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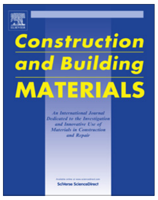

Experimental study on Portland cement pervious concrete mechanical and hydrological properties

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HIGHLIGHTS

- The average water permeability coefficient of PCPC was found 0.021 m/s.
- Smaller aggregate size produces a higher compressive strength in PCPC.
- Linear regression equations were developed for the compressive strength of PCPC.

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ABSTRACT

Pervious concrete layer is one of the effective concrete pavement mixes to address a number of important environmental issues, such as recharging groundwater and reducing storm water runoff. Portland Cement Pervious Concrete (PCPC) is produced by eliminating most or all of the fine aggregate in the mix, which allows interconnected void spaces to be formed in the hardened matrix. These interconnected void spaces allow the concrete to transmit water at relatively high rates. Twenty-four PCPC mixtures were prepared and tested to address the effect of different size fractions of coarse aggregate, water-to-cement ratio, cement content, and coarse aggregate volume on the relationships between compressive strength, tensile strength, porosity, and permeability. The mixtures used in this study consisted of either one or two aggregate sizes. Linear regression relationships were developed to establish relationships between density and porosity, compressive strength and permeability, tensile strength and permeability, and compressive strength and porosity. The results showed that properties such as permeability, porosity, are significantly affected by using either one or two coarse aggregate sizes in all concrete mixtures. Furthermore, density can be an effective factor for predicting compressive strength, and porosity. In this study, the maximum compressive strength was 6.95 MPa, which obtained by using one aggregate size of 9.5 mm with 250 kg/m^3 cement content. The obtained results showed that PCPC could be produced using one or two aggregate sizes at most.

1. Introduction

Pervious concrete is a mixture of Portland cement, water, coarse aggregate, and, in some cases, chemical admixtures and/or supplementary cementitious materials. The workability of fresh PCPC is usually decreased by the exclusion of fine aggregate. Therefore, a compaction effort must be applied in order to obtain desired properties, which includes compressive strength and permeability. The lack of fines also creates an open void structure, allowing water to infiltrate from the surface down through the interconnected voids. The porosity plays a major role in the hardened properties of pervious concrete. Past research has shown that the effective void content affects the compressive strength and water permeability of the hardened concrete. At higher porosity ratios, water permeability is increased, but the compressive strength is decreased [1 and 2], thus it is essential to optimize the effective void content in order to achieve the desired strength and permeability. Effective void content in pervious concrete typically ranges from 15 to 35% [3]. The desired void content may be achieved either by controlling the level of compaction effort and the aggregate proportions and properties.

Pervious concrete is a relatively new paving material valued for its use in the management storm water runoff. Pervious concrete may also improve land utilization by decreasing the need for detention basins [3]. It has environmental impacts such as water

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pollution removal and maintaining ground water levels. Tennis et al. [3] presented the results of two studies that showed very high water pollutant removal rates for pervious concrete. The tests performed in Virginia and Maryland showed 82 and 95% total suspended solids removal for pervious concrete, respectively. Larger void ratios will increase infiltration rates, but will significantly decrease the compressive strength. Recommended porosities range from 15% to 25% [4], which is mainly dependent on aggregate size and gradation. ACI Committee 522 recommended a minimum of 0.07 MPa of vertical pressure for compaction to be used to obtain the required porosity. Tennis et al. [4] reported that water-to-cement ratios between 0.27 and 0.30 are most commonly used.

According to [4], Pervious concrete has other benefits like increasing driver safety by preventing standing water on road surfaces, which decreases skidding and glare [5]. According to [6], pervious concrete could be used to reduce road noise because the void structure allows the air between the tire and the pavement to escape, producing a lower frequency road noise. The strength and structural performance of pervious concrete is more variable than traditional concrete, and depends mainly on the porosity [7].

Haselbach and Freeman [8] reported that porosity not only varies with changing water-to-cement ratios and compaction effort, but also varies with depth of the pavement. This vertical porosity distribution is caused by the surface compaction of pervious concrete, which leads to compact the top of the pavement more than the bottom. Haselbach and Freeman [8] assumed that the vertical porosity distribution is linear throughout the depth of the sample. The vertical porosity distribution could make maintenance actions such as vacuuming more effective because decreased porosity at the top of the pavement will trap solids in runoff near the surface. Since greater porosities may result in lower strengths, the vertical porosity distribution may decrease the tensile strength at the bottom of the pavement. Since pavements often fail due to the formation of tensile cracks at the bottom, the vertical porosity distribution should be considered in the design of pervious concrete pavements.

