Technical Note

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Evaluation of Polyphenylene Sulfide and Steel Fibers on Mechanical Properties of Pervious Concrete Pavement

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Abstract: Strength is the primary concern for Portland cement pervious concrete (PCPC) designs. Since PCPC has a high void ratio (often without fine aggregate due to the permeability requirement), compressive and tensile strengths tend to be lower than those of conventional concrete pavements. In this experimental study, PCPC mixes made with steel fibers and polyphenylene sulfide (PPS) fibers and various amounts of sand were evaluated. Mechanical properties, porosity, and permeability of the PCPC were tested. The results pointed out adding fibers to the mixes increased the concrete strength as well as void content. It is noteworthy to mention that PPS fibers performed better than steel fibers. Addition of a small amount of fine sand (approximate 7 % by weight of total aggregate) to the mixes with PPS fibers significantly improved the concrete strength.

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***Key words**: Fibers; Mechanical properties; Pavement; Pervious concrete.*

Introduction

Portland cement pervious concrete (PCPC) is a permeable pavement that captures rainfall and stores runoff before it infiltrates into the subsoil. PCPC consists of specially formulated mixtures of hydraulic cementitious materials, uniform open graded coarse aggregate—such as ASTM C-33 #8 or #89 (3⁄8 inch) (10 mm), #67 (3⁄4 inch)(19 mm), to #5 or #56 (1 inch) (25 mm)—and water. The ideal application for PCPC is around buildings (walkways, courtyards, etc.) and parking areas, as well as low-volume roadways [1-3]. PCPC may have some application on highways, where it could be used in shoulder and median construction for stormwater runoff mitigation. There may also be application for its use as a surface material to reduce hydroplaning, splash and spray, and mitigate tire-pavement noise. Permeable concrete pavements are claimed to help control contaminants in waterways, through reducing or eliminating runoff, and allowing treatment of potential pollutants [4]. PCPC is a high-quality product that needs skilled manpower, and its thickness is more than that of conventional concrete pavements; thus, the initial construction cost would be higher, compared to concrete pavements. Significant advantages of PCPC would offset the high construction costs [5].

Strength is often the primary concern for PCPC designs. Since PCPC has a high void ratio (15%-35%) [6-9] (often without fine aggregate due to the permeability requirement), compressive, tensile, and flexural strengths tend to be lower than those of traditional concrete. Wang [2] used river sand to replace approximate 7% coarse aggregate to improve the concrete strength. His study showed that seven-day compressive strength increased about 30 percent.

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Since the 1980s, remarkable research has gone into the development of fiber reinforced concrete to improve mechanical properties, such as compressive, flexural, and tensile strength [10-12]. Fibers in PCPC slightly increase the void content, permeability, and the splitting tensile strength of the PCPC [13-15].

The objective of this study is to evaluate the effect of Polyphenylene sulfide (PPS) and steel fibers with and without the presence of sand. Compressive strength, tensile strength, flexural strength, permeability, and porosity of various PCPC samples are assessed in the following study.

Experimental Work

Materials

Type II cement was used in all mixes based on the specification provided by ASTM C150 (Table 1). Gravel used in the test was uniformly graded, passing the ½” (12.5 mm) sieve but retained on No.4 (4.75 mm) sieve. River sand was used to replace up to 7% of the coarse aggregate. The grading curve of coarse and fine aggregates used within this study, which corresponds to ASTM 33 specifications [16], is shown in Fig. 1. The properties of the aggregates used are summarized in Table 2.

Fibers are used in mixes to improve the mechanical properties of

Table 1. Chemical Composition and Physical Properties of the Cement.

