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Durability, physical and mechanical properties of fiber-reinforced concretes at low-volume fraction

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HIGHLIGHTS

- Air content of concrete increased with fiber addition.
- Fibers caused variations in the permeability of concrete.
- Polypropylene and glass fiber concretes exhibited higher rate of rebar corrosion.
- Fiber addition can significantly affect the resistance against corrosion.
- This effect becomes significant in long-term exposure.

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ABSTRACT

Steel, polypropylene, and glass fiber concretes at low-volume fractions, which have been successfully used for crack control in many structural applications, were tested for different properties including water absorption, electrical resistivity, sorptivity, depth of chloride penetration, chloride profiles, rebar corrosion half-cell potential, and corrosion current density. Compressive strength and splitting tensile strength, flexural strength, and fracture toughness were also determined. Two different water–cement ratios and two curing types were used in the study. Fibers caused physical changes in concrete, which were reflected to the tested properties. The effect on durability was more significant in longer-term tests like corrosion. Moist curing was found to be more effective in fiber concrete for mechanical properties.
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1. Introduction

Fibers have been widely used for years in various civil engineering applications. The improved post-cracking tensile and flexural strength of fiber concrete leads to an increase in toughness. The main benefit of the use of fibers is the control of cracking.

Steel fibers are mainly used for crack control when ductile construction is required. Steel fiber volume as low as 0.5% was efficient in various applications like concrete pavements, slabs and tunnel linings [1–4]. Volume proportion of 0.1% glass and polypropylene fibers is sufficient for plastic and drying shrinkage cracking control [5,6].

In low volume concentrations, the effect of fibers is like a secondary reinforcement for concrete because fibers control cracking but they do not contribute to the load carrying capacity. Literature data shows that the improvement in compressive strength by low steel fiber content is very limited. Splitting tensile and flexural strengths were much more affected by the presence of steel fibers [7–12]. When the fiber volume increases from 0.5% to 1% or 1.5%, the effect of steel fibers on strength becomes more significant. This increase in fiber content is more directly reflected to tensile strength results [9–12]. However, there are also some results that indicate decrease in compressive [13,14] and flexural strength [12] by steel fiber addition. Previous research on polypropylene fiber concrete (PFC) and glass fiber concrete (GFC) is scarce compared to SFC. However, slight contribution to strength was reported in some research studies [9,15–17]. Their contribution to the toughness of concrete is more significant [16,18], but improvement in toughness by steel fiber addition is much better compared to other fibers [9].

Fiber addition may alter some physical properties of concrete. Increased porosity and permeability was reported in the literature. Huang [19] suggests that the volume of coarser capillary pores

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(50 nm or greater) as well as the permeability increase significantly with fiber addition in cement grouts. This result was also supported by another study of the same author [20]. Toutanji [21] attributed the significant increase in permeability of concrete with polypropylene fiber addition to the increase in the entrapped air content. An increase in air content was also observed in steel fiber concrete [22]. Polypropylene fibers caused an increase in rapid chloride permeability. This effect increased from 0% to 0.1%, 0.3%, and 0.5% by volume of concrete [23]. Higher polypropylene content was reported to cause an increase in porosity, absorption and sorptivity [24]. SEM analysis carried out in the study of Ramezanianpour et al. [25] shows higher porosity for the hardened cement paste (hcp) and interface between the hcp and aggregate in polypropylene fiber concrete. Their observation was supported by significantly lower compressive strength and ultrasonic pulse velocity results. However, rapid chloride permeability and sorptivity results were lower for fiber concrete. In another study polypropylene fiber concrete was found to have lower water permeability and carbonation depth [26]. According to other studies [27,28], steel, polypropylene and glass fibers caused a significant reduction in rapid chloride permeability.

This paper presents the results of an investigation about the durability of concrete using steel, polypropylene, and glass fibers. As shown in the literature, fibers may affect physical properties of concrete such as porosity and permeability. Such effects can be critical for the penetration of aggressive agents and can be harmful for the durability of concrete. The significance of the present paper is based on the use of typical low fiber volume concentrations which are widely used in various applications such as slabs, pavements, tunnel linings, pipes etc. and which are proved to be effective in control of cracking. Research on durability of fiber concrete, on the other hand is very limited and the results are contradictory. Therefore, the determination of concrete properties related to its durability can provide useful knowledge about the lifetime of these structures.

2. Experimental program

In the present study, durability of fiber reinforced concretes was compared to the control concrete mixture without fiber. Steel, polypropylene, and glass fibers were used. Fiber volume concentrations were selected according to their manufacturers' recommendations as the commonly used rates in construction practice for control of cracking due to load or shrinkage: 0.5% for steel fibers, 0.1% for polypropylene fibers, and 0.1% for glass fibers by volume of concrete. Two water–cement ratios (w/c = 0.65 and 0.45) were used in the study. The details of the materials and the test procedures are given below.

