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# *Influence of coarse aggregate granulometry on clogging in pervious concrete*

## Influencia de la granulometría del agregado grueso en la colmatación del concreto permeable

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**Abstract**

*The phenomenon of clogging in pervious concrete (PC) has been one of the main causes of the hydraulic useful life reduction. This phenomenon begins with the partial or total clogging of the pore network and consequently the reduction of the permeability coefficient. Considering that the porous network of the PC is directly related to the aggregate used, the present work aims to evaluate the influence of granulometry on the clogging of the PC. The results showed that the largest aggregate size ($D_{max}$=19 mm) favors the hydraulic properties of the material. However, the variation of the granulometry grading distribution (poorly graded and single-sized) does not generate a significant difference in such results. In terms of clogging, there was a marked effect on the type of the granulometry grading distribution, the use of poorly graded aggregates led to a lower permeability reduction due to clogging when compared to PCs with single-sized aggregates.*
*Keywords: Pervious concrete; porosity; permeability; clogging; grain size.*

**Resumen**

El fenómeno de la colmatación en el concreto permeable (CP) ha sido una de las principales causas de la reducción de la vida útil hidráulica. Este fenómeno comienza con la colmatación parcial o total de la red de poros y consecuentemente la reducción del coeficiente de permeabilidad. Considerando que la red porosa del CP está directamente relacionada con el agregado utilizado, el presente trabajo tiene como objetivo evaluar la influencia de la granulometría en la colmatación del CP. Los resultados mostraron que el mayor tamaño de agregado ($D_{max}$=19 mm) favorece las propiedades hidráulicas del material. Sin embargo, la variación de la distribución granulométrica (descontinua y uniforme) no genera una diferencia significativa en tales resultados. En cuanto a la colmatación, hubo un efecto marcado en el tipo de distribución granulométrica, el uso de agregados descontinuos condujo a una menor reducción de la permeabilidad debido a la poca reducción de permeabilidad dada por la colmatación en comparación con los CP con agregados de un solo tamaño.

**Palabras clave:** Concreto permeable; porosidad; permeabilidad; colmatación; tamaño de grano.

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# 1. Introduction

Pervious concrete (PC) is a special type of concrete that has a network of interconnected large pores achieved by the use of coarse aggregates, reduced amount of fines provided by the sand and cement paste volume just enough to provide a connection between coarse aggregates (ACI, 2010), (Pieralisi et al., 2016). PC produced with coarse aggregates of smaller diameters or with combinations of different discontinuous granulometry show improvements in mechanical strength. However, the opposite behavior is observed when it comes to hydraulic properties (permeability and infiltration rate) (Schaefer et al., 2011).

A recurring durability problem in PC is clogging, and it is associated with partial or total obstruction of the pores by sediment. (Sandoval et al., 2020), (Sandoval et al., 2022), (Haselbach et al., 2006),(Deo et al., 2010), (Mata and Leming, 2012) (Sandoval et al., 2022). The clogging phenomenon is directly influenced by the topographical, geological and hydrological characteristics of each region, as well as the technical specifications of each project (initial porosity and permeability, material proportions, and PC maintenance) (Joshi and Dave, 2021), (Huang et al., 2021). Since the clogging kinetics is directly related to the porous network of the PC, the granulometry of the aggregates plays a fundamental role in the useful life of PC. By modifying the porous network, it is possible to produce materials with a better behavior against the phenomenon of clogging.

The objective of this paper is to evaluate the influence of coarse aggregate granulometry on clogging kinematics, considering four aggregate size distributions and two compaction methods.

