

DEVELOPMENT AND PERFORMANCE EVALUATION OF CEMENT-FREE CONCRETE USING FLY ASH, LIME AND NANO SILICA FUME

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ABSTRACT: No ordinary cement here. Instead, fly ash steps in as the base ingredient. Not alongside but working through chemical shifts when hydrated lime enters. That lime does more than sit - triggers reactions vital for hardening. Into the mix also slips nano-silica fume, unseen but active. Together they form a blend that skips traditional Portland methods. Making it means fewer CO₂ releases at factories. Waste becomes worth - industrial leftovers get reused. Strength matters just as much as green claims. So testing ensures it holds up under real demands. Durability cannot lag behind standard materials. Aiming not to impress - but to perform where buildings rise. Tiny bits of silica go into the mix in small amounts, boosting how fast it reacts while plugging tiny gaps inside. Instead of just listing steps, picture this: fly ash shifts between zero and seventy percent, lime climbs as high as thirty, nano-silica sneaks in anywhere from nothing to six. Testing checks how easily it flows plus how much weight it handles when squeezed. Early on, the stuff built with nano-silica pushes back harder against breaking, lets less water sneak through. Denser? Yes. Tougher over time? Absolutely. Fly ash teams up with lime - not perfectly every time - yet often locks together well enough to help everything hold firm. One more thing - cutting out regular cement cuts pollution and saves money too. Because it leans less on ordinary Portland cement, this new blend slashes greenhouse gases while pushing greener building methods forward. Industrial leftovers such as fly ash find purpose here, easing landfill strain and preserving raw supplies. Wrap it up: mixing lime, fly ash, and tiny silica particles creates strong, clean concrete without emissions-heavy ingredients. When mixed right and checked closely, it performs just like standard concrete across many uses - both load-bearing and lighter-duty ones.

Key Words: Cement free concrete, Fly Ash , Hydrated Lime , Silica Fume , Pozzolanic Reaction, Compressive Strength .

INTRODUCTION

For centuries, concrete has built the backbone of human settlements - roads, bridges, pipes, factories. Not just today but since Rome ruled, it stands strong through time and weather. What holds it together. A substance called cement, most often one named Ordinary Portland Cement. Back in the 1800s, that mix changed everything: faster setting, tougher results, fit for almost any shape needed. Water kicks off a reaction in cement, creating a substance called C-S-H gel. This glue-like product holds bits of stone and sand tightly bound. Strength comes from how those pieces link through the formed gel. Thanks to its toughness and reliability, concrete made with cement dominates building work worldwide.

Yet here's the catch - making cement harms nature more than most admit. High heat, near 1450°C, breaks down limestone, a step that spills huge volumes of CO₂ straight into air. Burning fuel adds even more gas, while the chemistry itself lets loose still greater loads. Across Earth, factories turning out cement account for roughly 7 to 8 percent of human-made carbon pollution. That weight pushes climate shifts faster. Beyond gases, it guzzles raw stuff - clay, stone, oil - not one bit sparingly. Land pays a price; balance in ecosystems wobbles. As cities rise everywhere, demand swells, dragging heavier tolls on planet systems. Sustainability? It slips further each year. Old experiments with natural ashes - like those Romans put into seawater concrete - first hinted at ways to build without cement. Not until the 1980s did labs start taking such mixtures seriously, looking for greener options

beyond traditional gray powder. One waste product, from burning coal, turned out useful: fly ash carried just enough reactive glassy particles to react well. Instead of heat-heavy processes, mixing it with lime opens a different path - one where strength grows quietly through gel formation. Tiny doses of synthetic silica speed things up, weaving tight networks that glue everything together, molecule by molecule.