Chemical Analyses of Cement	Weight of Percent (%)
SiO_2	21.9
Al_2O_3	4.86
Fe_2O_3	3.3
MgO	1.15
CaO	63.33
SO_3	2.1
Physical Properties	
Specific Gravity	3.14
Specific Surface Area (cm^2/gr)	3050

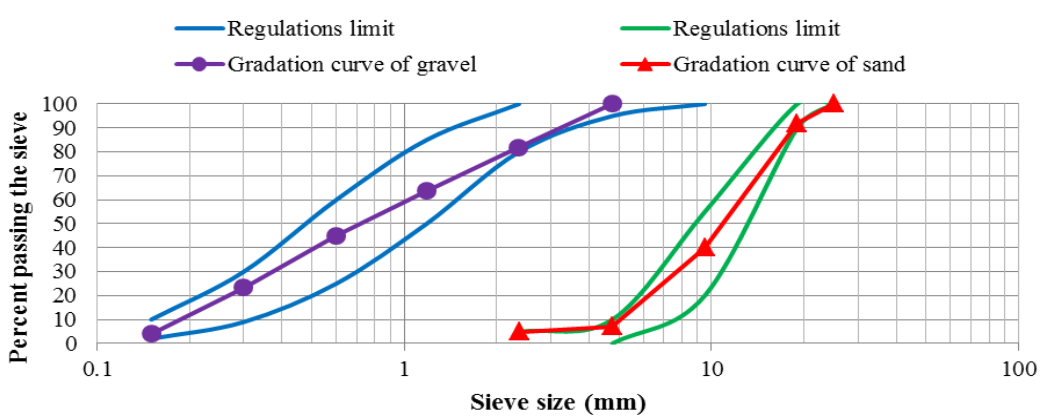

Fig. 1. Gradation Curve of Fine and Coarse Aggregate.

Table 2. Aggregate Properties.

Aggregates Type	Specific Gravity (gr/cm^3)	Fineness Modulus	Sand Equivalent (%)
Fine Aggregate	2.75	2.82	80
Coarse Aggregate	2.51	-	-

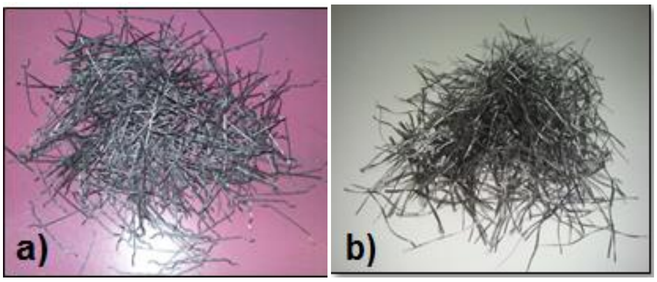

Fig. 2. a) Steel Fibers and b) Polyphenylene Fibers Used in PCPC.

PCPC and prevent the propagation of cracks in concrete. Fibers used in the study include two types of steel and polyphenylene sulfide. Polyphenylene sulfide is an engineered plastic and a high-performance thermoplastic. PPS fibers can be molded, extruded, or machined to high tolerances. PPS fibers in their pure solid form might be opaque white to light tan in color. The maximum service temperature is 218℃ (424℉). PPS fiber has not been found to dissolve in any solvent at temperatures below about 200℃ (392℉). PPS fibers are one of the most important high-temperature thermoplastic polymers because it exhibits a number of desirable properties. These properties include resistance to heat, acids and alkalies, mildew, bleach, aging, sunlight, and abrasion. It absorbs only small amounts of solvents and resists staining. The pictures of fibers are shown in Fig. 2. Fiber properties are shown in Table 3.

Mix Design

Nine mix designs, each divided into three groups, were used. Each group included mixtures with 3.5% and 7% sand, and one mixture without sand. for a total of nine mixtures. All concrete mix proportions used are summarized in Table 4.

Specimen Preparation

All specimens were made by rodding 25 times in three layers with vibration application for five seconds after rodding each layer. The samples were demolded after 24 hours and cured in a water bath in

Table 3. Properties of Fibers Used in Preparing the Pervious Concrete Mixtures.

Type	Length (mm)	Diameter (mm)	Thickness (mm)	Young Modulus (kg/cm^2 x10^5)	Specific Gravity (g/cm^3)
ST	36	0.7	-	16	7.8
PPS	50-54	-	0.07	3.5	0.90

Table 4. Mixture Proportions Used in the Study.

