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Original Article/Research

Evaluating plastic shrinkage and permeability of polypropylene fiber reinforced concrete

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Abstract

Plastic concrete is susceptible to develop cracks due to shrinkage in dry and windy conditions. Addition of fibers could reduce propagation of this crack. On the other hand, permeability determines the durability properties of concrete. This study evaluated strength, plastic shrinkage and permeability (gas and water) of concrete incorporating 'polypropylene' fiber (aspect ratio 300) in various proportions (viz. 0.10%, 0.15%, 0.2%, 0.25% and 0.3%) by volume of concrete. Plane concrete samples were also prepared and tested for reference purpose. Inclusion of 0.1% fiber gave minor reduction (2%) in compressive strength while the tensile strength increased by 39% with same fiber content compared to the plain concrete. A significant reduction in crack generation, appearance period of first crack and crack area between plane concrete and fiber reinforced concretes was found. The experimental result with inclusion of 0.1–0.3% fiber in concrete indicated that plastic shrinkage cracks were reduced by 50–99% compared to the plain concrete. For reference concrete (without fiber), test within the high temperature and controlled humidity chamber gave higher crack width than the acceptable limit (3 mm) specified by the ACI 224. With the inclusion of 0.1% fiber reduced the crack width down to 1 mm and the trend was continued with the addition of more fibers. However, results showed that with the addition of polypropylene fiber both water and gas permeability coefficient was increased. Therefore, it is concluded that the fiber reinforced concrete would work better for plastic shrinkage susceptible structural elements (flat elements such as slab); however, it requires careful judgement while applying to a water retaining structures.

Keywords: Fiber reinforced concrete; Plastic shrinkage; Water permeability; Gas permeability; Polypropylene fiber

1. Introduction

Plain, unreinforced cement concrete is a brittle material with a low tensile strength capacity but strong in compression (Nilson et al., 2012; Nemati, 2013). The weaknesses sometimes limit its use. Another fundamental weakness of concrete is that cracks start to form as soon as concrete is placed and before it has properly hardened. These cracks are a major cause of weakness in concrete particularly in large onsite applications leading to subsequent fracture and failure and general lack of durability (Sivakumar and Santhanam, 2007). The weakness in tension can be overcome by the use of conventional reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers (Ahmed et al., 2006).

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Plastic shrinkage is the contraction of the concrete due to water evaporation from the mixture. This causes the concrete to weaken and can lead to cracks, internal warping and external deflection (Ahmed et al., 2006; Sivakumar and Santhanam, 2007). Concrete shrinkage could be challenging during construction, especially for the flat structural elements for example the floors and slabs (Pietro, 2011). Three-dimensional volume changes in fresh concrete occur primarily due to rapid loss of surface bleed water on evaporation. These results in the rapid drawdown in pore water level, causing an increase in pore water pressure, which tends to bring the neighboring solid particles closer. All this leads to shrinking of cement paste; the restraint offered by aggregates leads to cracking on the surface of fresh concrete (Sivakumar and Santhanam, 2007). Plastic shrinkage cracks are typically observed in thin concrete elements with a high surface area to volume ratio (Rouhi et al., 2011). Fresh concrete is susceptible to plastic shrinkage cracking especially during hot, windy, and dry weather conditions (NRMCA, 2015). If the evaporation rate becomes significantly higher than bleeding rate, it can cause high tensile stresses to develop in the capillary pores in the surface zone of concrete that may be sufficient to exceed the tensile strength of concrete, especially at early ages (Pietro, 2011). In case of the surface cracks that develop as a result of plastic shrinkage remain unnoticed, they become channels for passage of external deteriorating agents and reduce long-term durability (Pietro, 2011). Precautions against plastic shrinkage cracking include preventing rapid drying of the surface of concrete and adopting good curing practices. Besides these, the use of fibers as a secondary reinforcing mechanism can help in mitigating the stresses developed upon drying (Ramujee, 2013). The addition of non-metallic fiber (polypropylene) has been reported to provide adequate tensile strength to concrete in addition to controlling shrinkage cracks (Sivakumar and Santhanam, 2007).

Permeability refers to the amount of water migration through concrete when the water is under pressure, and also to the ability of concrete to resist penetration of any substance, be it a liquid, gas, or chloride ion (Chen et al., 2001; Ahmed et al., 2006). This plays an important role in durability because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during heating or freezing (Desmettre and Charron, 2012). Therefore, higher the permeability lesser will be the durability (Miloud, 2005). Permeability of concrete is of interest also in relation to the water-tightness of liquid-retaining structures (Hoseini et al., 2009). The permeability of concrete is a function of the permeability of the paste (cement and water), and gradation of the aggregate, and the relative proportion of paste to aggregate (Roy, 2012). Decreased permeability improves concrete's resistance to re-saturation, sulfate and other chemical attack, and chloride ion penetration (Miloud, 2005).

