Surface Treatments of Subdenier Monofilament Polypropylene Fibers to Optimize Their Reinforcing Efficiency in Cementitious Composites

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ABSTRACT: The surface properties of polypropylene (PP) fibers have an important effect on their reinforcing efficiency in cementitious composites. Two new methods of modifying the surface of subdenier monofilament polypropylene fibers were introduced, as well as the performances of the fiber-reinforced mortar. The results show that the surface modification improved the mechanical performance of the fiber-reinforced mortars, such as compressive strength and flexural strength, and the reinforcing efficiency depends on the adopted method. The enhanced interfacial bonding between treated fibers and the cementitious matrix, compared with that of unmodified fibers, was investigated using scanning electronic microscopy. © 2004 Wiley Periodicals, Inc. J Appl Polym Sci 92: 2637–2641, 2004

Key words: reinforcement; subdenier monofilament PP fiber; surfaces; fibers; cementitious materials

INTRODUCTION

Polypropylene (PP) fibers have been used in cementitious materials for more than 30 years because of their unique advantages such as alkaline resistance, relatively high melting point, and low cost of the raw material. PP fiber–reinforced cementitious materials exhibit increased impact resistance, increased failure strain, and higher resistance to plastic and drying shrinkage cracking, which contribute to nearly all the cracks observed in concrete before loading.[1,2]

It is generally accepted that there is no physicochemical adhesion between PP fibers and cement, given that PP fibers have a hydrophobic surface and a lower modulus of elasticity than that of the matrix.[3] Bentur et al.[4] suggested two mechanisms that contribute to the bonding: interfacial adhesion and mechanical anchoring. Currie et al.[5] reported that bond performance can be adjusted by changing the geometry of PP fibers. To obtain better adhesion between PP fibers and the cement matrix, some methods have been used to modify PP fiber surface such as oxygen/fluorine oxidation,[1] bromine oxidation, sulfuric acid oxidation, water-soluble polymer treatment, polymer emulsion treatment, detergent treatment,[3] and water-soluble linear polyglycol treatment.[6] Their effects on mechanical properties of fiber-reinforced cementitious materials were also reported.

The PP fibers used for reinforcement are fibrillated, although monofilament PP fibers, especially subdenier monofilament PP fibers, are seldom reported for their utility in fiber-reinforcing cementitious composites. Subdenier monofilament PP fibers, with a large ratio of length/diameter, easy uniform dispersion, and much greater number of fibers compared with the same volume fraction of fibrillated PP fibers, are expected to have a relatively strong effect on the cementitious matrix. So, in the present study, two new methods for modifying the surface of subdenier monofilament PP fibers were used to increase the polarity of PP fiber surface, to obtain better interfacial action between PP fibers and the cementitious matrix, and further to achieve a composite with optimum properties.

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EXPERIMENTAL

Materials and mix proportions

The PP fiber used was characterized as follows: specific gravity, 0.90 g/cm^3; tensile strength, 400 MPa;

tensile modulus, 3500 MPa; fiber length, 6 mm; and denier, 1.0. The cement used was normal #525 Portland cement, fine aggregate siliceous sand (fineness modulus, 2.70), and specified grading. The mortar mix proportions used in this investigation were as follows: sand/cement ratio (S/C) = 2.5; water/cement ratio (W/C) = 0.44. All the mixes were of the same W/C and S/C ratios and the variable was fiber content (0.1 and 0.2%, v/v). The flow of mortars was maintained within 130 ± 10 mm by adding an approximate amount of naphthalene-based superplasticizer.

Surface-modification methods

Gamma rays from a ^{60}Co source preirradiation-induced graft copolymerization of acrylic acid onto subdenier monofilament PP fibers

Graft copolymerization of hydrophilic monomer onto subdenier monofilament PP fiber by using gamma rays from a ^{60}Co source as initiator by a preirradiation technique was previously reported.[7–9] In the present investigation, the hydrophilic monomer used was acrylic acid. The reaction process can be typically described as follows: the PP fibers were placed in glass tubes and irradiated under gamma rays from a ^{60}Co source. All irradiation was carried out at room temperature in the presence of nitrogen. Specified amounts of acrylic acid, ammonium ferrous sulfate, and distilled water were charged to the reaction flask. Then a given amount of irradiated PP fibers was added to the flask. The flask was immersed in a waterbath that was maintained at constant temperature. After the desired reaction periods, the PP fibers were washed with distilled water and allowed to dry naturally. The grafting yield was controlled by the irradiation time. To maintain the original mechanical properties of PP fiber, the grafting yield was controlled in the range of 3.5–5.0%.

