Partial Replacement of Cement with Fly ash in Concrete

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Abstract: This research investigates the utilization of fly ash, a byproduct of thermal power plants, as a partial replacement for cement in M25 concrete, aiming to enhance sustainability and mitigate environmental impact. The study focuses on evaluating the mechanical properties of concrete mixes incorporating varying percentages of fly ash, specifically 0%, 10%, 20%, 30%, and 40% by weight of cement. Compressive strength tests were conducted on concrete samples cured for 7, 14, and 28 days to assess the impact of fly ash on strength development over time. The experimental results revealed that the inclusion of fly ash significantly influences the compressive strength of M25 concrete. At early curing ages (7 days), mixes with higher fly ash percentages exhibited a slight reduction in compressive strength compared to the control mix (0% fly ash). However, as the curing period progressed, particularly at 28 days, a notable trend emerged. Concrete mixes incorporating fly ash demonstrated improved compressive strength, with the 20% and 30% fly ash replacement showing optimal performance. This indicates that fly ash contributes to long-term strength gain due to its pozzolanic reactions. By effectively utilizing this industrial byproduct, the environmental burden associated with cement production can be reduced, while simultaneously enhancing the long-term mechanical properties of concrete. Future research should explore the durability characteristics of these mixes and optimize the fly ash percentage for specific applications.

***Key Words*:** Fly Ash (FA), Workability, Compressive Strength, Split Tensile Strength, Flexural Strength.

INTRODUCTION

Concrete is a cornerstone of modern construction, essential for buildings and infrastructure. However, traditional concrete production, particularly cement manufacturing, contributes significantly to environmental concerns due to its high energy consumption and carbon dioxide emissions. Addressing these issues necessitates the exploration of sustainable alternatives and practices within the construction industry.

One promising approach is the partial replacement of cement with supplementary cementitious materials (SCMs), such as fly ash. Fly ash, a byproduct of coal combustion in thermal power plants, presents a valuable resource for enhancing concrete properties while mitigating environmental impacts. This material exhibits pozzolanic characteristics, reacting with calcium hydroxide in the presence of water to form cementitious compounds, thereby improving concrete strength, durability, and workability.

Fly ash is classified into Class F and Class C, depending on its calcium oxide content and the type of coal burned. Class F fly ash, derived from bituminous and anthracite coal, has lower calcium oxide content, while Class C fly ash, from sub-bituminous coal, has higher calcium oxide content. The use of fly ash in concrete offers several benefits, including reduced greenhouse gas emissions, improved workability, enhanced durability, and cost savings.

This research aims to investigate the effects of partially replacing cement with fly ash in concrete, focusing on its influence on workability, strength, and durability. By determining the optimal replacement percentages, this study seeks to promote the sustainable use of fly ash in concrete production, minimizing environmental impact while maintaining or enhancing structural performance. The study will evaluate parameters such as compressive strength, setting time, and long-term durability to assess the feasibility of fly ash as a viable cement substitute, contributing to greener and more sustainable construction practices.

HISTORY AND BACKGROUND

Concrete, a fundamental construction material, faces sustainability challenges due to the energy-intensive production of Portland cement, a major contributor to global CO_2 emissions. To mitigate this, supplementary cementitious materials (SCMs) like fly ash are explored. Fly ash, a byproduct of coal combustion, possesses pozzolanic properties, reacting with calcium hydroxide to enhance concrete strength and durability.Historically, the use of pozzolans dates back to ancient Roman concrete, demonstrating their long-term effectiveness. Fly ash incorporation reduces cement demand and offers technical benefits such as improved workability and durability. In India, projects like the Ghatghar Dam showcase fly ash's viability in large-scale infrastructure, with replacement levels reaching up to 70%.

Despite its advantages, variability in fly ash quality and potential delays in early-age strength development require careful consideration. This study aims to investigate the effects of partial cement replacement with fly ash, providing insights for sustainable concrete mix designs..

General Objective:

To investigate the feasibility and effectiveness of partially replacing cement with fly ash in concrete, aiming to enhance strength, durability, and workability while reducing environmental impact and construction costs.

