The Effect of Polypropylene Fibers on the Mechanical and Physical Properties of Foam Concrete

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***Abstract*— Foam concrete (FC) is a lightweight material composed of cement, water, and a foaming agent. Including the foaming agent significantly reduces the density of the concrete, making it lighter than conventional mixes. However, due to the absence of coarse aggregates, foam concrete generally exhibits lower mechanical properties than other lightweight concrete types. This study explores the potential of enhancing the mechanical properties of foam concrete by incorporating polypropylene fibers into the mixture. The research focuses on evaluating the influence of these fibers on key performance characteristics, aiming to improve the structural integrity of foam concrete, and, therefore aiding the mechanical properties. For this investigation, two types of cement were utilized: Type II cement with moderate heat of hydration, and Type IV pozzolanic cement. The findings of this study provide valuable insights into optimizing foam concrete for broader applications in construction, based on flexural, compressive strength and abrasion tests.** **Keywords—Foam concrete, Polypropylene fibers, Type II cement, Type IV (Pozzolanic) cement**

I. Introduction

In recent years, the construction industry has witnessed significant advancements aimed at optimizing building materials, reducing costs, and enhancing overall efficiency. One of the most notable innovations in this context is the development and use of lightweight concretes, particularly foam concrete (FC) [1]. Due to its low density, foam concrete significantly contributes to reducing the dead load of structures and considerably increases the speed of construction projects [2]. Additional advantages include reduced number of labors, lower execution costs, and easier transportation [3], [4]. One of the best properties of FC is their thermal insulation capacity, which aids energy efficiency of the whole structure.

Foam concrete is composed of three primary components: water, cement, and a foaming agent [5]. Despite its numerous benefits, foam concrete faces challenges in terms of mechanical and physical properties, which limit its application in certain structural scenarios [6]. Therefore, extensive research has been conducted to improve its performance by incorporating additives such as polypropylene fibers, micro silica, sand, and nanoparticles [7].

Polypropylene (PP) fibers are synthetic fibers made from a thermoplastic polymer known for its excellent chemical resistance, low density, and high tensile strength. These fibers are widely used in various industries, including textiles, geotextiles, packaging, and especially in construction materials such as fiber-reinforced concrete. Polypropylene fibers are primarily utilized in concrete to enhance its mechanical properties, particularly its tensile strength, crack resistance, and durability. Due to their hydrophobic nature, PP fibers do not absorb water, making them ideal for cement-based composites. They are also resistant to most chemicals and have good fatigue resistance [8]. This study focuses on evaluating the effects of polypropylene fibers on the mechanical and physical properties of foam concrete, aiming to make its use more reliable and widespread in construction applications.

II. Component Materials and Testing Methods

This study investigates the influence of polypropylene fibers on the mechanical and physical behavior of foam concrete by designing and testing 6 different mixtures. All mixtures were formulated based on the practical application of foam concrete as a filler material for building floors. The base components included Type II Portland cement, pozzolanic cement, water, and two types of foaming agents: chemical and protein-based, and additionally 12 mm polypropylene fibers.

Initially, a water-to-cement ratio (W/C) of 0.45 was selected. However, due to the low flowability observed under real construction site conditions, the ratio was increased to 0.6 to facilitate easier pumping to higher floors. All pre-trials and sample preparation were conducted over two working days at a construction site in Tehran: on the first day, mixes using chemical foam were prepared, while on the second day, after a thorough cleaning of the pumping system, mixes with protein-based foam were cast.

A wind pressure foam concrete machine was used to transport the concrete via an air compressor and hose system to the second floor. To simulate real-life project conditions and ensure accurate sampling, specimens were collected at the end of the hose line and poured into preprepared molds. It should be noted that all samples were obtained from the second floor (see Fig. 1).

Figure 1. Pouring the FC into molds.

Both types of cement used in this study (Type II and pozzolanic) were sourced from Tehran Cement Factory in 50 kg bags, with a fixed dosage of 250 kg/m³ across all mixes. Two foaming agents were employed: chemical foam from Parsman Shimi and animal-based protein foam from Azarkavin Co. The dosage of foam was approximately 1 liter per cubic meter of concrete.

The polypropylene fibers had a cut length of 12 mm and were used at a dosage of 0.2 kg/m³. This quantity was selected as the minimum effective amount to enhance mechanical properties while avoiding potential damage to equipment. Table 1 summarizes the amount of component materials used in the mixtures

TABLE I. QUANTITIES OF CONSTITUENT MATERIALS FOR 1 M³ OF FOAM CONCRETE

Component	Quantity (kg/m^3)
Cement	250
Water	150
Foam Agent	1
Fiber	0.2

Each mix was prepared with major care to simulate laboratory conditions. Water, cement, and foaming agent were added to the mixer first. After achieving a homogeneous base mix, the fibers were gradually added over one minute. The complete mixing process took 4 to 5 minutes. Once mixing was complete, the machine was sealed, and the foam concrete was pumped to the second floor. Sampling was done after one minute of discharge to ensure uniformity.