A low-permeability concrete requires a low w/c ratio and adequate moist-curing (Yi et al., 2011). However, as is the case with water flowing through the porous medium, the internal pore structure of concrete is assumed to play an influential role on gas flow. Therefore, the size and volume of capillary pores and their continuity are important (Ahmed et al., 2006). These in turn are controlled primarily by water-cement ratio and degree of hydration. Micro-cracks present in concrete are also considered to offer additional passages for the flow of gas, resulting in an increased of gas permeability. In addition to the geometrical characteristic of the microstructure of concrete, moisture conditions in the pores are important with respect to the gas permeability of concrete. Free capillary water that will first evaporate by ordinary drying has a pronounced influence on the flow of gas in concrete. Water-saturated concrete has virtually zero permeability of gas when measured by a pressure-induced gas method. Gas permeability increases with the progressive drying of the concrete (Sugiyama et al., 1996).

The research experimentally deals with the effects of polypropylene fiber inclusion on two important properties of concrete viz. plastic shrinkage and permeability (both water and gas under pressure). Corresponding effect on concrete strengths (compressive and tensile) are measured and discussed in this paper.

2. Materials and methods

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement with strength class 52.5 N was used. The percentage of clinker and gypsum in the cement was 95–100% and 0–5%, respectively while the specific gravity was found to be 3.15.

2.1.2. Superplasticizer

Retarding superplasticizer based on polycarboxylic ether was used as an admixture. This is commercially available in liquid form and dispensed into the concrete mixing water before adding it into the mix. Properties of admixture are given in Table 1.

2.1.3. Aggregate

Coarse sand was used as fine aggregate while crushed stone chips conforming to ASTM C33 was used as coarse aggregate. Both aggregates were obtained from Sylhet region of Bangladesh. Physical properties of aggregates

Table 1
Properties of superplasticizer.

Aspect	Light Brown liquid
Relative density	1.08 ± 0.01 at 25 °C
pH	$\geqslant 6$
Chloride ion content	<0.2%
Expected water reduction, (%)	>20
Conforming standards	ASTM C-494, EN 934-2, IS 9103

are shown in Table 2. Sieve analysis of coarse aggregate was conducted. A 20 mm nominal size stone chips was used for experimental work. Gradation of which was conformed to the recommendation in ASTM C33.

2.1.4. Fiber

Non-metallic fiber (polypropylene) was used for reinforcing and crack-resisting in concrete. According to the manufacturers, the material is resistant to high temperature, corrosion. It also gives high strength, chemical stability. The fiber content varied from 0.1% to 0.3% by volume. Properties of the fiber are given in Table 3.

2.2. Concrete mix proportions

Trial mixtures were prepared to obtain target strength of 35 MPa (at 28 days) with target slump value of 75–100 mm. In order to obtain the desired workability, only the superplasticizer dosage was varied during mixing with different proportions of fibers. Concrete mix design was conducted as per American Concrete Institute (ACI 211, 2009). The detailed mix proportions of constituent materials (SSD condition where applicable) to produce concretes, used for the study are presented in Table 4.

2.3. Concrete mixing, casting and curing

A total of eighteen plains concrete (12 for compression and split tensile strength test, 6 for gas and water permeability tests) and seventy-two fiber reinforced mixes were prepared. Concrete was mixed using a machine mixer. For every trial mix a 40 liter volume was considered. An appropriate quantity of coarse aggregate (SSD), fine aggregates (SSD) and cement, were first dry mixed for a period of 2 minutes. The superplasticizer was then mixed thoroughly with the mixing water and added to the mixer. Fibers were dispersed in the mixture to achieve a uniform distribution throughout the concrete, which was mixed for a total of 4 min. After mixing, the workability of concrete was determined using slump cone.

To perform the strength and permeability tests 150 mm cube specimens were prepared. The molds used for the purpose are fabricated with steel seat. Molds are having smooth base plates to support and are filled without leakage. Thin coat of mold oil is used in assembling the mold joints and between the sections of the mold. Similar coating of mold oil is applied between the contact faces of mold and the base plate to ensure that no water escape during filling. The interior surfaces of the assembled mold shall be thinly coated with mold oil to prevent adhesion of concrete. The concrete was placed in the mold and tamping is done using a standard rod. A smooth steel trowel was used to finish the fresh concrete surface. After casting, the samples were kept in mold for 24 h in an ambient temperature by covering with wet Hossain bag. After 24 h the specimens were removed from the molds and immediately submerged in clean fresh water to cure for 7 days and 28 days for strength test and 28 days for permeability tests.

Table 2
Physical properties of aggregates.

Property	Sand	Stone Chips
Bulk specific gravity (OD basis)	2.54	2.66
Absorption capacity (%)	1.34	0.69
Fineness modulus (FM)	2.62	–
Dry rodded unit weight (kg/m^3)	1590	1550

Table 3
Properties of the fibers used in the experimental works (JIATAI, 2015).

