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Original Research Article

Permeable Concrete Based on Construction and Demolition Waste Aggregates Used in Permeable Paving Slabs

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ABSTRACT

The recycling of construction and demolition waste is one of the solutions for reducing the environmental impacts, where residues can be used in permeable paving, produced with large recycled aggregates. The novelty herein is to conduct an experimental testing stage for producing permeable concrete slabs using coarse recycled aggregates from construction and demolition waste as a future application in permeable paving. The methodology consists of evaluating the effects of Construction and Demolition waste aggregates on the properties of permeable concrete in the fresh state and the hardened state. Permeable concrete slabs were produced based on five types of concrete mixtures, which can be applied as a final coating on soils with permeable profiles. A sustainable environment contributes to the improvement of knowledge and development on one of the applications of permeable concrete elements by recycling the waste generated by Civil Construction activities, mainly from non-renewable resources.

KEYWORDS

Recycling, Construction and demolition waste, Recycled aggregates, Permeable paving, Civil construction, Non-renewable resources.

INTRODUCTION

The construction industry-related environmental problems like scarcity of resources due to shrinking or even exhausted sources of raw materials and improper waste management lead to the unavoidable need for waste deposits (landfills) [1]. Buildings are the most significant contributors to environmental degradation [2]. The construction industry is responsible for 60% of global raw material extractions [3] – other sources say 40–50% [4] – and the demand has tripled in the period 1970–2017 [5].

The recycling of construction and demolition waste (CDW) is one of the solutions for reducing the impact on the environment due to the growing consumption of natural resources in civil construction and the disordered generation of its waste [6]. CDW recycling can be an opportunity to transform sources of expenditure into revenue or at least reduce these expenses [7]. CDW are materials from civil construction activities due to the construction of buildings, renovations and repairs to individual residences, commercial buildings and other

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structures, as well as all materials arising from the destruction of buildings and other structures [8]. Due to rapid construction business and urbanization growth, of the world's annual estimated CD waste, about 30% comes from the USA [9] and for China, it is about 30%–40% [10]. CD waste accounts for around 35 % of all waste produced in the European Union (EU), which represents 850 million tonnes per year [11].

According to ABRELPE [12], in Brazil, the average of collected CDW between the years 2015 and 2017 corresponds to 45.1 million Mg yearly, which generates an index of 218.9 kg per inhabitant yearly. The average annual estimate for collected MSW for the same period is 71.6 million Mg. It can be concluded that the CDW flow is significant since it has a value corresponding to 63.0% of the MSW flow collected in the country.

Studies have proven the feasibility of using recycled aggregates both in the coarse fraction [13] and in the fine one [14] for the production of concrete. Another more recent alternative is the application of permeable concrete elements constructed with CDW [15]. The standardization or regulation on the use of waste in the production of concrete varies from country to country, and the following can be identified as general requirements concerning aggregates: minimum resistance for use in the type of concrete in which it is used; present a minimum humidity index; do not react with cement or steel used in reinforcement; do not contain reactive impurities; have particle shape and particle size suitable for concrete production with good workability [16]. The recycled aggregates have variable properties, and, therefore, the concretes made tend to present variability in their properties. The knowledge of the properties and performance of recycled concrete can indicate its use based on limit values, standards, and recommendations [17].

A sustainable alternative that aims to reduce the impacts caused by the development of urban environments due to the increasing waterproofing of the soil in cities is permeable paving, produced with recycled large aggregates from civil construction [18]. Permeable paving is one of the compensatory measures for rainwater retention in urban environments, aiming at reducing the flows and volumes of these waters. The application of permeable concrete elements, built with CDW, extends and complements this compensatory measure from the perspective of a sustainable environment.

Internationally, field studies have been conducted on porous or water-retaining pavements in many cities, particularly in Japan [19]. Permeable pavements with concrete elements have been used in a wide range of applications, including pervious pavement for parking lots [20], rigid drainage layers under exterior mall areas [21], greenhouse floors to keep the floor free from standing water [22], help rainwater infiltrate into the soil [23], decrease urban heating [24], reduce traffic noise, and reduce flash flooding [25].

