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Study of permeable concrete for paving: an analysis of compressive strength

Abstract

The study of permeable concrete for pavements has emerged as a sustainable solution in the face of disorderly urbanization in Brazil, seeking to mitigate flooding events. The article, based on a bibliographic review of scientific articles from the last 20 years, uses sources such as Google Scholar, SciELO and the Catalog of Theses and Dissertations, covering languages such as English, Portuguese and Spanish. In addition to exploring the global context and presenting various applications of permeable concrete, the work also addresses its advantages, such as low cost and sustainability, as well as disadvantages, notably low resistance. Details on resistance, application standards, history and properties such as porosity and the curing process are thoroughly discussed. It also emphasizes the importance of permeable concrete in reducing urban flooding, highlighting its viability due to its affordable

production cost and high porosity. A review of case studies, highlighting the results of different permeable concrete mixes, contributes to understanding the complexity of its behavior, especially in relation to compressive strength. The article outlines crucial aspects, including coating typology, infiltration systems and general design requirements for this type of concrete. The coefficient of permeability is presented as a vital parameter, with detailed test methods for various coatings. The research emphasizes the need for prior evaluation of the permeability coefficient in the laboratory, underlining its importance in the effectiveness of permeable sidewalk. In short, the work provides a comprehensive guide for future research and practical applications of permeable concrete in paving, highlighting its potential as an environmentally responsible solution in urban contexts.
Keywords: Concrete; permeable; compression.

Estudo do concreto permeável para pavimentações: uma análise da resistência à compressão

Resumo

O estudo do concreto permeável para pavimentações emerge como uma solução sustentável diante da urbanização desordenada no Brasil, buscando mitigar eventos de inundação. O artigo, fundamentado em uma revisão bibliográfica de artigos científicos dos últimos 20 anos, utiliza fontes como Google Acadêmico, SciELO e Catálogo de Teses e Dissertações, abrangendo idiomas como inglês, português e espanhol. Além de explorar o contexto global e apresentar diversas aplicações do concreto permeável, o trabalho aborda ainda as suas vantagens, como o baixo custo e a sustentabilidade, bem como desvantagens, notadamente a baixa resistência. Detalhes sobre resistência, normas de aplicação, histórico e propriedades como porosidade e processo de cura são minuciosamente discutidos e também enfatiza a importância do concreto permeável na redução de enchentes urbanas, ressaltando sua viabilidade decorrente do custo de produção acessível e alta porosidade. A revisão de estudos de casos, destacando resultados de diferentes traços de concreto permeável, contribui para a compreensão da complexidade do seu comportamento, especialmente em relação à resistência à compressão. O artigo delineia aspectos cruciais, incluindo tipologia de revestimentos, sistemas de infiltração e requisitos gerais de projeto deste tipo de concreto. O coeficiente de permeabilidade é apresentado como um parâmetro vital, com métodos de ensaio detalhados para diversos revestimentos. A pesquisa enfatiza a necessidade de avaliação prévia do coeficiente de permeabilidade em laboratório, sublinhando sua importância na eficácia do pavimento permeável. Em suma, o trabalho fornece um guia abrangente para futuras pesquisas e aplicações práticas do concreto permeável na pavimentação, ressaltando seu potencial como solução ambientalmente responsável em contextos urbanos
Palavras-chave: Concreto; permeável; compressão.

1. Introduction

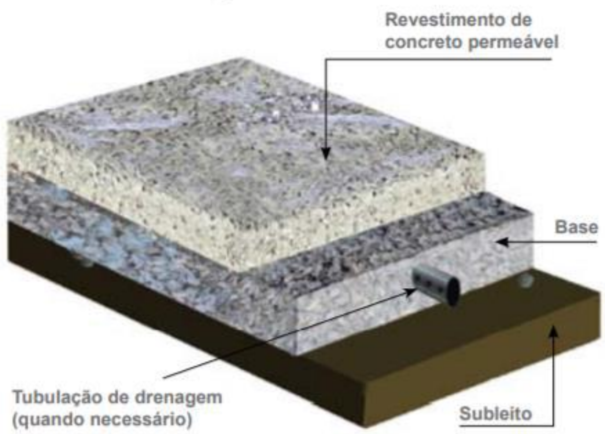
With each passing day, the growth in both the number and intensity of impacts caused by so-called natural disasters becomes increasingly evident. Due to the globalization of information, reports of events involving loss of life and property, particularly those associated with rainfall, appear almost daily. The negative effects of unplanned urbanization on stormwater runoff are wide-ranging and have been documented in numerous locations. In Brazilian cities, flood episodes caused by deficiencies in urban drainage systems have become recurrent, negatively affecting the population's quality of life and causing losses in the value of affected properties (LICCO, 2013).