Specimens were cast in molds 4×4×16 cm prisms. After casting, the specimens were cured under laboratory conditions at a temperature of 23 ± 2 °C.

In this study, the aim was to examine the physical and mechanical properties of foam concrete by evaluating its dry density and ultrasonic pulse velocity as physical parameters, and its compressive and tensile strengths as mechanical indicators. To assess the influence of polypropylene fibers on foam concrete, tests using two types of cement and two types of foam (chemical and protein-based) were conducted, maintaining a constant water-to-cement ratio of 0.6 throughout all mixtures. An overview of all mixtures is presented in the Table II.

TABLE II. OVERVIEW OF ALL MIXTURES

Mix	Cement	Foam	PP fibers
M1	Pozzolanic	Chemical	–
M2	Pozzolanic	Chemical	✓
M3	Type II	Protein	–
M4	Type II	Protein	✓
M5	Pozzolanic	Protein	–
M6	Pozzolanic	Protein	✓

III. TEST RESULTS AND DISCUSSION

In this study, to investigate the effect of polypropylene fibers on the physical and mechanical properties of foam concrete, six different mixtures were made and tested using two types of cement (Type II and pozzolanic), two types of foam (chemical and protein-based), prepared with and without polypropylene fibers. The parameters examined include dry density, ultrasonic pulse velocity (UPV), compressive strength, and tensile strength. All specimens for these tests are shown in Fig. 2.

Figure 2. All specimens prepared for the testing of hardened properties

Bulk density measurements were conducted in accordance with the SRPS EN 12390-7:2019 standard [9]. The results and percentage changes for each mixture compared to its fiber less counterpart is presented in the Table III. The addition of polypropylene fibers led to an increase in dry density across all three groups. The highest increase was observed in mixture 2 (17% when compared to mixture 1), while the lowest was in mixture 4 (2.8% when compared with mixture 3). This increase is attributed to improved cohesion within the cement matrix and reduced void content due to the presence of fibers.

TABLE III. BULK DENSITY FOR EACH MIXTURE AND THE CALCULATED INCREASE IN PERCENTAGES

Mix Design Group	Density without Fibers (kg/m³)	Density with Fibers (kg/m³)	Density Increase (%)
Mixtures 1 & 2	491	575	17%
Mixtures 3 & 4	468	481	2.8%
Mixtures 5 & 6	451	479	6.2%

The compressive strength test was carried out based on the SRPS EN 12390-3:2019 standard using axial loading [10]. Polypropylene fibers had the greatest effect in mixtures with chemical foam and pozzolanic cement, significantly improving the structure under compressive loads, see Table IV.

TABLE IV. COMPRESSIVE STRENGTH FOR EACH MIXTURE AND THE CALCULATED INCREASE (OR DECREASE) IN PERCENTAGES

Mix Design Group	Strength without Fibers (MPa)	Strength with Fibers (MPa)	Change in Strength (%)
Mixtures 1 & 2	0.84	1.19	Increase of 41.7%
Mixtures 3 & 4	0.77	0.80	Increase of 3.9%
Mixtures 5 & 6	1.38	1.60	Increase of 15.9%

As shown in the table, in most mix designs, the addition of polypropylene fibers resulted in improved compressive strength, especially in mixture 2, with a significant increase of 41.7%. The reported 42% increase in compressive strength should be taken with caution, as it concerns very small values, for which testing devices also have lower accuracy. Only mixture 4 showed a slight decrease, which can be attributed to laboratory error or specific material properties.

The tensile strength test was conducted based on the SRPS EN 12390-6:2024 standard using flexural loading [11]. An increase in tensile strength was observed in all mixtures, indicating the fibers' effectiveness in reducing cracking and enhancing internal bonding, see Table V.

The table shows that adding polypropylene fibers significantly enhances the tensile strength of foam concrete, especially in mixture 2, with nearly 60% improvement. No data was available for mixture 3 (without fibers), but the overall trend shows a clear positive impact. Illustration of the fracture mechanism for this test is shown in Fig. 3.

TABLE V. TENSILE STRENGTH FOR EACH MIXTURE AND THE CALCULATED INCREASE IN PERCENTAGES

Mix Design Group	Strength without Fibers (MPa)	Strength with Fibers (MPa)	Change in Strength (%)
Mixtures 1 & 2	0.12	0.19	Increase of 58.3%
Mixtures 3 & 4	—	0.15	Data for non-fiber mix not available
Mixtures 5 & 6	0.14	0.18	Increase of 28.6%

Figure 3. Tensile test strength using flexural loading

Ultrasonic Pulse Velocity test was performed to assess the uniformity and internal integrity of the concrete. An increase in velocity in fiber-reinforced samples indicates enhanced compaction and fewer microcracks. For example, mixture 4 showed a 5.9% increase in velocity when compared to mixture 3 (without fibers), indicating improved foam concrete compactness. Test results are shown in Table VI.

