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ANALYSIS OF THE RELATIONSHIP BETWEEN PERMEABLE CONCRETE PRODUCED FOR TWO TRAINS

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Abstract: One of the biggest problems faced in metropolises around the world is the impact of drainage. The rampant use of conventional concrete and asphalt is increasingly minimizing the infiltration of urban areas and consequently causing flooding problems that cause material damage and loss of life every year that could be avoided with the adoption of urban drainage techniques. One of these technologies that has been studied is the application of porous concrete, also known as permeable. In this research, the constitution technique was used for two specific traits of permeable concrete of 1:3 and 1:4 respectively for compression and traction tests in flexion in order to measure the degree of efficiency of these materials and subsequently made a plate for visually check the infiltration potential obtained. The compression values for the 1:3 and 1:4 ratios were respectively 9.31 and 10.64 MPa. As for the flexion traction test, the values obtained for the traits were respectively 0.88 and 0.48.
Keywords: Drainage; porosity; permeable concrete; subsurface runoff.

1. INTRODUCTION

The increase in new ventures on the planet would undoubtedly not be possible without the help of an important member – concrete.

According to Silva (1991) the best definition of concrete is the fact that it is one of the most important materials in civil construction. It can be obtained by mixing binder, fine aggregates and coarse aggregates with water.

On the other hand, nowadays it has become more and more interesting to research a new actor acting in the scenario – the porous concrete.

For Ferguson (2005) porous concrete (known as permeable) is defined as a special type of concrete that is characterized mainly by the absence of fines, and by producing a permeable and resistant structure. It is mainly used for paving as a compensatory flood dampening technique, with the aim of reducing the runoff of rainwater, and is indicated for places with moderate load traffic, such as parking lots and sidewalks.

Pervious concrete is considered a sustainable building material as it reduces stormwater runoff, improves the quality of groundwater recharge water and can reduce the impact of urbanization (ACI 522, 2010).

By studying the behavior of the resurgence of the urban zone in large population centers, such as, for example, the RMSP (Metropolitan Region of São Paulo). Its adoption makes it possible to increase the urban drainage area, minimizing the impacts generated by surface runoff in the form of floods. Becoming vital its study to guarantee its use in order to allow the increase of the time of concentration (tc) in areas with excessive conventional concrete and asphalt.

The purpose of this research was to present a case study on data related to the determination of a porous concrete mix with available materials in the region of the district of Barão Geraldo in the municipality of Campinas in the state of São Paulo, Brazil. This way, from the use of recyclable materials for the study, it is possible to present a viability to replicate in other areas similar in their geomorphological constitution. Always with the concern to evaluate the dosage and evaluation of the porous type concrete (permeable) made in relation to the available materials.

LITERATURE REVIEW

PERMEABLE CONCRETE

For Ferguson (2005) permeable concrete is a special type of concrete intended, mainly for paving, widely used in the United States and Europe, it is composed of *Portland cement,* open grade materials, coarse aggregate, little or no fine, additives and water.

According to Kim and Lee (2010) this specific concrete is used in sound barriers to reduce road noise by acoustic reflection. It is also important to point out, as Ospina and Erazo (2007) comment that permeable concrete is also used as a drainage device in retaining walls.

For the *American Concrete Institute* (ACI 522, 2010) defines that pervious concrete is a structure that has interconnected voids that allow water to pass through the surface by percolation process.

According to ACI 522 (2010), the main differences between conventional concrete and pervious concrete can be seen in table 1 (below).

It must be noted in Table 1 the differences between the types of concrete and always highlight the purpose of using each type of material. Since Alves and Costa (2007) properly comment that conventional concrete has high resistance and is made to be watertight, while permeable concrete is made to allow the passage of water and therefore has moderate resistance.

PERVIOUS CONCRETE PROPERTIES

According to Ospina and Erazo (2007) permeable concrete must have adequate granulometry to ensure the opening of pores that allow the passage of water through the material, preferably coarse aggregate with partial absence of fines. The idea is to simulate natural filtration in sandy soil. They also report that it must have a high porosity of 15 to 20%, which is achieved by limiting the mortar content between 20 and 30% and compressive strength of 7.0 MPa in 28 days.

Azañedo *et al.* (2007) report that porous concrete properties depend on granulometry, amount of cement, water+cement ratio and amount of voids. Azañedo *et al.* (2007) also define that the grade of the aggregate is one of the factors that interfere with the properties of porous concrete, as it influences strength and permeability, which are important properties for the performance of permeable concrete.

