Review on Characterization Of Construction Material Use for Polypropylene Fibre Reinforced Concrete (PFRC) and their properties

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Abstract: - Polypropylene Fiber Reinforced Concrete (PFRC) is an innovative construction material with the potential to transform traditional concrete construction practices. This paper explores the effects of various materials used in PFRC, focusing on cement, fine aggregate (sand), and coarse aggregate. Additionally, it investigates the impact of polypropylene fibers on the durability of concrete, specifically in terms of drying shrinkage, resistance to chloride penetration, and permeability. The study highlights how PFRC can address the limitations of conventional concrete by enhancing strength, durability, and resistance to common issues. Future research prospects, such as PFRC's application in rigid pavement construction and the use of modified polypropylene fibers.

1. Introduction

Polypropylene Fiber Reinforced Concrete (PFRC): A Path to Transformation in Construction

In the realm of innovative construction technologies and civil engineering, Polypropylene Fiber Reinforced Concrete (PFRC) stands as a transformative material, offering the potential to revolutionize traditional concrete construction methods. This groundbreaking building material has attracted significant interest due to its capacity to overcome the limitations of conventional concrete, enhancing strength and durability while simultaneously reducing issues such as corrosion, distortion, and cracking. PFRC's success is rooted in the complex interactions between the various materials that compose it, and this innovative material is setting a new course for the construction industry. Construction engineering is a rapidly evolving field, and seeking novel approaches to enhance the durability, performance, and sustainability of concrete remains a top priority. Traditional concrete, while widely used, has several inherent shortcomings. It can be susceptible to cracking, corrosion, and reduced longevity. PFRC offers a promising solution to these issues by harnessing the reinforcing power of polypropylene fibers. These fibers play a pivotal role in enhancing the material's properties, making it stronger, more durable, and resistant to common problems that plague conventional concrete. In paving applications, manufacturers strongly recommend the incorporation of polypropylene fibers. These fibers serve several crucial purposes. They reduce shrinkage and permeability, addressing two common issues in concrete. Additionally, they enhance impact resistance, abrasion resistance, and fatigue resistance, making PFRC suitable for a wide range of construction applications. This versatile material is well-suited to endure the demands of real-world construction projects while maintaining its structural integrity.

The development known as Polypropylene Reinforced Concrete (PFRC) could entirely transform traditional concrete mix designs. The characterization of building materials, which is essential for designing PFRC mixes, is the focus of this review study. This project holds immense significance as it may unlock the scientific principles that underpin the development of PFRC, shedding light on the intricate network of interactions governing its performance and behavior. Delving deeply into the characteristics and actions of the source materials that comprise PFRC is crucial to comprehending the complex nature of this innovative material. The key component of PFRC is polypropylene fiber, which serves as a reinforcing agent. These fibers are known for their strength and durability, making them an ideal choice for fortifying concrete. Their ability to reduce plastic shrinkage and permeability is particularly valuable in mitigating the common issue of concrete cracking. This reduction in permeability also helps in preventing corrosion, a problem that often plagues traditional concrete structures.

Furthermore, polypropylene fibers contribute to PFRC's exceptional impact resistance. This property is of great significance, especially in applications where the concrete structure may be subjected to external forces. The improved abrasion resistance of PFRC makes it ideal for structures that will be exposed to wear and tear over time, ensuring the material's longevity. The characteristic that sets PFRC apart from conventional concrete is its enhanced fatigue resistance. This means that the material can withstand repeated loading and unloading without experiencing structural degradation, making it an ideal choice for structures like bridges and pavements that endure constant stress and strain.In conclusion, Polypropylene Fiber Reinforced Concrete (PFRC) is poised to bring about a significant transformation in the construction industry. Its unique combination of enhanced strength, durability, and resistance to common concrete problems makes it a top choice for modern construction projects. The study of PFRC's building materials is pivotal in understanding the principles governing its development, ultimately leading to more innovative and sustainable construction practices. As construction engineering continues to advance, PFRC represents a beacon of progress in the pursuit of stronger, more resilient, and longer-lasting infrastructure.

2.Effect of materials used in Polypropylene Fibre Concrete

2.1 Cement:

The choice of cement type is a fundamental consideration in PFRC. The most common type used is Portland cement, known for its versatility and widespread availability. Different types of Portland cement, such as Type I, Type II, or Type III, offer various properties suitable for different applications. For example, Type I cement is often used in general construction, while Type III cement provides rapid strength development. Specialty cements, like sulfate-resistant or low-heat cement, can also be utilized depending on project requirements.

