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Mitigating Shrinkage Cracks in Concrete Structures through Fiber Reinforcement

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Abstract

Shrinkage cracks in concrete structures pose a critical challenge to their durability and aesthetic appeal. This research addresses this issue by investigating the effectiveness of fiber-reinforced concrete (FRC) in mitigating and reducing shrinkage cracks. A comprehensive experimental program is conducted, encompassing fiber types, includes polypropylene incorporated into concrete mixes. The study evaluates the impact of these fibers on fresh and hardened properties, mechanical performance, and durability characteristics of FRC. Through restrained and unrestrained shrinkage tests, the research provides valuable insights into the potential of FRC as a robust solution to enhance crack resistance in concrete structures. The findings aim to contribute to the advancement of sustainable and crack-resistant concrete construction.

Keywords

Fiber-Reinforced Concrete, Shrinkage Cracks, Concrete Durability, Crack Mitigation, Aggregate, Structural Integrity, Construction Materials.

Introduction:

Concrete, a ubiquitous building material, stands as the backbone of our modern infrastructure. However, its inherent susceptibility to shrinkage cracks poses a formidable challenge, both in terms of structural integrity and aesthetic longevity. Shrinkage cracks, arising from factors such as drying and temperature variations, not only compromise the durability of concrete structures but also their visual appeal.However, Shrinkage cracking is a major problem for concrete structures, especially for flat structures, such as highway pavement, slabs and walls. One method to reduce shrinkage cracks is to reinforce concrete with fibersin response to this challenge, this research delves into the exploration of an innovative and promising solution – Fiber-Reinforced Concrete (FRC). The study aims to investigate the efficacy of fiber polypropylene in mitigating and reducing shrinkage cracks. By integrating these fibers into concrete mixes, we embark on a comprehensive experimental journey, meticulously evaluating their influence on fresh and hardened properties, mechanical performance, and durability characteristics of FRC.The experimental program goes beyond traditional boundaries, encompassing a range of fiber types to ensure a nuanced understanding of their impact. From the controlled environments of the laboratory, we simulate real-world conditions through restrained and unrestrained shrinkage tests. Through these tests, our research seeks to unravel the intricate interplay between different fibers and their ability to enhance crack resistance in concrete structures.Beyond the realm of scientific inquiry, our objective is to contribute meaningfully to the advancement of sustainable and crack-resistant concrete construction. This research endeavors to offer valuable insights that transcend the confines of the laboratory, informing industry practices, and guiding the implementation of innovative solutions in real-world construction projects.As we navigate the complexities of concrete behavior and seek solutions to age-old challenges, the findings of this research aspire to usher in a new era in concrete construction characterized by sustainability, resilience, and an unwavering commitment to addressing the enduring challenge of shrinkage cracks.

Materials

Cementitious material and Chemical Composition

This study is based on the M20 grade of concrete, and the chemical characteristics of these cements are shown in bellow Table.

Chemical Components	Cement (%)
SiO2	22.25
AI2O3	3.38
Fe2O3	3.56
CaO	62.82
MgO	3.55
SO3	1.71
Na2O	0.22
K2O	0.64
Loss of Ignition	1.87

properties of these three fibers are shown in table 2.

Aggregate

The maximum size of aggregates and grading are considered to affect the ratio of fine to coarseaggregates, shrinkage, porosity, compaction ability, workability, and the amount of water and cement of concrete mixtures. The change in grading can directly influence the uniformity of concrete.

Fine and Coarse Aggregate grading

The most appropriate grading for the fine aggregates is dependent on the maximum size of coarse aggregates, cement content, type, and purpose of the mixture. For satisfying the workability purposes, in mixes with lower cement content or coarse aggregates with small sizes, the best type of grading for fine aggregates is the one that its passing sieve percentages are close to the maximums suggested by the standard. In this study, the grading of the fine aggregates provided from Various Researchers was performed using the procedure described in ASTM C 136 and compared and used with the ranges suggested in ASTM C 33 standard. Fig show the comparison between sieved fine aggregates and ASTM C33.

