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Effect of Polypropylene and Rock Wool Additives on the Mechanical Properties of Concrete Under Static and Dynamic Loads

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Abstract

The use of additives in concrete to improve its mechanical properties and increase its durability, especially under static and dynamic loading conditions, is one of the most important challenges and objectives in the construction industry. This study investigates the effect of polypropylene and mineral wool additives on the properties of micro-structured concrete. Samples of concrete were prepared with varying amounts of polypropylene (32%, 35%, and 40% by volume) and a combination of 25% polypropylene and 25% mineral wool. The experimental results revealed that the addition of polypropylene significantly reduced the compressive, flexural, and tensile strengths of the concrete compared to the control mix. However, the 35% polypropylene mix exhibited the highest compressive strength. Additionally, the inclusion of mineral wool further diminished the mechanical properties compared to the polypropylene-only mix, although the combination of 25% polypropylene and 25% mineral wool showed the best impact resistance. Regarding specific gravity, the results indicated that micro-structured concrete had a lower specific gravity compared to traditional concrete, with a further decrease in density observed as the percentage of polypropylene increased. The incorporation of both polypropylene and mineral wool additives contributed to this reduction in density, which may be beneficial in applications requiring lightweight concrete. The energy absorption and impact resistance tests showed that the 35% polypropylene mix performed the best in terms of energy absorption. However, the combination of polypropylene and mineral wool did not significantly improve energy absorption compared to the polypropylene-only samples. Overall, the study suggests that while the additives reduce certain mechanical properties, they can offer benefits in applications where lower weight and improved impact resistance are essential, such as in pavements and lightweight concrete structures. Concrete mixtures with higher polypropylene content can be considered for specific use cases where weight reduction and impact resistance are crucial.

Categories: Advanced Materials, Structural Engineering, Sustainable Technologies
Keywords: additives, polypropylene, rock wool, mechanical tests

Introduction

In recent years, considerable attention has been directed toward improving the properties of concrete using fiber additives, particularly polypropylene fibers (PPFs). Due to their lightweight nature, high strength, and corrosion resistance, these fibers play a vital role in enhancing the durability and performance of concrete [1]. Studies have shown that incorporating PPFs can improve the rheological properties of fiber-reinforced self-compacting concrete, although prolonged mixing may reduce some of these properties [2]. Moreover, the volume fraction and type of fibers significantly influence concrete behavior under cyclic loading, including compressive strength, flexural strength, energy absorption, elasticity modulus, and stiffness. The addition of polypropylene and steel fibers, especially at higher volumes, enhances strength and reduces crack widths in concrete [3]. Additionally, the random distribution of PPFs in concrete mixtures increases abrasion and freeze-thaw resistance, reduces volume expansions caused by sulfate attack and alkali-silica reaction, thereby enhancing concrete durability [4]. Comprehensive studies have demonstrated that combining PPFs with steel fibers simultaneously improves mechanical properties and durability of concrete [5,6]. Multiple investigations have revealed that PPFs not only increase tensile and flexural strength but also improve energy absorption capacity and significantly reduce plastic shrinkage and drying cracks [7-9]. The effects of fiber length and volume fraction on flexural and impact resistance are also critical factors [7]. From a durability perspective, research shows that PPFs can enhance concrete resistance against permeability, sulfate attack, and shrinkage [8]. However, despite numerous benefits, challenges such as compressive strength reduction at high fiber contents and difficulties in achieving uniform fiber dispersion remain, warranting further research [2,6]. Beyond these initial studies, recent research has further examined mechanical properties and performance of PPF-reinforced concrete and other additives. For instance, a statistical and experimental study employing Taguchi’s L9 orthogonal array evaluated the effects of PPF percentage, cement dosage, and curing time on compressive strength and dynamic modulus of polymer-impregnated concrete. Results indicated that PPF percentage had the greatest impact, with optimum properties achieved at 1% fiber content, 400 kg/m³ cement, and 28 days curing [10]. Another comprehensive experimental study evaluated compressive and flexural strengths of concrete batches incorporating polypropylene, steel, and macro synthetic fibers, including hybrid combinations. Fiber addition slightly affected compressive strength but significantly improved flexural strength, with polypropylene-steel hybrids exhibiting the highest flexural strength gains [11]. Regarding thermal resistance, a study on PPF-reinforced mortar demonstrated improved residual strength up to 400°C, with no significant difference between air and water cooling up to 600°C, although water-cooled specimens exhibited lower strength at 800°C [12]. Another investigation assessed the effect of polypropylene microfibers on fire resistance of reinforced concrete. Increased fiber content enhanced thermal insulation and reduced displacement during fire exposure, although compressive strength decreased [13]. Research on lightweight concrete-filled steel tubes containing rock wool waste under thermal loading revealed significant bond strength reduction at high temperatures; however, rock wool addition mitigated this loss to some extent [14]. Further studies identified 0.3% PPF content as optimal for compressive and flexural strength improvements, beyond which strength declined [15]. The use of waste polypropylene plastic as partial replacement for natural aggregates improved mechanical properties at low replacement levels but reduced strength at higher percentages [16]. Rock wool fibers were also found to enhance moisture resistance and performance of hot asphalt mixtures, with the greatest improvements observed at 1.5% fiber content [17]. Finally, the potential of rock wool waste as a supplementary cementitious material was reviewed, highlighting environmental and economic benefits. Replacing 10% of cement with rock wool waste achieved the lowest carbon footprint and cost [18]. These recent findings complement earlier results and underscore the importance of optimizing combined use of PPFs and mineral additives like rock wool to enhance overall concrete performance. Nevertheless, despite these promising advances, challenges remain in understanding the long-term effects, optimal dosages, and synergistic interactions of these additives in micro-structured concrete. The current study aims to investigate the influence of polypropylene and mineral wool additives on the mechanical properties and durability of micro-structured concrete. Experimental evaluation focuses on compressive, flexural, and tensile strengths, as well as impact resistance and specific gravity, to provide practical insights for developing lightweight, resilient concrete mixtures suited for modern construction applications where weight reduction and enhanced impact resistance are crucial.

