Performance Characteristics of Subdenier Monofilament Polypropylene Fiber Reinforced Mortars

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ABSTRACT: An experimental investigation on the properties of fresh and hardened mortars reinforced with subdenier monofilament polypropylene fiber (MMPPF) is reported. Fiber effects on properties of mortars were assessed. Properties studied were flow, unit weight, setting time, bleeding ratio, compressive strength, impact resistance, water infiltration, and flexural load-deflection. The results revealed that the addition of MMPPF had a positive effect on workability of fresh mortars, impact resistance, water impermeability, and flexural toughness, but had no positive effect on compressive strength. © 2004 Wiley Periodicals, Inc. J Appl Polym Sci 94: 2251–2256, 2004

Key words: subdenier monofilament polypropylene fiber; reinforcement; impact resistance; cementitious matrix

INTRODUCTION

Polypropylene fibers (PPF) in general have some unique properties that make them suitable for use in cementitious materials. The fibers are chemically inert and have high chemical resistance to mineral acids, bases, and inorganic salts. They are very stable and do not absorb water. The fibers have high tensile strength and are economical for commercial use. The low-modulus and high-elongation fibers are capable of large energy absorption.[1] Considerable research has been done on the performance of fibrillated polypropylene fiber (FPPF) reinforced cementitious materials.[2–6] FPPF reinforced cementitious materials have been finding increasing applications in slabs on grade, industrial floors, overlays, building walls, and slab elements. These applications are being encouraged by the improvements in cracking resistance, ductility, and impact resistance. There is less information available about the performance of monofilament polypropylene fibers (MMPPF) in cementitious materials,[7] especially about the subdenier monofilament polypropylene fiber reinforced cementitious materials. Therefore, the experimental research investigation reported herein focuses on a study of the properties of mortars reinforced with MMPPF.

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EXPERIMENTAL

Materials and mix composition

The cementitious matrices investigated in this work were all mortar mixes, with or without MMPPF. The main properties of the fiber used here are presented in Table I. The cement used was normal 525# Portland cement, fine aggregate siliceous sand with a fineness modulus of 2.70 and specified grading. The mortar mix proportions used in this investigation are as follows: sand : cement ratio = 2.5; water : cement ratio = 0.44. All the mixes are of the same W : C and S : C ratio and the variable is fiber content (0.1 and 0.2%, vol/vol). The flow of mortars was maintained within 130 ± 5 mm by adding an appropriate amount of naphthalene-based superplasticizer.

Specimen preparation and testing

There are three specimens cast for each test group. The specimens were cast as 40 × 40 × 160 mm prisms for compressive strength test according to ASTM C109. Flexural load-deflection tests were carried out on specimens 40 × 40 × 160 mm. The testing machine was an Instron dynamometer, which works with a load centered on the specimen, which was supported at the two ends (span of 120 mm), and the load-deflection diagram was recorded by a computer at a speed of 0.5 mm/min. The impact resistance was determined using the test method described in ACI Committee

TABLE I
Physical Properties of Polypropylene Fibers

Property	Value
Specific gravity (g/cm^3)	0.90
Tensile strength (MPa)	400
Tensile modulus (MPa)	3,500
Fiber length (mm)	6, 10
Denier	1.0 ± 0.1
Limited tensile ratio (%)	12

TABLE II
Effect of Fiber Volume on Flow and Unit Weight of Mortars

Length of fibers (mm)	% Fibers by volume	Flow (mm)	Unit weight (Kg/m^3)
6	0.1	136	2,230
	0.2	131	2,180
10	0.1	132	2,210
	0.2	126	2,165
Plain mortar	0	139	2,280

544.This test measures the number of blows required to initiate the first crack and fail the specimen under the effect of a hammer weighing 5.0 kg with a drop distance of 500 mm. All the specimens were covered with plastic after casting, demolded after 24 h, and then the specimens for compressive strength testing were placed in water maintained at 25°C for 28 days.

Three 30 × 30 × 280 mm prisms were used for the drying shrinkage test. The drying shrinkage test was commenced on the test prisms after an initial curing period of 7 days in water according to ASTM C157. Shrinkage strains were monitored for a period of 60 days of air drying at 22 ± 1°C and 55 ± 1% relative humidity.

Three 40 × 130 × 160 mm slabs were used for the water infiltration test. The specimens were cured at room temperature for 7 days. Thereafter, three test tubes were sealed at different points on these slabs. The test tubes were filled with water and the lowering of the water was measured against time (Fig. 1).

