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Development of a Simple and Fast Test Method for Measuring the Durability of Portland Cement Pervious Concrete

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**DEVELOPMENT OF A SIMPLE AND FAST TEST
METHOD FOR MEASURING THE DURABILITY OF
PORTLAND CEMENT PERVIOUS CONCRETE
(FINAL REPORT)**

**Submitted to
Portland Cement Association**

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ABSTRACT

Portland cement pervious concrete (PCPC) has been increasingly used in concrete pavements during recent years. In addition to strength and permeability, abrasion durability is another important property of PCPC. In this paper, three potential abrasion test methods (Cantabro, loaded wheel, and surface abrasion tests) were investigated for evaluation of abrasion and raveling resistance of PCPC. Eight mixes of PCPC made with different sizes of coarse aggregate and different additives (latex and fiber) were studied. The results indicated that all the three abrasion tests were effective and their results agreed with each other. The surface abrasion test exhibited the best sensitivity. The Cantabro test produced good repeatability and the lowest variation, whereas the variation from the loaded wheel and the surface abrasion tests was relatively high. Studded steel wheel and high wheel pressure were suggested for the loaded wheel abrasion test for PCPC abrasion testing. The results from all the three tests suggested that using small size aggregate (4.75mm) and/or adding latex and fiber could improve the abrasion resistance and compressive strength of PCPC. Addition of latex together with fiber provided the most significant improvement in the abrasion resistance of PCPC.

Keywords: Pervious concrete, Loaded wheel test, Cantabro Loss, Surface abrasion, Durability

1. Introduction

Portland cement pervious concrete (PCPC) is a special concrete that has high interconnected void content of 15 ~ 25% (1). Due to the open pore structure that allows high rates of water transmission, PCPC has been increasingly used on low traffic pavements and parking lots to reduce the amount of runoff water. The rapid drainage of water through interconnected voids can minimize wet weather spray, improve visibility, and minimize glare (2,3). Because of those advantages, PCPC is promising for application on conventional highway.

One of important concerns about the durability of pavement concrete is the abrasion and raveling under repeated traffic loading. Due to the reduced strength and contact area between neighboring aggregate particles, PCPC is more vulnerable than conventional portland cement concrete to cracking and raveling under traffic loads. How to characterize the durability property of PCPC is of great practical importance.

2. Objective and Scope

The objective of the present study was to investigate available laboratory test methods for evaluating abrasion and raveling resistance of PCPC. The three tests considered were the Cantabro, the loaded wheel abrasion, and the surface abrasion tests. Eight mixtures of PCPC made with two different aggregate sizes and different additives were prepared for the evaluation. Necessary modifications to the test setup and test procedures were also investigated in this study.

3. Potential Tests

The following potential tests were investigated in this study:

3.1. Cantabro Test

The Cantabro test, initially used in Europe and South Africa to characterize the durability and resistance to stone loss for open-graded friction course (OGFC) mixtures of hot-mix asphalt (HMA), has been introduced into the United States to determine the resistance of HMA to abrasion (4,5,6,7). OGFC is a porous asphalt mixture with typical air voids of 15%. Since PCPC has many similarities with HMA OGFC, the Cantabro test has the potential of testing PCPC for its durability and abrasion resistance under traffic loads.

The Cantabro test is conducted in the Los Angeles (LA) abrasion machine without the steel ball charges, as shown in Figure 1. The PCPC specimens before and after the Cantabro test are shown in Figure 2. The weight loss occurred during the test was used to characterize to the abrasion resistance of PCPC.

3.2. Loaded Wheel Abrasion Test

The loaded wheel tester (LWT) is commonly used to test the rutting potential of asphalt mixtures by applying a moving wheel load to the surface of an asphalt mixture sample. Several LWTs currently used in the United States include the Georgia Loaded Wheel Tester (GLWT), the Asphalt Pavement Analyzer (APA), the Hamburg Wheel Tracking Device (HWTD), the LCPC (French) Wheel Tracker, and the Purdue University Laboratory Wheel Tracking Device (PURWheel). Among these LWTs, APA is a modification of Georgia loaded wheel tester and is capable of evaluating rutting, fatigue cracking and moisture susceptibility of asphalt mixture (8). APA features controllable wheel load and contact pressure that are representative of actual field conditions (9,10) and thus has the potential of testing the durability and abrasion resistance of PCPC under traffic loads.

