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Utilization Of Fly Ash in Geopolymer Concrete for Sustainable Construction

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Abstract: The large – scale production of cement is posing environmental problems on one hand and unrestricted depletion of natural resources on the other hand. Each ton of Portland cement production results in loading about one ton of CO₂ in to the environment. Here, the present research work is focused on replacing the ordinary Portland cement in the concrete by fly ash. It is an eco-friendly alternate to cement. To enhance the performance of fly ash and increase early-stage strength an admixture sodium silicate is added. A total number of 12 cubes of size 150mm × 150mm × 150mm and a total number of 12 cylinders of diameter 150mm and height 300mm are prepared. The amount of fly ash used as a partial replacement ranges are 0%, 25%, 50%, 75% and 100%. The specimens are kept for curing at 7 days, 14 days and 28 days. After curing the mechanical properties of the specimen such as compressive strength and split tensile strength of the concrete are examined. The concrete with 25% replacement showed optimal performance.

I. Introduction

Fly ash, a by-product of coal combustion in thermal power plants, is a fine powder rich in silica and alumina making it a suitable precursor for geopolymerization. Unlike traditional Portland cement, which relies on hydration reactions, geopolymer concrete is produced through an alkali-activated reaction involving a highly alkaline solution. When fly ash is mixed with sodium silicate (Na₂SiO₃), the aluminosilicate compounds dissolve, undergo polycondensation, and form a rigid three-dimensional polymeric network, resulting in a hardened concrete-like material. Sodium silicate plays a crucial role in enhancing the geopolymerization process by providing additional silica, which strengthens the Si–O–Al bonds in the polymeric structure. This improves key mechanical properties, such as compressive strength, durability, and resistance to chemical attacks. Additionally, sodium silicate influences workability, setting time, and the rate of strength development, making it a vital component for optimizing the performance of geopolymer concrete. Utilizing fly ash-based geopolymer concrete presents significant environmental and economic advantages. It reduces reliance on cement production, which is a major source of CO₂ emissions, and promotes the beneficial reuse of industrial waste. Moreover, geopolymer concrete exhibits superior resistance to sulfate attack, lower permeability, and enhanced thermal stability, making it a viable alternative for sustainable construction applications. The integration of sodium silicate as an admixture further refines the mix design, ensuring a more efficient and durable geopolymer matrix suitable for modern infrastructure development.

II. Literature Review

This literature review examines existing studies on replacement of

cement with fly ash. This review aims to synthesize existing findings, identify gaps in knowledge, and provide a foundation for future research.

2.1 Properties of pervious concrete incorporating fly ash as partial replacement of cement: A review, Elnaz Khankhaje (2023)

They investigated the effects of fly ash on the properties of plain concrete and durability performance. They conducted the experiment for 10 – 50% replacement. Overall 10 – 30% has attained expected strength after that strength decreases. At 20% the concrete attains a higher strength. They concluded that the optimum substitution level of cement with Fly ash was obtained to be 10 – 30%. However, with increasing the level of replacement to higher than optimum (30–50%) affects the hydration procedure resulting a slower strength gain.

2.2 Experimental investigation on self – curing concrete with sodium lignosulphate by partial replacement of cement with fly ash”, Uppari Ramakrishna (2023)

They conducted an experiment to reduce the water usage. They utilized sodium lignosulphate as a self-curing agent and used fly ash as a replacement for cement to reduce the cost. The amount of fly ash used as a partial replacement ranges from 0% - 30%. They tested the specimen after 7, 14, and 28 days of curing. Their test results shows that at 20% replacement there is a biggest increase in the compressive strength.

