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THE USE OF POLYPROPYLENE FIBERS AGAINST PLASTIC SHRINKAGE CRACKING

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Plastic shrinkage cracking (PShC) occurs within a few hours after fresh concrete formed into the molds and it takes part on the surface of the concrete. When concrete formed into the molds, the aggregates settle because of the gravity and in contrast, water bleeds. If the rate of evaporation is higher than the rate of bleeding, surface of concrete starts to shrink. However, under the surface, the fresh concrete cannot shrink as much as the surface. Because of this condition, cracking occurs on the surface of concrete. In this respect, the quantity of PShC majorly depends on the temperature of concrete, temperature of air, rate of relative humidity and the wind velocity. Use of short fibers in concrete is one of the most effective ways to prevent concrete from PShC. The aim of this research was to evaluate the effect of polypropylene fibers having different geometries and content on PShC. For this purpose, the principles of ASTM C 1579 standard was considered. Results have shown that the use of polypropylene fibers in limiting PShC is obvious. Moreover, fibrillated fibers has shown better performance than monofilament fibers.

Keywords: Crack reduction ratio, Crack width, Fibrillated fiber, Fiber dosage, Monofilament fiber, Image processing.

1 INTRODUCTION

Plastic shrinkage cracking (PShC) is one of the problems encountered in application. It typically occurs on the surface of floor slab or bridge deck, which are exposed to hot, and windy environmental conditions, Boshoff and Combrinck (2013). If the tensile stress on surface of concrete reaches its tensile strength, several cracks occur. These cracks become a canal for external deteriorating agents and accelerate the ingression of harmful gasses and liquid solutions into the concrete. Consequently, the durability and service life of concrete is affected adversely, (Sivakumar *et al.* 2007, Boshoff and Combrinck 2013, Leemann *et al.* 2013). Regarding to PShC, many researches have been reported for decades. To minimize the risk of PShC, several parameters, such as mixture design, curing methods, chemical and mineral admixtures, surface finishing methods and secondary reinforcement have been investigated both on conventional and high performance concretes.

Fiber reinforcement is one of the most effective ways to reduce the risk of PShC, Rahmani *et al.* (2012). The use of short fibers in concrete and mortar is increasing in recent years. In literature, performance of steel, glass, synthetic and natural short fiber types against PShC has been broadly investigated with considering different combinations between dosage, geometry and type of fibers.

Steel, glass and polymeric fibers that have different shape and size are added to increase the durability of concrete, Pelisser *et al.* (2010). Apart from these, nature origin fibers such as flax and cellulosic ones are also being used to avoid PShC (Soroushian and Ravanbakhsh 1998, Boghossian and Wegner 2008). Several researches examining the synthetic fiber, which have same geometry, have shown that thinner and longer fibers have better performance on holding the cracks. The finer the fibers, the smaller the crack values for same fiber dosage (Ma *et al.* 2002, Banthia and Gupta 2006). However, the effectiveness of length of fiber reduces after a definite fiber length, Soroushian and Ravanbakhsh (1998).

In this research, the effect of polypropylene fibers, having different geometries and content, on limiting the PShC was investigated. The reference concrete mixture used in this research is C35. Average 28-day cube strength was found as 48.6MPa.

2 MATERIALS USED

CEM I 42.5 R class Portland cement with specific gravity of 3.17 gr/cm^3 was used in concrete mixtures. A commercially available superplasticizer with a specific gravity of 1.19 gr/cm^3 was used to obtain desired workability. 0-2 mm natural sand with specific gravity of 2.64 gr/cm^3 and 0-4 mm crushed sand with specific gravity of 2.76 gr/cm^3 were used as fine aggregates. A crushed stone with a maximum size of 16 mm and specific gravity of 2.76 gr/cm^3 was used as coarse aggregate. Monofilament polypropylene (MPP) and fibrillated polypropylene (FPP) fibers with 12 mm length were used as fiber reinforcement. Denier of MPP fiber is between 2.5 and 6 (diameter = 20–30 µm), and denier of FPP fiber is 1200.

3 MIXTURE PROPORTIONING

The design of concrete mixtures on which PShC tests has been performed is given in Table 1. In these mixtures, water/cement ratio was kept constant at 0.55. Three different dosages of polypropylene fibers were selected as 600, 900 and 1100 gr/m^3. Concrete mixtures with and without fiber reinforcement were denoted as REF, MPP600, MPP900, MPP1100, FPP600, FPP900 and FPP1100. In order to minimize the effect of superplasticizer on setting times of concretes, its amount for all mixtures was kept constant at 0.9% by the weight of cement.

Table 1. Mixture proportions (kg/m^3) of concretes.