# 2. Experimental Program

## 2.1 Materials properties

The material proportion used in this study is 1:3.26 (cement: coarse aggregate), with water-to-cement ratio (w/c) of 0.34 and cement content of 420 kg/m³. Portland cement type I was selected as the binder. Four different aggregate grading distributions see (Figure 1a) were analyzed: poorly graded with maximum size of 19 mm (B1D); single-sized of 19 mm (B1U); poorly graded with maximum size of 10 mm (B0D); single-sized of 10 mm (B0U). The coarse aggregate was also duly characterized considering the physical properties of the material. Sand (with grading distribution presented in (Figure 1b) was used as sediment to clog the PCs.
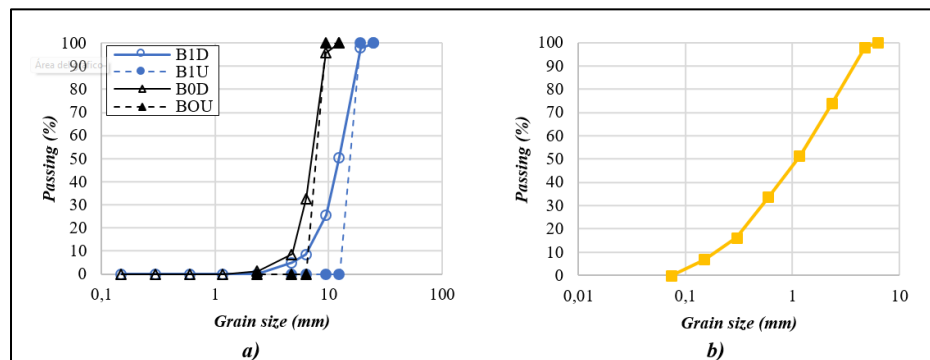


**Figure 1.** Granulometric curves: a) Coarse Aggregate and b) Sediment used.

## 2.2 Specimens preparation

Cylindrical specimens (100φx200mm) were produced using two compaction procedures: in two layers with 10 blows per layer using a Proctor Hummer (P); and in 3 layers with 12 blows per layer using a compaction rod (H). In total, 8 mixes were produced considering the combination of variables described (see (Table 1)). The PC mixtures were named with acronyms, the first three characters refer to the aggregate grade distribution (B1D; B1U; B0D; and B0U) and the last character refers to the type of compaction used P or H (Table 1S) supplementary material explains the nomenclature used for each PC mix.

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*Table 1. Coarse aggregate properties.*

| Coarse Aggregate | Specific gravity | Water Absorption (%) | Unit weight (g/cm³) | Materials finer than 75 µm (%) |
|---|---|---|---|---|
| B0 | 2.77 | 2.00 | 1.30 | 1.43 |
| B1 | 2.82 | 0.81 | 1.50 | 2.86 |

After the compaction process, the specimens were wrapped in plastic for the first 72 hours to ensure good curing conditions. Then, the specimens were demolded and submerged in water until the test date (as recommended by ACI 522R-10).

### 2.3    Test Methods

After the curing period (28 days), specimens were tested for their hardened density and porosity (measured according to ASTM C1754 (C.G. de Normas, 2016) see (Figure 2a ), their permeability with a constant head permeameter (measured according to (Sandoval et al., 2017) – see (Figure 2b)). Once these tests were finished, they were characterized for the clogging resistance test (measured according to (Sandoval, 2020) – see (Figure 2c)) using sand as sediment. All specimens were kept under submerged curing in between tests.
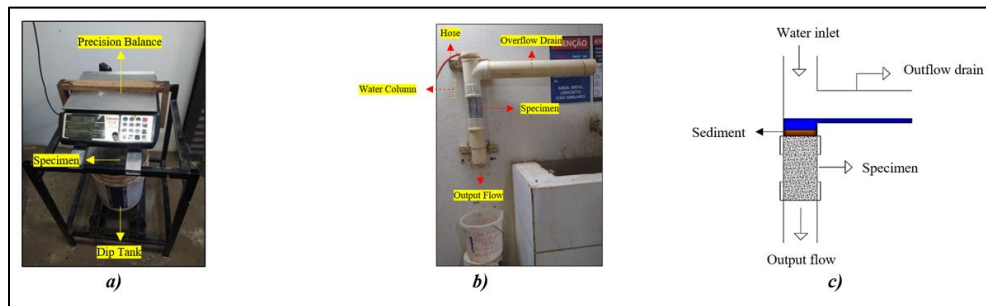


*Figure 2. Hydraulic test: a) Porosity, b) Permeability, and c) Clogging.*

## 3.    Results and discussion

### 3.1    Density, Porosity and Permeability

(Table 2) shows the average results of density, porosity, and permeability coefficient. The coefficient of variation (CV) calculated is presented in parenthesis. The porosities of all PC produced were within the range of 31.85% (B0DP) and 35.42% (B1UP), values that are in agreement with the literature (Huang et al., 2021), (Ling et al., 2022) (Putman and Neptune, 2011), (Peng et al., 2018), (Joshaghani et al., 2015). All PCs produced reached permeabilities above the minimum (>1 mm/s) according to ACI 522R-10 (Shaefer et al., 2011) [3] and ABNT NBR 16416: 2015 (ACI, 2010), (ABNT, 2015).