Water and superplasticizer

Drinking water was employed in all concrete mixtures for casting and curing purposes. A polycarboxylate based superplasticizer called P10. was used to achieve the preferable flow. It is used as a green liquid with pH of 7 ± 1 and specific gravity of 1.1 ± 0.02. The maximum chloride is limited to 500 ppm.

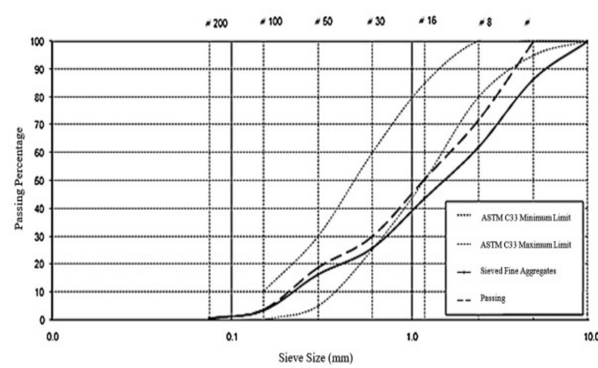
Procedure

As the purpose of this study is to investigate the drying shrinkage cracking of concrete, a self-compacting concrete mix design was employed. Four concrete mixtures were designed by the constant water/binder ratio of 0.37 including one control concrete and three fiber-reinforced concrete specimens with fiber contents of 0.1

Fibers

In order to investigate the effectiveness of using different polypropylene are used in the study. The physical to 0.3 percent (by volume). Following table presents the

Fig. Polypropylene Fiber



proportion and further details of all mixtures. The

preparation stage included the following steps: the initial mixing of coarse and fine aggregates with 25% of the mixture's water for one minute by mechanical mixer, the addition of cement and the remaining mixture's water, mechanically mix forone minute, the addition of fibers, and mechanically mix for two minutes for proper dispersion of fibers. It is important to know that in order to prevent the fibers to form a ball-shaped in the concrete mixture, they should first be mixed with water and then added to the mixture. Then, the fibers should be mixed with water and added progressively to the mixture for 20 s. Several specimens in different kinds and sizes were used, such as forty-eight 150 x300 mm cylindrical specimens, sixteen 75 x75 x285 mm prismatic specimens, and twelve ring model molds. The specimens were cast in two layers, and each layer was vibrated to remove the entrapped air voids using the vibration table. The slump flow test was carried out to evaluate flowability and the horizontal free flow (deformability) of SCC. The diameter of the spreading concrete was measured in two perpendicular directions and recorded as the slump flow. The average diameter in two perpendicular directions should be larger than 600 mm for a plain SCC. However, the final diameters of the concrete were less than 600 mm inasmuch as the mechanical performance of the fresh concrete depends very much on fiber types and dispersion. Therefore, the flowability of mixtures were not as high as conventional SCC without fibers and it was deemed sufficient for practical implementation with a slight vibration. Similar results were reported by Liao et al. [14]. Then, the specimens were kept under the wet blanket for 24 h and then demolded and cured in lime-saturated water at 23 ± 2 degreeC. The curing time for each specimen was in accordance with its testing standard. The volume fractions of fiber were chosen based on mixture characteristics. Mixing of fiber reinforced concrete needs careful conditions to avoid balling of fibers, segregation and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendency. The fiber contents in excess of 0.1-0.3% by volume are difficult to mix.

Concrete Mixture Properties

Mixture Abbreviation	Fiber Type	Fiber Content (Vol%)	Fiber density (kg/m3)	W/C Ratio	fine gravel (kg/m3)	Coarsegravel (kg/m3)	Compressive Strength(Mpa)
PC	-- -			0.37	387	155	42.2
PFRC	Monofilament	0.1 &0.3	0.91	0.37	387	155	46.5
SFRC	Fibrillate	0.3	0.6	0.37	387	155	46.1

Results and discussion:

The addition of a low volume fraction (0.1 – 0.3 %) of PP fibers is helpful to improve the microstructure and restrain the formation and growth of micro cracks in concrete. Moreover, the continuity and integrality of concrete will be improved, and the long-term tensile strength will be developed, which is beneficial to safety and durability of concrete structures. This study also shows that aspect ratio of fiber is an important parameter of fiber reinforcing concrete. Fiber with higher aspect ratio shows better improvement in micro cracksand whiledoing the tests for this study following are the results we considered as the for research.

