Special Concretes and Quality Assurance

Utilizing Polypropylene Fibers to Improving Concrete Durability and Cracking Level

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Abstract:

The use of polypropylene fiber to reinforce the mechanical properties of concrete & cement products is an effective method. In this research, the effect of polypropylene (PP) fiber with different weight percent and length on the physical and mechanical properties of concrete is studied. The test result shows that with adding of PP fiber to concrete, plastic shrinkage is properly decreased. The increase of aspect ratio (L/D) of PP fibers improves the capability of fibers to reduce cracks. In addition, the use of the certain amount of PP fibers in concrete mixture leads to intensifying of some mechanical properties and durability parameters while the other mechanical properties of concrete remain almost unchanged.

Keywords: Fiber Concrete, Polypropylene Fiber, Plastic Shrinkage, Mechanical Properties.

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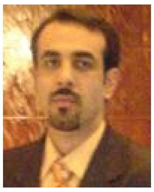

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Introduction

Common concretes have some shortcomings such as shrinkage and cracking, low tensile and flexural strength, poor toughness, high brittleness, low shock resistance and so which restrict their applications. To overcome these deficiencies, additional materials are added to improve the performance of concrete [1].
Fiber reinforced concrete (FRC) is a cement-based composite material that has been developed in recent years. It has been successfully used in construction with its excellent flexural-tensile strength, resistance to splitting, impact resistance and excellent permeability, and frost resistance. It is an effective way to increase toughness, shock resistance, and resistance to plastic shrinkage cracking of mortar.
Several types of fibers, both manmade and natural, have been incorporated into concrete. The use of natural fibers in concrete precedes the advent of conventional reinforced concrete in historical context [2-5]. However, the technical aspects of FRC systems remained essentially undeveloped. Since the advent of the fiber reinforcing of concrete in 1940's, a great deal of testing has been conducted on the various fibrous materials to determine the actual characteristics and advantages for each product.
Fiber reinforced concrete composite properties, such as crack resistance, reinforcement and increase in toughness depend on the mechanical and bonding properties of the fiber and matrix, as well as fibers quantity and distribution within the matrix. In relation to the elastic modulus, fibers are divided into two types, those whose elastic modulus is less than the elastic modulus of the matrix: i.e. cellulose fiber, polypropylene fiber, polyacrylonitrile fiber, etc. and those whose elastic modulus is greater than the elastic modulus of the matrix: i.e. asbestos fibers, glass fiber, steel fiber, carbon fiber, aramid fiber, etc. Many researches have been done to study the feasibility of adding fiber to concrete as an additive and show its advantages. One of the main technological problems is the micro cracking of concrete. The cracking is mainly generated by thermal shrinkage. It appears when the tensile stress developed by shrinkage is greater than the tensile strength of concrete. Fibers control the propagation of cracks primarily and limit the crack width [6]. To reduce the phenomenon of shrinkage and the induced cracking, satisfactory results are obtained by adding fibers.
The objective of this study is to evaluate the physical and mechanical properties of various fiber reinforced concretes, containing polypropylene fibers with different lengths and diameters.

Materials and experimental methods

Ordinary Abyek cement conforming to IS 12269 is used for the concrete mixtures. River sand with a specific gravity of 2.65 (g/cm^3) and fineness modulus of 2.64 (g/cm^3) was used as the fine aggregate. The specification of employed polypropylene fibers for application in concrete is provided in table 1 which is produced by PP Fiber Prod. Co,.
Trial mixtures are prepared to reach the strength of 40 MPa at 28 days, along with a good workability. Table 2 shows the detail of mixture proportions for the study.
The sand, cement, and other additives are primarily mixed in dry form using a pan mixer with 100 kg capacity for 2 minutes. The super plasticizer is mixed with water and is then added to the dry mixture. Fibers are dispersed by hand in the mixture up to 4 minutes to achieve a uniform distribution throughout the concrete.

Contribution of polypropylene fibers to reduction of drying shrinkage crack

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 fibers.

