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GREEN CONCRETE: ENHANCING STRENGTH AND WORKABILITY FOR SUSTAINABLE CONSTRUCTION

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Article Info

Abstract

This study looks into the viability of employing fly ash and limestone powder as partial replacements for cement in green concrete, which could replace regular concrete. The goal is to preserve mechanical efficiency and reliability while mitigating ecological impact, especially carbon dioxide emissions. Compressive capacity, flexibility, and long-term sustainability indices were assessed experimentally for different mix amounts. According to the findings, green concrete mixtures that have been optimized can both meet structural needs and provide substantial environmental advantages. The construction sector is one of the major consumers of natural resources and contributors to environmental deterioration, owing to the widespread use of cement in concrete manufacturing. This environmentally friendly concrete substitute provides considerable sustainability advantages by adding eco-friendly elements such as fly ash and limestone powder. This study looks into the feasibility and performance of substituting conventional concrete with green concrete that includes fly ash and limestone powder as partial cement replacements. The paper analyzes the mechanical properties, environmental benefits, and practical challenges of using these materials. Experimental results indicate that green concrete can achieve comparable strength and durability while significantly reducing carbon emissions and overall costs.

Keywords:
Green Concrete; Self-compacting Concrete; Limestone Powder; Fly ash; Sustainable Construction.

INTRODUCTION:

Nowadays, cement is used to make concrete in almost the same way; thus, it is important to blend other ingredients to use less cement. Concrete is a popular building material globally, partly because of its versatility and strength. The manufacturing of cement, a key element in concrete, is energy-intensive and contributes to 7% of world CO_2 emissions. Green concrete uses alternative materials like industrial byproducts to reduce environmental impact. Minerals that occur naturally. This study replaces cement with fly ash and limestone powder, which are easily available and have been found to improve concrete characteristics. Dr. Hajime Okamura proposed self-compacting concrete in Japan in 1986, and it was regarded as a unique sort of concrete. Beginning in the early 1990s, various countries acquired an interest in it, and its application gradually and quickly became popular. Concrete is considered the most internationally used building material, given its exceptional performance in compressive strength and workability. Green concrete represents a paradigm shift in the construction industry, moving towards environmentally sustainable practices. Originating in Denmark in 1998, this innovative approach integrates ecological considerations throughout the concrete lifecycle, from material sourcing to structural application. Contrary to its name, "green concrete" doesn't refer to color, but rather to its reduced environmental footprint. It achieves this by utilizing waste materials as partial cement substitutes, leading to cost-effectiveness through decreased waste disposal and energy consumption. This approach not only enhances durability but also significantly reduces the heat energy required during manufacturing, thereby minimizing environmental impact [1].

Essentially, green concrete provides an environmentally friendly alternative to traditional concrete, maintaining similar structural properties while prioritizing ecological responsibility. This research helps develop eco-friendly construction materials and encourages a more ecologically conscious built environment [2]. A variety of components, including cement, aggregates, water, and admixtures, are combined to create concrete. As a result of recent infrastructure growth, we are using excessive amounts of cement to build concrete structures[3, 4]. The global establishment industry's reliance on ordinary Portland cement (OPC) creates a huge environmental concern. OPC, which is the major binder in traditional concrete, accounts for around 8% of worldwide catastrophic carbon dioxide emissions and consumes roughly 3% of global energy.

Furthermore, the concrete sector is a leading consumer of natural aggregates and freshwater, placing immense strain on these vital resources. As projected future concrete demands rise, the depletion of natural resources and environmental contamination will escalate. As a result, the development and implementation of "green concrete" is critical to meeting construction needs sustainably. Green concrete, defined as any concrete with a lower embodied energy and carbon footprint compared to ordinary OPC concrete, offers a potential approach to reduce the environmental impact of traditional construction processes and conserve natural resources [5, 6].

The building industry is an important contributor to carbon dioxide emissions due to its heavy usage of Portland cement, a building material that emits huge amounts of CO_2 during manufacture. To solve this environmental issue, green concrete has evolved as a viable option that incorporates industrial byproducts and natural additives.

This study focuses on the production of green concrete with fly ash and crushed limestone being partial replacements for cement. Fly ash, a pozzolanic ingredient, increases strength and durability, whilst limestone powder improves workability and minimizes shrinkage[7]. The combination of these elements reduces cement usage, therefore lowering the environmental impact of building materials manufacturing[8].

Through optimizing the combination design., curing methods, and performance evaluation, this study aims to develop an eco-friendly, cost-effective, and durable alternative to traditional concrete. The implementation of such green concrete can significantly contribute to sustainable construction, energy efficiency, and waste reduction in the building industry.

Year	Author	Objective	Methods	Materials	Conclusion
2021	**[9]**	To look into the effects of lime powder, fly ash, silica powder, and their combinations on the new and hardened characteristics of self-compacting mortars.	Experimental investigation involving the creation and testing of self-compacting mortars with various SCM compositions.	Lime powder, fly ash, silica powder (ZP), Portland Cement, Quartz Sand.	Combinations of SCMs, specifically LSP and zinc phosphate, have better qualities than individual SCMs. The combination of LSP and ZP successfully reduced shrinkage and porosity while boosting compressive strength. The LSP/ZP blend outperformed the LSP/FA blend. A 20% replacement of cement with an LSP and ZP blend resulted in the best overall fresh and hardened qualities of the self-compacting mortars.
		To investigate new supplemental cementitious material (SCM) blends, especially LSP and zinc phosphate, as effective substitutes for fly ash in SC mortars.	Evaluation of fresh mortar properties, including flow characteristics and pore pressure.		
2021	**[10]**	Analyze the potential of RCA as an environmentally friendly alternative to natural coarse aggregates (NCA).	Characterization of RCA's physical, mechanical, and chemical properties.	Cement, water, pozzolanic ingredients (such as fly ash and silica fume), recycled concrete aggregates (RCA), natural coarse aggregates (NCA), and different concrete additives are all included.	According to the study's findings, high-performance structural concrete can successfully incorporate recycled concrete aggregates (RCA) as long as the right treatment techniques and mix design modifications are implemented. Making it a green and sustainable substitute for natural aggregates.

		Talk about how RCA affects the structural performance, fresh and hardened qualities, and durability of concrete.	Assessments of the effect of RCA on durability, flexural strength, compressive strength, workability, and shrinkage	RCA replacement levels in concrete range from 0% to 100%, and the impact on durability and mechanical qualities is evaluated.	
2022	**[11]**	The research intends to examine the impacts of substituting cement with calcined clay and fly ash in mortar mixes, along with the application of limestone powder as a partial substitute for sand.	The investigation comprised three stages: substituting cement with calcined clay and fly ash in different proportions. Partially substituting sand mixed with limestone powder. Strengthening the mortar using hybrid steel fibers. An assessment was made of the mortar's properties in both fresh and hardened states, as well as its environmental effects on reductions in CO_2 emissions.	Cement, calcined clay, fly ash, limestone powder, ultra steel fibers, and steel nail fibers.	According to the study, substituting 25% of the cement with calcined clay led to a 21% rise in compressive strength after 28 days. In mixes with 35% CC + 15% FA, replacing sand with 20% limestone powder enhanced workability and raised compressive strength by 13%. The best improvements in mechanical properties were achieved through hybrid fiber reinforcement with 0.175% USF and 0.325% SNF. Moreover, the use of 30% CC + 20% FA as substitutes for cement and 30% LP as a substitute for sand led to a reduction in CO_2 emissions of about 41%. This indicates that green mortar could be a viable method for sustainability and for minimizing environmental impact

