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CHLORIDE PERMEABILITY AND IMPACT RESISTANCE OF POLYPROPYLENE-FIBER-REINFORCED SILICA FUME CONCRETE

H. Toutanji,[1]* S. McNeil,* and Z. Bayasi†
*University of Alabama in Huntsville, Huntsville, AL 35899, USA
†San Diego State University, San Diego, CA 92782, USA

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ABSTRACT

Permeability and impact resistance of polypropylene-fiber-reinforced concrete mixtures containing silica fume with variable design proportions were studied. Two fiber lengths were considered, 12.5 and 19 mm, and four fiber volume fractions, 0, 0.1%, 0.3%, and 0.5%. Silica fume was used as a replacement by weight of cement. Two silica fume contents were used, 5% and 10%. Results showed that the incorporation of polypropylene fibers increased the permeability of conventional concrete. The addition of silica fume improved fiber dispersion in the cementitious matrix, causing a significant reduction in the permeability of the polypropylene fiber reinforced concrete. Moreover, the addition of silica fume was noted to significantly enhance the polypropylene fiber effectiveness in improving the impact resistance of concrete.

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Introduction

Polypropylene fibers have generally been used as a secondary reinforcement for concrete materials. In most cases, volume fractions of polypropylene fibers for this application ranged from 0.1% to 0.5%. They were found beneficial in reducing shrinkage cracking and improving impact resistance of concrete (1). No additional precautions are generally needed for mixing or manufacturing of concrete with polypropylene fibers. Some researchers, however, suggested the reduction of aggregate content in order to increase the effectiveness of polypropylene fibers in concrete. In general, while polypropylene fibers have shown little contribution to flexural strength, they have shown significant improvement in shrinkage cracking, impact resistance and ductility of concrete. Polypropylene fibers are chemically inert and have relatively high tensile strength and an acceptable resistance to temperature (165°C average melting point and 130°C average for highest safe temperature). However, the disadvantage of polypropylene fibers is their low elastic modulus (2).

Silica fume is added to concrete to improve strength and reduce permeability. But there are other properties that are favorably affected by the incorporation of silica fume, including: modulus of elasticity (3), drying shrinkage (4,5), bonding (concrete steel), (6),

[1]To whom correspondence should be addressed.

TABLE 1
Permeability and impact resistance test results.

Test Group	Mix No.	Silica Fume (%)	Fiber Volume (%)	Fiber Length (mm)	Permeability (coulombs)	Impact Resistance (No. of blows)
1	1	0	0	—	3162	5
	2	0	0.1	19	8332	20
	3	0	0.3	19	8614	42
	4	0	0.5	19	11905	73
2	5	5	0	—	1723	7
	6	5	0.1	19	2001	42
	7	5	0.3	19	2352	59
	8	5	0.5	19	3556	87
3	9	10	0	—	841	8
	10	10	0.1	19	496	48
	11	10	0.3	19	737	88
	12	10	0.5	19	971	153
4	13	0	0.1	12.7	4510	31
	14	0	0.3	12.7	6370	36
	15	0	0.5	12.7	6796	71
5	16	5	0.1	12.7	1167	46
	17	5	0.3	12.7	1160	72
	18	5	0.5	12.7	1904	92
6	19	10	0.1	12.7	752	104
	20	10	0.3	12.7	737	166
	21	10	0.5	12.7	493	210

For all the above mixes: water/binder = 0.41; superplasticizer/binder = 1%; aggregate/binder = 4.0; and sand/gravel = 1.0.

and resistance to reinforcing steel corrosion and sodium sulfate attack due to low permeability to water and chloride ions (7–9). On the other hand, some unfavorable properties are associated with the addition of silica fume to concrete, such as loss of slump and reduction in ductility (10).