PERMEABILITY OF PERVIOUS CONCRETE

As reported by Tartuce (1990) permeability is the property that identifies the possibility of water passing through the material. This passage can be by filtration under pressure, by diffusion through capillary conduits and by capillaries.

Mehta and Monteiro (2008) complement in later research that the interconnection between voids in concrete makes it permeable to water. This is an important property considering concrete exposed to air, attacks from aggressive water or the action of atmospheric agents.

It must be taken into consideration, the fact that, according to Kim and Lee (2010), the drainage capacity of porous concrete depends on the size of the aggregate and the density of the mixture. In this case, the total number of voids is greater the smaller the size of the aggregates.

COMPRESSIVE STRENGTH OF PERVIOUS CONCRETE

Lian and Zhuge (2010) evaluated the compressive strength and permeability for different types of aggregates and grades. The type of rock from which the coarse aggregate is obtained affects the strength of pervious concrete, regardless of its grade. This can be attributed to the difference in compressive strength, particle shape and texture of the aggregate itself. The researchers also state that the particles that have high water absorption do not produce high resistances, because the paste around the aggregate loses water, and produces an even weaker transition zone.

In studies carried out by Huang *et al.* (2009) the use of fine aggregate increases

Type	Compressive Strength (MPa)	Integral Components to the type of concrete		
		Sand	gravel	Additions
Conventional	20 to 60	From 30 to 50% of the total aggregate.	Well graduated, rounded grains.	Optional
Permeable	3 to 30	Little or none.	Open grading, angular grains (gravel and pebbles).	Water reducer, setting retardant and air entrainer.

Table 1: Relationship between the properties of conventional and pervious concrete.

Source: *American Concrete Institute* (ACI 522, 2010).

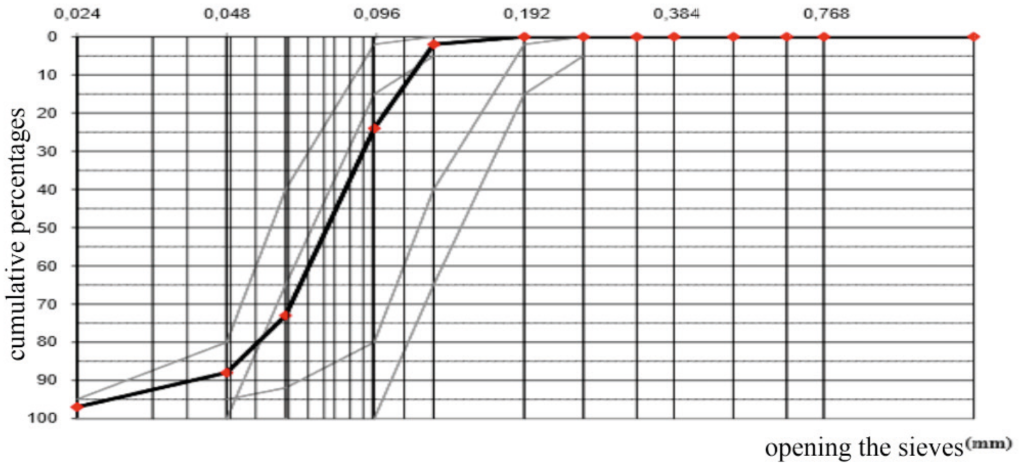

Figure 2: Grainometric characterization of coarse aggregate (NBR NM 248, 2003).

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resistance, despite representing a small loss of permeability. The recommended fine content between 9.5 and 4.75 mm is around 20%, which guarantees little interference in the behavior of the concrete, that is, the concrete will present good resistance and permeability. In general, low resistance is associated with high porosity.

TRANSITION ZONE

According to Mehta and Monteiro (2008) concrete is composed of three phases, which include: the cement paste, the aggregate, and the transition zone between the two, as shown in figure 1 below.

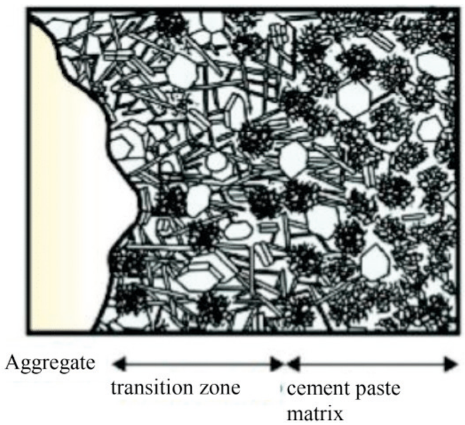

Figure 1: Diagrammatic representation of the transition zone and the cement paste matrix (MEHTA and MONTEIRO, 2008).