2.3 Recycling of biomass and coal fly ash as cement replacement material and its effect on hydration and carbonation of concrete”, E. R. Teixeira (2019)

This paper focuses on the experimental study of hydration and

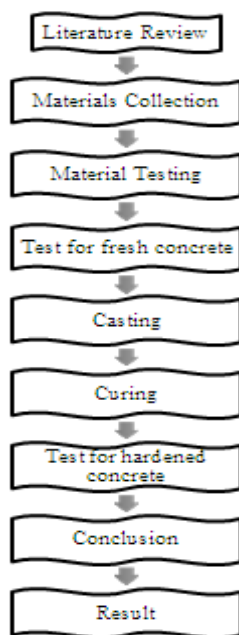
carbonation of cementitious pastes containing biomass fly ash and coal fly ash. Four different cement pastes were set which consists of 100% cement, 50% cement – 50% coal fly ash, 50% cement – 50% biomass fly ash, 50% cement – 25% coal fly ash – 25% biomass fly ash. The results showed that pastes with 50% cement and 50% biomass fly ash increases the hydration rate when compared to cement paste and pastes with coal fly ash.

2.4 Experimental and microstructural analysis on fly ash – GGBS based geopolymer concrete under ambient curing condition”, A. Krishna Rao (2023)

The authors investigated the effects of varying proportions of fly ash and Ground Granulated Blast Furnace Slag (GGBS) on the properties of geopolymer concrete (GPC). The specific mix examined contained 40% fly ash – 60% GGBS, 60% fly ash and 40% GGBS. The results indicated that increasing the GGBS content in the mix led to enhanced early-age compressive strength and a denser microstructure, as observed through Scanning Electron Microscopy (SEM) analysis. This suggests that incorporating higher percentages of GGBS in fly ash-based GPC can improve both mechanical and microstructural properties under ambient curing conditions.

III. Methodology

This chapter outlines the procedures followed to collect, analyse, and interpret data, ensuring the reliability and validity of the findings.



IV. Materials and Methods

The primary materials used in this study includes cement, sand, coarse aggregate, fly ash, sodium silicate and water. In this research different proportion of cement and fly ash are used with 25%, 50%, 75% and 100% replacement of cement with fly ash.

1. Cement

Cement is a key binding material in concrete, responsible for holding the aggregate (fine and coarse) together. Cement with fine aggregate produces mortar for masonry and cement with sand

and gravel produces concrete. Ordinary Portland Cement (OPC) grade 43 is used.

2. Fine Aggregate

Fine aggregate, commonly sand is used to fill voids between coarse aggregates in concrete, improving workability, strength, and durability. M sand is used here.

3. Coarse Aggregate

Coarse aggregate consists of crushed stone or gravel, providing strength, stability, and volume to concrete. It enhances load-bearing capacity and reduces shrinkage. 20mm size aggregate is used here.

4. Fly ash

Fly ash is a by-product of coal combustion used as a pozzolanic material in concrete. Class F fly ash is used in this project. It is used as a partial replacement for cement in various proportions. It improves workability, strength, durability, and resistance to chemical attacks while reducing cement use. It enhances long-term strength but may slightly delay setting time.

5. Sodium Silicate

Sodium silicate, also known as water glass, is used in concrete as a surface hardener, sealer, and accelerator. It improves strength, durability, and water resistance. It also reduces porosity and dust formation, making concrete surfaces more wear-resistant.

6. Water

Water is a crucial component in concrete, facilitating the hydration of cement to form a strong binding matrix. Only clean, potable water should be used. The water-cement ratio is critical - excess water weakens concrete, while insufficient water reduces workability.

V. Preparation of The Specimen

1. Mould

The mould is used to prepare the concrete cubes to test their compressive strength. The most common size is 150mm × 150mm × 150mm. The moulds consists of a main body, base plate and side clamps or bolts to ensure a tight leak-proof assembly. The mould must be cleaned after each use, oiled to prevent rusting, and stored in a dry environment.

2. Mixing

Mixing is the process of combining cement, fine aggregate, coarse aggregate, water and admixtures to achieve a uniform and workable mixture. Over-mixing can reduce workability, under-mixing leads to weak concrete.

3. Casting

Casting is the process of placing the freshly prepared concrete into moulds to achieve the desired shape and strength. The interior surface of the mould should be filled with crude oil before casting for easy demoulding. The concrete should be placed within the setting time of the concrete. It should be placed layer by layer.

4. Compaction

Compaction is the process of removing entrapped air to achieve a

dense, strong and durable structure. Compaction can be done using tamping rods or rammers. Proper compaction enhances strength, durability and impermeability preventing cracks.

