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ARTICLE

Investigation of Mechanical Properties of High-Performance Steel and Polypropylene Fiber Reinforced Concrete

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ABSTRACT

Fiber reinforcement significantly enhances the strength, toughness, and durability of concrete by reducing the propagation of microcracks in the concrete matrix. With the rising demand for high-performance concrete (HPC), this study investigates the mechanical properties of HPC with varying proportions of polypropylene (PP) and steel (ST) fibers. Supplementary cementitious materials (SCMs) toward partial replacement of ordinary Portland cement (OPC) were incorporated to prepare HPC mixes as a ternary composite system using Fly Ash (FA), Silica Fume (SF), and Ground Granulated Blast Furnace Slag (GGBS). Each HPC mix comprised two SCMs, accounting for 20% of the mass fraction of the OPC binder. The study encompassed fiber percentages ranging from 0 to 0.075% PP and 0 to 2% ST, incorporating them into the HPC mixes with gradual increases of 0.025% for PP and 0.5% for ST fiber by mass fraction. All HPC mixes were tested for mechanical properties using compressive and split tensile strength tests. The influence of SCMs on HPC was studied using X-ray diffraction (XRD) for microstructural analyses. It was found that the compressive and split tensile strengths of HPC increased up to an optimal fiber percentage and then decreased.

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A comparison of the test results of high-performance fiber-reinforced concrete with those of plain HPC revealed significant improvements in compressive and splitting tensile strengths by 26.59% and 57.74%, respectively. Also, the XRD analysis revealed that the composition of the SCMs in HPC was a significant and effective solution for the mechanical properties of the concrete.

Keywords: Low Carbon Cement; High-Performance Concrete; Mechanical Properties; Supplementary Cementitious Materials; Polypropylene Fibers

1. Introduction

Rapid urbanization and the increasing complexity of infrastructure projects demand innovative construction materials that can withstand harsh environmental conditions and extreme loads while ensuring sustainability. In recent decades, there has been a significant increase in the demand for HPC, as there is a growing need to construct durable and sustainable structures. Modern infrastructure projects such as high-rise buildings, bridges, and marine structures require materials that offer superior mechanical strength, durability, and resistance to environmental degradation. Additionally, rising concerns over climate change and the depletion of natural resources have made it imperative to explore sustainable alternatives for concrete production. However, achieving an optimal balance between strength, workability, and sustainability in HPC remains a challenge, particularly when incorporating various fibers and SCMs. Hybrid fiber reinforcement, in which ST and PP fibers are combined in optimized proportions, has shown promising results in balancing strength and ductility while minimizing crack propagation [1].

Researchers have conducted numerous studies focusing on the development of technologies aimed at enhancing the strength of concrete. Despite significant progress in the development of fiber-reinforced cement-based composites since the 1960s, their widespread use in construction has been hindered by a lack of standardized practices and high costs [2]. Various studies have shown that the incorporation of ST and PP fibers into HPC not only improves its mechanical properties but also enhances its crack resistance, corrosion resistance, and flexibility [3–5]. These fibers enhance energy absorption and impact resistance, making HPC suitable for seismic-prone regions and structures subjected to dynamic loads, such as bridges and tunnels [6,7].

Nevertheless, using industrial wastes or by-products as SCMs to replace OPC partially is a common practice for addressing the sustainability and durability of concrete structures and mitigating carbon emissions/footprints and environmental impacts [8,9]. The combination of FA, SF, and GGBS in HPC is known to provide a well-balanced mix of pozzolanic activity, improved workability, and enhanced durability, making it a preferred choice for high-performance applications. Researchers have used a combination of these three SCMs to create a ternary composite system for concrete mix design. The use of FA is known to improve workability and enhance the formation of additional Calcium Silicate Hydrate (C-S-H) gel through its pozzolanic activity in the concrete matrix. This, in turn, improves properties such as the strength and durability of FRC [10–12]. The addition of SF to OPC enhances the early-age mechanical properties of HPC [13]. It also offers additional benefits, such as improved corrosion resistance, and helps prevent bleeding and segregation, resulting in a more versatile and durable construction material [14–16]. GGBS improves the FRC's matrix interface and microstructure of FRC, enhancing flexural strength and toughness [17,18]. This approach aligns with the global sustainability goals and green construction initiatives, promoting eco-friendly materials in the building sector.