Among the common field applications of silica fume concrete are bridge overlays and industrial floors. These applications are encouraged due to the low permeability and high strength of the silica fume concrete. Fibrillated polypropylene fiber concrete has found increasing applications in slabs on grade, industrial floors, and overlays, due to its enhanced impact resistance and reduced cracks. The use of silica fume concrete reinforced with fibrillated polypropylene fibers thus warrants investigation. By achieving a decreased permeability and increased impact and cracking resistance, a material with superior properties for overlay applications can be achieved. This paper studies the role of silica fume in enhancing the effectiveness of fibrillated polypropylene fibers as concrete reinforcement. The results presented in this paper will provide more information on the mechanism of action of fibrillated polypropylene fibers in reinforcing concrete materials.

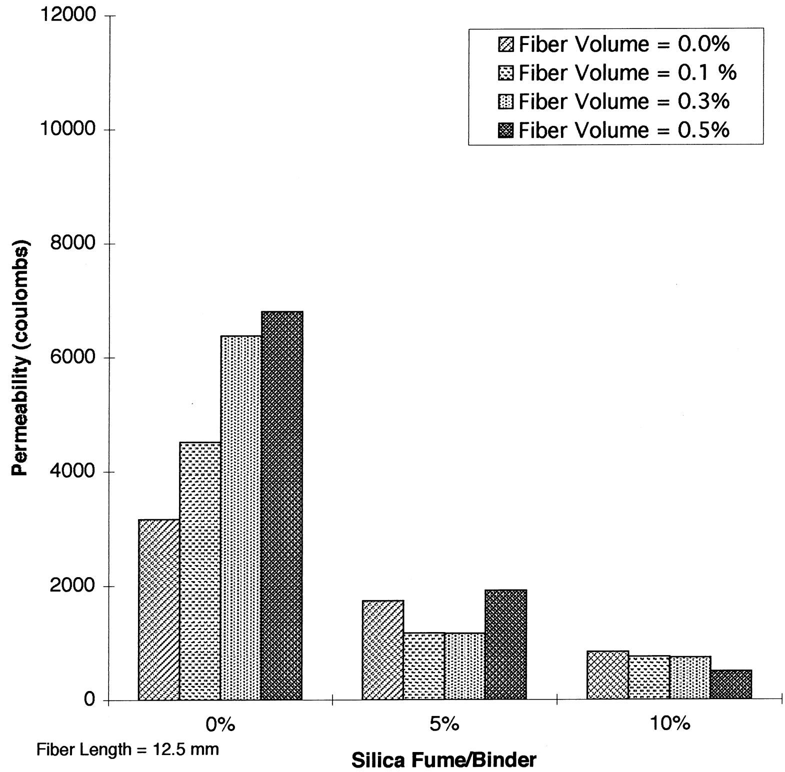

FIG. 1.
Effect of silica fume on the permeability of polypropylene-fiber-reinforced concrete (fiber length 12.5 mm).

Experimental Program

The following materials were used in this study: a) ASTM Type I Portland cement; b) silica fume with a silicate (SiO_2) content of 96% and an average particle size of 0.15 μm (11); c) a naphthalene formaldehyde sulfonate based superplasticizer which was adopted for its effectiveness in silica fume concrete (12); d) natural river sand and gravel, with a maximum aggregate size of the gravel of 9 mm; and e) fibrillated polypropylene fibers with a specific gravity of 0.91, with a tensile strength ranging between 550 and 760 MPa, a modulus of elasticity of 3,500 MPa, and a melting point of 160°C (13). The weight of cementitious materials was considered equal to the sum of the weights of cement and silica fume. Silica fume was used as a partial replacement of cement by weight.

The mixtures of polypropylene fiber silica fume concrete were divided into six groups, as presented in Table 1. The constituent variable in each group was the polypropylene fiber volume fraction, which ranged between 0 and 0.5%. Silica fume contents by weight were selected as 0% for groups 1 and 4, 5% for groups 2 and 5, and as 10% for groups 3 and 6. Fiber lengths were chosen as 19 mm for groups 1, 2, and 3, and as 12.5 mm for groups 4, 5, and 6.