NEED FOR CEMENT-FREE CONCRETE

Concrete use climbs fast as building work expands, relying heavily on Ordinary Portland Cement to hold things together. Yet making this cement harms nature in serious ways. Heating limestone until it breaks down needs intense heat, pulling from oil, coal, or gas supplies while pouring out thick clouds of carbon dioxide. This single sector pumps out around 7 to 8 percent of Earth's CO₂ emissions each year. As ice melts, weather shifts, and ecosystems weaken, finding greener options feels less like choice - more like necessity. Old methods now push us toward new answers.

IMPORTANCE OF CEMENT -FREE CONCRETE

Concrete without cement helps push greener building methods forward. With nations aiming to balance carbon output, shifting toward cleaner materials matters more every year. Removing most or all traditional cement slashes CO₂, since clinker production is so emission heavy. Structures built this way leave a lighter mark on the planet, quietly changing how things are made. Because fly ash is often nearby, concrete without cement might save money in some areas. Rather than paying to get rid of waste, factories can send it to builders who need it. That shift lowers expenses for building projects. It helps nature at the same time as budgets.

LITERATURE REVIEW

1. **2001, Sabir's** team looked closely at how metakaolin and heated clays behave when mixed into concrete. Though their study didn't center on fly ash or tiny silica particles, it revealed something useful - ultra-fine reactive materials can make concrete stronger and last longer. That idea lines up well with swapping out regular cement for alternative binders. So even without targeting specific additives, the work still backs the move toward less cement in mixes.
2. (2) Concrete made with lots of fly ash might just step in where regular cement once ruled. Instead of relying on ordinary Portland cement, this approach leans heavily on industrial leftovers. When mixed right, fly ash holds up well under pressure - no need to sacrifice toughness. Strength stays solid even when cement fades out of the recipe. Ideas about skipping cement

entirely gain weight through such findings. The original thinking came from **Malhotra and Mehta** back in 2002.

3. Starting off, tiny bits of silica speed up how cement mixes with water. These small parts help form new material by offering spots where reactions begin. The way the mixture holds together gets stronger because gaps inside become smaller. Evidence shows such nanoparticles change how the paste forms over time. Results back up their role in making concrete more durable. Using them fits well when looking for different ways to bind materials. Work done by **Li and others in 2004** laid out these effects clearly.
4. Early reactions get a boost when tiny silica particles are present, according to findings by **Bjornstrom and team in 2004**. These small bits speed up how fast C-S-H forms, packing the structure tighter sooner. Because of this shift in timing and density, alternatives to ordinary Portland cement can benefit just fine. The role of nano-silica fits well within such mixtures, helping them evolve faster from start.
5. Looking into how long geopolymer materials last when exposed to sulfates, **Bakharev back in 2005** found they hold up well under harsh chemistry. Because of this behavior, cement-free concrete using different binding agents gains a solid point on longevity.
6. Nanotechnology might change how concrete behaves, according to Sobolev and **Ferrada-Gutierrez back in 2005**. Because of tiny particles like nano-silica, materials pack tighter and react faster. Strength goes up while liquids pass through less easily, thanks to these additives. Their research supports using nano-silica even when there is no cement involved.
7. From their lab tests, **Hardjito and Rangan in 2005** explored how fly ash turns into geopolymer concrete. Results showed it often matches regular concrete squeeze strength - sometimes beats it. Because of its makeup, it withstands harsh chemicals better and cracks less when drying out. People now reference their methods when deciding ingredient mixes or heat treatments. Years later, engineers still rely on those early blueprints.
8. Concrete gains strength when fly ash is finer and cured well, **Thomas pointed out in 2007**. Because of this, using lime along with nano-silica creates strong mixtures without cement. His work sheds light on how these materials interact effectively. Though not obvious at first, small changes in processing make a noticeable difference.