5. Curing

Curing is the process of maintaining adequate moisture, temperature and time to ensure proper hydration of cement and achieve the desired strength and durability. Common curing method include water curing. The curing period of concrete is 7 days, 14 days and 28 days.

VI. Test for Hardened Concrete

Testing of hardened concrete is necessary to ensure that the concrete meets the required strength, durability and quality standards for safe and long-lasting structures. It helps in verifying whether the concrete mix design and curing process have achieved the desired strength. These tests also detect potential defects, cracks or weaknesses preventing structural failures. The compressive strength test is the most common, where concrete cubes are tested under compression to determine their load-bearing capacity.

6.1 Compressive Strength Test

The compressive strength test is a fundamental mechanical test used to determine the ability of a material to withstand axial compressive forces. It is necessary because,

1. It ensures the structural integrity, durability and safety of construction material.
2. Knowing their compressive strength helps in designing structures that can withstand applied forces without failure.
3. It also helps in quality control, ensuring that materials meet industry standards and perform as expected.

The test is conducted by applying a gradually increasing load to the specimen, until it fails. The maximum load sustained by the specimen before failure is recorded and divided by the cross-sectional area to obtain the compressive strength, typically expressed in mega pascals (MPa). The cubes used in this test is of the dimension 150mm × 150mm × 150mm. The cubes are tested after cured for 7 days, 14 days and 28 days. The results determines the strength of the concrete.



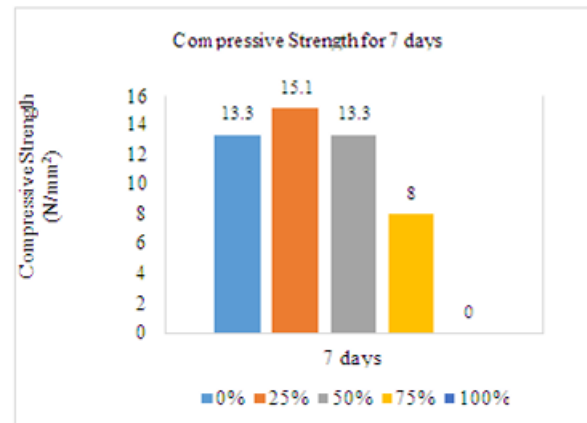
Figure 1: Compressive Strength Test

Formula:

$$\text{Compressive strength} = \frac{\text{Crushing load (KN)}}{\text{Area of cross section (m}^2\text{)}}$$

Table 1: Compressive Strength for 7 days

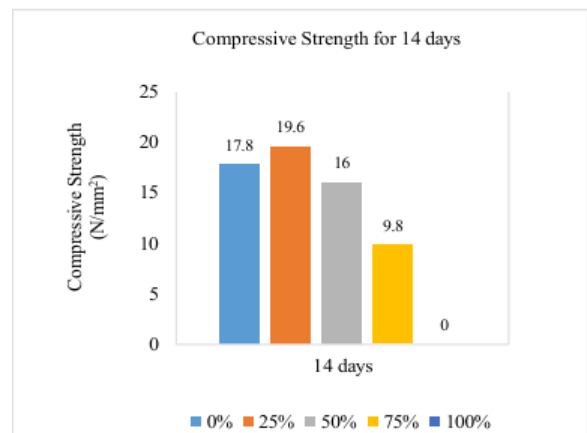
Sl. No	Replacement of cement with fly ash	7 days (N/mm ²)
1	0%	13.3
2	25%	15.1
3	50%	13.3
4	75%	8
5	100%	0



