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A Comparative Study on the Workability and Durability of Fly Ash Concrete with Glass and Polypropylene Fibers

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ABSTRACT:

This research investigates fly ash concrete, a sustainable alternative to traditional concrete, exploring its potential when reinforced with two types of fibers: glass and polypropylene. (This option emphasizes the eco-friendly aspect of fly ash concrete). The study incorporates fly ash at a 30% replacement rate for Ordinary Portland Cement (OPC) in the control mix, promoting environmental responsibility in construction practices. The investigation focuses on two key properties: compressive strength and workability. Slump tests assess the workability of fresh concrete mixes with varying fiber content (0.1% to 0.5%). Results indicate that workability decreases with the addition of fibers, with glass fiber content leading to a more significant reduction (170 mm slump) compared to polypropylene fibers (140 mm slump). The primary focus then shifts to compressive strength, a crucial mechanical property. Six concrete mixes are created for each fiber type, with increasing fiber content. Compression tests conducted on cured specimens (7, 14, and 28 days) reveal promising results for both fiber types: On glass fibers a progressive increase in compressive strength is observed with increasing fiber content up to 0.5%, culminating in a peak strength of 48.48 MPa. This suggests that glass fibers effectively bridge cracks within the concrete, enhancing its ability to withstand compressive forces. Polypropylene Fibers is similar to glass fibers, incorporating polypropylene fibers also leads to a positive impact on compressive strength. The mix with 0.2% polypropylene fibers reaches the highest value of 45.63 MPa. However, the optimal content for this specific mix design appears to be around 0.2%.

Keywords: Fly Ash, Glass Fiber, Polypropylene Fiber, M40, Optimum Percentage, Testing, Workability.

Introduction:

Regular concrete is great for building, but making the cement in it is bad for the environment. Also, fly ash, a leftover from burning coal, is often just dumped in landfills. This project is testing a new kind of concrete that uses less cement and instead mixes in fly ash by adding tiny fibers, like polypropylene and glass, to make the concrete even tougher.

As we know concrete is strong but brittle, and researchers have been looking at ways to improve it by adding the optimum quantity of fly ash and fibers at different concentrations. In search of improved concrete, researchers Kou and Poon (2013) have investigated the use of various "SCMs" (Supplementary Cementitious Materials), including fly ash. Despite being a leftover material, fly ash turns out to be a great addition to concrete in many ways. The substantial enhancement in the mechanical and durability properties of concrete is attributed to the intensified pozzolanic reaction of fly ash. Other scientists (Lanh Si Ho and Trong Phuoc Huynh) have been studying the 30% fly ash samples that achieved the highest mechanical properties and durability. The reference to specific research (Kou and Poon, 2013 and Lanh Si Ho and Trong Phuoc Huynh) likely refers to a study that involved a 30% replacement of cement with fly ash.

Polypropylene fibers are a promising option due to their affordability, ease of use, and ability to make concrete tougher and more crack-resistant. This is especially useful for structures like tunnels and sprayed concrete that need to bend a little without breaking. The addition of polypropylene fibers significantly improves the compressive strength of concrete compared to plain concrete.

Glass fiber plays a key role in keeping construction projects economical. Compared to traditional steel reinforcement, glass fibers can offer a more budget-friendly option, potentially leading to significant cost savings. Additionally, concrete reinforced with glass fibers boasts superior crack resistance, which translates to less frequent repairs and maintenance down the line. But the economic benefits don't stop there. The lighter weight of glass fiber concrete reduces transportation costs for pre-made elements and allows for slimmer designs or less concrete overall. On top of that, glass fibers enhance the overall durability of concrete, potentially extending the lifespan of structures and reducing replacement costs. While the cost-effectiveness of glass fiber can vary depending on specific factors, it presents a valuable alternative with its potential for significant savings and improved performance in the construction industry.

Polypropylene and glass fibers are popular choices for reinforcing concrete, enhancing its mechanical properties. This also suggests a pessimistic outlook for investors on the economy, as they see greater uncertainty in the short rather than long term. Through a systematic approach, the ideal dosage of fibers can be identified, balancing the benefits of enhanced performance with considerations of cost and workability.

