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Suitability of Concrete Reinforced with Synthetic Fiber for the Construction of Pavements

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ABSTRACT

Shrinkage cracking of concrete is a major problem in plain cement concrete pavements especially in tropical regions. To overcome shrinkage cracking of plain concrete, sometimes the addition of synthetic fiber to the concrete mix is suggested. This paper briefly discusses the effects of addition of polypropylene discrete and fibrillated fibre on the properties of a paving grade concrete mix of 48 MPa compressive strength at 28-day. Six concrete mixes with fiber dosages 0.05%, 0.10% and 0.15% by volume fraction besides the control concrete mix were manufactured. Discrete and fibrillated polypropylene fiber was used in this study. The properties such as settlement, compressive strength, drying shrinkage, and abrasion resistance of the concrete were evaluated. The study suggested a significant reduction in settlement and drying shrinkage without significant change in compressive strength for the concrete mixes reinforced with fiber. Further, an improved abrasion resistance for the concrete mixes reinforced with fiber was also observed.

Keywords: Concrete; synthetic fiber; drying **s**hrinkage; settlement; abrasion resistance.

INTRODUCTION

Plain portland cement concrete exhibits brittle behavior. Consequently, the material possesses a low tensile strength as well as a low tensile strain capability. Concrete is prone to have numerous micro- and macro-cracks during its setting and hardening process. Use of synthetic fiber in concrete has been advocated by several researchers (Bentur and Mindess, 2007; Balaguru and Shah, 1992; Banthia and Gupta 2006; Kumar et al, 2012; ACI Committee 544, 1982) for improving some specific properties of the concrete. Thoroughly mixed and dispersed microfibers are effective in reducing plastic shrinkage cracking as they delay the process by which the micro cracks coalesce to form large, macroscopic cracks known as macro cracks (Lawler et al, 2002). In this way, the addition of synthetic fibers modifies the properties of concrete matrix. Polypropylene (PP) fiber is widely used for this purpose in the construction industry (Zollo, 1984). The effect of fibers on the properties of concrete varies depending on their type, length, aspect ratio, concrete mix etc.

Polypropylene fibers are available in three different forms; Monofilaments, Multifilament and Fibrillated (Hannant, 1978). Monofilament fibers are single strand of fibers having uniform cross-sectional area and produced in an extrusion process Multifilament is a yarn consisting of a number of continuous filaments or strands. Most textile filament yarns are multifilament. The diameters of the multifilament fibers depend on the number of monofilament fibers used, and how they are combined to form a yarn. Fibrillated fibers are manufactured in the form of films or tapes that are slit in such a way that they can be expanded into an open network to allow penetration of cementitious materials (Figure 1). Fibers are finally cut to the desired lengths. During the mixing, due to friction with aggregates, the fibrillated fiber expands in to a net (Bayasi and Mclntyre, 2002).

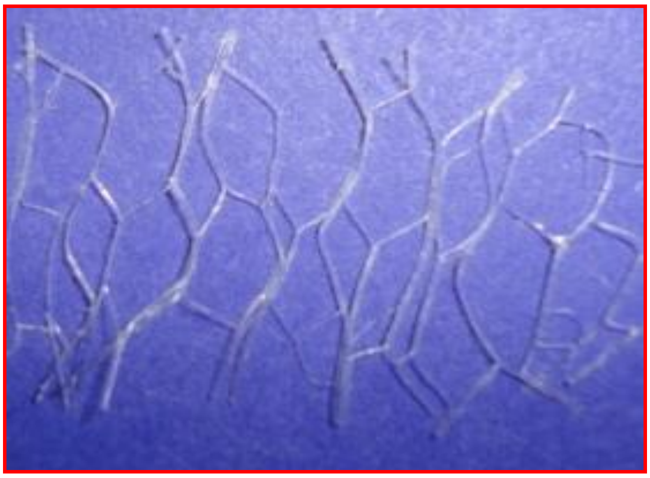

Figure 1. A typical view of polypropylene fibrillated fiber used in this investigation