As shown in Figure 3, APA was utilized in this study to test the abrasion resistance of PCPC. Since PCPC has much higher stiffness than asphalt mixture, a higher load level (5.5 kN for each wheel) was selected for this abrasion test to provide a higher abrasion force. At the initial stage of this study, steel wheel of smooth surface was used. However, only a very small amount of abrasion was observed due to the smooth wheel surface and the relatively high strength and stiffness of PCPC. The weight loss was less than 0.5%. It was determined that the wheels need to be modified by adding steel studs onto the surface of the wheels (Figure 3) to increase the severity of the abrasion. The studs were 5 mm in diameter and protruded 1.5 mm from the wheel surface. By using studded steel wheel, the wearing and abrasion occurring during the test were significantly improved. Figure 4 shows the specimens after the loaded wheel abrasion test.

3.3. Surface Abrasion Test (ASTM C944)

The surface abrasion test (ASTM C944) is a standard test method to determine the resistance of conventional concrete or mortar to surface abrasion by using rotating-cutter method. The surface abrasion test has been successfully used in the quality control of highway and bridge concrete subject to traffic (11). It has been used by other researchers to evaluate the surface abrasion resistance of PCPC under different curing conditions (12) and has the potential of evaluating the abrasion/raveling resistance of PCPC.

As shown in Figure 5(a), a rotating cutter is mounted in the abrasion device to apply an abrasion force on the surface of PCPC specimens. After the test, the specimen was brush cleaned and its weight loss was recorded and used as an indicator of the abrasion resistance of PCPC.

4. Methodology

4.1. Material Preparation

Eight mixtures of PCPC were used for the evaluation of these three tests (Table 1). The basic mix proportion was cement:coarse aggregate:water = 1:4.5:0.35 (by weight). Two

gradations of single-sized limestone, 9.5 mm (3/8 in.) and 4.75 mm (No. 4), were used as coarse aggregate. Two additives, SBR latex and polypropylene fiber, were added to improve strength and abrasion resistance of PCPC. Typically PCPC has no or little fine aggregate. However, considering the effect of sand for improving the strength of PCPC, a small amount of natural sand was incorporated in the mixes. The specimens were made and cured in the standard curing room for 28 days and cut into specific size for testing.

4.2. Compressive Strength and Porosity tests

The specimens were tested at 28d for compressive strength and porosity to verify that the designed PCPC had sufficient strength and permeability. Three 100 mm-diameter and 200 mm high cylindrical specimens were tested for compressive strength according to ASTM C 39. Three 150 mm-diameter and 100 mm high specimens were used for the porosity test. In the porosity test, the CoreLok device was utilized to measure the void content, which is intimately related to permeability. The Corelok vacuum-sealing method is usually used to determine the density of asphalt mixtures with high air voids such as OGFC (13) and has been successfully applied to PCPC.

4.3. Cantabro Test

The Cantabro testing involves recording the initial weight of individual sample, placing it in the LA abrasion, and then rotating it for 300 revolutions at the rate of 30 revolutions per minute. 150 mm diameter by 100 mm height cylinder specimens were used in the test. The weight loss after the Cantabro test (called Cantabro Loss) is calculated in percentage using Equation (1).

$$\text{Cantabro Loss} = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

where, Cantabro Loss = Weight loss, %;

W_1 = Initial sample weight, g;

W_2 = Final sample weight, g.

4.4. Loaded Wheel Abrasion Test

The specimen used in the loaded wheel abrasion test was 300mm x 125mm x 75mm beam. The abraded area was 116 cm² on the 300mm x 125mm surface. Three specimens were tested for each group. After cleaning the specimen surface and measuring the initial weight, specimens were put into APA for 5500 times fatigue test. The weight loss from this test was calculated in percentage with Equation (1) to evaluate the abrasion resistance of PCPC.