2023	**[4]**	To examine how nanosilica (NS) influences the characteristics of self-compacting concrete (SCC).	To enhance the ratios of nanosilica in SCC mixtures that include silica fume (SF), fly ash (FA), and limestone powder (LSP).	To enhance the ratios of nanosilica in SCC mixtures that include silica fume (SF), fly ash (FA), and limestone powder (LSP).	The optimal mechanical properties of SCC were observed when 3% nanosilica (NS) was added to a mixture that included 10% silica fume (SF) and 15% limestone powder (LSP), all measured by weight of the cement. For compressive strength, bond strength, and modulus of elasticity, the SFNS3 mixture exhibited the greatest values of mechanical properties. The newly mixed concrete also demonstrated good flowability.
		To assess how high temperatures affect the compressive strength of the SCC.	To assess how high temperatures affect the SCC's compressive strength	To assess how high temperatures affect the compressive strength of the SCC.	
2024	**[12]**	To assess and contrast the ecological effects of using blended concretes with 'low carbon' cement compared to OPC concrete, in connection with compressive strength.	Life Cycle Assessment (LCA) for measuring the carbon equivalents produced in the manufacturing of CEM I and low-carbon concretes.	Ordinary Portland cement (OPC) Limestone Fly ash (FA)	When low-carbon concrete that includes limestone and FA is used, CO2-eq emissions are significantly reduced in comparison to those from conventional OPC concrete. Compared to limestone cement blends, the use of OPC and FA together produced concrete with greater strength and reduced CO2-eq values. Transportation's CO2-eq emissions were minimal, averaging under 4% of the total CO2-eq per mix.
		In order to quantify the carbon emissions and compressive strengths of binary and ternary SCMs concrete mix designs in comparison to OPC.	Evaluation of mechanical properties of concrete mixes through compressive strength tests at 28 days.		
2024	**[13]**	To study the impact of accelerated carbonation on concrete made with	Experimental investigation involving	Calcium sulfoaluminate, cement, Fly ash at 20%,	Over time, the carbonation depth in CSA cement concrete diminished with the incorporation of FA.

		calcium sulfoaluminate (CSA) cement.	the creation and testing of CSA cement concrete mixtures with various supplementary cementitious materials (SCMs).	Remediated fly ash at 20%, and Limestone powder at 15% 35% mix of FA and LP.	· The impact of LP and the FA-LP combination on carbonation depth was inconsistent. · The inclusion of LP or FA enhanced mechanical properties, but combining the two did not have this effect. The microstructural analysis showed that ettringite was the main phase in samples subjected to moist curing, while calcium carbonate polymorphs were found in samples subjected to carbonation curing. · The research underscores how various SCMs affect the durability and microstructural properties of CSA cement concrete.
		To assess the effects of fly ash (FA), remediated fly ash (RF), and limestone powder (LP) on the mechanical, durability, and microstructural characteristics of CSA cement concrete.	Assessment of mechanical characteristics: compressive strength, splitting tensile strength, elastic modulus, drying shrinkage, and bulk resistivity.		
2024	**[14]**	To examine the corrosion of steel and the critical chloride content in concrete that includes calcined kaolinite clay, fly ash, and limestone powder.	Concrete specimens were subjected to the tidal zone in a real sea environment for durations of 1 year and 2 years.	Ordinary Portland cement (OPC), Calcined kaolinite clay, Fly ash, and Limestone powder	According to the study's conclusions, incorporating calcined kaolinite clay into concrete leads to reductions in the chloride diffusion coefficient, critical chloride content, and steel weight loss. Due to its lower Portlandite content, concrete with calcined kaolinite clay demonstrated extended rebar depassivation times. After two years, the ternary binder system comprising cement, calcined clay, and fly ash demonstrated superior performance, characterized by the lowest chloride diffusion coefficient, the highest
		To assess the diffusive capacity of chloride ions and the compressive strength of concrete.	Laboratory study of depassivation time and critical chloride content in an		

			accelerated marine environment		compressive strength, and no weight loss of embedded steel.
2025	**[15]**	To devise a method for processing fly ash from Energy from Waste facilities to create a material appropriate for use as a Supplementary Cementitious Material in building material manufacturing. This means eliminating detrimental contaminants such as chlorides, sulfates, and heavy metals from the FA.	The authors propose a novel two-step process: **Aqueous Treatment:** Fly ash is mixed with water to dissolve and remove chlorides. **High-Temperature Treatment:** The remaining ash is heated in a furnace with silica and a reducing agent (graphite) to remove sulfates and heavy metals.	Fly ash from a municipal waste incineration plant.	The proposed procedure can efficiently eliminate chlorides, sulfates, and heavy metals from EfW fly ash, resulting in a material whose composition resembles that of blast furnace slag, a recognized SCM. This treated fly ash could serve as a sustainable substitute for conventional SCMs in the concrete industry.
2025	**[16]**	To assess the carbonation and chloride resistance of self-compacting concretes (SCCs) that have a reduced cement content through the use of fly ash (FA), metakaolin (MK), and hydrated lime (HL)	Binary, ternary, and quaternary mixtures of SCCs with high-early-strength Portland cement, fly ash, metakaolin, and hydrated lime were	Portland cement, Class B fly ash, metakaolin, hydrated lime, coarse crushed aggregate, fine river aggregate, tap water, and a polycarboxylate-based superplasticize	The research showed that SCCs with a lower cement content (ranging from 120 to 200 kg/m³) can provide satisfactory durability. Hydrated lime addition led to a reduction in carbonation depth of up to 33% and enhanced chloride resistance. By incorporating metakaolin and fly ash, the diffusion of chloride ions was significantly reduced, leading to enhanced

			used in the study. It encompassed laboratory examinations, including tests for chloride-ion migration, accelerated carbonation, electrical resistivity, void indices, and compressive strength.	r	durability of SCCs. The results emphasize that SCCs containing less cement may fulfill durability criteria and lessen environmental effects.
2025	**[17]**	To examine the influence of using fly ash to partially replace cement in roller-compacted concrete (RCC) mixtures.	Experimental investigation employing different fly ash proportions (0%, 40%, and 50%) as substitutes for cement in RCC mixtures	Ordinary Portland cement, Fly ash sourced from the Paiton steam-electric power station located in East Java, Indonesia.	It is possible to use fly ash as a partial replacement for cement in RCC while maintaining workability. All mixtures were found to be workable according to the Vebe time test, meeting RCC criteria. After 28 days, the highest compressive strength and splitting tensile strength were observed with 40% fly ash used as a partial substitute for cement. References and associated material
		To investigate the workability of fresh concrete and the mechanical properties of hardened concrete with different percentages of fly ash.	Tests of splitting tensile strength and compressive strength on hardened concrete samples.		
2025	**[18]**	To assess the reactivity of three varieties of fly ash (derived from bituminous coal, sugarcane bagasse,	Thermogravimetry (TGA/DTG) to detect Portlandite	Utilized ashes from Bituminous coal (BIT), sugarcane	Coal and sugarcane bagasse ashes showed high contents of reactive SiO_2 and Al_2O_3 and were suitable substitutes for lime in construction materials.

		and hazardous waste) as supplementary cementitious materials through lime substitution in pastes.	decomposition.	bagasse (CAN), and hazardous waste (UHW and THW).	
		To assess the contribution to the circular economy by reducing environmental impact and promoting sustainable construction.	Scanning Electron Microscopy (SEM) for microstructure observation.		Fly ash replacements contribute to lowering CO_2 emissions and reduce natural resource depletion in the cement industry.