According to the Civil Defense (2015), flooding is defined as the overflow of a watercourse reaching its floodplain or wetland area. Floods or rises are understood as the increase in water level in the drainage channel due to higher flow, reaching the channel's maximum capacity without overflowing. Waterlogging refers to the temporary accumulation of water in specific places due to drainage system deficiencies, while flash floods correspond to concentrated surface runoff with high transport energy, which may or may not be associated with areas subject to fluvial processes.

The consequences of these processes include the depletion of drainage networks' capacity and the emergence of numerous waterlogging points, which contribute to urban flooding and traffic problems (LAMB, 2014). One type of device used to mitigate flood events is permeable pavement (ARAÚJO et al., 2000).

Permeable pavement is a structure that allows the passage of water and air through its layers. It is a resource that can be applied to urban public infrastructure, enabling the infiltration of stormwater by absorbing part or all of the runoff through a permeable surface into a uniformly graded gravel reservoir constructed above the subgrade. The subgrade refers to the prepared foundation soil that supports the pavement (VIRGILIIS, 2009). Figure 1 illustrates a typical cross-section of permeable pavement in concrete, showing three layers: the permeable concrete surface, the drainage base with piping, and the subgrade.

Figure 1 - Typical cross-section of permeable concrete pavement



Source: Marchioni e Silva (2013).

The challenges associated with intense rainfall events have become recurrent in certain Brazilian cities. Each year, during the rainy season, rising watercourses inundate buildings and public roads, resulting in a series of tragedies that, in many cases, could be prevented through appropriate engineering interventions. By aligning technological innovation with sustainability, permeable concrete emerges as a viable solution to the critical problem of soil impermeability. Its application in urban works allows stormwater to infiltrate through interconnected voids and percolate into lower soil layers, thereby recharging the aquifer. Nevertheless, despite its ecological soundness and alignment with sustainable practices, the use of permeable concrete remains uncommon in current construction practices.

The overarching aim of this study is to provide technical information and performance characteristics of permeable concrete, illustrating how its application may contribute to mitigating flood events. More specifically, it seeks to:

Identify the agents responsible for reducing void content in permeable concrete, which contributes to water accumulation; Analyze the functioning of urban drainage systems; Discuss the benefits and limitations of permeable concrete; Examine the relationship between impermeability and concrete strength.

2. Research Metodology

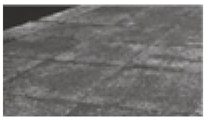
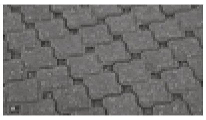
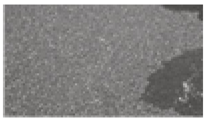
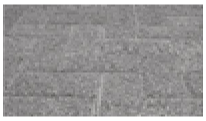
To prepare this work, a literature review was conducted based on scientific articles on pervious concrete and an analysis of the use of this material was presented, verifying its performance in infiltration capacity and reduction of rainwater runoff, culminating in the reduction of flooding events. To search for the articles, the online databases Google Scholar, SciELO, and the Catalog of Theses and Dissertations were used to find scientific articles in English, Portuguese, and Spanish, referring to the last 20 years, using the descriptors: "pervious concrete," "concrete with voids," "history of pervious concrete," "number of voids in pervious concrete," "pervious concrete in practice," "floods: main factors," "pervious concrete execution methods."

In 2015, another step was taken in Brazil towards improving permeable concrete technology, with the development of ABNT NBR16416:2015 entitled “Permeable Concrete Pavements – Requirements and Procedures”, with the aim of establishing the minimum requirements for the design, specification, execution and maintenance of permeable concrete pavements, built with interlocking concrete piece coverings, concrete slabs or concrete pavements cast on site (ABNT, 2015).

2.1. Paving Types

Permeable concrete paving, according to NBR 16416:2015, can be installed using the following typologies, as shown in Table 1.

Table 1: Paving Types

	Pavimento com revestimento constituído por peças de concreto com juntas alargadas		Pavimento com revestimento constituído por placas de concreto permeável.
	Pavimento com revestimento constituído por peças de concreto com áreas vazadas.		Pavimento com revestimento constituído por placas de concreto permeável.
	Pavimento com revestimento constituído por peças de concreto permeável.		

Source: ABNT NBR 16416, adapted (2015).