The cementitious content in PFRC mix designs is another vital factor. A higher cement content generally results in increased strength and durability, but it can affect workability. Proper proportioning is essential to balance these factors and achieve the desired concrete characteristics.

2.2 Fine Aggregate (Sand):

The choice of fine aggregate, typically sand, plays a significant role in the PFRC mix. The gradation of the sand, which refers to the distribution of particle sizes, can impact workability, water demand, and the overall performance of the concrete. A well-graded sand, with a balanced particle size distribution, is often preferred for optimal results.The cleanliness of the fine aggregate is also crucial. Impurities in the sand, such as clay, silt, or organic matter, can negatively affect the concrete's durability and workability. Clean, high-quality sand is essential for producing PFRC with consistent properties.

The shape of the sand particles is another consideration. Rounded or angular particles can influence workability, with rounded particles typically leading to better flow and reduced internal friction. The choice of sand shape should align with the specific project requirements.

2.3 Coarse Aggregate:

Coarse aggregates, such as crushed stone or gravel, are vital components of PFRC. The size and gradation of coarse aggregates significantly affect workability, strength, and durability. Well-graded, uniformly sized aggregates are desirable to ensure a homogeneous mix and consistent concrete properties. The type of coarse aggregate used can also impact PFRC. Choices include crushed stone, gravel, and lightweight aggregates. Each type has its own set of characteristics, affecting the concrete's density and overall strength. Like fine aggregates, the cleanliness of coarse aggregates is essential for high-quality PFRC. Impurities or contaminants can weaken the concrete and reduce its long-term durability. Ensuring that the coarse aggregates meet specific quality standards is essential.

3. Effect of Polypropylene Fibre on Durability of Concrete: -

3.1 Drying shrinkage is the natural process of concrete volume decreasing due to the evaporation of water in the air, which is an inescapable detrimental change for concrete structures. It is linked to the movement of moisture and the characteristics of pores within the concrete. Polypropylene fibres (PPFs) are frequently incorporated into concrete to mitigate microcracking resulting from drying shrinkage. Previous research demonstrates a substantial reduction in drying shrinkage with the incorporation of PPFs. Leong et al. [1] introduced PPFs into lightweight concrete at varying volume percentages of 0.15%, 0.3%, and 0.5%. Their findings revealed a positive impact of PPFs on reducing drying shrinkage. Similarly, Saje et al. conducted a comparative study on the shrinkage behaviour of high-performance concrete with and without PPFs, concluding that the addition of PPFs significantly diminished drying shrinkage. The optimal PPF content was found to range from 0.25% to 0.5% by volume when considering both shrinkage and workability.

Alrshoudi et al. explored the use of waste PPFs in prepacked aggregate concrete in concentrations ranging from 0% to 1.2% by volume. They observed a decrease in the drying shrinkage of the concrete when PPFs were added. Notably, the drying shrinkage of PPF-reinforced concrete exhibited a decreasing trend initially, followed by an increase. Figure 1 illustrates that the concrete with 0.75% PPF content exhibited the lowest drying shrinkage. Additionally, the incorporation of PPFs, in combination with steel fibers, can lead to further reductions in the drying shrinkage of concrete. Afroughsabet et al. reported a significant decrease in concrete drying shrinkage by introducing PPFs and steel fibers. They determined that the most effective reduction in drying shrinkage was achieved with a combination of 0.3% PPFs and 0.7% steel fibers, resulting in a substantial 26% reduction in drying shrinkage compared to plain concrete. [2]

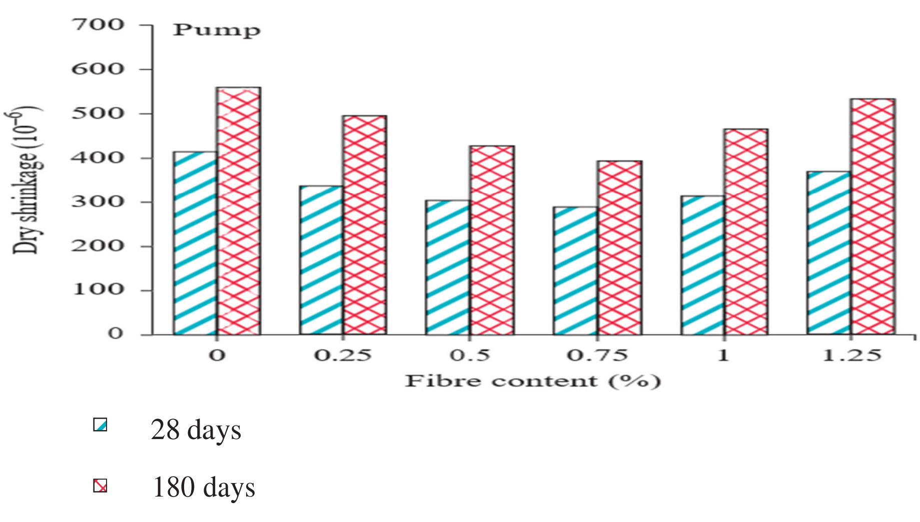

FIgurE 1: Drying shrinkage concrete at 28 and 180 days [3].