This study explores the use of supplementary cementitious materials (SCMs) like fly ash and limestone powder to make green concrete, eliminating the need for traditional cement ingredients. One key objective is to substitute fly ash and limestone powder for cement, enhancing the sustainability of concrete. Research by [9] and [10] demonstrates that combining lime powder (LSP) with zinc phosphate (ZP) and using recycled concrete aggregates (RCA) can improve compressive strength and workability, while reducing porosity and shrinkage. The study also investigates the mechanical characteristics of limestone powder and fly ash, showing improvements in concrete's strength and durability. Furthermore, Public-private partnerships (PPPs) in construction projects have been explored for their utilization, effectiveness, and challenges in Pakistan [19, 20]. The role of artificial intelligence (AI) in project management has also been explored, highlighting its influence on efficiency and decision-making in construction [21]. Moreover, the use of agro-industrial waste, such as sugarcane bagasse ash and silica fumes, as supplementary cementitious materials has demonstrated potential in enhancing concrete performance [22]. The combination of fly ash and hemp in concrete is contributing to eco-friendly building practices, further supporting sustainable construction methods [23].

The incorporation of SCMs not only improves mechanical properties but also reduces CO_2 emissions. Studies by [11] and [12] show that blends of calcined clay, fly ash, and limestone powder enhance compressive strength and workability while cutting CO_2 emissions. Additionally, research by [14] and [16] highlights how SCMs like calcined kaolinite clay and metakaolin improve durability by enhancing chloride resistance and reducing carbonation depth. These findings confirm that green concrete offers a promising solution for sustainable construction with improved performance and reduced environmental impact.

This study presents an economical and environmentally friendly substitute for regular Portland cement (OPC) for black stabilizing cotton soil (BCS) by mixing limestone calcined clay cement (LC3) with bagasse ash (BA). It demonstrates that BA incorporating LC3 enhances soil strength, reduces swelling, and improves durability, while significantly lowering carbon emissions. Unlike previous studies, it explores the combined effects of BA and LC3, bridging a key knowledge gap. The research confirms that BA with 40% LC3 at a 0.50 water-cement ratio provides optimal performance, making it a viable, eco-friendly solution for geotechnical construction, particularly in developing regions [24]. The significance of green concrete using fly ash and limestone powder lies in its ability to reduce cement consumption, lower CO_2 emissions, and promote sustainable construction. By utilizing industrial by-products and natural fillers, this approach enhances durability, workability, and cost-effectiveness while minimizing environmental impact. The novelty of future research focuses on advanced material combinations, 3D-printable concrete, carbon sequestration, and self-healing technologies. Innovations such as nano-materials, alkali activation, and intelligent concrete will further enhance strength, resilience, and energy efficiency, paving the way for next-generation eco-friendly infrastructure.

METHODOLOGY:

A systematic process is used to assure sustainability, durability, and performance while making green concrete with fly ash and limestone powder. When making green concrete with fly ash and limestone powder, a methodical process was used to guarantee sustainability, performance, and durability. Limestone powder serves as a filler to increase workability and lower cement consumption, while fly ash, a pozzolanic substance, improves long-term strength. Water, fine and coarse aggregates, and, if required, chemical admixtures like accelerators (to increase early strength) and superplasticizers (to improve flowability) were mixed with these materials. The fly ash, limestone powder, and some Portland cement were first mixed using dry mixing. Wet mixing came next, in which water and aggregates were added gradually while keeping the water-to-cementitious ratio between 0.35 and 0.45.[25]A nominal mix ratio of 1:2:4 (cement:sand: coarse aggregate) was used to create M15-grade concrete, with fly ash accounting for 5% and limestone powder for 15% of the cement. After being poured into molds, the freshly mixed concrete was allowed to cure for 7, 14, and 28 days. The specimens were examined for compressive strength, water absorption, shrinkage, and workability (slump test) after curing. Furthermore, estimates of CO_2 reduction were used to assess the environmental impact of partial cement replacement, confirming the green concrete mix's ecological advantages.[26].

MANUFACTURING PROCESS:

Preparation of Raw Materials: Keep fly ash and limestone powder in different silos. Make sure the aggregates are properly graded and dried. Clean and process recycled aggregates to get rid of contaminants.

Material Preparation:

The following supplies were employed in the investigation:
The ratio of concrete mix is 1: 2: 4. Five percent of the cementitious ingredient is fly ash 15% of the total cementitious material is made up of limestone powder. The water-to-cementitious ratio is determined by the materials' reactivity. 60% and 65% of the overall volume is made up of aggregates.

MATERIALS PROPERTIES:

CEMENT: Any kind of adhesive material, in general; however, in a more focused context, the binding agents utilized in the construction. When mixed with water, the finely ground particles that make up this kind of cement solidify into a hard mass. Hydration, a chemical process, produces a high surface area gel or submicroscopic crystals by mixing cement ingredients with water and causing setting and hardening. Because of their hydrating properties, which even enable them to set and solidify in water, construction cements are commonly referred to as hydraulic cements. The most important of these is Portland cement.

Table 1. Properties of Cement

SR.NO	PROPERTY	VALUE
1.	Specific gravity	3.15
2.	Initial setting time	33 Min
3.	Final setting time	600 Min

Fig 1. 43 Grade Cement

In this research, we used 43 Grade cement as a replacement. Ordinary Portland Cement (OPC) of this kind is frequently utilized in regular construction projects. OPC is appropriate for a variety of building applications due to its strength, durability, and adaptability.

Table 2. Characteristics of Fine Aggregate

SR.NO	PROPERTY	VALUE
1.	Specific Gravity	2.53
2.	Water absorption	0.5% - 2.0%
3.	Particle shape	Sub-angled to rounded
4.	Sieve size	4.75 mm

Table 3. Characteristics of Course Aggregate

SR.NO	PROPERTY	VALUE
1.	Specific Gravity	2.90
2.	Maximum size	10mm - 20 mm
3.	Water absorption	0.1% - 2.0%

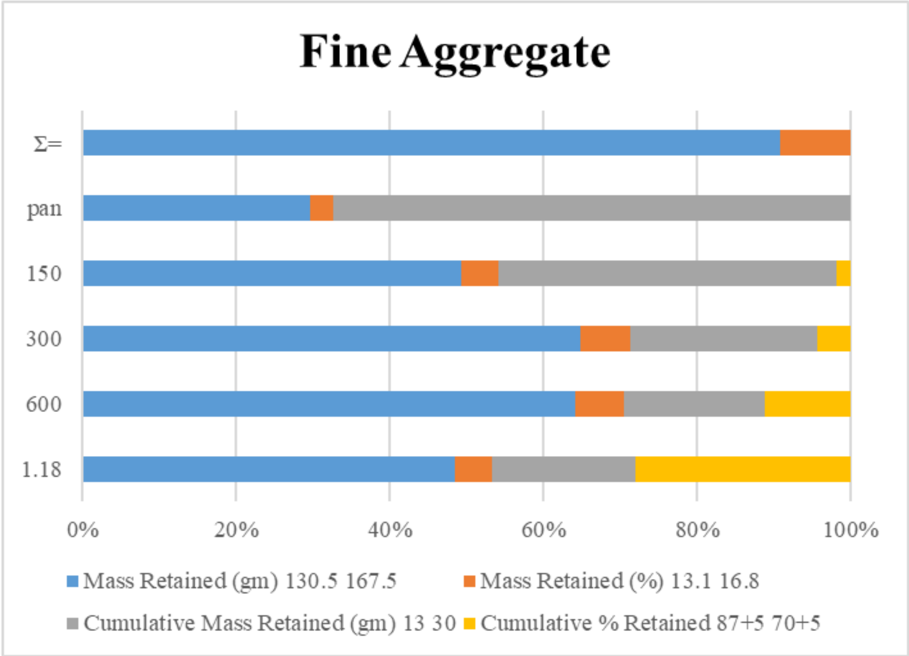
Table 4:Sieve Analysis of Fine Aggregate

Sieve Size (mm)	Mass Retained (gm)	Mass Retained (%)	Cumulative Mass Retained (gm)	Cumulative % Retained	Cumulative % passing
4.75	130.5	13.1	13	87+5	95-100
2.36	167.5	16.8	30	70+5	80-100
1.18	103.5	10.4	40	60	50-85
600	217	21.8	62	38	25-60
300	226.5	22.7	85	15	10-30
150	107.5	10.8	96	4	2-10
pan	44	4.4	100	0	----
Σ=	996.5	100.000			

The total retained weight and the weight of the original sample are calculated as follows:

$$\frac{1000 - 996.5}{1000} = \times 100 = 0.35\%$$

The Fineness Modulus is calculated as follows: F.M = (13 + 20 + 40 + 62 + 85 + 96 + 100) × 100 / 3 = 100. Thus, based on the (F.M.), the average size of our sample is (0.6 mm).



