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The effect of the cementitious paste thickness on the performance of pervious concrete

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HIGHLIGHTS

- Developed a new method to characterize cement paste thickness of pervious concrete.
- Related cement paste thickness with key performance criteria of pervious concrete.
- Validated the effect of design variables on the cementitious paste thickness.

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ABSTRACT

The performance of pervious concrete is dictated by the void structure features such as the size of coarse aggregate, void volume, void size, void distribution, and the amount of cement used. Pervious concrete consists of coarse aggregate surrounded by a thin layer of Portland cement paste. The amount of cement used affects the aggregate coating thickness, which has an effect on the porosity and other mechanical properties of the concrete. The void size is not purely governed by the size of coarse aggregate, but the aggregate size, gradation, and the thickness of cement paste. A higher porosity of the material does not ensure a higher permeability, as the permeability is a function of the void surface area, void size, and distribution. In this study a correlation is made between key pervious concrete properties such as the porosity, permeability, compressive and tensile strength versus the cement paste thickness. A thicker cement coating will lead to a lower percolation rate by reducing the porosity, however, this could have a positive effect on other desirable mechanical properties, such as compressive/tensile strength and permeability. This research focus on proportioning the coarse aggregate, cement content, and the void content in order to correlate the cement paste thickness to the key properties of pervious concrete. This was completed through a controlled concrete mix-design, a controlled laboratory preparation technique and an analysis of the hardened concrete cross-section.

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1. Introduction

1.1. Background

Pervious concrete is a sustainable alternative to conventional paving materials as it facilitates water infiltration while maintaining its structural performance. The ability to allow water to penetrate through this material allows for a superior storm-water run-off control and control of nonpoint source pollution (NPS). NPS pollution results from land runoff, precipitation, drainage and seepage and has been identified as a cause of receiving water quality degradation in the United States [1]. Most of this runoff is due to impervious pavements in large parking areas, roadways, and roofs. Pervious concrete is a sustainable alternative to impervious pavements that can greatly influence the control of runoff and NPS pollution. It is documented that pervious concrete helps in groundwater recharge.

Pervious concrete consists of coarse aggregate surrounded by a thin layer of Portland cement paste. The amount of cement used affects the aggregate coating thickness, which has an effect on the porosity and other mechanical properties of the concrete. The infiltration performance of pervious concrete is dictated by the void structure features such as the size of coarse aggregate, void volume, void size, void distribution, and the amount of cement used [2]. A higher porosity of the material does not ensure a higher permeability, as the permeability is a function of the void surface

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area and void size [3]. The void size is not purely governed by the size of coarse aggregate, but both the aggregate size and the thickness of cement paste. In this study a correlation will be made between the porosity versus the cement paste thickness. A thicker cement coating will lead to a lower percolation rate by reducing the porosity, however, this could have an effect on other desirable mechanical properties, such as strength, absorption, freeze/thaw capabilities, durability, etc. Reports have shown that pervious concrete is to have a void content in the range of 11–35% [4,5]. The work by Kevern et al. [6] describes that pervious concrete contains two types of void systems: (i) intentionally designed porosity that facilitates water penetration and (ii) entrained air in the mortar (cementitious material) that surrounds the aggregate. Montes et al. define the porosity of pervious concrete as the percent volume of voids with respect to the total volume of the specimen. It is further articulated by describing the "effective porosity". The effective porosity is described as the portion of the total void space that is active in the fluid permeability process, which excludes the "inactive porosity" sights. Montes et al. point out that not all the porous spaces are effective in holding and available for fluid flow, which is grouped as the "inactive porosity". Some porous spaces can be isolated (closed off) from other void spaces and will not be able to transmit fluid. This behavior is expected in highly compact or small coarse aggregate (4.75 mm) pervious concrete as smaller voids have the ability to retain the trapped fluid due to surface tension effects and capillary action. Wimberly et al. [7] report the effective porosity as the fraction of total porosity that was allowed to drain in 30 min, called the "rapid flow" porosity, in which a the fluid would rapidly flow, or drain, from the pervious concrete sample. However, this method has an increase in variability due to the high possibility of unknowns.