Length (mm)	6 ± 1
Diameter (μm)	20 ± 5
Aspect ratio (l/d)	300
Density (g/cm^3)	1.36–1.38
Elongation at break (%)	⩾15
Tensile strength (MPa)	⩾500
Color	Natural white
Materials form	Polyester
Type of the fiber	Monofilament
Recommend adding amount	0.2–0.3% of mixes

2.4. Concrete strength testing

Concrete compressive strength was determined in cube specimens were determined following EN 12390-3 (2009) while the split tensile strength was determined as per EN 12390-6 (2000). The tensile splitting strength is given by the formula:

$$f_{ct} = \frac{2F}{\pi L d} \tag{1}$$

where, f_{ct} is the tensile splitting strength, in MPa or N/mm^2; F is the maximum load, in Newtons; L is the length of the line of contact of the specimen, in millimeters; d is the designated cross-sectional dimension, in millimeters.

2.5. Shrinkage testing

Shrinkage test was carried out according to ASTM C490. In this regard a total of three plain concrete and fifteen fiber reinforced mixes were prepared. The slab specimen mold of dimension 500 × 250 × 75 mm was prepared (Fig. 1a). A thin polyethylene sheet was placed over the base to eliminate base friction between the concrete and base. After mixing, the concrete was poured into the slab mold and exposed to a specific environment comprising of constant temperature of 35 ± 1 °C (Fig. 1b), a relative humidity of 60 ± 1% in a controlled chamber. The slabs were then checked visually for any signs of cracking at approximately 30-min intervals and image was captured. The slabs (inside the molds) were kept in this environment for 24 h. The time of occurrence of first crack was noted for

Table 4
Concrete mix proportions used in the study.

MIX	Water (kg/m^3)	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Superplasticizer (kg/m^3)	Fiber content	
						(kg/m^3)	%
F_1	150	440	1000	735	3.30	0.0	0
F_2	145	440	1000	735	3.96	2.30	0.1
F_3	148	440	1000	735	3.96	3.50	0.15
F_4	150	440	1000	735	3.96	4.65	0.2
F_5	154	440	1000	735	3.96	5.80	0.25
F_6	156	440	1000	735	3.96	7.00	0.3

all slabs during the experimental work (Gupta and Islam, 2014).

2.6. Permeability testing

To evaluate the liquid and gas incorporation and consequent possible deterioration of the concrete, permeability (both water and gas) was measured on hardened specimens according to EN 12390-08 (2009). For the permeability test 150 mm cube specimen was used. The specimen tested for permeability was cured for 28 days before measurement. Experimental set up for both water and gas permeability test was shown in Fig. 2.

2.6.1. Water permeability test in harden concrete

After placing the concrete specimen in the permeability testing apparatus a water pressure of (500 ± 50) kPa for (48 ± 2) hours were applied. After applying the pressure for the specified time, the specimen was removed from the apparatus. The specimen was then split in half, perpendicularly to the face on which the water pressure was applied. As soon as the split face has dried to such an extent that the water penetration front can be clearly seen, the water front on the specimen was marked. The maximum depth of penetration under the test area was recorded to the nearest mm. Then using the test data water permeability co-efficient was measured. To measure the coefficient of water permeability by flow, the Darcy's Law (given in Eq. (2)) was applied as the flow is continuous.

$$K = \frac{QX}{Ah} \tag{2}$$

where, Q is the volume flow rate given in (m^3/s); A is the cross-sectional area of the test specimen in (m^2); h is the head of water given in (m); X is the specimen thickness in the direction of flow or depth of penetration (m); K is the water permeability co-efficient (m/s).

2.6.2. Gas permeability test in harden concrete

The test rig used to measure gas permeability illustrated in Fig. 2(c). It is an apparatus which measures gas flow in core concrete and it has mainly three components:

- a confining pressure unit (bar), which is applied to core concrete at a given pressure;
- pore pressure unit, which directly give the pore pressure in 'psi' of a core concrete for a given confining pressure; and
- gas flow rate, which directly give the gas flow in 'Normal cubic centimeters per minutes' (Ncc/min) of a core concrete for a given confining pressure.

For the gas permeability test, 150 mm cubic specimen was used and the specimen was cured for 28 days. After 28 days, the sample was first split into two parts in concrete

