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Study of high strength fly ash concrete

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ABSTRACT

The viability of creating high-performance concrete with polypropylene fibers for reinforcement and high-volume Class C fly ash in place of cement is examined in this study. To assess the impact of fly ash replacement levels (40 and 50%), aggregate-binder ratios (1.50, 1.75, and 2.00), and polypropylene fiber volume fractions (0.15% to 0.30%) on compressive and split tensile strength, an experimental program was created. The findings show that while a 50% replacement level often performed poorly, an optimized mix using 40% fly ash and a low aggregate-binder ratio of 1.50 achieved improved compressive strength. Compressive strength increased somewhat with the addition of polypropylene fibers; the ideal volume percentage was found to be 0.25%. Importantly, fiber inclusion increased split tensile strength by 10–25%. For 50% fly ash mixtures with a 1.50 aggregate-binder ratio, benefits were most noticeable after 28 days of curing. It was discovered that the water-binder ratio was inversely related to the strength results; depending on the fly ash content, a lower ratio (0.35-0.40) was ideal for tensile performance. According to the study's findings, concrete with an ideal blend of 40% fly ash, 1.50 aggregate-binder, and 0.25% polypropylene fibers has exceptional mechanical qualities and effectively strikes a balance between structural performance and the environmentally friendly usage of industrial waste.

Keywords: Fiber, fly ash, aggregate binder ratio, compressive strength, concrete

1. Introduction

Meeting the constantly rising demand for high-performance building materials while also lessening its substantial environmental impact is a twofold issue facing the global construction industry. The main binder in traditional concrete, ordinary Portland cement (OPC), contributes significantly to this footprint, contributing about 8% of world CO_2 emissions. The hunt for sustainable supplementary cementitious materials (SCMs) to partially replace cement in concrete mixtures has been fueled by this environmental issue.

Fly ash, a fine powder extracted from coal-fired power stations' flue gases, is one of the most promising SCMs. In addition to keeping fly ash out of landfills and lessening its environmental impact, using it in concrete improves the material's workability and long-term durability through pozzolanic reactions. In particular, Class C fly ash is a particularly effective choice for higher-volume replacement of OPC due to its high calcium concentration, which gives it self-cementing capabilities in addition to its pozzolanic nature.

Although there are obvious sustainability advantages to high-volume fly ash (HVFA) concrete, worries about its mechanical characteristics—specifically, its early-age strength development and tensile performance—have limited its use. Because concrete is naturally brittle and weak in tension yet strong in compression, it frequently cracks uncontrollably under stress. Discrete fibers are commonly added to increase tensile strength, toughness, and crack resistance in order to counteract this. Due to its chemical inertness, dispersibility, and efficiency in preventing plastic shrinkage cracking, polypropylene fibers are a common option for this use.

Nevertheless, a thorough comprehension of the complementary impacts of polypropylene fiber reinforcing and high-volume Class C fly ash is still developing. Research is still being done to determine the ideal ratios of fly ash replacement, aggregate-binder ratio, and fiber volume fraction needed to strike a compromise between sustainability and excellent performance, especially in compressive and split tensile strength. How these factors interact and what combination produces the best mechanical properties are unknown.

Thus, the purpose of this study is to methodically examine the viability of employing high-volume Class C fly ash in place of cement to produce high-performance concrete reinforced with polypropylene fibers. An experimental program was created to assess how important mix design parameters, such as the percentage of fly ash replacement (40 and 50%), aggregate-binder ratios (1.50, 1.75, and 2.00), and volume fractions of polypropylene fiber (0.15% to 0.30%), affected the concrete's compressive and split tensile strengths. The research's conclusions are meant to offer a verified mix design that maximizes mechanical performance and encourages the environmentally friendly usage of industrial waste.

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2. Literature Review

Research on sustainable concrete technology is fueled by the cement industry's well-documented environmental impact. An estimated 0.9 tons of CO_2 are produced during the manufacturing of one ton of Ordinary Portland Cement (OPC), which makes a substantial contribution to global greenhouse gas emissions (Worrell et al., 2001). The hunt for additional cementitious materials (SCMs) to lower the clinker factor in concrete has been sparked by this. One of the most accessible and used SCMs is fly ash, which is a byproduct of burning coal in thermal power plants. Its usage in concrete has two positive environmental effects: it lowers the need for cement and gives an industrial waste product a useful use instead of being dumped in a landfill [1].