(a)

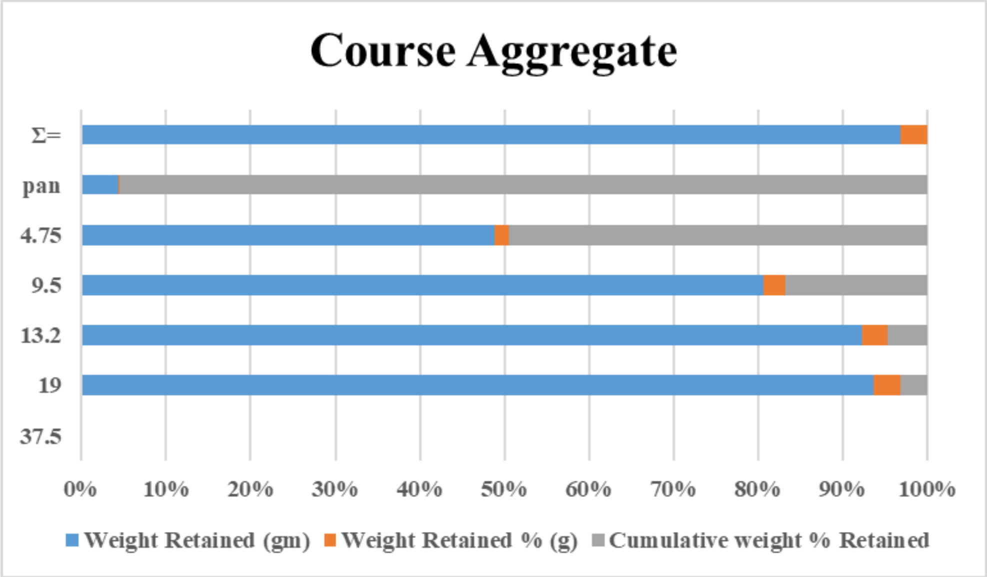
Table 4:Sieve Analysis of Course Aggregate

Sieve Size (mm)	Weight Retained (gm)	Weight Retained% % (g)	Cumulative weight% % Retained	Cumulative % passing	Specification of the limit
37.5	0	0.0	0	100	95-100
19	825.5	27.5	28	72-5	35-70
13.2	1603	53.5	81	19	----
9.5	466.5	15.6	97	3+5	10-30
4.75	98.5	3.3	100	0	0-5
pan	4.5	0.2	100	0	----
Σ=	2998.5	100.000			

The retained weight and the original sample weight are calculated as follows:

$$\frac{3000-2998.5}{3000} \times 100 = 0.05\%$$

The maximum size of the sieve that is coarser than the one retaining 15% is 13.2 mm.



(b)

Fig 2:Sieve Analysis of fine & coarse aggregate graph (a) fine (b) coarse

(a) **(b)**

Fig 3:Sieve Analysis of Course Aggregate (a) Course (b) fine

FLYASH: Fly ash is a significant by-product of the operations of coal-fired power plants. The finely separated particles are extracted from the exhaust gases using electrostatic precipitators. We call these particles fly ash. Fly ash is the most widely used pozzolanic material worldwide. Every year, about 75 million tons of fly ash are produced, and disposing of it has become a major problem. In India, only about 5% of fly ash is used; the remainder needs to be disposed of. Approximately 1.5 tons of raw materials are needed to make 1 ton of Portland cement, and 1 ton of CO_2 is released into the atmosphere during production.

Table 5: Properties of Fly ash

SR.NO	PROPERTY	VALUE
1.	Specific Gravity	2.1–2.7
2.	Initial Setting Time	90 minutes
3.	Final Setting Time	750 - 850 Min
4.	Fineness (retained)	45 (µm sieve)
5.	Strength contribution	Increases strength over a long curing period (28 to 90 days)
6.	Environmental benefits	Reduces CO_2 emissions

Fig 4: Fy Ash{ burned coal}

LIMESTONE POWDER: is composed of fine calcium carbonate (CaCO3) and crushed limestone. In green concrete, it is commonly used to partially replace cement, improving workability and sustainability while lowering shrinkage. The filler action of limestone powder increases the packing density of concrete, resulting in a denser microstructure and reduced water consumption. Fly ash or other additional cementitious materials are frequently mixed with limestone powder in sustainable concrete to further lower the CO2 emissions linked to conventional cement. This combination produces environmentally friendly, reasonably priced concrete with enhanced performance qualities[27].

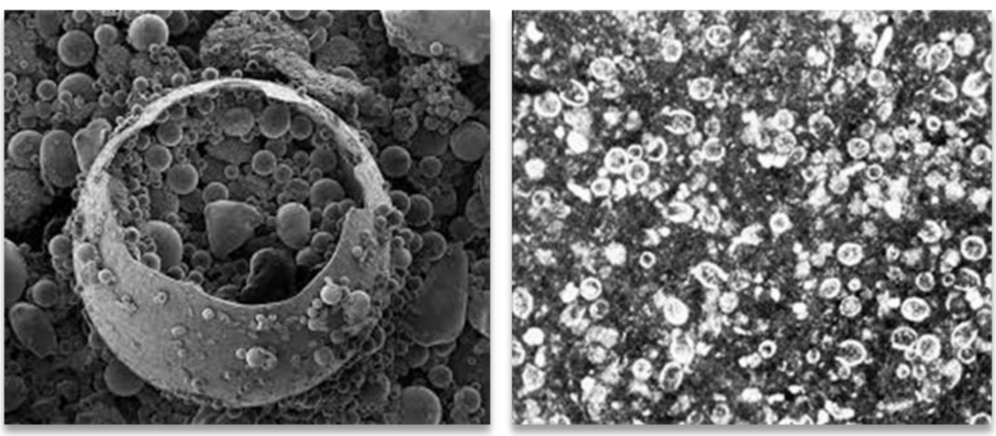
Table 6: Properties of LIMESTONE

SR.NO	PROPERTY	VALUE
1.	Specific Gravity	**2.6 – 2.7**
2.	Initial Setting Time	30-60 minutes
3.	Final Setting Time	650 Min
4.	Fineness (retained)	90 (µm sieve)

Fig 5: Lime Stone Powder

CHARACTERISTICS OF FLY ASH AND LIME

Fly ash and limestone powder are two popular additives used to make green concrete, and each one gives the combination unique properties. It gradually reacts with calcium hydroxide in the presence of water to produce additional cementitious compounds over time. This pozzolanic reaction enhances the long-term strength and durability of concrete. Fly ash particles require less water in the mixture and enhance workability because of their diminutive dimensions and ball-like form. Fly ash, however, needs long curing times to reach peak performance because of its delayed reactivity, which means it makes little contribution to early strength development. On the other hand, calcium carbonate makes up the majority of limestone powder, which is a non-pozzolanic filler. It contributes significantly to the workability, cohesion, and flexibility of fresh concrete without undergoing a chemical reaction to produce compounds that increase strength. Its tiny particle size increases packing density and decreases porosity by filling in spaces between bigger cement and aggregate particles. Limestone powder does not substantially add to long-term strength, even though it can slightly increase early-age strength by offering nucleation sites. Consequently, fly ash gradually increases the strength of green concrete, whereas limestone powder improves workability throughout the process. By combining them, concrete's fresh and hardened qualities may be better controlled, its cement content can be decreased, and sustainability is enhanced.