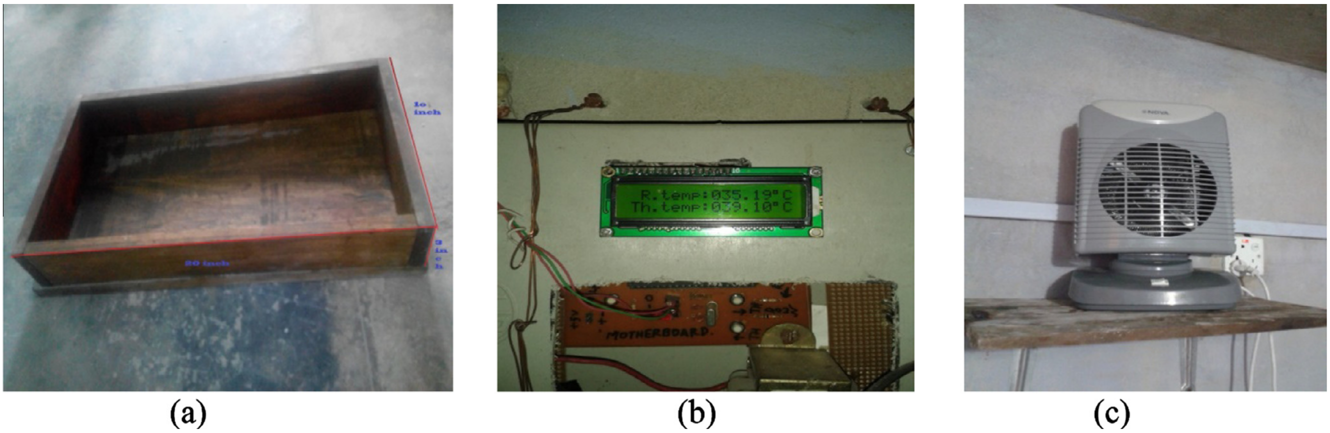
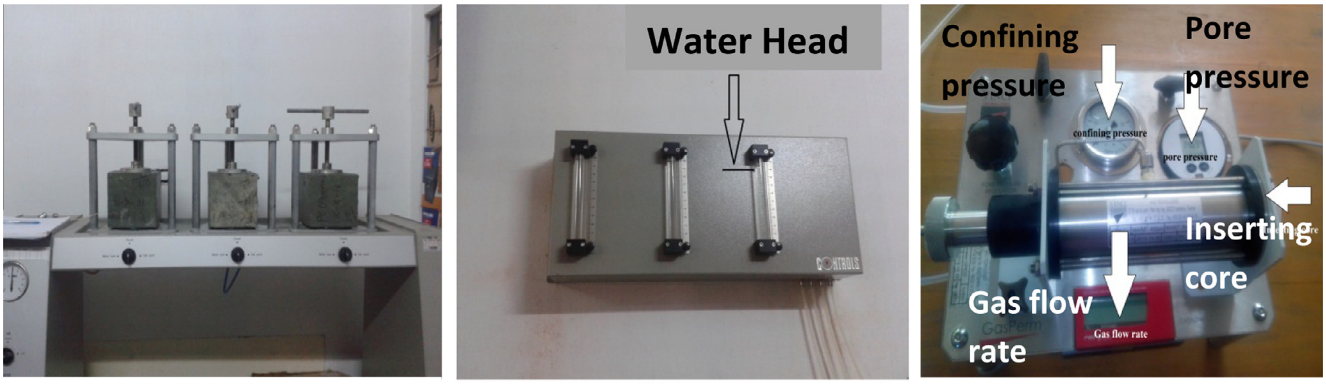


Figure 1. (a) Slab mold 500 × 250 × 75 mm; (b) Environmental chamber; temperature control arrangement; and (c) Heater fan to control the temperature.



(a) (b) (c)

Figure 2. (a) Water permeability testing apparatus (b) water flow rate measurement through the concrete specimen (c) gas permeability testing apparatus.

cutting machine. After splitting, the one part of split sample was brought into core plugging machine to get concrete core sample. The size of the cored sample was Ø25 × 75 mm. Then the core sample was trimmed using trimming machine to get desired concrete core sample. Finally, using gas permeability testing apparatus gas coefficient of permeability was measured directly by catalog excel sheet which give the value in 'mili-darcy'. The overall testing procedure is shown in Fig. 3.

