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ABSTRACT BOOK

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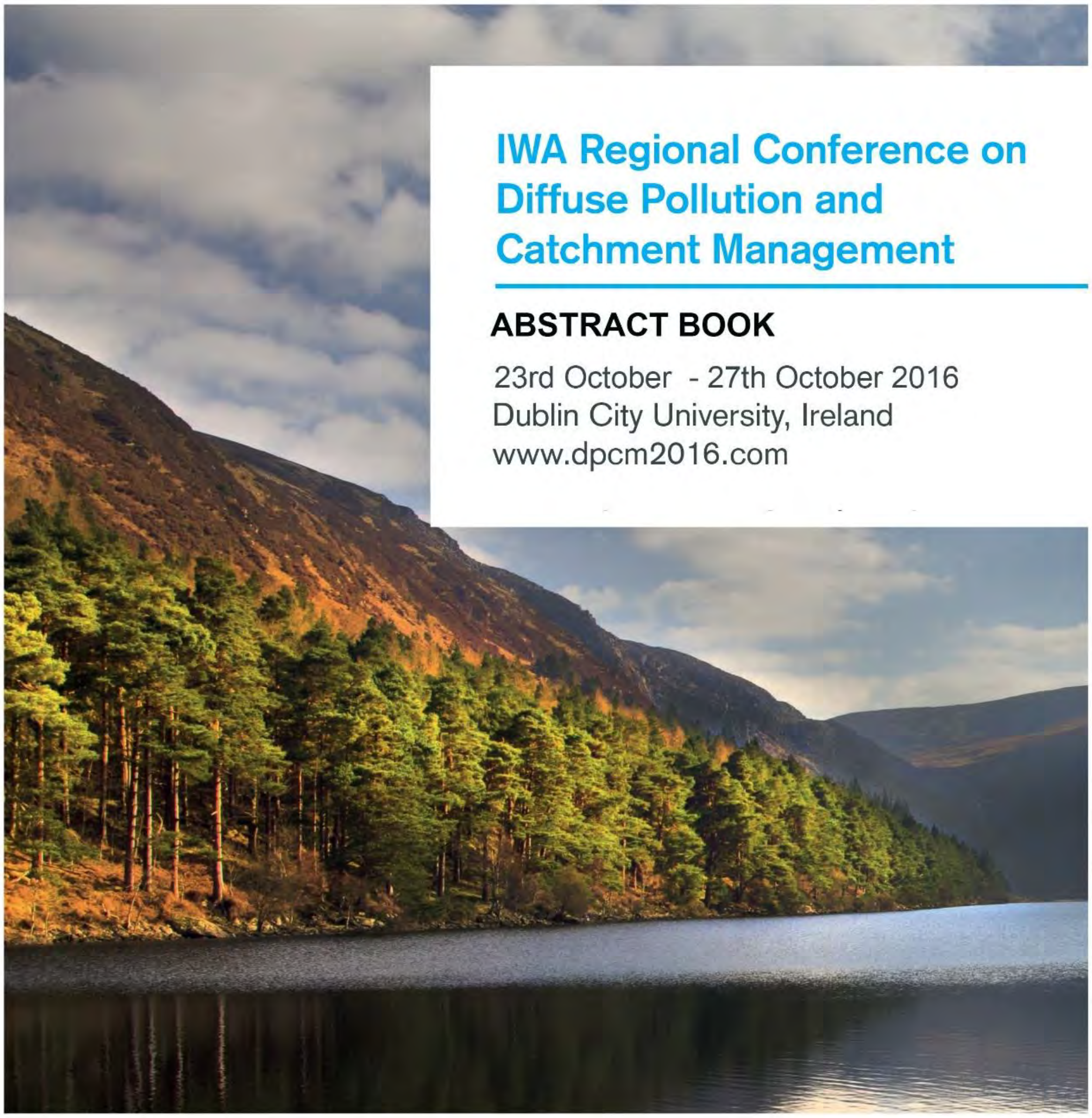

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Filtration Mechanisms on Porous Asphalt