2.2. Infiltration System

The choice of infiltration system depends on the soil characteristics or design constraints (ABNT NBR 16416:2015).

• The first method presented in ABNT NBR 16416 is total infiltration, in which all precipitated and runoff water reaches the subgrade and infiltrates.

• The second method is partial infiltration, in which part of the precipitated and runoff water reaches the subgrade and infiltrates, while part of the water is temporarily stored in the permeable structure, then removed by the drain.

• The third method is a system without infiltration, in which the precipitated and runoff water is temporarily stored in the permeable structure and does not infiltrate the subgrade, then removed by the drain.

2.3. General Design Requirements

The design of a permeable pavement must consider the type of use and the location of installation. The materials and thicknesses of the layers to be installed must simultaneously meet the mechanical and hydraulic design requirements (ABNT NBR 16416:2015).

The mechanical design of the pavement must use recognized methods appropriate for each type of surface, considering the soil saturation condition when choosing full or partial infiltration systems (ABNT NBR 16416:2015).

When designing the surface layer, the design must meet at least the values specified in Table 1. It is the designer's responsibility to assess whether these values are sufficient to meet the abrasion and load-bearing conditions appropriate to the type of traffic anticipated in the design (ABNT NBR 16416:2015).

2.4. Sub-base and/or base layer requirements

The sub-base and/or base layer must be made of open-grain stone materials and must meet the specifications in Table 1 of ABNT NBR 16416:2015.

Table 1: Specification for sub-base and/or base material

Proprerties	Method	Specification
Los Angeles Abrasion	ABNT NBR NM 51	< 40%
Void Ratio	ABNT NBR NM 45	≥ 32%
California Bearing Ratio (CBR)	ABNT NBR 9895	≥ 80%
Material passing through a 0.0075 mm mesh screen	ABNT NBR NM 46	≤ 2%

Source: ABNT NBR 16416; (2015).

The recommended particle size distribution in Table 2, shown below, of ABNT NBR 16416:2015, is for sub-base and/or base materials.

Table 2 - Recommended particle size distribution for sub-base and/or base materials

Sieve with mesh opening	Percentage retained by mass % Sub base	Base
75,0 mm	0	-
63,0 mm	0 a 10	-
50,0 mm	30 a 65	-
37,5 mm	85 a 100	0
25,0 mm	90 a 100	0 a 5
19,0 mm	95 a 100	0 a 35
12,5 mm	-	40 a 75
4,75 mm	-	90 a 100

2,36 mm	-	95 a 100

Source: ABNT NBR 16416; (2015).

It is worth noting that the constituent layers of the pavement, made with permeable concrete slabs, are similar to conventional ones.

2.3. Bedding Layer Requirements

The bedding layer only applies to projects using permeable interlocking paving or paving with permeable concrete slabs. It must be a uniform, constant, uncompacted layer. The maximum allowable variation is ± 5 mm from the specified thickness.

For proper bedding layer construction, open-grain stone materials must be used, meeting the specifications in Table 4 of ABNT NBR 16416:2015, with the bedding material having a maximum characteristic dimension (MCD) of 9.5 mm according to ABNT NBR 7212.

For the bedding material's particle size distribution, the recommended values are those in Table 3 below.

Table 3 - Recommended particle size distribution for bedding material

Sieve with mesh opening	Percentage retained by mass %
12,5 mm	0
9,5 mm	0 a 15
4,75 mm	70 a 90
2,36 mm	90 a 100
1,16 mm	95 a 100

Source: (ABNT NBR16416; 2015).

2.3. Grout Material Requirements

Grouting material is used only in permeable interlocking paving projects, where water infiltration must occur through widened joints or voids between the pieces. The grout must be made of open-grain stone materials meeting the specifications in Table 3 of ABNT NBR 16416:2015, with its maximum specification dimension changed to ≤ 1/3 of the smallest width of the joint or void area.

The grout material must fill the joints or void areas up to 5 mm below the top of the pieces after compaction. The grain size distribution of Table 5 of ABNT NBR 16416:2015 is recommended for this material.

2.4. Permeability Coefficient

Permeable pavement, regardless of the type of surface used, must have a permeability coefficient greater than 10-3 m³/s (NBR 16416, 2015) upon construction. The permeability coefficient can be pre-evaluated in a laboratory, testing only the surface layer or the surface along with the entire pavement structure. Table 4 lists the considerations for determining the permeability coefficient in the field and in the laboratory.

