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Experimental study on polypropylene fiber reinforced concrete with partial replacement of cement by fly ash and ggbs

Mrs. Sheetal R. Kathikar[a], Mr. Nikhil M. Wankhede[b]

[a]Assistant professo, Kavikulguru institute of technology and science, Ramtek,Nagpur, India
[b]Civil Engineering student, kavikulguru institute of technology and science,Ramtek, Nagpur, India

A B S T R A C T :

This experimental study investigates the effect of polypropylene fibers reinforcement on the strength and durability of M40 grade concrete, wherein the OPC (ordinary Portland cement) is partially replaced with 20% FA (fly ash) and 20% GGBS (Ground Granulated Blast Furnace Slag). The primary objectives are to develop a sustainable, eco-friendly concrete mix by reducing the OPC 53 grade of cement usage, and to analyze the influence of different proportional (1%,1.5%,2%) by weight of cement of PPF (polypropylene fibers) on the mechanical properties of concrete [11]. The OPC 53 grade of cement generates heat during hydration and emits more CO_2 so to reduce the effect of HOH, FA and GGBS used. The compressive and split tensile strength were evaluated at different curing period. The findings reveal that while early age (7days) strength is lower due to the slower reactivity of FA and GGBS, the 28 days strength shows significant improvement. Among the tested mixes, the concrete with 1.5% polypropylene fibers exhibited optimal performance in terms of strength and durability. This study highlights the potential of combining mineral admixtures and fiber reinforcement to produce high performance, sustainable concrete.

Keywords: OPC (Ordinary Portland Cement), FA (Fly Ash), GGBS (Ground Granulated Blast Furnace Slag), HOH (Heat of Hydration), CO_2 (Carbon dioxide) PPF (Polypropylene Fibers)

1. Introduction

As wide range construction generally OPC 53 grade of cement is used. It has high compressive strength making it suitable for high strength concrete application this cement gain strength rapidly but this cement generates more heat during hydration, which can lead to thermal cracking and other issues in large concrete pours and OPC 53 cement generated more CO2 emission than some other type of cement to minimizing these issues it is partially replaced by other cementitious material such as fly ash and GGBS (Ground Granulated blast furnace slag), the GGBS and fly ash can dilute the cement content and GGBS has latent hydraulic property so it can lowering the temperature rise during hydration which leads to reduce the amount of heat generated during hydration reducing the risk of thermal cracking, GGBS is a byproduct of the steel industry. GGBS concrete typically has a lower embodied carbon compared to traditional Portland cement concrete, making it a more sustainable choice for construction projects. The production of GGBS requires significantly less energy compared to the production of Portland cement. GGBS concrete exhibits enhanced durability and resistance to various forms of degradation. This reduces the need for future repairs and maintenance, leading to long-term environmental and economic benefits. By utilizing GGBS, we reduce the need for extracting and processing raw materials like limestone and clay, which are used in the production of Portland cement. Fly ash, a byproduct of coal combustion in power plants, offers several advantages when used as a partial replacement for cement in concrete. Fly ash improves the workability of fresh concrete, making it easier to mix, place, and finish. Fly ash concrete exhibits enhanced resistance to sulphate attack, alkali-aggregate reactions, and freeze-thaw cycles, leading to increased durability and longevity. Fly ash concrete has lower permeability, which improves its resistance to water and chloride ingress, further enhancing its durability. Cement production is energy-intensive and contributes significantly to greenhouse gas emissions. Replacing a portion of cement with fly ash reduces the carbon footprint of concrete production. Utilizing it in concrete production helps to reduce waste and conserve natural resources. For increasing the tensile strength of concrete, the polypropylene fibres are used it's a thermoplastic polymer derived from propylene, a hydrocarbon monomer it has High impact strength, making it resistant to breakage, Good tensile strength, providing good mechanical properties.