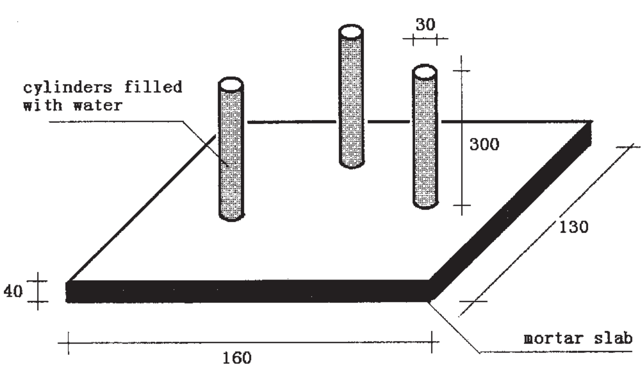

Figure 1 Schematic view of water infiltration test.

RESULTS AND DISCUSSION

Flow and unit weight of mortar

The subdenier monofilament polypropylene fiber used for the research performed well. Results of the test for flow and unit weight are given in Table II. The flow of the fiber-modified mortars was tested according to ASTM C230. The unit weight and flow for all mixtures were different depending on the fiber lengths and fiber contents. The unit weight of specimens reinforced with MMPPF is lower than that of specimens without fibers; this is probably due to the fact that there is relatively poor contact between the fiber and the matrix at the actual interface resulting from the hydrophobic surface of polypropylene fibers. The greater the fiber content, the larger the specific areas of fibers and the greater the voids between the fiber and the matrix interface, the lower the unit weight of specimens reinforced with higher fiber content. This result was inconsistent with the previous report,[1] which revealed that the unit weight for various mixtures was almost the same, implying that different fiber volumes do not influence the unit weight of cementitious materials. The present result indicates that MMPPF reinforced cementitious materials have different observed characteristics compared with MPPF or FPPF reinforced ones, originating from the small diameter of MMPPF.

The flow of all specimens reinforced with MMPPF is lower than that of specimens without fibers and it decreases with the increase of fiber content. The reason is that the fibers distributed in the matrix form a network, which restrains the flow of the fresh mortars.

Setting time

The times of setting for plain and MMPPF reinforced mortars are shown in Figure 2, which were tested according to ASTM C953. The error bars in Figures 2 to 6 represent the standard deviation. The initial and final setting times decrease with the addition of polypropylene fibers. Similar experimental phenomena were observed for the FPPF reinforced mortar systems.[8] The reduction of setting time is expected to reduce the period of exposure prior to setting of fresh mortars to the dry environment, which is responsible for plastic shrinkage cracking.

Bleeding

The bleeding ratio for plain and fiber reinforced mortars is shown in Figure 3, which was tested according to ASTM C940. There was a significant decrease in the bleeding ratio of mortar with the addition of MMPPF.

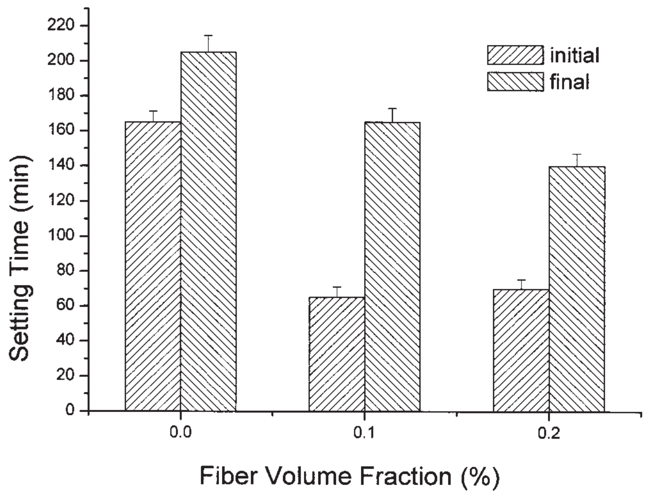

Figure 2 Effect of fiber content on setting time of mortar.

