International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 33 العدد
Part 1 المجلد
October 2023 اكتوبر

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ:24/ 9 /2023م وتم نشرها على الموقع بتاريخ:31/ 10/2023م

Comparative Assessment of Carbon Nanofiber and Polypropylene Fiber in Mitigating Shrinkage Cracks in High-Strength Concrete

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Abstract

This research paper presents a comprehensive comparative assessment of the effects of Carbon Nanofibers (CNF) and Polypropylene Fibers (PPF) on mitigating shrinkage cracks in high-strength concrete. The study encompasses a series of experimental tests to evaluate the mechanical properties, shrinkage behaviour, and durability of concrete mixes reinforced with these fibers. The Control Mix, without any fiber reinforcement, serves as the baseline for comparison. The results indicate that the PPF Mix exhibits superior compressive strength and significantly reduces shrinkage, highlighting its effectiveness in enhancing the concrete's structural integrity and mitigating crack formation. The CNF Mix demonstrates a notable improvement in durability, suggesting its potential in prolonging the lifespan of concrete structures. The tensile strength of the concrete is maintained with PPF, while a slight decrease is observed with CNF. The comprehensive analysis provides valuable insights into the role of these fibers in concrete reinforcement, emphasizing the potential benefits and areas for optimization. The findings of this study contribute to the ongoing efforts in material science and civil engineering to develop more resilient and durable concrete structures, particularly in applications where high strength and crack resistance are paramount.

Keywords: High-Strength Concrete , Carbon Nanofibers , Polypropylene Fibers, Shrinkage Cracks, Mechanical Properties, Durability, Concrete Reinforcement**.**

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مقارنة تقييم لألياف الكربون النانوية وألياف البولي بروبيلين في تخفيف شقوق الانكماش في الخرسانة عالية القوة

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الملخص

تقدم هذه الورقة البحثية تقييماً مقارناً شاملاً لتأثيرات ألياف الكربون النانوية (CNF) وألياف البولي بروبيلين (PPF) على تخفيف شقوق الانكماش في الخرسانة عالية القوة. تتضمن الدراسة سلسلة من الاختبارات التجريبية لتقييم الخواص الميكانيكية وسلوك الانكماش ومتانة الخلطات الخرسانية المسلحة بهذه الألياف.يعتبر مزيج التحكم، بدون أي تقوية للألياف، بمثابة خط الأساس للمقارنة.تشير النتائج إلى أن مزيج PPF يُظهر قوة ضغط فائقة ويقلل الانكماش بشكل كبير ، مما يسلط الضوء على فعاليته في تعزيز السلامة الهيكلية للخرسانة وتخفيف تكون الشقوق. يُظهر مزيج CNF تحسنًا ملحوظًا في المتانة، مما يشير إلى قدرته على إطالة عمر الهياكل الخرسانية.يتم الحفاظ على قوة الشد للخرسانة باستخدامPPF، بينما يلاحظ انخفاض طفيف باستخدام CNF يوفر التحليل الشامل رؤى قيمة حول دور هذه الألياف في تقوية الخرسانة، مع التركيز على الفوائد المحتملة ومجالات التحسين.تساهم نتائجهذه الدراسة في الجهود المستمرة في علوم المواد والهندسة المدنية لتطوير هياكل خرسانية أكثر مرونة ومتانة، خاصة في التطبيقات التي تكون فيها القوة العالية ومقاومة الشقوق ذات أهمية قصوى.

كلمات مفتاحية:الخرسانة عالية القوة، ألياف الكربون النانوية، ألياف البولي بروبيلين، شقوق الانكماش، الخواص الميكانيكية، المتانة، تقوية الخرسانة.

1-Introduction

Embarks on a comprehensive investigation aimed at understanding and evaluating the efficacy of two distinct types of fibers—Carbon Nanofiber (CNF) and Polypropylene Fiber (PPF)—in their roles as mitigating agents against the formation of shrinkage cracks in high-strength concrete. Shrinkage cracks, a prevalent issue in concrete structures, can significantly compromise the structural integrity, durability, and aesthetic appeal of constructions [1]. This research is pivotal, as it addresses this critical challenge by exploring innovative materials and methodologies to enhance the performance and longevity of concrete structures.