Materials And Methods

Aggregates

The fine-grained siliceous aggregates, including silica sand and silica powder, were sourced from companies located in Azandarian County, Hamadan Province, and microsilica from the Ferroalloy Industries Company in Azna County, Lorestan Province. Sieve analysis was performed on these aggregates according to ASTM D6913 [19], classification was carried out according to ASTM D2487 [20], and hydrometer testing followed ASTM D7928 [21]. The Atterberg limits were determined according to ASTM D4318 [22]. Figures *1* and 2 show the particle size distribution curves of the silica sand and silica powder, respectively.

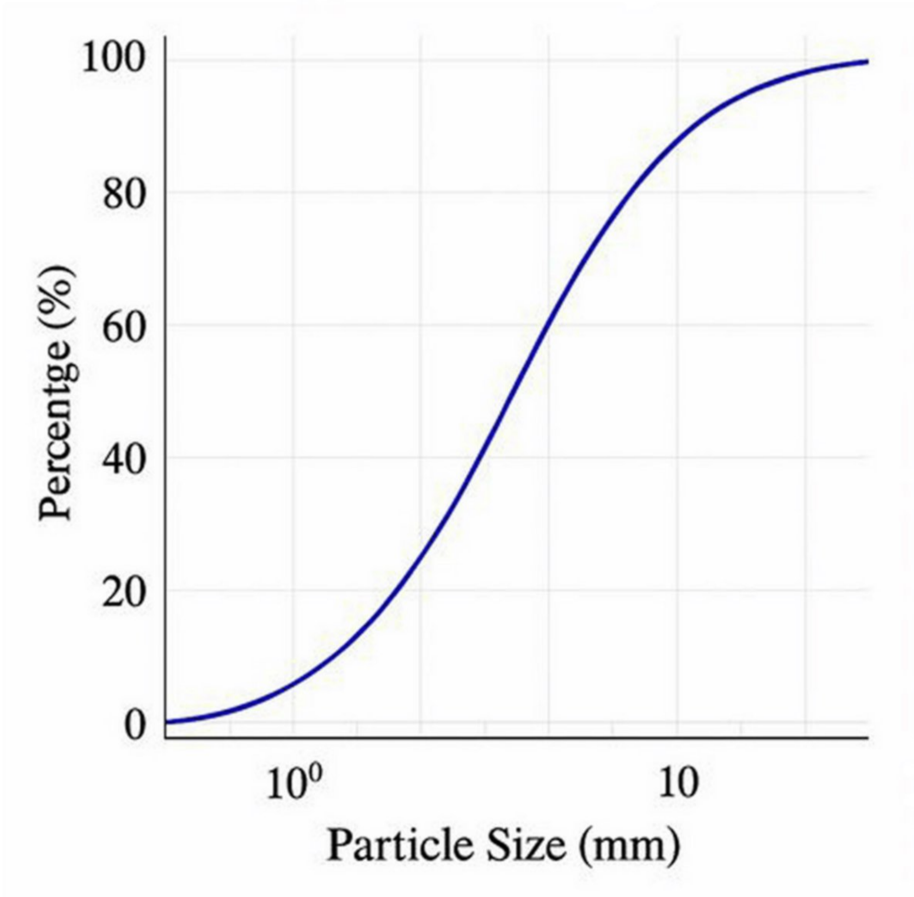

FIGURE 1: Particle size distribution of silica sand

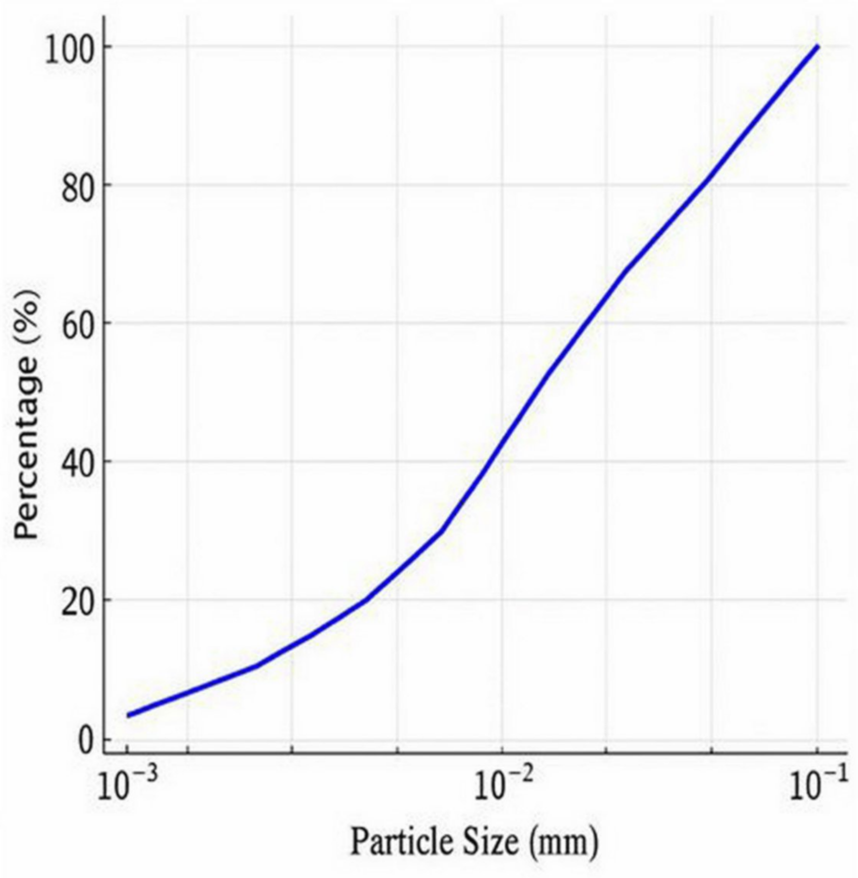

FIGURE 2: Particle size distribution of silica powder

Polypropylene and rock wool additives

The polypropylene and rock wool additives were used in granular form and as volumetric percentages in the sample. Figures 3 show the polypropylene and rock wool additives used in the study. The additives were used at volumetric percentages