The porosity is the ratio of the volume of voids to the total volume of the specimen. Some of the voids in pervious concrete are not effective in carrying water through the material. The voids that are active in carrying water through the material are frequently called the “effective voids”. Some methods for finding the porosity of pervious concrete only calculate the effective voids. In order to avoid the confusion created by discrepancies in the definition of “effective voids”, Montes et al. [9] recommended finding the total porosity of pervious concrete using a water displacement method. The water displacement method is based on Archimedes’ principle of buoyancy, which states that the buoyancy force is equal to the weight of the fluid displaced. The dry mass, the submerged mass, and the total volume must be known to calculate the porosity using the displacement method. The total porosity should be more directly correlated to the compressive strength because all the voids, regardless if they are “effective or not”.

Pervious concrete is not usually as strong as traditional concrete for similar mixes and thicknesses. The matrix of pores that allow water to flow through the material also decreases its strength. Traditional concrete has compressive strength ranging from 24 to 34 MPa and tensile strength ranging from 2.4 to 4.1 MPa [10], while pervious concrete has compressive strength ranging typically from 3.4 to 27.5 MPa and tensile strength ranging from 1.0 to 3.4 MPa [4]. However, higher pervious concrete strengths are possible. Yang [11], reported that pervious compressive strength and tensile strength as high as 50 MPa and 6.0 MPa, respectively, can be reached by including 2 admixtures: silica fume and superplasticizer.

The compressive strength of pervious concrete depends primarily on porosity, which is highly dependent on aggregate size, shape and gradation. Crouch et al. [12], reported that a uniformly graded aggregate will result in a higher compressive strength, as well as a higher void ratio. A uniformly graded aggregate is also beneficial for field installations because it is harder to over-compact. Crouch et al. [12] also stated that smaller aggregates will produce a higher compressive strength than larger aggregates, and will result in similar porosities. Although it is intuitive that increasing aggregate size would produce a higher porosity, this is not the case. Larger aggregate will produce larger voids, but since the aggregate has less surface area per volume for the cement paste to stick to, excess paste will partially fill in the voids [12]. According to Erickson [13], pervious concrete containing crushed aggregate shows superior performance to pervious concrete. Delatte et al. [14] performed testing on pervious concrete samples obtained from Indiana, Kentucky, and Ohio. The samples were collected from driveways, parking lots, storage pads, sidewalks, patios, and bike paths. The researchers summarized qualitatively distresses observed at each of the test sites like cracking and raveling, and calculated the total porosity of the samples using the same water displacement method that was used in this study.

2. Research objective and scope

The objective of this study is to investigate the mechanical properties and permeability of PCPC under different key parameters. The key factors are coarse aggregate size, coarse aggregate volume, water-to-cement ratio, and cement content. The effect of these parameters on the mechanical properties such as compressive strength, the split tension strength the flexural strength, and permeability of all mixtures were measured according to ASTM standards.

3. Experimental program

Pervious concrete is produced by mixing water, cement, and uniformly graded coarse aggregate. A total of 24 concrete mixtures were prepared and tested. All mixtures were produced using 100% Portland cement and with w/c of 0.30, 0.35, and 0.40, respectively. All mixtures were designed with either one or two sizes of crushed limestone aggregates. The single size of aggregate defined as the size of sieve on which, 100% of aggregate was retained but all passed the sieve above Crushed limestone aggregates of sizes 4.5, 9.5, and 12.5 mm were used in this study. The mixes proportions are summarized in Table 1. The dry rodded unit weight and void ratio of the aggregates in this study were measured using ASTM C29 [15], and were determined to be 115 lb/ft^3 and 32%, respectively [15]. Type I Portland cement having a specific gravity of 3.15 and conforming to the requirements of ASTM C 150, was used for preparing all the concrete mixtures. Mixtures were produced from one aggregate size and a 50-to-50 blend of two aggregate sizes as shown in Table 1. All mixtures were proportioned to achieve appropriate permeability, porosity, and unit weight to be evaluated. In addition, mechanical properties such as, compressive strength, split tensile strength, and the modulus of rupture were also investigated. All concrete specimens used in the abovementioned tests were prepared in accordance with [16] “Standard Practice for Making and Curing Concrete test Specimens in the Laboratory.

Standard 100 mm × 200 mm diameter cylinders (Fig. 1) were used for compressive strength and water permeability tests on hardened concrete while typical 200 mm × 400 mm cylinders were used for the split tensile test; both tests were performed at 28-days. A150 × 150 mm × 530 mm standard molds were used for the flexural strength test. All specimens were de-molded after 24 h and stored in the curing room at 95% relative humidity. The compressive strengths were reported based on the average of three results taken from three nominally identical specimens. The permeability test was measured using the constant head method permeameter designed by [3], similar apparatus was built by the authors and the permeability coefficient was calculated using Darcy’s law as given below:

$$K = \frac{A_1 L}{A_2 t} log \frac{h_1}{h_2} \quad (1)$$

where A_1 and A_2 are the cross-sectional areas of the sample and the tube respectively, and L is the length of the specimen. For a typical specimen geometry, and same initial and final heads, the coefficient of permeability is given as:

$$k = \frac{A}{t} \quad (2)$$

where A is a constant, which in this study was 0.084 m. Fig. 2 shows the permeability apparatus used in this study.