Building upon previous research, this study deeper into optimizing a percentage of fly concrete formulation for enhanced performance and environmental sustainability. We leverage the knowledge that 30% fly ash effectively replaces cement while maintaining workability. Here, we focus on identifying the optimal dosage of fiber reinforcements – both polypropylene and glass fibers – to maximize the concrete's mechanical properties.

The impact of incorporating various fiber types and contents on the properties of high-grade concrete is investigated in this research (M40). The experiment involves creating two sets of concrete specimens ranging from 0.1% to 0.5%, into the concrete mix design. Two separate sets of specimens will be created: Five concrete mixes (G1 to G5) will be formulated with increasing percentages of glass fibers within the designated range. Similar to the glass fiber sets, five concrete mixes (P1 to P5) will be prepared with varying polypropylene fiber content. These specimens will undergo rigorous testing at three key intervals: 7, 14 and 28 days after casting.

2. MATERIALS AND MIX PROPORTION

2.1 MATERIAL

2.1.1 CEMENT

The concrete mix in this research used UltraTech OPC 53-grade cement, a strong and reliable type commonly used in construction projects. This cement meets the Indian standard (BIS IS:12269-1987) for quality. It's known for its strength, durability, and ease of use, making it a versatile choice for many building applications.

To ensure its performance, the researchers tested the cement for several key properties. These tests checked how long it takes for the cement to harden (setting time), how easily it mixes with water (consistency), and how finely ground the particles are (fineness). The detailed test results are likely included in a separate table for further reference.

The cement sets in 35 minutes, has a standard consistency of 33%, and a fineness modulus of 4%, with a specific gravity of 3.15.

The physical and chemical test are given in table 2.1.1(a) and table 2.1.1(b)

PHYSICAL TEST

Sr. No.	Tests and properties of cement	Test Data
1	Primary setting time	35 minutes
2	Ultimate setting time	35 minutes
3	Standard consistency	33 %
4	Fineness modulus	4 %
5	Specific gravity	3.15

Table 2.1.1(a)

CHEMICAL TEST: -

Sr no.	Properties	Test results	Requirement As 3812 (Part 1)-2013)
1	Loss on Ignition - (%by mass)	2.6	4.0 max
2	Chloride Content (%by mass)	0.003	0.1 max
3	Sulphuric Anhydride	3.27	3.5 max

4	Magnesia	4.36	6.0 max
5	Insoluble residue	2.65	5.0 max

Table 2.1.1(b)

2.1.2 FLY ASH

A by-product of coal-fired power plants, fly ash is a fine powder with spherical particles. This sustainable material finds use in concrete production as a supplementary cementitious material, enhancing properties like strength and workability.

A fly ash specific gravity of 2.2 g/cc typically indicates a significant amount of calcium oxide (CaO) and classifies it as a Class C type of fly ash. This type of fly ash contains higher levels of calcium oxide and is often derived from sources with higher calcium content such as bituminous and lignite coals. It may also have some pozzolanic properties, which can be useful in concrete applications. Class C fly ash is known for its cementitious properties and is used as a supplementary cementitious material.

The physical and chemical test are given in table 2.1.2

Sr no.	Properties	Test results	Requirement As 3812 (Part 1)-2013)
1	Loss on Ignition - %	0.320	5.0 max
2	Silicon dioxide (SiO2) in Percent by mass	62.02	35 min
3	Calcium Oxide (CaO) Content -%	1.46	--
4	Magnesium Oxide (MgO) Content -%	Below 0.5	5.0 max
5	Total Sulphur as Sulphur trioxide (S03) in per cent by mass	Below 0.1	3.0 max
6	Chloride Content -%	0.03	0.05 max
7	Silicon Dioxide (SiO2) +Aluminum oxide (AL2O3) +Iron oxide in percent by mass	94.02	70% min
8	Specific gravity	2.2	
9	Fineness test	30 gm	
10	Normal consistency	35%	

Table 2.1.2

2.1.3 FIBER

These thin, glass fibers are 14 microns wide (filament diameter) and come in two lengths, 6 or 12 millimeters. They are made from a special kind of glass that resists damage from chemicals (Alkali Resistant Glass Fiber) and have a high surface area (105 square meters per kilogram) which helps them bond well with concrete. its specific gravity is 2.6.

