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Short communication

Comparison between the falling head and the constant head permeability tests to assess the permeability coefficient of sustainable Pervious Concretes

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A R T I C L E I N F O

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A B S T R A C T

The use of Pervious Concrete (PC) increased in the last years as an alternative to solve the run-off problem. PC shows a high percentage of empty spaces/gaps, which vary from 10 to 35%, facilitating the flow of rain and water through its structure. PC presents higher k permeability coefficient compared to conventional concrete. Permeability is the main property of PC, although there is no standardized method that guarantees the correct and precise measurement of such property in laboratory conditions. Currently, two main methodologies are used to assess the permeability coefficient: the falling head and the constant head permeability tests. In that regard, the American Concrete Institute recommends the use of the first method, although no comparison was done between them. Furthermore, the recommendations do not consider the use of sustainable aggregates during the production of the PC. In this study, the permeability tests were explained and used to assess the permeability coefficient of different mixes of PC produced with sustainable aggregates. The experimental results were used to analyze the relationship between the porosity and the permeability of concrete and compare the performance of the falling head and constant head permeability tests. The study presents the advantages of performing the constant head permeability test to assess the permeability of the PC.

1. Introduction

Floods have devastating consequences and effects on the economy, environment, and people in many regions of the world. In 2004, intense rains caused 414 deaths and potable water supply problems in the Dominican Republican. In Brazil, in January 2011, rainfalls reached 95% of the expected for that month in Rio de Janeiro, collapsing the city's traffic due to an inefficient drainage system, which was unable to deal with precipitations of this nature. In 2011, in Haiti, more than 1600 people disappeared and 900 died due to floods [1–4].

Floods are caused by environmental factors, such as the current climate change and the lack of drainage systems that, many times, are not sufficient to deal with above average precipitation events [4]. In that sense, developing countries like Colombia are investing billions of dollars in infrastructure to improve their drainage systems and, therefore, prevent disasters caused by climate changes [5].

These problems are magnified in cities. Floods and rainwater management issues are caused by waterproof areas that hold the

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water on the surface of the streets, impeding their normal functioning and becoming an imminent risk to the population. Currently, most of the materials used in construction present low permeability [6]. The use of these materials in the cities change the hydrological cycle in a radical way, as rainwater stops infiltrating in the soil and becomes run-off. In response to that, researchers are focused on searching for new materials that allow the passage of the water through their structure without altering their mechanical properties, guaranteeing fast water absorption. In that sense, Pervious Concrete (PC) is among these materials [7].

PC is a special concrete that presents high porosity, providing great drainage capacity and thus the ability to reduce the flow of rainwater present on the surface of the material [8]. PC may be the answer to problems caused by floods in cities, but it still needs further and more in-depth studies. In that sense, there is a lack of standardization, even though the American Institute of Concrete (ACI) presented a recommendation to the use of PC in civil construction: ACI 522R-10 [9].

Regarding the use of PC, its permeability is one of the most important properties that have to be considered in a project. Considering the recent scientific literature, to assess this characteristic, two tests can be performed: the falling head permeability test [10] and the constant head test [11], which are performed in a laboratory, and the test described by the American Standards ASTM C1701 and the NCAT permeameter method [12], which is performed in situ. Regarding the ones used in the laboratory, the tests reach very different coefficients as demonstrated by many authors [9,13,14]. However, the ACI recommends both tests, it is clear that there is no standard to determine permeability in PC in the laboratory [15]. Notice that, the permeability of concrete is related to its porosity. The higher the number of interconnected voids within the concrete, the higher its permeability coefficient will be [6,13,16,17]. Apart from that, this coefficient may be affected by the presence of the aggregates used to produce the concrete [16,18]. In that regard, the ACI recommendation only considers conventional aggregates and therefore, new studies are required to understand how the permeability of concrete is affected when using sustainable aggregates from construction and industrial waste.

The present study aims to compare the laboratory tests used to assess the permeability, the falling head, and the constant head tests, regarding the use of sustainable aggregates. To fulfill this objective, the porosity and the permeability of four PC produced with a conventional basalt aggregate and three sustainable aggregates (blast furnace slag, ceramic waste and recycled concrete aggregates) are assessed. The experimental results are used to statistically compare the differences between the tests considered.

2. Methodology

2.1. Materials

The materials used in this study to produce sustainable PC were cement, water, and aggregates. Regarding the first, a Portland cement CP II-F-32 (Brazilian denomination [19]) was used. Notice that this cement was chosen due to the current environmental tendency of reduction of the amount of clinker. In that sense, it presents a 6–10% of limestone filler addition [20]. Potable water was used in the production of mixes. Finally, four types of aggregates were selected: basalt, blast furnace slag (BFS), ceramic waste (CW) and recycled concrete aggregates (RCA). A sample of each type of aggregate is shown in Fig. 1. It is important to remark that the use of BFS, CW, and RCA in construction entails important environmental advantages [5] and basalt is a common aggregate considered as a reference in this project.

Fig. 2 presents the grading curves of the aggregates. The maximum aggregate size was 9.5 mm for all of them. Notice that this is the minimum value recommended by the ACI [9] to produce PC. The grading curves show a uniform grading for all the aggregates. In that sense, the uniformity coefficients (C_u) of Basalt, BFS, CW, and RCA are equal to 2.20, 1.80, 2.16 and 1.86, respectively. These values are close; hence, the difference of the aggregate grading distributions is considered not significant [21].

Furthermore, the content of the powdery material and the water absorption of the aggregates were assessed following the requirements of the Brazilian standards NBR NM 46/2003 [22] and NBR NM 53/2003 [23], respectively. Notice that these two properties are important to adjust the additional water during the production process to maintain equal water/cement ratios for all mixes [24]. The results obtained are presented in Table 1. This shows how the powdery material and the water absorption are related, since the higher is the former, the higher is the latter. The highest values were obtained for CW and RCA, and the lowest by BSF, as expected [8,18].

2.2. Mix design

All samples were produced with 1367 kg of aggregates, 420 kg of cement and a water/cement ratio (w/c) equal to 0.34 (water content equal to 143 kg). These proportions were established considering the ACI recommendations [9]. Notice that an addition of mixing water was included taking into account the water absorption of each aggregate (Table 1). Table 2 presents the adjustment in terms of water addition (water content + water absorption). In that context, the water absorption in liters (l) was calculated using the percentage of water absorption and considering the mass of aggregates. Hence, the effective water/cement ratio was the same for all mixes [24].

2.3. Production process

The concretes were mixed for a total time of 5 min and then the specimens were cast using cylinder molds (100ϕ × 200 mm). The mixtures were compacted using a flow table, with 20 blows/layer with a total of 2 layers [5]. Then, the specimens were demoulded at age 24 h and kept in a curing room up to 28 days. A total of 84 specimens were produced in this project.