Table 4: Determination of permeability coefficient in the field and in the laboratory

Type of investment	Thest Method	Permeability coefficient of newly constructed pavement (m/s)
Concrete piece (widened joints or hollow areas)	Evaluation locations	
Pervious concrete piece	Laboratory/field	$> 10^{-3}$
Pervious concrete slab	Appendix A	
Pervious concrete cast-in-place	ABNT NBR 13292 or appendix A	

Source: ABNT NBR 16416 (2015).

According to NBR 16416, all types of paving can use the method described in its appendix A for the preliminary assessment of the permeability coefficient. In this case, the test must be performed on a pavement segment with an area of at least 0.5 m². This segment can be tested simultaneously with the layers planned to compose the pavement structure, following the same design thicknesses, or with only the paving layer. The bedding and grouting layers, as applicable, must follow the preliminary assessment of permeable interlocking paving and permeable concrete slab paving.

2.3. Specific Gravity of Cast-in-Place Concrete

According to NBR 16416, the specific gravity of cast-in-place concrete must be assessed in accordance with NBR 9833 upon receipt of fresh concrete. If verification is necessary, the assessment must be performed in accordance with NBR 9778, with the concrete in a hardened state.

If the evaluation is performed on fresh concrete, the test must be performed using a container with a capacity of 5 dm³, with characteristics specified in ABNT NBR NM 47. Molding must be performed in two layers, with 20 blows applied per layer, using a 4.5 kg socket and a height of 45 cm. (NBR 16416; 2015)

The specific gravity of the concrete is acceptable, both in the fresh and hardened state, if the value specified in the design is equal to the value obtained in the tests, with a tolerance of ± 80 kg/m³. The minimum value to be determined in the design may be 1600 kg/m³. (NBR 16416: 2015)

2.4. Visual inspection and dimensional evaluation of concrete parts or slabs

According to NBR 16416:2015, the parts or slabs must be manufactured to meet the following characteristics:

a. Homogeneous appearance, with regular edges and right angles, free of burrs or flaking of the concrete;

b. Regular edges on both faces and side walls;

c. Thickness with a minimum nominal measurement equal to or greater than that specified, with higher measurements being able to be specified in projects in multiples of 20 mm;

d. Dimensional tolerance for length, width, and thickness of ± 3 mm in relation to the respective nominal measurements.

3. Development

3.1. Definition and Characteristics

According to Finocchiaro (2017), pervious concrete, also known as pervious concrete or porous concrete, has as its main characteristics a high void ratio. It is a mixture of binder, coarse aggregate, and water, prepared with little or no fine aggregate, which allows the passage of a large volume of water.

Strength is inversely proportional to permeability. As the porosity of concrete increases, its compressive strength decreases. Therefore, there are limitations to the use of pervious concrete, which is therefore recommended for locations where low compressive strength is not a limiting factor (FINOCCHIARO, apud GIRARDI; 2017).

According to DNIT (2006), concrete used in paving must have a characteristic compressive strength greater than or equal to 20 MPa. This strength is called fck, a very important mechanical quantity in the construction of concrete structures, including paving.

Table 05 - Characteristic compressive strength and thickness of the permeable coating according to each type of coating

Coating Type	Requirement Type	Minimum Thickness (mm)	Characteristic Mechanical Strength (MPa)	Test Method
Concrete piece (widened joints or voids)	Pedestrian traffic Light traffic	60 e 80	≥ 35,0	ABNT NBR 9781 Compressive strength at 28 days
Pervious concrete piece		60 e 80	≥ 20,0	
Pervious concrete slab		60 e 80	≥ 2,0	
Pervious concrete cast-in-place		60 e 100	≥ 1,0 e ≥ 2,0	ABNT NBR 15805 Flexural tensile strength

Source: (BOTTEON, adapted by the author; 2017).

The ABNT NBR 9781/2013 standard establishes the methods and requirements for conducting tests to produce concrete paving pieces for pedestrian traffic, motor vehicles, bicycle paths, and product storage areas.

3.2. History

Increased urbanization and the growing number of impervious areas have resulted in an increase in the number and intensity of urban flooding events, thus prompting the search for alternative drainage techniques to restore the infiltration capacity of runoff water to its original dynamics, prior to waterproofing (SUZUKI et al., 2013).

Pervious concrete was first manufactured in Europe in 1852. The technique for using this material in structural conditions originated in Germany and was first applied in 1920 (FLEMING, 2002). It began to be used in the United Kingdom in the 1930s, but only became widely used in the 1940s, through the Wimpey no-fines house system. France was one of the first European countries to use draining asphalt mixes, in 1977, and in the following years numerous projects were completed using this technology (BOTTEON; 2017).