ranging from 0.5% to 3%, with increments of 0.5%, to determine their optimal effect on mechanical properties. In the preliminary stage of this study, polypropylene and rock wool were investigated in volumetric fractions ranging from 0.5% to 3.0% in increments of 0.5%. These initial mixes were tested to observe overall trends in mechanical behavior. Based on these observations, the representative percentages of 32%, 35%, and 40% polypropylene, along with a 25% polypropylene + 25% rock wool combination, were selected for detailed reporting, as they demonstrated the most significant variations in compressive, tensile, flexural, and impact performance. This ensured that the reported results capture the critical differences in behavior among the mixes.

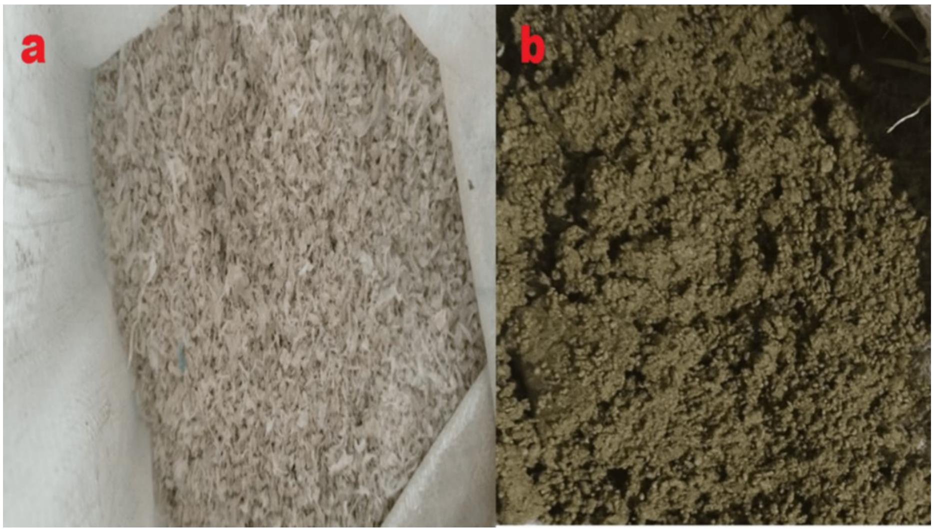

FIGURE 3: Additives (a) polypropylene, (b) rock wool

Cement

The Portland Type II cement used in this study was obtained from Saman Gharb Industries in Kermanshah, Iran. Chemical and physical quality control tests were conducted on the cement in accordance with ASTM standards, and the results are presented in Table *1*.