1.1. Literature review

Mr. Krishna Prasad Pandey and Professor Dr. Raghabendra Yadav (2023) [7] This study examines the impact of ground granulated blast furnace slag (GGBS) and polypropylene fibers on the characteristics of self-compacting concrete (SCC). The utilization of GGBS, a by-product of the iron and steel sector, presents multiple benefits, such as diminished environmental impact, increased workability, and superior durability. The existing research robustly endorses the utilization of GGBS as a partial substitute for cement in concrete. Research indicates that GGBS, because to its pozzolanic characteristics, enhances long-term strength, diminishes heat of hydration, and improves resistance to sulfate attack and alkali-silica reaction. The integration of polypropylene fibers into concrete has been extensively documented to boost its mechanical qualities, notably tensile and flexural strength, while also improving its resistance to cracking and impact loads. Prior studies have investigated the synergistic effects of GGBS and fibers on traditional concrete, revealing enhancements in strength and durability. Nevertheless, scant study has concentrated on the influence of these components on the fresh and hardened characteristics of SCC. This study seeks to enhance the current knowledge base by examining the ideal replacement ratios of GGBS and the influence of polypropylene fibers on the flowability, passing ability, viscosity, and mechanical properties of SCC. The fresh properties observed for a 20% replacement of cement with GGBS and polypropylene fiber were superior to those for 5%, 10%, and 15% replacements. Consequently, the findings indicate that an increase in GGBS replacement enhances the workability of concrete. Augmenting the GGBFS content in the concrete mix enhances the flow characteristics of self-compacting concrete. The toughened properties, such as compressive strength and flexural strength of SCC, improve with the addition of GGBS up to 20%.

Saman Hedjazi and Daniel Castillo (2022) [3] This study examines the effect of polypropylene fibers on the mechanical characteristics and ultrasonic pulse velocity (UPV) of concrete. Prior studies have thoroughly investigated the incorporation of fibers, such as polypropylene, to improve the mechanical properties of concrete, encompassing compressive strength, tensile strength, and impact resistance. Three Various studies have employed non-destructive testing (NDT) techniques, such as Ultrasonic Pulse Velocity (UPV), to evaluate the in-situ condition and forecast the compressive strength of concrete. The existing research delineates recognized correlations between Ultrasonic Pulse Velocity (UPV) and compressive strength in plain concrete. The inclusion of fibers in the concrete matrix might substantially modify the propagation of ultrasonic vibrations, potentially rendering these established correlations invalid. This study seeks to fill this gap by examining the influence of polypropylene fibers on UPV readings and formulating a novel empirical equation that precisely forecasts the compressive strength of PFRC using UPV data. This research advances the reliability of NDT techniques for assessing the quality and performance of fiber-reinforced concrete structures.

B.K. Varun and Harish B.A. (2018) [10] This research explores the utilization of fly ash and GGBS as extra binding materials for cement, resulting in the development of M30 grade concrete with fly ash and GGBS as partial cement replacements. They emphasized that the utilization of fly ash and GGBS as substitutes for cement not only enhances the technical qualities of concrete but also aids in the mitigation of environmental degradation. This article concluded that compressive strength diminishes as the proportion of fly ash replacing cement increases, resulting in a drop in both compressive and split strength. The compressive strength of fly ash concrete increases with a 20% cement replacement, while a 40% replacement results in a drop in strength. It is recommended to utilize fly ash at a replacement level between 20% and 40% for optimal results. The study indicates that low volume replacement (20% fly ash, 20% GGBS, 60% OPC) yields superior results compared to high volume replacement (40% fly ash, 20% GGBS, 40% OPC) at all curing ages.

Poornima M. Reddy and colleagues (2017) [8] The incorporation of polypropylene fibres (PPF) into concrete substantially influenced its characteristics. Elevated PPF content typically diminished workability, as indicated by a reduction in slump. Nonetheless, this was counterbalanced by enhancements in mechanical strength. Compressive, split tensile, and flexural strengths initially augmented with increasing PPF percentages, attaining peak values at 1.5% fiber content. Beyond this juncture, strength increases either stabilized or diminished. The 1.5% PPF mix demonstrated significant strength improvements relative to the control concrete, with increases of 22.68% in compressive strength, 24.56% in tensile strength, and 33.11% in flexural strength. The data indicate that the correct dosage of PPF can markedly improve the performance of concrete buildings.

