Construction and Building Materials 52 (2014) 494–503

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

A method for comparing cores and cast cylinders in virgin and recycled aggregate pervious concrete

Cristián Gaedicke [a,*], Armando Marines [b,1], Farel Miankodila [c,2]

[a] Department of Engineering, California State University, East Bay, 25800 Carlos Bee Blvd, Hayward, CA 94542, United States
[b] Concrete Technological Center, Holcim Apasco, Prolongación Isidro Fabela No. 1517, Mexico City, Mexico
[c] Department of Engineering, California State University, East Bay, 25800 Carlos Bee Blvd #VBT347, Hayward, CA 94542, United States

HIGHLIGHTS

- A method for comparing cores and compacted pervious concrete cylinders is proposed.
- The method was validated using virgin aggregate and a recycled aggregate blend.
- No difference in unit weight between cores and compacted cylinders was found.
- Permeability of cores was 20% lower than compacted cylinders of equivalent porosity.
- Strength of cores was 17% lower than compacted cylinders of equivalent porosity.

ARTICLE INFO

Article history:
Received 19 July 2013
Received in revised form 5 November 2013
Accepted 12 November 2013
Available online 13 December 2013

Keywords:
Pervious concrete
Core
Compaction
Recycled aggregate

ABSTRACT

A method of comparing the performance of pervious concrete cores and compacted cylinders is proposed. This approach uses cylinders subjected to different compaction levels via a Proctor-hammer to create curves that relate the concrete porosity and the desired property. The cores are then compared to the corresponding curve values that match the core's porosity to create adjustment factors for unit weight, permeability, and compressive strength. Cores were comprised of pea gravel, limestone, and recycled aggregate concrete mixtures. Experimental results show that, compared to compacted cylinders of the same porosity, cores have on average the same unit weight, 20% less permeability, and 17% lower compressive strength.

1. Introduction

1.1. Background

Pervious concrete has been used as a sustainable alternative to conventional paving materials during the last 30 years due to its ability to allow for water infiltration while maintaining structural performance [1]. Water passes through an interconnected network of voids in the pervious concrete structure resulting from constrained use of fine aggregates, uniform gradation, and low water-to-cementitious-material ratio [2]. In addition to its infiltration capacity, pervious concrete has been used to remove pollutants from stormwater runoff, improve skid resistance, and reduce the tire–pavement noise interaction [3–5]. Furthermore, pervious concrete has reduced heat storage capacity, which helps mitigate the urban heat island effect [6–8].

Porosity, which ranges from 18% to 25%, is one of the key properties of pervious concrete and directly influences the permeability and mechanical properties of the material [2]. For instance, pervious concrete mixtures with high porosity tend to demonstrate higher permeability but poor strength, whereas low-porosity mixtures show superior strength but generally have a lower permeability [9–13]. As a pavement section is designed for a given water storage capacity, a lower porosity in the concrete would significantly reduce its ability to store water and slowly infiltrate it to the ground. In addition to porosity, other essential pore structure features, such as pore size, volume fraction, specific surface area, mean free spacing, and connectivity of pores, strongly influence the properties of any open-grade structure material and need to be considered when studying the mechanical response and water infiltration capabilities of a pervious concrete pavement [14–17].

Pervious concrete mixtures are proportioned to achieve a design value of porosity that guarantees a balance between the

* Corresponding author. Tel.: +1 (510) 885 2208; fax: +1 (510) 885 2678.
E-mail addresses: cristian.gaedicke@csueastbay.edu (C. Gaedicke), armandomarines@gmail.com (A. Marines), farel.miankodila@gmail.com (F. Miankodila).
[1] Tel.: +52 (55) 5724 0000; fax: +52 (55) 5724 0252.
[2] Tel.: +1 (510) 461 0156; fax: +1 (510) 885 2678.

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.11.043

water storage capacity of the pavement and its desired mechanical properties [2]. For instance, Sumanasooriya et al. developed a novel methodology for mixture proportioning based on particle packing concepts to attain a desired porosity in pervious concrete mixtures [18]. The approach relies on relationships between material volume and amount of compaction effort applied. Although mixture proportioning is a major contributing factor, the compaction energy and construction methodology are also variables that affect the porosity, consequently influencing the properties and performance of pervious concrete [14]. Care must be taken during field placement to ensure a proper bond between the aggregates and the paste without compromising the hydrological abilities of the pervious concrete system.