3.2 Resistance to Chloride Penetration Chloride penetration resistance is a critical factor in the durability of concrete structures. Chloride ions can infiltrate concrete through capillary action, diffusion, and penetration, accelerating the corrosion of reinforcement and compromising concrete's longevity. The pore size distribution and structure of concrete can be improved by incorporating fibers, and polypropylene fibers (PPF) are commonly used to reduce and block micropores, thereby reducing the likelihood of chloride ion penetration. However, the effectiveness of PPF-reinforced concrete in resisting chloride ion penetration is influenced by various factors, including the amount, length, diameter, and ratio of coarse and fine fibers.Research by Liu et al. [4] has shown that PPF can decrease concrete porosity, prevent shrinkage cracks, and enhance concrete's resistance to chloride ion penetration. Their findings indicate that with a volumetric PPF content of 1.5% or less, the depth of chloride ion penetration into concrete is reduced. Furthermore, PPF demonstrates superior performance in improving chloride ion penetration resistance compared to glass fiber, as illustrated in Figure 2.

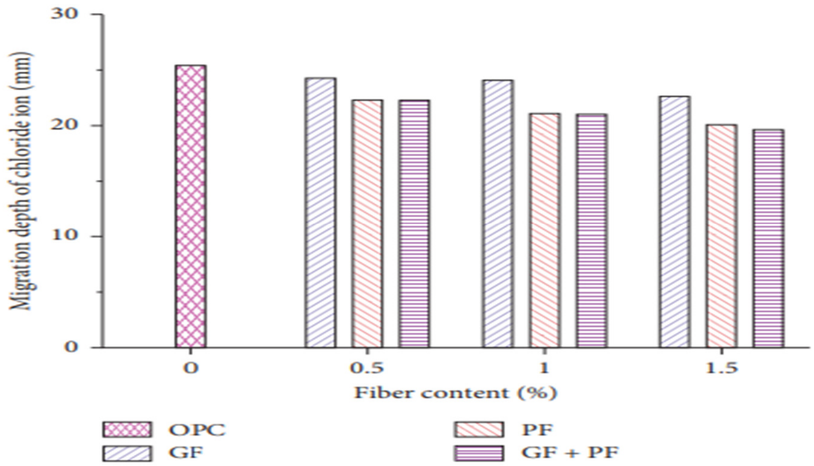

Figure 2: Chloride penetration depth [4].

Guo et al. [4] observed that as the fiber content increased, the electric flux of concrete initially decreased and then increased. Excessive PPF, however, reduced the workability of concrete, causing mortar and PPF to have reduced adhesion. This led to the creation of pores in the interfacial transition zone (ITZ) between PPF and mortar, providing pathways for chloride ions to penetrate, ultimately decreasing the resistance to chloride ion penetration. Liu and Hu [5] investigated the effects of single and mixed fibers on chloride ion penetration in concrete. Their findings align with those of Guo et al. [6], showing that the chloride diffusion coefficient for single fibers initially decreased and then increased with content. Additionally, coarse PPF had a bridging effect on macrocracks, while fine PPF effectively inhibited microcracks. A balanced ratio of course and fine fibers is necessary to prevent the growth of both macro- and microcracks, significantly enhancing concrete's resistance to chloride ion penetration. A study by [7] examined the impact of steel fiber and PPF on the chloride diffusivity of high-strength concrete. It was discovered that PPF-containing concrete exhibited a lower chloride migration coefficient compared to concrete without PPF. However, the addition of both fiber types significantly increased the chloride migration coefficient due to the increased conductivity of steel fibers. Based on Fick's second law, Liu et al. [2] developed a diffusion model for chloride ions in fiber-reinforced concrete. The model's predicted results closely matched the actual test results. A sensitivity analysis of the model revealed that variables such as fiber diameter, fiber content, aggregate size, and aggregate volume content influenced the resistance of concrete to chloride ion penetration.

