Construction and Building Materials 126 (2016) 875–885

Contents lists available at ScienceDirect

Construction and Building Materials

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

Using carbon fiber composites for reinforcing pervious concrete

Milena Rangelov, Somayeh Nassiri *, Liv Haselbach, Karl Englund

Washington State University (WSU), United States

HIGHLIGHTS

- Cured carbon fiber composite material (CCFCM) pieces were mechanically refined and processed to certain shape and size fraction for incorporation in pervious concrete (PC).
- CCFCM incorporation resulted in improved workability as evident in lower and more consistent porosity of the reinforced PC (rPC), compared to the control (plain PC).
- Incorporation of CCFCM yielded in improved mechanical properties of PC.

ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form 10 June 2016
Accepted 13 June 2016

Keywords:
Pervious concrete
Carbon fiber composite
Mass loss
Cantabro
Surface abrasion
Compressive strength

ABSTRACT

Pervious concrete (PC) pavement applications are growing in popularity due to the environmental and stormwater management benefits that PC can offer. However, relatively low mechanical properties and durability of PC, comparing to conventional Portland cement concrete (PCC), limit its use for vehicular applications. In this study, different size fractions of cured carbon fiber composite material (CCFCM) pieces were incorporated into a PC mixture (rPC) in three volume fractions. The goal was to determine the physical and mechanical properties of rPC in comparison to the corresponding properties of plain PC (control). Seven mixture designs were prepared in order to investigate the effect of CCFCM volume fractions as well as CCFCM particle sizes. The test results indicated that CCFCM addition enhanced the workability of the PC mixtures. rPC mixtures presented higher average infiltration rates when compared to the control mixture. Improvements in mechanical properties were seen on 28-day compressive strength (4–11%), 7-day tensile strength (11–46%) and in modulus of elasticity (6–45%). In terms of resistance to mass loss in Cantabro and surface abrasion, rPC mixtures presented various behaviors, with one mixture containing the highest volume fraction and a combined size fraction, outperforming the control in both tests. Overall, the results of this study indicate that incorporation of CCFCM is promising in improving physical and mechanical properties of PC.

1. Introduction

Pervious concrete (PC) pavement is one pavement out of the suite of permeable pavements that simultaneously serves stormwater runoff management and supporting vehicular or pedestrian traffic. PC is growing in popularity among municipalities and transportation agencies for applications such as bike lanes, pedestrian walkways, sidewalks, parking lots, low-volume roadways and others. The increased application is mainly due to PC's environmental benefits, such as underground water system restoration and stormwater runoff reduction. When used as a pavement surface course, PC can also mitigate traffic noise [1] and potentially reduce the heat island effect [2,3].

PC is prepared with similar ingredients as conventional Portland cement concrete (PCC), however with none or small amounts of fine aggregate and a lower amount of water. The elimination of fines together with the gap (open) gradation of coarse aggregate, typical for PC, provides an interconnected system of air voids (15–35 percent) that facilitates the flow of water [4]. Due to the lack of fine aggregate, the coarse aggregate grains in PC are bounded solely by a thin layer of cement paste, resulting in lower mechanical properties of PC comparing to conventional PCC, where coarse aggregate is embedded in the matrix. Typical values of 28-day compressive strength for PC range from 2.8 to 28 MPa [4,5] as opposed to 20–40 MPa for traditional PCC.

---

* Corresponding author at: Washington State University, 248 PACCAR Environmental Technology Building, 2001 East Grimes Way, Pullman, WA 99164-5815, United States.

E-mail address: snassiri@wsu.edu (S. Nassiri).

http://dx.doi.org/10.1016/j.conbuildmat.2016.06.035
0950-0618/© 2016 Published by Elsevier Ltd.

Despite the gain in popularity, PC is relatively young in the application, research, and development. Current initiatives for improving PC properties include enhanced surface resistance to abrasion, increased mechanical properties, improved freeze-thaw (F-T) durability and the resistance to deicer salts when used in regions with cold climate, as well as better workability for more consistent placing at different environmental conditions. Lately, numerous improvements have been introduced to the PC mixture design to address the above-stated objectives by the addition of various reinforcing elements or modifying additives. Examples of studies that focused on improving the mechanical properties include the implementation of various fibers in PC, which resulted in increases in compressive, tensile and flexural strength [6–8]. Rehder et al. (2014) [9] reported that polypropylene fibers introduced improvements in residual flexural strength of PC.

In terms of durability, the addition of polypropylene fibers was found to enhance the F-T durability of PC [10,11]. The latter study showed that 56-mm long fibers at the dosage of 3 kg/m^3 were particularly beneficial in terms of increasing F-T durability [11]. Other studies focused on improving durability to abrasion and reported that the use of polypropylene [11,12] and cellulose fibers [8] increased the surface abrasion resistance of PC. It was also found in another study that the addition of styrene butadiene rubber (SBR) latex to the PC mixture can improve compressive strength and abrasion resistance [12]. According to a study by Yang (2011), partial replacement of cement with silica fume tends to increase the F-T durability of PC, as well as the resistance against deicer salt [10]. Further, the use of sand as a partial replacement of coarse aggregate (five to 10 percent by the mass) was shown to improve the F-T durability of PC [13].