9. Starting off, **Duxson and colleagues** looked into how geopolymers are built, handled, and used across industries. Instead of traditional methods, they found that materials like fly ash and slag - when triggered by certain chemicals - can create solid binders. While examining performance traits, these mixtures showed high heat tolerance, stood up well against corrosive substances, yet also lowered ecological harm. Because of these features, such systems might one day take the place of ordinary cement without losing strength.
10. **Barbhuiya and team** looked at how high-fly-ash concrete behaves when mixed with hydrated lime and silica fume. Early reactions got a boost because lime sped things up. Strength went way up thanks to silica fume - both squashing and pulling forces held better. Together, those extras made the inside structure tighter, leaving fewer gaps. Less space between particles opened doors for mixes using little or no cement.
11. Starting off, **Provis and van Deventer in 2009** looked into how geopolymers form along with changes in their tiny internal structure when activated by alkaline substances. Instead of just listing steps, they detailed the actual chemistry behind building strong, three-part silicon-aluminum frameworks. Because of these formations, materials gain impressive resistance and toughness over time. Beyond theory, their research helps shape ways to make geopolymer concrete from waste like fly ash found in industry.
12. Concrete gets a boost when tiny particles join the mix. Tiny bits of silica change how fast the material sets. These small elements patch gaps inside the structure. Strength goes up because of their presence. Early results look good, so do those seen later on. Less cement can be used without losing quality. That idea came from looking closely at past work. **Sanchez and Sobolew took a close look back in 2010.**
13. Back in **2011, Nazari and Riahi** took a close look at how nano-silica changes high-strength concrete. Strength gains showed up clearly under pressure and when bent. Pores inside shrank quite noticeably. Tiny structures within the mix grew more tightly packed. Because of these shifts, slipping nano-silica into test batches made solid sense.
14. Looking into how tiny silica particles affect concrete, **Rashad took a close look back in 2013.** Strength and resilience get a boost - so long as the material spreads evenly through the mix. Evidence piles up showing it works well even without regular cement. A full picture emerges, pointing toward smarter choices in building materials.
15. Concrete needs grow fast as cities expand, pushing pressure on building supplies. When towns swell, materials like cement become critical players in development patterns. **A 2007 housing plan pushed greener options in construction work across regions.** Making regular cement pulls heavily from earth's reserves during manufacturing phases. Each batch released into air systems adds more CO₂ than earlier steps allowed. One way to tackle the problem? Using geopolymer concrete from fly ash - leftover stuff from coal power stations. Across India, heaps of it exist though hardly anyone uses it fully yet. Workability gets better when superplasticizers come into play. Strength steps up thanks to tiny particles like nano silica or nano carbon bits mixed in. What does this research do? It looks at how cement-like substances without CO₂ impact geopolymer concrete behavior.
16. Looking at high-volume fly ash mixed with hydrated lime and nano-silica, **Gunasekera and team in 2020** checked how it affects strength and internal structure. Because of nano-silica, water reactions kicked off faster, particles fit together better, showing clear jumps in strength within days along with solid improvement by day 28. Work like their points toward using nano-silica in mixes without much cement, helping them perform well.
17. A mix without cement was created by **Roychand and team in 2021**, meant for sewer pipelines, built from fly ash, tiny silica particles, slag, along with lime that absorbed water. Better protection against acidic damage emerged in their testing, when measured next to regular Portland cement material. Because there's no leftover calcium hydroxide, the structure holds up longer. Environments that wear down typical concrete do less harm to this version.

OBJECTIVES OF THE PROJECT

1. One way to begin is by examining how fly ash behaves on its own. Lime's role shows up clearly when tested separately. Nano silica reveals subtle effects only under close observation. Each material brings something distinct when mixed without cement. Their combined actions shift depending on proportions. Close attention uncovers patterns others might miss.
2. Starting with fly ash, mix designs form without cement by blending varying amounts of lime alongside nano silica. Different ratios shape each batch, altering performance quietly behind the scenes. Proportions shift step by step, guided by material behavior rather than fixed rules. Through gradual adjustments, workable mixes emerge under changing conditions. Testing reveals how these elements interact when

cement is fully left out. Each version reflects a balance found among components playing distinct roles.