4.5. Surface Abrasion Test

Beam specimens of 300mm x 125mm x 75mm were used in the surface abrasion test. Two locations on the 300mm x 125mm surface were tested for each specimen. The diameter of the abraded circular area is 82.5 mm and the area is 53.5 cm². The normal constant load was 98 N, rotation speed was 200 times/min and the test period was 6 mins.

After cleaning specimen surface and measuring the initial weight, the specimen was fastened in the abrasion device for testing.

Equation (1) was used to calculate the weight loss in percentage from this abrasion test to evaluate the abrasion resistance of PCPC.

4.6. Sensitivity and Repeatability

Sensitivity is an indication of whether a test can differentiate samples with different properties. The sensitivities of the three tests were compared in this study. The result ranges and the ratios of the lowest results to those of the control mix were calculated and compared for the three tests. Low ratio value and high range indicate that a test is capable of differentiating different samples and thus the test method has a good sensitivity.

The coefficient of variation (CV), the ratio of standard deviation to the mean, is a normalized measure of variety and can be used to compare the variation of data sets with different units or mean values. CVs of the test results were calculated in this study to evaluate the repeatability of these tests. Low CV value means high repeatability.

5. Results and Discussion

5.1. Strength and Porosity Test

Typical pervious concrete has just enough cementitious paste to coat the coarse aggregate particles while preserving the interconnectivity. Thus, compared with conventional PCC, PCPC normally has relatively lower compressive strength ranging from 2.8 to 10 MPa (14). Figure 6 presents the compressive strength results of the PCPC studied. It can be seen that the compressive strength of the PCPC mixtures ranged from 5 to 15 MPa,. Addition of latex and fiber and/or using small size aggregate (4.75mm) generally improved the compressive strength. Moreover, compressive strength can be used as an indicator of the abrasion resistance of PCPC. Generally, the higher the strength, the higher the abrasion resistance. Thus, it's estimated that adding latex and fiber and/or using small size aggregate (4.75mm) might be effective in improving the abrasion resistance.

Typically, PCPC has void content of 15 to 25% to ensure sufficient permeability (15). Figure 7 presents the porosity results of PCPC. It can be seen that the porosity results ranged from 20% to 30%, which indicates that the designed PCPC had enough permeability. Figure 8 presents the plot of compressive strength versus porosity. It can be seen that generally the higher porosity, the lower compressive strength.

5.2. Cantabro Test

Figure 9 presents Cantabro loss results. It can be seen that the results could clearly show difference among the tested PCPC mixes, indicating that this test was sensitive enough to

differentiate PCPC mixes with different properties. Generally, using small size aggregate (4.75mm) and/or adding latex and fiber reduced the Cantabro loss, which agreed well with the compressive strength results.

Figure 9 also shows that the Cantabro loss range was within 35% and 80% (1200~2800g), indicating that more than half of the specimen weight was lost during the test for some mixes. The possible reason for this was that some of the specimens fallen apart due to the crash in the test rather than were abraded away because of their low strength. In this case, the test protocol (300 revolution) may be too severe. Less revolutions will be investigated as a potential way to mitigate the weight loss value and to improve the effectiveness of the test.

5.3. Loaded Wheel Abrasion Test

Figure 10 presents the loaded wheel abrasion test results. It can be seen that the test results clearly showed the difference among tested PCPC mixtures. Generally, using small size aggregate (4.75mm) and/or adding latex and fiber could reduce the weight loss, which was in good agreement with the results from the strength and the Cantabro tests. The weight loss values from this test fell within the range of 0.5%~2% (33~101g). The low percent weight loss was mainly due to the relatively small abraded area (116 cm²) compared to the specimen size.