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***Table 2.*** *Experimental results and CV (in parenthesis).*

| Mix | Density (kg/m³) | Porosity (%) | Permeability (mm/s) |
|---|---|---|---|
| B0UP | 1893.95 (0.8%) | 32.62 (5.3%) | 5.11 (0.1%) |
| B0UH | 1885.99 (1.8%) | 32.84 (5.7%) | 5.74 (0.1%) |
| B0DP | 1927.37 (1.6%) | 31.85 (7.1%) | 4.64 (0.1%) |
| B0DH | 1917.82 (2.7%) | 32.61 (10.7%) | 5.35 (0.1%) |
| B1UP | 1860.84 (0.7%) | 35.42 (7.0%) | 7.98 (0.1%) |
| B1UH | 1855.11 (0.7%) | 34.63 (6.2%) | 7.85 (0.1%) |
| B1DP | 1914.16 (1.7%) | 32.89 (5.4%) | 5.69 (0.1%) |
| B1DH | 1875.80 (2.1%) | 33.82 (4.3%) | 7.55 (0.2%) |

ANOVA and Tukey HSD Test were performed to evaluate if the differences observed between composition and compaction process applied were significant. The significance level considered was 0.05.

For the same aggregate grading distribution, the compaction process did not significantly affect density and porosity. The PCs with aggregates of a maximum size of 19 mm and compacted using a rod (B0UH and B0DH) showed higher permeability values (p-value ≤ 0.05 in all ANOVA comparisons and p-value < 0.036 in Tukey's HSD test). then the ones compacted with a Proctor Hummer (B0UP and B0DP). However, the compaction process did not significantly affect the permeability of concrete with aggregates of a maximum size of 10 mm.

No significant differences in density and porosity were found when comparing poorly graded and single-sized aggregates with the same compaction process. However, the use of poorly graded aggregates led to a reduction in permeability regardless of the maximum aggregate size analyzed.

Even though significant differences in density and porosity were not observed when comparing the variation of the maximum aggregate size, the permeability increased (p-value ≤ 0.05 in all ANOVA comparisons and p-value < 0.05 for 95% of multiple comparisons in the Tukey's HSD test) in PCs with larger aggregates.