3. Checking how well concrete without cement flows, using common lab methods like the slump trial. Testing its behavior begins here, through routine checks that show performance. A usual method - slump measurement - helps see if it moves right. This looks at flow traits by applying familiar procedures step by step. Standard trials reveal whether mix works smoothly during placement.
4. Testing how strong cement-free concrete is when squeezed, pulled apart, or bent helps understand its performance under different forces. Strength under pressure reveals load capacity, while resistance to cracking shows durability during real-world use. Each measure gives insight into where this material might work well - or fail.
5. One way to look at how tiny glass particles affect toughening and inner patterns in concrete without cement. A closer peek shows these minuscule specks shifting how the mix sets up. Sometimes strength climbs when those bits spread through the paste. The weave inside change, not always predictably. Tiny spaces rearrange as the material firms up.
6. Cement-free mix stands against regular concrete in a test of strength. One watches how each holds up under pressure instead of assuming results. Performance shows through stress trials rather than guesses on paper. Trial outcomes shape conclusions without leaning on past beliefs.
7. To determine the optimum mix proportion that provides maximum strength and durability.
8. To assess the potential of cement-free concrete as a sustainable and eco-friendly construction material.

SCOPE OF THE PROJECT

1. Investigation of the physical and chemical properties of fly ash, lime, and nano silica.
2. Development of different mix proportions for cement-free concrete.
3. Checking how easy concrete is to work with often involves tried-and-true methods like the slump test.
4. Concrete samples get tested for how much squeeze they can take after resting seven days. Following that, another round happens when two weeks have passed since pouring. By the fourth week mark, one last check measures their full resistance to pressure.
5. Concrete without cement gets tested for how it handles pulling apart plus bending forces.
6. Analysis of the influence of nano silica on the strength and durability of the concrete.

METHODOLOGY

Looking at how things are done comes down to the step-by-step approach taken during testing, especially when

checking how well concrete without cement works. For this work, batches of concrete used fly ash, hydrated lime, and nano-silica instead of traditional binders, each mix adjusted in amount. Once gathered, ingredients got weighed carefully before blending together and poured into molds shaped like cubes. These molded samples then sat in a curing environment for spans of 7, 14, 21, or 28 days. When ready, they went through checks - like measuring how much pressure they could take - to see how strong they turned out.

Materials Used- Fly ash, Hydrated lime, Nano Silica Fume, Fine Aggregate, Coarse Aggregate, Water.

Fly Ash:- Fine powder left after burning crushed coal gives rise to fly ash. This type of material, specifically Class F, served as the main binding agent in the study.

One key ingredient for making cement-free concrete came from trusted suppliers, helping keep tests steady and results clear. From a local power station or builder's yard, fly ash arrived carefully packed, then kept away from damp to stay usable.



Fig :1 collection of fly ash

Hydrated Lime:- Starting with quicklime, water gets carefully added to make hydrated lime. Calcium hydroxide forms during this step, which helps fly ash work in concrete without cement. From a nearby shop came the material used here. Stored away it stayed - sealed tight - to block dampness and outside air.



Fig :2 Collection of Hydrated lime

Nano-Silica fume:- Tiny glass-like particles, made of disordered silicon dioxide, pack a huge surface relative to their size. Used here in low amounts, these fine specks boosted how much force the material could handle.

Out of nowhere, nano-silica powder arrived by mail order from a web-based lab vendor - handled with care because the particles are incredibly tiny. Sand showed up first among the materials, followed closely by larger stone bits, both pulled from nearby builders' supply yards. Testing happened afterward, just to check if grain sizes lined up with what official guidelines expect. Before anything mixed, a wash cycle cleared off dirt and stray debris from every batch.



Fig :3 collection of nano silica fume

Fine Aggregate :-Small stones washed down by rivers made up the fine material in this work, fitting what the standard calls Zone II under IS 383:2016. Though nature shaped them, rules still classified their size. Each grain passed tests before entering mixtures. Water carried these particles for ages before collection. Their smooth edges came from long travel. What settles here meets a national benchmark. Roundness matters more than color when blending. Dust levels stayed low due to constant washing. Shape affects how things hold together later. Size range fits right into mid-grade sorting.