The transition zone is the portion of the paste in contact with the coarse aggregate particles of small thickness between 10 and 50 μm and is normally weaker than the other two components. (MEHTA and MONTEIRO, 2008)

According to Huang *et al.* (2009) studies of the concrete microstructure show that the interface between the aggregate and the cement paste has a direct influence on the behavior of the concrete under tension. Generally, dense concrete fails first in the cement matrix and then in the interface region.

MATERIALS

AGGREGATES

As Mehta and Monteiro (2008) state, the granulometry affects both the strength and the permeability of hardened concrete. Aggregate exerts a great influence on the properties of concrete, being the main responsible for the unitary mass, modulus of elasticity and dimensional stability of concrete. These properties of concrete depend mainly on the density and strength of the aggregate. That is, the chemical and mineralogical composition of the solid phases is less important than their physical characteristics.

For Mehta and Monteiro (2008) the strength of the aggregate has no direct influence on the strength of conventional concrete, except if the aggregate is very brittle. Still, the strength is not directly influenced by the size and shape of the aggregate.

CEMENT

Portland cement is generally used, but special cements can be used according to the exposure conditions and type of curing, since porous concrete cures quickly due to its honeycomb structure, which allows the air circulation.

A large consumption of cement will produce a more resistant concrete, on the other hand it reduces the percentage of interconnected voids, losing its infiltration capacity. It is recommended to use cement consumption between 270 $kg.m^{-3}$ and 415 $kg.m^{-3}$ to follow the strength and permeability requirements (AZAÑEDO *et al.* 2007).

RELATIONSHIP BETWEEN WATER AND CEMENT

For Ospina and Erazo (2007), permeable concrete has its compressive strength inversely related, but the relationship is even more complex due to the fact that water acts as a lubricant when it comes to consolidation and must vary from 0.35 to 0.5 when it is is done by compression.

Azañedo *et al.* (2007) report that the amount of water has a great influence on the properties of the mixture. In the fresh state, a small amount of water results in a loose mass with low resistance and a large amount of water generates a paste that seals the voids and washes the cement from the surface of the aggregate, producing a low resistance to surface wear.

ADDITIVES

Ferguson (2005) states that additives are substances added to concrete to improve its properties such as mechanical strength and durability. Chemical additives are usually found in liquid form and are added to concrete in small amounts. For Tartuce (1990) additives are used according to the need to obtain products with superior quality, because they modify or provide properties to the fresh or hardened material, making them more workable, more resistant to mechanical and chemical requests or even making them more economical and durable.

It must be noted that chemical additives are mainly classified according to the function they have, for example: Plasticizers reduce mixing water with a gain in workability and increase slump without causing loss of cement paste in the aggregate. According to Fergusson (2005) retarder additives delay the setting time of cement during transport, it is used for porous concrete cast in situ in order to avoid the loss of mixing water and the need for a high water+cement factor (a+c).

Kim and Lee (2010) state that mineral additives are used in order to improve consistency and reduce the size of the transition zone between the aggregate and the mortar, which is considered the least resistant part of the set.

In a study carried out by Azañedo *et al.* (2007) used the ACI method for the dosage of permeable concrete, recommendations of the 522 committee and studies carried out by American organizations. In these studies, the experiment was carried out in three stages, in the first, the characteristics of the aggregates and cement that would be used were studied, and initial traces were determined. Since in the three traces, the amounts of all materials were modified, but in all traces there was little fine aggregate. After evaluating the best performance of the previous traits, the second step was carried out, which consisted of adding plastic strips at different percentages to the best of the three traits. Thus, the trait that presented the best behavior was chosen to improve its properties with a water-reducing additive and synthetic fiber for reinforcement.

PERMEABLE CONCRETE CHARACTERISTICS

CONCRETE IN THE FRESH STATE

According to ACI 522R-10, among other characteristics, in the fresh state, permeable concrete has zero *slump* and is not liquefied. Taturce (1990) argues that for concretes of dry consistency the slump can vary from 0 to 20 mm and energetic vibration must be used.