5.4. Surface Abrasion Test

The results from the surface abrasion test are shown in Figure 11. It is observed that the different PCPC mixtures could be clearly differentiated with this test. It can also be seen from Figure 10 that using small size aggregate (4.75mm), and/or adding latex and fiber could increase the abrasion resistance of PCPC. This was very consistent with the results from the Cantabro and the loaded wheel abrasion tests. The weight loss values ranged from 0.2% to 0.5% (11~28g) for this test. In the case of low weight loss value, the inspection of the tested specimen showed that only several small aggregate particles were abraded away from the specimen, which could be attributed to the small abraded area (53.5 cm²) and short testing period (6 min).

5.5. Comparison of the Three Abrasion Tests

Figure 12 presents weight loss of the three abrasion test versus the compressive strength. Table 2 presents the comparison of specimen size, test period, test equipment, test results value, ratio of lowest result to that of the control mix and CVs of the three tests. The comparison of the three abrasion tests was summarized as follows:

1. It can be seen from Figure 12 that, for porous concrete made with large size aggregate (9.5mm), the higher compressive strength, the higher abrasion resistance.
2. The surface abrasion test used the smallest specimen. The specimens having a circular area of 82.5mm in diameter could be used for the surface abrasion test.

3. The test equipment was readily available for the three tests. Only a simple modification (adding studs onto steel wheels) was needed for the loaded wheel abrasion test.
4. The weight loss results from the Cantabro test were much higher and the results from the loaded wheel abrasion and the surface abrasion tests were much lower due the difference in nature between these tests.
5. The loaded wheel abrasion test exhibited the lowest ratio of 45%, followed by the surface abrasion test with 58%. The Cantabro test gave the highest ratio of 62%. All of the three tests exhibited sufficient sensitivity.
6. The CVs of the compressive strength and porosity results were 10% and 8%, respectively. The Cantabro test had the lowest CV of 11.1%, followed by the loaded wheel abrasion test with 19%. The surface abrasion test produced the highest CV of 32%. Researchers at Iowa State University reported that the surface abrasion test had a CV of 31% (14).

6. Conclusions

The Cantabro, loaded wheel, and surface abrasion tests were evaluated and compared. Eight mixes of PCPC made with different sizes of coarse aggregate and different additives (latex and fiber) were studied. Based on the results from this study, the following can be concluded:

1. The loaded wheel abrasion test had the best sensitivity and sufficient repeatability among the three tests. Studded steel wheel and high wheel pressure were suggested for this test for PCPC abrasion testing.
2. The surface abrasion test was also effective for evaluating the abrasion resistance of PCPC though its results had relatively large variance. Longer test period was suggested to increase the severity of the test and enhance its effectiveness.
3. The Cantabro test had fairly good sensitivity and repeatability. However, it also gave high values of weight loss and was not as effective as the other two tests for the evaluation of the abrasion resistance of PCPC. A fewer revolutions were recommended as a potential way to improve its capability.
4. The results from the three tests indicated that using small size aggregate (4.75mm) and/or adding latex and fiber could improve the abrasion resistance and compressive strength of PCPC.

Acknowledgement

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Table 1 PCPC mix proportions

Aggregate Size	Group	Cement (kg)	Coarse Aggregate (kg)	Water (kg)	Natural Sand (kg)	Latex (kg)	Fiber (kg)
9.5mm (9.5mm~ 12.5mm)	Control	311.9	1403.6	109.2	98.3		
	Fiber	311.9	1403.6	109.2	98.3		0.9
	Latex	306.9	1381.2	91.3	96.7	30.7	
	Fiber + Latex	306.9	1381.2	91.3	96.7	30.7	0.9
4.75mm (4.75mm ~9.5mm)	Control	329.8	1483.9	115.4	103.9		
	Fiber	329.8	1483.9	115.4	103.9		0.9
	Latex	324.5	1460.3	96.5	102.2	32.5	
	Fiber + Latex	324.5	1460.3	96.5	102.2	32.5	0.9

