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Film-forming ability of flowable cement pastes and its application in mixture proportioning of pervious concrete

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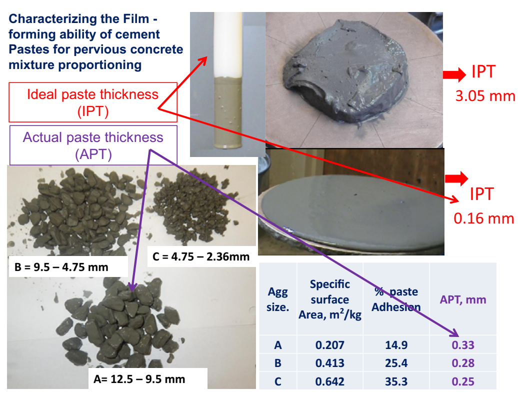
HIGHLIGHTS

- The concept of paste film-forming ability is introduced.
- Two paste film-forming ability test methods were developed.
- The effect of *w*/*c* ratio and superplasticizer dose on film-forming ability is studied.
- The effect of aggregate properties on paste film-forming ability is explained.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, the concept of paste film-forming ability is introduced as a parameter for mixture proportioning of pervious concrete. Two new test methods are also developed. The two methods characterize film-forming ability in two conditions. The first method characterizes the ability of a cement paste to form a stable film on a smooth nonabsorbent vertical surface. The paste thickness measured from this test is called, *Ideal Paste Thickness* (IPT). The second test characterizes the ability of cement paste to adhere and remain on an aggregate surface; this paste thickness is called *Actual Paste Thickness* (*APT*). The IPT can be used as a standardized parameter to evaluate the film-forming ability of cement pastes. The APT can be used to study the formation of cement paste films on pervious concrete aggregates. In this study IPT and APT of sixteen superplasticized cement pastes were evaluated. The pastes were prepared from four water to cement (*w*/*c*) ratios (0.23, 0.27, 0.32 and 0.37).

1. Introduction

Portland Cement Pervious Concrete (PCPC) is a special type of concrete with interconnected pores that allow water to pass through. Though PCPC existed in the construction industry for several decades, recently it has gained unprecedented attention because of its environmental benefits [1]. Applications of PCPC include exposed parking lots, lightly trafficked pavements, walkways, drains and shoulders in which precipitation is intended to drain down to the substrate soil. Additionally, PCPC can be used in urban pavements to reduce urban heat island effect and noise generated from tire-pavement interaction [2–5].

Abbreviations: IPT, Ideal Paste Thickness; APT, Actual Paste Thickness; PCPC, Pervious Concrete.

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The matrix of PCPC is formed from an agglomeration of paste coated aggregate particles. Workability in PCPC is provided through the lubricating action of the paste [6]. Consequently, when the matrix is hardened, strength is developed in the paste and transferred to the aggregate through bonding. The stability of the entire matrix is maintained through bond and contact load transfer between the paste-coated aggregates. Thus, the role of cement paste in PCPC is significant in both fresh and hardened properties of PCPC [6,7].

Workability of PCPC refers to various characteristics such as mixability, dischargeability, finishability and compatibility [8]. To attain satisfactory workability, it is important to account for workability during mixture proportioning. However, due to lack of scientific procedures, the current approach for attaining workability is based on trial–error approach [1]. Often this kind of approach leads to unpredictable performance and results in mixes with various workability issues. To resolve this issue, researchers in the past have attempted to correlate paste flowability with workability properties of PCPC [7,9]. For instance, Chindaprasirt et al., have correlated paste flow with design void content of workable PCPC mixes [7]. Similarly, the NRMCA mix design method suggests a certain paste spread for good PCPC workability [9]. Though paste flowability can be correlated with PCPC workability as in these examples, in cannot be used as a standard parameter for all PCPC mixtures. This is particularly true when the paste volume, design voids and aggregate gradation significantly change from mix to mix [10]. Therefore, this work introduces the concept of paste film-forming ability as an additional parameter for characterizing cement pastes for PCPC applications. This parameter can be used to characterize the stability of the paste at different flowability levels. It also be used to characterize the ability of a cement paste to form a stable film on aggregates that have different surface textures and moisture conditions. The paste film-forming ability coupled with paste flowability can be used for selecting cement pastes for PCPC applications.