The behavior of FRC under loading can be understood from the figure 1 [7]. The plain concrete structure cracks into two pieces when it is subjected to the peak tensile load and cannot withstand further load or deformation. The fiber reinforced concrete structure cracks at the same peak tensile load, but does not separate and can maintain a load to very large deformations. The area under the curve shows the energy absorbed by the FRCs when it is subjected to tensile load. This can be termed as the post cracking response of the FRCs. The real advantage of adding fibers is when fibers bridge these cracks and undergo pullout processes, such that the deformation can continue only with the further input of energy from the loading source.
For determining the effect of adding fiber to the concrete, tests are carried out using narrow rings of concrete next to rigid steel rings according to the method that used in previous research works [8-10]. An original

process makes it possible to measure the crack widths and follow the extension of cracking. A video camera continuously films the crack created at different levels (top, middle and bottom). Observations begin at the birth of the crack and continue until the end of the test (approximately 4 weeks). Images have the size of 15 mm × 15 mm. They are exploited with an image analysis process. The image is divided into 512 × 512 pixels. After image analysis, the value of changes in sample length and width are measured (table 3). The dimensions of the sample and the measurement setup are shown in figure 2.

If fibers are added to the matrix, free shrinkage decreases. However, this decrease is very large, especially at the early stage, as shown in Table 3. When a crack is formed in fiber-reinforced concrete, fibers that bridge the crack prevent it from opening more. With the action of shrinkage, fibers transmit forces over the crack and thus create tensile stresses along the ring. If loads transmitted by fibers are very small, as for composites containing very low volumes of fibers, then the second crack will not be formed because the tensile stress transmitted over the crack is smaller than the tensile strength of the matrix. When the fiber percentage is increased, more cracks with smaller widths are displayed. Experimental results confirm this tendency. The evolution of cracking with time issued by image analysis for the volume fraction of 0.1% is shown in figure 3. It can be derived that the widest crack width and the total crack width decrease when fibers are added.

Result and discussion

Mechanical properties of fiber concrete

Table 4 shows the result of the strength of fiber reinforced concrete. Fibers added have no influence on 7 and 28 day samples. Excremental bending results show that fiber reinforced samples have higher bending strength than without fiber samples. Figure 4, shows slipping of the polypropylene fiber during the bending test. A little change through the tensile test is observed on samples with 0.3% fiber that is due to contribution of fiber in tensile load before fracture of the samples.

Toughness is based on the total energy absorbed prior to complete failure. The main properties influencing toughness and the maximum loading of fiber reinforced concrete are based on the type of fibers used, volume fraction of the fiber, the aspect ratio and the orientation of the fibers in the matrix.

What should be pointed out is that it is a kind of supplement effect rather than an increasing strength effect when adding a low volume fraction of PP fibers with a low elastic modulus to make the long-term tensile strength of concrete goes up. As the elastic modulus of PP fibers is only one fourth of that of hardened concrete, according to the simple law of mixture, the PP fiber reinforced concrete will lose some strength compared with control concrete[15,16]. From the results of Table 4, we can find that at the early age, the strengths of concretes containing PP fibers are all lower than that of the corresponding concrete with no fibers. However, after 28 days, with the increase of shrinkage and micro-defects of control concrete, the tensile strength sensitive to micro cracks descends. For those concretes containing fibers, due to the anti-cracking effect of PP fibers, which reduce the formation and growth probability of micro cracks, and keep the integrality of concrete, the tensile strength improves synchronously with the hydration process as the compressive strength.

Bending toughness results of sample (area under curve of load – displacement) are shown in table 5. It can be concluded that fiber using in concrete has a significant effect on toughness and its indexes as shown in table 6. Furthermore with increase in fiber length and dosage, energy absorption and toughness indexes improved. Crack width decrease as a result of energy absorption improvement.

By adding the fiber in concrete durability parameter of concrete was improved as it shown in table 6. Also it can be concluded that because o f low concrete density, the effect of fiber length and dosage have no significant effect on the samples.

Effect of fiber aspect ratio on crack control

One of the more important properties of the 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 5, 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.

Advantages and Disadvantages of the Fiber Reinforced Concrete.

Fiber reinforced concrete has started to find its place in many areas of civil infrastructure applications where the need for repairing, increased durability arises. According to the result obtained in this study and other research work mentioned in the literature, 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 sluice-ways, 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 the 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 the 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 by the use of FRC overrides this disadvantage.

Conclusion

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 the fiber is an important parameter of fiber reinforcing concrete. Fiber with higher aspect ratio shows better improvement in micro cracks.