CONCRETE IN THE HARDENED STATE

According to Tartuce (1990) the hardening of concrete results in the cohesion developed between the crystals that form in the cement paste. In the hardened state, permeable concrete must present a number of voids between the percentage of 15 to 35% and simple compressive strength ranging from 2.8 to 28 MPa (ACI 522R-10). The DNIT states that concrete destined for the execution of rigid pavements must have a flexural tensile strength of 4.5 MPa, and, among other characteristics, present less volumetric variation, less susceptibility to cracking and good performance in relation to traffic efforts and environmental action.

METHODOLOGY

The focus of this research was to evaluate the properties of a pervious concrete obtained with common materials in the region of Campinas (SP) in the state of São Paulo, Brazil.

In the research, the trace determination was obtained using coarse aggregates, with no fines, no additives and no wet curing. Thus, a characterization of the materials was performed, then the trace was established and the specimens were later produced. The tests were carried out in the laboratories of the Faculty of Civil Engineering and Architecture (FEC) at Unicamp.

CHARACTERIZATION TESTS

GRANULOMETRY TEST

A dosage of tests obtained by Monteiro (2010) was used and for the determination of the granulometric composition the NBR NM 248 (2003) standard was used after the reduction of the sample made by quartering according to the auxiliary standard NBR NM 27 (2001), in which the material was placed on a mechanical sieve shaker. It must be noted that quartering is the process of dividing mineral samples into two aliquots, representative of the total sample. One of the parts goes on to be analyzed, while the other is stored as a reserve sample for future characterizations, analyzes and/or certifications.

After the previous phases, the retained masses were weighed and the retained percentages were represented in the granulometric curve, as shown in figure 2 below.

With regard to the coarse aggregate, this has other characterization parameters such as the fineness modulus and the characteristic maximum diameter. The fineness modulus is a widely used reference parameter, obtained by adding the retained percentages accumulated in the normal series sieves. The characteristic maximum diameter is the maximum size that corresponds to the opening of the sieve in which a percentage less than or equal to 5% is retained, as reported by Monteiro (2010).

The results obtained are shown in Table 2 below.

Maximum dimension (mm)	fineness modulus
11.9	5.8

Table 2: Grainometric characterization of coarse aggregate.

DOSAGE TEST

According to NBR 12655 (2001) and according to Monteiro (2010) the empirical dosage can be performed for class C10 concrete with a minimum consumption of 300 kilograms of cement per cubic meter. For this dosage, the consumption of 420 kg of cement per cubic meter of concrete was established, as previously obtained by Monteiro (2010).

According to Monteiro (2010) as there is no standardized dosage method, to determine the mix, the water+cement ratio (a+c) was used as a basis, and the consensus among most previous works that indicate that the highest resistances are obtained from starting from the 1:4 and 1:3 compositions (cement: aggregate).

In the composition of the test, zero gravel of micaschist rock and Portland cement CP II F-32, originating in the study region, was used, as previously surveyed by Monteiro (2010).

MOLDING TEST OF THE SPECIMENS

To evaluate the characteristics of pervious concrete, cylindrical and prismatic specimens were molded in accordance with NBR 5738 (2003). The cylindrical specimen obtained in the dimensions of 15 cm in diameter and with a height of 30 cm. The prismatic specimen was a beam 50 cm long, 15 cm wide and 15 cm high (as shown in Figure 3).

Figure 3: Preparation of permeable concrete specimens in the laboratory.

Figure 4 (below) shows the molds made of the permeable concrete that was the focus of the research, in which they were demoulded after 24 h at the time of molding and later tested after 28 days in relation to the compression test, according to NBR 5739 (1994). Regarding the prismatic specimens, they were demolded after 48 h and the flexion traction test was also performed after 28 days, in compliance with NBR 12142 (2010).

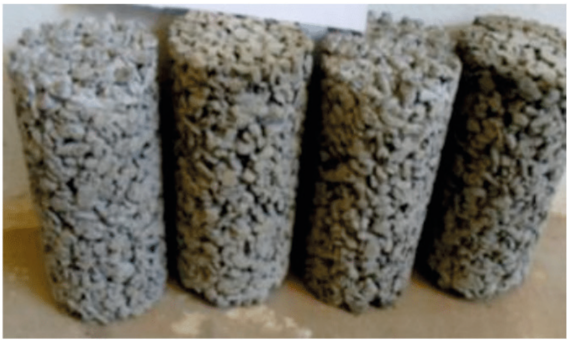

Figure 4: View of the permeable concrete specimens.