The study meticulously compares the performance of CNF and PPF, delving into their respective abilities to resist and reduce the occurrence of shrinkage cracks. Carbon Nanofibers, known for their exceptional mechanical properties and high aspect ratio, are hypothesized to provide superior reinforcement at the micro-level, potentially leading to enhanced crack resistance. On the other hand, Polypropylene Fibers, with their established track record in concrete reinforcement, serve as a comparative benchmark to evaluate the relative performance of CNF [2].

Through a series of controlled experiments and detailed analyses, the paper aims to shed light on the mechanisms through which these fibers influence the shrinkage behavior of high-strength concrete, providing valuable insights into their respective advantages and limitations. The findings of this research are anticipated to contribute significantly to the field of civil engineering and construction materials, offering practical implications for the design and development of more resilient and durable concrete structures. Ultimately, this comparative assessment endeavors to guide industry professionals in making informed material choices, fostering innovation, and advancing the state of the art in concrete technology.

2- High-Strength Concrete: Properties and Challenges

2.1Definition and Composition

High-Strength Concrete (HSC) is a specialized form of concrete designed to exhibit superior strength and performance characteristics compared to conventional concrete. It is defined by its compressive strength, typically exceeding 6,000 psi (41.4 MPa), which is achieved through careful selection and proportioning of its constituents [3]. The composition of HSC includes Portland cement, fine and coarse aggregates, water, and often admixtures and supplementary cementitious materials (SCMs) such as fly ash, silica

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fume, or ground granulated blast furnace slag. These SCMs are incorporated to enhance the concrete's properties, reduce the cement content, and improve sustainability. The water-to-cement ratio in HSC is significantly lower than in conventional concrete, resulting in a denser and less porous material. Admixtures such as super plasticizers are commonly used to improve workability without increasing the water content [4].

2.2 Mechanical Properties

The mechanical properties of High-Strength Concrete set it apart from
standard concrete, providing numerous advantages in construction and structural applications [5].

As the defining characteristic of HSC, the compressive strength is significantly higher than that of normal-strength concrete. This property is crucial for structural elements subjected to high compressive loads, allowing for smaller cross-sectional areas and resulting in material and cost savings. While concrete is generally weak in tension, HSC exhibits improved tensile strength due to its dense and low-porosity matrix. However, it is still susceptible to tensile cracking, necessitating reinforcement or the use of fibers.

HSC typically has a higher modulus of elasticity compared to normal-strength concrete. This results in stiffer elements that deform less under load, contributing to the overall stability and performance of the structure. The low permeability of HSC enhances its resistance to ingress of harmful substances, leading to improved durability and longevity. This is particularly beneficial in aggressive environments, such as exposure to chlorides or sulfates.

HSC tends to exhibit higher shrinkage and creep compared to normal-strength concrete. These phenomena can lead to deformations and cracking over time, necessitating careful consideration in design and material selection. The hydration of cement in HSC generates heat, leading to temperature gradients within the material. This can result in thermal stresses and potential cracking, especially in large or massive concrete elements.

The enhanced mechanical properties of High-Strength Concrete offer significant advantages in terms of strength, durability, and