Divya S. Dharan and Aswathy Lal (2016) [2] This study examines the impact of varying proportions of blended polypropylene fibers on the mechanical properties of concrete, namely compressive strength, flexural strength, split tensile strength, and modulus of elasticity. In light of India's swift expansion, there is an escalating demand for high-strength, high-performance concrete to satisfy the rising requirements of contemporary construction. Fiber reinforced concrete (FRC) has emerged as a viable alternative, providing superior structural integrity and durability relative to traditional concrete. The mechanical properties of FRC are greatly affected by the kind, geometry, distribution, orientation, and density of the embedded fibers. Polypropylene fibers, noted for their lightweight and synthetic properties, have attracted considerable interest for their ability to enhance crack resistance and overall reinforcement in concrete buildings. Multiple research have investigated the influence of different fiber kinds, including polypropylene, on the mechanical characteristics of concrete. Prior studies have shown that polypropylene fibers can significantly improve the tensile strength, flexural strength, and impact resistance of concrete, hence increasing its resistance to cracking and brittle failure. This study enhances the existing knowledge by assessing the impact of varying percentages of blended polypropylene fibers on the essential mechanical properties of concrete, offering critical insights for optimizing fiber content and enhancing the overall performance of fiber-reinforced concrete structures in India. The compressive strength of concrete reinforced with 1.5% blended length polypropylene fibers exhibits a 17% improvement compared to conventional concrete. The boost in split tensile strength is 22%, in flexural strength is 24%, and in modulus of elasticity is 11% relative to conventional concrete. The experimental investigations demonstrated to be the most effective approach in producing robust and durable concrete. It is noticed that 1.5% fiber in concrete produces maximum strength.

Milind V. Mohod (2015) [6] The findings of this study regarding the impact of polypropylene fibers (PPF) on high-strength concrete (HSC) are consistent with existing studies in the domain of fiber-reinforced concrete (FRC). The noted decrease in early-age shrinkage and moisture loss with the incorporation of PPF aligns with several research evidencing PPF's capacity to alleviate these issues. The fibers' bridging effect within the concrete matrix mitigates microcracking, a primary factor in early-age shrinkage. The reduction in workability with elevated fiber content is extensively established in the literature. Fibers enhance the viscosity of the fresh concrete mixture, complicating the processes of mixing, transporting, and placing. Concerning mechanical qualities, the study identified an optimal fiber content for compressive strength; nevertheless, existing literature indicates that the influence of fibers on compressive strength is typically less significant than their effect on tensile and flexural strength. The notable improvement in tensile and flexural strength at optimal fiber doses corresponds with current research findings. Fibers serve as a supplementary reinforcement, connecting fissures and inhibiting their expansion. The determination of an optimal fiber content for improved mechanical qualities is well-documented in FRC research. Excessive fiber doses may result in fiber interference, diminished matrix density, and complications in mixing and placing. This research offers significant insights into the behavior of PPF-reinforced high-strength concrete (HSC). However, further research is essential to explore long-term durability, impact on other properties (e.g., impact resistance, fatigue resistance), and the cost-effectiveness of PPFRC in diverse applications.

S. Arivalagan (2014) [1] Blast furnace slag is a by-product of the iron producing sector. Iron ore, coke, and limestone are introduced into the furnace, causing molten slag to float on the molten iron at temperatures ranging from around 1500°C to 1600°C. The molten slag comprises 30% to 40% silicon dioxide (SiO_2) and approximately 40% calcium oxide (CaO), resembling the chemical composition of Portland cement. After the molten iron is extracted, the residual molten slag, primarily consisting of siliceous and aluminous material, is rapidly water-quenched, resulting in the formation of glassy granules. These glassy granules are subsequently dried and ground to the requisite size, known as Ground Granulated Blast-furnace Slag (GGBS). This paper demonstrates that GGBS concrete exhibits superior water impermeability, enhanced corrosion resistance, and improved resistance to sulphate attack. It was observed that a 20% replacement of cement with GGBS resulted in increased strength at 28 days, attributed to the filler effect of GGBS. Consequently, it is established that GGBS can serve as an alternative material for cement, thereby reducing cement consumption and construction costs. The utilization of industrial waste benefits the environment and conserves natural resources.

A.H.L. Swaroop et al. (2013) Reference [9] Cement is the most crucial component of concrete. The manufacturing process of this raw material generates significant CO_2 emissions. CO_2 emissions are widely recognized as catalysts for detrimental environmental alterations. Currently, researchers strive to reduce industrial CO_2 emissions. The most efficient method to reduce CO_2 emissions in the cement business is to replace a portion of cement with alternative materials. This material is referred to as supplementary cementing materials (SCMs). This work presents M30 grade concrete (1:1.21:2.77), utilizing Ground Granulated Blast Furnace Slag (GGBS) and fly ash as supplementary cementitious materials (SCMs). Incorporating these components at varying amounts and curing them in H_2SO_4 solution and water. The study concluded that the performance of concrete with 20% fly ash and GGBS exceeds that of conventional aggregate concrete (CAC) after 28 and 60 days of typical water curing. The experimental study indicates that the strength of fly ash concrete increases with a 20% cement replacement, while it decreases with a 40% replacement. Therefore, it is recommended to utilize fly ash for a cement replacement of 20-40% to achieve optimal results.

