CHAPTER 70

Permeable concrete pavement elaborated with civil construction residue

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ABSTRACT
Currently, with urban expansion, there are two major issues of concern: soil sealing and the generation of civil construction waste (RCC). Soil compaction and asphalting make it difficult for water to infiltrate, which can lead to flooding in lower areas. The waste generated, when disposed of irregularly, causes obstruction of roads, the proliferation of vectors, silting of streams and rivers, etc. The use of permeable concrete pavements made with RCC aggregates is an innovative and sustainable solution to this problem. Therefore, this research proposes to incorporate recycled aggregates in the production of structural concrete, for later application in permeable pavements. 2 m 2 of permeable pavement were built, 1 m 2 made with blocks containing RCC, and 1 m 2 with blocks containing natural aggregate. The performance of the pavements was verified through tests of compressive strength and permeability, showing the positive interference of the construction residue in the pavement drainage.

Keywords: permeable pavement; recycled construction aggregate; mechanical and hydraulic tests

1 INTRODUCTION

Nowadays, with the growing increase in the urban demographic aspect, there is a social primacy to propose measures to mitigate the problems encountered and subsidize actions, in the sense of correcting and avoiding future complications in an area favored by urban expansion.

Considering that soil compaction and asphalting make it difficult for water to infiltrate, which can lead to flooding in the lower areas, the following are worrying issues arising from the rampant expansion of the urban perimeter: soil sealing and the generation of construction waste. civilian (RCC). The use of permeable concrete pavements made with RCC aggregates is an innovative and sustainable solution to this problem.

According to Tucci et al. (2006, apud Alves, 2015), urbanization generates numerous changes in society, being preponderant in the hydrological cycle, such as: reduction of infiltration in the soil and accumulation of water on the surface, which has as a direct consequence the increase in surface runoff and maximum flows; being the main reasons for the occurrence of floods in large urban centers.

NBR 16416:2015 defines permeable concrete as “concrete with interconnected voids that allow water percolation by gravity”. According to Duarte and Kronka *et al* . (2006, *apud* , BELINE, 2019): “Permeable concrete is a type of concrete with a high rate of interconnected voids, prepared with little or no fine aggregate, which allows the unobstructed passage of large amounts of water”.

In Brazil, the standard that regulates the use of permeable concrete in pavements is NBR 16416:2015. Some minimum parameters are required for the pavement to be permeable, including mechanical strength, which may vary according to pavement thickness, use and type. According to scientific research carried out so far, it is known that the recycled aggregate allows a great percolation of water through its structure, on the other hand, the material does not present good resistance to compression. In general, for any pavement to be considered permeable, the standard mentions a minimum compressive strength of 20 MPa and a minimum permeability of 0.1 cm/s.

It is known that the recycling of civil construction waste is currently not used with its full applicability, since only 17 million of the 87.2 million cubic meters of waste produced during a year are reused (Abrecon, 2018).

The recycling and reuse of civil construction waste are great possibilities in sustainable management to minimize the negative effects processed by the construction industry in terms of solid waste generation. In addition, they have a high exploratory potential, since they have unique characteristics, such as the effectiveness in the hydraulic conductivity capacity (OLIVEIRA, 2017).

Furthermore, the use of construction waste, according to Safiuddin *et al.* (2011, apud Alves, 2016), solves the disposal problem, reduces landfill space, conserves natural resources, reduces transport costs and environmental pollution, thus protecting the ecological balance.

Therefore, the basic foundation for the development of this research lies in the fact that the use of permeable pavements provided with RCC tends to minimize problems of both soil permeability and the accumulation of construction waste, since recycled aggregates can be used in large quantities. considerable gaps and material voids make it possible to achieve self-draining mixtures.

Finocchiaro and Girardi (2017) developed a research with aggregates from RCC, in which, through the analysis of the compressive strength and the percolation speed of water in the specimens, they observed that the concrete containing recycled aggregate did not present satisfactory results of compressive strength, on the other hand, offered excellent results in terms of water percolation time.