Table 2. Physical and mechanical properties of the various Polypropylene Fiber.

Sample Type	Length of fiber in mm	Type of Polypropylene Fiber	Diameter (mm)	Aspect Ratio	Tensile Strength (mpa)	Elastic Modulus (GPa)	Failure Strain (%)	Fiber Volume (%)
F1	12	Monofilament	0.22	54.54	450	5.0	18	0.1
F2	19	Monofilament	0.46	89.36	450	5.0	18	0.1
F3	12	Monofilament	0.46	26	480	5.5	19	0.3
F4	12	Fibrillate	0.75	0.16	450	5.0	16	0.3

Effect of fiber aspect ratio on crack control

One of the more important properties of concrete fiber is aspect ratio (length divided per diameter). It is well known documented that fiber in concrete have a bridge effect and very sensitive with size of used material in mixed design. In figure, it can be concluded that with increase in fiber length and decrease in fiber diameter crack width decrease significantly. This due to that with increase in aspect ratio of fiber specific area increase and consequently mechanical entanglement fiber in concrete increased.

Fig. Crack With width in FRC with 0.1% and 0.3% Polypropylene Fiber.

Cracking patterns in both control specimen and concrete with fiber are shown in aboveFig. The difference in cracking width is obvious between these two kinds of restrained concrete. In order to quantify measuring the width cracking, each picture showed which types of fiber used Fig. To rebuild the entire image, the part of images that had overlap were cut and connected to each other along the length of the crack. Each results was used in gray color as an input for image processing. This image showed the crack with white color on a black background. Then, to measure the crack width, perpendicular lines were drawn along the cracks, as shown in above Fig. So, this image helps calculate crack width values in small increments.

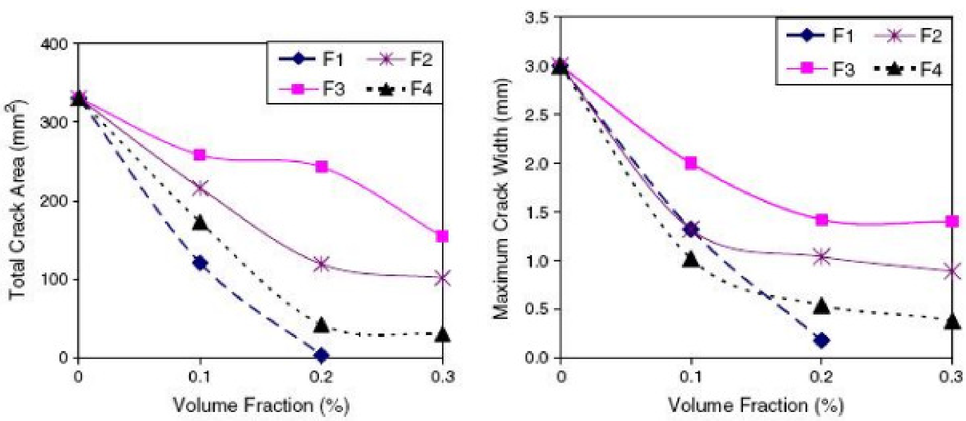
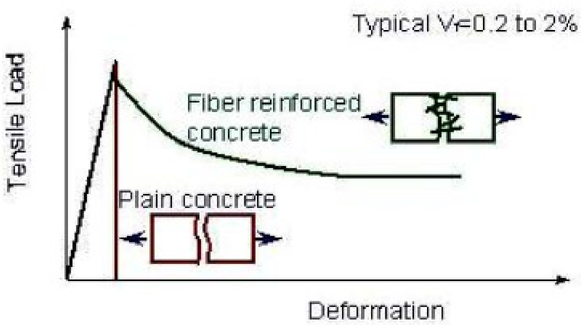


