37th Cement and Concrete Science Conference **Paper Number 060**
11-12 September 2017
University College London

CLOGGING POTENTIAL OF PERMEABLE CONCRETE

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ABSTRACT

Permeable concrete is used to reduce local flooding in urban areas. However, it is prone to clogging by particulate matter and requires regular maintenance. This paper reports on the performance of permeable concrete exposed to different clogging test methods to further understand this complex phenomena. New methods were developed to study the clogging effect and to define a clogging potential. The tests involve applying flowing water containing sand and/or clay in cycles through the sample and measuring the change in flow rate. Clogging depends on the applied solution and exposure method used. Significant permeability reductions were observed in all samples, particularly when simultaneously exposed to sand and clay. This is because flocculated clay adhered to surface of sand particles and this caused increased clogging.

1. INTRODUCTION

Permeable concrete, also known as pervious concrete, is used to reduce local flooding in urban areas as it allows storm water to flow through normally impermeable infrastructure. A typical permeable pavement system consists of a top permeable concrete layer placed above a sub-base coarse aggregate layer and subgrade soil. Permeable concrete is primarily used in car parks, pedestrian footpaths, cycle paths and other low-traffic areas. Permeable concrete captures suspended solids, P, N, Zn, Cu and motor oil, improving stormwater and groundwater quality. It is also reported to improve skid resistance and minimise heat island effects in cities [1].

However, performance of permeable concrete degrades over time due to clogging caused by a build-up of particles [2, 3, 4]. Several laboratory studies have investigated the effect of sediment type on clogging of permeable concrete [e.g. 2, 4-9], but the findings from existing studies are not always consistent. This can be attributed to differences in the clogging material, sample pore structure, exposure conditions and other variables. A comprehensive review of this topic was recently presented [10].

The overall aim of this study is to develop a fundamental understanding of this issue and to develop new forms of permeable concrete that are more durable and resistant to clogging. The outcome of this work will help alleviate urban flooding and contribute to more advanced sustainable infrastructure development.

2. EXPERIMENTAL PROGRAM

2.1. MIXTURE PROPORTION AND SPECIMEN PREPARATION

Materials used in permeable concrete are the same as in normal concrete, but the mix proportioning is different. The aim in permeable concrete mix design is to achieve a balance between porosity, compressive strength, paste content and workability.

Permeable concrete samples with porosity from 11-30% were prepared using CEM I and Thames Valley aggregate at water/cement (w/c) ratio of 0.35 (Table 1). Samples were cast in steel moulds (100^3 mm^3) and Perspex tubes (100Ø × 150 mm) by compacting in three layers for 25 s each using a vibrating table. Samples were covered with polyethylene sheet and wet hessian for the first 24 hours, then de-moulded and cured at 20°C, 95% ± 5% RH for 28 days before being tested for porosity, permeability and compressive strength.

Table 1. Mixture proportions of permeable concrete samples.

	Mix			
	11%P	**19%P**	**26%P**	**30%P**
Cement* (kg/m³)	315	255	180	105
Aggregate (kg/m³)**	1481	1581	1581	1581
Water (kg/m³)	110	89	63	37
w/c	0.35	0.35	0.35	0.35
Paste vol. (%)	21	17	12	7
Porosity (%)	11	19	26	30

*CEM I 52.5N complying with BS EN 197-1:2011 was used as the binder in all samples.
**Thames Valley siliceous gravel (passing 14 mm, retained on 1.25 mm sieve) with specific gravity of 2.51 and 24-h absorption of 1.76%. No fine aggregates were used in any of the mixtures.

2.2. CLOGGING AND PERMEABILITY DETERMINATION

Samples were subjected to water flow containing fine sand and/or bentonite clay over many cycles to simulate clogging using a falling head permeability cell. Two exposure methods were used: 1) combined "sand and clay" and 2) alternate "sand or clay" loading, as detailed in Table 2. The permeability (k) was measured during each flow cycle.

Table 2. Clogging methods used in this study.

Clogging method *	
Combined "Sand and clay" (S & C)	**Alternate "Sand or clay" (S / C)**
All cycles: 62 g of fine sand** (0.8 g/cm²) was spread evenly on sample surface. 300 g of bentonite clay** mixed in 9 L of water (33.3 g/L) forming a slurry was then applied on top of the sample.	**Odd number cycles:** 62 g of fine sand (0.8 g/cm²) was spread evenly on the surface. Subsequently, 9 L of water was applied on top of the sample.
	Even number cycles: 300 g of bentonite clay was mixed in 9 L of water (33.3 g/L) and forming slurry was applied on top of the sample.

*Experimental runs were repeated until (k→0) or (Δk→0).
**Particle size of fine-grained river sand and bentonite clay was < 1.25 mm.