Coarse Aggregate :-A mix of crushed stone, around 20 mm in size, went into the tests. This larger gravel type helped form the concrete batch. The pieces were rough and broken, not smooth. Each sample followed the same grain pattern. Size consistency mattered throughout the process. Material came straight from the quarry run. Testing relied on uniform chunks only.

Water :- From time to time, clean drinking-grade water went into both blending and hardening the concrete mix.

MIX CALCULATION FOR M20 CONCRETE USING FLYASH, HYDRATED LIME AND NANO SILICA FOR 1m³

1. Dry Volume of Concrete

- Dry Volume = 1 × 1.54 = 1.54 m³

2. Mix Ratio

Assumed mix ratio: 1: 1.5: 3

Total parts: 1 + 1.5 + 3 = 5.5

3. Volume of Each Material

Binder Volume

$$\frac{1}{5.5} \times 1.54 = 0.28 \text{ m}^3$$

Fine Aggregate Volume

$$\frac{1.5}{5.5} \times 1.54 = 0.42 \text{ m}^3$$

Coarse Aggregate Volume

$$\frac{3}{5.5} \times 1.54 = 0.84 \text{ m}^3$$

4. Convert Binder Volume to Weight

Density of binder ≈ 1440 kg/m³ = 0.28 × 1440 = 403 kg

Total binder ≈ 400 kg per m³

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M1 Mix:

Fly ash = 70%

Hydrated lime = 30%

Fly ash = 400 × 0.70 = 280 kg

Hydrated lime = 400 × 0.30 = 120 kg

M2 Mix:

Fly ash = 70%
Hydrated lime = 28%
Nano silica = 2%

Fly ash = 280 kg

Hydrated lime = $400 \times 0.28 = 112$ kg

Nano silica = $400 \times 0.02 = 8$ kg

M3 Mix:

Fly ash = 70%
Hydrated lime = 27%
Nano silica = 3%

Fly ash = 280 kg

Hydrated lime = $400 \times 0.27 = 108$ kg

Nano silica = $400 \times 0.03 = 12$ kg

M4 Mix:

Fly ash = 70%
Hydrated lime = 24%
Nano silica = 6%

Fly ash = 280 kg

Hydrated lime = $400 \times 0.24 = 96$ kg

Nano silica = $400 \times 0.06 = 24$ kg

6. Aggregate Quantity

1. Fine Aggregate Density $\approx 1600 \text{ kg/m}^3 = 0.42 \times 1600 = 672$ kg
2. Coarse Aggregate Density $\approx 1500 \text{ kg/m}^3 = 0.84 \times 1500 = 1260$ kg
3. Water Requirement Assume Water-Binder Ratio = $0.50 = \text{Water} = 400 \times 0.50$

MIXING PROCESS

Dry Mixing

Concrete blending happened inside a lab setting, aiming for even consistency throughout. Right at the start, each component - fly ash, hydrated lime, nano-silica, fine sand, plus coarse stones - got weighed precisely based on set ratios. With everything dry laid out, these elements went into an empty mixing space, stirred well so binders could spread evenly among the grains.



Fig :4 dry mixing

Water addition

Later on came the slow addition of measured water into the dry blend, with constant stirring throughout. Mixing went on until everything felt even and ready to shape without clumping. Attention stayed sharp so every part blended well, avoiding any small knots in texture. Right after finishing, the batch moved straight into filling molds shaped like cubes, set aside later for checks.



Fig :5 Adding of water

Final mixing

Next came the slow pour of water into the blend of fly ash, hydrated lime, nano-silica, fine and coarse aggregates - already stirred dry. With everything inside, spinning it longer made sure texture turned even, ready to use.