Although the benefits of using SCMs in concrete are well documented, the interaction between different fiber types and SCMs within HPC remains an active research area. Using SCMs in combination with OPC in concrete offers several advantages in improving durability and sustainability. However, the potential for enhancing mechanical properties through the use of fiber content has been found to have limitations. This particular study focused on investigating the mechanical properties of HPC with various types of fibers, including ST and PP fibers. The analysis specifically examined the concrete's strength and split tensile strength behavior under different fiber variations. Furthermore, a detailed microstructural analysis utilizing XRD was employed to gain a deeper insight into the behavior of SCMs in the concrete mix. Through XRD, valuable data on the formation of C-S-H gel and the concentration of different components, such as SiO_2 and $Ca(OH)_2$, in the mix were obtained, rather than focusing solely on the fibers. XRD analysis provides a deeper understanding of the hydration mechanisms and phase transformations occurring within HPC, which are crucial for optimizing its mechanical performance [19,20]. This confirms the formation of additional hydration products, such as C-S-H and calcium aluminosilicate hydrate (C-A-S-H), which improve compressive strength and durability.

This research contributes to developing high-performance, sustainable construction materials and offers valuable insights into optimizing FRC for enhanced mechanical performance and durability. The findings of this study have the potential to aid in formulating HPC mixes with improved efficiency, making them more viable for large-scale construction projects. By optimizing the fiber proportions and SCM combinations, this research provides a framework for designing cost-effective high-strength concrete that minimizes material waste while maximizing structural efficiency. The findings of this study are particularly relevant for designing earthquake-resistant structures, offshore platforms, and high-load-bearing pavements where both mechanical strength and durability are critical.

Moreover, by addressing both the mechanical and microstructural aspects, this research aims to bridge the knowledge gap between laboratory experiments and practical applications, ultimately supporting the advancement of durable and sustainable concrete solutions. These findings can help bridge the gap between experimental research and real-world applications, potentially leading to cost-effective, eco-friendly concrete solutions for future infrastructure projects.

2. Materials, Mix, and Testing Conditions

2.1. Materials

In this study, OPC grade 43 (b) was used as the main binder to produce HPC mixes following the IS 10262 [21]. To enhance sustainability and durability, SCMs such as FA, SF, and GGBS have been incorporated as partial replacements for OPC. Each mix contained a ternary combination of OPC with two SCMs to evaluate their collective influence on FRC's mechanical and microstructural properties. The chemical composition and physical properties of all cementitious materials were determined either through laboratory testing or sourced from supplier data, ensuring compliance with Indian Standard codes IS 8112 for OPC [22], IS 3812 for FA [23,24], IS 15388 for SF [25], and IS 12089 for GGBS [26]. The chemical and physical properties of these materials are listed in **Table 1**.

Table 1. Chemical composition and physical properties of cement and SCMs [27].

Properties	SI Unit	OPC	FA	SF	GGBS
Chemical Composition (%)					
SiO_2	-	14.19	43.81	72.22	31.24
Al_2O_3	-	8.63	45.84	1.28	16.60
Fe_2O_3	-	-	2.15	2.70	0.41
CaO	-	71.51	2.18	3.09	39.04
MgO	-	2.12	0.97	5.21	9.31
SO_3	-	1.66	-	2.37	0.95
K_2O	-	0.70	2.54	9.54	0.54
Na_2O	-	0.20	-	2.75	-
Physical Properties					
Specific surface area	m^2/kg	334	600	19000*	372*
Specific gravity	-	3.15	2.40	2.20	2.91

Note: *Data from the data sheets provided by the supplier has been considered. These comply with the relevant IS standards [24,25] and were selected for improved workability. While they deviate from general construction practices, the reduced pozzolanic activity ensures that actual conditions will yield superior strength outcomes.