(a) **(b)**

Fig. 6: Scanning electron micrographs for (a) fly ash and (b) lime

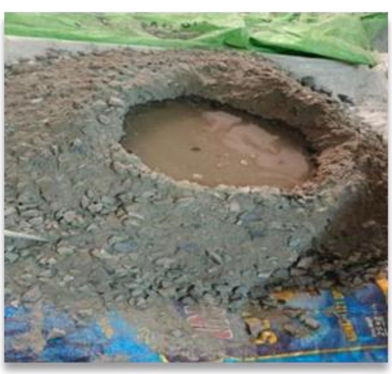
➢ **<u>Mixing Process</u>**

1. Dry Mix: First, mix fly ash, limestone powder, and cement (if used) in a concrete mixer.
2. Add Aggregates: Add coarse and fine aggregates to the mix.
3. Water & Admixtures: Gradually add water and superplasticizers for better flow and workability.
4. Mixing Time: 3-5 minutes to ensure uniform consistency. Molding & Curing
5. Pour the mix into molds or formwork.

Flow Chart of Green Concrete Manufacturing

SAND + CEMENT ADD LIMESTONE POWDER

ADD FLY ASH



MAKE A MIXTURE

POUR IN MOULD

➢ **Curing Methods**:

1. Wet curing for at least 7-28 days for durability.
2. CO_2 curing (carbonation curing) for ultra-low carbon concrete.

Fig 7: Moulds in Curing Tank 650L

Test Methods:

Further quality tests and performance of green concrete:

a. Slump test: Measures the workability of the concrete using the Slump Cone Apparatus, which includes a metal cone, a tamping rod, and a base plate.
b. The compression strength test: Determines the concrete's compressive strength using UTM.

Preparation: When doing research in a laboratory, test objects in the shape of concrete blocks are created using the laboratory experimental method. The Punjab Tianjin University of Technology will be the site of this study. Standard cube and cylinder molds were used to cast the concrete specimens, which were then examined after 7, 14, and 28 days for:

1. Workability (test of slump)
2. Compressive force
3. Durability tests (sulfate attack resistance, water absorption)

➢ LAB MACHINES AND EQUIPMENT

Fig 8:Precision Digital Weighing Balance

Fig 9:Hand Trowel or Spatula

Fig 10:Sieve Shaker **Fig 11:Curing Tank: 650L** **Fig 12:Vibrating**

Table

CONCRETE MIXER

MODEL NO: 55-CO199/9A

Applications: Pan-type models have been selected for use in laboratories to prepare concrete specimens and samples. They ensure the best possible homogeneity and efficient blending.

Fig 13: Concrete Mixer

HOT AIR OVEN: MODEL NO: 10-D1398

Ovens can be used for Sample Drying. Evaporated and Dehydration..Lab Oven used for Drying Asphalt, Soil, and Concrete Samples. Temperature range (0°C to 200°C). Capacity of the drying chamber (780 Liters)

1. Shelves (3) **2.**Weight (200 kg)

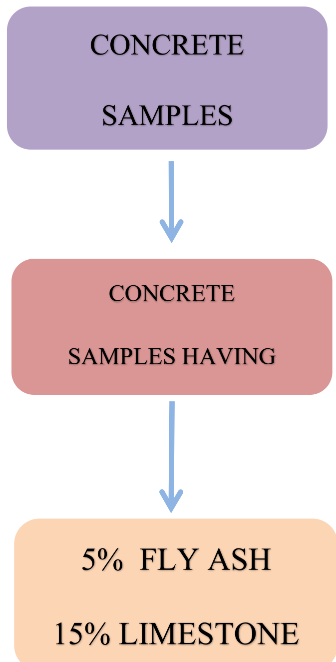
Fig 14:Hot Air Oven

TEST STANDARDS:

Table 7: Standards of tests

Sr. No	Name of test	Standards
1.	**Slump test**	ASTM C143 / IS 1199
2.	**Compressive strength test**	ASTMC39/C39M
3.	**Tensile strength test**	ASTMC496/C496M
4.	**Durability test**	ASTM C1012 / IS 456

TEST PROGRAM:



SLUMP TEST:

Fresh Concrete Tests (Before Setting)

Slum cone: Uses a slump cone to gauge how workable the concrete is.

Workability Slump Test: Verifies that the mixture pours smoothly into molds. Setting Time Test: This test makes sure that the timing is correct because fly ash can cause delays in setting. For self-compacting mixes, the flow table test guarantees smooth mold filling.

Fig 15: Slump Cone

. Here's the analysis of the slump test result:

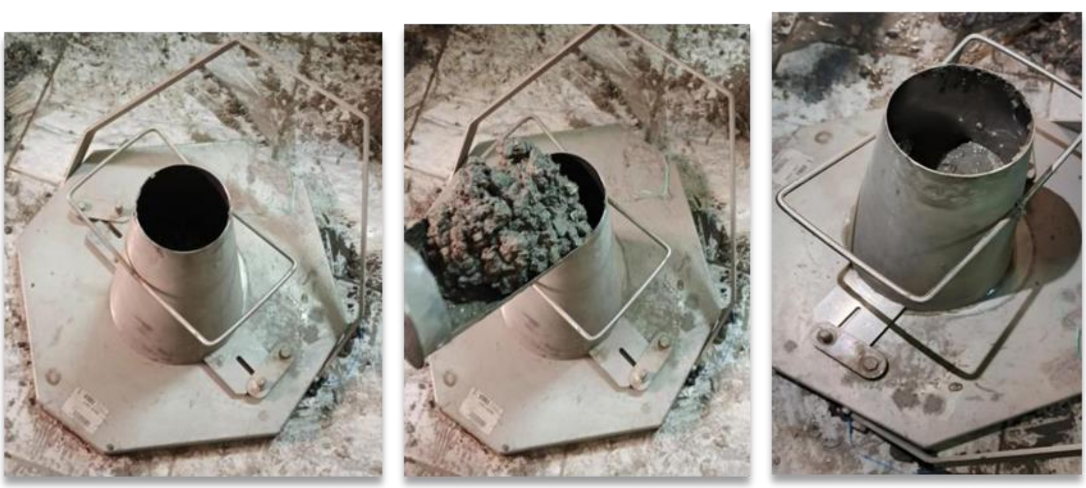
To measure the height, a ruler is positioned close to the concrete. About 17.5 cm is where the top of the slumping concrete is located. The standard height of a slump cone is 30 cm.

Slump Calculation:

Slump=30 cm−17.5 cm=12.5 cm

Slump Value: 12.5 cm

A slump of 12.5 cm indicates good workability, Suitable for structures with moderate reinforcement, Easy to place and compact without segregation. This slump is typical for general reinforced concrete work, such as beams, slabs, and columns.