Gentil et al. (2020, apud Rizvi, 2010) performed compressive strength tests on permeable concrete with recycled aggregate from civil construction, analyzing several traits. The authors verified that, as the content of recycled aggregate in the concrete increases, the values of compressive strength of the mixtures decrease.

According to Monteiro (2010), the consumption of cement is directly proportional to the strength of the concrete and indirectly proportional to the permeability, since the void index decreases considerably with the increase of the binder, thus hindering the passage of water.

Simões (2021) found, with the study of several traces of permeable concrete made with RCC, that the increase in the amount of aggregate significantly decreases the amount of cement paste, thus increasing the void index present in the mixture and the capacity of concrete percolation.

Strieder (2020) also used RCC to make permeable concrete. In his research, traces of 1:3 and a w/c ratio of 0.3 were used, with six concretings being made: one with 100% of natural aggregate and another five with 20%, 40%, 60%, 80% and 100% of replacement of natural aggregate by recycled one. Based on the results, there was approximately a 30% decrease in compressive strength as 100% of the RCC was added.

In summary, the common purpose among the various researches carried out is the primordiality in the reduction of waste from civil construction, through its use as an aggregate in the sector itself. This solution, in addition to minimizing the problem of waste disposal, contributes to reducing the use of natural aggregates, which are already scarce, and may also contribute to the insertion of drainage mixtures in paving. However, the use of RCC still needs to be studied and discussed, given the heterogeneity of the material. Therefore, this research proposes to produce permeable concrete with recycled aggregates from RCC and to verify its efficiency in the application of permeable concrete pavements.

2 MATERIAL AND METHODS

Previously, in order to make it possible to apply the permeable concrete blocks, the soil of the settlement site was analyzed through the compaction test, according to NBR 6427:2016 and NBR 7182:2021 , Index test Support California (or CBR), following the provisions of NBR 9895:2016, and the study of the permeability coefficient of the soil, which used a permeameter made at the institution itself and which follows NBR 13292:2021, in order to meet the parameters established in Annex B and in table B.2 of NBR 16416:2015. Figure 1 shows the soil compaction, CBR and permeability tests.

FIGURE 1. Soil tests: compaction (left), CBR (center) and permeability (right).

Considering the test results, through calculations, the mechanical and hydraulic sizing of the base layer and sub-base was carried out, guided by Annex B of NBR 16416:2015, reaching the values of 20 cm of gravel 1 for the layer of sub-base and 5 cm of coarse sand, capable of passing completely through the 9.5 mm sieve, to the base layer, thus totaling 30 cm of base/sub-base thickness, following the provisions of NBR 16416:2015, which establishes the use of stone materials of open granulometry for the implantation of the base and/or sub-base, where the specifications of tables 1 and 2 of the referred standard must be met.

Subsequently, the activities of excavation, cleaning, leveling and compaction of the land began, in order to meet the minimum slope of 1% exposed in NBR 16416:2015, avoid irregularities and directly contribute to the draining role of the pavement.

Subsequently, for the manufacture of permeable blocks, the 1:3.5 mix was chosen for its better performance in the mechanical and hydraulic requirements analyzed, based on the results of research by Furini (2021) and Simões (2021). Table 1 shows the consumption of materials used in the research.

TABLE 1. Consumption of materials per line (Kg/m ^{3}).

Dosage determination by the IPT method - USP

Dosage managed / Mortar amount / Unitary dosage (mass) a/c relation / Material consumption

Cement-sand-coarse Cemeny/ sand/ pebble/ CCR

Determinação do traço pelo método IPT - USP									
Traço trabalhado	Teor de argamass	Traço Unitário (em massa)			Relação a/c	Consumo total de mateiais (Kg)			
		Cimento	Areia	Graúdo		Cimento	Areia	Pedrisco	RCD
100% pedrisco	0,22	1	0	3,5	0,270	561,441	0,000	1965,045	0,000
60P/40RCD	0,22	1	0	3,5	0,550	561,441	0,000	1179,027	651,426