3. Result and discussion

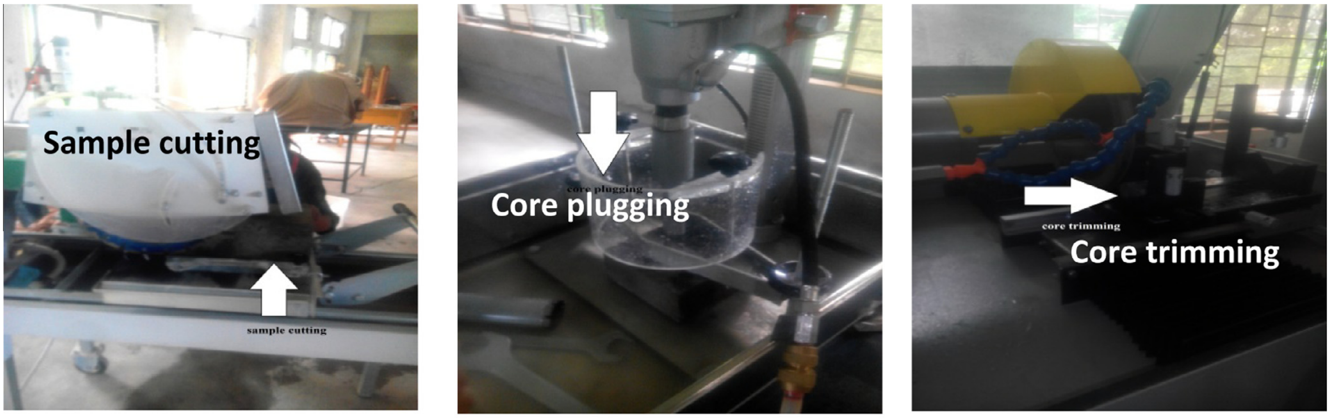
3.1. Compressive strength

Concrete compressive strength data compared to those of other research papers are given in Table 5. With the allowance suggested in ACI 211 (2009), the target mean strength for laboratory was set to 43.5 MPa. Relationship between the polypropylene fiber content and corresponding 28 day concrete compressive strength with respect to the control concrete is shown in Fig. 4.

Addition of the polypropylene fiber in the concrete mix has a little effect on its compressive strength. With increasing fiber content, compressive strength of concrete decreased slightly. The addition of fiber creates more Interfacial Transition Zone (ITZ) in concrete which might affect the compressive strength. A maximum of 10% reduction in compressive strength (with respect to the control concrete) was noted with addition of 0.3% volume of fibers in the concrete. Study with binary combination of steel (0.8% fixed) and polypropylene fiber (0–0.4%) showed reduction in compressive strength after polypropylene fiber amounting more than 0.2% (shown in Table 5; Parveen and Sharma, 2013). But the compressive strength of concrete increased up to 0.2% addition of polypropylene fibers. The increase in the compressive strength (up to 0.2% polypropylene fiber with 0.8% steel fiber) might cause by the effect of steel fibers.

3.2. Tensile strength

Concrete tensile split strength test results are given in Table 6. Relationship between the polypropylene fiber content and corresponding concrete tensile split strength with respect to the control concrete are shown in Fig. 5. It is observed that, addition of polypropylene fibers to a



(a) (b) (c)

Figure 3. (a) concrete cutting machine (b) core plugging machine (c) core trimming machine.

Table 5
Compressive Strength characteristics of fiber reinforced concrete.

Concrete Mix	Compressive strength at 28 days (MPa)	Polypropylene fiber + 0.8% steel fiber *	Compressive strength (MPa) after 28 days
F_1	44.8	0%	39.82
F_2	44.0	0% + 0.8%	40.50
F_3	43.4	0.1% + 0.8%	40.90
F_4	42.3	0.2% + 0.8%	42.82
F_5	41.5	0.3% + 0.8%	40.02
F_6	40.3	0.4% + 0.8%	39.58

* Parveen and Sharma, 2013

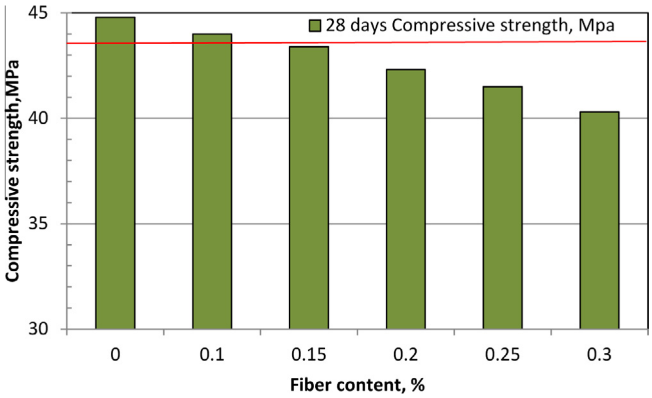


Figure 4. Variation in compressive strength of concrete with fiber content.

concrete mixture is beneficial to the tensile properties of concrete. The fibers act as crack arresters in the concrete matrix. Tensile splitting strength of concrete was found more than the control (0% fiber) concrete with fiber addition up to about 0.25% above which the tensile strength was found lower than the control concrete.

The 28 day split tensile strength increases about 10–39% with up to 0.25% fiber addition. Best result achieved for 0.1% fiber addition and approximately 39% increase in the tensile splitting strength was noted. With addition of higher volume of fibers though the tensile strength of concrete was decreased slightly, it was remained comparable with the control concrete up to fiber volume addition of 0.25%. Related research shows that polypropylene fiber with the combination of steel fiber (0.8%) increases the split tensile strength of concrete when the polypropylene fibers addition up to 0.3% and then reduction in split tensile strength is also observed. Strength increase up to 60% occurs when the percentage of polypropylene fiber addition was up to 0.3%. Beyond 0.3% fiber addition decrease in split tensile strength is observed.

Table 6
Split tensile Strength characteristics of fiber reinforced concretes.