Specific Objectives:

- Optimization of Fly Ash Content:To determine the ideal percentage of fly ash replacement (e.g., 10%, 20%, 30%, etc.) that provides the best balance between strength, durability, and workability.
- Mechanical Properties Analysis:To evaluate the compressive, tensile, and flexural strength of fly ash-based concrete at different curing ages (7, 14, 28 days).
- Durability Assessment:To study the resistance of fly ash concrete to sulfate attack, chloride penetration, water absorption, and acid exposure.
- Workability and Setting Time Evaluation:To analyze the slump value, flowability, and initial and final setting time of fly ash concrete compared to conventional concrete.
- Environmental Impact Analysis:To quantify the reduction in CO_2 emissions and natural resource consumption by replacing cement with fly ash.
- Economic Feasibility Study:To compare the cost-effectiveness of fly ash concrete with traditional concrete by assessing material costs, availability, and potential savings.
- Long-Term Performance Study:To investigate the structural integrity and durability of fly ash concrete under real-life exposure conditions.
- Standardization and Practical Implementation:To develop guidelines and recommendations for the safe and effective use of fly ash as a cement substitute, ensuring compliance with industry standards such as IS codes, ASTM, and ACI guidelines.

SCOPE OF THE STUDY

The study on the partial replacement of cement with fly ash in concrete focuses on evaluating its effects on the material's properties and sustainability. The scope of this experiment includes:

1.Material Selection:

- Use of Ordinary Portland Cement (OPC) as the primary binder.
- Utilization of Class F or Class C fly ash as a partial replacement for cement.
- Inclusion of aggregates, water, and admixtures (if necessary) for concrete mix preparation.

2.Replacement Levels:

Experimenting with different replacement percentages (e.g., 10%, 20%, 30%, and higher if applicable) to analyze the impact on concrete performance.

3.Concrete Properties Analyzed:

- Fresh Properties: Workability, setting time, and slump test.
- Mechanical Properties: Compressive strength, tensile strength, and flexural strength at different curing periods (7,14 and 28 days).
- Durability Properties: Water absorption, sulfate resistance, alkali-silica reaction, and permeability tests.

4.Testing Methods:

- Standardized tests as per ASTM, IS, or other relevant codes.
- Comparison of fly ash-based concrete with conventional concrete.

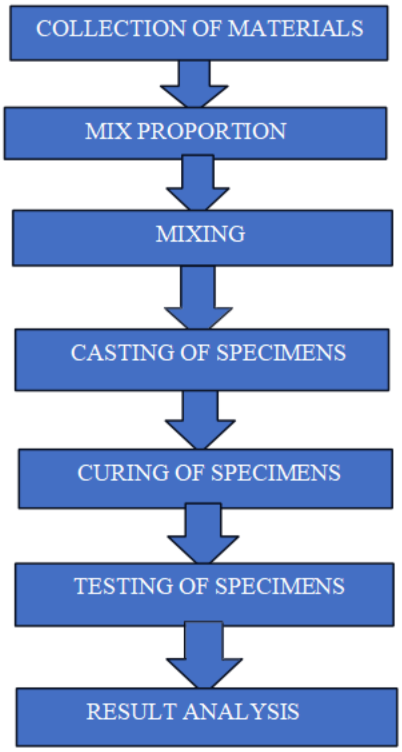
5.Environmental and Economic Assessment:

- Evaluation of CO_2 reduction and sustainability benefits.
- Cost comparison between conventional concrete and fly ash-modified concrete.