DENSIFICATION TEST

According to Monteiro (2010) in some countries, pervious concrete is commonly cast *in situ,* therefore the most used consolidation technique is roller compaction. In order to avoid concrete segregation, the consolidation carried out in the research was performed on a vibrating table with cycles of 30 seconds for each layer. Also, the number of layers was established according to NBR 5738 (2003), in three layers for prismatic and cylindrical specimens. Figure 5 shows the appropriate molded materials.

Figure 5: View of the consolidation preparation on a vibrating table for cylindrical and prismatic bodies.

PHYSICAL PROPERTIES OF PERMEABLE CONCRETE

VOID INDEX AND ABSORPTION

The void ratio and water absorption were determined according to the test specified by NBR 9778 (1987).

Test Phase	Trace 1:3	Trace 1:4
Water absorption (%)	5.59	6.19
Volume of voids (%)	15.15	16.52

Table 3: Data from the water absorption test by immersion and voids index (NBR 9778).

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SPECIFIC MASS

The specific mass of the concrete was determined by the test described in the NBR 9778 (1987) standard.

Test Phase	Trace 1:3	Trace 1:4
Specific mass dry sample (g.cm $^{-3}$)	2.55	2.58
Specific mass of saturated sample (g.cm $^{-3}$)	2.76	2.80

Table 4: Data from the concrete specific mass (ρ) test (NBR 9778).

CONTROL TESTS

According to the NBR 12655 standard, the concrete acceptance control tests that must be carried out according to the topics below:

CONSISTENCY TEST OR SLUMP TEST

The consistency test (as shown in figure 6) was carried out by slumping the truncated cone according to NBR NM 67 (1998) and previous studies.

Figure 6: Preparation of the consistency test (*Slump Test*).

The test was carried out by applying 25 blows with a rod to each of the three layers, after which the mold was removed and the concrete settlement was measured, as shown in figure 7.

Figure 7: Measuring *Slump Test* Rebate.

According to Monteiro (2010) the standard provides that if the concrete mass collapses when removing the mold in a way that prevents the measurement of settlement, the test must be disregarded and a new determination must be made on another portion of concrete from the sample. And if consecutive landslides occur in the two tests, the concrete is not necessarily considered plastic and cohesive for the application of the slump test. The slump tests of the two traits were considered collapsed, that is, the concrete is not necessarily plastic and cohesive to be evaluated by this test.

SIMPLE COMPRESSIVE STRENGTH TEST

Simple compression tests were carried out in accordance with the NBR 5739 (2003) standard. The values obtained in the results and discussions chapter are presented in tables 5 and 6.

FLEXURAL TRACTION TEST

To perform the tensile test on prismatic molds, it was carried out in accordance with NBR 12142 (2010). In this test, the specimen with a prismatic section is submitted to bending, with loads in two symmetrical sections, until failure occurs. Figure 8 shows a representative drawing of the test in question.

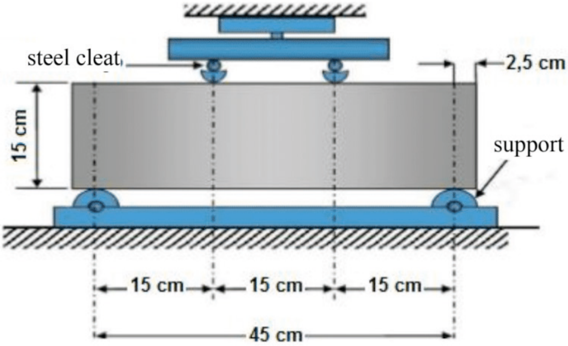

Figure 8: Schematic diagram of the flexion traction test (Monteiro, 2010).

Figure 9 shows the test carried out in the FEC laboratory for the study of permeable concrete for prismatic molds.

Figure 9: View of the tensile flexion test being carried out in the laboratory.

Obtaining flexural tensile strength is performed in the middle third with the values forwarded and evaluated by equation 1 (below).

$$\sigma_{máx} = \frac{P \times L}{B \times h^2} \qquad \text{Equation 1}$$

Where:

P = breaking load, in KN;

L = free distance between supports, in mm;

B = part width, in mm; It is

h = height of the part, in mm.

The results of the flexion traction test obtained are presented in tables 7 and 8 in the chapter results and discussions.

PERMEABILITY

Regarding the permeability test, a plate was made for each characteristic trait to demonstrate the permeability obtained in concrete, being a more visual analysis than precisely tested in the laboratory. Figure 10 shows the flow potential obtained in the slab, showing the degree of infiltration generated by the 1:4 ratio for the voids present in the permeable concrete slab. The same happened in the 1:3 trace.