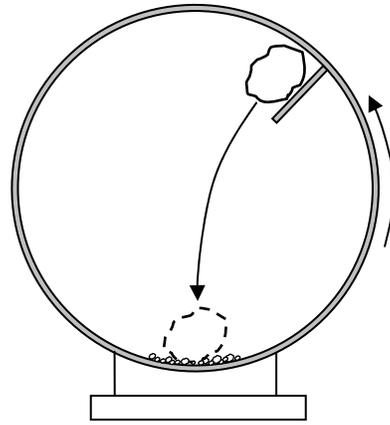
Table 2 Comparison of investigated abrasion tests

Items	Cantabro Loss Test	Loaded Wheel Test	Surface Abrasion Test
Specimen Size	150mmØ x 100mmH (6in.Ø x 4in.H) cylinder	300mm x 125mm x 75mm (12" x 5" x 3") beam	300mm x 125mm x 75mm (12" x 5" x 3") beam *
Test Equipment	LA abrasion machine	APA with studded wheels	Rotating-cutter Device
Test Period	10min	1.5h	6 min
Weight Loss	1200~2800 g (35~80%)	33~101 g (0.6~1.8%)	11~28 g (0.2~0.5%)
Overall CV	10%	19%	32%
Ratio of the lowest result to the result of the control group	62%	45%	58%

*:According to ASTM C944, the rotating-cutter surface abrasion test was primarily intended for use on the top ends of 150 mm (6in.) diameter concrete cores and mortar specimens.



(a) Los Angeles abrasion machine



(b) Illustration of Cantabro Loss test

Figure 1 Cantabro Loss test



Figure 2 Specimens before (left) and after (right) Cantabro Loss Test



(a) Asphalt Pavement Analyzer (APA)

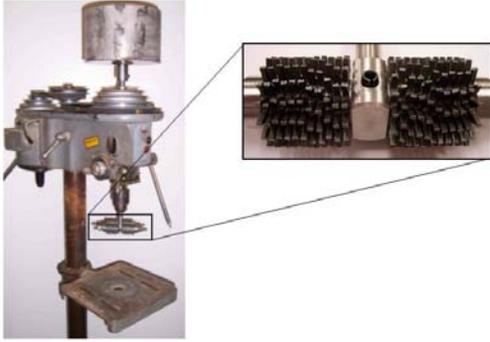


(b) Studded steel wheels

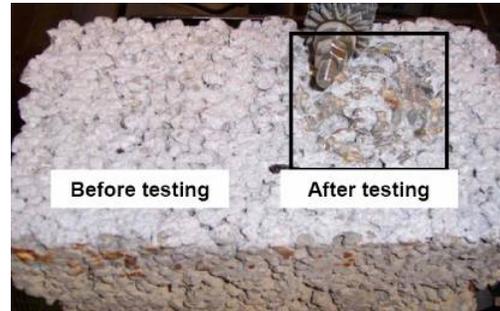
Figure 3 Loaded wheel abrasion test



Figure 4 Specimens after loaded wheel abrasion test



(a) Rotating-Cutter Drill Press



(b) specimens before and after test

Figure 5 Surface abrasion test (after (14))