In summary, PPF can significantly enhance concrete's resistance to chloride ion penetration, but the fiber diameter, content, and proportion of course and fine fibers are crucial factors influencing this resistance. While there are optimal technical parameters, the results can vary due to differences in concrete mix, fiber quality, testing procedures, and other variables. [2]

3.3 The permeability of concrete is a critical factor that affects its performance and durability. In the early stages of concrete, as the surface moisture rapidly evaporates and the concrete undergoes significant dry shrinkage, microcracks are prone to develop on its surface. However, the addition of polypropylene fibers (PPFs) to concrete can help mitigate segregation and reduce water evaporation. Moreover, PPFs are effective in preventing cracks from propagating from the exterior to the interior of the concrete, thereby enhancing the concrete's resistance to permeability. Several studies have highlighted the positive impact of PPFs on fresh and hardened concrete. PPFs can prevent fresh concrete from segregating and improve the uniformity of the concrete mixture [8]. At the hardened stage, concrete containing PPFs exhibits fewer and finer cracks compared to concrete without PPF. This suggests that PPFs can reduce the likelihood of microcrack coalescence in concrete, significantly improving its permeability [9] [2].

Ramezanianpour et al. [10] examined the influence of PPF content ranging from 0.5% to 4% on the water permeability of concrete. Their results demonstrated that the depth of water penetration in concrete decreased with the addition of PPFs. Interestingly, the depth of water penetration initially decreased and then increased with the PPF content. Concrete with a PPF content of 0.7 kg/m³ exhibited the minimum depth of penetration, which was 30% lower than that of concrete without PPF. Behfarnia and Behravan conducted a study on fiber-reinforced concrete used in water tunnels. They compared the water absorption of concrete with PPFs and steel fibers at volume contents ranging from 0.4% to 0.8%. The use of PPFs resulted in up to a 45% reduction in water absorption, indicating a significant enhancement in concrete impermeability. However, steel fibers had a more pronounced effect on reducing water absorption compared to PPF. Guo et al. [11] analyzed the impact of multisize polypropylene fibers on concrete impermeability. The results showed that fine fibers with diameters of 0.026 mm and 0.1 mm had a noticeable inhibitory effect on micropores, while coarse fibers with a diameter of 0.8 mm were more effective in inhibiting macropores. Moreover, concrete mixed with both coarse and fine PPFs exhibited higher impermeability compared to concrete with single-diameter PPFs.

The compressive strength of concrete demonstrated a linear relationship with the logarithm of the impermeability coefficient. It was noted that cracks became more tortuous and the crack surfaces rougher with an increase in PPF content. Furthermore, increasing the fiber length or the ratio of fiber diameter to fiber diameter in ultra-high-strength concrete enhanced impermeability. An increased fiber content and length also more effectively inhibited crack development in concrete. However, some research results, such as those by Islam and Das [12], suggested that an increase in PPF content led to an increase in concrete permeability. The authors proposed that this phenomenon might be attributed to excessive fiber content. In summary, the impermeability of concrete is influenced by factors such as fiber content, diameter, length, and other variables. Within a certain range, impermeability tends to increase with fiber content but decrease with fiber diameter. Thus, the addition of PPFs with reasonable fiber diameter and content can effectively inhibit the generation and development of cracks in concrete, enhancing its impermeability.

4. Conclusion

In the realm of pioneering construction technologies and civil engineering, Polypropylene Fiber Reinforced Concrete (PFRC) is poised to revolutionize traditional concrete construction practices. This innovative construction material has garnered substantial attention for its potential to address the limitations of conventional concrete. It offers enhanced strength and durability while mitigating issues such as corrosion, deformation, and cracking. The success of PFRC hinges on the intricate interactions among its constituent materials, charting a new path for the construction industry. Despite its widespread use, traditional concrete has inherent drawbacks, including susceptibility to cracking, corrosion, and reduced longevity. PFRC offers a promising remedy for these issues by harnessing the reinforcing capabilities of polypropylene fibers. These fibers play a crucial role in bolstering the material's properties, rendering it stronger, more robust, and resilient against common problems afflicting traditional concrete.

In applications like paving, manufacturers strongly advocate for the inclusion of polypropylene fibers. These fibers serve several critical functions, such as reducing shrinkage and permeability, addressing prevalent concrete concerns. Furthermore, they enhance resistance to impact, abrasion, and fatigue, making PFRC suitable for a broad spectrum of construction applications. This versatile material is well-equipped to withstand the rigors of real-world construction projects while preserving its structural integrity. The development of Polypropylene Fiber Reinforced Concrete (PFRC) has the potential to revolutionize traditional concrete mix designs. A comprehensive understanding of the characteristics and interactions among the materials constituting PFRC is pivotal in comprehending the intricate nature of this groundbreaking material. At its core, PFRC relies on polypropylene fiber as a reinforcing agent. These fibers are renowned for their strength and durability, rendering them an ideal choice for fortifying concrete. Their capacity to reduce plastic shrinkage and permeability is particularly valuable in addressing the common issue of concrete cracking. Moreover, this reduction in permeability aids in preventing corrosion, a common challenge faced by conventional concrete structures.