6.Applications:

- Suitability for different construction projects such as pavements, buildings, bridges, and precast concrete elements

METHODOLOGY



MATERIALS
1Cement
2.Fly Ash
3.Fine Aggregate
4. Coarse Aggregate
5.Water

1. Cement:

Cement is a material that has cohesive and adhesive properties in the presence of water. The main reason for using Ordinary Portland Cement in this study is that, this is by far the most common cement in use and is highly suitable for use in general concrete construction when there is no exposure to sulphates in the soil or groundwater These consist primarily of silicates and aluminates of lime obtained from limestone and clay. There are different types of cement, few of them are
. Ordinary Portland Cement . Portland Slag Cement

Ordinary Portland Cement (OPC)

Ordinary Portland Cement(OPC) is the basic Portland cement and is best suited for use in general concrete construction. It is of three types, 33 grade, 43 grade, 53 grade. One of the important benefits is the faster rate of development of strength. Portland slag cement is obtained by mixing Portland cement clinker, gypsum and granulated blast furnace slag in suit able 6 proportion and grinding the mixture to get a thorough and intimate mixture between the constituents. This type of cement can be used for all purposes just like OPC. It has lower heat of evolution and is more durable and can be used in mass concrete production..

Table : Test Results on Cement

S. No	Tests	Test results	Codal Values
1	Standard Consistency	32%	25%-35%
2	Specific Gravity	3.12	Range (3-3.15)
3	Fineness of Cement	9%	(not less than 10%)

2. FlyAsh

Fly ash, a coal combustion byproduct, serves as a sustainable cement replacement in concrete, reducing CO_2 emissions and enhancing durability. Its spherical particles improve workability and reduce water demand. This project evaluates fly ash's effectiveness in concrete, aiming to determine optimal replacement percentages. Using IS standards, various mixes with 10% to 40% fly ash are tested for workability, compressive, split tensile, and flexural strengths, as well as sulfate and chloride resistance. The results will identify the best fly ash ratio for balanced strength, durability, and environmental benefits.

Table : Test Results On Flyash

S. No	Tests	Test results	Codal Values
1	Specific Gravity	2.92	Range (2.5-3.0)

3. Fine Aggregate

Fine aggregate is material passing through an IS sieve that is less than 4.75 mm gauge be yond which they are known as coarse aggregate. Coarse aggregate form the main matrix of the concrete, whereas fine aggregate form the filler matrix between the coarse aggregate. The most important function of the fine aggregate is to provide workability and uniformity in the mixture. The fine aggregate also helps the cement paste to hold the coarse aggregate parti cle in suspension. According to IS 383:1970 the fine aggregate is being classified in to four different zone, that is Zone-I, Zone-II, Zone-III, Zone-IV. Also, in case of coarse aggregate maximum 20 mm coarse aggregate is suitable for concrete work. But where there is no restric tion 40 mm or large size may be permitted. In case of close reinforcement 10 mm size also used

Table: Grading Of Fine Aggregates (Is 383-1972) Percent Percentage Passing For Fine Aggregate

IS Sieve Size	Zone-I	Zone-II	Zone-III	Zone-IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 microns	15-34	35-39	60-79	80-100
300 microns	5-20	8-30	12-40	15-50
150 microns	1-10	0-10	0-10	0-15

Table : Test Results On Fine Aggregate

S. No	Tests	Test results	Codal Values
1	Specific Gravity	2.78	Range (2.6-2.9)
2	Fineness Modulus	3.08	Range (2.9-3.2)

4. Coarse Aggregate

concrete is a mixture of cementious material, aggregate, and water. Aggregate is commonly considered inert filler, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete. Although aggregate is considered inert filler, it is a necessary compo nent that defines the concrete's thermal and

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elastic properties and dimensional stability. The aggregate strength is an important factor in the selection of aggregate. The shape and texture of aggregate affects the properties of fresh concrete more than hardened concrete. Concrete is more workable when smooth and rounded aggregate is used instead of rough angular or elon gated aggregate. Two sizes of course are used one 16 mm passing through 12.5 mm retained and other 25 mm passing through 20 mm retained. As per IS: 2386-1963 recommendations the properties of coarse aggregates were determined.

Table Test Results On Coarse Aggregate

S. No	Tests	Test results	Codal Values
1	Specific Gravity	2.78	Range (2.6-2.9)
2	Fineness Modulus	6.71	Range (5.5-8.0) (coarse sand)

5. Water

Water to be used in the concrete work should have the following properties:

1.It should be free from injurious amount of oil, acids, alkaline, or other organic or inorganic impurities

2.It should be free from iron, vegetable matter or other any type of substances, which likely to have adverse effects on concrete or reinforcement.