Kolli Ramujee (2013) [5] The incorporation of fibers in concrete has garnered considerable attention in recent years for their capacity to improve qualities such as strength, hardness, and durability. A multitude of studies has investigated the impact of various fiber kinds, including steel, glass, and synthetic fibers like polypropylene, on the mechanical properties of concrete. Prior studies have shown that the addition of polypropylene fibers can significantly enhance the tensile strength and impact resistance of concrete, hence increasing its resistance to cracking and brittle failure. These fibers are recognized for their superior strength-to-weight ratio, exceptional resistance to chemical degradation, and comparatively low cost, rendering them a compelling choice for reinforcing concrete buildings. Polypropylene fibers markedly improve the post-cracking performance of concrete, resulting in enhanced ductility and energy absorption capacity. The incorporation of fibers can alleviate the damage inflicted by abrupt impacts, enhancing the concrete's resistance to shock loads. Research indicates that fiber reinforced concrete demonstrates enhanced flexural strength relative to conventional concrete, rendering it more appropriate for applications involving substantial bending loads. Certain studies indicate that polypropylene fibers can mitigate shrinkage and creep deformations in concrete, resulting in enhanced dimensional stability.

Saeid Kakooei, et al (2012) [4] This study examines the impact of polypropylene fibers on the compressive strength, permeability, and electrical resistivity of concrete incorporating both coral and siliceous materials. Prior studies have thoroughly investigated the use of fibers, especially polypropylene, to improve the mechanical characteristics of concrete, including tensile strength and impact resistance. Additionally, studies have shown that fiber insertion can improve the longevity of concrete by lowering permeability and moderating the intrusion of hostile chemicals, such as chloride ions, which can lead to corrosion of reinforcing steel. The influence of aggregate type on concrete characteristics is thoroughly documented. Coral aggregates, although commonly found in coastal areas, may possess distinct properties compared to conventional siliceous aggregates, potentially affecting the overall performance of the concrete. Previous research has investigated the incorporation of coral aggregates in concrete, yielding inconsistent findings concerning their compressive strength and durability. This research enhances the existing knowledge by assessing the synergistic effects of polypropylene fibers and aggregate type (coral versus siliceous) on the fundamental properties of concrete, offering critical insights for material selection and concrete structure design in coastal settings.

1.2. Aim

To investigate the impact of adding polypropylene fibers and partially replacing OPC 53 grade cement with GGBS and Fly ash on the strength and durability of concrete.

1.3. Objectives

- To reduce the uses of ordinary Portland cement and to improve the eco-friendly materials.
- To determine the compressive strength and split tensile strength of concrete.
- To determine the strength of concrete at different proportion of polypropylene fibers.

1.4. Methodology

The methodology of the work consists of

1. Study of materials
2. Collection of materials
3. Laboratory Test
4. Mix Design M40 grade
5. Casting of cubes and cylinder
6. Test on specimens
7. Result Analysis

1.5. Test on materials

Table no. 1:- Laboratory tests on materials

Sr. no.	Materials	Tests	Values Obtained
1	Cement	Specific Gravity	3.15
		Initial setting time	40min.
2	Fine Aggregate	Specific Gravity	2.61
		Fineness modulus	2.81
3	Coarse Aggregate	Specific Gravity	2.55
		Water absorption	0.65
4	Fly ash	Specific Gravity	2.18
5	GGBS	Specific Gravity	2.89
6	Polypropylene fibers	Specific Gravity	1.08
		Aspect Ratio	572
		Tensile strength	648MPa

1.6. Mix Design

M40 Grade of mix Proportioning-
Cement :- 370kg
Fine Aggregate :- 693kg
Coarse Aggregate :- 1225kg
Water :- 147.87kg

2. Illustrations

Concrete cubes are commonly used to determine the compressive strength of concrete. As per IS 516:1959 Standard cube size 150 mm × 150 mm × 150 mm. Concrete is filled in three layers, each layer compacted using a tamping rod (25 strokes per layer). After casting, the cubes are demolded after 24 hours and cured in water for 7, 14, or 28 days.
Cylindrical specimens are generally used for testing split tensile strength and sometimes compressive strength. Standard size: *150 mm diameter × 300 mm height (as per IS 5816:1999), Like cubes, they are cast in layers and compacted properly. Cured similarly to cubes under controlled conditions

(a) **(b)**

Fig. 1 - (a) Cube mould; (b) Cylinder mould.