5. Future Research Prospects

Polypropylene Fiber Reinforced Concrete (PFRC) exhibits a vast array of potential applications and presents promising future research prospects. One such area of exploration lies in its utilization for rigid pavement construction. Studies have indicated that incorporating polypropylene fibers into concrete can significantly enhance its durability and flexural strength. This suggests that PFRC could play a pivotal role in ensuring the longevity and robustness of rigid pavements, which are subjected to substantial load-bearing requirements. As a result, future research endeavors in this domain could focus on optimizing PFRC mix designs for rigid pavement applications, further advancing the construction industry's quest for enduring and resilient infrastructure.

Enhancing the interaction between modified PPF and concrete performance is a critical aspect of this study. Surface modification methods prove effective in strengthening the bond between PPF and cement. Resolving issues within the Interfacial Transition Zone (ITZ) between PPF and cement mortar is paramount. To address this, we employ an amphiphilic modifier inspired by tea stains. This innovative modifier actively attracts calcium ions and triggers localized mineralization, facilitating the deposition of more hydration products on the fiber's surface. Consequently, the ITZ between the fiber and cement mortar is fortified, positively influencing the microstructure of the cement paste. The incorporation of modified fibers further elevates concrete performance. As a result, we conducted a comprehensive analysis of how modified fibers impact the cement paste's hardening process to gain a deeper understanding of the intricate relationship between fibers and concrete. Additionally, when maintaining identical performance requirements for concrete, the addition of modified fibers enables a reduction in the cement proportion. In such cases, the mix design must be recalibrated to align with performance criteria. Building upon this foundation, we delve into exploring the correlation between hardened paste properties and macroproperties, ultimately leading to parameter optimization and control based on concrete performance requirements.

6. Authors' Contributions

The author has been responsible for conducting literature searches, drafting the original manuscript, and verifying the accuracy and proper presentation of the study and literature work.

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5. References

Bibliography

[1] G. W. Leong, ” Construction and Building Materials,, 2020.

[2] Y. Liu, Review on the Durability of Polypropylene, School of Civil Engineering and Architecture, Anhui University of Science and Technology, Huainan, Anhui 232001, China, Received 2 December 2020; Revised 12 April 2021; Accepted 19 May 2021; Published 8 June 2021.

[3] H. M. M. M. T. e. a. F. Alrshoudi, Journal of Building Engineering, vol. 32, Article ID 101522, 2020.

[4] Q. C. Z. W. J. B. H. a. C. P. X. Q. S. Guo, “Effects of fibres on permeability of high performance concrete for, ” China Concrete and Cement Products, vol. 12,, 2019.

[5] S. M. Liu and H. Y. Hu, “Study of mechanical and resistance to chloride ion penetration properties of hybrid polypropylene, Engineering Journal of Wuhan University, vol. 52, pp. 131–138, 2019.

[6] Q. C. Z. W. J. B. H. a. C. P. X. Q. S. Guo, “Effects of fibres on permeability of high performance concrete for, China Concrete and Cement Products, vol. 12,pp. 48–51, 2019.

[7] L. B. a. P. J. M. M. V. Afroughsabet, “,e effect of steel and polypropylene fibers on the chloride diffusivity, Composites Part B: Engineering, vol. 139, pp. 84–96, 2018.

[8] P. Matar and J. J. Assaad, “Concurrent effects of recycled aggregates and polypropylene fibers on workability and key strength properties of self-consolidating concrete,”, struction and Building Materials, vol. 199, pp492–500, 2013.

[9] Y. Z. E.-H. Y. a. K. H. T. Y. Li, vol. 116, pp. 168–178, 2, 20019.

[10] M. E. S. A. G. a. H. N. A. A. Ramezanianpour, “Laboratory study on the effect of polypropylenefiber on durability, and physical and mechanical characteristicof concrete for application in sleepers,”, Construction andBuilding Materials, vol. 44, pp. 411–418,, 2013.

[11] Z. Q. Guo, “Experimental study on the impermeability omulti-scale polypropylene fibre concrete,”, Master thesis,Chongqing University, Chongqing, China,, 2018.

[12] G. M. S. I. a. S. Das, “Evaluating plastic shrinkage and permeability of polypropylene fiber reinforced concrete,”, International Journal of Sustainable Built Environment, vol. 5pp. 345–354, 2016.