Despite the efforts outlined above, describing the characterization of the void systems of pervious concrete, there is still uncertainty in how different pervious concrete mixtures will affect the void systems within the concrete. The coarse aggregate in pervious concrete is typically single-sized [8], in which the coarse aggregate is all the same size. In this case, the remaining variables in the design mixture will be the amount of cement, the amount of water and the amount of compaction energy. Adjusting any of these variables will inherently affect the paste thickness surrounding the aggregate, therefore affecting the void system. Thicker paste thickness surrounding the aggregate results in a lower void percentage and thus a lower permeability (performance). These factors are only attributed to the mixture design and other factors such as placement (compaction) techniques are not considered.

1.2. Objectives

The objective of this study is to develop a correlation between the cementitious paste thickness to the performance of pervious concrete. This was completed through limiting the coarse aggregate size (two sizes), proportioning the cement content (low, medium, and high), and controlled laboratory compaction technique. The proportioning was coordinated through a refined concrete mix-design and the laboratory compaction technique was limited to three compaction energy levels. The paste thickness was analyzed by specimen cross-sectional analysis of the hardened concrete and hand measurements. This study aims to establish new understanding of pervious concrete through a unique investigation of the material to help guide future mixture designs. This was measured by investigating the effect of the cementitious paste thickness on the performance of pervious concrete, such as strength, permeability, and porosity.

2. Experimental program

2.1. Materials

Two sizes of aggregate were used in this study in order to determine how the paste thickness correlates with varying sizes of aggregate. The two sizes are 9.54-mm (3/8-in.) and 6.35-mm (1/4-in.) limestone, which were obtained from local quarries in Hays County, Texas. The two sizes were chosen to reflect typical pervious concrete coarse aggregate sizes [8]. Type I/II cement was used, which was obtained locally. The specific gravity, water absorption, voids, and unit weight of each aggregate size is shown in Table 1.

In order to focus this study on the cementitious paste thickness, other variables were minimized as much as possible, such as aggregate type, cement type, water-to-cement ratio, sample size, admixtures, supplementary cementitious materials, etc. Therefore, only a single aggregate type, a single cement type, and no admixtures were used for this study.

2.2. Mixture proportions

Six mixtures with a water-cement ratio of 0.33 were proportioned based on the methods described in ACI 522 R-10 [8]. The experimental design consisted of two limestone aggregate sizes and three compaction levels as described in Section 2.3. Due to the three compaction levels and two aggregate sizes the total varying mixtures amounted to 18 sample groups, as shown in Table 2. Mixtures were prepared using a rotating drum mixer and mixed in accordance to ASTM C192-15 [9].

2.3. Experimental methods

2.3.1. Laboratory compaction techniques

Three compaction levels were used in this study to provide a range of porosity quantities that would mimic in-place pervious concrete systems. In order to produce a broad spectrum of compaction while simultaneously managing test variables the three compaction levels were (i) uncompacted, which provides the low end of the compaction spectrum as the concrete was simply placed into the molds, (ii) two layers compacted with a 9.54-mm (3/8-in.) tamping rod five times per layer, which provides an approximate middle compaction level, and (iii) three layers compacted with a 2.5-kg (5.5-lb) standard proctor hammer having a height of fall

Table 1
Physical properties of aggregates.

Property	Standard	Unit	Limestone (9.54 m)	Limestone (6.35 mm)
Unit weight	ASTM C29	kg/m^3 (lb/ft^3)	1442 (90.0)	1458 (91.0)
Water absorption	ASTM C127	%	2.33	3.54
Bulk specific gravity$_{ssd}$[a]	ASTM C127	–	2.57	2.58
Bulk specific gravity$_{od}$[b]	ASTM C127	–	2.51	2.52
Voids	ASTM C29	%	29.36	30.15

[a] ssd, saturated surface dry condition.
[b] od, oven dried condition.