This can be attributed to the fact that the fibers possibly reduce the settlement of heavier mix constituents (e.g., sand), thereby reducing the upward movement of water in the mortars.[8]

Compressive strength

Compressive strength test results are shown in Figure 4. The results indicated that the presence of subdenier monofilament polypropylene fibers had negative effects on compressive strength and that the compressive strength decreases with an increase of fiber content. This is probably due to the reduction of the density of the specimens. The density of fiber reinforced specimens decreases with the increase of fiber content. This indicates that there is higher air content in fiber reinforced specimens compared with unreinforced specimens. This result was consistent with previous reported results.[1–4]

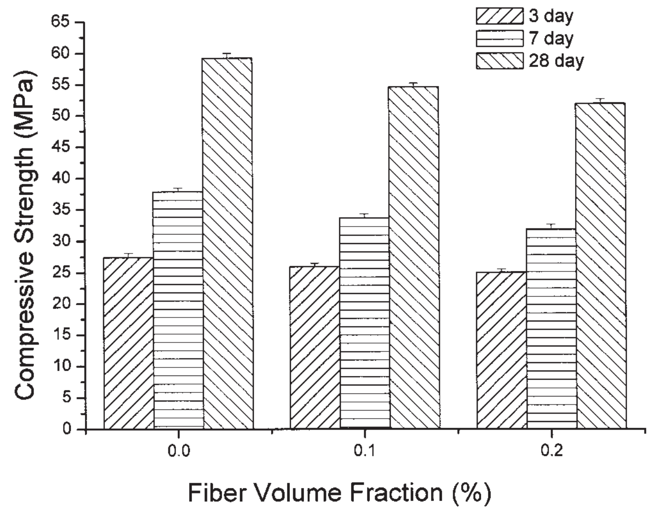

Figure 4 Relationship between fiber content and compressive strength.

Impact resistance

Figures 5 and 6 indicate that the blow numbers to initiate the first cracking in mortars were almost unaffected by the presence of fiber. However, the number of additional blows to propagate or open the cracks to failure changes dramatically. The failure blow numbers increase with the increase in fiber content (Fig. 5) and in length of fiber (Fig. 6). This is because the bonding between fibers and matrix is mainly mechanical anchoring. The longer the fiber, the stronger the anchoring action. Our result herein is inconsistent with the results reported by Ramakrishnan et al.,[1] who reported that the number of blows

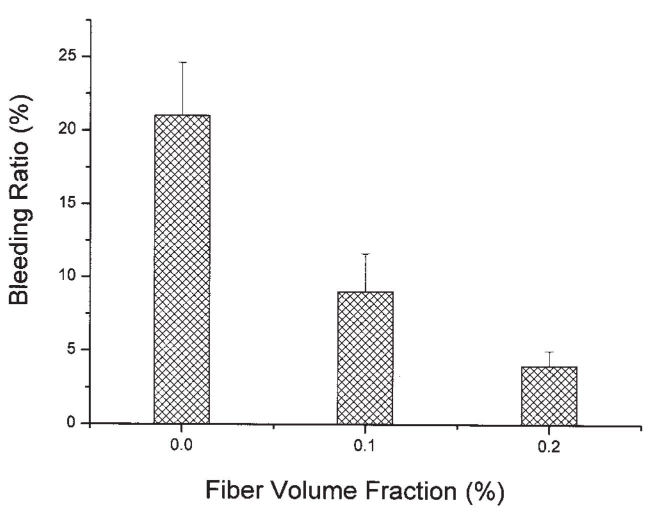

Figure 3 Relationship between fiber content and bleeding ratio.

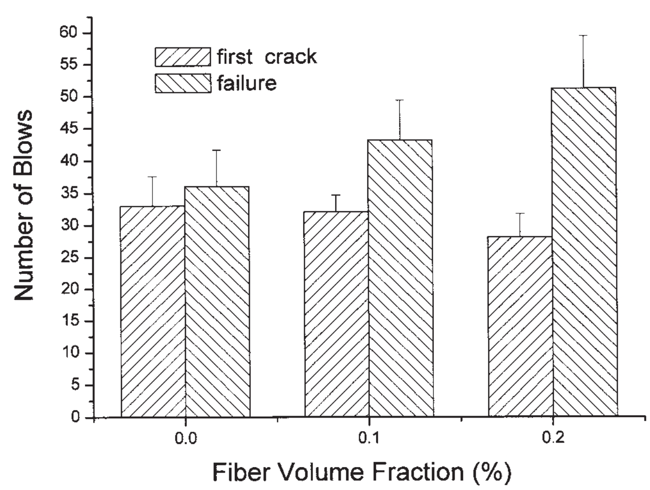

Figure 5 Relationship between fiber content and impact resistance (fiber length: 6 mm).