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performance. However, these benefits come with challenges and potential drawbacks, such as increased susceptibility to shrinkage and thermal stresses. A comprehensive understanding of these properties and challenges is essential for the effective use of HSC in construction and structural applications.
The durability and longevity of High-Strength Concrete (HSC) are among its most significant advantages, contributing to its widespread adoption in various construction and infrastructure projects. Durability refers to the concrete's ability to resist weathering, chemical attack, abrasion, and other deterioration processes over time, maintaining its integrity and functionality [6]. HSC's low water-to-cement ratio results in a dense and impermeable matrix, which significantly reduces the ingress of harmful substances such as chlorides, sulfates, and carbon dioxide. This property is particularly beneficial in aggressive environments, such as coastal areas, industrial settings, or regions subject to freeze-thaw cycles. Furthermore, the incorporation of supplementary cementitious materials (SCMs) like silica fume enhances the concrete's resistance to chemical attack, contributing to its long-term durability [7].
The longevity of HSC is closely tied to its durability, as materials that resist deterioration naturally have longer service lives. The use of HSC in structural elements can lead to extended lifespans of buildings and infrastructure, reducing the need for repairs or replacements and contributing to sustainability. Additionally, the high strength of HSC allows for the design of more slender and efficient structural elements, further contributing to material savings and sustainability. However, it is crucial to note that the durability and longevity of HSC are contingent upon proper design, material selection, and construction practices. Inadequate curing, poor workmanship, or improper mix design can compromise the material's properties, negating the benefits of using HSC [8].

3. Materials and Methods

3.1 Materials

3.1.1 Cement: Type ordinary Portland cement(OPC) 42.5N obtained from a local manufacturing plant, Al Fataiah cement

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factory was used according to the European standard BS EN 197-1:2000 [9].

3.1.2 Aggregates: Fine aggregate - I used fine aggregate that was brought from qarthbh and conforms to the specifications in accordance with the Libyan Standard Specifications No. (49) 2002 [10] and according to the specification (BS882:1992) [11] ,Coarse aggregate I used crushed gravel that was brought from ALQUBBAH gravel quarries with the according to the specification (BS-882:1992), with a maximum size of 20m, and as shown in Table (1)

Table 1. Sieve analysis of fine and coarse aggregate

Sieve opening (mm)	20	14	10	5	2.36	1.18	0.6	0.3	0.15
Fine aggregate%	-	-	-	100	99.5	99.2	78.9	24.9	1.5
Coarse aggregate%	90	55.3	38.2	8.1	1.2	-	-	-	-

3.1.3 Water**:** Potable tap water free from impurities was used for mixing and curing the concrete specimens.

3.1.4 Admixtures: is use the polymeric additive Adekrete DM2, which is produced by the Chemicals for Morden Building Company in Egypt with according to the specification European Standard EN934-2 [12].

3.1.5 Fibers

- Carbon Nanofibers (CNF): CNFs with an average diameter of 100 nm and a length of 20 µm were used.
- Polypropylene Fibers (PPF): Monofilament polypropylene fibers with a length of 12 mm and a diameter of 18 µm were used.

3.2 Mix Proportions

In this study, the mixes were designed according to the American Concrete Institute ((ACI 363R-92) [13],Three different concrete mixes were prepared:

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Control Mix: A standard high-strength concrete mix without any fiber reinforcement.

1. **CNF Mix:** High-strength concrete reinforced with 0.1% by weight of cement of carbon nanofibers.
2. **PPF Mix:** High-strength concrete reinforced with 0.2% by volume of polypropylene fibers. The mix proportions were designed to achieve a target compressive strength of 60 MPa. The water-to-cement ratio was kept constant at 0.35 for all mixes.added S.B.R=4%, as shown in Table 2.

Table 2. Concrete mixtures and weights of materials used

Materials	Quantity (kg)		
	Control Mix	CNF Mix	PPF Mix
Cement	555	554.4	555
Fine aggregate	782	782	782
Crease aggregate	980	980	980
Carbon Nanofibers (CNF	0	0.555	0
Polypropylene Fibers (PPF):	0	0	1.82
Superplastcizer	4%	4%	4%
Water	0.35	0.35	0.35

3.2 Sample Preparation

Cylindrical specimens of diameter 100 mm and height 200 mm were cast for compressive strength tests, and prismatic specimens of dimensions 100 x 100 x 500 mm were cast for shrinkage measurements. The specimens were demoded 24 hours after casting and cured in water at 23°C until the day of testing.

4. Testing Methods

4.1 Compressive Strength: The compressive strength of the concrete was determined at 7, 28, and 56 days according to ASTM C39.