Treatment of subdenier monofilament pp fibers with surface–active agents

The subdenier monofilament PP fibers were dipped in a solution of nonionic surfactant (OP-10, 0.5 wt %) or in a solution of anionic surfactant [sodium dodecyl sulfonate (SDS), 0.5 wt %] for 10 min, and dried at room temperature.

Specimen preparation and testing

All materials were mixed by a suitable method so that the treated fibers or untreated fibers were distributed uniformly in the mortars. Fresh mortars were tested in terms of initial flow and wet density. Specimens (40 × 40 × 160) were prepared for the compressive strength and flexural strength tests. All the specimens were covered with plastic after casting, demolded after 24 h, and placed in water maintained at 25°C for up to 28 days before testing. After 28 days the hardened mortars were measured for both compressive and flexural strengths, tested according to JGJ 70-90.

RESULTS AND DISCUSSION

Effect of treatment methods on subdenier monofilament PP fiber properties

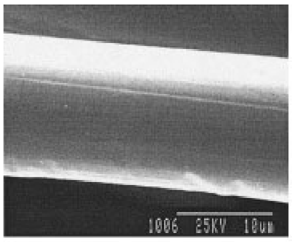
A major effect of the treatment could be observed on the subdenier monofilament PP fiber surfaces, as characterized by SEM. The surface of the untreated fiber was smooth [Fig. 1(a)]. Acrylic acid grafting treatment resulted in the formation of poly(acrylic acid) on the surface; poly(acrylic acid) can enhance the polarity of the PP fiber surface [Fig. 1(b)]. The fiber surfaces treated with different surfactants showed some significant changes, observed by SEM. SDS is a crystalline salt, so the surface of the SDS-treated fibers is much rougher and has some solid substance on it [Fig. 1(c)]. OP-10 is a water-soluble polymer and is prone to form film, so the surface of the OP-10–treated fibers is relatively smooth, but shows some substance adhesive to it [Fig. 1(d)].

Microstructure of the fiber-reinforced mortars

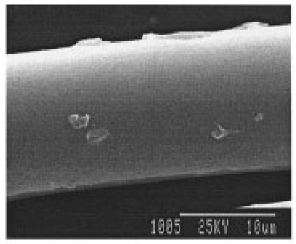
The matrix around the fibers was usually very dense. However, the microstructure of the paste in the vicinity of the fiber surface could change drastically, depending on the surface treatment of the fibers. In the untreated fibers, the contact between the fibers and the matrix was poor, and shows no indication of adhesion [Fig. 2(a)]. Much denser interfaces were observed in fibers treated with acrylic acid [Fig. 2(b)]. In these cases, some penetration of the paste into the surface was observed [Fig. 2(c), (d)].

Freshly mixed mortar

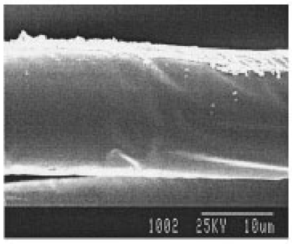
Freshly mixed mortars were tested for flow and density. The results of the tests are presented in Table I. The density for all mixtures was different, depending on the types of fibers and the fiber content. The unit weight of specimens reinforced with grafted and OP-10–treated fibers is higher than that of specimens reinforced with untreated fibers. That is probably attributable to the fact that there is a relatively tight contact between the treated fiber and the matrix at the actual interface, resulting from the increase in interfacial bonding. The reason that the unit weight of specimens reinforced with SDS-treated fibers is lower than that of specimens reinforced with untreated fibers is that the SDS introduces many enclosed microbubbles into the specimens. The microbubbles also resulted in a higher degree of flow. In addition, all mortar specimens re-