Locally available non-reactive coarse and fine aggregates were utilized in the concrete mix, ensuring their physical properties conformed to the specifications outlined in Indian Standard IS 2386 [28,29]. The aggregates were subjected to a grading process through sieve analysis following the guidelines prescribed in IS 383 [30] to achieve the required particle size distribution. The coarse aggregate used in the study had a maximum nominal size of 12.5 mm, with 100% passing through the 12.5 mm sieve and retained on the 4.75 mm sieve, ensuring uniformity in particle size and minimizing segregation. The fine aggregate, classified under Grading Zone II as per IS 383, passed through a 4.75 mm sieve while being retained on a 150 µm sieve, thereby meeting the necessary gradation requirements for optimal workability and strength development. The well-graded nature of the aggregates contributed to improved particle packing density, reduced void content, and enhanced mechanical performance of the HPC mix. The specific physical properties, including the bulk density, specific gravity, water absorption, and fineness modulus of both coarse and fine aggregates, are listed in **Table 2**. Each mix contained different proportions of steel and polypropylene fibers, and their physical and mechanical properties, as provided by the supplier, are listed in **Table 3**.

2.2. HPC Mix Proportions

Each HPC mix consisted of three cubical specimens measuring 100 × 100 × 100 mm for compressive strength testing. Three cylindrical specimens, each with a diameter of 100 mm and a height of 200 mm, were used for tensile strength testing. To ensure statistical reliability and consistency, the reported mechanical strength values were derived from the mean of three identical specimens for each mix, thereby minimizing the inconsistencies in the experiment. The mix proportions were designed for M60-grade concrete, as shown in **Table 4**.

Table 2. Physical properties of fine and coarse aggregates [27].

Characteristics	SI Unit	Fine aggregates	Coarse aggregates
Specific gravity	-	2.67	2.70
Fineness modulus	-	2.73	6.88
Loose bulk density	kg/m^3	1412	1321
Water absorption	%	0.82	0.86

Table 3. Physical and mechanical properties of ST and PP fibers [27].

Properties	SI Unit	Steel (ST)	Polypropylene (PP)
Material type	-	Low carbon drawn round wire	Virgin Polypropylene
Length	mm	30 (Hook end)	22
Aspect ratio (approx.)	-	40	857
Diameter	mm	1.00	0.028
Tensile Strength	MPa	1300	-

Table 4. HPC M60 mix proportions.

Materials	SI Unit	Mix-H5	Mix-H6	Mix-H7
Cement	kg/m^3	450	450	450
Fly ash	kg/m^3	90	-	90
Silica fume	kg/m^3	90	90	-
GGBS	kg/m^3	-	90	90
Fine aggregate	kg/m^3	678	678	678
Coarse aggregate	kg/m^3	1107	1107	1107
Water (w)	kg/m^3	157.5	157.5	157.5
Superplasticizer	kg/m^3	4.6	4.6	4.6
w/b	-	0.35	0.35	0.35
w/(b+c)	-	0.25	0.25	0.25
Density	kg/m^3	2577	2577	2577

Note: b is the cement, c is the total SCMs, and w is the water.

Non-FRC specimens were selected for XRD analysis to isolate the effects of SCMs, excluding fiber-induced microstructural variations, thereby facilitating a clear understanding of the hydration and pozzolanic reactions occurring within the concrete matrix. After strength testing, fragments of the broken non-FRC specimens were carefully collected and ground into a fine powder to ensure a homogeneous and representative sample. These samples were extracted from the core regions of the concrete specimens to eliminate surface contamination or carbonation effects, which could skew the XRD results. The three different mixes with varying ternary combinations of SCMs were labeled Mix H5, Mix H6, and Mix H7 for reference.

Each HPC mix was designed to contain different combinations and quantities of PP and ST fibers, based on the mass fractions of the mix, to analyze their individual and combined effects on the mechanical properties of concrete. The selection of fiber proportions was based on previous studies and optimization trials, ensuring that both ST and PP fibers were incorporated in practical and effective ranges. The mix proportions included PP percentages of 0.00, 0.025, 0.050, and 0.075, and ST percentages of 0.00, 0.50, 1.00, 1.50, and 2.00. These mixes were labelled as P00, P25, P50, P75, and S00, S05, S10, S15, and S20, respectively, to represent their statistics. The quantities of the reinforcements are listed in **Table 5**. This classification was then used to prepare a detailed statistical and graphical interpretation of trends in strength development, aiding in identifying the optimal fiber combination.

Table 5. Fiber reinforcement quantities.