Figure 10: Presentation of the test of the product obtained with the percolation system (infiltration) in the 1:4 ratio.

RESULTS AND DISCUSSIONS

COMPRESSION TEST

According to Monteiro (2010) permeable concrete without additive has a compressive strength of 7 to 14 MPa for concrete with fines, as also reported by Azañedo *et al.* (2007). And when without fine values between 12 and 19 MPa (LIAN and ZHUGE, 2010).

The present research obtained an average compressive strength of 10.64 MPa for the 1:4 mix and 9.31 for the 1:3 mix. Tables 5 and 6 show the test values in a more descriptive way.

CP number	Trace 1:4 and a+c 0.30	
	Maximum load (kgf)	Resistance (MPa)
1	8900	11.29
two	8100	10.35
3	8100	10.35
4	8200	10.55
Average	**8325**	**10.64**

Table 5: Compressive strength test.

CP number	Trace 1:3 and a+c 0.26	
	Maximum load (kgf)	Resistance (MPa)
1	7400	9.45
two	6800	8.68
3	7300	9.39
4	7600	9.70
Average	**7275**	**9.31**

Table 6: Compressive strength test.

The values obtained and presented in Tables 5 and 6 represent acceptable strengths considering that the concrete does not have any type of chemical or mineral addition.

It is important to point out that according to Azañedo *et al.* (2007) additions can increase compressive strength values around the range of 14 MPa to 20 MPa, and Lian and Zhuge (2010) state that additions of polyethylene strips, values can increase in the order of 19 MPa to 46 MPa, being still superplasticizer materials.

TENSION IN FLEXION TEST

According to reports by Monteiro (2010) in previous research on this topic, which is the focus of this research, permeable concrete actually showed flexural tensile strength of around 3.0 MPa, as Azañedo et al. (2007).

For the study carried out, the average value obtained for the 1:4 and 1:3 traits were respectively 0.48 MPa and 0.88 MPa, as shown in Tables 7 and 8 below.

CP number	Trace 1:4 and a+c 0.30	
	Maximum load (kgf)	Resistance (MPa)
1	1300	0.45
two	1200	0.50
Average	**1250**	**0.48**

Table 7: Bend traction test.

CP number	Trace 1:3 and a+c 0.26	
	Maximum load (kgf)	Resistance (MPa)
1	2200	0.90
two	2100	0.85
Average	**2150**	**0.88**

Table 8: Flexural traction test in 28 days.

Despite the low values obtained in tables 7 and 8 being lower than those raised by Azañedo (2007), the use of this concrete as a structural part of pavements must be discarded. But, one must not rule out its use for the purpose of coating for moderate load traffic.

When evaluating the aggregate used, it did not present a granulometric distribution within the grading limits defined by NM 248 and required by NBR 7211 for the production of concrete.

The material obtained in the research was not cohesive, so the slump test could not be used to measure the consistency, and what could be observed is that permeable concrete has little workability, and the consolidation process must be carried out with great care. in order to avoid segregation of the cement paste (MONTEIRO, 2010).

Regarding the water+cement ratio (a+c) of 0.30, together with a greater amount of cement, it presented the best results in terms of compressive strength and flexural tensile strength. Although the amount of water is extremely important with regard to concrete properties such as compressive strength and workability, the water+cement ratio alone does not produce high strength.

When evaluating the 1:3 mix, it showed a smaller volume of voids compared to the 1:4 mix, this is due to the fact that the first mix has a greater amount of cement compared to the second, and the cement interconnects the pores, decreasing the amount of voids and permeability with a small increase in compressive strength, as Monteiro (2010) previously reported.

With regard to curing, this plays an important role in tensile strength in bending. The results of flexural tensile strength may have been caused by the lack of wet curing and the low water+cement ratio that resulted in a weak and porous transition zone, this is a hypothesis to be investigated in future studies. Therefore, it is recommended that studies be carried out in order to determine the influence of wet curing on the tensile strength of permeable concrete.

CONCLUSION

Environmental concern is important and, without a doubt, the continuous study of improvements in the process of urban drainage to avoid damage to property and human lives and to guarantee a more balanced environment.

In the research carried out, the permeable concrete obtained can undoubtedly be an additional tool for the urban water management of rainwater.

Studying materials that are more locally available can be a way to make local drainage feasible in order to use what is best locally, thus lowering the cost of drainage works and increasing local employability by hiring local labor for carry out work *on site*.

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