Fig :6 Mixing

Table -1 Percentage of mixes

Mix	Fly Ash (%)	Hydrated Lime (%)	Nano Silica (%)
Mix 1	70	30	0
Mix 2	70	28	2
Mix 3	70	27	3
Mix 4	70	24	6

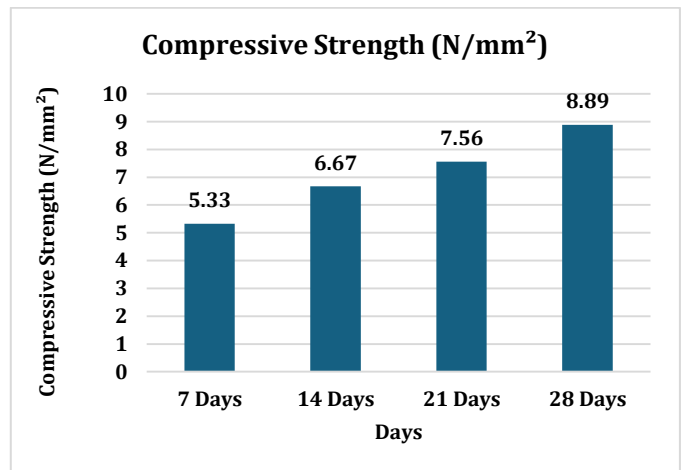


Chart -2 Compression Test of New Binder Cubes With 0%Silica (mix 1)

Table :2 Slump cone Test and results

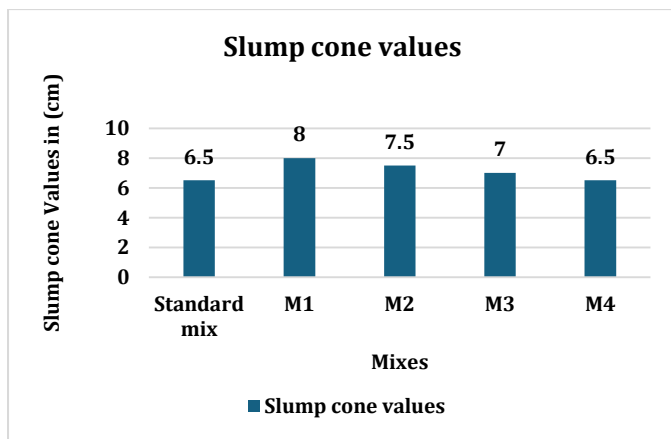


Chart -1 Slump Cone Values

Mix	Slump Value (mm)	Type of Slump
Standard concrete	65mm	True slump
Mix 1	80 mm	True slump
Mix 2	75 mm	True slump
Mix 3	70 mm	True slump
Mix 4	65 mm	True slump

Table :3 Compressive Strength Test and Results

Mix	7 Days	14 Days	21 Days	28 Days
Mix 1	120	150	170	200
Mix 2	220	230	270	290
Mix 3	350	370	390	430
Mix 4	310	330	350	370

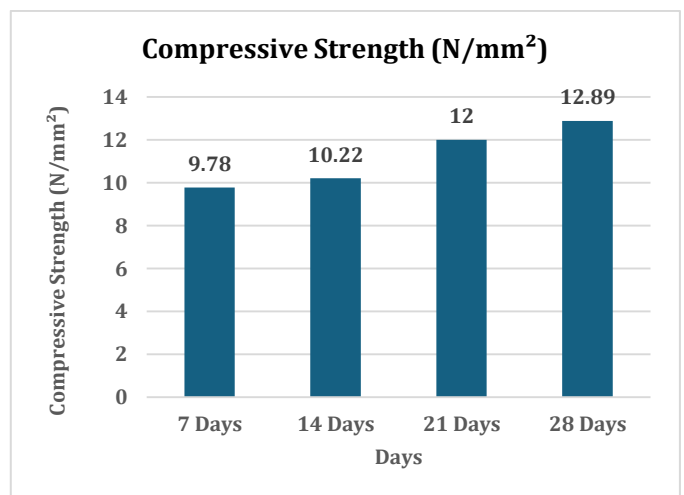


Chart -3 Compression Test of New Binder Cubes With 2%Silica (mix 2)