According to Dumke (2005), starting in the 1960s, asphalt mixes were created using open-grain asphalt, thus being applied, for the most part, over an existing asphalt layer. With a high void ratio, resulting from the open-grain aggregates, these mixes absorb water runoff through their voids more efficiently, reducing or eliminating the existing water layer on the surface. In 2009, the University of São Paulo developed a research project in which a parking lot of approximately 1,600.00 m² was paved partially with permeable asphalt and partially with interlocking porous concrete blocks. This demonstrated the water absorption capacity of these two comparative scenarios and contributed to the development of porous concrete technology (BOTTEON; 2017).

2.3. Applications

Pervious concrete can be used in a variety of applications, including sidewalks, parking lots, light-traffic streets, squares, tennis courts, infill panels, slope stabilization, ceilings, hydraulic structures, greenhouses, and retaining walls. Its use is limited to areas with low or light traffic flow (SCHMENGLER, 2020).

It can also be used as a transition zone in dams, along rock masses, and is currently being used more frequently in external areas of buildings, industries, and residences, trails, and pedestrian areas (BEECHAM et al., 2010).

2.4. Advantages and Disadvantages

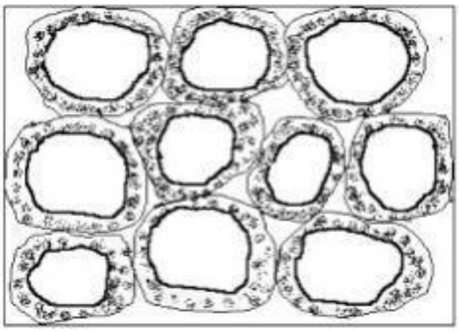
The main advantages of using pervious concrete include low production, construction, and maintenance costs, reduced flood peaks, reduced or eliminated major drainage projects, no need for specialized labor, sustainability, and the possibility of reusing any captured rainwater (SCHMENGLER, 2020).

Its disadvantages include its limited use in light traffic areas due to its low compressive strength, a shorter service life compared to conventional concrete, and the need for regular inspections (WOJAHN, 2020).

2.5. Properties

Pervious concrete can also be called porous concrete, mainly due to the property that distinguishes it from conventional concrete: its high porosity. This property is due to the absence or smaller amount of fine aggregates (sand), and is composed exclusively or predominantly of coarse aggregates (gravel) coated with a thin layer of paste. Figure 2 shows how pervious concrete has a significant number of voids, differing from conventional concrete, which has small or micro voids (RAMADHANSYAH, 2014).

Figure 2: Illustration of pervious concrete



Source: Ramadhansyah (2014).

To characterize pervious concrete, the Colorado Ready Mixed Concrete Association (CRMCA, 2009) suggests:

• 15% to 25% void content;

• Concrete mix density: range of 1682 kg/m3 to 2082 kg/m3;

• Cementitious content: range of 267 kg/m3 to 326 kg/m3;

• Water-cement ratio: ranges from 0.26 to 0.35.

Because pervious concrete has high porosity, the curing process is crucial to prevent excessive water loss. The curing process should also begin immediately after paving is completed, with the concreted area covered with a plastic sheet for seven days to control water loss (TENNIS, 2004). To mitigate water loss, the American Ready Mix Concrete Association (NRMCA, 2008) reports that it is common to use water absorption retardant and stabilizing additives to balance the process. This prevents an increase in the amount of water in porous concrete, as this can lead to a loss of durability and strength. The correct amount of water can be determined when the paste acquires a certain moisture sheen, without becoming liquefied (NRMCA, 2008).

Although unusual, NRMCA (2008) allows for the use of fine aggregate, but requires a homogeneous coarse aggregate grain size range, as shown in Table 6.

Table 06: Porous concrete component proportions

Component	Proportion
Cement	270 a 415 kg/m³
Aggregate	1190 a 1480 kg/m³
Water/Cement	0,27 a 0,34
Aggregate/Cement	4 a 4, 5:1

Fine/Coarse Aggregate	0 a 1:1

Source: NRMCA (2008).

3. Results

For the purposes of analyzing the results, several studies related to pervious concrete were listed, namely Monteiro (2010), Brito and Santos (2010), Castro (2015), and Schwetz et al. (2015), which are detailed below.

Monteiro (2010) analyzed two different mixes of pervious concrete. The first mix (T1) was prepared with a water/cement ratio of 0.26 and a cement/coarse aggregate ratio of 1:3. The second mix (T2) was prepared with a water/cement ratio of 0.30 and a cement/aggregate ratio of 1:4. The research involved the use of zero-grade gravel and Portland cement CP II F, with the production of cylindrical and prismatic molds. Several tests were performed on the specimens, including void ratio, water absorption, dry and saturated specific gravity, simple compressive strength, and flexural tensile strength.