(a) **(b)** **(c)**

(d) **(e)** **(f)**

Slump Test

(g) **(h)** **(i)**

Fig 16: Fresh Concrete Tests {a,b,c,d,f,g, i}

Hardened Concrete Tests (After Curing):

As seen in the image, a Universal Testing Machine (UTM) is used to test the mechanical properties of materials. It is capable of performing several static tests, including: Test of Compressive Strength (7, 14, 28 Days). Guarantees that strength is attained for use in molds. Mold resistance to moisture is ensured by the water absorption test. Shrinkage Test: This test verifies that fly ash may lessen shrinkage. These are a few pictures of a compressive strength test:

(a) (b) (c)

Fig 17: Compressive Strength Test in Universal testing machine{a,b,c}

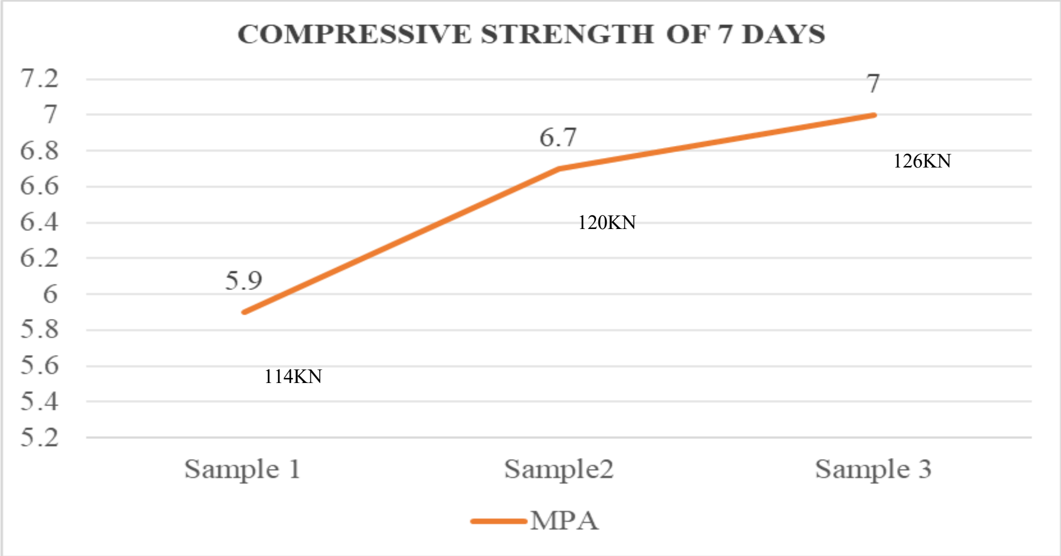


Fig 18: After seven days, the compressive strength test

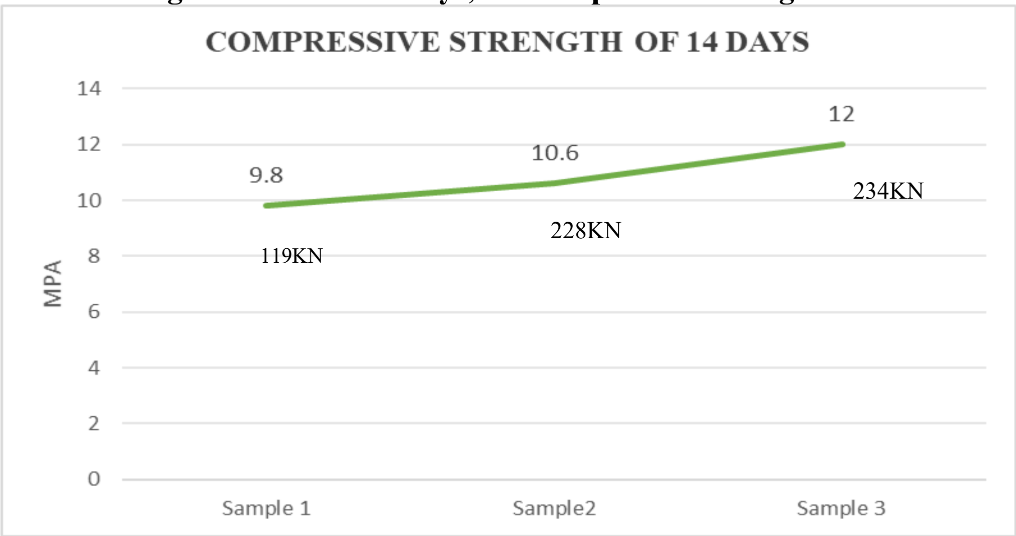


Fig 19: Test of compressive strength after 14 days

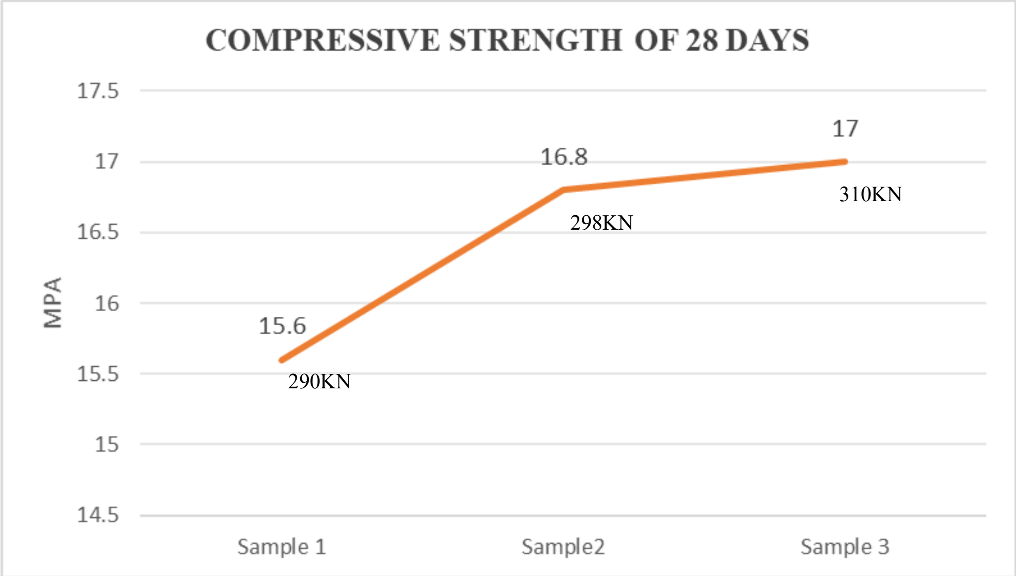


Fig 20:Test of compressive strength after 28 days

RESULTS

Table 8: Standards of tests

SR. NO	NAME OF TEST	RESULTS		
1.	Slump test	12.5 cm (Good Workability)		
2.	Compressive strength test	**7 days:** 6.5 MPA	**14 days:** 10.8 MPA	**28 days:** 16.4 MPA

A nominal mix design that corresponds to M15-grade concrete was employed in this investigation. The main binder was Ordinary Portland Cement (OPC) of grade 43, with fly ash and 15% limestone powder used as partial substitutes. Tests of compressive strength were performed at 7, 14, and 28 days. The findings showed that the respective compressive strengths were 6.5 MPa, 10.8 MPa, and 16.4 MPa. According to these results, the modified mix satisfies and even surpasses the 15 MPa strength requirement for M15-grade concrete. Fly ash increased long-term strength through pozzolanic reactions, and the addition of limestone powder improved workability and density. Overall performance shows that this green concrete mix is both environmentally friendly and structurally sound, despite early-age strength development being a little slower.

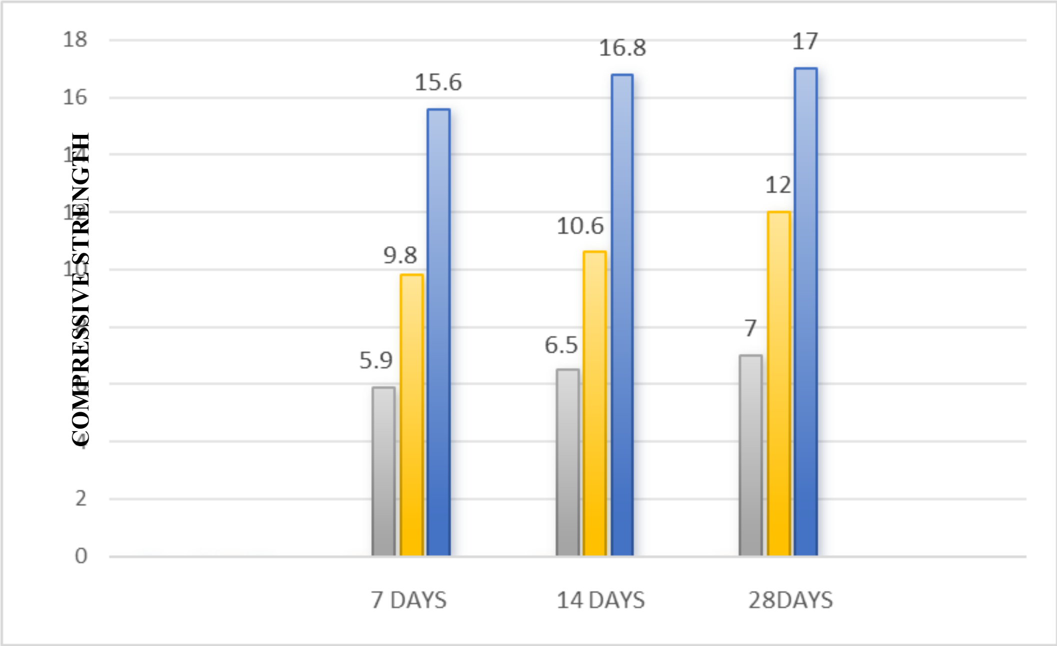


Fig 21: Compressive strength test of (7,14,28 days)