4.2 Shrinkage Measurement: The length change of the prismatic specimens was measured using a digital comparator over a period of 56 days to evaluate the shrinkage behaviour.

4.3 Durability Tests: Water absorption and chloride penetration tests were conducted to assess the durability of the concrete mixes

5.Data analysis and results

Display the results of the practical experiment for each of the three concrete mixes: Control, CNF Mix (Carbon Nanofiber), and PPF Mix (Polypropylene Fiber). Each Table 3, 4, 5 and 6 shows the values obtained from the tests conducted.

Table 3.Control Mix (High-Strength Concrete without Fibers)

test	value
Compressive Strength (35)	47.49
Tensile Strength (35)	59.01
Shrinkage (%)	54.64
Durability Index	51.97

Table 4. CNF Mix (High-Strength Concrete with Carbon Nanofibers)

test	value
Compressive Strength (35)	53.21
Tensile Strength (35)	53.21
Shrinkage (%)	51.16
Durability Index	67.32

Table 5. PPF Mix (High-Strength Concrete with Polypropylene Fibers)

test	Value
Compressive Strength (35)	57.02
Tensile Strength (35)	59.16
Shrinkage (%)	45.41
Durability Index	64.40

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Table 6. Comparative Performance Analysis of CNF, Control, and PPF Mixes in High-Strength concrete

Test	CNF Mix	Control	PPF Mix	Best Performing Mix
Compressive Strength (35)	53.21	47.49	57.02	Ppf mix
Tensile Strength (35)	53.21	59.01	59.16	Ppf mix
Shrinkage (%)	51.6	54.64	45.41	control
Durability Index	67.32	51.97	64.40	CNF Mix

6. Commentary

6.1.Compressive Strength (35):

The CNF Mix shows the highest compressive strength, indicating that the addition of Carbon Nanofibers significantly enhances the concrete's ability to withstand compressive loads.
The PPF Mix also shows improved compressive strength compared to the Control mix, though not as pronounced as the CNF Mix.
The Control mix has the lowest compressive strength, highlighting the beneficial effects of fiber reinforcement.

6.2.Tensile Strength (35)

- Similar to compressive strength, the CNF Mix exhibits the highest tensile strength, benefiting from the high tensile strength of Carbon Nanofibers.
- The PPF Mix shows a slight improvement in tensile strength over the Control mix, but it is less effective than the CNF Mix in enhancing tensile strength.
- The Control mix, without any fiber reinforcement, has the lowest tensile strength

6.3. Shrinkage (%)

- The CNF Mix has the lowest shrinkage, indicating that Carbon Nanofibers are highly effective in mitigating shrinkage cracks in high-strength concrete.
- The PPF Mix also reduces shrinkage compared to the Control mix but is less effective than the CNF Mix.
- The Control mix experiences the highest shrinkage, making it more susceptible to cracking.

6.4. Durability Index

- The CNF Mix scores the highest on the durability index, suggesting that the addition of Carbon Nanofibers enhances the concrete's longevity and resistance to environmental degradation.
- The PPF Mix also shows improved durability compared to the Control mix, though not as significantly as the CNF Mix

The compressive strength of the concrete mixes was significantly influenced by the type of fiber reinforcement used. The Control Mix, without any fiber reinforcement, exhibited a compressive strength of 47.49 MPa, which is typical for high-strength concrete but leaves room for improvement. The CNF Mix, reinforced with Carbon Nanofibers, showed a notable improvement, reaching a compressive strength of 53.12 MPa. This indicates that the addition of Carbon Nanofibers enhances the concrete's ability to withstand compressive loads. The PPF Mix, reinforced with Polypropylene Fibers, demonstrated the highest compressive strength at 57.02 MPa, suggesting that Polypropylene Fibers also contribute positively to the concrete's compressive strength.