Graph 1: Compressive Strength for 7 days

Table 2: Compressive Strength for 14 days

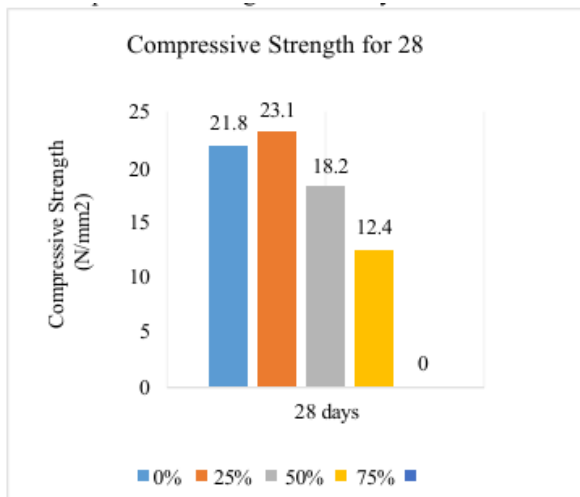
Sl. No	Replacement of cement with fly ash	14 days (N/mm ²)
1	0%	17.8
2	25%	19.6
3	50%	16
4	75%	9.8
5	100%	0



Graph 2: Compressive Strength for 14 days

Table 3: Compressive Strength for 28 days

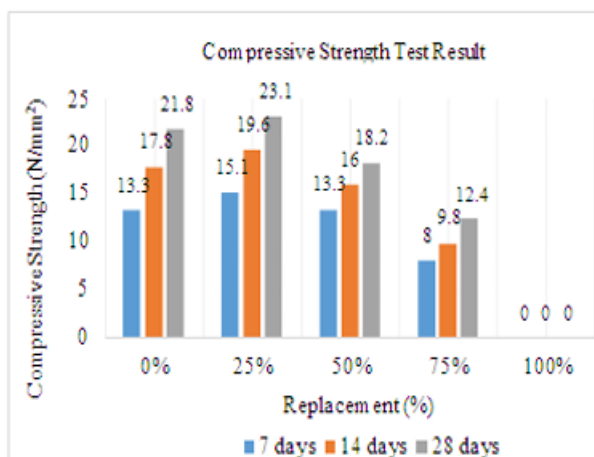
Sl. No	Replacement of cement with fly ash	28 days (N/mm ²)
1	0%	21.8
2	25%	23.1
3	50%	18.2
4	75%	12.4
5	100%	0



Graph 3: Compressive Strength for 28 days

Table 4: Compressive strength test result of all the mixes at 7, 14 and 28 days of curing

Sl. No	Replacement of cement with fly ash	7 days (N/mm ²)	14 days (N/mm ²)	28 days (N/mm ²)
1	0%	13.3	17.8	21.8
2	25%	15.1	19.6	23.1
3	50%	13.3	16	18.2
4	75%	8	9.8	12.4
5	100%	0	0	0



Graph 4: Compressive strength test result of all the mixes at 7, 14 and 28 days of curing

6.2 Split Tensile Strength Test

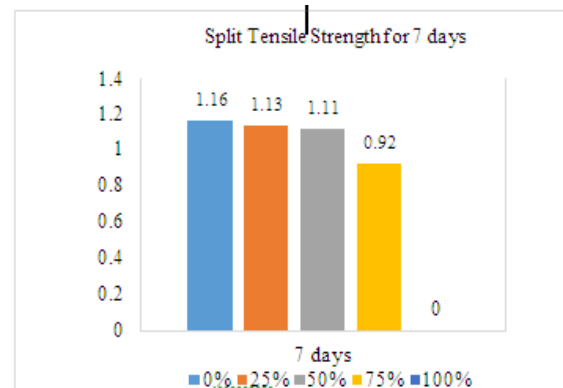
The split tensile strength of concrete generally shows a significant increase from 7 days to 14 days and then reaches its highest value at 28 days.



Figure 2: Split Tensile Strength Test

Table 5: Split Tensile Strength for 7 days

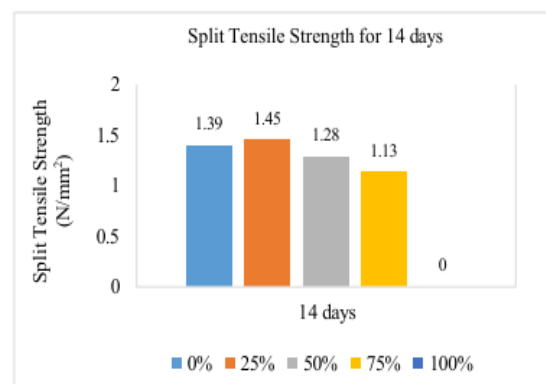
Sl. No	Replacement of cement with fly ash	7 days (N/mm ²)
1	0%	1.16
2	25%	1.13
3	50%	1.11
4	75%	0.92
5	100%	0



