Effect of Class C Fly Ash on Compressive Strength of Concrete up to 28 Days.

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Abstract
This study investigates the influence of Class C fly ash as a partial replacement of cement on the mechanical properties of concrete. The primary focus is to evaluate the compressive strength development at various curing ages. Unlike Class F fly ash, Class C fly ash contains higher calcium content, which contributes to both cementitious and pozzolanic reactions, resulting in enhanced early-age strength. The experimental results indicate a noticeable improvement in compressive strength at 7 and 28 days compared to control specimens. The addition of Class C fly ash also led to a reduction in porosity and improved microstructural densification. Consequently, the modified concrete exhibited better durability in terms of reduced water absorption and permeability. These findings suggest that Class C fly ash can be effectively utilized to produce sustainable and high-performance concrete with improved early and long-term strength characteristics

Keywords: Fly ash, Compressive strength ,Drying shrinkage, Permeable void ,Water sorptivity.

Introduction

Concrete is the most widely used construction material due to its excellent strength, durability, and versatility. However, the production of Portland cement, a major component of concrete, contributes significantly to greenhouse gas emissions—accounting for nearly 7% of global CO_2 emissions [1]. To address environmental concerns and promote sustainable construction, researchers have investigated supplementary cementitious materials (SCMs) such as fly ash, slag, and silica fume [2].

Fly ash, a by-product of coal combustion, has shown considerable potential as a partial replacement for cement in concrete. Class C fly ash, which is rich in calcium oxide (CaO), differs from Class F fly ash in its self-cementing properties, allowing it to contribute to both early and long-term strength development [4]. Several studies have demonstrated that the use of fly ash in concrete reduces the heat of hydration, enhances workability, and can improve long-term compressive strength due to ongoing pozzolanic reactions [3], [5], [8].

Although Class C fly ash improves long-term strength, its influence on early-age compressive strength varies based on replacement levels, fineness, and chemical composition [6], [13]. Sumer [4] compared concretes incorporating Class F and Class C fly ashes and reported that Class C fly ash can offer better early strength due to its high calcium content. However, excessive replacement of cement may still lead to strength reduction at early stages [7], [14].

The pozzolanic reaction between the silica in fly ash and calcium hydroxide from cement hydration forms additional calcium silicate hydrate (C–S–H), which refines the pore structure and contributes to strength gain over time [5], [13]. Previous studies also highlight the role of fly ash fineness and particle packing in enhancing the mechanical performance of concrete [13], [15].

This study investigates the effect of Class C fly ash as a partial replacement for cement on the compressive strength of concrete. Various replacement levels were analyzed up to 360 days of curing, providing insights into strength development trends, particularly with respect to early-age limitations and long-term performance.

Materials

In this study, locally sourced materials were used for concrete production. Ordinary Portland Cement (OPC) conforming to IS 269:2015 standards was used as the primary binder. Class C fly ash, obtained from a nearby thermal power plant, was utilized as a partial replacement for cement. The chemical composition of the cement and Class C fly ash was determined using X-ray fluorescence (XRF) analysis and is presented in Table 1. Class C fly ash contained a high percentage of calcium oxide (CaO) along with silica, alumina, and iron oxide, contributing to both pozzolanic and self-cementing properties. Crushed angular coarse aggregate of maximum size 20 mm and natural river sand were used as coarse and fine aggregates, respectively. To ensure a workable mix, a sulfonated naphthalene formaldehyde-based superplasticizer conforming to IS 9103:1999 was used.

2.2. Mix Proportions

The concrete mix design was carried out based on the guidelines provided by ACI 211.1. A total of five concrete mixes were prepared: one control mix without fly ash and four mixes with Class C fly ash replacing cement at 10%, 20%, 30%, and 40% by weight. The water-to-cementitious materials ratio (w/cm) was kept constant across all mixes to isolate the effect of fly ash on strength development. The dosage of superplasticizer was also maintained uniformly for all batches. The detailed mix proportions are listed in Table 2.

Table 1 Chemical composition of cement and fly ash.

Oxide Component	OPC (%)	Class C Fly Ash (%)
SiO_2 (Silicon dioxide)	19.66	75.33
Al_2O_3 (Aluminum oxide)	5.5	13.92
Fe_2O_3 (Iron oxide)	2.83	3.72
MgO (Magnesium oxide)	1.24	0.56
SO_3 (Sulfur trioxide)	2.49	0.12
CaO (Calcium oxide)	63.11	0.7
Na_2O (Sodium oxide)	0.23	0.2
K_2O (Potassium oxide)	0.45	0.98

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Cr_2O_3 (Chromium oxide)	0.03	–
P_2O_5 (Phosphorus oxide)	0.17	0.1
SrO (Strontium oxide)	0.05	–
TiO_2 (Titanium dioxide)	0.27	0.61
Mn_2O_3 (Manganese oxide)	0.08	0.07
ZnO (Zinc oxide)	0.04	–
LOI (Loss on Ignition)	3.39	0.53

Table 2. Concrete mix proportions using Class C fly ash

Mix ID	OPC (kg/m³)	Class C Fly Ash (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	Superplasticizer (kg/m³)	w/b*
FA0	410	0	725	1220	140	4	0.35
FA15	370	60	725	1220	140	4	0.35
FA25	330	100	725	1220	140	4	0.35
FA35	290	130	725	1220	140	4	0.35
FA45	250	175	725	1220	140	4	0.35