Group	Mix Number	Cement	Fiber	V_f (%)	Gravel	Sand %	Sand kg	Water	SP
1	A.1	340		0	1500	0	0	93	3.5
	A.2	340		0	1447.5	3.5	52.5	93	3.5
	A.3	340		0	1395	7	105	93	3.5
2	B.4	340	PPS	0.3	1500	0	0	93	3.5
	B.5	340		0.3	1447.5	3.5	52.5	93	3.5
	B.6	340		0.3	1395	7	105	93	3.5
3	C.7	340	ST	0.5	1500	0	0	93	3.5
	C.8	340		0.5	1447.5	3.5	52.5	93	3.5
	C.9	340		0.5	1395	7	105	93	3.5

22-25℃ for 28 days. For each mix design, two 15cm by 30cm cylinders were used for both compression and splitting tensile strength tests, including three samples for each one. Three 10 by 10 cylinders were used for each mix design to evaluate the porosity. A total of 81 samples were used for 9 mixes.

Test Methods

In the present study, the slump test was performed for fresh concrete based on ASTM C143 [17]. PCPC void ratio was tested at 7 days. Compressive strength, splitting tensile strength, flexural strength, and water permeability were tested at 28 days. Compressive strength tests were performed according to ASTM C39 [18].

Splitting tensile strength tests were performed based on ASTM C496 [19]. Flexural strength tests were performed based on ASTM C78 [20]. The void content of the PCPC samples was measured by taking the difference in weight between an oven dry sample and an under water sample, and using Eq. (1) [21].

$$P = \left(1 - \left(\frac{W_2 - W_1}{Vol\,.\,\rho_W}\right)\right)100(\%) \quad (1)$$

P = total porosity, %
W_1 = weight under water, kg
W_2 = oven dry weight, kg
Vol = volume of sample, cm^3
ρ_w = density of water, kg/cm^3

Permeability is an important feature of pervious concrete since the material is designed to perform as a drainage layer in pavement structures. The permeability of mixtures was determined using a falling head permeability test apparatus. The test was performed using several water heights, which represented values that a pavement may experience. The average coefficient of permeability "k" was determined using Eq. (2), which follows Darcy's law and assumes laminar flow [22].

$$k = \frac{aL}{At}\ln\left(\frac{h_1}{h_2}\right) \quad (2)$$

where:
k = coefficient of permeability, cm/s
a = cross sectional area of the standpipe, cm^2
L = length of sample, cm
A = cross-sectional area of specimen, cm^2
t = time in seconds from h_1 to h_2
h_1 = initial water level, cm
h_2 = final water level, cm

Results and Discussion

Porosity

Fig. 3 presents the porosity results for all samples and the effect of steel fibers, PPS, and sand on porosity. It is seen that most of the mixtures had porosities ranging from 21.3% to 28.9%, which is within the acceptable range [23]. Steel and PPS fibers have no significant effects on the porosity if used alone. Porosity is reduced by using sand.

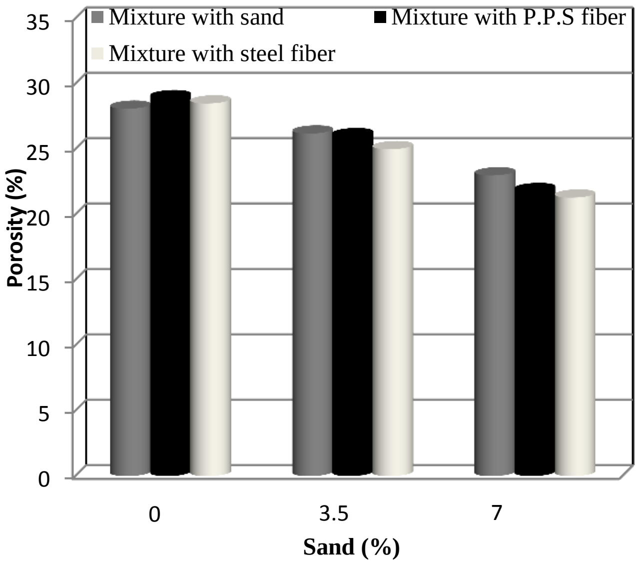

Fig. 3. Effect of Fibers and Sand on Porosity.