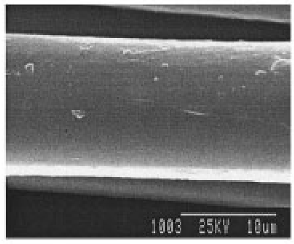
1a. Original PP fiber × 4000



1b. PP fiber grafted acrylic acid monomer × 4000



1c. PP fiber treated by immersion in SDS solution × 4000



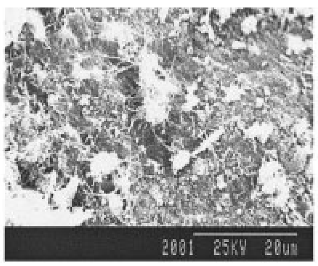
1d. PP fiber treated by immersion in OP-10 solution × 4000

Figure 1 SEM micrographs of the surface of PP fibers treated with various methods.

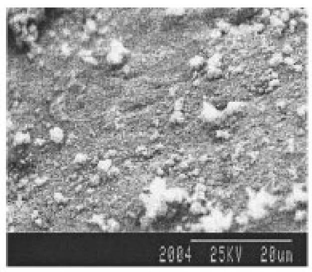
inforced with treated fibers were placed with relative ease and compacted using a vibrating table. Fresh mortar specimens had very little or no surface bleeding and no segregation.

Compressive strength

Compressive strength test results are shown in Figure 3. The compressive strength of the mortar reinforced

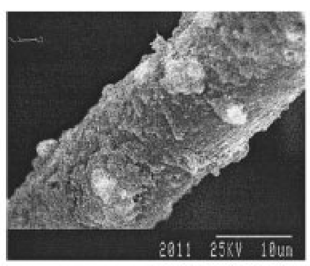


2a. Interface between the untreated fibers and matrix × 2000



2b. Interface between the grafted fibers and matrix × 2000

2c. The surface of PP fibers treated with SDS in matrix × 1500



2d. The surface of grafted PP fiber in matrix × 3000

Figure 2 SEM micrographs of the interface of subdenier PP fiber–reinforced cementitious composites.

TABLE I
Properties of Fresh Mortars

Type of fibers	Fiber volume fraction (%)	Flow (mm)	Density (kg/m^3)
Untreated F	0.1	136	2230
	0.2	131	2180
Grafted F	0.1	132	2350
	0.2	128	2310
OP-10 F	0.1	133	2260
	0.2	130	2235
SDS-F	0.1	142	2190
	0.2	138	2170
Plain mortar	0	139	2280

with acrylic acid–grafted fibers was higher than that of the mortars reinforced with untreated fibers. This result agreed with a previously reported result,[1] which revealed that the increase in polarity of PP fiber surface has a positive effect on the compressive strength of fiber-reinforced cementitious materials. The compressive strength of the mortar reinforced with OP-10–treated fibers was slightly higher than that of the mortars reinforced with untreated fibers, a result that contradicts a previously reported result,[6] which revealed that the effect of nonionic surfactant–treated PP fibers on compressive strength was negative. However, the compressive strength of the mortar reinforced with SDS-treated fibers was almost the same as that of the mortars reinforced with untreated fibers. This is probably attributable to the fact that the increase in strength resulting from the increase in interfacial bonding was counteracted by the air bubbles entrained by the SDS. The increase in PP fiber volume fraction did not have a positive effect on the compressive strength of reinforced mortar, given the lower elastic modulus of the PP fibers compared with that of the mortar matrix. This result agreed with that of previous studies.[10]

Flexural strength

Figure 4 represents the flexural strength of fiber-reinforced mortars. Of all the mortars, plain mortar has the lowest flexural strength. As for the fiber-reinforced mortars, their flexural strength tends to be different from their compressive strength. Regardless of the treatment methods of fiber surface, the flexural strength increases with increasing fiber volume fraction. The grafted fiber–reinforced mortars have the highest flexural strength among the fiber-reinforced mortars at the same fiber volume fraction. This is attributed to the increase in polarity of PP fiber surface and modified interface between fiber and cementitious materials. Accordingly, the flexural strength of OP-10–modified fiber-reinforced mortars is higher than that of SDS-modified fiber-reinforced mortars at the same fiber volume fractions. The effect of surfactant-treated fibers on flexural strength is consistent with the findings of some researchers, such as Peled et al.,[3] who reported that surfactant treatment of PP fiber is effective in enhancing the flexural strength.