DESIGN MIX

A mix M25 grade was designed as per IS 10262:2009 and the same was used to prepare the test samples

S.No	Concrete Type	Concrete Design Mix Proportion (By Weight)				Cement Replacement By Fly Ash
		W/C Ratio	C	F.A	C.A	
1	Mix 1	0.4	1	1.01	2.5	-
2	Mix 2	0.4	0.9	1.01	2.5	0.1
3	Mix 3	0.4	0.8	1.01	2.5	0.2
4	Mix 4	0.4	0.7	1.01	2.5	0.3
5	Mix 5	0.4	0.6	1.01	2.5	0.4

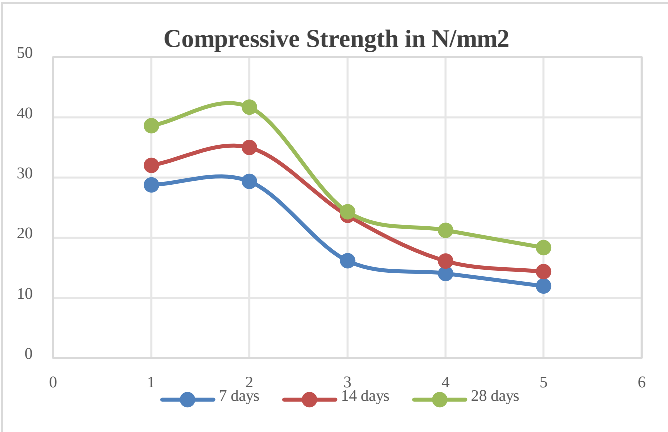
RESULTS AND DISCUSSIONS

COMPRESSION & SPLIT TEST

Standard metallic cube moulds (150*150*150 mm) were casted for compressive and split strength. A table vibrator was used for compaction of the hand filled concrete cubes.

Concrete grade	**Concrete type**	**Average ultimate compressive strength at**		
		7 days (N/mm^2)	**14 days (N/mm^2)**	**28 days (N/mm^2)**
M25	Mix 1	28.77	32	38.59
	Mix 2	29.33	34.96	41.67
	Mix 3	16.15	23.7	24.3
	Mix 4	14.04	16.11	21.22
	Mix 5	11.93	14.31	18.33

Fig: Compressive strength testing



Graph: Compressive strength

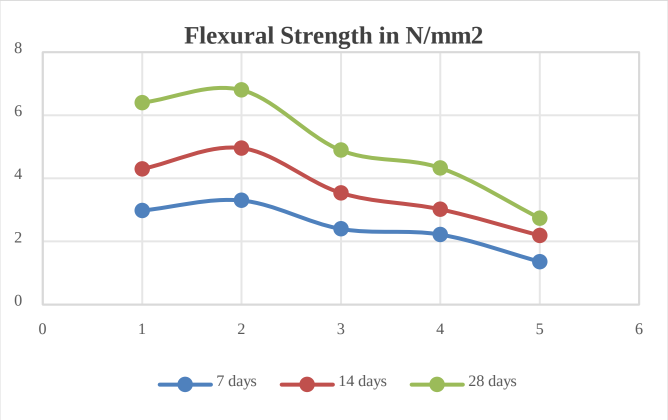
FLEXURAL STRENGTH (N/mm^2)

Flexural strength increased with curing time across all mixes, though fly ash inclusion generally reduced it compared to the control. Mix 2 (10% fly ash) showed a slight improvement over the control at later ages, indicating a complex fly ash influence on bending resistance.