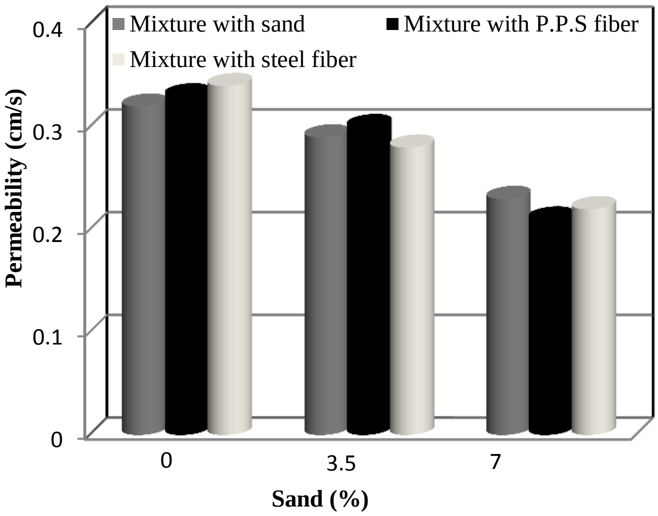

Fig. 4. Effect of Fibers and Sand on Permeability.

Permeability

The permeability results are presented in Fig. 4. It is evident that all the pervious mixtures had permeability values between 0.8 and 1.2 cm/s, which is within the satisfactory range [23] and can be used as a drainage layer for PCPC. According to Fig. 4, the effect of steel fibers, natural sand, and PPS fibers on permeability were similar to the porosity test results. Although addition of the fibers could lead to a reduction in permeability, the permeability values were reasonable compared to the established requirement of drainage [23].

Compressive Strength

The effects of PPS fibers, steel fibers, and sand on the compressive strength are shown in Fig. 5. It is evident the addition of sand, steel and PPS fibers could increase the compressive strength of concrete mixtures, even if they're used on their own. PPS fibers increased the compressive strength up to 15 percent. Steel fibers increased the compressive strength about 6 percent. Adding natural sand increases the amount of cement mortar, thus increasing the contact area between neighboring aggregate particles. Subsequently, the increased contact area results in strength improvement. In comparison with steel fibers, PPS fibers have better interlock with aggregates, due to their higher flexibility, causing a further increase the compressive strength by 31 percent.

Tensile Strength

Fig. 6 compares the effects of PPS fibers, sand, and steel fibers on the splitting tensile strength. Fig. 6 shows the effect of sand on the splitting tensile strength was not as significant as that of compressive strength. However, the effect of PPS accompanied by sand was significant in increasing the splitting tensile strength of pervious concrete and increased this parameter about 32 percent. Fig. 6 also shows that the effect of steel fiber on the splitting tensile strength was less than its effect on the compressive strength. The addition of fiber provides a small increase in the splitting tensile strength of the control mix. Addition of sand and steel fibers showed a better result, and increased tensile strength of the PCPC about 25 percent. PPS fibers and sand performed better in comparison to sand and/or steel fiber used in pervious concrete, as shown in Fig. 6.

Flexural Strength

Fig. 7 shows the effects of using fibers and different amounts of sand on the flexural strength. Similar to tensile strength, with the addition of sand and fibers, the flexural strength of PCPC fibers is significantly increased. Sand increased the flexural strength noticeably. PPS and steel fibers increased the flexural strength up to 28% and 20%, respectively. PPS fiber performed better than steel fiber due to its higher length and flexibility.

Summary and Conclusions

This study found that pervious concrete mixture proportions can be optimized for strength, permeability and porosity with sand, or sand and fibers. Based on this study, the following conclusions are made:

- Using both sand and fiber could produce PCPC with proper drainage and strength properties.
- Fibers and sand could both decrease the porosity and permeability of pervious concrete and increase the compressive strength of pervious concrete. Best results are obtained when both sand and PPS fiber are used. If sand and fibers are not used together in the PCPC, the tensile strength of the samples would not improve significantly.
- In PCPC with sand and PPS fibers, the compressive strength, flexural strength, and tensile strength of the samples increased up to 65%, 55% and 57%, respectively.
- In PCPC with sand and steel fibers, the compressive strength, flexural strength, and tensile strength of the samples increased up to 51%, 50%, and 47%, respectively.