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Table 1. Physical and mechanical properties of the various fibers used

Code	Length (mm)	Type	Diameter (mm)	Aspect ratio	Specific gravity	Tensile strength (MPa)	Elastic modulus (GPa)	Failure strain (%)
F1	12	Monofilament	0.22	54.54	0.91	450	5.0	18
F2	19	Monofilament	0.46	86.36	0.91	450	5.0	18
F3	12	Monofilament	0.46	26	0.91	480	5.5	19
F4	12	Fibrillate	75	0.16	0.91	450	5.0	16

Table 2. Concrete mixture proportions used in the study

Sample code	Cement (kg/m^3)	Water (kg/m^3)	Water-cement percentage (W/C)	Super plasticizer dosage (%)	Fiber	
					Type	Volume fraction % (per 1 m^3)
P0	350	184	0.40	1.35	-	-
P1	350	184	0.40	1.35	F1	0.1
P2	350	184	0.40	1.35	F2	0.1
P3	350	184	0.40	1.35	F3	0.3
P4	350	184	0.40	1.35	F4	0.3

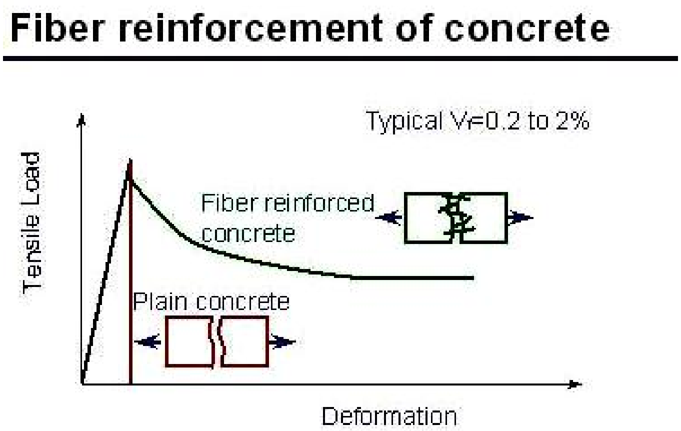

Figure 1. Tensile load versus deformation for plain and fiber reinforced concrete [7].

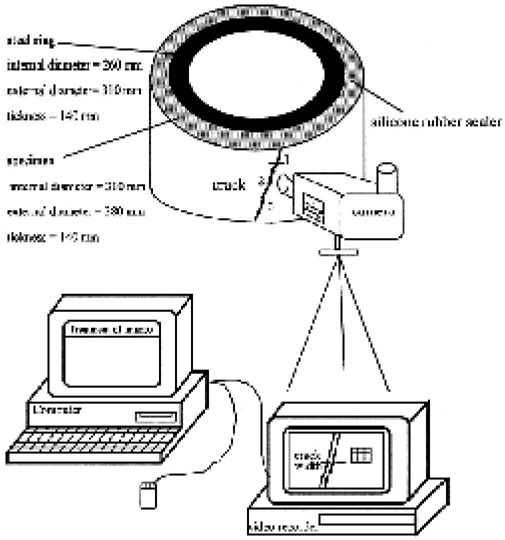

Fig 2. Test setup to measure crack width using image analysis and dimensions of the ring specimen.

Table 3. Value of changes in sample crack width (mm)

Sample Code	crack width (mm)				
	P 0	P 1	P 2	P 3	P4
After 1 day	2.92	0.84	0.84	0.86	0.83
After 2 day	3.52	1.54	1.86	1.90	1.65
After 3 day	3.94	1.72	2.28	2.34	1.94
After 7 day	4.66	2.80	3.54	3.73	2.95
After 14 day	7.54	5.48	5.32	4.38	5.2
After 28 day	8.78	5.56	5.58	5.18	5.7