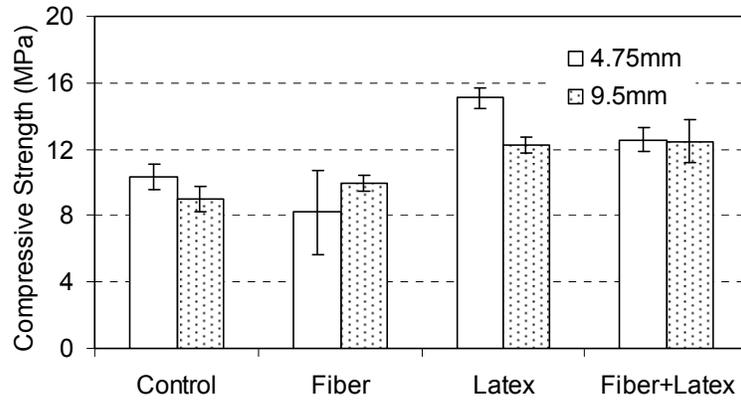


Figure 6 Compressive strength test results

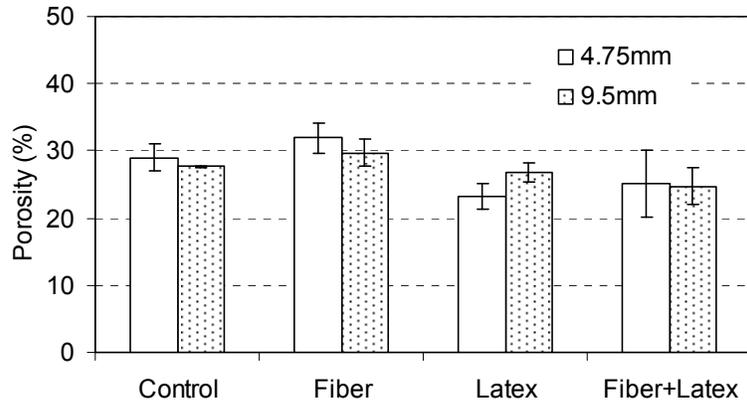


Figure 7 Porosity test results

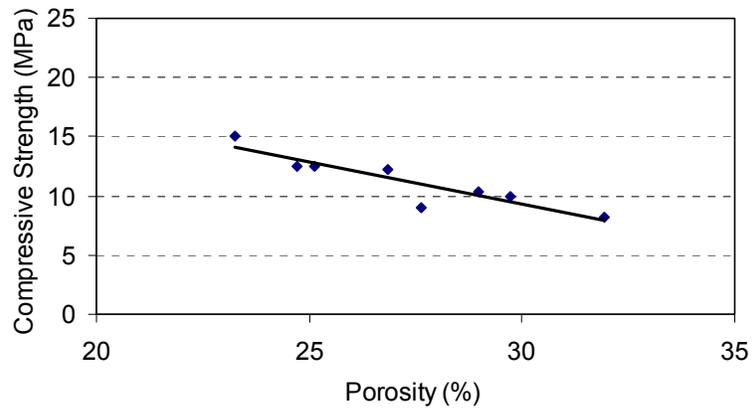


Figure 8 Compressive Strength versus Porosity

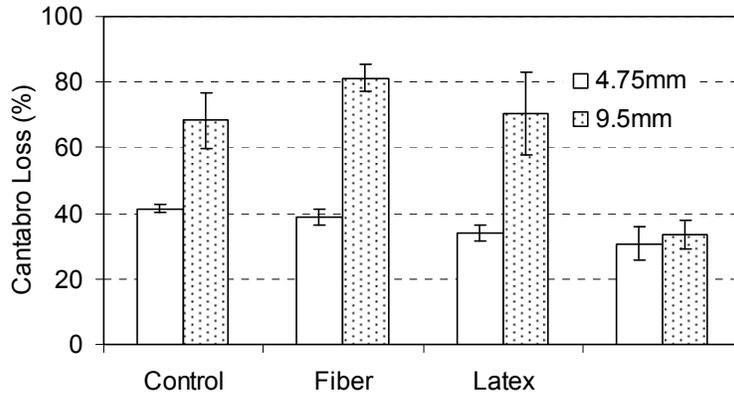


Figure 9 Cantabro Loss test results

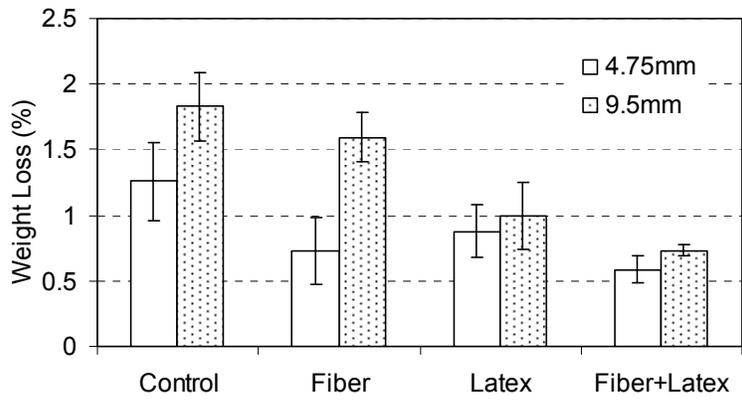


Figure 10 Loaded wheel abrasion test results