Based on its chemical makeup, fly ash is often divided into two groups: Class F (low-lime) and Class C (high-lime). The study's focus, class C fly ash, has both pozzolanic and self-cementing qualities and normally contains more than 20% lime (CaO) (ACI Committee 232, 2003). In comparison to Class F fly ash, this permits larger replacement levels of OPC, which typically range from 20% to 40% by mass of cementitious material. Class C fly ash's spherical particle form, which produces a "ball-bearing" effect, makes fresh concrete easier to work with. A denser microstructure and increased long-term strength and durability are the results of the pozzolanic interaction between the calcium hydroxide from cement hydration and the silica in fly ash in hardened concrete [2].

To optimize sustainability benefits, the idea of high-volume fly ash (HVFA) concrete—generally defined as having more than 40% fly ash by mass of the total cementitious material—has been investigated. According to research by Malhotra and Mehta (2002), HVFA concrete might achieve higher durability against alkali-silica reaction and sulfate attack, as well as outstanding long-term mechanical qualities. The trade-off linked to high replacement levels, however, is a recurring theme in the literature: inferior early-age strength development because of the slower pozzolanic response rate in comparison to cement hydration (Bilodeau & Malhotra, 2000). A possible obstacle to wider adoption could be this delayed strength growth, which can affect formwork removal times and building timetables. In order to balance performance and economic viability, more research is also needed to determine the ideal binder concentration and aggregate-binder ratio for HVFA systems, especially with Class C fly ash [3].

Concrete's low tensile strength and quasi-brittle nature, which make it prone to cracking, are inherent limitations of concrete, notably HVFA concrete. The use of distinct fibers is a tried-and-true method to get around this flaw. The main purpose of polypropylene (PP) fibers, which are synthetic fibers with a high melting point and chemical resistance, is to prevent plastic shrinkage cracking. They can, however, also affect the tensile strength and post-cracking behavior of hardened concrete, according to a number of studies (Song et al., 2005). By bridging across microcracks and transferring stress, PP fibers function as a three-dimensional reinforcement that can boost toughness and energy absorption capacity [4]. A crucial factor is the volume fraction of fibers; moderate quantities (usually 0.1% to 0.5%) are typical since higher percentages might negatively impact workability and compaction without correspondingly increasing strength [5].

Although fiber-reinforced concrete and HVFA concrete have been the subject of much individual research, studies examining their combined effects are less common, and the results sometimes appear inconsistent. According to some studies, fibers can successfully make up for HVFA mixtures' decreased early-age tensile strength (Yao et al., 2021). According to other research, the fiber-matrix interfacial bond may be strengthened by the increased matrix density brought about by fly ash hydration, which could maximize the effectiveness of the fiber reinforcement [6].

But there is a glaring lack of knowledge on how important mix design factors—more especially, the amount of fly ash substituted, the aggregate-binder ratio, and the dose of polypropylene fiber—interact to affect the mechanical characteristics of Class C HVFA concrete. There is no clear definition of the ideal fiber volume fraction for a specific fly ash content and binder proportion. Additionally, more research is needed to clarify how fibers affect the long-term strength development of HVFA mixes, especially those with extremely high replacement levels (such as 50%)[7].

3. Objectives

Following objective studied in the work:

1.All To determine the optimal mix proportions, specifically the cement-to-fly-ash ratio and water-to-binder ratio, for producing high-strength concrete.

2. To evaluate the compressive strength development of concrete with varying levels of Class C fly ash replacement and water-to-binder ratios at 28, 56, and 90 days.

4. Experimental Program

The objective of this work is to evaluate key mechanical properties—compressive strength and split tensile strength—for concrete mixtures incorporating high-volume fly ash, both in plain and fiber-reinforced forms.

With an emphasis on comparing the compressive and split tensile strengths of plain and fiber-reinforced mixtures, an experimental study was carried out to evaluate the mechanical performance of fly ash concrete.

4.1 Materials used for casting.

Ordinary Portland Cement (OPC) of 53-grade, which complies with IS: 12269-1987, Class C fly ash, fine and coarse aggregate, potable water, and polypropylene fibers were the materials employed in this experimental study.

The fine aggregate was natural river sand. Crushed granite with a nominal size of 20 mm made up the coarse aggregate, which was held on a 12.5 mm sieve. It had a fineness modulus of 6.78 and a specific gravity of 2.68. According to IS: 2386 (Part III), the fine aggregate's characteristics, such as its bulk specific gravity and water absorption, were assessed.