These polypropylene fibers possess a length of 12 mm and a diameter of 24 mm, exhibiting a remarkable tensile strength of 550 MPa. This translates to superior resistance against tensile forces, effectively mitigating crack propagation within the concrete. Additionally, the polypropylene fibers boast a low specific gravity of 0.91, ensuring negligible contribution to the overall weight of the composite material.

The photos of glass fiber and polypropylene are given in fig 2.1.3(a) and 2.1.3(b)

fig 2.1.3(a)

fig 2.1.3(b)

2.1.4 AGGREGATE

Coarse aggregate has a specific gravity of 2.87. In simpler terms, this means the coarse aggregate is slightly heavier than water (water has a specific gravity of 1). Coarse aggregate is typically gravel or crushed rock used in concrete.

Fine aggregate has a specific gravity of 2.5. This means the fine aggregate is also denser than water, but slightly lighter than the coarse aggregate. Fine aggregate is usually sand used to fill gaps between the coarse aggregate particles.

2.2 MIX COMPOSITION

This research investigates how different types and quantities of fibers influence high-quality concrete (M40). To determine the compressive strength, cube samples (150mm x 150mm x 150mm) were prepared from concrete poured into oiled steel molds. This concrete mix design followed IS 10262:2019 standards, and curing adhered to ASTM C192 (2019) specifications. (fig 2.2.(i) indicates cube sample)

fig 2.2.(i)

The concrete mix will contain 30% fly ash as a partial replacement for cement, with the remaining 70% being cement. This fly ash mix serves as the control group for comparison. Two sets of concrete specimens will be created to explore the impact of fibers: Five concrete mixes will be formulated with varying glass fiber content, ranging from 0.1% to 0.5% of the total mix volume. Similar to the glass fiber sets, five concrete mixes will be prepared with increasing polypropylene fiber content, also ranging from 0.1% to 0.5% of the total mix. Concrete cubes will be tested at 7, 14, and 28 days to determine their ability to resist compressive forces (like weight pushing down).

The concrete mix design used for the experiment included same combinations of cement, sand, aggregates, water and fly ash including various combinations of Polypropylene fibers, which were denoted by different codes such as P1, P2, P3, P4 and P5 containing 0.1%, 0.2%, 0.3%, 0.4% and 0.5% polypropylene fiber. The combinations of glass fibers, which were denoted by different codes such as G1, G2, G3, G4 and G5 contained 0.1%, 0.2%, 0.3%, 0.4% and 0.5% glass fiber respectively. For comparing the above mixes, the normal concrete mix is denoted by M.

Material quantity of polypropylene fiber are given in table 2.2.1 and glass fiber in table 2.2.2

Mixes	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Fly ash (kg)	Water (kg)	Polypropylene fibers (kg)	Polypropylene fibers content in %
M	17.46	20.33	39.85	5.76	6.98	-	-
2) P1	17.46	20.33	39.85	5.76	6.98	0.017	0.1%
3) P2	17.46	20.33	39.85	5.76	6.98	0.035	0.2%
4) P3	17.46	20.33	39.85	5.76	6.98	0.052	0.3%
5) P4	17.46	20.33	39.85	5.76	6.98	0.070	0.4%
6) P5	17.46	20.33	39.85	5.76	6.98	0.087	0.5%

Material quantity of polypropylene fiber are given in table 2.2.1

Mixes	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Fly ash (kg)	Water (kg)	Glass fiber (kg)	Glass fiber content in %
M	17.46	20.33	39.85	5.76	6.98	-	-
G1	17.46	20.33	39.85	5.76	6.98	0.017	0.1%
G2	17.46	20.33	39.85	5.76	6.98	0.035	0.2%
G3	17.46	20.33	39.85	5.76	6.98	0.052	0.3%
G4	17.46	20.33	39.85	5.76	6.98	0.070	0.4%
G5	17.46	20.33	39.85	5.76	6.98	0.087	0.5%