Polypropylene (PP)			Steel (ST)		
Labels	%	kg/m^3	**Labels**	%	kg/m^3
P00	0.000	-	**S00**	0.00	-
P25	0.025	0.64	**S05**	0.50	12.88
P50	0.050	1.28	**S10**	1.00	25.77
P75	0.075	1.93	**S15**	1.50	38.65
-	-	-	**S20**	2.00	51.54

2.3. HPC Mixing Process

First, the materials in the mix proportion were weighed and thoroughly dry-mixed to achieve homogeneity. A polycarboxylate-based superplasticizer (MasterGlenium SKY 8777) was added to the potable water and gradually introduced into the dry mix over a period of one to two minutes, ensuring even dispersion. The PP and ST fibers were incorporated in a controlled manner after the initial wet mixing stage, ensuring their uniform distribution to avoid the formation of weak zones within the concrete matrix. ST fibers were first added to minimize fiber balling, followed by PP fibers, ensuring gradual integration into the mix. The mixing process took approximately four minutes, during which the slurry reached good consistency and workability. The mix was then poured into three 100 × 100 × 100 mm cube molds and three 100 × 200 mm cylinder molds, followed by vibration and compaction. The molds were left to dry for 24 hours and demolded the following day. The specimens were then subjected to controlled water curing at 27 ± 2 °C for six days and later under controlled temperature conditions of 20 ± 2 °C and relative humidity of 60 ± 5% to achieve the considered design strength at 28 days. Special curing practices have been adopted to simulate real-world conditions where prolonged water curing is unavailable, such as in large-scale infrastructure projects or precast elements [27]. To study the effect of fiber reinforcement on the mechanical properties of HPC, three different mixes, Mix-H5, Mix-H6, and Mix-H7, were prepared with varying percentages of PP and ST fibers.

2.4. Testing

The compressive strength of the cubical specimens and the split tensile strength of the cylindrical specimens were tested according to IS 516 [31] and IS 5816 [32]. A compression testing machine with a maximum loading capacity of 2000 kN in the Advanced Concrete, Steel, and Composites Division, CSIR-CBRI, Roorkee, was used to test the mechanical properties of the specimen. The machine was calibrated to the nearest two decimal values to ensure accurate measurement. The testing load was applied at a constant rate of 140 kg/cm^2/min or 2.28 kN/sec.

Furthermore, the XRD method used an X-ray diffractometer in the Building Materials and Environmental Sustainability Division, CSIR-CBRI, Roorkee, for microstructural analysis. A continuous scanning in the 2-theta range of 5° to 80° using a Cu Kα radiation at 1.542 Å, 40kV voltage, and 40mA current was applied to obtain peak intensities. The goniometer utilized a minimum step size of 0.02°. The obtained XRD patterns were analyzed to detect the presence of crystalline hydration products such as C-S-H, calcium hydroxide (CH), ettringite, and unreacted cementitious phases. The relative peak intensities of CH and C-S-H were used to assess the hydration efficiency and pozzolanic activity of SCMs in the concrete matrix. Additionally, the XRD data were correlated with mechanical strength results to evaluate the effect of SCMs and fiber interactions on phase transformations.

3. Results

This study examined the variations in the compressive strength of concrete using three different mixes of HPC, each with varying proportions of PP and ST fibers. The extensive raw data of the compressive and split tensile strength results of 20 fiber-reinforced specimens across three different mixes are shown in **Figures 1–3**, and exhibit some common trends. The optimal percentages of fiber for all three mixes were found to be 0.025% for PP and 1.5% for ST. The standard deviation for compressive strength ranged from 2.5 to 7.5 MPa, while that for split tensile strength ranged from 0.3 to 1.5 MPa. The specimens labeled P25+S15 (0.025% polypropylene and 1.5% steel) exhibited compressive strengths of 26.59%, 10.07%, and 13.25% for Mix-H5, Mix-H6, and Mix-H7, respectively. The specimen labeled P00+S15 yielded the best results for the split tensile strength, with maximum increases of 19.04%, 57.74%, and 21.97% for Mix-H5, Mix-H6, and Mix-H7, respectively. Mix-H5 exhibited the highest compressive strength gain of 26.59%, whereas Mix-H6 showed the most significant improvement in split tensile strength, with a remarkable 57.74% increase, emphasizing the effectiveness of fiber synergy in optimizing HPC performance. The standard deviation for compressive strength value ranged from 2.5 to 7.5 MPa. The standard deviation for tensile strength values ranged from 0.3 to 1.5 MPa.