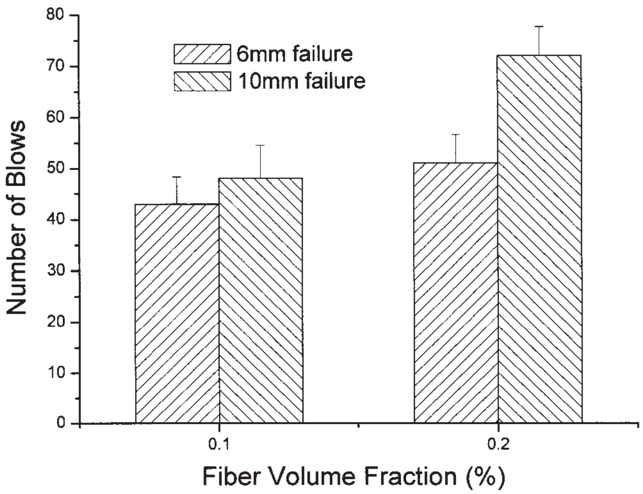

Figure 6 Relationship between fiber content and impact resistance.

necessary to initiate first cracking for fiber reinforced specimens was much higher than that for plain specimens. The difference may be attributed to the property discrepancy of the fibers used in the two studies.

Drying shrinkage

The drying shrinkage test data for plain and fiber reinforced mortars are shown in Figure 7. The results indicate that the drying shrinkage of mortars depends upon various factors, such as age of mortars, fiber content, and fiber lengths. The drying shrinkage decreases with the increase of fiber content, and further decreased when longer fiber was used at the same volume content of fiber.

Water infiltration

Mortars shrink when subjected to a drying environment. One of the methods to reduce the adverse effects of shrinkage cracking is to reinforce it with short, randomly distributed fibers.[6] PP fibers have been used in cementitious matrix mainly to reduce shrinkage cracking. The arrest of shrinkage cracks in fresh mortars by fibers could lead to the reduction of water infiltration compared with plain mortar. Figure 8 presents the water infiltration test data. The water infiltration of the mortars reinforced with MMPPF is much lower than that of the mortars without PP fibers. The presence of fibers reduces the shrinkage cracking. The length of fibers and fiber content have influence on the water infiltration; the longer length and higher content somewhat have a positive effect. For this reason, MMPPF with a large length/diameter ratio is more effective for the reduction of water infiltration.

Load-deflection

Flexural load-deflection curves of plain mortar and reinforced mortar with the fiber volume fraction of 0.2% are shown in Figure 9. Comparing the area underneath the load-deflection curves, the addition of polypropylene fibers increases slightly the flexural toughness of mortars. In addition, the mortars without fibers ruptured abruptly when flexural load increased, and the flexural load dropped to almost zero. The mortars reinforced with fibers ruptured smoothly, and the flexural load was maintained at some values as the deflection increased. The results are consistent with the research findings of Ramakrishnan et al.,[1] who report an insignificant gain in flexural toughness of concrete due to the addition of the monofilament

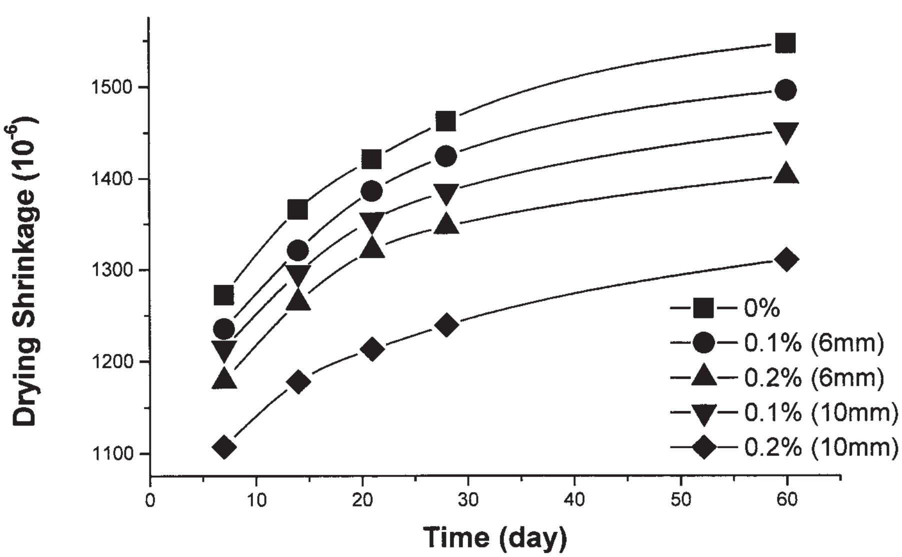

Figure 7 Variation of drying shrinkage of mortars with time.