Several researchers (Qi and Weiss, 2003; Banthia and Gupta, 2006) have reported that finer PP fiber is more effective in reducing the width of plastic shrinkage cracking than coarser fiber. The compressive and tensile strength of the concrete reinforced with low volume of PP fiber are not significantly different from those of the unreinforced matrix (Kumar et al, 2012; Hasaba et al, 1984; Ramakrishnan et al, 1987.) Some researchers (Hasaba et al, 1984; Banthia and Dubey, 1999; Banthia and Dubey, 2000) have reported increase in flexural strength of concrete reinforced with PP fiber. Very limited works on concrete reinforced with fibrillated fibre are reported in literature. Ramakrishnan et al 1999, observed a slight increase (0.7- 2.6%) in flexural strength of concrete reinforced with fibrillated fiber at the dosage of 0.1% by volume while at fiber content 0.2 - 0.3% by volume they observed slight decrease in flexural strength. In the this work, the effect of addition of polypropylene discrete fibers and fibrillated fiber on settlement, compressive strength, drying shrinkage and abrasion resistance of a paving grade concrete mix with respect to unreinforced concrete mix has been evaluated and discussed.

EXPERIMENTAL STUDY

Materials

The materials used included ordinary portland cement, well graded crushed quartzite coarse aggregate of nominal maximum size 20 mm, land quarried concrete sand, tap water, polycarboxylate ether-based high range water reducing agent (HRWRA) and polypropylene (PP) multifilament discrete as well as fibrillated fiber of maximum 18 mm in length. Seven concrete mixes that included a control mix with no fiber and six mixes containing different fiber volume fractions as listed in Table 1, were used in this study.

Table 1. Details of the concrete mixes and their 28-day compressive strength

Description	Mix designation and proportions						
	S-1	S-2	S-3	S-4	S-5	S-6	S-7
Fibre type	No	PP	PP	PP	PP Fibrillated	PP Fibrillated	PP Fibrillated
Fibre dosage, % by volume	No	0.05	0.10	0.15	0.05	0.10	0.15
28-day compressive strength, MPa	48.1	55.5	54.0	48.0	55.0	46.5	55.0

The mix proportions of the control concrete mix (S-1) were as follows:

C: A: S: W/C :: 1: 2.48: 1.62: 0.38

with 0.35% HRWRA by mass of the cement. All concrete mixes were prepared in a tilted drum mixer. All ingredients except water and HRWRA were mixed in dry state for few seconds in a concrete mixer. Then ¾ of total required water was added to the mix and mixing was further continued for a couple of minutes. The HRWRA was added in remaining $1/4^{th}$ water and added to the mix in the final stage of mixing. The mix was further mixed for another couple of minutes. Upon completion of mixing, the properties at fresh state were evaluated.

Preparation and curing of test specimens

From each concrete mix, 150 mm cube specimens for evaluation of compression strength, 75 x 75 x 285 mm beam specimens for drying shrinkage and 500 x 500 x 100 mm slab specimens for abrasion resistance and 150 mm diameter and 300 mm height cylindrical specimens for settlement and bleeding were cast from concrete mixes containing fiber and without fiber. The specimens were demoulded after 24 hours of casting and curing in steel moulds. Thereafter, the demoulded specimens were marked for identification and kept submerged in a curing tank at a temperature ($27^0 \pm 2\ ^0$C) till the age of testing.

Testing methods

Fresh mix properties

Experimental investigations to determine fresh concrete mix properties i.e. slump, bleeding and settlement were conducted by using standard procedures. 150 mm diameter and 300 mm height cylindrical moulds were filled with fresh concrete and were fitted with two dial gauges for the measurement of the settlement.

Compressive strength

Compressive strength of each concrete mix was determined using 150 mm cube specimens using IS 516, 2000. Three specimens of each mix were tested to determine the average compressive strength of concrete mixes at 28 days.