The unique characteristics and behavior of pervious concrete make the sampling and evaluation methods used in conventional concrete difficult to apply in pervious mixtures as they may not be representative and consistent. As a result, the American Society of Testing and Materials (ASTM) through its subcommittee C09.49 on pervious concrete has developed a number of standards to measure such properties as infiltration rate, resistance to degradation, and fresh density. ASTM C1688, one of the most essential standards in quality control of pervious mixtures, was designed to evaluate the density and void content of fresh pervious concrete. However, the standard is used as means of verifying that the aforementioned properties correspond to those specified by the designer in the mix proportioning, and the results do not necessarily reflect the performance of the material after it has been placed.

A number of studies have compared the properties of laboratory cast specimens and core samples obtained in the field [19]. The conventional method for compacting cylinders using a ½-in. rod has been found to be inappropriate for the casting of laboratory specimens of pervious concrete. Instead, pervious concrete samples have been compacted using a Proctor hammer with more consistent results. Other tools and techniques, such as a pneumatic press, rollers, hand tamping, Marshall hammer, and vibration tables have also been evaluated [11,20–23]. Table 1 summarizes the methods utilized and the most important findings from the studies.

Despite the numerous efforts cited above, the method that best matches the properties of in-place pervious concrete varies with the characteristics of the mixture under consideration given a specific paste content, aggregate type, and size, along with field placement and compaction techniques. Consequently, a method to accurately compare cores and compacted cylinders is needed to properly control the quality and assess the performance of pervious concrete placed in the field.

1.2. Objectives

The objective of this study is to develop a method of comparing the properties of cores and compacted cylinders for a wide range of mixtures made of different aggregate types and percentage of cement replacement by slag. This study aims to develop a series of adjustment factors that would account for discrepancies in unit

Table 1
Compaction techniques evaluated from the literature.

Reference	Compaction techniques	Observations
Ghafoori and Dutta [1]	• A 2.27-kg (5-lb) hammer was used to apply 8 different levels of compaction • A 2.27-kg (5-lb) hammer was used to apply 8 different levels of compaction	Hand-rodded specimens showed similar properties to those obtained in samples compacted at 33 J/m^3
Suleiman et al. [20]	• Rodding 25 times in 3 layers and vibration for 5 s at 0.127 mm (0.005-in.) and 0.086 mm (0.0034-in.) amplitudes	Compaction significantly affects pervious concrete properties
Rizvi et al. [21]	• 3 layers with 25, 15, and 5 rods per layer • 2 layers with 20 and 10 blows of a standard Proctor hammer per layer	Samples compacted by 10 blows of the Proctor hammer per layer achieved the most consistent results
Mahboub et al. [22]	• Molds were filled in one layer and compacted at 0.007 MPa (10 psi) using a pneumatic press • Rodding as described in ASTM C192	The traditional method of rodding cylinders does not accurately represent the conditions of a roller-compacted slab
Brown [23]	• Rodding 25 times in 3 layers • Jigging method described in ASTM C29 • Compaction as a percentage of volume • Weight vs. volume method	The weight versus volume method produced pervious specimens with the most consistent results
Putman and Neptune [19]	• 3 layers each rodded 10,15, and 25 times • 2 layers rodded 25 times • Dropping the mold from a height of 50 mm • Cores extracted from 600-mm square slabs compacted using the same technique and of the same thickness as the field slab	Rodded cylinders had a greater degree of variability than those compacted using the other methods. Cores extracted from slabs had properties that were most similar to the in-place pavement

Table 2
Physical Properties of Aggregates.

Property	Standard	Unit	Pea gravel (P)	Limestone (L)	RCAB (R)
Unit weight	ASTM C29	kg/m^3 (lb/ft^3)	1,588 (99.1)	1,471 (91.8)	1,411 (88.0)
Water absorption	ASTM C127	%	0.95	2.47	4.12
Bulk specific gravity$_{ssd}$ [a]	ASTM C127	–	2.61	2.57	2.42
Bulk specific gravity$_{od}$ [b]	ASTM C127	–	2.59	2.50	2.32
Voids	ASTM C29	%	38.48	41.15	41.57

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