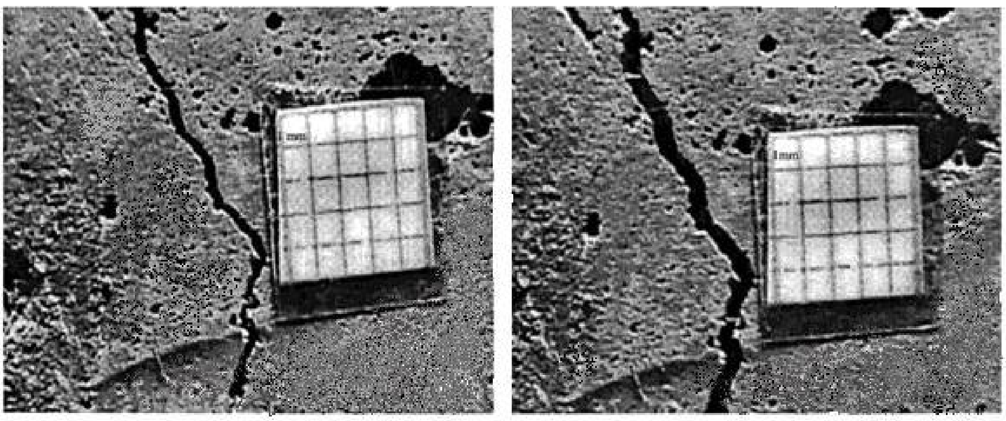

Fig. 3. Crack width in FRC with 0.1% and 0.3% polypropylene fiber.

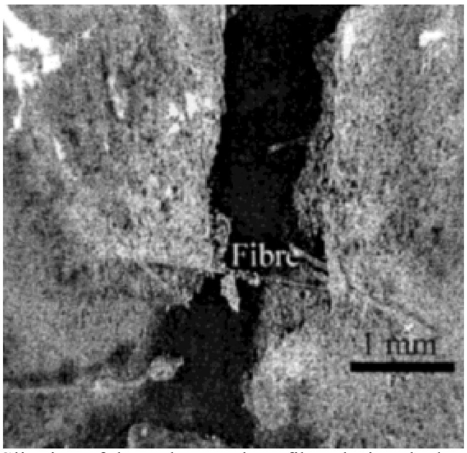

Figure 4. Slipping of the polypropylene fiber during the bending test.

Table 4. Result of fiber reinforced concrete strength

Samples Code / Strength Properties (MPa)	P 3	P 2	P 1	P 0
Compression (7 days)	38.4	41.7	42.3	39.4
Compression (28 Days)	49.3	51.6	51.8	49.0
Tensile (Brazilian)	11.0	10.0	10.0	9.5
Bending	9.7	8.9	9.2	8.7

Table 5 . toughness indexes of samples

Samples code / Toughness Indexes	P 3	P 2	P 1	P 0
Bending Toughness (kg.m)	2.53	2.31	1.22	.73
toughness index I_5	1.25	1.28	1.29	-
toughness index I_{10}	1.47	1.52	-	-
toughness index I_{20}	1.68	-	-	-

Table 6. durability parameter of the samples

Samples Code / durability parameter	P 0	P 1	P 2	P 3
water infusion (mm)	14.2	14	13.5	13.4
Air permeability (m^2)	6.58	6.60	6.50	6.48

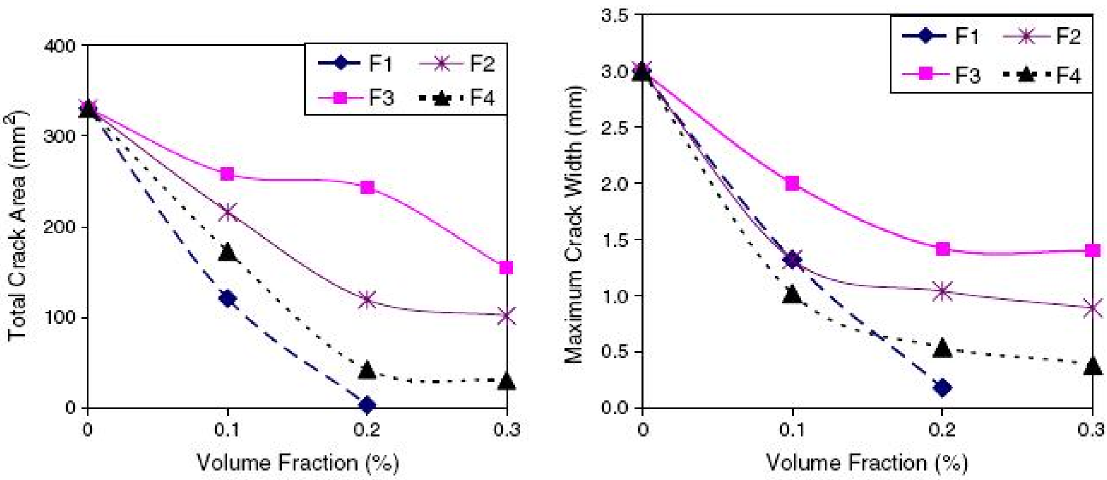

Figure 5. Maximum crack width and total crack area of different samples