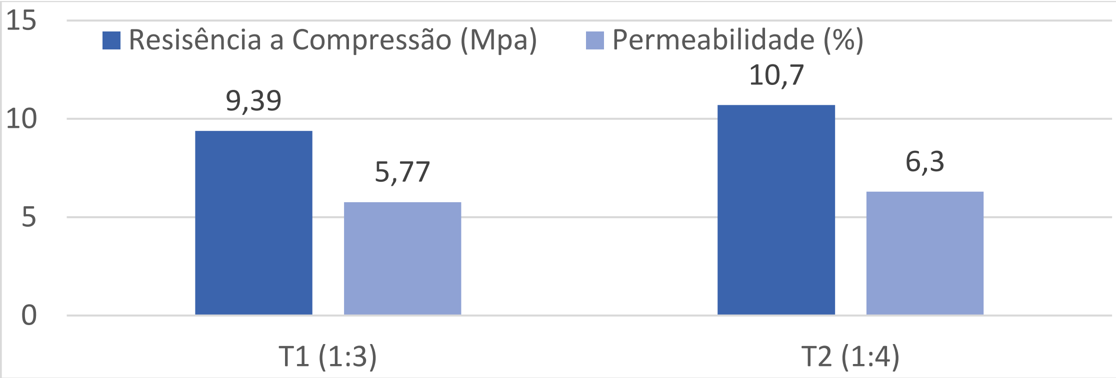
All of these tests were conducted 28 days after molding. The specimens were compacted on a vibrating table for both cylindrical and prismatic molds. The procedure consisted of vibrating each layer for 30 seconds, with three layers per specimen (PC). The results obtained by the author are detailed in Table 7. It is important to note that permeability was assessed visually.

Table 7: Results found by Monteiro (2010)

Water absorption (%)		**Void Volume (%)**		**Axial compressive strength (MPa)**	
T1	**T2**	**T1**	**T2**	**T1**	**T2**
5,77	6,3	15,25	16,67	9,39	10,7
Specific mass of the dry sample (g/cm^3)		**Specific mass of the saturated sample (g/ cm^3)**			
T1	**T2**	**T1**	**T2**		
2,64	2,65	2,8	2,81		

Source: Adapted from Monteiro (2010).

Figure 3: Compressive strength of Monteiro tests



Source: Adapted from Monteiro (2010).

Examining the results, it is observed that, despite the differences in the mixes, both in the w/c ratio and in the aggregate content, the axial compressive strengths were similar. Furthermore, it is noteworthy that the increase in cement consumption, combined with the reduction in the w/c ratio, resulted in a reduction in strength, although this reduction was insignificant.

Santos (2017) analyzed three different mixes, shown in Table 8, and found, based on the results presented in Figure 3, that mixes 1 and 3 with a higher water/cement ratio obtained better axial compressive and flexural tensile strengths than mix 2, with a lower w/c ratio. These results agree with an analysis that indicates a minimum w/c ratio for cement hydration. For mixes 1 and 3, which have the same w/c ratio, the strengths found by the author indicate that the lower the aggregate content, the greater the strength of the pervious concrete. Compaction was performed with a metal rod and a vibrating table. For cylindrical specimens subjected to the axial compression test, 15 blows were applied per layer in three layers. For prismatic specimens subjected to the flexural tensile test, 50 blows were applied divided into 62 two layers. After the metal rod blows were applied, all specimens were subjected to a seven-second vibrating table.

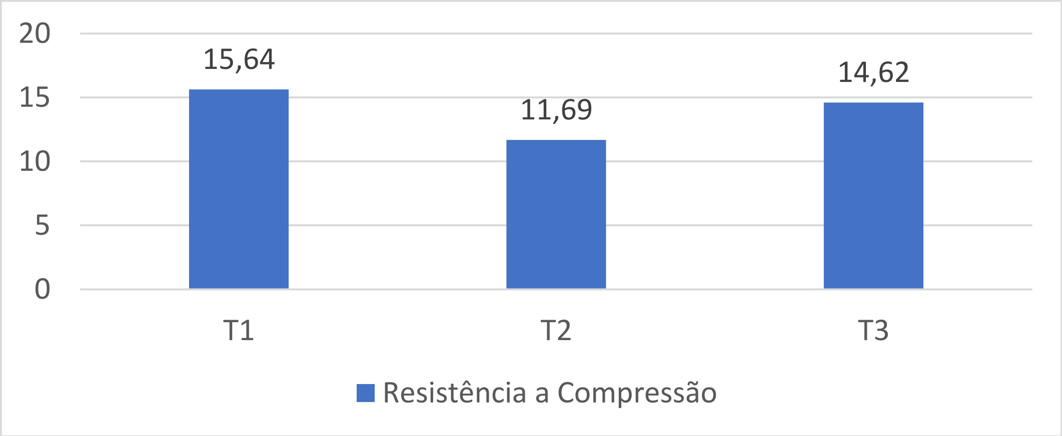
Table 8 – Traits studied by Santos (2017)