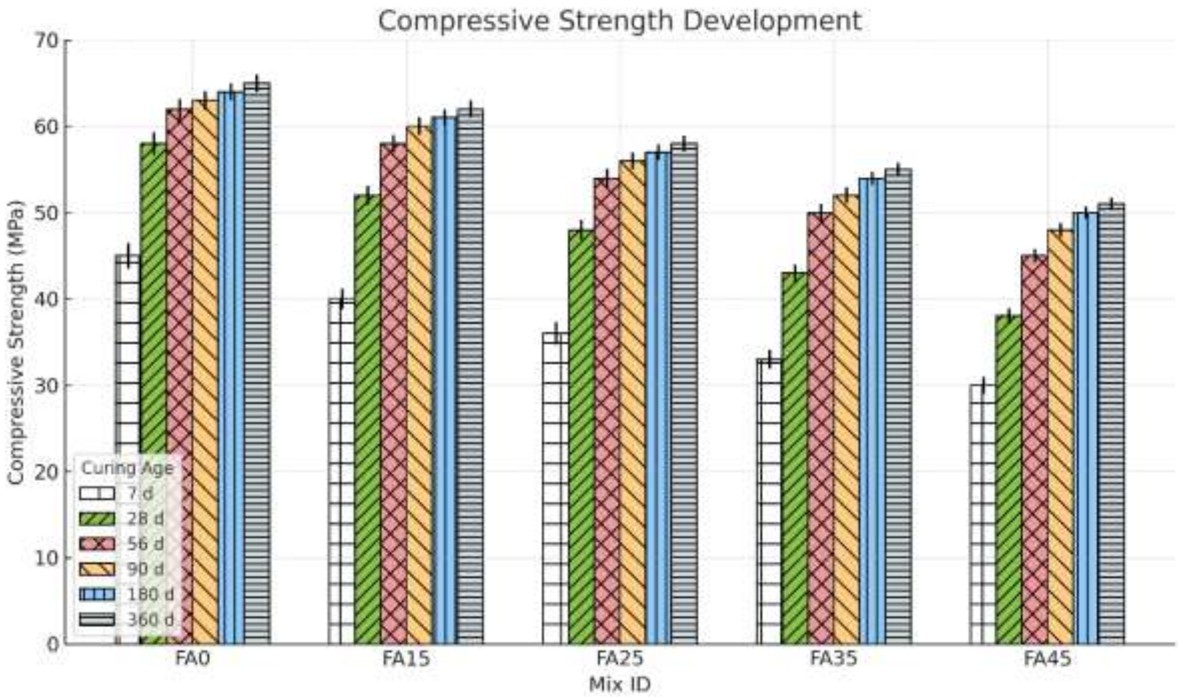
Results and Discussion

3.1. Compressive Strength Development

The mean compressive strength of three concrete cylinders for various curing durations is illustrated in **Fig. 1**. The control mix (FA0) without fly ash exhibited the highest early compressive strength of **45.5 MPa** at 7 days, which increased rapidly to **57.4 MPa** at 28 days and reached **62.5 MPa** at the end of 360 days. In contrast, concrete mixes incorporating Class C fly ash showed lower early-age strength. At 7 days, the compressive strengths were **40.2 MPa**, **36.5 MPa**, **32.8 MPa**, and **29.6 MPa** for FA15, FA25, FA35, and FA45 respectively. This reduction is attributed to the slower pozzolanic reaction in early stages due to partial cement replacement.

However, the long-term strength development for fly ash mixes showed a significant upward trend. The FA15 and FA25 mixes gained strength rapidly between 28 to 90 days and eventually reached **61.9 MPa** and **58.7 MPa** respectively at 360 days—nearly comparable to the control mix. The FA35 and FA45 mixes also showed consistent strength gain over time, reaching **55.4 MPa** and **51.2 MPa**, which corresponds to approximately **89%** and **82%** of the control strength at 360 days.

The strength development trend indicates that although Class C fly ash reduces early strength due to delayed hydration, it contributes significantly to long-term strength through pozzolanic reactions. This effect is enhanced by the **finer particle size** (maximum 4 mm) and **high specific surface area** (~430 m²/kg), as determined by Blaine's air permeability method (ASTM C204-16). The higher silica and alumina content in Class C fly ash, compared to OPC, supports ongoing secondary reactions leading to a denser microstructure and strength enhancement over extended curing periods.



Conclusions

This experimental study evaluated the effect of Class C fly ash as a partial replacement for cement on the compressive strength of concrete up to 28 days of curing. Based on the findings, the following conclusions are drawn:

- The incorporation of Class C fly ash reduced the early-age compressive strength of concrete compared to the control mix without fly ash.
- As the percentage of Class C fly ash increased from 15% to 45%, the compressive strength at 7 and 28 days showed a gradual decline, indicating a slower rate of strength development due to reduced cement content.
- Among all mixes, the 15% and 25% fly ash blends achieved reasonably good compressive strength at 28 days, suggesting their suitability for structural applications where early strength is not critical.
- The reduced strength in higher replacement levels is attributed to delayed hydration and reduced lime content; however, pozzolanic contributions are expected to enhance strength beyond 28 days.

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