(kg/m^3)	REF	MPP600	MPP900	MPP1100	FPP600	FPP900	FPP1100
Cement				350			
Natural Sand				303			
Crushed Sand				614			
Crushed Stone				931			
MPP	-	0.6	0.9	1.1	-	-	-
FPP	-	-	-	-	0.6	0.9	1.1
Water				192,5			
Superplasticizer				3,15			

4 MIXING AND PLACING

Concrete mixtures were mixed using a rotary pan mixer of 50 liters capacity. Initially, coarse aggregate, fine aggregate and cement were put into the pan and mixed dry for 30 seconds. By reserving some of it, water added to mixer slowly. After that superplasticizer was mixed into the reserved water and added to the mixer. Finally, the fibers were added in the mixture. Workability of concrete was determined by using slump test. The concrete was placed into the molds and vibrated on a vibration table. A smooth steel screed was used to finish the concrete surface. Screeding procedure was done by making sawing motion, on the long edge direction of the mold.

5 SPECIMEN DIMENSIONS AND ENVIRONMENTAL CONDITIONS

Laminated board molds with dimensions of 355x560x95 mm were used. According to ASTM C 1579, molds have three stress risers. But to achieve greater crack areas and provide the criteria of minimum average crack limit of 0.5 mm two additional restraints added to system. Photo and cross-section of mold and environmental chamber are given in Figure 1.

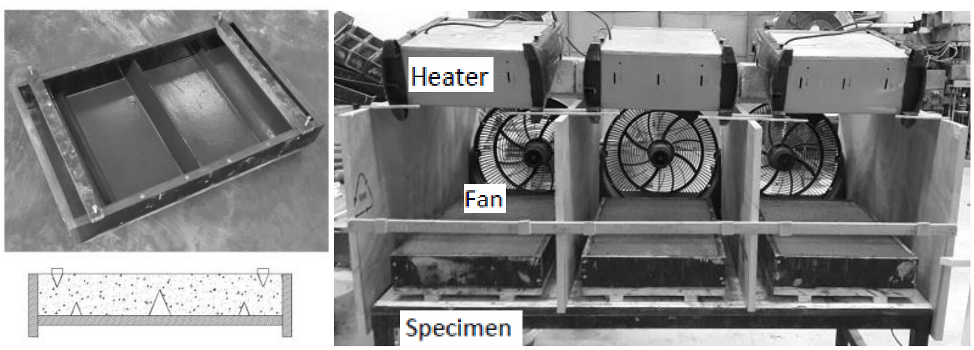

Figure 1. Photo and cross-section of mold used (left), environmental chamber (right).

The concrete specimens were placed into the environmental chamber after casting. To obtain sufficient evaporation rate, a fan with air velocity of 16~17 km/h and an infrared heater were used. At the end of the experiment, temperature and relative humidity on the surface of samples were measured as 43±3°C and 17±3%, respectively. Evaporation rate was measured as 1.09 $kg/m^2.h$ which achieved the criteria of 1.0 $kg/m^2.h$.

The specimens were kept in the environmental chamber for 4 hours. After first crack became visible, photos of specimen were captured in 30 minutes intervals and used to measure total crack area, total crack length and maximum crack width.

6 RESULTS AND DISCUSSION

6.1 Slump Test, Setting Time Test and Crack Initiation Times

Slump values and crack initiation times are given in Table 2. Addition of fibers reduced slump values significantly. However, the consistency of the fiber reinforced mixtures were good enough to obtain a well compaction. All the mixtures could easily be formed into the molds by the vibration of four seconds.

Table 2. Slump values and crack initiation times.

Mixture ID	Slump (cm)	Crack Initiation (min.)
REF	16	90
MPP600	4	85
MPP900	1.5	102
MPP1100	3	98
FPP600	4	96
FPP900	2	94
FPP1100	3	100

Final setting time was determined only for reference concrete mixture and measured as 135 minutes. As seen in Table 2, crack initiation times extended with increasing fiber dosage.

6.2 Plastic Shrinkage Test

For all of the mixtures two specimens were tested and the crack characteristics were determined by means of image processing. The crack maps for plain, MPP and FPP fiber reinforced mixtures for different dosages are shown in Figure 2. Average of total crack area, total crack length, average crack width, maximum crack width measurements and calculated crack reduction ratio (CRR) values are given in Table 3. Crack reduction ratio of total crack area and average crack width calculated with formula given below.

$$CRR = \left(1 - \frac{\text{Average crack width or total crack area of fiber reinforced mixture}}{\text{Average crack width or total crack area of reference mixture}}\right) \text{x} 100 \qquad (1)$$

Table 3. Average of total crack area, total crack length, average crack width, maximum crack width measurements and calculated CRR values.