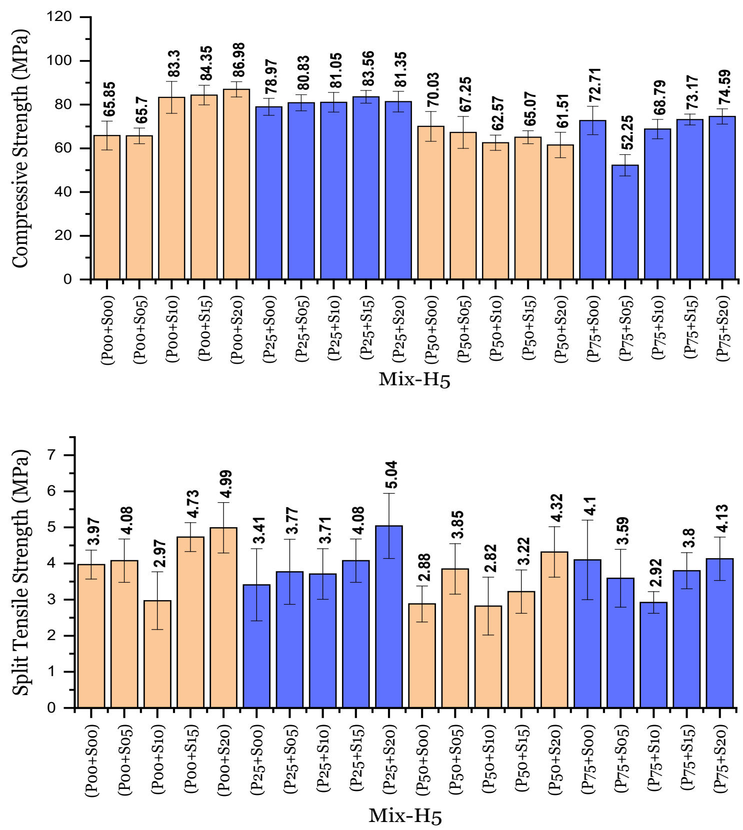

Figure 1. Compressive and split tensile strength of Mix-H5.

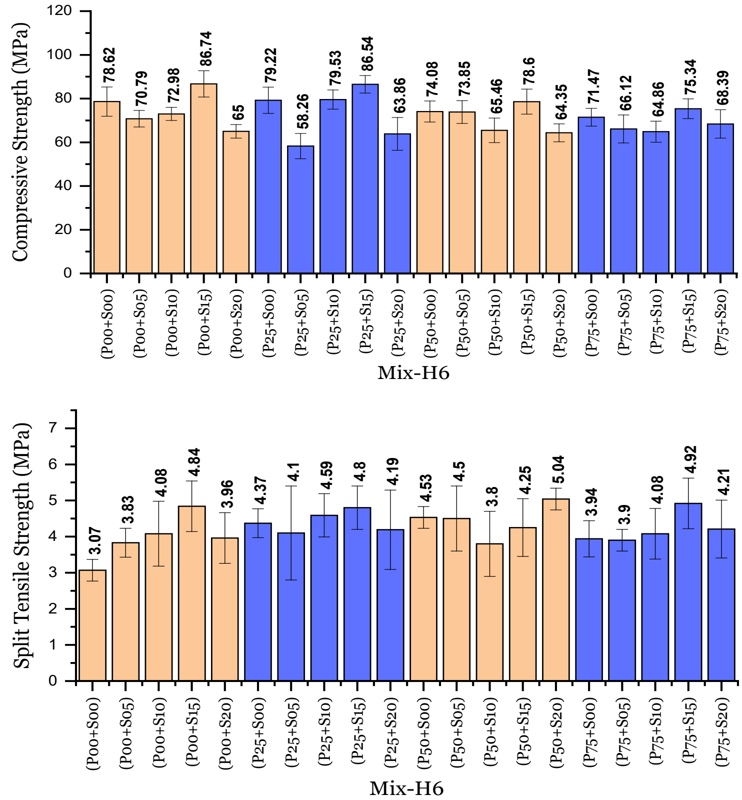

Figure 2. Compressive and split tensile strength of Mix-H6.