Chemical Properties	%	Physical and Mechanical Properties	Value
Silicon Dioxide (SiO_2)	20.86	Compressive Strength (kg/cm²) - 3 days	249
Aluminum Oxide (Al_2O_3)	4.36	Compressive Strength (kg/cm²) - 7 days	299
Iron Oxide (Fe_2O_3)	4.2	Compressive Strength (kg/cm²) - 28 days	339
Calcium Oxide (CaO)	65.08	Specific Gravity (g/cm³)	3.24
Magnesium Oxide (MgO)	1.78	Blaine Fineness (m²/kg)	321
Sodium Oxide (Na_2O)	0.12	Initial Setting Time (min) - Vicat	84
Potassium Oxide (K_2O)	0.58	Final Setting Time (min) - Vicat	148
Sulfur Trioxide (SO_3)	2.3		
Loss on Ignition (LOI)	0.81		

TABLE 1: Chemical and physical quality control test results of the cement used in this study

Superplasticizer

A polycarboxylate ether-based superplasticizer (P10-3R) was used to enhance workability and reduce water content. In all mixtures, the water-to-cement ratio (w/c) was fixed at 0.38. The superplasticizer was added at 0.8% by weight of cement. This dosage was selected based on preliminary trials to ensure adequate workability and uniform consistency across all mixes.

Experimental program

Initially, to determine the appropriate mix design, four series of cubic concrete samples were prepared without additives using different combinations of cement, silica sand, silica powder, and micro silica. Based on these preliminary results, the optimal mix design was selected, and subsequent concrete mixes were formulated for detailed testing. Silica sand and silica powder were sourced from companies in Azandarian, Hamedan Province, Iran, and micro silica was obtained from Ferroalloy Industries in Azna County, Lorestan Province, Iran. The materials underwent particle size distribution, classification, and hydrometer tests according to ASTM D6913, ASTM D2487, ASTM D7928, and ASTM D4318 standards [19-22]. Polypropylene and rock wool additives were used in granular form at volumetric percentages ranging from 0.5% to 3% with increments of 0.5% to determine their optimal effect on mechanical properties. Based on preliminary tests, the representative percentages of 32%, 35%, and 40% polypropylene, and a 25% polypropylene + 25% rock wool combination were selected for detailed reporting, as these showed the most significant differences in mechanical performance. Figures 3 illustrate the additives used in the study. Portland Type II cement from Saman Gharb Cement Industries, Kermanshah, Iran, was used throughout. The concrete mixing procedure involved combining all dry components in a mechanical mixer at low speed (140 rpm) for 2 minutes to achieve uniform distribution. Fibers were added gradually during the dry mixing stage to prevent clumping. Subsequently, 80% of the total required water was gradually added while mixing continued at medium speed (285 rpm) for 3 minutes after the addition of a polycarboxylate ether-based superplasticizer. This procedure ensured a homogeneous and workable concrete mixture. Standard sampling was performed to prepare specimens for compressive, tensile, flexural, and impact strength tests. After 48 hours, specimens were removed from molds, considering the slow setting at low temperatures, and cured in a water tank at 18-22°C (Figure 4). Images of the specimen preparation process are shown in Figure 5. Additional explanation added: This approach allows for controlled evaluation of fiber effects and avoids fiber clustering. The volumetric percentages reported capture the critical variations in mechanical performance, while preliminary trials ensured consistency across mixes.

FIGURE 4: Curing of concrete samples in a curing water tank at a temperature of 18-22 degrees Celsius according to BS-1881 standard

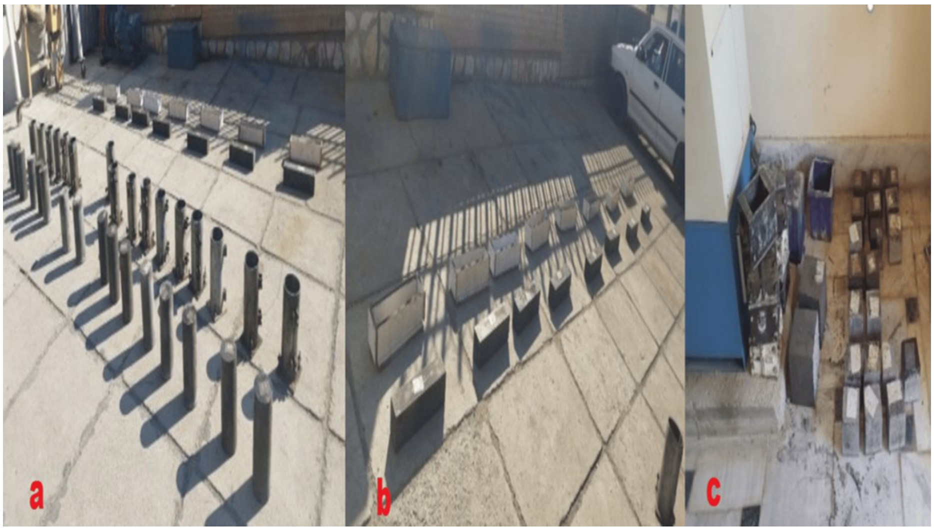

FIGURE 5: Image of (a) tensile, compressive, flexural, and impact strength test samples (before cutting), (b) flexural strength test specimens, (c) compressive strength test specimens

Compressive strength tests were carried out on cubic specimens (100 × 100 × 100 mm) using a digital concrete compression testing machine in accordance with the BS 1881 standard at 7 and 28 days. Flexural strength tests were performed on beam-shaped samples (100 × 100 × 500 mm) at 28 days following ASTM C293 [23]. The test setup and procedure are shown in Figure 6. Brazilian tensile tests (splitting tensile tests) were performed on cylindrical specimens (300 × 150 mm) according to ASTM C496 [24]. A compressive load was applied diametrically on the cylinder at 28 days, and the tensile strength was calculated as:

$$Ft = 2P / (\pi \cdot L \cdot d)$$

where Ft is the tensile strength, P is the applied load at failure, L is the length of the cylinder, and d is its diameter. Additional explanation added: Each test was performed in triplicate (n = 3), and the mean values with standard deviations were reported to ensure reliability. Early-age strength tests (<7 days) were not conducted due to resource limitations, which is acknowledged as a study limitation.