TABLE VI. ULTRASONIC PULSE VELOCITY FOR EACH MIXTURE AND THE CALCULATED INCREASE IN PERCENTAGES

Mix Design Group	Ultrasonic Pulse Velocity without Fibers (m/s)	Ultrasonic Pulse Velocity with Fibers (m/s)	Velocity Increase (%)
Mixtures 1 & 2	1452	1684	15.9%
Mixtures 3 & 4	1547	1639	5.9%
Mixtures 5 & 6	1756	1811	3.1%

The Ultrasonic Pulse Velocity test is illustrated in Fig. 4. The time was measured and then the values of velocity were calculated based on time and length of the specimen.

Figure 4. Ultrasonic pulse velocity test illustration

In the flowchart shown in Fig. 5, bulk density, tensile strength, compressive strength and cracks results are compared, indicating improved performance in all parameters when polypropylene fibers are used.

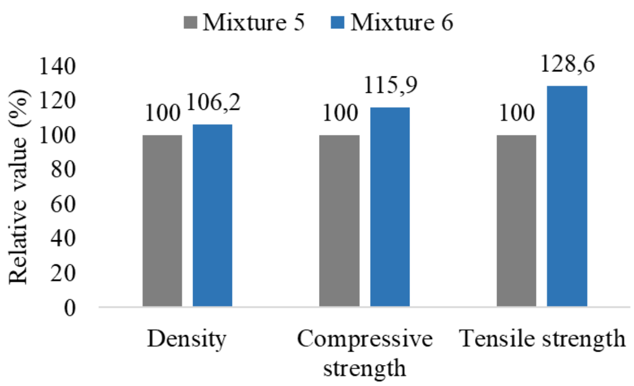

Figure 5.Comparison of physical and mechanical properties between mixtures with fibers and without fibers.

IV. Conclusions

Results show that the inclusion of polypropylene fibers slightly increases the density of the foam concrete, but has a significant positive effect on its mechanical properties. For instance, a comparison between mixture 5 (without fibers) and mixture 6 (with fibers) reveals that a mere 6.2% increase in density led to a 15.9% improvement in compressive strength and a 28.6% increase in tensile strength. Therefore, the addition of fibers is recommended as an effective means to enhance performance while potentially reducing cement demand.

Mixtures 1 and 2 utilized chemical foam, while mixtures 5 and 6 were made with protein-based foam. The results indicate that combining fibers with chemical foam significantly enhances the mechanical performance of foam concrete, leading to approximately 41% increase in compressive strength and 58% increase in tensile strength. Therefore, fibers act as an effective complement to chemical foam, enabling noticeable improvements in performance and potential cement reduction.

On the other hand, these results also reveal that the difference between chemical and protein foams becomes negligible when fibers are used. This suggests that the presence of fibers diminishes the direct influence of foam type on the overall quality of foam concrete. For instance, the compressive strength of the fiber-reinforced mix with chemical foam was 1.19 MPa, while with protein foam it was 1.60 MPa. However, the tensile strength of the mix with chemical foam was 0.19 MPa, compared to 0.18 MPa for the protein foam. These findings highlight that, in the presence of fibers, the foam type has a limited impact on tensile strength and a moderate effect on compressive strength.

The best overall performance was observed in the mix using pozzolanic cement, protein-based foam or chemical-based foam, and fibers. Future studies should focus on reducing the cement content in this optimal mix to help minimize environmental pollution caused by cement production, while maintaining or even enhancing concrete performance.

Also, as the fiber content was constant across all fiber-reinforced mixes in this study, it is recommended that future research investigates the effects of varying fiber dosages. The aim should be to identify the minimum cement content required to maintain desirable mechanical properties, contributing to more sustainable construction practices.

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SAŽETAK

Pjenobeton je laki građevinski materijal sastavljen od cementa, vode i sredstva za pjenjenje. Prisustvo sredstva za pjenjenje značajno smanjuje gustinu betona, čineći ga lakšim od konvencionalnih betonskih mješavina. Ipak, zbog odsustva krupnog agregata, pjenobeton uopšteno pokazuje slabija mehanička svojstva u poređenju sa drugim vrstama lakih betona. Ovo istraživanje ispituje mogućnosti poboljšanja mehaničkih karakteristika pjenobetona primjenom polipropilenskih vlakana u betonskoj mješavini. Istraživanje je fokusirano na procjenu uticaja ovih vlakana na ključna svojstva predmetnog materijala, sa ciljem unapređenja strukturne otpornosti pjenobetona, a samim tim i njegovih mehaničkih svojstava. U eksperimentalnom dijelu korišćene su dvije vrste cementa: cement tipa II normalne toplote hidratacije i cement tipa IV – pucolanski cement. Dobijeni rezultati pružaju dragocjene uvide u optimizaciju pjenobetona za širu primjenu u građevinarstvu, na osnovu ispitivanja čvrstoća pri savijanju i pritisku, kao i otpornosti prema habanju.

UTICAJ POLIPROPILENSKIH VLAKANA NA MEHANIČKA I FIZIČKA SVOJSTVA PJENOBETONA

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