Mixture Aggregate	Mixture Aggregate content W/C ratio	Mixture Aggregate

content W/C ratio		content W/C ratio
1	3	0,33
2	3,5	0,3
3	4	0,33

Source: Adapted from Santos (2017).

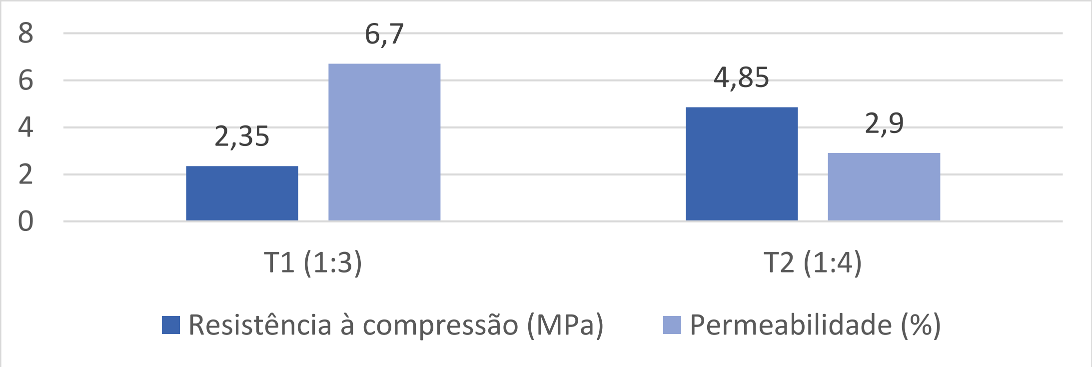
Figure 4: Resistance encountered by Santos (2017)



Source: Adapted from Santos (2017).

In the study conducted by Castro (2015), two mixes (T1) and (T2) with cement/aggregate ratios of 1:3 and 1:4, respectively, were analyzed (Figure 4). The author maintained a constant water/cement ratio of 0.30 for both mixes, using CP IV cement and 0 gravel. The mixes were compacted manually, with 15 blows per layer, distributed in three layers. The specimens were subjected to submerged curing for up to 28 days, at which point the tests were performed. The results are shown in Figure 5.

Figure 5: Results from Castro (2015)

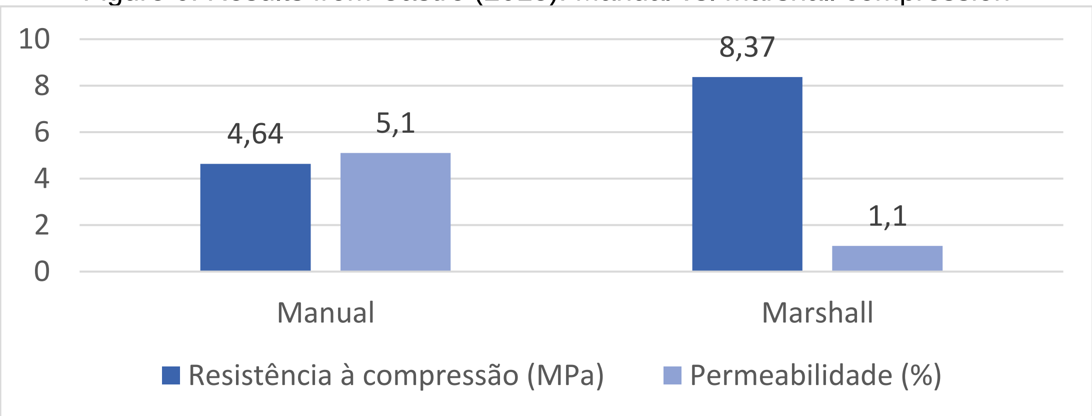


Source: Adapted from Castro (2015).

