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Strength properties of nylon- and polypropylene-fiber-reinforced concretes

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Abstract

The strength potential of nylon-fiber-reinforced concrete was investigated versus that of the polypropylene-fiber-reinforced concrete, at a fiber content of 0.6 kg/m^3. The compressive and splitting tensile strengths and modulus of rupture (MOR) of the nylon fiber concrete improved by 6.3%, 6.7%, and 4.3%, respectively, over those of the polypropylene fiber concrete. On the impact resistance, the first-crack and failure strengths and the percentage increase in the postfirst-crack blows improved more for the nylon fiber concrete than for its polypropylene counterpart. In addition, the shrinkage crack reduction potential also improved more for the nylon-fiber-reinforced mortar. The above-listed improvements stemmed from the nylon fibers registering a higher tensile strength and possibly due to its better distribution in concrete.

Keywords: Mechanical properties; Concrete; Fiber reinforcement; Shrinkage

1. Introduction

Concrete is a tension-weak building material, which is often crack ridden connected to plastic and hardened states, drying shrinkage, and the like. The cracks generally develop with time and stresses to penetrate the concrete, thereby impairing the waterproofing properties and exposing the interior of the concrete to the destructive substances containing moisture, bromine, acid sulfate, etc. The exposure acts to deteriorate the concrete, with the reinforcing steel corroding. To counteract the cracks, a fighting strategy has come into use, which mixes the concrete with the addition of discrete fibers [1,2]. Because of the mixing action, the fibers are uniformly distributed throughout the concrete in all directions. In the fresh concrete, the uniformly distributed fibers reinforce against the formation of plastic shrinkage cracks. In the hardened concrete, the uniformly distributed fibers disallow the microcrack from developing into macrocracks and potential troubles. In addition, these fibers bridge and therefore hold together the existing macrocracks, thus reinforcing the concrete against disintegration. The concrete-reinforcing fibers include metal, polymer, and various others. Among the polymer fibers, the polypropylene fibers enjoy popularity in the domain of concrete [3–13] and the nylon fibers show a rising acceptance [14,15]. The polypropylene fibers claimed contribution to the concrete performance subjected to crack opening and slippage [4]. Furthermore, the fibers reinforced the performance under not only compression, flexure, and tension [7], but also under impact blows [9] and plastic shrinkage cracking [10]. On the other hand, the nylon fibers stepped up the performance after the presence of cracks [14] and sustained high stresses [15]. However, the establishment was awaiting as to how the polypropylene fibers compete with the nylon rivals in advancing the performance of concrete under compression, tension, flexure, etc., and in shrinkage cracking control.

In this paper, the strength properties and shrinkage cracking control of nylon-fiber-reinforced concrete were under investigation, in comparison with those of the polypropylene-fiber-reinforced concrete counterpart.

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2. Experimental program

2.1. Materials

The materials used for the nonfibrous control concrete mixture consisted of the normal Type I Portland cement, the gravel having a maximum size of 2.54 cm, and the river sand having a fineness modulus of 2.9. Approximately 300 kg/m^3 of cement and 194 kg/m^3 of mixing water were used with 1050 kg/m^3 gravel and 850 kg/m^3 sand for the nonfibrous concrete mixture. To the nonfibrous mixture, the nylon and polypropylene fibers were both added at the concentration of 0.6 kg/m^3 for the nylon- and polypropylene-fiber-reinforced concretes. The properties of the two types of fibers appear in Table 1.

2.2. Mixing and curing

The procedures for mixing the fiber-reinforced concrete involved the following. Firstly, the gravel and sand were placed in a concrete mixer and dry mixed for 1 min. Secondly, the cement was spread and dry mixed for 1 min. Thirdly, the mixing water was slowly added and mixed for 2 min. After which, the specified amount of fibers was distributed and mixed for 3 min. Lastly, the freshly mixed fiber-reinforced concrete was fed into the cylinder molds for the compressive and splitting tensile strength specimens measuring 15×30 cm, and into the beam molds for the flexural specimens measuring 15×15×53 cm.

After the feeding operation, each of the specimens was allowed to stand for 24 h before demolding, stored in lime water at 23 °C for 28 days, and then removed and kept at room temperature until the time of testing. Following the removal, some of 15×30 cm specimens were employed for assessing the impact strength of the control and fiber-reinforced concretes. For the assessment, each of the specimens was cut into four cylindrical discs for the impact specimens, each measuring 15×6.4 cm.

2.3. Drop weight test

The impact strength assessment followed the ACI committee 544 recommendations [16], which subjects an impact specimen to repeated blows. The number of blows to the first visible crack on the specimen top served as the first-crack strength; the number of blows to the ultimate failure of the specimen, the failure strength. The stage of the failure is clearly recognized by the fractured specimens butting against the lugs on the base plate.

Table 1
Physical properties of nylon and polypropylene fibers

Fiber type	Fiber length (mm)	Specific weight	Elastic modulus (GPa)	Tensile strength (MPa)	Melting point (°C)
Nylon	19	1.14	5.17	896	225
Polypropylene	19	0.91	4.11	413	160

2.4. Fiber distribution

The in-concrete distribution of nylon and polypropylene fibers was approximated through the distribution of these fibers in the mixing water. To approximate the distribution, 3 g of nylon and polypropylene fibers were respectively introduced into a 5×40 cm cylindrical glass measure filled with 1000 g of the mixing water. After the introduction, the measure was stopped, vigorously agitated, and allowed to stand for 2 h. Next to the standing procedure, the volume of the suspension containing the fibers was measured.

2.5. Shrinkage crack reduction potential test

The shrinkage crack reduction potential of nylon and polypropylene fibers in concrete was evaluated by assessing the potential of these two types of fibers in the rich and no-coarse-aggregate cement mortar consisting of cement and sand at the ratio of 1:1.5. The fibrous mortar was molded into the 60×60×6 cm test slab by using a steel mold. The interior faces of the mold and the base plate received a thin layer of lubricant to eliminate the friction between the mortar and the base plate. Immediately after the molding operation, the slab was exposed to an air stream at a speed of 12 to 16 km/h. The exposure lasted 24 h, followed by the measurements of width and length of the plastic shrinkage cracks appearing on the slab face. According to the widths, the cracks fell into four categories: large, medium, small, and hairline. The cracks about 3 mm wide were the large ones, assigned a weighted value of 3. The cracks about 2, 1, and 0.5 mm wide were the medium, small, and hairline ones, respectively, and the corresponding weighted values were 2, 1, and 0.5.

To each crack, the crack length multiplied by the weighted value was the weighted average value. The sum of the weighted average values for the cracks in a slab was the total weighted value. Comparing the total weighted values between the fibrous and nonfibrous slabs quantified how the nylon and polypropylene fibers reduced the sensitivity of the concretes to plastic shrinkage cracks.

3. Results and discussion

3.1. Dispersion characteristic

The volume of the nylon fiber containing suspension was about 25% of the capacity of the glass measure, which was a 5% increase over that of the polypropylene fibers containing suspension. The increase indicates that compared to the polypropylene fibers, the nylon fibers claimed a slightly