### 3.2 Clogging Resistance

(Figure 3) shows the average of the results obtained with the clogging test considering a critical charge of sediment arriving in the material. The ordinate shows the permeability in percentage, where 100% corresponds to the initial permeability (without clogging) measured at 28 days. The abscissa shows the sediment charge added during the test.
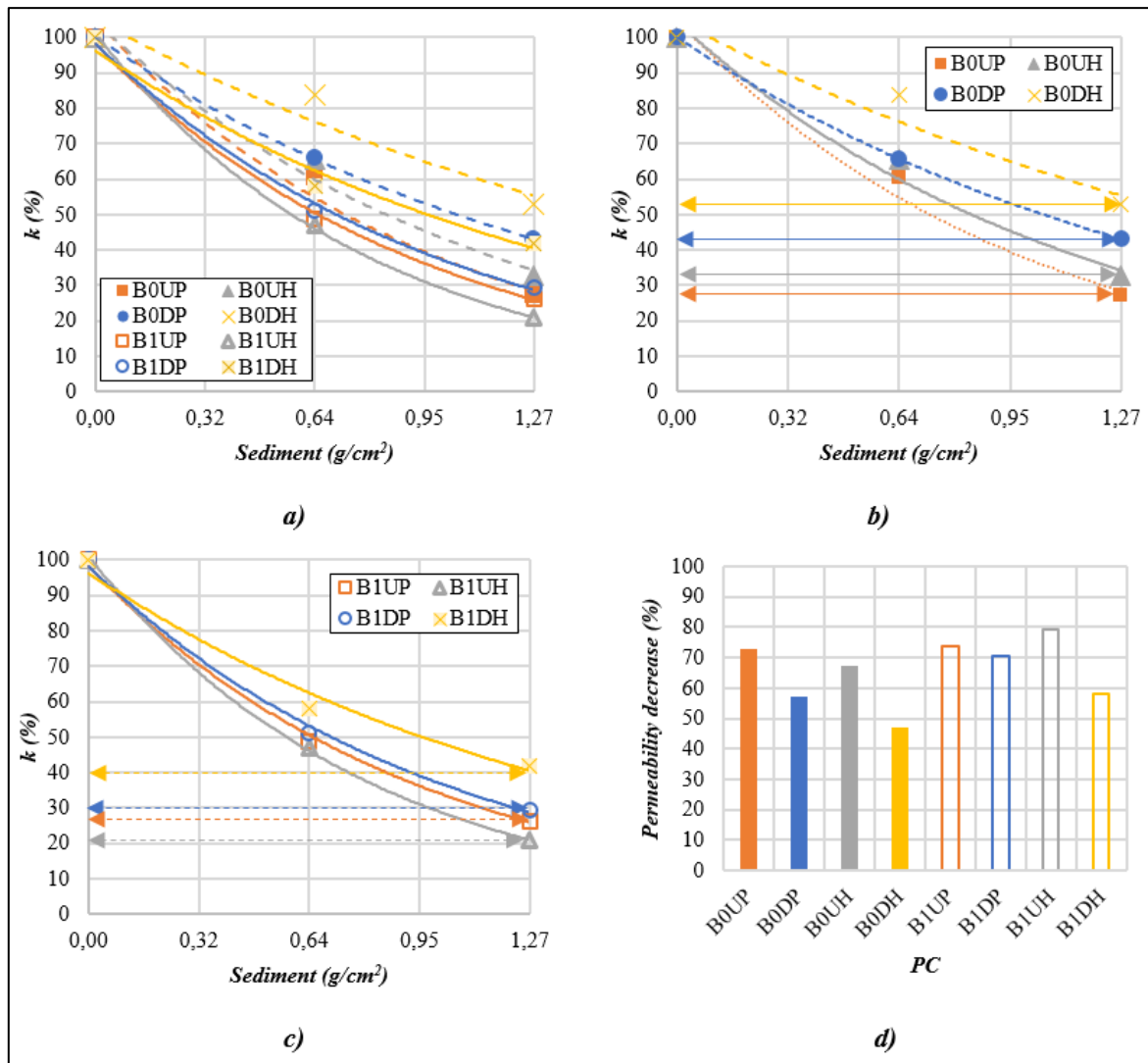
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**Figure 3.** *Clogging Results.*

PCs produced with aggregates with a maximum diameter of 19 mm (B1) showed greater permeability loss. PCs with larger pores (as those produced with aggregate with a maximum diameter of 19 mm) are more susceptible to clogging with sand (sediment used in the test), as they have larger connection throats (Sandoval et al., 2022).

For the same aggregate maximum diameter of 10 mm and compaction process, the use of poorly graded aggregates (B0DP and B0DH) led to a lower permeability reduction due to clogging when compared to PCs with single-sized aggregates. B0DP and B0DH reached approximately 57% and 47% permeability reduction, while the B0UP and B0UH reached decreases in permeability of 73% and 67%.

## 4. Conclusions

The present paper has evaluated the influence of coarse aggregate maximum diameter and the aggregate grading distributions on clogging in pervious concrete The following conclusions may be derived based on the analysis of the experimental studies conducted here:

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*• The variation of maximum aggregate size, aggregate grading distribution, and compaction process analyzed in this research showed no significant differences in density and porosity.*
*• An average increase of 40% in permeability was observed in PCs produced with aggregates of a maximum diameter of 19 mm when compared to PCs produced with aggregates of a maximum diameter of 10 mm.*
*• PCs produced with aggregate with a maximum diameter of 19 mm were more susceptible to clogging with sand (sediment used in the test), as they presented larger pores and larger connection throats than PCs produced with aggregates of a maximum diameter of 10 mm.*

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