A pozzolanic mineral additive called Class C fly ash was utilized in place of some of the cement. Certain combinations included 12 mm long fibrillated polypropylene fibers that were commercially available. For mixing and curing, potable water from the lab supply was utilized. For the designated mix proportions, all examples were cast and cured in accordance with the applicable Indian Standard codes.

Every specimen was produced using standard molds that complied with IS: 10086-1982. For testing of compressive strength, 150 mm cubes were utilized, and for tests of split tensile strength, 150 mm diameter by 300 mm high cylinders were employed.

5. Result and Discussion

The compressive strength was evaluated using a 2000 kN capacity compression testing machine. A 150 mm cube specimen was placed between the machine's loading surfaces, and a load was applied axially at a constant rate until specimen failure occurred. The compressive strength was calculated as the ratio of the ultimate crushing load to the cross-sectional area of the specimen.
This test was conducted on all concrete mixtures at curing ages of 28, 56, and 90 days. The effects of key variables—water-binder ratio, aggregate-binder ratio, fly ash replacement percentage, and polypropylene fiber volume fraction—on compressive strength are analyzed and discussed in the following sections. The corresponding experimental results are presented in Figures 4.1

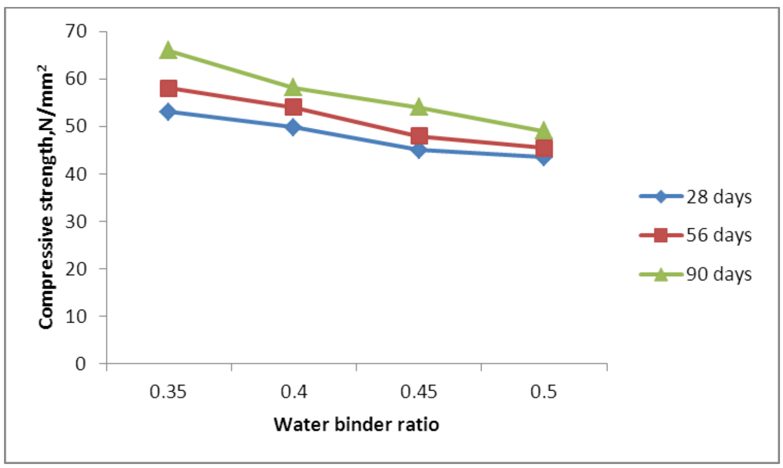

Fig. 1 - Compressive strength of 30% Fly ash concrete of A/B =1.50

Figure 4.1 illustrates the compressive strength development of 30% fly ash concrete mixes with different water-binder (w/b) ratios over 28, 56, and 90 days. The mix with a w/b ratio of 0.35 consistently demonstrated the highest compressive strength at all ages. As expected, strength gain was lowest at 28 days and increased with longer curing time. The improvement in strength from 28 to 90 days ranged from 10.3% to 24.5%, depending on the w/b ratio. The mix with a w/b ratio of 0.5 exhibited the lowest strength at 28 and 56 days. Furthermore, a significant strength disparity was observed between the optimal and poorest-performing mixes; the compressive strength of the 0.35 w/b ratio mix was 21.8% higher than that of the 0.5 w/b ratio mix at 28 days, and this gap widened to 37.0% by 90 days. The compressive strength of all mixes increased with longer curing periods. Specifically, strength gains ranged from 3.33% to 6.55% between 28 and 56 days, and from 16.33% to 26.0% between 28 and 90 days. Notably, the mix with a water-binder (w/b) ratio of 0.40 exhibited a significant improvement in compressive strength by the age of 90 days.

6. Conclusions

The water-binder (w/b) ratio significantly influences the split tensile strength of fly ash fiber-reinforced concrete. A clear inverse relationship was observed; as the w/b ratio increases, the split tensile strength decreases.

The optimal w/b ratio was found to depend on the fly ash content:

- For 30% fly ash concrete, a w/b ratio of 0.35 yielded the highest split tensile strength at all ages.
- For 40% fly ash concrete, the optimal w/b ratio was 0.40.

Conversely, mixes with 50% fly ash and higher w/b ratios (0.45 and 0.50) exhibited minimal strength gain at 28 days. This is attributed to the higher binder content and the slower rate of the pozzolanic reaction. However, significant improvement in split tensile strength for all mixes was observed beyond 28 days of curing, indicating continued long-term strength development.

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