Concrete mix	Tensile splitting strength at 28 days (MPa)	Polypropylene fiber + 0.8% steel fiber *	Tensile strength (MPa) at 28 days
F_1	3.03	0%	3.10
F_2	4.20	0% + 0.8%	3.15
F_3	3.93	0.1% + 0.8%	3.72
F_4	3.58	0.2% + 0.8%	4.09
F_5	3.06	0.3% + 0.8%	4.95
F_6	2.69	0.4% + 0.8%	3.85

* Parveen and Sharma, 2013

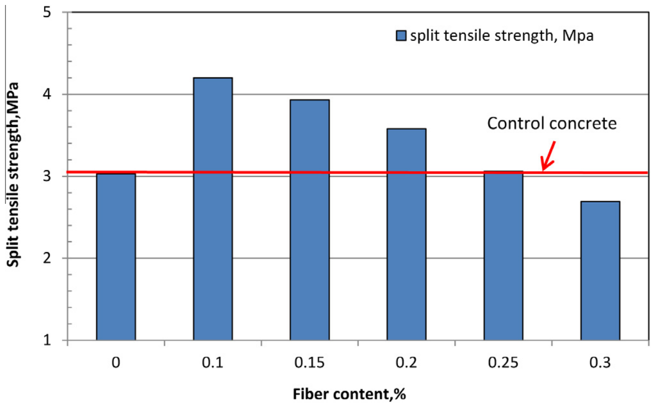


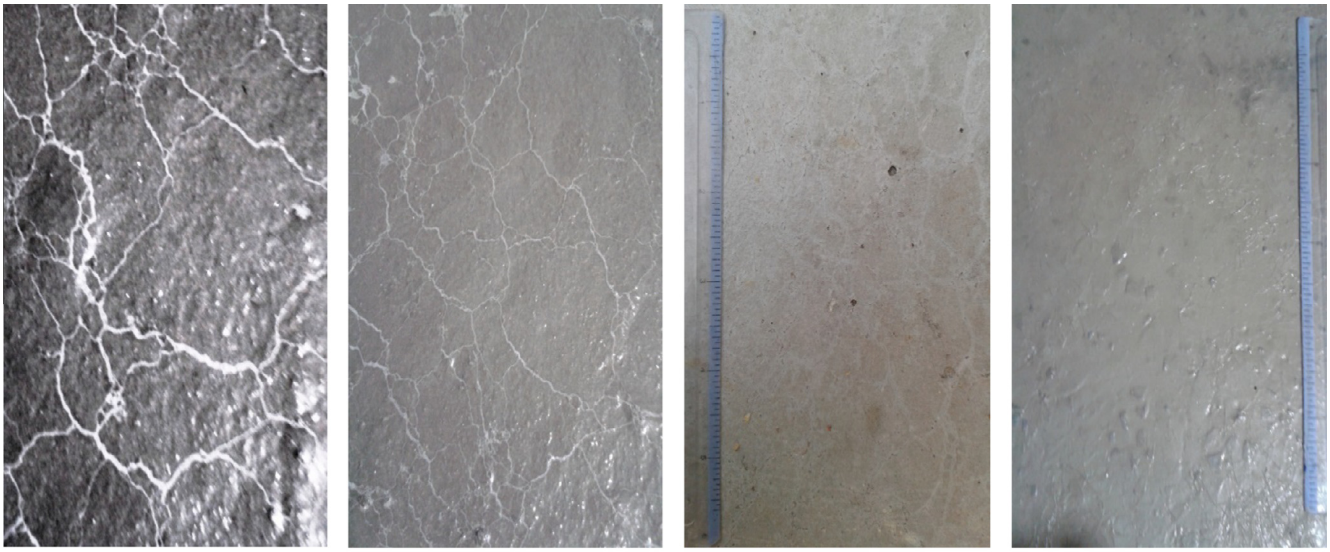
Figure 5. Variation in tensile splitting strength of concrete with fiber content.

3.3. Shrinkage tests

As soon as the specimens were prepared, those were placed in the controlled temperature and humidity chamber and observed periodically. For control concrete, approximately after 150 min (since water was added), a fine hairline crack was observed running throughout the width of the slab. This fine crack, which could have possibly been caused due to settlement, was found to widen upon further drying. In case of fiber reinforced concrete specimens, the appearance of the first crack took as long as more than 7 h. The appearance period for fiber reinforced concrete was thus 3-time longer than plain concrete. Samples of shrinkage cracked concrete are shown in Fig. 6. These phenomena could be attributed to the availability of bleed water on the top surface, which delays drying of the surface and possible reinforcing the concrete by the polypropylene fiber. In case of F6 concrete (Fig. 6d) no crack was visible.

Images of the cracks were captured using an optical zoom camera. Subsequently, the captured images were processed and edited with image analysis software to get a clear crack profile. The captured images were printed and cracks were drawn using tracing paper. After that, the tracing papers in which cracks were drawn were scanned. Then the scanned images were edited with suitable computer software to remove noise. The images were then analyzed by computer image analysis software to quantify the percentage area cracked. Crack measurements comprise of the crack width (average) and percentage of total crack area. Example images after the processing operations are given in Fig. 7.