A conventional drum mixer was used. The mixing procedure used was as follows:

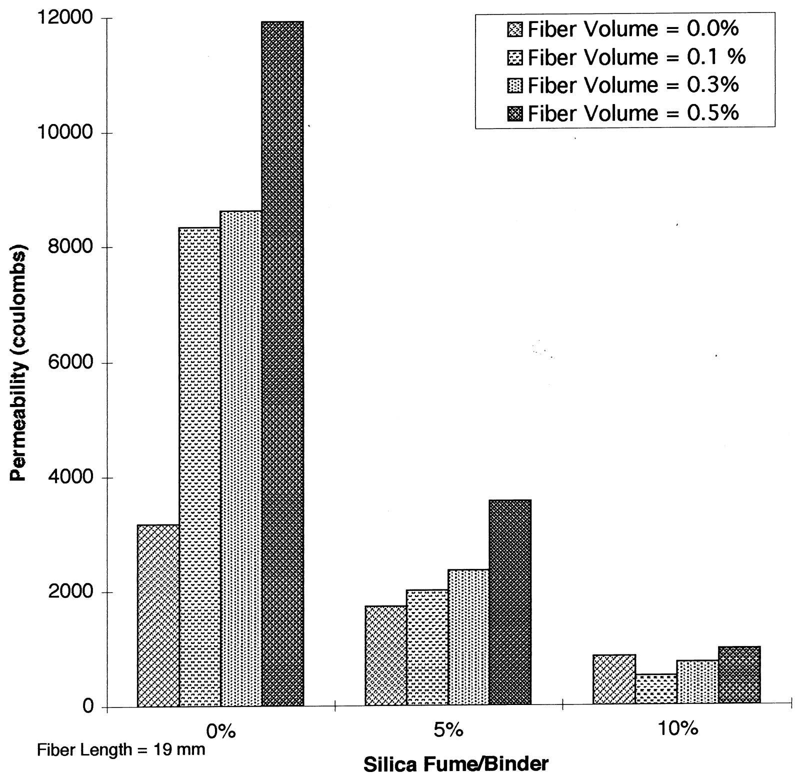

FIG. 2.
Effect of silica fume on the permeability of polypropylene-fiber-reinforced concrete (fiber length 19 mm).

- Place half of the aggregates (sand and gravel) in the mixer and start the mixer;
- Add half of the mixing liquids (water-superplasticizer mixture) to the running mixer;
- Add the silica fume with a small amount of mixing liquids to preserve fluidity and workability of the mixture;
- Add the remainder of the aggregates followed by cement and the remainder of mixing liquids. The mix at this stage should in a plastic state and relatively cohesive without excessive fluidity so that a uniform dispersion of fibers can be achieved;
- Add the polypropylene fibers to the running mixer. The fibers must be added slowly and individually without touching or sticking to the sides of the mixer;
- Continue mixing for 5 min., stop mixing for 3 min., and finish by mixing for 2 extra min.

Since the fibers used herein are collated into bundles, the 5-min. mixing period after fiber addition was used to enhance fiber dispersion in the mix. The fibrils connecting the individual fibers in the bundle are to be ruptured during mixing so that each single fiber is separated from the bundle and dispersed in the mix. It is worth mentioning that a single fiber (after separation) is characterized by having extending fibrils that enhance bond to the concrete matrix and, consequently, the fiber-reinforcement effect. The required separation of bundles into single fibers in fresh collated fibrillated polypropylene fiber concrete mandates that the