2. Experimental design, materials, and methods

2.1. Experimental setup

In this study, the film-forming property and flowability of 16 cement pastes are evaluated. The pastes were prepared from four *w*/*c* (*w*/*c* = 0.23, 0.27, 0.32 and 0.37). The superplasticizer (SP) doses were varied from 0.05% to 0.475% solid by the weight of the cement. Four levels of SP were used with respect to each *w*/*c*. The initial SP dose, which causes flow, was determined from preliminary experiment. Once the initial SP doses were determined, the experiments were run by increasing the SP doses with rate of 0.05%. Then the experiments in each *w*/*c* ratio were run for four increments. The test matrix used for this experiment is presented in Table 1.

Table 1
Experimental data points.

SP dose % solid	*w*/*c*			
	0.23	0.27	0.32	0.37
0.025				*
0.05				
0.075				*
0.1			*	
0.125				*
0.15			*	
0.175		*		*
0.2			*	
0.225		*		
0.25			*	
0.275		*		
0.3				
0.325	*	*		
0.35				
0.375	*			
0.4				
0.425	*			
0.45				
0.475	*			
0.5				

2.2. Materials

The cement used for this experiment was a Type I Portland cement meeting ASTM C 150 specifications. The chemical and physical properties of the cement are given in Table 2. Adva 190 Superplasticizer manufactured by Grace Construction Chemicals was used at different dosage rates. This SP is a polycarboxylic ether based product with solid content of 31%. Tap water was used to mix the pastes according to the specified *w*/*c* ratios. The amount of water added was adjusted for the water in the SP.

Table 2
Chemical composition of Portland cement.

Oxide	Composition (%)
SiO_2	20.6
Al_2O_3	5.1
Fe_2O_3	3.4
CaO	64.5
MgO	1.0
SO_3	3.1
Loss on ignition (%)	1.1
Insoluble residue (%)	0.25

2.3. Paste preparation

The pastes were prepared in a standard Hobart mixer with a 5-l bowl capacity and three mixing speeds. The entire cement content and 70% of the water required were mixed for 2 min at speed 1, then the SP, along with the remaining water was added to the cement paste; at this time, the mixing was stopped and the sides of the mixer bowl were scraped (for 15–30 s); and the paste was again mixed for 3 min [11].

2.4. Marsh cone and mini slump tests

The flowability of the cement paste was characterized by using Marsh cone and Mini slump tests. Several researchers have used the Marsh cone test to characterize the fluidity of cement pastes [4–6]. In the present study, a plastic cone manufactured locally (as per European standard, EN 445) with a nozzle diameter of 9 mm was used. Before the test, the mold was fixed on a wooden stand, 40 mm above the inlet of the collecting jug and 1000 ml of paste was poured into the cone, and the time required for 500 ml paste to flow was recorded [11]. The flow times describe the fluidity of the paste; higher the flow time, lower is the fluidity of the paste. Important information that can be obtained from Marsh cone test is the saturation dose of superplasticizer [12]. The Marsh cone test can also be used to describe the pour-ability of the paste for two-stage mixing process. Two-stage mixing process is a type of mixing procedure in which the paste is mixed separately and later added to the aggregate to create the PCPC mixture.

The spreadability of the paste was characterized by Mini slump test which was initially suggested by Aïtcin [13] and used by several others [11,14]. The cone used has a truncated shape, with height = 57 mm, bottom diameter = 38 mm and top diameter = 19 mm. Once the cone was filled with cement paste, it was gently lifted up by allowing the cement paste to drain down and spread. Finally, the spread diameter was measured in two orthogonal directions and average of the two readings was taken as the spread diameter.

2.5. Paste-film forming property

2.5.1. The concept of paste film-forming ability

There are two important paste characteristics that need to be considered while designing cement pastes for PCPC applications; these are flowability and film-forming ability. The higher the flowability of the paste, the higher will be the workability of the concrete. However, in PCPC if the paste is too fluid it will not be able to form a stable film on the aggregates surface. This can lead to paste drain-down, which can cause poor compressive strength and poor permeability due to sealing of the bottom surface of the pavement. For this purpose, the concept of paste-film forming ability is introduced as a parameter for characterizing cement pastes for PCPC applications. Two new paste film characterizing methods are also developed for this purpose. The two methods characterize film-forming ability in two conditions. The first