Figure Maximum crack width and total crack area of different samples

Results further indicate that while polypropylene fibers in general are effective in controlling plastic shrinkage cracking in concrete, a finer fiber is generally more effective than a coarser one were more effective than other comparable coarser fibers, and a longer fiber is often more effective than a shorter one. Fibrillated polypropylene fiber at a very low fiber volume of 0.1-0.3% was also an outlier as the effect of this fiber on reducing crack area was lower than the test accuracy (in-batch test variability). Amongst synthetic fibers having the same denier fiber was the most effective, This clearly indicated that a longer fiber of the same denier is more effective. This further implies that polypropylene fibers develop a poor bond with the cementitious matrix at early age and a longer fiber length is necessary for an efficient transfer of stress across a crack. Also a comparison between fiber indicates that a finer denier fiber is more effective than a coarser denier fiber. This is expected as a finer fiber would have a larger surface area over which it would bond with the cementitious matrix and thus result in a greater transfer of tensile stress to the fiber. Also, at a given fiber volume fraction, a finer fiber will have more number of fibers crossing a crack, hence a higher crack growth resistance.

Fiber fibrillations provide an effective mechanical anchorage sufficient to overcome the otherwise poor adhesion between fiber and the matrix. It is also likely that the fibrillated fibers disperse better than their monofilaments counterparts. To study the effect of fiber fibrillation, monofilament fibers were compared to fibrillated fibers. Crack areas for fibers (fibrillated) when compared to monofilament fibers of the same length indicate that fiber was the most effective followed and then Also fibrillated fibers when compared to, indicate that were very similar in reducing the crack area but the reduction in crack area with was marginal. Unfortunately, the length and denier of these fibers was not identical, hence the effect of fibrillation on crack area could not be clearly established. This graph shows tensile load and deformation in the Plain and fiber reinforced Concrete (FRC).

Advantages and Disadvantages of Fiber Reinforced



Concrete.

Fiber reinforced concrete has started to find its place in many areas of civil infrastructure applications where the need for repairing and increased durability arises. According to the result obtained in this study and other research work mentioned in the introduction, it can be concluded that FRCs will be used in civil structures where corrosion can be avoided at the maximum. Fiber reinforced concrete is better suited to minimize cavitation /erosion damage in structures such as sluiceways, navigational locks and bridge piers where high velocity flows are encountered. A substantial weight saving can be realized using relatively thin FRC sections having the equivalent strength of thicker plain concrete sections. When used in bridges it helps to avoid catastrophic failures. Also, in the quake prone areas the use of fiber reinforced concrete would certainly minimize human casualties. In addition, polypropylene fibers reduce or relieve internal forces by blocking microscopic cracks from forming within the concrete.

The main disadvantage associated with fiber reinforced concrete is fabrication. The process of incorporating fibers into the cement matrix is labor intensive and costlier than the production of the plain concrete. In addition, the real advantages gained using FRC overrides this disadvantage.

Conclusion

- The addition of fibers does not seem to have any considerable effect on compressive strength of the concretes. Only a small increase was observed due to the fibers' contribution in tolerating a few percentages of tensile strength under stresses.
- The maximum drying shrinkage strength was highly dependent on fibers' modules of elasticity. In this regard, fibers have the highest module of elasticity in comparison with polypropylene or other types fibers which caused the greatest increase in tensile strength of the concrete before initial cracking.
- In concrete samples with a fiber content of 0.1-0.3 percent (by volume), the maximum restrained drying shrinkage strains were measured equal to 30 micro strains for polypropylene fibers, respectively.
- The physical properties of fibers have direct effects on reducing the cracking width. Polypropylene fibers also showed better performance in preventing crack development due to their longer length and surface serrulation. In concrete samples with polypropylene fiber content of 0.1-0.3 percent (by volume), the average width of cracks was calculated to be 32 percent lower than plain concrete, respectively. By adding the fibers into plain concrete, the cracking was reported to be reduced from 4 to 26 percent.
- Workability is observed to be decreasing with the addition of polypropylene fiber.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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