CONCLUSIONS

Based on the results presented in this article, the following conclusions can be drawn:

1. The surface status of subdenier monofilament PP fibers treated with the above-mentioned

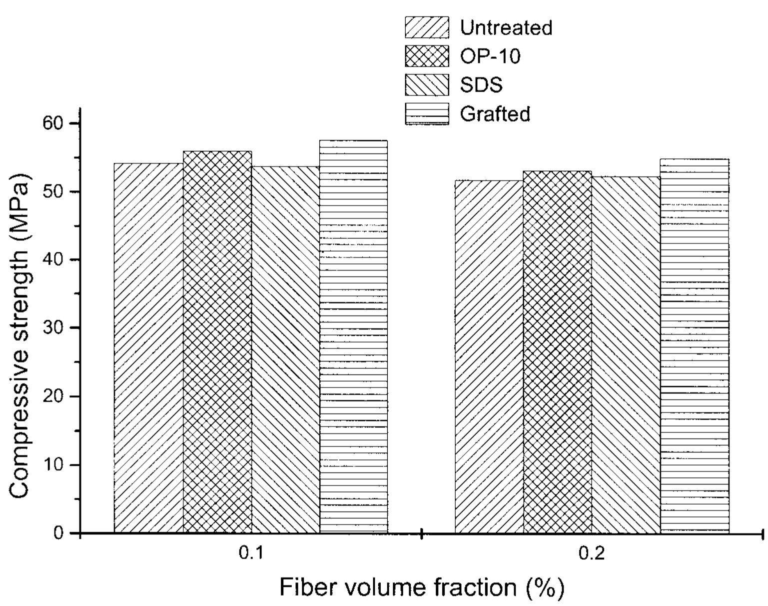


Figure 3 Box plots of compressive strength of treated fiber–reinforced mortars versus fiber volume fraction.

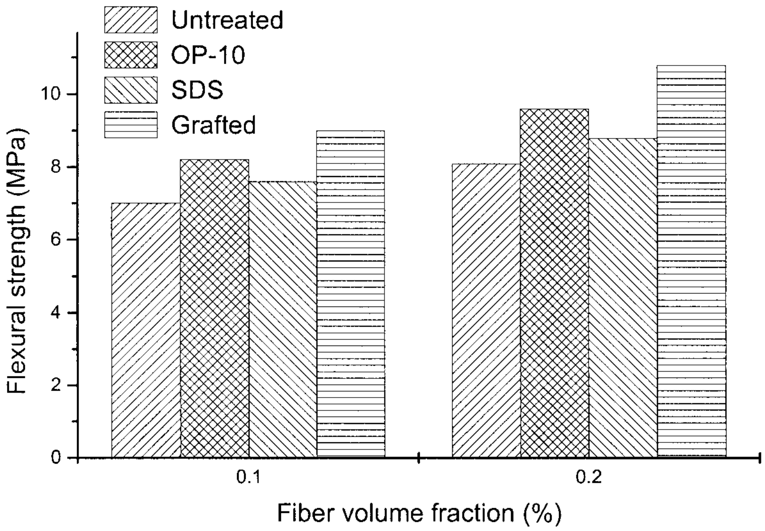


Figure 4 Box plots of flexural strength of treated fiber–reinforced mortars versus fiber volume fraction.

methods is different from that of untreated PP fibers.

2. Observed by SEM, the interfacial bonding between the treated subdenier monofilament PP fibers and the cementitious matrix can be improved.
3. Of all the treatment methods mentioned above, the preirradiation-induced graft copolymerization of acrylic acid is the most effective. The PP fibers grafted with acrylic acid enhanced both the compressive strength and the flexural strength.
4. The subdenier monofilament PP fibers treated with OP-10 enhanced both the compressive strength and the flexural strength.
5. The subdenier monofilament PP fibers treated with sodium dodecyl sulfonate are not effective in enhancing the compressive strength and flexural strength because of the entrained air bubbles.

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