3. Test and Result

Table 2:- Conventional Concrete

Sr. no.	Compressive strength 7 days (MPa)	Compressive strength 28 days (MPa)
1	22.5	41.97
2	23.2	43.50
3	25.3	44.07

Table 3:- Mineral Admixtures concrete

Sr. no.	Compressive strength 7 days (MPa)	Compressive strength 28 days (MPa)
1	19.6	36.45
2	2022	40.5
3	19.2	37.43

Table 4:- Mineral admixture+1% PPF

Sr. no.	Compressive strength 7 days (MPa)	Compressive strength 28 days (MPa)
1	14.48	39.88
2	15.61	38.84
3	17.7	34.27

Table 5:- Mineral admixtures +1.5% PPF

Sr. no.	Compressive strength 7 days (MPa)	Compressive strength 28 days (MPa)
1	20.8	39.86
2	18.69	37.505
3	22.37	39.00

Table 6:- Mineral admixture +2% PPF

Sr. no.	Compressive strength 7 days (MPa)	Compressive strength 28 days (MPa)
1	19.58	37.13
2	19.41	38.89
3	18.5	36.97

Table 7:- Conventional Concrete

Sr. no.	Tensile strength 7days (MPa)	Tensile strength 28 days (MPa)
1	2.15	2.70
2	2.46	2.79
3	2.35	3.07

Table 8:- Mineral admixtures

Sr. no.	Tensile strength 7days (MPa)	Tensile strength 28 days (MPa)
1	2.06	3.46
2	2.02	3.25
3	1.90	3.405

Table 9:- mineral Admixtures +1% PPF

Sr. no.	Tensile strength 7days (MPa)	Tensile strength 28 days (MPa)
1	1.49	2.95
2	2.12	2.93
3	2.02	2.93

Table 10:- Mineral Admixtures +1.5% PPF

Sr. no.	Tensile strength 7days (MPa)	Tensile strength 28 days (MPa)
1	1.83	2.9
2	1.96	3.30
3	2.1	3.00

Table 11:- Mineral admixtures +2% PPF

Sr. no.	Tensile strength 7days (MPa)	Tensile strength 28 days (MPa)
1	1.29	2.64
2	1.3	2.60
3	1.5212	2.16