Material quantity of glass fiber are given in table 2.2.2

3. COMPRESSIVE STRENGTH TEST ON CUBES AND IT'S RESULT

3.1 COMPRESSIVE STRENGTH TEST ON CUBES

The compressive strength test of the concrete specimens was conducted according to the Indian Standard code IS 516: 1959, which provides guidelines for the testing of concrete. To measure the compressive strength of each mix, the experimenters conducted the test on three concrete cubes on average, using a testing machine that applies a gradually increasing compressive force until the cube failed (Fig. 3.1.(i) indicates failure of cube sample). The compressive strength was measured in units of force per unit area. The compressive strength tests were conducted at different curing periods for different mixes. The mixes M, P1, P2, P3, P4, P5, G1, G2, G3, G4 and G5 were tested at 7, 14, and 28 days of curing.

Compressive strength = $\frac{Failure\ load(N)}{Cross\ setional\ area(mm^2)}$

Fig 3.1.(i)

Ordinary Portland Cement (OPC) grade 53 is used, with a 30% replacement of fly ash based on the mass of cement. For casting 9 cubes, a total of 120.51 kg of concrete is needed, incorporating glass fibers.

In total mixes, the following materials are used:

Cement: 14.00 kg

Fine aggregate: 21.18 kg

Coarse aggregate: 41.51 kg

Fly ash: 6.00 kg

Water: 7.27 kg

With an additional 20% for wastage.

Glass fiber and polypropylene fiber percentages vary across the mixes: 0.1%, 0.2%, 0.3%, 0.4%, and 0.5%, equivalent to 0.014 kg, 0.028 kg, 0.042 kg, 0.056 kg, and 0.070 kg, respectively.

3.2 RESULT

The compressive strengths of glass fibers are given in Table 3.2.1, and their graphical representation is shown in Figure 3.2.(i). Similarly, the compressive strengths of polypropylene fibers are given in Table 3.2.2, and their graphical representation is shown in Figure 3.2.(ii).

ID	Cement (%)	Fly Ash (%)	Glass Fiber (%)	Compressive Strength (Mpa)			Workability (mm)
				7 Days	14 Days	28 Days	
M40 (M)	70	30	0.0	23.02	31.7	38.8	
M40-G1	70	30	0.1	27.55	33.48	39.7	170
M40-G2	70	30	0.2	27.85	37	41.63	160
M40-G3	70	30	0.3	28.59	37.33	42	145
M40-G4	70	30	0.4	32.15	37.48	43.11	130
M40-G5	70	30	0.5	32.29	41.33	48.48	120

Table 3.2(a)