FIGURE 6: (a) Digital concrete breaker jack according to BS-1881 standard, (b) performing a flexural strength test according to ASTM C293 standard

The impact resistance test was conducted using a falling weight method according to ACI 544. The impact hammer weighed 4.54 kg (10 lbs) and fell from a height of 457 mm (18 inches) onto concrete discs with a diameter of 150 mm and a thickness of 64 mm. This setup matched the impact energy specified in ACI 544 and used a 6-inch mold as prescribed. The test was applied to fiber-reinforced concrete specimens incorporating rock wool, polypropylene, and combinations of these fibers at the selected volumetric percentages. The impact testing setup is shown in Figure 7a, and the mold and hammer for laboratory compaction tests (AASHTO T180-D) are shown in Figure 7b [25]. Additional explanation was added: The gradual addition of fibers during dry mixing minimized clumping and ensured relatively uniform distribution, although quantitative fiber orientation was not measured, which is noted as a limitation. The results provide comparative insight into the effect of different fiber types and combinations on impact resistance.

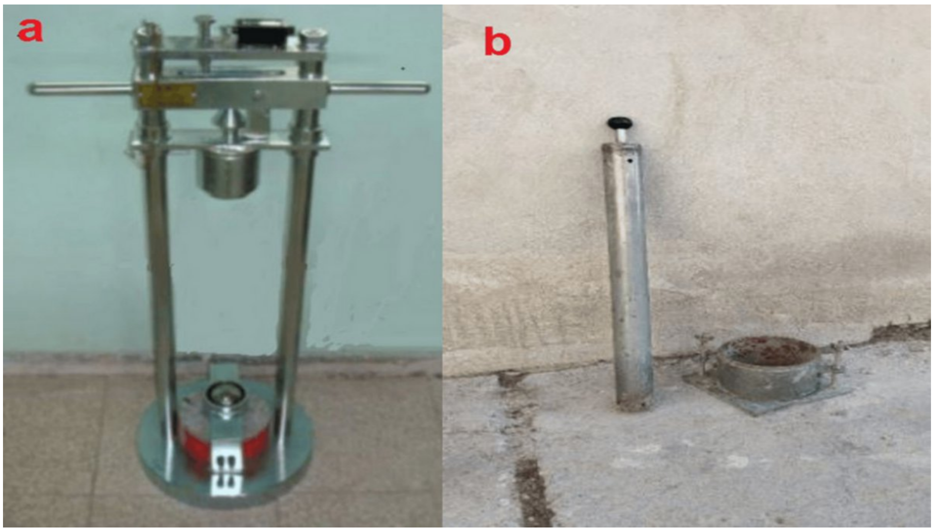

FIGURE 7: (a) Impact testing setup; (b) the mold and hammer used for the laboratory compaction test

Results And Discussion

Results of flexural strength tests

Flexural strength tests were conducted according to ASTM C293 on beam-shaped specimens with dimensions of 500 × 100 × 100 mm at 28 days of age. The results of the tests are provided in Tables 2 and 3.

Mix Design No.	10	14	16	17
Polypropylene Additive (Vol.%)	0	32	35	40
Bulk Density (SSD) (g/cm³)	2.23	2.10	2.03	2.01
Flexural Strength (kg/cm²)	204	131	138	116

TABLE 2: The table presents the flexural strength results of samples made without additives and with various percentages of polypropylene

SSD, Saturated Surface Dry

Mix Design No.	13	15	18	19
Polypropylene Additive (Vol.%)	0	25	25	30
Rock Wool Additive (Vol.%)	0	30	25	25
Bulk Density (SSD) (g/cm³)	2.28	2.05	2.00	1.99
Flexural Strength (kg/cm²)	248	110	111	108

TABLE 3: The table presents the flexural strength results of samples made without additives and with various percentages of polypropylene and rock wool

SSD, Saturated Surface Dry

The results indicated that incorporating 32%, 35%, and 40% by volume of polypropylene reduced the flexural strength compared to the additive-free control sample. The highest flexural strength was observed at 35% polypropylene, suggesting an optimal fiber distribution that enhances matrix cohesion. The combined use of polypropylene and rock wool further reduced flexural strength compared to mixtures containing only polypropylene. In samples with 25% polypropylene and 25% rock wool, a significant decline in flexural strength was observed, likely due to increased porosity and reduced matrix integrity. A similar study investigated the effect of incorporating rock wool fibers into lightweight concrete and found that higher fiber content increased permeable voids and reduced mechanical strength, which aligns with the observed decrease in flexural strength when polypropylene and rock wool were combined in the present study [26]. A reduction in bulk density was also noted in modified samples compared to the reference concrete. This decrease in density is attributed to increased air entrapment and the lower specific weight of fiber materials, which may be beneficial in lightweight concrete applications and structures requiring reduced self-weight. These findings align with ACI 544 studies on fiber-reinforced lightweight concrete. The results of this study demonstrated that although the incorporation of polypropylene and rock wool reduces the flexural strength of concrete, the decrease in density, improved energy absorption, and enhanced impact resistance make these mixtures suitable for lightweight pavements and structures requiring energy dissipation. Comparison with ASTM C1609 [27] suggests that for structural applications under flexural loading, the use of complementary materials such as nano-silica or hybrid fibers could enhance mechanical performance. Flexural strength tests were conducted according to ASTM C293 on beam-shaped specimens with dimensions of 500 × 100 × 100 mm at 28 days of age.