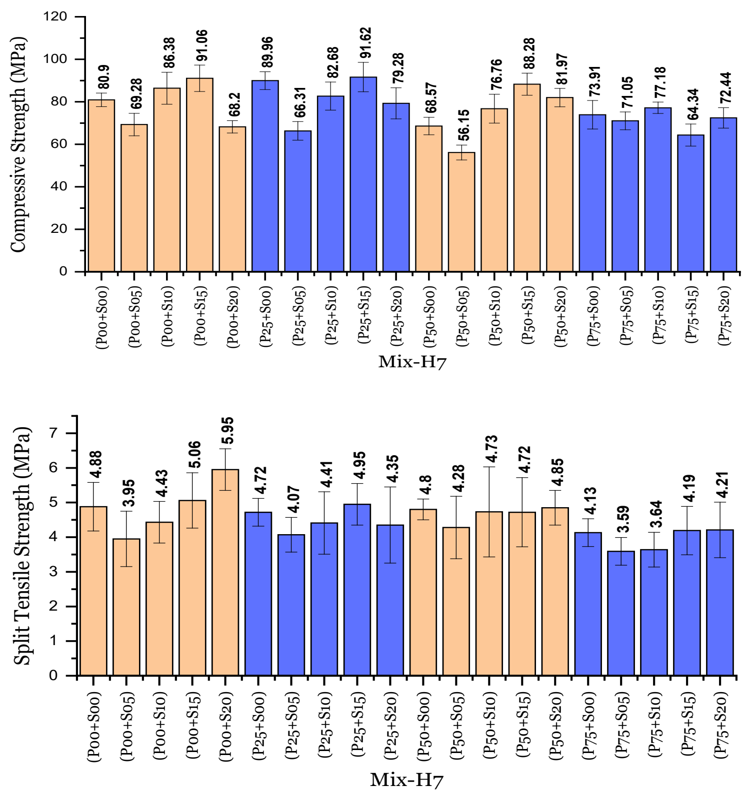

Figure 3. Compressive and split tensile strength of Mix-H7.

The XRD graphs of the three mixtures, **Figures 4–6**, show prominent peaks for six compounds: ettringite, calcium hydroxide ($Ca(OH)_2$), silica/quartz (SiO_2), calcium oxide (CaO), alite (C_3S), and belite (C_2S). SiO_2 in mix-H6 exhibited the most prominent peak, whereas ettringite exhibited the least notable peak. These compounds are crucial indicators of the concrete matrix's hydration process and microstructural characteristics. The relative intensities of these peaks provide insights into the phase transformations, secondary hydration reactions, and overall mineralogical composition of HPC.

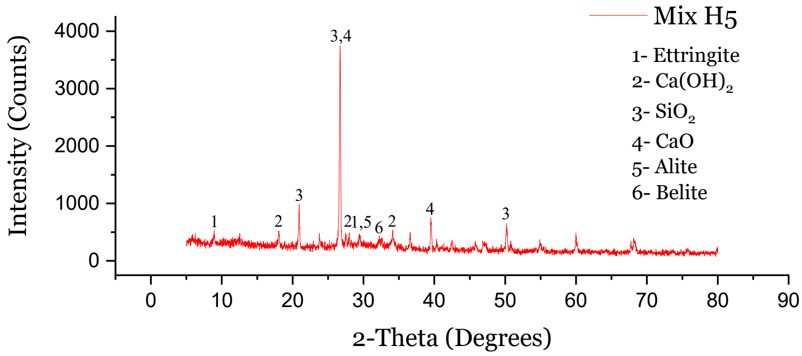

Figure 4. XRD graph of HPC Mix-H5.

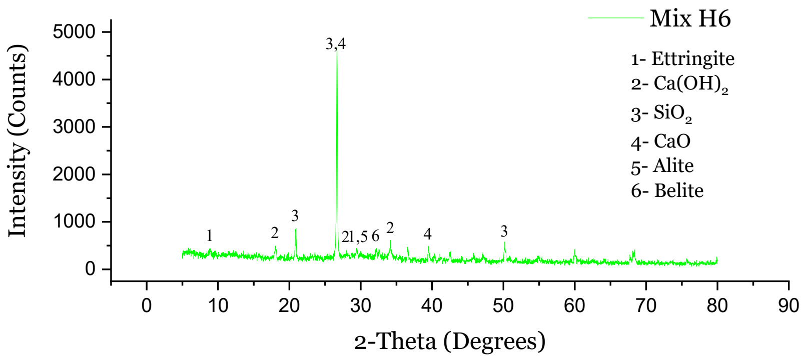

Figure 5. XRD graph of HPC Mix-H6.