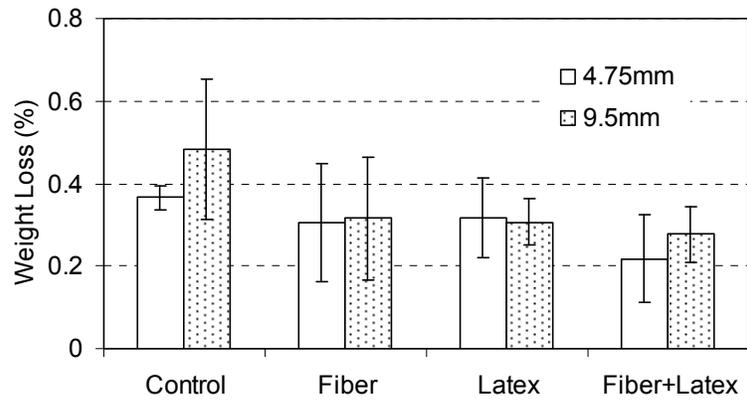


Figure 11 Surface abrasion test results

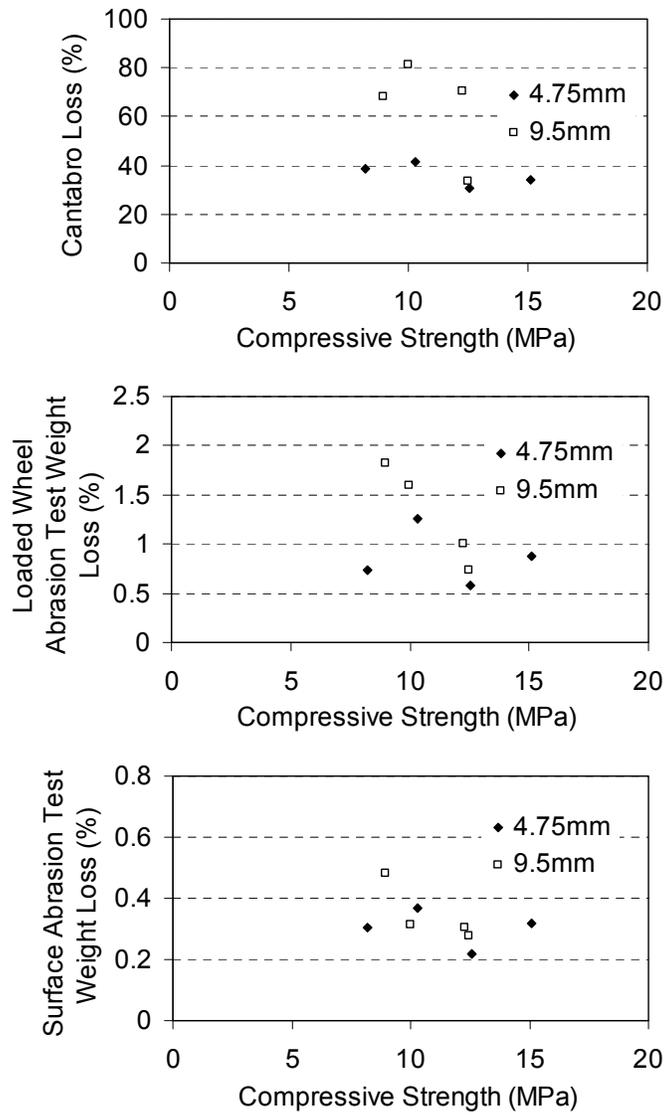


Figure 12 Three abrasion test results versus compressive strength

APPENDIX

Laboratory Evaluation of Abrasion Resistance of Portland Cement Pervious Concrete

(Accepted by **ASCE Journal of Materials in Civil Engineering** as a technical note, in press.) Laboratory Evaluation of Abrasion Resistance of Portland Cement Pervious Concrete