Specimen ID	Fiber Dosage (gr/m^3)	Total Crack Area (mm^2)	Total Crack Length (mm)	Average Crack Width (mm)	Max. Crack Width (mm)	CRR of Total Crack Area (%)	CRR of Average Crack Width (%)
REF	-	188	450	0.42	0.98	-	-
MPP600	600	134	425	0.31	0.79	28.9	24.7
FPP600	600	113	424	0.27	0.74	39.9	36.2
MPP900	900	67	410	0.16	0.44	64.1	60.6
FPP900	900	90	468	0.19	0.48	52.1	53.9
MPP110	1100	43	342	0.13	0.47	76.9	69.5
	1100	33	347	0.09	0.34	82.5	77.3

The effect of fiber type and dosage on the average crack width, maximum crack width and total crack area can be seen in Figure 3. From these figures, it is obvious that, for both fiber types, as the fiber dosage increases average and maximum crack widths decreases significantly. CRR of "average crack width" for MPP fiber mixtures are 24.7, 60.6, and 69.5% for the fiber dosages of 600, 900 and 1100 g/m^3, respectively. "Maximum crack width" values of MPP fiber mixtures, on the other hand, were reduced from 0.98mm to 0.79, 0.44 and 0.47 mm for the fiber dosages of 600, 900 and 1100 g/m^3, respectively. Similar trend can also be observed for the FPP fiber mixtures. CRR of "average crack width" for FPP fiber mixtures are 36.2, 53.9, and 77.3% for the fiber dosages of 600, 900 and 1100 g/m^3, respectively.

"Maximum crack width" values of FPP fiber mixtures, on the other hand, were reduced from 0.98 mm to 0.74, 0.48 and 0.34 mm for the fiber dosages of 600, 900 and 1100 g/m^3, respectively. Based on the results obtained, it can be concluded that for a given dosage, the performance of FPP is likely better than MPP.

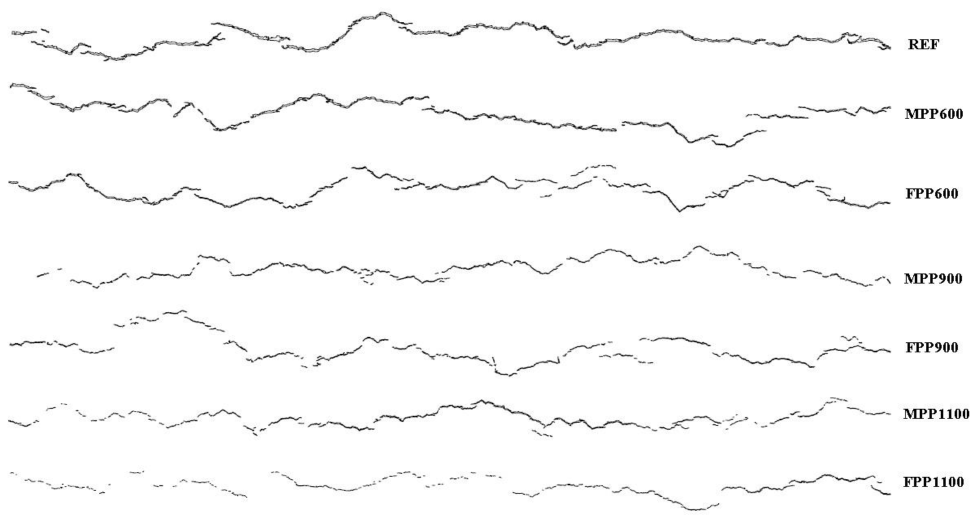

Figure 2. Crack maps of mixtures.

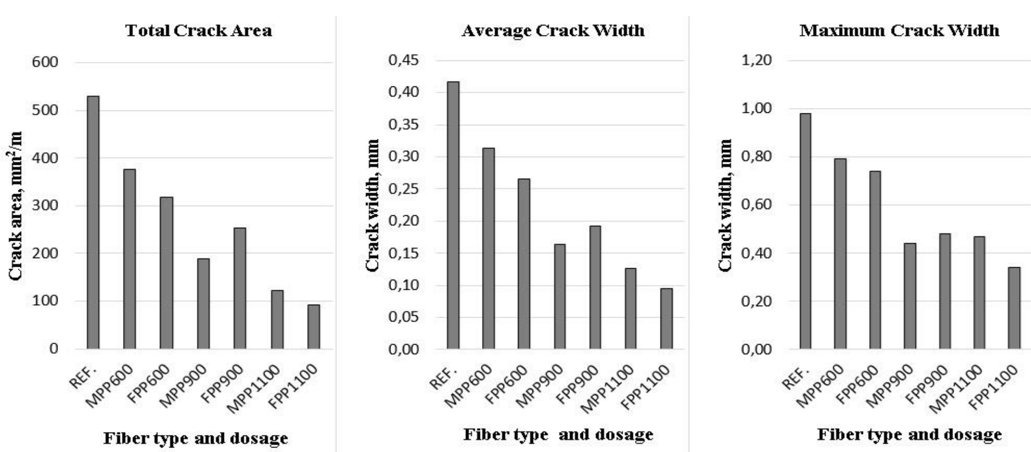

Figure 3. The effect of fiber type and dosage.

7 CONCLUSIONS

Within the limits of experimental work, the following conclusions can be drawn:

- Addition of fibers significantly reduced slump values of fresh concretes.
- For both fiber types, as the fiber dosage increases average and maximum crack widths decreases significantly.
- It is found that, for a given dosage, the performance of FPP is likely better than MPP.
- It is recommended that it will be better to isolate experimental setup from air conditions with converting the setup into the closed system. It is important for repeatability of testing.

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