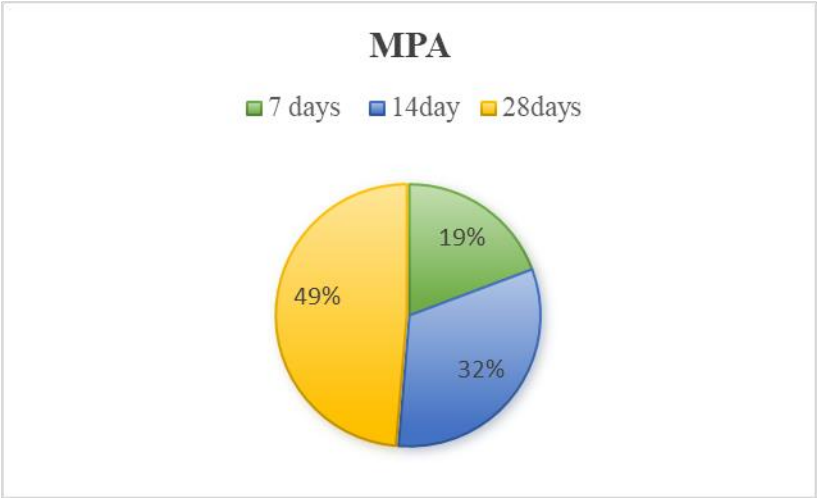


Fig 22: Pie Chart (%)

DISCUSSION

In the process of making green concrete, fly ash and limestone powder drastically cut down on the amount of cement used, which improves sustainability and lowers carbon emissions. While limestone powder serves as a filler, enhancing workability and compactness, fly ash, a pozzolanic substance, combines with calcium hydroxide to improve long-term strength and durability. When these ingredients are combined, they improve workability, durability, and resistance to chemical attacks, making it a viable and environmentally responsible substitute for conventional concrete. However, compared to conventional Portland cement (OPC), concrete with a high fly ash component gains strength more slowly in the beginning, which could affect construction schedules. For both structural and non-structural uses in green infrastructure, the optimum mix design guarantees a balance between sustainability and mechanical performance. The proportion of replacement, curing time, and mix design all affect the compressive strength (MPa) of concrete blocks made with fly ash and limestone in place of cement. These are approximate strength values derived from studies and real-world uses. Concrete samples made using a nominal M15 grade concrete mix that contained 15% lime and 5% fly ash as partial cement substitutes were subjected to a compressive strength test. The measured values were 6.5 MPa at 7 days, 10.8 MPa at 14 days, and 16.4 MPa at 28 days. As is common with concrete development, these results demonstrate a progressive increase in compressive strength with curing time. Crucially, the modified mix not only meets but slightly exceeds the necessary standard, as evidenced by the 28-day strength of 16.4 MPa, which is higher than the target strength for M15 grade concrete (15 MPa)[28]. The kind of supplementary cementitious materials (SCMs) used is a significant factor affecting the concrete mix's strength development. Lime and fly ash were used in this study as partial cement substitutes. Although fly ash's pozzolanic nature is generally recognized to contribute to strength gain at later ages, and lime primarily improves workability and early hydration, the results obtained here indicate that the combination of 15% lime and 5% fly ash was effective even after a 28-day curing period[29]. The mix not only met but also marginally exceeded the expected strength for M15 grade concrete, as evidenced by the 28-day compressive strength result of 16.4 MPa. This implies that the ideal quantity of fly ash was utilized, enough to aid in the development of strength through pozzolanic reactions without unduly delaying it. Furthermore, adding lime probably enhanced the fineness and particle packing, which raised density and improved microstructure and helped to increase strength both early and later. It is highly probable that the compressive strength will continue to rise after 28 days based on my mix design (5% fly ash and 15% lime), particularly because fly ash's pozzolanic reaction is known to occur more slowly than regular Portland cement's hydration.[30] The particular mixture and ratios employed here worked well within the typical 28-day testing window, despite common worries about delayed strength gain when using fly ash.

This illustrates how carefully chosen and balanced SCMs can improve concrete mix performance, promoting sustainable building practices without sacrificing structural soundness.

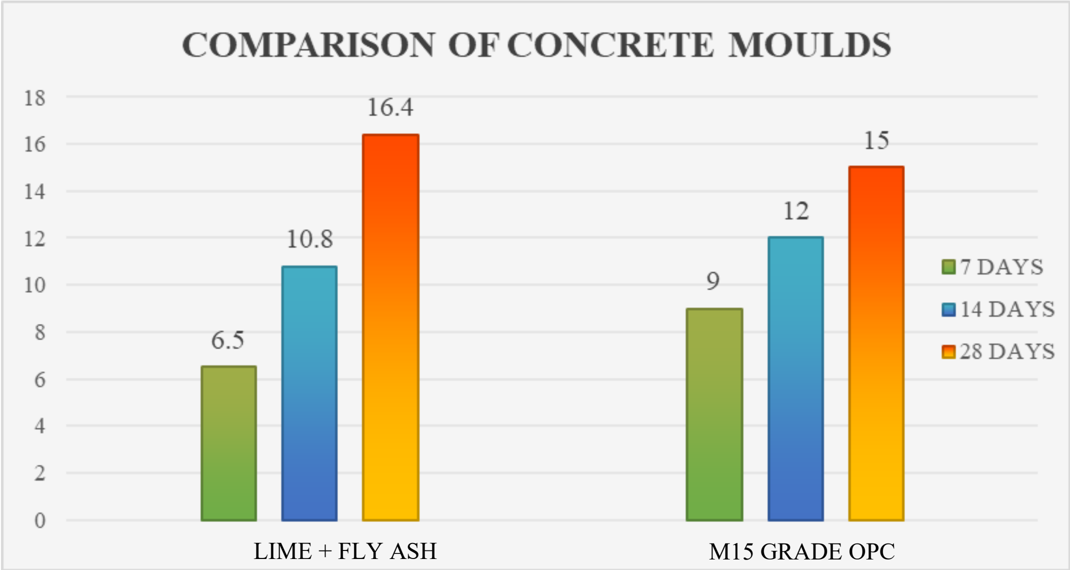


Fig.22: Comparison of concrete moulds (lime+fly ASH/ (15 grade) OPC)

There is a noticeable difference in the strength development over time between the modified concrete mix (which contains 15% lime and 5% fly ash) and the standard control mix when comparing their compressive strengths. Because fly ash's pozzolanic activity is delayed, the modified mix's compressive strength at 7 days was 6.5 MPa, while the control mix's was 9 MPa. This suggests a slower early-age strength gain. After 14 days, the modified mix's pressure was 10.8 MPa, which was still marginally lower than the control's 12 MPa. At 28 days, however, the modified mix outperformed the control with a strength of 16.4 MPa, whereas the control mix only managed to reach 15 MPa[31]. This pattern demonstrates fly ash's potential for long-term strength when used in place of some of the cement. It is anticipated that the modified mix's compressive strength will continue to rise after 28 days, possibly reaching noticeably higher values after 56 or even 90 days because fly ash reacts more slowly and adds strength at later stages of curing. Lime also improves density and workability, which over time increases strength. These findings support the sustainability and long-term advantages of using fly ash and lime in concrete.