It is noted that the mix with the lowest aggregate content provided superior mechanical strength, accompanied by a reduction in permeability. The compaction method plays a crucial role in the properties of pervious concrete, and this aspect was investigated by Castro (2015). The author molded two other sets of samples, both with a w/c ratio of 0.30 and a cement/aggregate ratio of 1:4, similar to mix (T2), but composed of a mix of aggregates (90% zero-grade gravel and 10% medium-grade sand). In the first group, compaction was performed manually, following the aforementioned procedure, with three layers and 15 socket blows each. The second group underwent compaction using a Marshall compactor, typically used in asphalt concrete mixes. In this case, compaction with the Marshall socket was performed at normal power, consisting of 45 blows distributed across three layers. The results obtained can be seen in Figure 5.

The results indicate that the samples compacted using the Marshall compaction process, due to the greater amount of energy applied, demonstrated superior mechanical strength compared to those compacted manually. However, due to the reduction in voids caused by the intense compaction energy, a 20% decrease in permeability was observed in the samples compacted using the Marshall compaction process compared to those compacted manually.

Figure 6: Results from Castro (2015): Manual vs. marshall compression



Source: Adapted from Castro (2015).

Initially, it is not feasible to identify a behavioral pattern, since the compressive strength results showed significant dispersion. There is no clear relationship between the observed strengths and the curing method to which the samples were subjected. The main conclusions derived from the literature review of the studies fundamental to this research are consolidated in Table 8. These conclusions provide an overview of the relevant findings in the field of study that supported the investigation.

Table 8 - Summary of main conclusions

Author	Trait	Cement and aggregates	Compaction and curing	Main conclusions
Monteiro (2010)	T1 - a/c = 0,26, M = 3 T2 - a/c = 0,30, M = 4	CP II F B0	Vibrating table in 3 layers 30 seconds each Curing not specified	Compressive strengths - T1: 9,3 MPa -T2: 10,7 MPa
Santos (2017)	T1 - a/c = 0,33, M = 3 T2 - a/c = 0,30, M = 3,5 T3 - a/c = 0,33, M = 4	CP V Composition between B0 and B1	Cylindrical CP 3 layers of 15 strokes each + 7s on a vibrating table and prismatic CP 2 layers of 25 strokes each + 7s on a vibrating table Curing in a humid chamber	Compressive strengths - T1: 15,6 MPa - T2: 11,6 MPa - T3: 14,6 MPa
Castro (2015) analysis "A"	T1 - a/c = 0,30, M = 3 T2 - a/c = 0,30, M = 4	CP IV B0	3 coats of 15 strokes each Cure submerged in water	Compressive strengths - T1: 4,8 MPa -T2: 2,3 MPa
Castro (2015) analysis"B"	a/c = 0,30, M = 4	CP IV B0	Manual and Marshall, both with 3 layers of 15 strokes each. Manual and Marshall, both with 3 layers of 15 strokes each. Manual and Marshall, both with 3 layers of 15 strokes each.	- Marshall compaction resulted in superior strength - Marshall compaction permeability 20% lower than manual compaction - Marshall compaction resulted

Castro (2015) analysis "C"	a/c = 0,30, M = 4	CP IV 2 Granulometric compositions: 100% B0 and 90% B0 and 10% sand	3 coats of 15 strokes each Cure submerged in water	Compressive strengths - 100% B0: 2.3 MPa - 90% B0 and 10% sand: 4.6 MPa

Source: research data (2024).

3. Final Considerations

With urban growth came the need to build streets and roads, creating impermeable soil, preventing water infiltration, which consequently causes flooding. To overcome this adversity, methods were developed to improve urban drainage, one of which was pervious concrete.

Information was understood, such as that the relationship between void volume and compressive and flexural tensile strengths is inversely proportional, meaning that for pervious concrete to have high strengths, the mix must have the smallest possible void volume.

Therefore, it was clear that there is no standard behavior among results found by different authors that indicates an influence of the void ratio on mechanical strengths. This heterogeneity highlights the complexity of pervious concrete's behavior and the influence of factors such as densification, aggregate type, and curing process. The compilation of this information in Table 10 provides an overview of the main conclusions of the literature review, serving as a guide for future research and practical applications in the development of this material. Therefore, it is understood that not only the void ratio, but also the materials used, the mix design, and the mixing, compaction, and curing procedures adopted by each author greatly contribute to the strength of pervious concrete.

It is also concluded that pervious concrete is viable for paving because of its low production cost, which would reduce drainage system costs, allowing for a reduction in its dimensions, and its high porosity, which allows water infiltration through its areas, allowing it to be well absorbed by the soil, ensuring the urban drainage system.

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