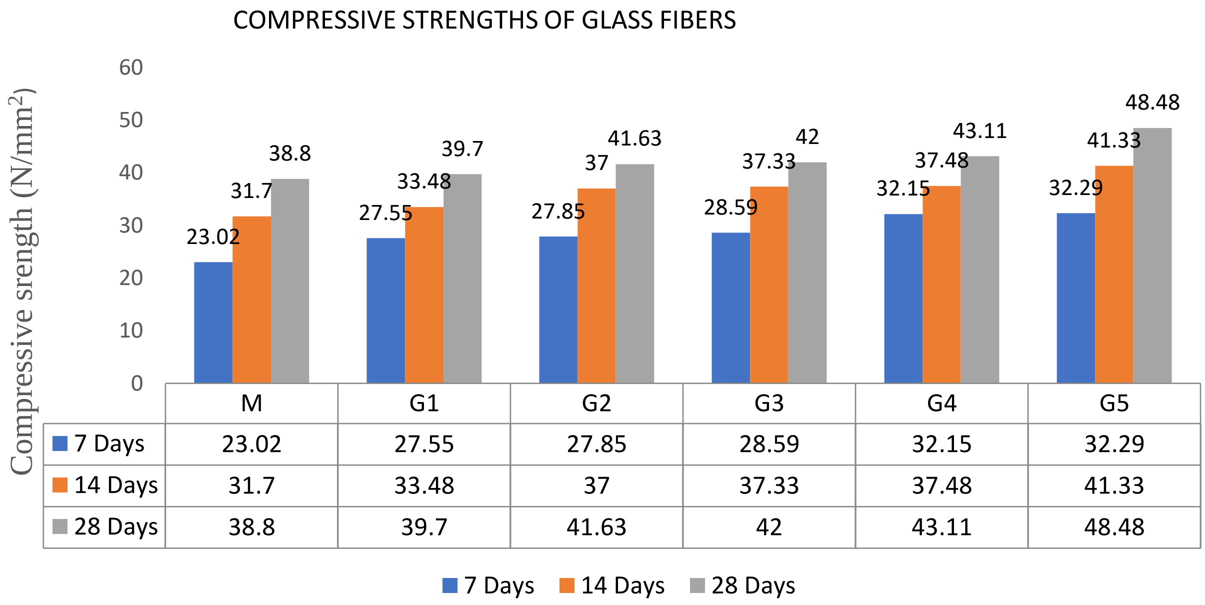


Fig. 3.2.(i)

The presented results on table 3.2(a) indicate that incorporating glass fibers leads to a progressive increase in compressive strength as the fiber content increases up to 0.5%. The concrete mix containing the highest glass fiber content (0.5%) exhibits the strongest performance, reaching a compressive strength of 48.48 MPa. This suggests that glass fibers effectively improve the concrete's ability to resist compressive forces.

ID	Cement (%)	Fly Ash (%)	Polypropylene Fiber (%)	Compressive Strength (Mpa)			Workability (mm)
				7 Days	14 Days	28 Days	
M40(M)	70	30	0.0	23.02	31.7	38.8	
M40-P1	70	30	0.1	22.96	34.37	41.92	140
M40-P2	70	30	0.2	24.74	35.26	45.63	130
M40-P3	70	30	0.3	25.48	35.11	43.56	120
M40-P4	70	30	0.4	24.29	28.59	41.78	110
M40-P5	70	30	0.5	21.11	26.07	39.41	100

Table 3.2(b)