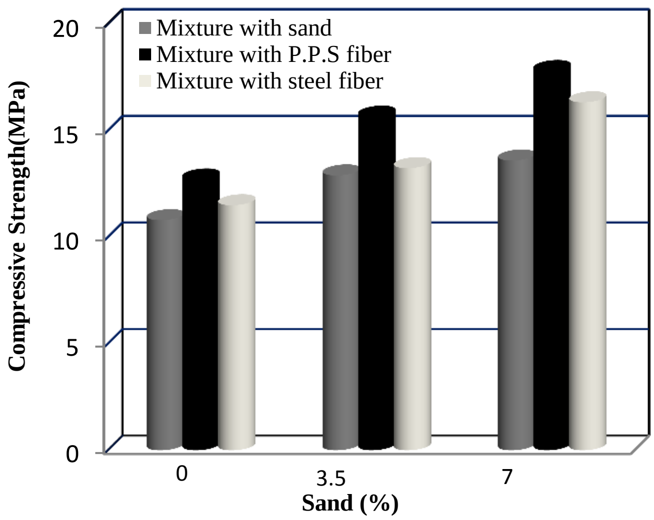

Fig. 5. Effect of Fibers and Sand on Compressive Strength.

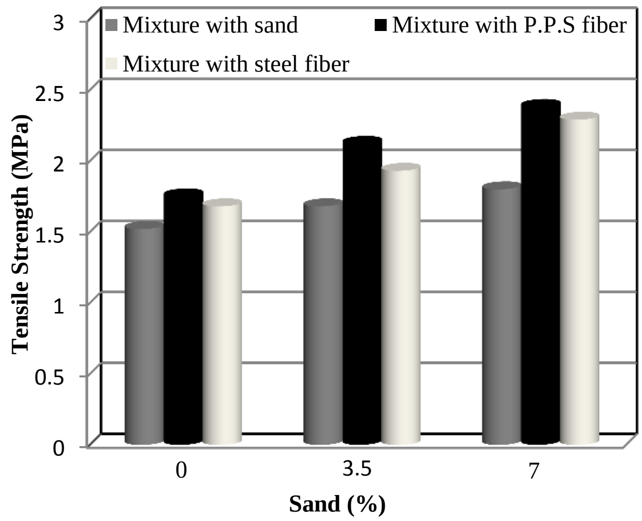

Fig. 6. Effect of Fibers and Sand on Tensile Strength.

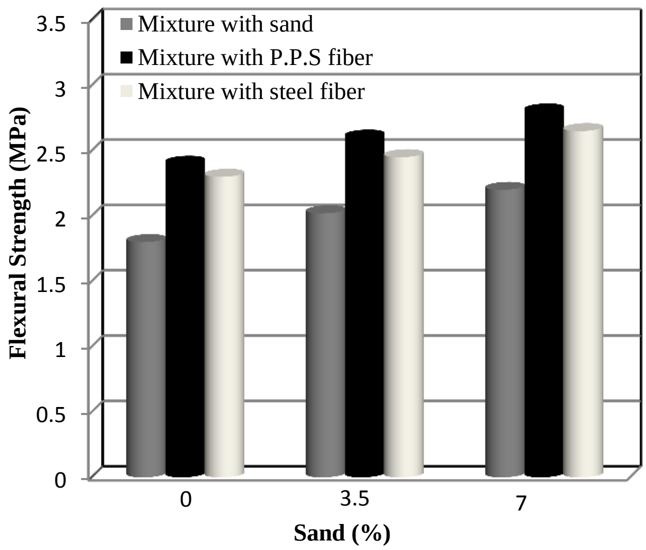

Fig. 7. Effect of Fibers and Sand on Flexural Strength.

- PPS fibers, if accompanied by sand, have significant effects on improving the tensile and flexural strengths of pervious concrete.
- Fiber length has a significant effect on the tensile and compressive strength of pervious concrete in this study. This is because fibers with higher length were dispersed and evenly distributed throughout the PCPC mixture.

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