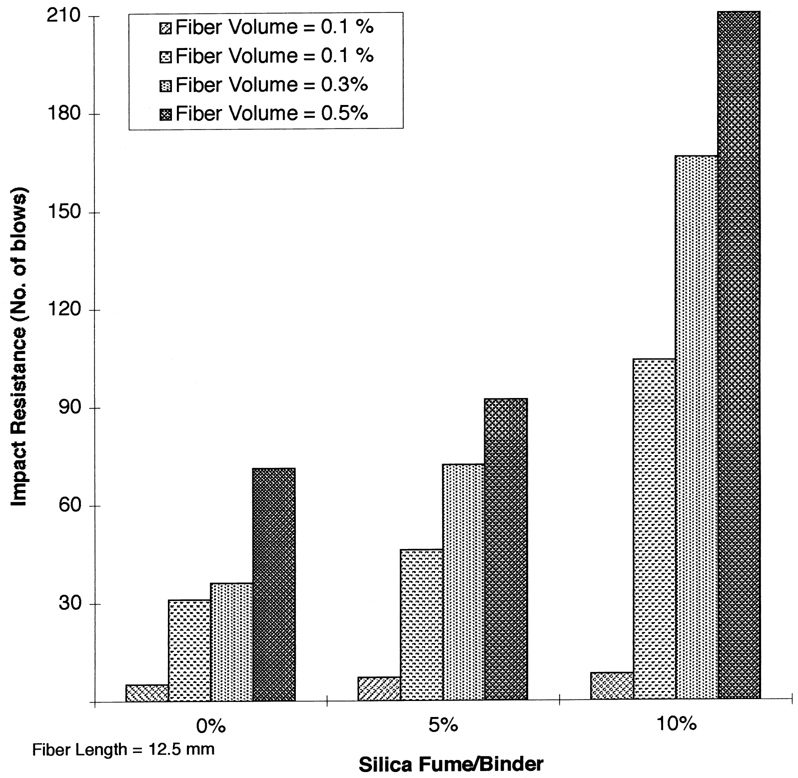

FIG. 3.
Effect of polypropylene fibers on the impact resistance of concrete (fiber length = 12.5 mm).

fresh mix be relatively plastic and cohesive in order to enhance fiber distribution in the mix. Silica fume's effect on increasing the stickiness and cohesiveness of concrete can be an advantageous in this regard.

Over 50 specimens were made. The hardened fibrous concrete specimens were placed in their molds in three different layers. Each layer was vibrated for 30 s or until a thin film of bleed water appeared on the surface of the layer. The specimens were kept covered with plastic sheets in their molds for 24 h. The specimens were unmolded at an age of 1 day. They were then placed in a curing box (22°C and 100% RH) for 7 days. Consequently, the specimens were removed from the curing box and placed in a regular laboratory environment until the testing age of 30 to 35 days.

The following concrete specimens were constructed and tested using standard test procedures:

a) Cylindrical specimens measuring 100 mm in diameter and 200 mm in height were constructed and tested with the accordance to the rapid chloride permeability test, AASHTO T277 (14). This test procedure consisted of sawing a slice (core) of 50 mm thickness from the 100 × 200 mm cylindrical specimen. The slice was painted on the sides with epoxy paint, which works as an insulator. Then, the core was placed under a vacuum suction to evacuate all air from the internal voids of the core. While the vacuum suction was maintained, the core (slice) was submerged in de-aired water so that the

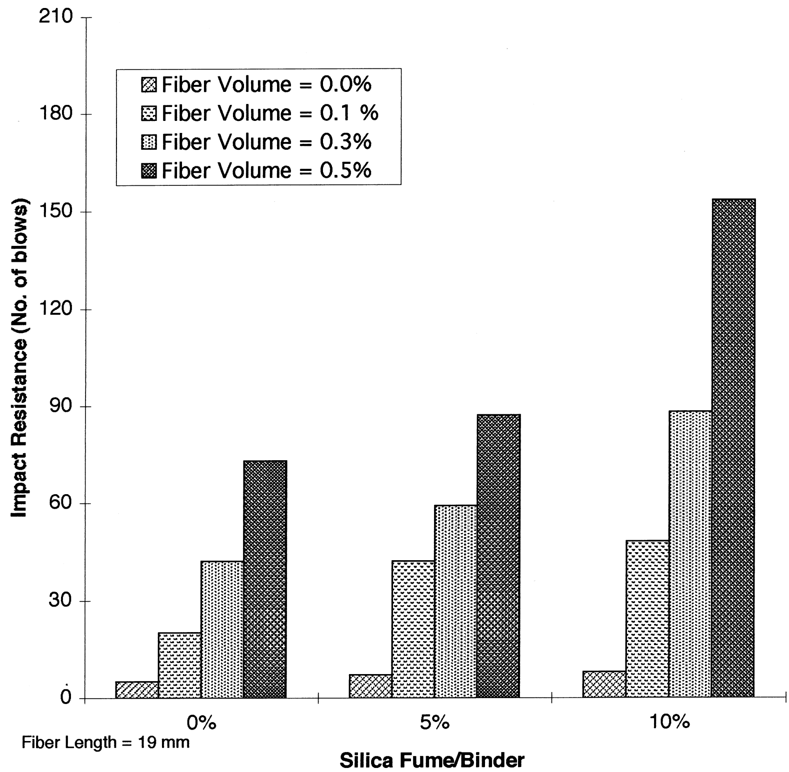

FIG. 4.
Effect of polypropylene fibers on impact resistance of concrete (fiber length = 19 mm).