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Introduction

The term "urban diffuse pollution", also known as non-point pollution, indicates a collective of pollutants that doesn't originate from a single source, but are products of land use and human activity in the urban area (Woods-Ballard, Kellagher et al. 2007). Particulate matter (PM) plays the role of a vector for the transport of these pollutants, such as heavy metals, organics and nutrients, and they end up being washed out by stormwater runoff (Sansalone, Kuang et al. 2008); (McDowell-Boyer, Hunt et al. 1986) (Marchioni and Becciu 2014)). Pervious pavement behaves as a water treatment system and improves runoff water quality through process of sedimentation, filtration, adsorption, biodegradation and volatilization (Woods-Ballard, Kellagher et al. 2007). Porous mixture surfaces have been widely used as a surface layer in pervious pavements. The structural porous matrix is constituted of coarser aggregates bonded with asphaltic or cementitious binder, and allows water to infiltrate at the same time that provides sufficient traffic support (Kuang, Ying et al. 2015). Material characteristics, as total and effective porosity, tortuosity and pore parameters, impact filtration mechanisms within the porous media, and consequently the filtration capacity. They also affect the permeability due to the clogging causing service life reduction. This study analyses the filtration mechanism on porous asphalt using porosity and pore parameters obtained through X-Ray Computed Microtomography (X-ray microCT).

Methods

Porous asphalt slabs were produced with a mixture of SBS (Styrene-Butadiene-Styrene) modified bitumen with a 4.1% content by weight, dimension of 50 x 26 x 5 cm and 20% of void content. From this slab was extracted a specimen with dimension of 7.8 x 7.8 x 5 cm used for the X-RAY µCT analysis.

The sample was scanned using the X-ray µCT NSI X25 system (NSI Inc., Rogers, MN, USA) available at Politecnico di Milano, equipped with a Dexela detector with 75 µm pixel pitch allowing for the acquisition of 1536 x 1944 pixel radiographies at full-binning with 16 bit encoding. The X-ray beam was set to 110 kVp and 48 µA, and a frame-rate of 6.6 Hz was adopted together with a 13 frame-averaging (to reduce noise), leading to 1800 angular projections. From the cone-beam geometry, the estimated voxel size resulted 61.88 µm with a zoom-factor equal to 1.21 .

3D tomo-reconstruction was performed using a modified Feldkamp algorithm in the version provided by efX-CT commercial software (NSI Inc.). Approximately 2.5 hours were required on a Work STation HP Z820 with 8 CPUs INTEL XEON(R) E52630 @2.6 GHz, and NVIDIA GPU GeFOrce GTX 80 Ti.

The obtained slices (with 8 Gbyte storage) were processed offline in a Matlab R2015b environment (Gonzalez and Woods 2016). The images were first converted to binary (black and white), where the solid pixels would represented the pores (white color) (Fig.1).

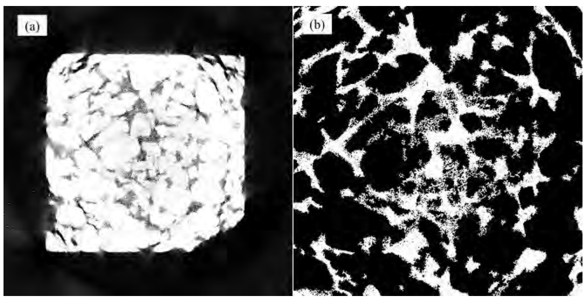

Fig. 1. (a) Original image acquired on the X-RAY µCT and (b) binary image used on the analysis.

The identification of the pores consisted in identifying a solid pixel *p* and use a flood-fill algorithm to label all the pixels connected to *p*. Each group of connections represented a pore.

The total porosity (φ_t) was determined according Eq.1, where V_c indicates the volume for each connections, obtained by weighting all pores in each connections, V denotes the total volume and m is the total number of connections

$$\emptyset_t = \frac{\sum_{i=1}^{m} V_{Ci}}{V} \qquad \text{Eq. 1}$$

To calculate the effective porosity (φ_e) all the connected components that didn't have pixels on the first layer (z=0) and on the last layers were excluded, and exclusively the connections that went all the way through the sample were considered. Then the effective porosity was computed according to Eq. 2.

$$\emptyset_e = \frac{\sum_{i=1}^{m} V_{ei}}{V} \qquad \text{Eq. 2}$$

Where V_e is the volume for each effective connected connections, obtained by weighting in all the connected pores, V is the total volume and m is the total number of connected connections

It was computed for each pore the area and the equivalent diameters, i.e. the diameter of a circumference covering the same area as the pore, and the pore size distribution [$PSD_{(pore)}$]. These parameters are essential to determine the behavior of the porous material in the presence of fluid, solute and PM loading (Kuang, Ying et al. 2015).