According to the experimental findings and previous research, such as the study "Compare the Strength of Cement Mortar vs. Lime Mortar," [32] lime mainly serves as a filler agent that increases the concrete mix's density and plasticity. It improves the mix's cohesiveness and workability, which is especially advantageous in applications where application ease is crucial, like plaster and masonry mortar. Lime, however, lacks the pozzolanic or cementitious qualities necessary to significantly enhance the strength development of concrete[33].

The research paper explicitly states that "the addition of lime does not increase the strength of concrete, it only increases the density and workability"[34]. Lime works best when used in balanced amounts with reactive additional elements like fly ash to create structural grade green concrete[35].

This corresponds to the test findings in this paper, where a concrete mix with 15% lime and 5% fly ash produced a 28-day compressive strength of 16.4 MPa, marginally above the control mix strength of 15 MPa. This strength indicates that the altered mix could be used in structural applications where moderate load-bearing capacity is acceptable and is sufficient for M15 grade concrete. While fly ash helped to increase strength over time, lime enhanced density and workability. These findings show that, when used in appropriate ratios, lime and fly ash can efficiently replace some of the cement without affecting the performance of the concrete.

The observed 28-day compressive strength of 16.4 MPa in the modified mix reflects the long-term strength development potential of fly ash. While lime itself does not significantly contribute to strength through chemical reactions, it acts as a filler that enhances particle packing and improves early-stage workability. Fly ash, a pozzolanic material, reacts more slowly with calcium hydroxide released from cement hydration and continues to develop strength beyond 28 days. Given the positive trend observed in this study, it is expected that the compressive strength of this mix will continue to increase with longer curing durations, potentially showing further gains at 56 or 90 days.[36]Therefore, combining lime and fly ash in a balanced ratio can offer a sustainable and cost-effective alternative in concrete production, particularly for M15 grade applications.

In contrast, fly ash, a pozzolanic material, reacts slowly with calcium hydroxide released during cement hydration and contributes to strength development over a longer curing period, often beyond 28 days. Based on engineering implications, such a mix may not be ideal for applications requiring high early strength, but it proves to be effective for situations like mass concrete or non-structural applications where long-term strength development is prioritized over early performance. This highlights the importance of aligning material choices, such as the inclusion of fly ash and lime, with the performance requirements and timeline of the specific construction project. Proper planning can harness the environmental and economic benefits of such sustainable mixes without compromising structural reliability in the long term.[37].

Mix designs must carefully balance cement replacements with proper reactivity and curing procedures to meet conventional strength requirements for structural applications within the usual 28-day design window. The concrete mix used in this study, which contained 15% lime and 5% fly ash, had a 28-day compressive strength of 16.4 MPa, which is slightly higher than the nominal M15 control mix's strength of 15 MPa. This suggests that appropriate proportions and curing can produce acceptable structural-grade performance even when cement is partially replaced.

There are several reasons for the positive strength result. Although it makes a minimal contribution to the long-term development of strength, finely crushed limestone, or lime, is mainly used as a micro-filler, enhancing particle packing and workability in the early stages. In contrast, fly ash is a pozzolanic substance that gradually combines with calcium hydroxide to increase strength after 28 days. According to this delayed reactivity, strength could increase even more at 56 or 90 days, particularly in the presence of ideal curing conditions.

Using limestone powder as a partial cement replacement at 5–15% usually maintains or slightly improves compressive strength, while higher levels (20–30%) tend to dilute the binder and reduce strength, according to established engineering data.

Similarly, because fly ash is pozzolanic, replacements between 15 and 30 percent can increase long-term strength, while replacements between 40 and 50 percent may reduce early strength. Because of better workability and microstructure densification, the cautious application of 5% fly ash balanced with 15% lime in this instance proved advantageous for early strength gain.

However, careful control of the water-to-binder (w/b) ratio (ideally between 0.4 and 0.5), the use of superplasticizers, thorough compaction, and adequate curing are essential to consistently meeting or surpassing strength targets.

Any deviation, like inadequate curing or too much water, could lessen the strength gain and effectiveness of pozzolanic reactions. In the future, adding high-reactivity supplemental cementitious materials, increasing fly ash by a small amount to 10–15%, and lowering the lime content to 10–12% may all help to increase the strength potential of such green concrete mixes.

By using less cement, these modifications, along with the best curing times, will help guarantee that the concrete not only satisfies structural strength requirements but also advances sustainable building objectives.

CONCLUSION:

1. According to the study, it is both technically and environmentally advantageous to use 15% limestone powder and 5% fly ash in M15-grade concrete. The modified mix uses less cement and emits less CO_2 while meeting and surpassing required strength targets. Longer curing times (up to 90 days), different mix ratios, and the addition of chemical admixtures for improved performance should all be investigated in future research.
2. The sustainable potential of fly ash and lime concrete for both structural and non-structural uses is highlighted in this study. The strength attained indicates that it can be used for structural elements that bear light loads. The blend offers better workability, lower carbon emissions, and the possibility of long-term performance improvement. With the right curing and mix ratios, fly ash's pozzolanic activity and lime's filler effect help create a denser matrix that supports improved durability over time.
3. The use of lime concrete not only improves mechanical performance but also fits in nicely with international sustainability objectives. It supports healthier indoor environments, improves moisture and temperature regulation, and works well with conventional building techniques. However, careful consideration of the water-to-binder ratio, compaction, and curing is necessary to achieve consistent performance. When the lime-fly ash ratio is improved or more reactive SCMs are added, this mix design can be widely used in civil engineering projects where strength and environmental responsibility are top concerns.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study has several limitations that should be noted despite the encouraging results. A fixed replacement ratio of 15% lime and 5% fly ash was used in the design of the concrete mix, which might not be the best ratio for all structural applications. Fly ash is known to significantly increase strength after 28 days, but the strength development was only tracked for that long. As a result, there is still some untapped potential for long-term performance. Furthermore, considering the low reactivity of lime, the study did not include chemical admixtures, which could have improved workability and strength. The results may not be directly applicable to higher-grade concrete used in more demanding structural elements because the experimental scope was restricted to M15 nominal mix concrete. Additionally, environmental variables that could affect strength results, like temperature and humidity during curing, were not properly regulated. To maximize performance and increase applicability, future studies should investigate different replacement ratios, longer curing times (56 to 90 days), and the incorporation of admixtures.

FUTURE DIRECTIONS FOR RESEARCH:

To find the best ratios that strike a balance between early-age strength and long-term performance, future research should concentrate on optimizing the mix design by investigating different replacement levels of fly ash and lime. To fully capture the pozzolanic contribution of fly ash and evaluate its potential for long-term strength development, longer curing times than 28 days—especially up to 56 or 90 days—should be studied. The workability and mechanical qualities of green concrete may be greatly improved by adding chemical admixtures like superplasticizers, particularly when lower water-to-binder ratios are utilized. Furthermore, microstructural analysis methods like X-ray diffraction (XRD) and scanning electron microscopy (SEM) may offer a more profound understanding of the hydration processes and the creation of compounds that contribute to strength.

The feasibility of fly ash and lime concrete for structural and environmental applications would be further established by research into durability parameters like permeability, resistance to sulfate attack, and freeze-thaw cycles. To facilitate the broader use of green concrete in contemporary construction, future research should generally focus on improving the harmony between mechanical performance and environmental sustainability.

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