water filled all the voids. The core or slice was then placed under the effect of a 60 v electric field with one side subjected to a 3% NaCl solution and the other side to a 0.3 normal NaOH solution for 6 h. The electric charge that passed through the specimen was used to represent the specimen's permeability. Two permeability slices were obtained from the mid-height of the cylindrical specimen. These slices were tested and the average of the two tests was used as a representative value of permeability.

b) Cylindrical specimens measured 150 mm in diameter and 63.5 mm in height were constructed and tested in accordance with the impact strength testing procedure, ACI 544 Committee (15). This test measures the number of blows required to fail a cylindrical specimen under the effect of the impact of a hammer weighing 44.6 N dropped from a height of 457 mm. The number of blows required to fail the specimen measures the impact resistance.

Test Results

Test results for permeability and impact resistance of fibrillated polypropylene-fiber-reinforced silica fume and plain concrete are presented in Table 1. Figures 1 and 2 illustrate the effects of silica fume on the permeability of unreinforced and fiber reinforced concrete.

Figures 1 and 2 present the permeability results of polypropylene fiber concrete with fiber length of 12.5 mm and 19 mm, respectively.

The incorporation of polypropylene fibers increased the permeability of plain concrete (containing no silica fume). This is attributed to the fact that polypropylene fibers increase the void content in plain concrete due to the lack of cohesiveness of the cement matrix and poor dispersion of fibers. With increasing fiber length from 12.5 mm to 19 mm, concrete specimens with and without silica fume exhibited an increase in permeability (Figs. 1 and 2).

The addition of silica fume resulted in the reduction of the permeability of polypropylene-fiber-reinforced concrete. The reduction in permeability is an indication of the efficient dispersion of fibers caused by matrix cohesiveness. The addition of 5% silica fume resulted in a significant reduction in permeability. However, the increase of silica fume content from 5 to 10% had a little effect on the reduction of permeability. This behavior was similar regardless of fiber length.

The effect of silica fume on the impact resistance of polypropylene fiber concrete is shown in Figures 3 and 4. Test results showed that the addition of silica fume further improves the impact resistance of polypropylene-fiber-reinforced concrete. This may be the result of better dispersion of polypropylene fibers due to the addition silica fume. Regardless of the fiber fractions and fiber lengths, the impact resistance was significantly increased with the addition of silica fume. The increase in the impact resistance seemed to be proportional to the increase of silica fume content. The optimum increase was seen in specimens with fiber length of 19 mm and silica fume content of 10%. The addition of silica fume exhibited no effect on the impact resistance of the unreinforced concrete specimens.

Conclusions

The following conclusions can be drawn from this study:

1. The incorporation of polypropylene fibers increased the permeability of concrete specimens containing no silica fume.
2. The addition of silica fume lessens the effect of fibers on the permeability of concrete. The reduction in permeability due to silica fume may be attributed to the efficient dispersion of fibers that achieved by the increased cohesiveness of the cementitious matrix.
3. Reducing fiber length from 19 mm to 12.5 mm, with an equivalent volume fraction, resulted in a decrease in the permeability of plain and silica fume concrete.
4. The reduction in permeability is not proportional to the increase in the silica fume content. The addition of 5% silica fume resulted in a significant reduction in permeability. However, the increase of silica fume content from 5 to 10% exhibited little effect on the reduction in permeability.
5. The addition of silica fume enhanced the impact resistance of polypropylene fiber concrete, but has no effect on the unreinforced concrete.

Acknowledgments

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