Results of Brazilian tensile (splitting) test

The Brazilian tensile (splitting) test was conducted on cylindrical samples with dimensions of 300 mm × 150 mm. The tensile strength of the samples is calculated using the formula $F_t = 2P / (\pi.L.d)$, where P is the applied load, L is the length, and d is the diameter of the sample. The results of the tensile tests are presented in Tables *4* and 5.

Mix No.	Sample No.	Polypropylene Granule (%)	Sample Dimensions (Cylindrical)		Density (g/cm³)	Maximum Load P (kg)	Indirect Tensile Strength (kg/cm²)	Average Direct Tensile Strength (kg/cm²)
			Height (h) (cm)	Diameter (d) (cm)				
10	1-10	0	30	15	2.27	30070	3.42	42
	2-10		30	15	2.27	29850	3.42	
14	1-14	32	30	15	2.08	21080	2.96	30
	2-14		30	15	2.08	20812	2.95	
16	1-16	35	30	15	2.05	21980	3.09	31
	2-16		30	15.1	2.05	22110	3.11	
17	1-17	40	30	15	2.03	19720	2.77	28
	2-17		30	15.02	2.02	19560	2.77	

TABLE 4: Brazilian tensile strength results (splitting test) without additive and with various percentages of polypropylene

Sample No.	Specimen No.	Polypropylene Content (Vol.%)	Rock Wool Content (Vol.%)	Cylinder Dimensions		Density (g/cm³)	Maximum Applied Load PPP (kg)	Indirect Tensile Strength (kg/cm²)	Average Indirect Tensile Strength (kg/cm²)
				Height h (cm)	Diameter d(cm)				
13	1-13	0	0	3.3	15	2.32	33980	47.6	48
	2-13			3.3	15	2.32	33856	47.9	
15	1-15	25	30	1.3	15	2.05	22190	31.3	31
	2-15			1.3	15	2.05	21788	30.8	
18	1-18	25	25	1.3	15	2.02	22920	32.3	32
	2-18			1.3	15	2.01	22420	31.7	
19	1-19	30	25	3.3	15	1.99	22490	31.3	31
	2-19			1.3	15	1.98	21060	29.7	

TABLE 5: Indirect tensile strength results of concrete samples without additive and with various percentages of polypropylene and rock wool

The results presented in Tables *4* and 5 from the indirect tensile tests show the effects of varying percentages of PPFs and combinations with rock wool on the tensile strength of concrete. According to Table *4*, the addition of polypropylene at 32%, 35%, and 40% led to a decrease in tensile strength compared to the control sample (without additives). For instance, the tensile strength of the concrete with 32% polypropylene reduced to 2.96 kg/cm², a decrease from the control sample, which had a tensile strength of 3.42 kg/cm². Similar reductions were observed with 35% and 40% polypropylene, where the tensile strengths decreased to 3.09 and 2.77 kg/cm², respectively. Table *5*, which examines the combination of polypropylene and rock wool, reveals that this mixture improves the tensile strength of concrete, but it still remains lower than the control sample. The mix containing 25% polypropylene and 30% rock wool had a tensile strength of 31.3 kg/cm², a significant decrease compared to the control, which had a tensile strength of 47.6 kg/cm². A similar reduction in tensile strength was found for the 25% polypropylene and 25% rock wool mix, where the strength was recorded as 32.3 kg/cm². These results indicate that increasing the percentage of PPFs in the concrete mixture leads to a reduction in tensile strength. This can be attributed to the clustering of fibers, which negatively impacts the integrity of the concrete matrix, causing the formation of microcracks. Nevertheless, when PPFs are combined with rock wool, the tensile strength is somewhat improved compared to using polypropylene alone. This observed trend aligns with previous studies [28], which found a reduction in tensile strength with higher amounts of polymer fibers and attributed this decline to fiber clustering and a weakened concrete matrix. However, in line with other findings [29], it is important to note that a lower volume fraction of PPFs can enhance the long-term tensile strength of concrete. This improvement is due to the fibers' ability to restrict the formation and propagation of microcracks, thereby enhancing the overall continuity and structural integrity of the concrete. This ultimately results in better performance and durability of the concrete under various loads.