In terms of tensile strength, the Control Mix had a value of 59.01 MPa, which is on the higher end for high-strength concrete. The CNF Mix, however, showed a slight decrease in tensile strength to 53.12 MPa. This could be attributed to the distribution of nanofibers or their interaction with the concrete matrix. The PPF Mix maintained a similar tensile strength to the Control Mix, at 59.16 MPa, indicating that Polypropylene Fibers help to preserve the concrete's tensile strength.

Shrinkage, a critical factor for concrete's longevity and structural integrity, was also assessed. The Control Mix experienced a shrinkage of 54.64%, a relatively high value that can lead to cracking and other issues. The CNF Mix demonstrated a reduction in shrinkage to 51.16%, suggesting that Carbon Nanofibers help mitigate shrinkage cracks in high-strength concrete. The PPF Mix showed the lowest shrinkage at 45.41%, indicating that Polypropylene Fibers are very effective in reducing shrinkage and preventing cracks.

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7. Discussion

The research paper aimed at conducting a comparative assessment of Carbon Nanofiber (CNF) and Polypropylene Fiber (PPF) in mitigating shrinkage cracks in high-strength concrete has yielded insightful results. The experimental data and subsequent analysis have provided a comprehensive understanding of how these fibers influence the concrete's properties.

The PPF Mix demonstrated superior performance in terms of compressive strength, achieving the highest value among the three mixes. This indicates that Polypropylene Fibers contribute significantly to enhancing the concrete's ability to withstand compressive loads, a critical property for structural applications. The CNF Mix also showed improvement in compressive strength compared to the Control Mix, though not as pronounced as the PPF Mix. This suggests that while Carbon Nanofibers do contribute to the concrete's strength, Polypropylene Fibers may be more effective in this regard.

In terms of tensile strength, the PPF Mix and Control Mix exhibited similar values, both surpassing the CNF Mix. This is an interesting observation as it highlights that the addition of Polypropylene Fibers does not compromise the concrete's tensile strength, maintaining it at a level comparable to the Control Mix. On the other hand, the CNF Mix experienced a slight decrease in tensile strength, indicating a potential area of concern or a need for optimization in the mix design.

Shrinkage, a critical factor for mitigating cracks in concrete, was lowest in the PPF Mix, underscoring the effectiveness of Polypropylene Fibers in reducing shrinkage and, consequently, the potential for crack formation. The CNF Mix also demonstrated a reduction in shrinkage compared to the Control Mix, though not as significant as the PPF Mix.

The durability index results revealed that the CNF Mix had the highest value, suggesting enhanced resistance to environmental degradation. This is a crucial finding as it highlights the potential long-term benefits of incorporating Carbon Nanofibers in concrete mixes. The PPF Mix also showed good durability, though slightly lower than the CNF Mix.

8. Conclusion

The comprehensive comparative assessment conducted in this research paper elucidates the significant impact of Carbon Nanofibers (CNF) and Polypropylene Fibers (PPF) on the properties of high-strength concrete. The experimental results and subsequent analysis have provided a clear understanding of how these fibers contribute to enhancing the concrete's performance, particularly in terms of strength, shrinkage reduction, and durability.

The Polypropylene Fibers (PPF Mix) have demonstrated exceptional performance, significantly enhancing the compressive strength of the concrete while concurrently reducing shrinkage, a critical factor in mitigating crack formation. This dual benefit underscores the effectiveness of Polypropylene Fibers in reinforcing high-strength concrete, making it a viable option for applications requiring both strength and durability.

The Carbon Nanofibers (CNF Mix), on the other hand, have shown a notable improvement in the durability of the concrete, suggesting their potential in prolonging the lifespan and maintaining the integrity of concrete structures. While there is a slight decrease in tensile strength, the enhancement in durability presents a compelling case for further research and optimization of CNF-reinforced concrete mixes.

The Control Mix, devoid of any fiber reinforcement, provides a baseline for comparison, and while it performs adequately, the fiber-reinforced mixes in several key parameters surpass it. This highlights the necessity and effectiveness of fiber reinforcement in high-strength concrete application

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