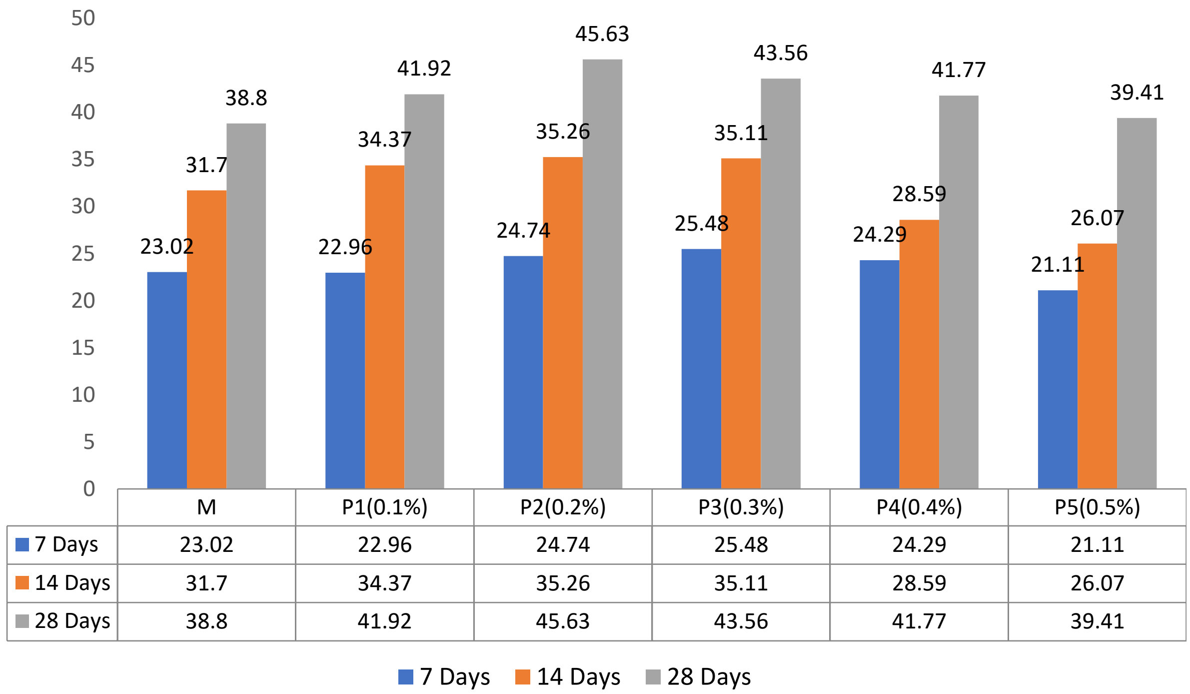
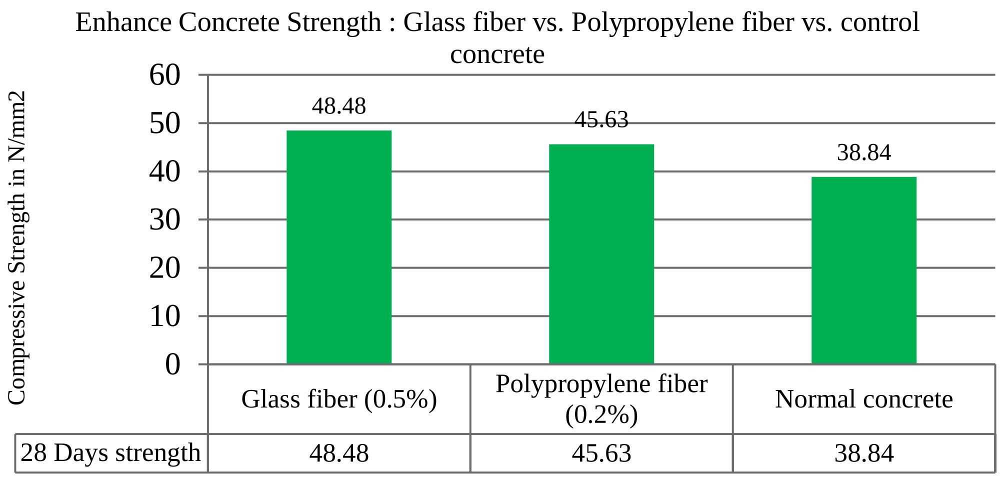


Fig. 3.2.(ii)

Incorporating polypropylene fibers demonstrates a positive impact on compressive strength, with the 0.2% mix achieving the highest value of 45.63 mpa. While polypropylene fibers generally show a strengthening effect, the optimal content for this specific mix design appears to be around 0.2%.

3.4 CONCLUSION



The results were impressive. Concrete mixes containing glass fibers exhibited a progressive increase in compressive strength with increasing fiber content. The highlight was the M5 mix (0.5% glass fiber) achieving a remarkable 48.48 MPa after a 28-day cure. This translates to a significant 24.82% improvement compared to the control specimen, showcasing the exceptional strengthening effect of glass fibers.

Polypropylene fibers also demonstrated a positive influence. The M2 mix (0.2% polypropylene fiber) reached a peak compressive strength of 45.63 MPa at the 28-day mark, representing a respectable 17.48% increase over the control mix.

Both fiber types enhance the workability and compressive strength of fly ash concrete, with glass fibers generally leading to a greater improvement in compressive strength at the investigated content levels.

DECLARATION OF COMPETING INTEREST

The authors of this research paper declare that they have no conflicts of interest that could be perceived to influence the objectivity of the presented findings. This includes any financial interests, such as research grants or affiliations with companies that produce fly ash, glass fibers, polypropylene fibers, or concrete. Additionally, there are no personal relationships with individuals or organizations that could be seen as biasing the research.

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