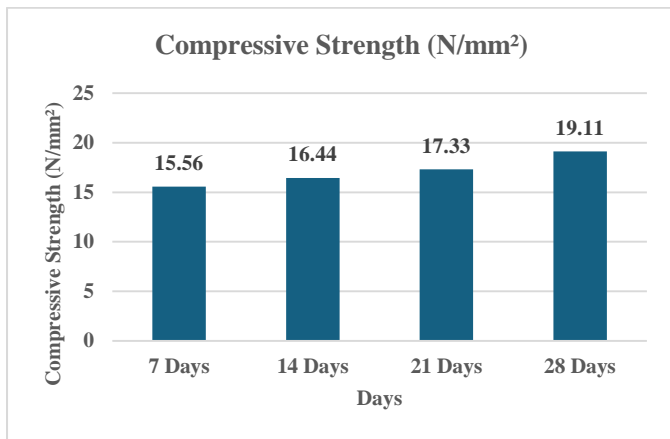


Chart -4 Compression Test of New Binder Cubes With 3%Silica (mix 3)

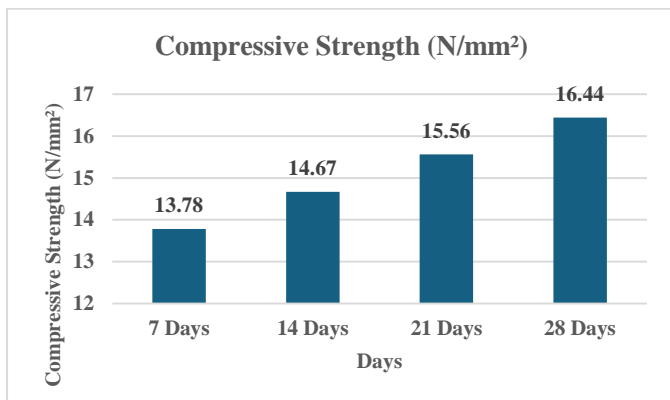


Chart -5 Compression Test of New Binder Cubes With 6%Silica (mix 4)

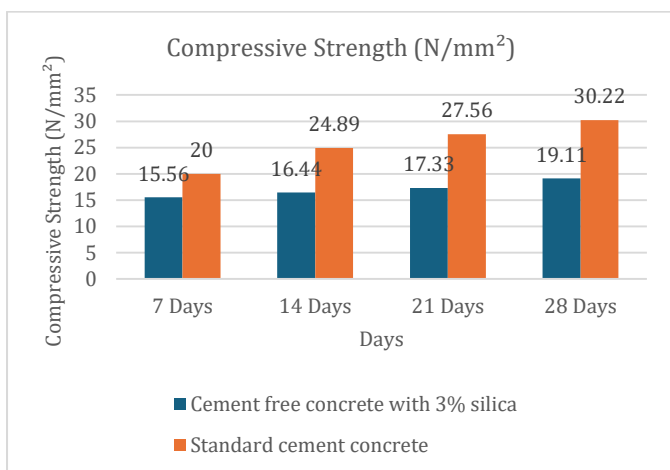


Chart -6 comparison of compression strengths of standard concrete and cement-free concrete.

RATE ANALYSIS

Rate Analysis is the process of calculating the cost of one unit of work by considering the cost of materials, labour, equipment, transportation, overheads, and contractor's profit.