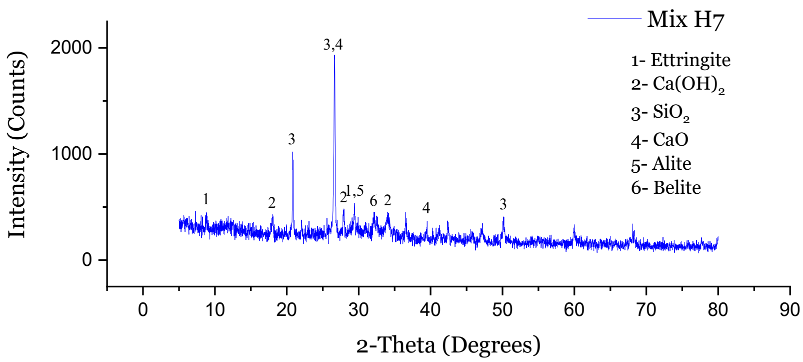

Figure 6. XRD graph of HPC Mix-H7.

4. Discussions

As shown in **Figures 1–3**, the sudden decrease in compressive strength observed in some specimens during the S05 trials was due to a disruption in the uniformity of the structure caused by the addition of fibers. The addition of fibers can lead to localized stress concentrations and improper compaction, which negatively affect strength development. However, the gradual increase in strength with increasing ST fiber content of the specimen was due to the high tensile strength of steel, which helped distribute stresses across the cracks. ST fibers also provide concrete with a post-cracking strength similar to that of reinforcement, which increases its strength even after cracking occurs at some point. The decrease in strength after a gradual increase in the ST fiber content is due to the disruption in the uniformity of the concrete caused by the excessive presence of fibers. Beyond an optimal fiber dosage, strength reduction occurs because of fiber agglomeration, which creates weak zones within the concrete matrix and hinders proper hydration [32]. The similar behavior of the strength results was found to align with that of Thomas and Ramaswamy [5].

Additionally, the use of polypropylene reinforcement negatively affects the compressive strength of concrete. Increasing the amount of PP fibers reduced the strength of the concrete. This occurs because the fibers can cause the formation of microcracks and increase the porosity in the concrete matrix by not being integrated properly with the C-S-H gel, which weakens the Interfacial Transition Zone (ITZ). The only time an increase in strength is observed is when using 0.025% PP reinforcement (P25) to help hold the microcracks together. However, the fibers disrupted the matrix beyond this threshold, compromising the compressive strength.

The variations in performance across Mix-H5, Mix-H6, and Mix-H7 highlight the role of SCMs in influencing fiber effectiveness, suggesting that pozzolanic activity and microstructural refinement contribute to the observed strength gains. It is clear that Mix-H7, with 20% SCMs added by cement content, exhibited the highest compressive and split tensile strengths. The XRD analysis revealed significantly lower peaks for alite (C_3S) and belite (C_2S) phases across all three HPC mixes. This suggests a high degree of hydration had already occurred, resulting in the conversion of these primary clinker phases into secondary hydration products such as C–S–H. Mix-H7 had a lower presence of SiO_2 than the other mixes owing to the absence of SF. SF is known to improve concrete strength by fostering $Ca(OH)_2$ formation and reacting with it to produce an additional C-S-H gel [33]. Substituting 20% or more of the cement with silica increases the concrete porosity and reduces the formation of $Ca(OH)_2$, which is a source of calcium for C-S-H formation in the primary strength-giving phase, leading to a less robust matrix. Similar results regarding silica fume incorporation were also found in studies by Uzbas, Aydin, and Bhandari et al. [34–37].

Moreover, partial cement replacement by SF reduces the density and strength of concrete [15]. Mix-H7 contained relatively less CaO than the other two mixes, suggesting that this component was used for C-S-H formation, making it the most effective mix. Mix-H5 had a higher silica content than Mix-H6 because FA contained more SiO_2 than GGBS, which may account for its lower strength than Mix-H6.

