results from Fig 3.2 indicate a consistent trend. At 28 days, mixes AF10 and AF20 exhibit no noticeable variation in compressive strength when compared to the control mix. However, mixes AF30, AF20LS5, AF20LS10, and AF20LS15 show a significant improvement, with each demonstrating an 11.1% increase in compressive strength. This suggests that these mixes outperform the control mix, showcasing enhanced durability and strength properties. The uniform improvement across AF30 and the AF20LS variations highlights their effectiveness in potentially achieving superior performance in structural applications.

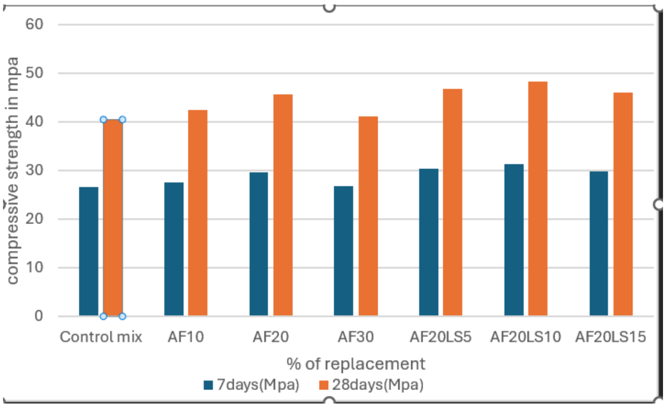

Fig.3.2 compressive strength

3.3 Split Tensile Strength

The split tensile strength results showed in the fig.3.3 indicates the improvement with the addition of Alccofine and lime sludge. The control mix had strengths of 1.93 MPa at 7 days and 2.98 MPa at 28 days. With Alccofine, strength increased, reaching a peak at 20% replacement (AF20) with 2.04 MPa at 7 days and 3.15 MPa at 28 days. Further addition to 30% (AF30) caused a slight drop. When lime sludge was added along with 20% Alccofine, the strength further improved. The highest value was recorded for AF20LS10 with 2.10 MPa at 7 days and 3.24 MPa at 28 days, indicating this mix as the most effective combination. Beyond this, a slight reduction was observed at 15% lime sludge.

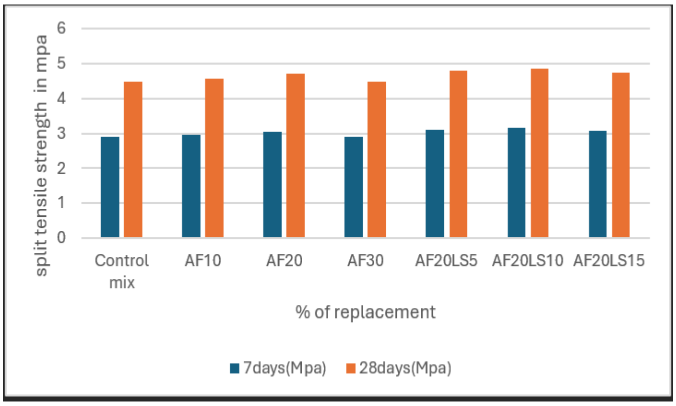

Fig.3.3 Split Tensile Strength

3.4 Flexural Strength

The flexural strength results showed in the fig.3.4 gives consistent improvement with the addition of Alccofine and lime sludge. The control mix had values of 2.90 MPa at 7 days and 4.47 MPa at 28 days. Replacing cement with 20% Alccofine (AF20) gave the best results among Alccofine-only mixes, reaching 3.06 MPa at 7 days and 4.72 MPa at 28 days. A slight drop was noted at 30% replacement (AF30). When lime sludge was combined with 20% Alccofine, strength further increased, with AF20LS10 achieving the highest flexural strength—3.15 MPa at 7 days and 4.86 MPa at 28 days. Beyond this, a minor reduction was seen at 15% lime sludge, indicating that 10% lime sludge was the optimal dose for improving flexural strength.

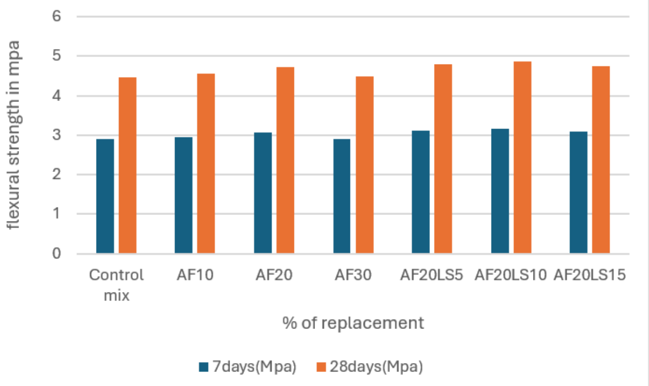

Fig .3.4 flexural strength

4. CONCLUSIONS

- The AF20 mix showed the highest slump value of 114 mm, indicating improved workability with 20% Alccofine replacement.
- Compressive strength improved with Alccofine up to 20% (AF20), showing a 29.65 MPa (7 days) and 45.62 MPa (28 days), compared to the control mix.
- The AF20LS10 mix achieved the highest compressive strength of 48.25 MPa at 28 days, proving it to be the most effective mix for strength enhancement.
- The maximum split tensile strength of 3.24 MPa at 28 days was recorded for the AF20LS10 mix, showing better crack resistance.
- The AF20LS10 mix recorded the highest flexural strength of 4.86 MPa at 28 days, indicating enhanced bending resistance.
- The increased flexural performance indicates that the modified concrete matrix with Alccofine and lime sludge offers better resistance to bending forces, making it suitable for structural applications like beams and slabs where flexural stresses are critical.

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