Shrinkage determination

Prismatic concrete specimens (75 by 285 mm) were prepared for conducting drying shrinkage test. The test was conducted at 28 days according as per IS-1199: 1959 (Figure 2). The beams were demoulded after 24 hrs of casting and curing in steel mould. Thereafter, the demoulded specimens were marked for identification and kept submerged in a curing tank at room temperature ($27^0 \pm 2^0$C) for the period of 28 days and initial length was measured. After the initial reading, the specimens were dried in at a temperature of 50 ± 1^0C and 17% relative humidity and then length changes were determined. The specimens were subjected to a cycle of drying, cooling and measurement of length until constant length was attained, that is, when the difference between the two consecutive readings separated by a period of drying of at least 44 hours, followed by cooling for at least four hours, is less than 0.02 mm. The drying shrinkage was calculated as the difference between the original wet measurement and the dry measurement expressed as the percentage of wet length.

Figure 2. A concrete specimen under drying shrinkage test

Abrasion resistance

Abrasion resistance of concrete slab was determined at 28 days following the procedures of ASTM C 779 as shown in Fig.3. The abrasion machine consists of three discs, which rotate about their vertical axis and at the same time also travels on circular paths at a speed of 12 revolutions per minute in a planetary motion. During the rotation of discs silicon powder falls from the cup (attached at top of the shaft) at the rate of 4 to 6 gm/min which helps in abrading the slab surface. After five minutes of initial charge the abrasion depth is measured with the help of a micrometer, at the each end 5 readings were taken. This represents the initial reading. Abrasion charge is again applied for the period of thirty minutes and abrasion depths are measured. This process is further continued for a period of thirty minutes and final abrasion depths were measured in mm. Difference between the average initial and average final depths give total abrasion of horizontal slab in mm. Average depths obtained on duplicate specimens are reported here.

Figure 3. A concrete slab under abrasion testing

RESULTS AND DISCUSSION

Properties of fresh concrete

The test results of slump, bleeding and settlement of concrete are listed in Table 2. Results show that the addition of fiber both discrete as well as fibrillated has a detrimental effect on the workability of concrete mix. They further exhibit more slump reduction for concrete mixes containing discrete fiber than fibrillated fiber. Increase in slump reduction with increase of fiber content may also be seen in Table 2, which is similar to earlier reported results.

Table 2. Slump, bleeding and settlement of concrete mixes

Description	Concrete Mix						
	S-1	S-2	S-3	S-4	S-5	S-6	S-7
Slump, mm	75	35	18	15	50	45	28
Bleeding	No	No	No	No	No	No	No
Settlement, mm	2.17	--	1.25	--	--	0.5	--

No noticeable bleeding from any concrete mix (with and without fiber) was observed (Table 2). The results show maximum settlement for control concrete mix than the mixes with fiber. Fibrillated fiber reduces concrete settlement more effectively than the multifilament fiber. This reduction in settlement of concrete containing fiber may be attributed to the action of fibers in the mix similar to the formation of a three- dimensional sieve, stopping the air passing up through the sieve and preventing the aggregate from pass down (Hobbs, 1971).

Compressive strength

Table 1 show that the addition of synthetic fiber to the concrete mix has no adverse effect on 28 days compressive strength of concrete in comparison to the control mix.

Drying shrinkage

Figure 4 shows the drying shrinkage test results. A reduction in drying shrinkage up to 40% of that of the control concrete may be observed for both the fibers. This reduction in shrinkage is attributed to the higher tensile strength of fibers that enable it to carry more tensile stresses in comparison of plain concrete. Further, early age volume changes in concrete cause weakened planes and cracks to form; growth of these micro shrinkage cracks is inhibited by mechanical blocking action of the fibers. A better performance for the fibrillated fiber in controlling drying shrinkage than discrete fibre is obvious. This may be due to better stabilization of matrix by the net of fibrillated fiber.