The edited image was then analyzed and percentage of total crack was also estimated using image 'J' computer



(a) F1 (0% fiber) (b) F2 (0.1% fiber) (c) F4 (0.2% fiber) (d) F6 (0.3% fiber)

Figure 6. Shrinkage crack in concrete slabs (area covered 6.0″ × 4.5″).

(a) F1 (0% fiber) (b) F2 (0.1% fiber) (c) F3 (0.15% fiber) (d) F4 (0.2% fiber)

Figure 7. Shrinkage crack in concrete slabs 150 × 90 mm (drawn in tracing paper from printed image).

software. A picture of overall procedure is shown in Fig. 8. The results obtained from image analysis are shown Table 7 and Fig. 9.

The percentage of crack decreases with addition of fiber as shown in Fig 9(a). Using about 0.30% fiber (by volume) literally no plastic shrinkage cracks was observed. With the addition of 0.10–0.25% fibers, visibly restrained the crack width compared to control sample (shown in Fig. 9b). The crack width reduced by 72–93% with the addition of fiber up to 0.25%. The shrinkage cracking is reduced by 50–99% by addition of fibers up to 0.30%. According to the recommendation of ACI 224 (2007) the plastic shrinkage crack width should be within 3 mm. Though this was not satisfied for the control concrete (Fig. 9b), with the addition of fiber these criteria were also satisfied. In general fiber could act as crack-bridge and therefore, contribute against shrinkage cracking occurrence. Sivakumar and Santhanam (2007) studied shrinkage characteristics of 0.5% fiber (combination of steel and polypropylene) reinforced concrete and found reduction in plastic shrinkage crack ranging between 49% and 99%. It was also observed that polypropylene fiber addition was more effective than steel fiber against shrinkage cracking.

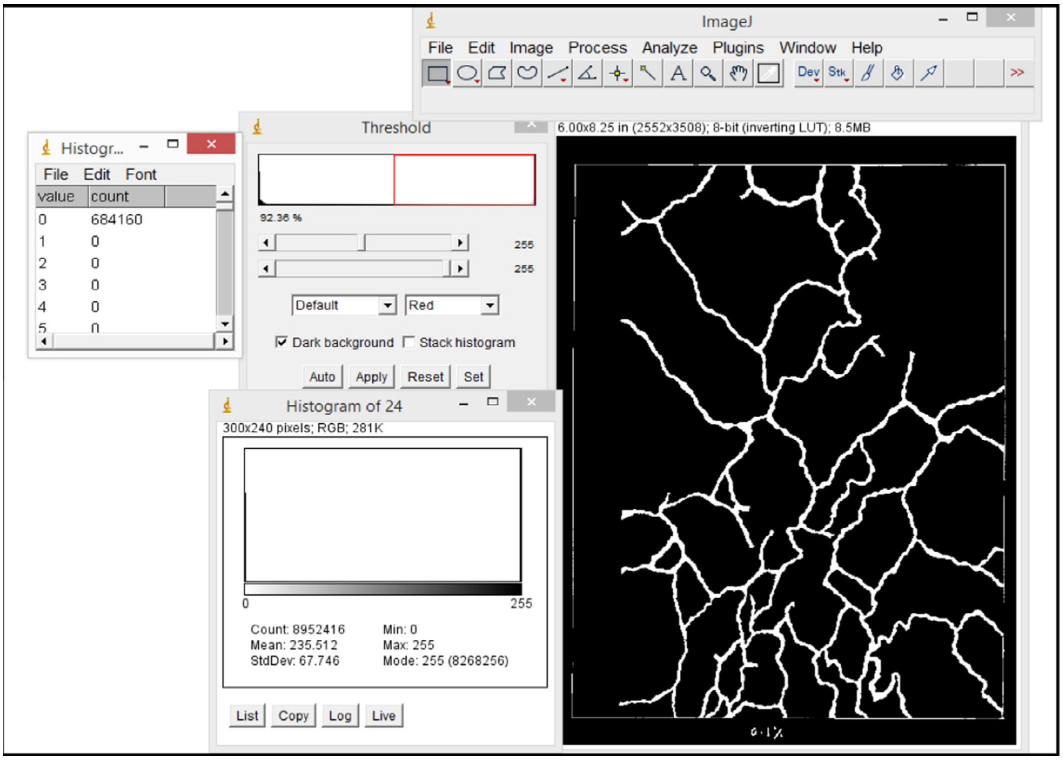


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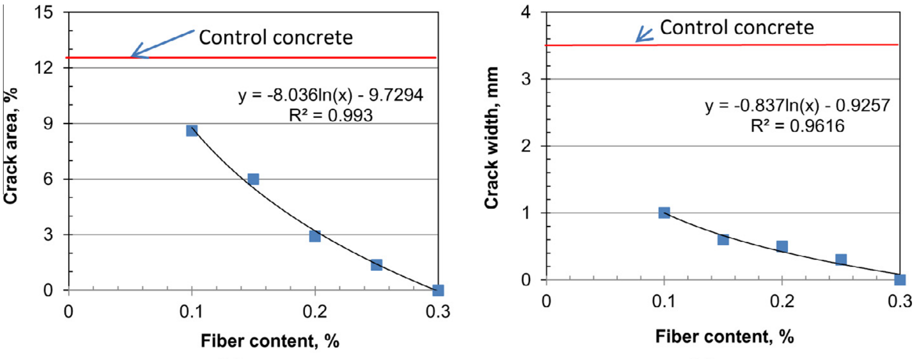
Figure 8. Image analysis for shrinkage crack (control concrete specimen).