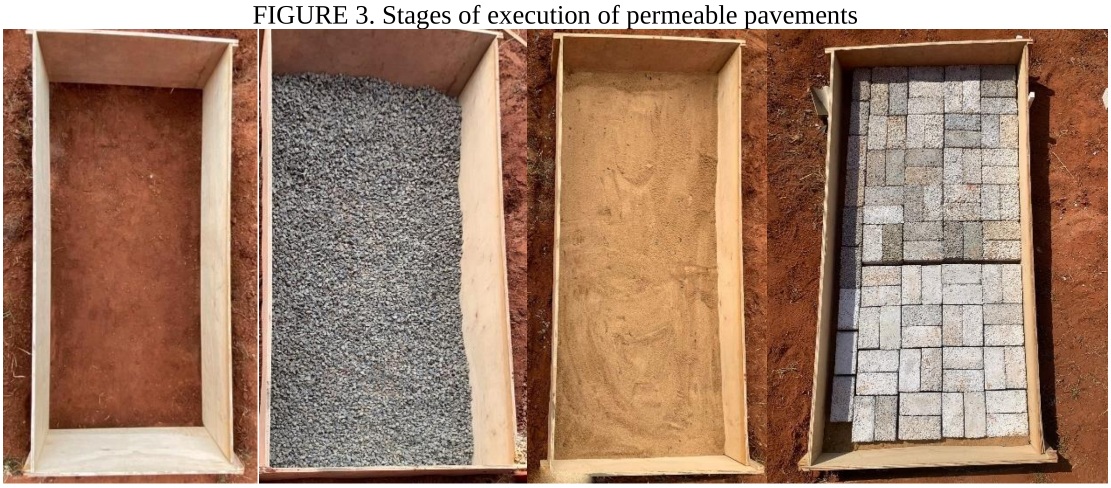
A control mixture (100% gravel) served as a comparative basis for a mixture containing 40% RCC in place of natural aggregate. A total of 50 rectangular concrete pieces (20x10x6cm) were molded for each analyzed trait, in order to cover a total area of 1.0 m². Cylindrical pieces (10x20cm) were also made for visual and mechanical characterization of the concrete (compressive strength according to NBR 5739:2018).

The molding of the specimens followed the recommendations of NBR 5738:2016. After being removed from the mold, the pieces remained until the test date (28 days) in a humid chamber for complete and effective curing. Molding and curing of the specimens are shown in Figure 2.

FIGURE 2. The casting of concrete blocks (left) and immersion curing (right).

Before laying the pieces, the horizontal stability of the system was guaranteed through the placement of lateral retainers, made of wood and fixed to the base of the floor with the aid of pickets. The application of the concrete pieces was performed manually, respecting leveling, square and alignment. The floor segments of $1m^2$ each were created in an outdoor area, located next to the IFSP Civil Construction Materials Laboratory, Votuporanga/SP campus. Figure 3 shows the stages of soil preparation, as well as the laying of concrete blocks.

FIGURE 3. Stages of execution of permeable pavements



After laying the pavement, in order to verify the *in situ water infiltration rate* , the permeability test, described by ASTM C1701, recently incorporated into NBR 16416:2015, was carried out. With the device properly positioned (Figure 4), the test method described in Annex B of the Brazilian standard was used, where an infiltration ring with 30cm of internal diameter was used, in order to collect the necessary data to obtain the rate of infiltration (k) *in situ* , described by equation (1).

FIGURE 4. Test to obtain the permeability coefficient of pavements

$$k = \frac{C \times m}{(d^2 \times t)}$$ (Equation 1)

on what:
k: infiltration rate, mm/h;
m: mass of infiltrated water, kg;
d: inner diameter of the cylinder for all percolated water, mm;
t: time required for all the water to percolate, s;
C: SI system unit conversion factor, with a value equal to 4,583,666,000.

The research was carried out entirely at the Materials Analysis Laboratory and the Soil Mechanics Laboratory at IFSP – Campus Votuporanga, São Paulo, which has all the equipment and materials needed to carry out the research. The RCC aggregate was supplied by the company Mejan Ambiental de Votuporanga-SP and the other materials used, such as gravel and cement (Portland CP V-ARI), were supplied by the institution and acquired in the region itself.