The higher SiO_2 peak in Mix-H6 suggests a slower pozzolanic reaction of FA because unreacted silica remains in the mix, indicating the ongoing secondary hydration process. FA is known for its delayed pozzolanic activity because it requires calcium hydroxide from cement hydration to react and form an additional C-S-H gel. Unlike SF, which reacts rapidly owing to its fine particle size and high reactivity, FA gradually reacts over time, leading to higher residual silica content in the early-stage XRD analysis.

5. Conclusions

This study provides insight into the impact of fiber reinforcement in high-strength steel and polypropylene FRC. The key findings of this study are as follows:

The optimal dosage of fiber is crucial for enhancing strength. The compressive and split tensile strengths of HPC increase with the addition of fiber up to a certain optimal content. Beyond this point, however, strength starts to decrease. This reduction in strength is due to fiber agglomeration, which disrupts the concrete matrix, decreases workability, and creates stress concentrations that adversely affect mechanical performance.

ST fibers play a crucial role in enhancing the mechanical properties of materials by improving ductility, energy absorption, and toughness. They provide post-cracking strength even when used beyond the optimal dosage, making them particularly advantageous for seismic-resistant structures, impact-resistant pavements, and applications prone to fatigue. The results demonstrated a direct correlation between the content of ST fibers and mechanical strength, highlighting their importance in enhancing both initial and residual strength properties.

Polypropylene fibers have a negative impact on compressive strength. While they primarily function as microcrack inhibitors rather than enhancing strength, using higher dosages can lead to issues such as concrete matrix discontinuities and increased porosity. This happens because of poor bonding with the C-S-H gel, which weakens the ITZ and ultimately reduces compressive strength. However, when used in minimal amounts (0.025%), PP fibers can effectively reduce shrinkage cracks and improve crack resistance at an early stage.

Optimized proportions of fiber and SCMs improve mechanical performance. The most effective HPC mix identified in this study contains 0.025% PP and 1.5% ST fibers by mass, which effectively balances workability, strength, and durability. Furthermore, replacing 20% of the cement with FA and GGBS enhances hydration efficiency, strength development, and sustainability. This combination makes the mix particularly suitable for long-term durability in aggressive environments.

Excessive amounts of SF can negatively affect the properties of concrete. While SF is known to refine the microstructure and enhance strength when used in lower dosages, replacing 20% of cement with SF can lead to a decrease in density and compressive strength. This reduction is likely due to increased water demand, reduced availability of $Ca(OH)_2$, and the formation of a more porous matrix. These findings emphasize the importance of carefully proportioning SF to achieve a balance between strength, workability, and durability.

Reproducing similar results is challenging because of the small specimen size, whereas fiber segregation, bleeding, and heat of hydration may be more pronounced in larger structures. However, this study lays a strong foundation for advancing high-performance and sustainable concrete technologies, offering valuable insights into optimizing fiber reinforcement and SCMs to achieve superior mechanical and durability properties. This study contributes to developing eco-friendly, resilient, and structurally efficient construction materials tailored for large-scale infrastructure projects by bridging the gap between laboratory research and practical applications. The findings have far-reaching implications for the design of seismic-resistant buildings, high-rise structures, bridges, and heavy-load pavements, ensuring enhanced strength, crack resistance, and long-term performance while promoting sustainability and reducing the environmental footprint of cement-based construction.

Future research can build upon these results by exploring the influence of nano-additives and alternative fiber types to enhance mechanical properties and sustainability. Although water absorption tests were conducted for aggregates, no such evaluation was performed on HPC specimens. Since water absorption directly influences concrete's durability, permeability, and long-term performance, future studies may consider performing this test on HPC using automated weighing methods [38] or computer vision techniques [39] or fire resistance [40]. With a growing emphasis on green construction, integrating hybrid fiber reinforcement with industrial waste-derived SCMs can pave the way for next-generation concrete solutions that meet environmental and engineering demands.

Author Contributions

A.M.: methodology, formal analysis, investigation, and writing – original draft preparation; R.K.: conceptualization, methodology, validation, formal analysis, investigation, resources, writing – original draft, writing – review and editing, and supervision; B.A.G.: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing – review and editing, supervision, project administration, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

The data used in this study are available from the corresponding authors upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

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