2.1. Materials

Portland cement CEM I 42.5 R, crushed limestone coarse aggregate having 19 mm maximum size as well as river and crushed sand fine aggregates were used. Superplasticizer (SP) was polynaphthalene sulfonate high range water reducing admixture. Steel fibers were cold drawn wire fibers with hooked ends and glued in bundles. Polypropylene fibers were multi-filament fibers. Glass fibers were multi-filament alkali-resistant fibers. General properties of the fibers are given in Table 1.

Table 1
General properties of fibers.

	Steel	Polypropylene	Glass
Length (mm)	35	13	12
Diameter (mm)	0.55	0.022	0.014
Length/diameter	64	591	857
Density (g/cm^3)	7.85	0.91	2.68
Tensile strength (MPa)	1100	400	1700
Modulus of elasticity (GPa)	200	3.5–3.9	72
Number of fibers (kg)	14,500	224 million	2.1 million

2.2. Concrete mixes and test methods

Compositions of the concrete mixes are given in Table 2. The slump test was carried out according to ASTM C143. For all mixes, the target slump was determined as 17 ± 2 cm. Superplasticizer content was first determined in the control mixes to reach the target slump value for each concrete type which was then increased to reach the same slump in the fiber reinforced concrete mixes. Density and air content of fresh concrete were determined according to ASTM C138.

Six 100 × 200 mm cylindrical specimens were cast for each mix at both curing types: air curing in laboratory conditions and moist curing in lime saturated water. Three of them were used to measure the compressive strength (ASTM C39). The other three specimens were used to test for the splitting tensile strength (ASTM C496). Two 100 × 100 × 500 mm beam specimens for each mix at moist curing only were tested as shown in Fig. 1 for flexural strength (ASTM C293). Flexural toughness was calculated by taking the area under the load–deflection curve after peak stress.

Resistivity of concrete was measured with a two-probe resistivity-meter. For each test, holes were drilled to a depth of 8 mm and filled with a conductive gel at four different locations on the surface of concrete. The average of four readings was taken as the resistivity of concrete.

Water absorption by weight of concrete was determined according to ASTM C642. Sorptivity test was carried out according to ASTM C1585 (Fig. 2). Two specimens were tested for each type of concrete and the average of two results was used to determine the rate of absorption.

Chloride penetration test was carried out by using two different testing methods. For the first method, 100 × 200 mm cylindrical specimens were used. The specimens were immersed in a 35 g/l NaCl solution. At selected ages (7, 14, 28, 56, and 91 days), two specimens of each mix were taken out of the solution and broken into two pieces as in splitting tensile test. The split faces of each piece were sprayed by 0.1 M $AgNO_3$ solution for determining the depth of chloride penetration. The split

Table 2
Concrete mixes.

kg/m^3	w/c = 0.65	w/c = 0.45
Cement	310	400
Water	201.5	180
Coarse aggregate (2–10 mm)	581	575
Coarse aggregate (8–19 mm)	473	468
River sand	560	554
Crushed sand	237	235
SP for control concrete	1.9	7
Steel fiber and SP (respectively)[a]	39.25–3.5	39.25–9
PP fiber and SP	0.91–3.8	0.91–9
Glass fiber and SP	2.68–5.2	2.68–10.2

[a] In each fiber reinforced concrete mix, superplasticizer used was different. Fiber and superplasticizer contents are written in the same row for each concrete mix.

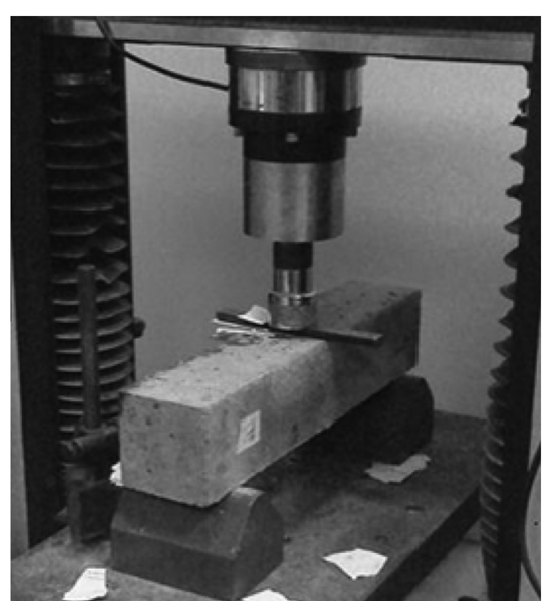

Fig. 1. Flexure-toughness test set-up.

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