Impact strength test results

To evaluate the impact resistance of the concrete mixes, the impact strength test was performed using a laboratory compaction hammer (AASHTO T180 [25]) with a 10-pound hammer and a free-fall height of 18 inches. Tables *6* and 7 summarize the results for different mix compositions. The impact strength results of the samples with varying percentages of polypropylene and rock wool additives are presented in Tables *6* and 7. The analysis of these results demonstrates the influence of polypropylene and rock wool on the impact resistance of the concrete. In Table *6*, the impact strength results for samples with different percentages of polypropylene are shown. The control group (without additives) exhibited the highest impact resistance, requiring 27-28 impacts for the first crack and 30-32 impacts for failure. The impact energy for the first crack was 5.29 N·m, and for failure, it was 6.11 N·m, indicating good resistance to impact. As the polypropylene percentage increased, especially in samples with 32%, 35%, and 40% polypropylene, a significant reduction in impact resistance was observed. In the 32% polypropylene sample, the number of impacts for the first crack decreased to 12-15 impacts, and for failure, it was 16 impacts, showing a considerable drop compared to the control group. The impact energy also decreased to 2.44 N·m for the first crack and 3.26 N·m for failure. In the 40% polypropylene samples, the impact resistance drastically decreased, requiring only 7-10 impacts for the first crack and 12-16 impacts for failure. This reduction in impact resistance was accompanied by a decrease in impact energy, which was

1.63 N·m for the first crack and 2.24 N·m for failure. Table 7 presents the results for samples with varying percentages of both polypropylene and rock wool. The sample without additives (polypropylene and rock wool) showed excellent performance, requiring 36-38 impacts for the first crack and 40 impacts for failure. The impact energy for the first crack was 7.32 N·m, and for failure, it was 8.14 N·m. When rock wool was added, the impact resistance decreased. In the combination of 25% polypropylene and 30% rock wool, the number of impacts for the first crack was 7-9 impacts, and the impact energy was 1.63-2.04 N·m. In the combination of 25% polypropylene and 25% rock wool, the number of impacts for the first crack was 16-20 impacts, with an impact energy of 3.87 N·m. The results indicate a negative effect of the additives, especially polypropylene and rock wool, on the impact resistance of concrete. Samples with polypropylene and rock wool exhibited lower resistance to impact compared to the control samples, and as the percentages of polypropylene and rock wool increased, the reduction in resistance became more pronounced. In conclusion, these results highlight the need for careful selection of the optimal percentages of additives to prevent a decrease in the mechanical properties of concrete. Choosing the appropriate amount of polypropylene and rock wool additives can help improve the concrete's performance under impact. Consistent with the findings of this study, research has demonstrated that hybrid fiber systems-specifically those combining polypropylene with steel fibers-enhance fracture energy due to the bridging effect of the rigid fibers [8]. Investigations on pumice-based lightweight concrete confirmed the improvement in fracture resistance, which supports the enhanced impact strength and fracture energy observed in our samples with polypropylene additives.

Plan Number	Sample Number	Polypropylene Percentage (%)	Sample Dimensions (mm)	Number of Impacts for First Crack	Average Number of Impacts for First Crack	Impact Energy for First Crack (N.m)	Number of Impacts for Failure	Average Number of Impacts for Failure	Impact Energy for Failure (N.m)
10	1-10	0	64 × 150	27	26	5.29	32	30	6.11
	2-10		64 × 150	25	28				
14	1-14	32	64 × 150	11	12	2.44	16	16	3.26
	2-14		64 × 150	13	15				
16	1-16	35	64 × 150	24	24	4.89	29	28	5.7
	2-16		64 × 150	23	27				
17	1-17	40	64 × 150	8	8	1.63	12	11	2.24
	2-17		64 × 150	7	10				

TABLE 6: Impact strength results of samples without additives and with varying percentages of polypropylene additives

Plan Number	Sample Number	Polypropylene Percentage (%)	Rock Wool Percentage (%)	Sample Dimensions (mm)	Number of Impacts for First Crack	Average Number of Impacts for First Crack	Impact Energy for First Crack (N.m)	Number of Impacts for Failur200*e	Average Number of Impacts for Failure	Impact Energy for Failure (N.m)
13	1-13	0	0	64 × 150	37	36	732	42	40	8.14
	2-13			64 × 150	34	38		38		
15	1-15	25	30	64 × 150	7	8	163	10	10	2.04
	2-15			64 × 150	8	9		9		
18	1-18	25	25	64 × 150	17	16	326	17	19	3.87
	2-18			64 × 150	14	20		20		
19	1-19	30	25	64 × 150	9	12	244	16	15	3.05
	2-19			64 × 150	7	13		13		

TABLE 7: Impact strength results of samples without additives and with varying percentages of polypropylene and rock wool additives