3. RESULTS

3.1. INITIAL PERMEABILITY

Fig. 1 shows that the initial permeability increases with porosity as expected. Interestingly, some samples displayed near zero permeability despite having porosities in the range of 10-19%. These samples were affected by "paste drain down" causing localised porosity blockage (Fig. 2). Concretes with porosity < 15% had very low water percolation due to a lack of interconnected voids. Samples with porosities > 25% were very permeable, but had low compressive strengths (Fig. 3).

3.2. COMPRESSIVE STRENGTH

The compressive strength of permeable concrete is influenced by several factors such as cement content, w/c ratio, aggregate characteristics and extent of compaction during placement. Fig. 3 presents compressive strength as a function of porosity for different permeable concrete samples. Compressive strengths ranged from 6-30 MPa and was inversely correlated with porosity as expected.

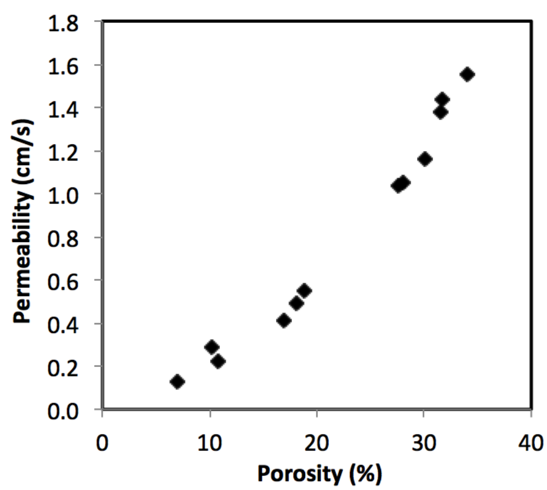

Figure 1. Correlation between permeability and porosity.

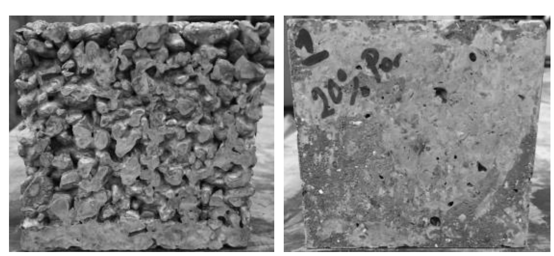

Figure 2. Sample as cast (left) and rotated (right), showing the bottom is blocked by paste drain down.

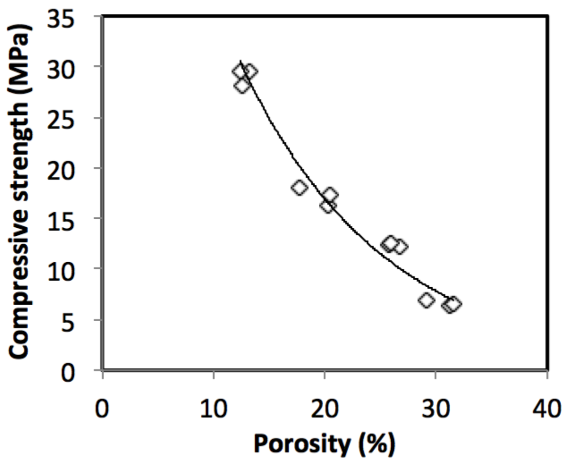

Figure 3. Correlation between compressive strength and porosity for permeable concrete samples.

3.3. PERMEABILITY REDUCTION DUE TO CLOGGING

Fig. 4 presents permeability as a function of clogging cycles. It can be seen that permeability is highest initially and gradually decreases with clogging cycle, due to closing of pore channels causing porosity reduction and/or tortuosity increase. The number of cycles required for complete clogging ranged from 3 to 8 and this increased with porosity. The 11% porosity samples clogged the fastest, presumably due to smaller pore volume and size distribution that prevents particles entering the sample and greater tortuosity that traps particles leading to accumulation. Also, paste drain down (Fig. 2) produced concretes with dense paste-rich lower layers with poor infiltration capacity. Comparing Figs. 4a and 4b, it can be seen that the combined "sand and clay" method caused more severe permeability degradation because each cycle consists of simultaneous application of sand and clay. However, the behavior of all mixes is relatively consistent for both exposure methods.

3.4. CLOGGING POTENTIAL

We define clogging potential as: a) ratio of the porosity drop to initial porosity ($\Delta\phi/\phi i$), and b) ratio of permeability drop to initial permeability ($\Delta k/ki$). The change in porosity and permeability were measured between the first two cycles where the greatest reduction occurred (Fig. 5). We can also define clogging potential as the number of cycles required to reduce porosity (or permeability) to half the initial value. The results presented in Fig. 5 show that highest clogging potential occurred in samples exposed to combined "sand and clay" clogging. The deposition pattern in clogged samples depends on the size of particles relative to pore size. Sand and flocculated clay particles larger than pores are retained on the top surface forming a blanket deposition layer, while finer sand particles tend to be trapped within the permeable concrete away from the surface. Very fine bentonite clay particles pass through the sample.