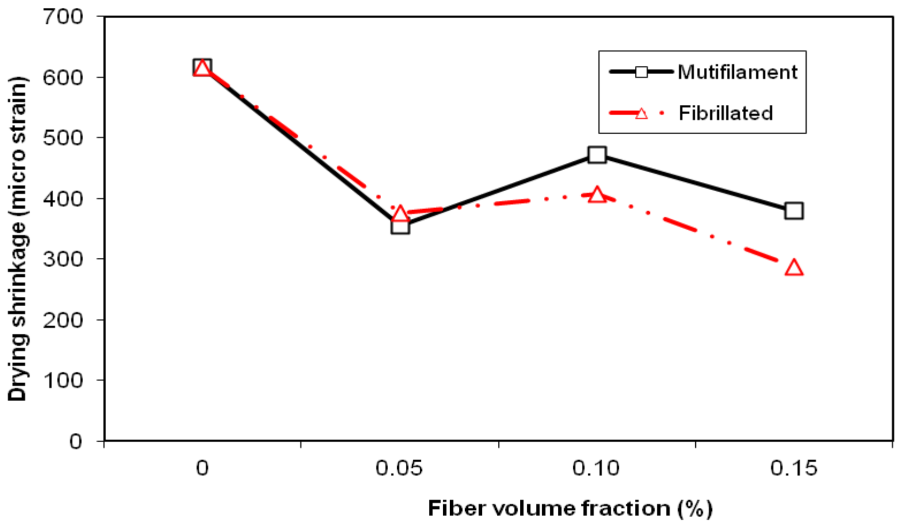

Figure 4. Drying shrinkage vs. fiber volume fraction

Abrasion Resistance

Abrasion resistance was measured in term depth of the abraded concrete surface. The results obtained on duplicate specimens are shown in Figure 5. The results show a significant reduction (up to 29%) in abrasion depth for concrete containing fiber in comparison to control concrete indicating an increased abrasion resistance for those mixes. This increased abrasion resistance for the concrete containing fiber is mainly due to discourage of the development of large capillaries pores due to bleed water migration to the surface leading to improvement in microstructure of surface zone concrete. Another reason for the enhancement in abrasion resistance could be the bonding between the fibers and the concrete matrix that might have not allowed the particles to move away during the testing. It may be concluded that for the same volume fraction of fiber, multifilament as well as fibrillated fiber have similar effect on the abrasion resistance of the concrete.

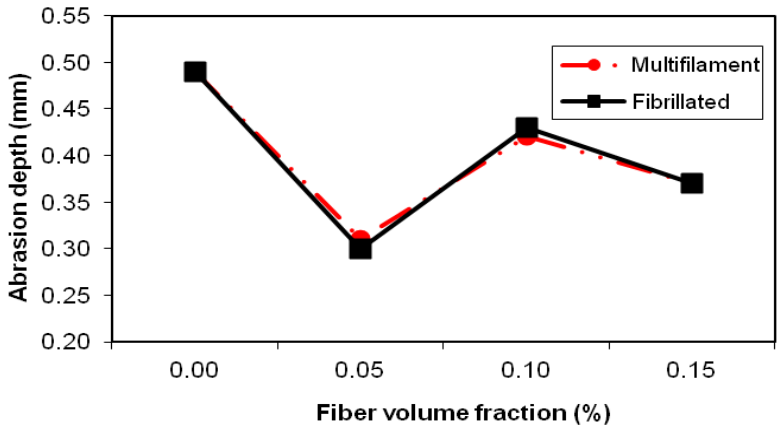

Figure 5. Abrasion depth vs. fiber volume fraction

CONCLUSIONS

The major conclusions that emerged from the experimental work are as listed below:

- Fibrillated fibre is more effective in reducing the settlement of concrete than multifilament fiber. However, it has lesser effect on slump reduction than multifilament fiber at the same fiber content.
- There is no adverse effect of the addition of multifilament and fibrillated fiber on 28-day compressive strength of concrete.
- Fibrillated fiber performs better than multifilament fiber in controlling drying shrinkage of concrete.
- Concrete containing fibrillated fiber performs similar to concrete containing multifilament fiber in the development of abrasion resistance.
- Concrete reinforced with polypropylene fibrillated fiber may be used in the construction of concrete pavements.

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