Table -5 Cost Comparison

Binder Type	Fly Ash (kg)	Lime (kg)	Silica Fume (kg)	Cement (kg)	Total Cost (₹)
M1 (Fly Ash 70% + Lime 30%)	280	120	0	—	2040
M2 (Fly Ash 70% + Lime 28% + nano Silica Fume 2%)	280	112	8	—	2440
M3 (Fly Ash 70% + Lime 27% + nano Silica Fume 3%)	280	108	12	—	2640
M4 (Fly Ash 70% + Lime 24% + nano Silica Fume 6%)	280	96	24	—	3240
Cement Binder	—	—	—	400	3200

Purpose of Rate Analysis

1. To determine the unit cost of construction work.
2. To estimate the total cost of a project.
3. To check whether the contractor's quoted rate is reasonable.
4. To prepare detailed estimates and budgets.

Table -4 Market prices (approx)

Material	Rate (₹/kg)
Fly Ash	3
Hydrated Lime	10
Nanno Silica Fume	60

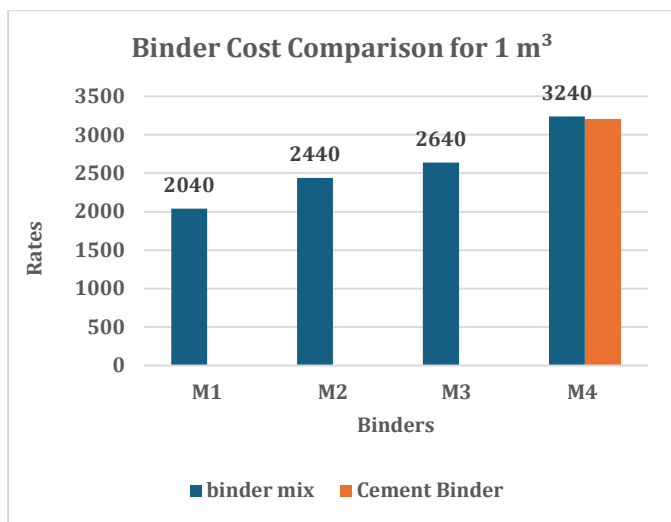


Chart -7 Cost comparison

CONCLUSIONS

1. A new binder emerged without cement, built from fly ash combined with hydrated lime. Success came through real testing, showing it can step in for regular Portland Cement. Feasibility showed up in performance, not just theory. This path opens doors minus reliance on traditional materials. Proof lives in the results, quiet but clear.
2. Starting with silica fume made the chemical process stronger, so the material held together more tightly. Because of that change, overall durability increased noticeably.
3. Compressive strength peaked at 4 weeks - reaching 19.11 N/mm² - with mixture M3. That blend held 70% fly ash, while lime made up most of the rest, sitting at 27%. A small portion, just 3%, came from silica fumes. Peak performance emerged clearly here, standing out among the others.
4. Strength went up over time in every batch, showing that concrete without cement can still gain durability as it hardens. Each mix followed a similar path, slowly building firmness through extended curing periods.
5. Starting at first, the early hardening phase stayed inside normal ranges. Later on, the point when it fully

set matched up closely with regular cement once silica fume was mixed in.

6. Fine movement in the mix stayed within expected range across all batches, delivering consistent slumping behavior - yet stiffness began creeping in as more silica got added. Concrete held its shape but slowed down when richer in fine powder.
7. Water amounts stayed between 0.43 and 0.50 compared to binder, showing careful balance across every mix. Though exact needs differed slightly, each blend used moisture efficiently. Because of that, consistency remained steady without excess. Still, small shifts in proportion mattered. Even so, results showed reliable control throughout testing.
8. Looking at the numbers, mix M1 came out cheaper than regular cement without losing strength. Not far behind, M2 also cut costs but still held up well under pressure. Then there is M3 - same story, less expense, yet strong enough for standard use. Each of these alternatives manages savings while doing what they need to do.
9. A surprise twist unfolded when fly ash, normally discarded, stepped into the spotlight. Waste took center stage, quietly cutting down pollution. Sustainability got a nudge - not through grand gestures but small shifts. Factories shrugged off old habits. Smokestack leftovers found new purpose, grounding progress in what was once overlooked.

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