In this study, cured carbon fiber composite materials (CCFCM) in various particles size fractions and volume fractions were incorporated into the PC mixture to potentially improve various properties. Currently, there are limited opportunities to reutilize excess material and the end-of-life products generated during the production of synthetic composites, such as carbon fiber composites (CFC). One procedure is to isolate the fibers from the composite by a chemical solvent or through pyrolisis. However, costs associated with these thermal or chemical processes can be significant and result in a low-quality and high-price carbon fiber product. CCFCM used in this study were processed using a low-energy mechanical procedure, aiming to preserve the original composite structure of fiber materials and cured resin and thereby the properties of the original CCFCM.

The main objective of this study was to evaluate the feasibility of incorporating refined CCFCM elements into PC mixtures (hereafter reinforced PC (rPC)), while examining mixability, workability, and compaction of the PC. As part of the study, the physical, hydraulic and mechanical properties of rPC were also established and compared to the corresponding properties of plain PC.

2. Materials

2.1. Pervious concrete mixture design

PC mixtures were prepared with Type I/II ordinary Portland cement, and crushed basalt coarse aggregate. Coarse aggregate had a nominal maximum size of 9.5 mm, the specific gravity of 3.102, and 3.11 percent water absorption. Coarse aggregate was incorporated into the mixture in saturated surface dry (SSD) condition. No fine aggregate was included in the PC mixture. Fifteen percent of the Portland cement by mass was replaced with Type F fly ash. Desirable workability was obtained with water to cementitious materials ratio (w/cm) of 0.24. Rheology-modifying chemical admixture, V-MAR VSC500 from W.R. Grace & Co. was used to delay the setting, providing more workability time. Implemented admixture dosage was determined based on the producer's specifications as 980 ml per 100 kg of cementitious material [14]. PC mixture was designed following the mixture design procedure available in ACI 522-R-10 [4], using a target porosity of 27 percent. The final PC mixture design and the proportioning of the PC constituents are provided in Table 1.

Table 1
PC Mixture composition and proportioning.

Material	Amount per m^3 of PC
SSD coarse aggregate [kg]	1632.0
Fine aggregate [kg]	0.0
Water [kg]	95.7
Type I/II cement [kg]	337.2
Class F fly ash [kg]	59.5
Admixture [ml]	3888.0
CCFCM elements [kg]	8.0 (0.5% volume) 15.6 (1% volume) 23.4 (1.5% volume)

2.2. Processing of cured carbon fiber composite materials

CCFCM were processed at the Composite Materials and Engineering Center (CMEC) at Washington State University (WSU). The materials were first shredded and then hammer-milled through a 25.4-mm screen to separate the coarsest particles. Subsequently, the CCFCM elements were differentiated into four fractions by further mechanical screening: (C) combined: particles smaller than 3.35 mm, (L) large: particles smaller than 3.35 mm and larger than 2 mm, (M) medium: particles smaller than 2 mm and larger than 0.841 mm, and (S) small: particles smaller than 0.841 mm (retained on the pan). Particle size distribution is presented in Fig. 1. Fig. 2 presents four different CCFCM fractions. As seen in Fig. 2, coarse and flaky CCFCM elements were contained in C and L fractions, while the S and M mainly contained particles in the form of fibers. It is noteworthy that CCFCM elements obtained by hammer-milling cannot be referred to as "carbon fibers", but rather as carbon fiber composite elements. Each "element" contains a dense network of carbon fibers bonded by the thermoset resin used in the original composite.

3. Experimental design

An experiment was designed to investigate the effect of different CCFCM volume fractions, as well as different CCFCM element particle size fractions on PC properties. Therefore, the experiment included one control PC mixture, three rPC mixtures containing

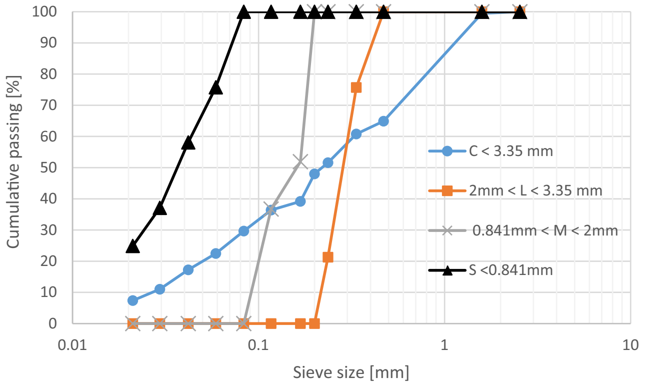

Fig. 1. Particle size distribution of CCFCM elements.