Results of the Saturated Surface Dry (SSD) specific gravity test

Simultaneously with the flexural, tensile, and compressive tests, the Saturated Surface Dry (SSD) specific gravity of the samples was measured. The average results are presented in Tables *8* and 9. Analysis of the results indicates that the specific gravity of the microstructure concrete is lower than that of normal concrete. As the percentage of polypropylene additive increases, the specific gravity of the samples decreases. Additionally, the use of both polypropylene and mineral wool additives, at the mentioned percentages, leads to a reduction in specific gravity compared to the sample without any additives. A detailed comparison of the SSD specific gravity results reveals a consistent trend where higher polypropylene content correlates with a notable decrease in density. This can be attributed to the low density of PPFs, which replace denser cementitious materials in the matrix. The reduction is most pronounced in samples containing 40% polypropylene, with a bulk density of 2.00 g/cm^3, compared to the control sample with 2.25 g/cm^3. Similarly, in Table *9*, the addition of both polypropylene and mineral wool results in a further decrease in SSD specific gravity. The lowest density (1.97 g/cm^3) is observed in the mix containing 30% polypropylene and 25% rock wool. This suggests that rock wool, although denser than polypropylene, contributes to porosity and alters the concrete's compactness, reinforcing the observation that hybrid fiber systems reduce density due to entrapped air voids and weak fiber-matrix interfaces. Studies demonstrate that the incorporation of fibers or mineral additives into concrete can notably enhance its mechanical properties. One study observed an increase in tensile strength and an improvement in the internal structure of concrete with the addition of different fibers [30], while another emphasized enhanced flexural strength and a more compact microstructure in green concrete reinforced with water-soluble fibers and mineral additives [31]. Comparing these results to those obtained in the tensile and impact strength tests, it is evident that a decrease in SSD specific gravity corresponds with a reduction in tensile and impact resistance. This correlation is particularly evident in mixes with excessive fiber content, where poor dispersion and clustering of fibers may contribute to microstructural inconsistencies. Thus, optimizing fiber volume fraction is crucial to maintaining a balance between weight reduction and mechanical performance. These findings highlight the need for further research into optimizing fiber distribution techniques to mitigate density reduction while preserving structural integrity. Future studies could explore alternative fiber combinations or pre-treatment methods to enhance fiber-matrix adhesion, thereby improving the mechanical properties of lightweight fiber-reinforced concrete systems. In line with the findings of this study, previous research also confirms the impact of fiber addition on the density and mechanical properties of concrete [32]. Specifically, the incorporation of 2%, 6%, and 10% PPFs resulted in a mass reduction of 59, 157, and 290 kg per cubic meter, respectively, compared to conventional concrete. This reduction in density is consistent with the trend observed in the current study, where higher fiber content correlates with a decrease in specific gravity. Furthermore, it has been reported that while the addition of PPFs enhances the compressive strength of concrete at lower fiber percentages, such as 2%, higher contents can lead to a decrease in unconfined compressive strength. This observation is in line with the current findings, where excessive fiber content resulted in reduced mechanical performance, particularly in tensile and impact strength tests. These outcomes emphasize the importance of optimizing fiber content to maintain a balance between weight reduction and mechanical performance in fiber-reinforced concrete systems.

Mix Design Number	10	14	16	17
Polypropylene Additive (Vol. %)	0	32	35	40
Saturated Dry Bulk Density (g/cm³)	2.25	2.11	2.05	2.00

TABLE 8: Average results of Saturated Surface Dry (SSD) specific gravity for samples without additives and with various percentages of polypropylene

Mix Design Number	13	15	18	19
Polypropylene Additive (Vol. %)	0	25	25	30
Rock Wool Additive (Vol. %)	0	30	25	25
Saturated Dry Bulk Density (g/cm³)	2.30	2.04	2.00	1.97

TABLE 9: Average results of Saturated Surface Dry (SSD) specific gravity for samples without additives and with various percentages of polypropylene and mineral wool

Conclusions

Based on the experiments conducted and the analysis of the results obtained from various tests on the structural concrete with polypropylene and rock wool additives, the following conclusions can be drawn

Effect of Polypropylene on Concrete Properties
The study revealed that adding polypropylene at various percentages (32%, 35%, and 40% by volume) to the micro-structured concrete mixture significantly decreased its compressive, flexural, and tensile strengths. However, a 35% polypropylene mix showed the highest compressive strength, while the flexural strength remained highest with 35% polypropylene, although lower than that of the control mix.

Influence of Mineral Wool
The combination of polypropylene and mineral wool additives further reduced the mechanical properties compared to the control mix. The 25% polypropylene and 25% mineral wool mixture exhibited the best impact resistance, although the combination generally led to a decline in strength and energy absorption capacity compared to the use of polypropylene alone.

Specific Gravity Findings
The specific gravity of the micro-structured concrete was found to be lower than that of traditional concrete, with a decrease in specific gravity observed as the percentage of polypropylene increased. The incorporation of both polypropylene and mineral wool additives contributed to this reduction in density, which may affect the overall weight and structural properties of the concrete.

Energy Absorption and Impact Resistance
The study also highlighted that the energy absorption and impact resistance of the samples were significantly improved with a 35% polypropylene mixture. However, the combination of both polypropylene and mineral wool did not show significant improvements in energy absorption compared to the polypropylene-only samples.

Applications and Practical Considerations
While the additives led to a reduction in certain mechanical properties, the results suggest that for applications where lower weight is desired without compromising the basic structural integrity (such as in pavements or lightweight concrete structures), the combination of polypropylene and mineral wool additives may still be beneficial. The concrete mixtures with higher polypropylene content could be considered for specific use cases where impact resistance and weight reduction are crucial.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

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