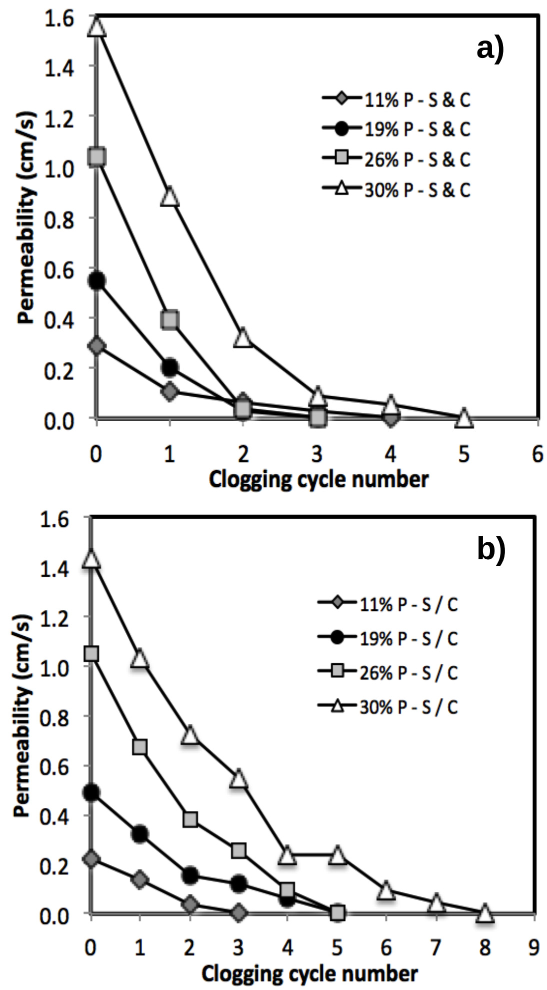

Figure 4. Permeability of samples exposed to (a) combined "sand & clay" and (b) alternate "sand / clay" clogging method.

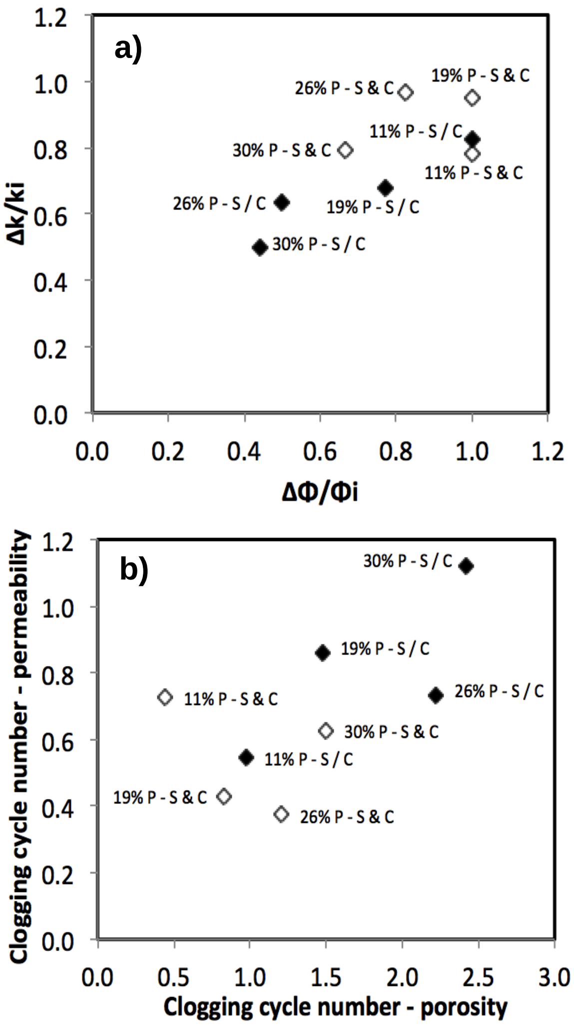

Figure 5. Clogging potential of permeable concrete samples calculated using two different methods: a) Δk/ki against Δϕ/ϕi where k is permeability and ϕ is porosity; and b) clogging cycle number for 50% reduction in permeability against clogging cycle number for 50% reduction in porosity.

4. CONCLUSIONS

New laboratory tests to study clogging in permeable concrete have been developed. Significant permeability reductions were observed in all samples exposed to sand and clay in solution. Clogging occurred due to large sand and flocculated clay particles retained on the top surface of samples. Lower porosity samples had a greater loss in permeability due to smaller pore size, higher tortuosity and paste drain down that traps particles. Complete clogging occurred after 3 to 8 cycles, depending on sample porosity and exposure method. Two methods were used to define clogging potential. Permeable concrete samples with porosities of 26% and 30% exposed to alternate “sand or clay” clogging method had the lowest clogging potential, retaining considerable proportion of their initial permeability. This study highlights the need to develop new permeable concretes that are more resistant to clogging.

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