Graph 5: Split Tensile Strength for 7 days

Table 6: Split Tensile Strength for 14 days

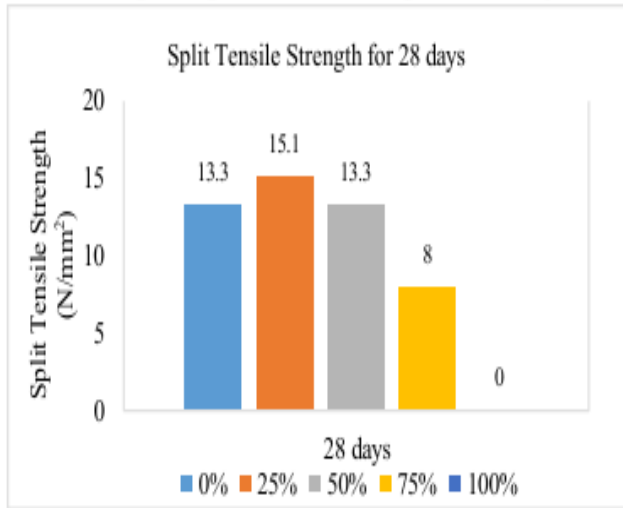
Sl. No	Replacement of cement with fly ash	14 days (N/mm ²)
1	0%	1.39
2	25%	1.45
3	50%	1.28
4	75%	1.13
5	100%	0



Graph 6: Split Tensile Strength for 14 days

Table 7: Split Tensile Strength for 28 days

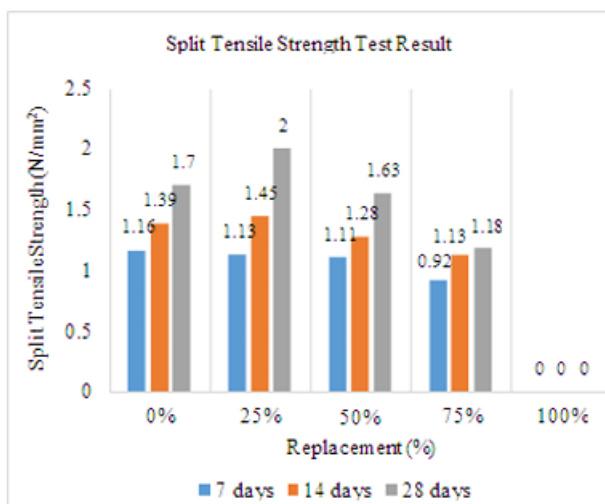
Sl. No	Replacement of cement with fly ash	28 days (N/mm ²)
1	0%	1.7
2	25%	2
3	50%	1.63
4	75%	1.18
5	100%	0



Graph 7: Split Tensile Strength for 28 days

Table 8: Split Tensile strength test result of all the mixes at 7, 14 and 28 days of curing

Sl. No	Replacement of cement with fly ash	7 days (N/mm ²)	14 days (N/mm ²)	28 days (N/mm ²)
1	0%	1.16	1.39	1.7
2	25%	1.13	1.45	2
3	50%	1.11	1.28	1.63
4	75%	0.92	1.13	1.18
5	100%	0	0	0



Graph 8: Split Tensile strength test result of all the mixes at 7, 14 and 28 days of curing

VII. Conclusion

- The experimental results demonstrated that fly ash significantly enhances the workability, durability and strength of concrete.
- Key findings indicate that an optimal percentage of fly ash replacement improves compressive strength over time.
- From the tests conducted, it was observed that concrete with 25% fly ash replacement showed optimal performance in compressive strength and durability.
- However early strength was lower compared to ordinary cement concrete, adding an admixture (i.e., Sodium Silicate) enhance its setting time improves its early strength, making it comparable to or even greater than cement concrete.

VIII. Reference

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