Table 7
Crack characteristics of fiber reinforced concretes.

Type of concrete	Total crack (%)	Avg. crack width (mm)	Reduction of crack (%)	Polypropylene fiber + steel fiber*	Reduction of crack (%)*
F_1	12.39	3.5	–	0%	–
F_2	8.60	1.0	31.58	0% + 0.5%	48.58
F_3	5.98	0.6	52.75	0.12% + 0.38%	60.41
F_4	2.90	0.5	77.59	0.25% + 0.25%	78.05
F_5	1.37	0.3	90.86	0.38% + 0.12%	89.21
F_6	0.0	0.0	100	0.5% + 0%	99.87

[*] Sivakumar and Santhanam (2007).



(a) (b)

Figure 9. Relationship between fiber content and (a) percentage of crack; and (b) crack width of concrete.

Table 8
Permeability characteristics of fiber reinforced concretes.

Type of concrete	Water permeability coefficient ($k_w \times 10^{-12}$) m/s	Gas permeability coefficient ($k_g \times 0^{-10}$) m^2
F_1	5.94	47.92
F_4	14.89	49.30
F_5	24.19	76.71
F_6	30.65	181.03

Figure 10. Waterfront penetration depth on splited cube after permeability test.

3.4. Permeability tests

Water and gas permeability tests were performed for plain concrete and fiber reinforced concrete (fiber content 0.2%, 0.25%, 0.3%) for which the results are given in Table 8. In general, inclusion of polypropylene fiber increases both water and gas permeability of concrete. The water permeability coefficient of a plain concrete was 5.94×10^{-12} m/s while with the addition of 0.2% fiber this increased to 14.88×10^{-12} m/s and this continued to increase with fiber content up to 0.3%. A sample photograph of water penetration front in concrete is given in Fig. 10. To calculate the penetration depth, an average of 10 measurements was considered. On the other hand, gas permeability coefficient (k_g) for plain concrete was found to be 47.92×10^{-10} m^2 which increased by 60% with the addition of fiber up to 0.25%. Further increase in fiber content (0.3%) the gas permeability increased excessively. As mentioned earlier the fiber may increase ITZ and can act as a bridge between pores which might increase the water and gas permeability coefficients. This research considered a minimum of 0.2% fiber content for permeability test. Further study can be carried out with 0.1% and 0.15% fiber content to check optimum fiber content in relation to other concrete parameters tested such as strength and shrinkage. Earlier researches (Singh and Singhal, 2011; Miloud, 2005) show that the permeability of concrete remains similar order with the inclusion of steel fibers (0–0.4%) compared to the current research with polypropylene fibers. Being relatively rigid in nature the steel fiber may act similar to the other ingredients of concrete which might not be applicable for polypropylene fibers.

4. Conclusion

This paper reported experimental results of plastic shrinkage crack and permeability (both gas and water) of concrete incorporating of 'Polypropylene' fiber. The following conclusions can be drawn from the results discussed earlier:

- With the addition of polypropylene fiber (0.1–0.3%) the compressive strength of the concrete decreased by 2–10% which is minor compared to the control concrete. The optimum fiber content for the compressive strength is 0.1% for which reduction of compressive strength of this content is about 2%.
- Maximum effect (39% increase) on tensile strength was noted with 0.1% fiber inclusion and with the increase in fiber content the strength was gradually decreased. However, the result was higher than that obtained for control concrete up to fiber content 0.25%.
- Plastic shrinkage cracks were reduced by 50–99% compared to the control concrete by addition of 0.1–0.3% fiber.
- With an increase in the non-metallic fiber (polypropylene) content, the crack width significantly reduced by 72–93% for up to 0.25% fiber and cracks almost eliminated with 0.3% fiber addition. While the crack with of plain control concrete was above the recommended limit, addition of fiber reduced the width within the acceptable limit (3 mm) specified by the ACI 224 (2007).
- With the addition of polypropylene fiber both water and gas permeability coefficients were increased. This might suggest restricting the use of polypropylene fiber content in the case of structural elements exposed to water (such as water tanks, dams, spillways, swimming pools) and harmful gases. Further work can be carried out with 0.1% and 0.15% polypropylene fiber to examine the optimum fiber content with respect to permeability characteristics of concrete.
- In general, inclusion of 0.1% polypropylene fiber was found to be beneficial for concrete considering compressive (2% reduction) and tensile (39% increase) strengths and shrinkage (50% crack reduction and 32% crack with reduction) properties of concrete under this study.

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