Table: FlexuralStrength Values

Mix	**7 days**	**14 days**	**28 days**
Mix 1 (0% Fly ash)	2.98	4.3	6.4
Mix 2 (10% Fly ash)	3.3	4.96	6.8

Mix 3 (20% Fly ash)	2.4	3.54	4.89
Mix 4 (30% Fly ash)	2.22	3.02	4.33
Mix 5 (40% Fly ash)	1.36	2.19	2.74



Graph: FlexuralStrength

SPLIT TENSILE STRENGTH (N/mm^2)

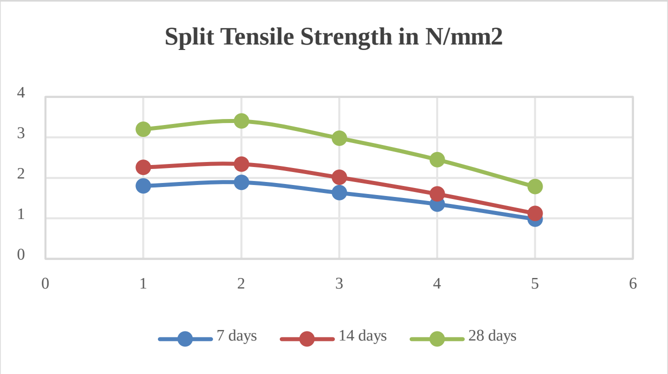
The specimens were demoulded after 24 hours and subsequently immersed in water for different age of testing. For each age three specimens were tested for the determination of average compressive and split strength. Test was performed on compression testing machine having capacity of 200 MT. Figurs show compressive and split strength testing setup on testing machine.

Fig: Split strength testing

Split tensile strength increased with curing, but fly ash generally lowered it. Mix 2 (10%) showed a slight improvement over the control at later ages. Higher fly ash percentages resulted in significantly reduced tensile strength, particularly at early ages.

Table: Split Tensile Strength

Mix	**7 days**	**14 days**	**28 days**
Mix 1 (0% Fly ash)	1.8	2.26	3.2
Mix 2 (10% Fly ash)	1.89	2.34	3.4
Mix 3 (20% Fly ash)	1.63	2.01	2.98
Mix 4 (30% Fly ash)	1.35	1.6	2.45
Mix 5 (40% Fly ash)	0.98	1.12	1.78



Graph: Split Tensile Strength

Conclusion:

This study investigated the impact of fly ash as a partial cement replacement in M25 concrete, focusing on compressive, flexural, and split tensile strengths at 7, 14, and 28 days.

Quantitative Analysis:

Compressive Strength:

The control mix (Mix 1, 0% fly ash) exhibited the highest compressive strength at all curing ages.

Mix 2 (10% fly ash) showed a slight increase in compressive strength compared to the control at 14 and 28 days, indicating a potential benefit at this replacement level.

Higher fly ash percentages (20%, 30%, 40%) resulted in a significant reduction in compressive strength, particularly at early ages.

Mix 1 compressive strength at 28 days was 38.59 N/mm^2.

Mix 2 compressive strength at 28 days was 41.67 N/mm^2.

Flexural Strength:

Flexural strength increased with curing time for all mixes.

Mix 2 (10% fly ash) demonstrated a marginal improvement over the control mix at later ages.

Higher fly ash percentages led to a decrease in flexural strength.
Mix 2 flexural strength at 28 days was 6.8 N//mm^2.

Split Tensile Strength:

Split tensile strength also increased with curing time.
Similar to flexural strength, Mix 2 (10% fly ash) showed a slight increase in split tensile strength compared to the control.
Higher fly ash percentages significantly reduced split tensile strength.
Mix 2 split tensile strength at 28 days was 3.4 N//mm^2.

Qualitative Analysis:

Fly ash incorporation, particularly at higher percentages, negatively impacted early-age strength development.
However, a 10% fly ash replacement (Mix 2) showed a slight improvement in compressive, flexural, and split tensile strengths at later ages, suggesting an optimal replacement range.
The study highlights the complex interaction between fly ash and concrete matrix, influencing strength development over time.

In conclusion, while fly ash offers sustainability benefits, its use in M25 concrete requires careful optimization to balance early-age strength concerns with long-term performance enhancements. The 10% replacement level yielded the most promising results, indicating its potential for practical applications.

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