3.1. Result Comparison

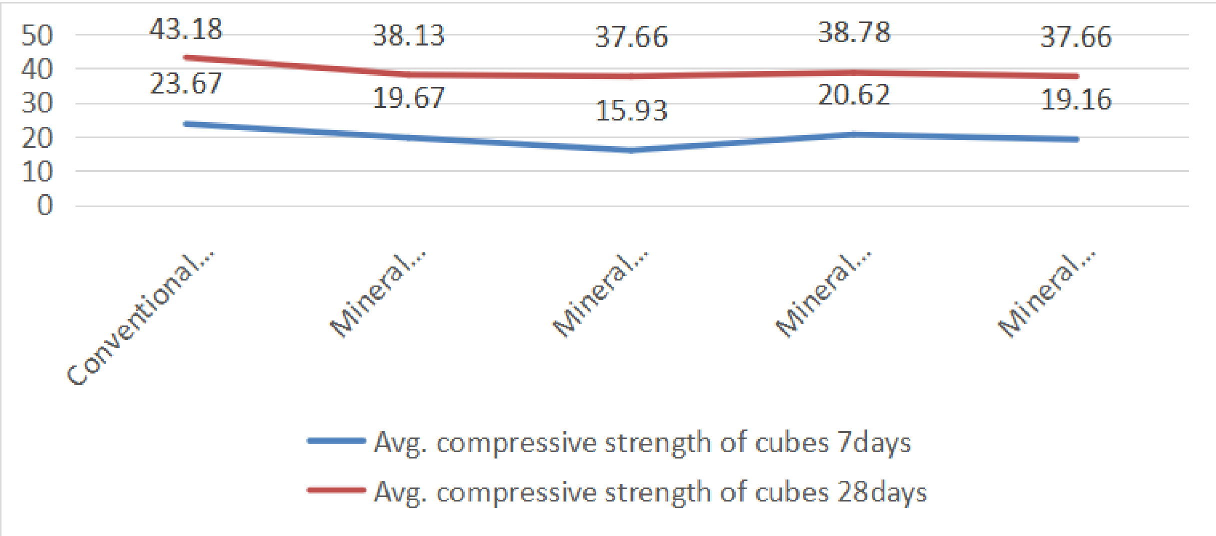

Fig. 2- Average Comparison Between Compressive strength of Concrete

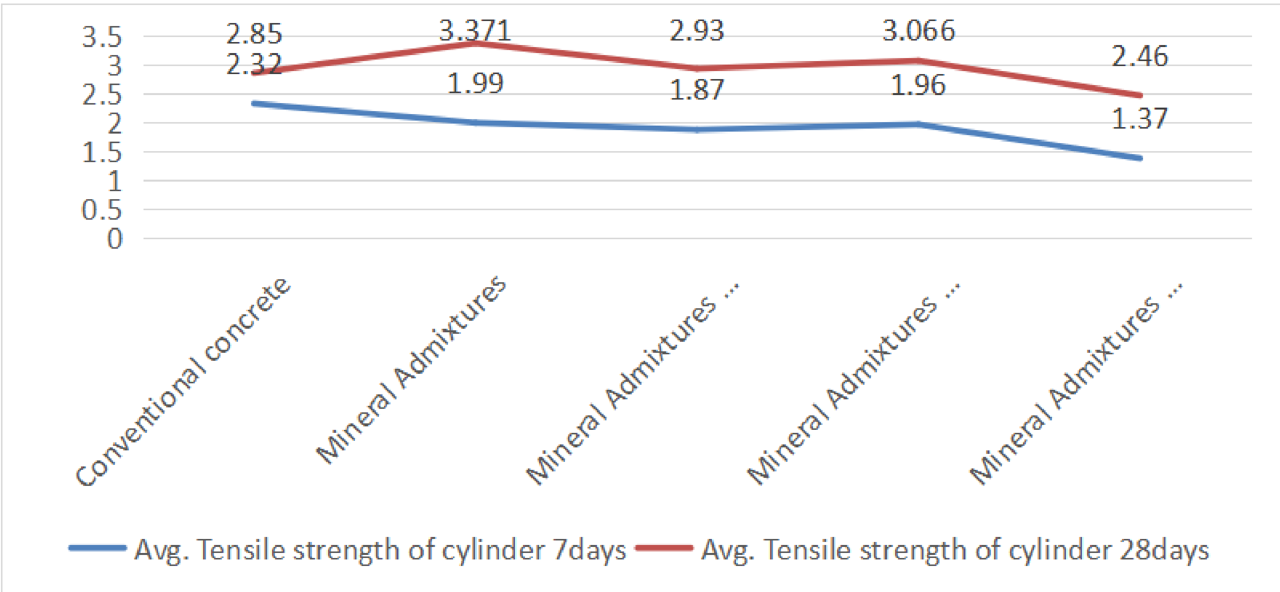

Fig. 2- Average Comparison Between tensile strength of Concrete

4. Conclusion

1. The initial strength (7 days) of concrete significantly drops when mineral admixtures replace part of cement, especially when

combined with 1% fibers.

2. The 28 days strength also follow the similar pattern, though the drop is less severe, indicating mineral admixtures require time to develop strength.
3. 1.5% polypropylene fibers with mineral admixtures appear to offer the best balance-regaining some of the lost strength compared to mineral only or 1% fibers mixes.
4. Adding 2% polypropylene fibers does not improve the strength further and slightly reduces it, suggesting possible fiber clustering or negative effect on workability and bonding.
5. Based on all over the result the project concluded that the optimal mix in this experiment seems to be mineral admixtures with 1.5% of polypropylene fibers, offering a good compromise between sustainability (replacing cement) and maintaining strength over time. Going beyond 1.5% fibers may lead to diminishing return or even adverse effects.

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