3 RESULTS AND DISCUSSION

Table 2 presents the values of the compressive strength of the control concrete and containing 40% of civil construction waste. Considering that NBR 16416:2015 requires a minimum characteristic compressive strength of 20 MPa, and analyzing the results obtained, it can be said that both concretes meet the standard.

Considering that the addition of recycled aggregate in the mixture causes a reduction in strength (a fact already verified in the literature), research presents reference values many times lower than 20 MPa for permeable concrete produced with aggregate from RCC. Strieder *et al.* (2020) arrived at mixtures with strength values ranging between 12.17 and 24.59 MPa. Faria *et al.* (2019) produced mixtures with values between 14.3 and 26.3 MPa. Tavares and Kazmierczak (2016) reached values ranging from 8.98 to 22.11 MPa. Comparing the results obtained with those found in the bibliography, it is visible that the concrete elaborated fits the expected.

TABLE 2. Values of the compressive strength (MPa) of the studied concretes.
Dosage / Resistance to compression (Mpa)
Dosage contro
CCR

Traço		Resistência à compressão (MPa)					
		CP1	CP2	CP3	CP4	CP5	Média
1:3,5:0,55	TCONTROLE	32,88	33,43	28,30	31,34	33,35	31,86
	40% RCC	20,92	22,54	20,80	23,91	24,15	22,46

In terms of permeability of concrete blocks, NBR 16416:2015 allows evaluating this property through the test described in Annex A thereof or following the requirements of NBR 13292:2021. In this research, we chose to follow the instructions and recommendations in Annex A of NBR 16416:2015, as shown in Figure 5.

FIGURE 5. Permeability test of concrete blocks: control (left) and with RCC (right) .

Considering the results of the permeability coefficient of the concretes (Table 3) and the minimum value established normatively (0.001 m/s), found in Table 3, it is stated that all mixtures complied with the standard. The permeability gain is evident when adding the RCC, increasing the value by more than 64% when incorporating 40% of residue.

TABLE 3. Permeability coefficient k values recorded (m/s).
Dosage / Permeability Coefficient (m/s)
Dosage control / average

Traço		Coeficiente de permeabilidade (m/s)			
		k1	k2	k3	Média
1:3,5:0,55	TCONTROLE	0,0112	0,0102	0,0098	0,0104
	40% RCC	0,0185	0,0161	0,0168	0,0171

Evaluating the permeability of the pavements, the infiltration rate (k) *in situ was obtained* , which was 0.0717 m/s for the pavement with RCC and 0.0509 m/s for the control; values well above the 0.0171 m/s found in the specimens studied. Junior (2019) also points out this increase in hydraulic performance in the pavements produced. It should also be noted the efficiency with respect to the permeability of pavements with RCC, which exceeds by approximately 40% the coefficient of the common pavement.

4 CONCLUSIONS

It is a fact that the draining floor presents itself as an efficient alternative in urban drainage and, consequently, in the fight against surface runoff, since it allows the direct reduction of the constant accumulation of water in traffic routes; together with the use of civil construction waste, these floors become extremely useful for planning cities and for improving the population's quality of life. For this reason, the development of permeable pavements with alternative materials that can provide a higher rate of infiltration, as in the case of civil construction waste proposed in this research, becomes of great importance, not to mention the reduction of accumulated waste and the reduction of use of already scarce natural aggregates.

The incorporation of recycled aggregate in the production of concrete pavements is advantageous for its hydraulic performance, since mixtures with 40% of RCC managed to overcome the permeability coefficient of the control mixtures by more than 60%. The mechanical performance results reaffirmed the literature propositions, since the compressive strength suffers damage when adding the residue; fact, however, that did not make it impossible to reach the resistance prescribed by norm.

Finally, the production of permeable pavement makes it possible to verify the effectiveness of recycled concrete in terms of water percolation. In addition, the contribution of the correct preparation of the base that will receive the pavement is noted so that the permeability remains high.

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