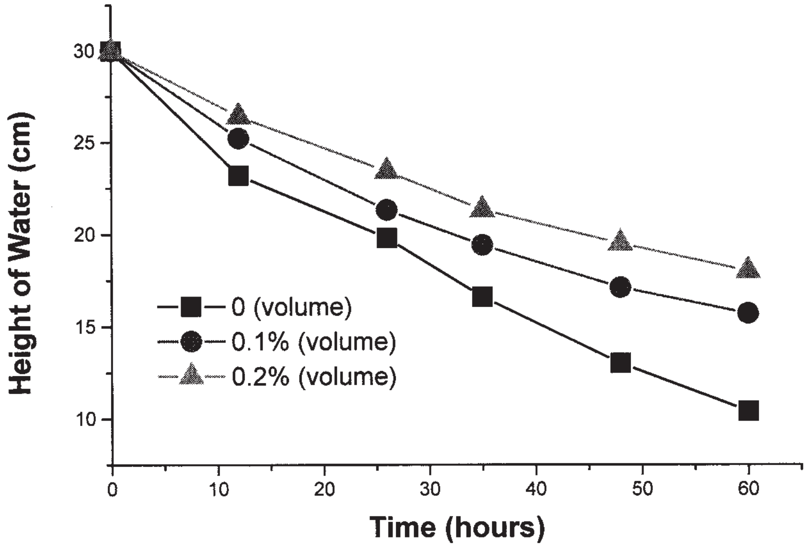

Figure 8 Relationship between fiber content and water infiltration of mortars.

polypropylene fibers. Compared with the flexural toughness of fibrillated polypropylene reinforced concrete,[4] the monofilament polypropylene does not have the same effect as fibrillated polypropylene. The rupture strain of fiber reinforced mortars is much higher than that of plain mortars.

CONCLUSION

The effects of subdenier monofilament polypropylene fibers at volume fractions from 0.1 to 0.2% on the fresh and hardened mortars were investigated experimentally. Based on the results presented in this paper and observations made during mixing, casting, and testing, the following conclusions can be drawn:

1. Fiber reinforced mortar mixtures exhibit good workability though a decrease in flow is found with the addition of fiber. Placement and compaction is done with relative ease.
2. Fiber reinforced mortar mixtures have almost no bleeding, and the setting time decreases compared with that for plain mortars.
3. The unit weight of fiber reinforced mortars is lower than that of plain mortars, and the unit

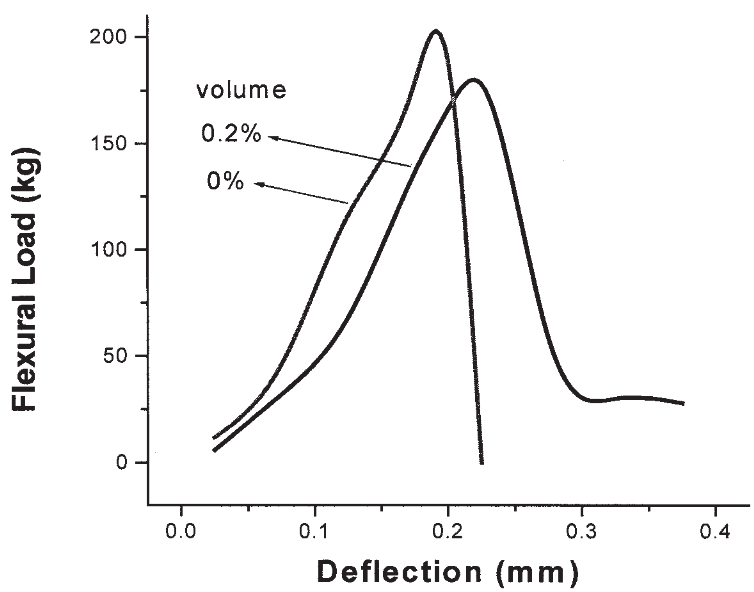

Figure 9 Flexural load-deflection curves for plain and fiber reinforced mortars.

weight of fiber reinforced mortars decreases with an increase in the fiber fraction.
4. The addition of fiber has no positive effect on the compressive strength, even the fiber reinforced mortars show a slight drop in compressive strength.
5. The inclusion of fibers significantly enhances the number of blows to failure, but shows almost no changes in the number of blows to first crack.
6. The addition of fiber had a positive effect on water impermeability, and the extent of the influence depends on the fiber length and fiber volume fraction.
7. The inclusion of fibers enhances slightly the flexural toughness of mortars, but the rupture strain of fiber reinforced mortars is larger than that of plain mortars.
8. The addition of fiber reduces drying shrinkage, and the amount of reduction depends on the fiber length and fiber volume fraction.

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