The pore average diameter (d_m) and particle diameter (d_p) are important parameters that govern the particle transport. Three main mechanisms of transport can be distinguished: surface (cake), straining filtration and physical-chemical filtration. When the particles are relatively larger as compared to the media the –particles will not penetrate the surface and will be retained, forming the so called surface cake. That cake will increase in thickness over time and start behave itself like a filter, reducing also the permeability of the media. That behavior is observed when $d_m/d_p < 10$ (McDowell-Boyer, Hunt et al. 1986).

The straining filtration, meaning the trapping of particles on pore throats that are too small to allow their passage, will likely happen on the narrow range of $10 < d_m/d_p < 20$ and plays an important role in pollutants removal (Auset and Keller 2006) (McDowell-Boyer, Hunt et al. 1986). Smaller particles can only be removed by physical-chemical filtration mechanisms, normally when $d_m/d_p > 20$. In this case the mechanism will depend basically on the particle diameter, whereas particles with $d_p > 5$ µm will be under the effect of gravitational sedimentation and with $d_p < 5$ µm by the effect of Brownian motion. These mechanism are also identified in pervious pavements (Teng and Sansalone 2004).

Results

Due to the simplicity of test methods, total porosity (φ_t) is often used to analyze the behavior of porous media even though the effective porosity (φ_e) is the critical factor governing hydraulic features(Kuang, Ying et al. 2015). For the investigated sample, it resulted φ_t = 18.58% and φ_e = 18.35%. This circumstance can be due to the presence of large pores, the most of which interconnected, that play a major role on the porosity (Table 1). On Fig. 2 is shown the estimated probability density function of the pore diameter [$PSD_{(pore)}$].

Mean pore area (mm^2)	7.34
Median pore area (mm^2)	1.70
Mean pore diameter (mm)	2.21
Median pore diameter (mm)	1.47

Table. 1. Pore parameters.

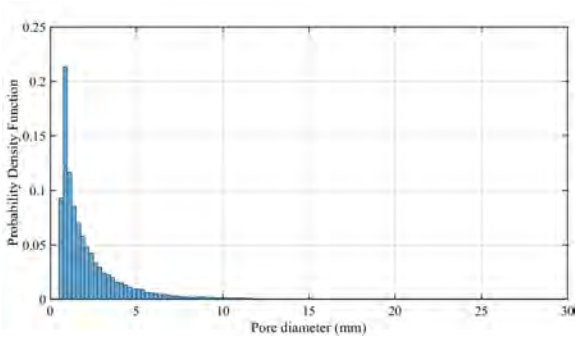

Fig. 2. Probability density function of the pore diameter $(PSD)_{pore}$.

To analyze the particle transport mechanisms it was used as a reference an inorganic ground silica with particle size distribution (PSD) according Fig 3. Considering this material and the porous asphalt sample, 27% of the particles would be retained within the surface, 27% of particles could be under the effect of straining filtration while 46% of the particles could only be retained by physical-chemical processes (Fig. 3). In fact, considering that such porous asphalt possesses relatively large pores, the pavement would not be expected to retain a finer material. On the contrary, a porous asphalt with smaller pore diameters would retain more sediment-size particles and this would imply an increase in filtration efficiency.

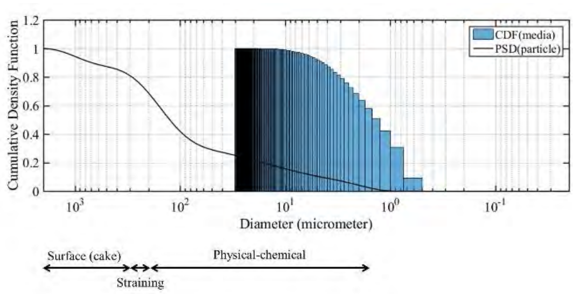

Fig. 3. Ruling filtration mechanisms for the reference sediment material $[PSD_{(particle)}]$ and cumulative density function of the pore diameter $[(CDF)_{pore}]$ of the porous media.

Discussion and Conclusions

In this study the X-RAY µCT technique has quantified porosity and pore parameters that otherwise are difficult to obtain. Such parameters permit a better understanding of the filtration mechanisms and therefore the filtration efficiency, and also be used as input information for models such as storm water management model (SWMM) and computational fluid dynamics (CFD).

For future developments, in situ loading during scanning will be considered (Fedele, Ciani et al. 2014), even in the presence of water saturating the connected porosity inside the material sample, possibly combined with Volume Digital Image Correlation (3D_Volume DIC) algorithm allowing to extract more accurate three dimensional displacement fields within the bulk material at different measurement scales (Fedele, Galantucci et al. 2013).

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Disclosures

The authors have nothing to disclose.