In Brazil's scenario, the generation of waste and its management is a real concern for the construction sector. Another factor is the scarcity of good natural aggregates near urban areas. In this way, the recycling of construction and demolition waste is presented as one of the solutions to reduce the impact caused to the environment. Another critical problem in Brazilian cities is related to soil waterproofing, and permeable paving is presented as a technological alternative that contributed to the reversal of this phenomenon. The application of permeable concrete elements, built with recycled construction and demolition aggregates, extends and complements this compensatory measure from the perspective of a sustainable environment.

The present work aims to promote technological advances in the theme of what would be the concept of "low impact urban development", focusing on the promotion of compensatory technique through permeable pavements using construction waste in order to provide stormwater management that works as a solution to existing urban problems related to rainwater runoff.

This work aims to evaluate the structural feasibility of using coarse aggregates of recycled construction and demolition residues from civil construction as a partial or total substitute for conventional aggregate for the production of permeable concrete elements for the use of permeable paving in urban environments. The work is also aimed at evaluating, on a small scale, the efficiency of coatings with permeable surfaces in the control of the generation of surface runoff and observing the influence of recycled coarse aggregates when they are applied in coatings of sidewalks, uncovered internal areas of buildings and for parking of light vehicles.

The experimental program carried out included the following parts: collection and crushing of recycled aggregates for construction and demolition, characterisation of these aggregates, the definition of the features, characterisation of these features, moulding of the specimens, mechanical tests for the evaluation of the strength of the concrete, analysis of the results of the tests of resistance of the specimens and moulding of permeable concrete slabs made of recycled aggregates.

The novelty of this study consists of the contribution to improve knowledge on two aspects; one is about the characteristics of recycled construction and demolition aggregates in civil construction, and the other is about the behaviour of permeable concretes constituted of these aggregates in the construction of porous pavements. The integration of these two sustainable measures could reduce the use of non-renewable resources from the environment and promote applying the resources of recycling construction and demolition waste to the construction of permeable pavement.

MATERIALS AND METHODS

CDW originates in three forms, namely, renovations and maintenance, new construction, and demolition, as depicted in **Figure 1**.

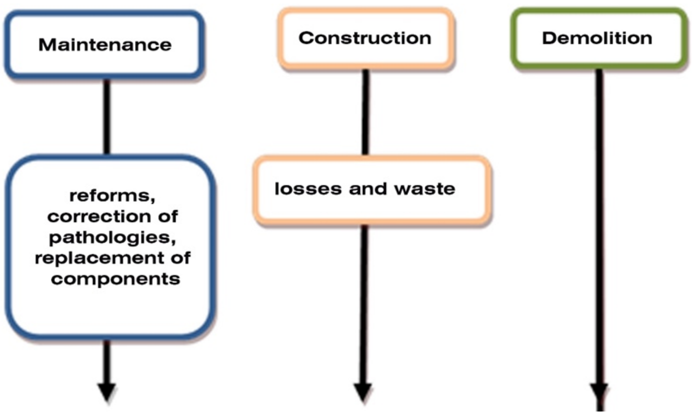


Figure 1. Three forms of construction and demolition waste generation

In 2014, construction and demolition (CD) activities generated 1.13 billion tonnes in China [26], in excess of 850 million tonnes of waste in the European Union (EU) [27], and over 530 million tonnes in the United States [28]. The construction sector in the EU is the highest producer of waste when compared with other economic sectors, accounting for 35% of the total waste generation [11]. The waste generation is very high and constitutes sufficient reason for serious and rapid measures to contain the advance of the problem.

Experimental campaign

This work describes the designing stage of the experimental campaign for the production of permeable pavements as a future application on an urban scale using CDW. The effects of recycled aggregates on the mechanical properties of permeable concrete are evaluated in the fresh state (embedded air content and workability) and in the hardened state (axial compressive strength, tensile strength by diametrical compression, tensile strength in bending and modulus of elasticity). The produced concrete slabs, composed of five types of permeable concrete mixtures, can be applied as a final coating on soils with permeable profiles.

The experimental campaign includes the following parts: collection and crushing of recycled construction and demolition aggregates, characterization of these aggregates, the definition of traces, moulding of specimens, mechanical tests for the evaluation of concrete strength, analysis of the results of strength tests of the specimens, and moulding of permeable concrete slabs which consist of recycled aggregates.

The following is the design stage of the experimental campaign for the production of permeable pavements using construction and demolition waste (CDW). The effects of recycled aggregates on the mechanical properties of permeable concrete were evaluated in the fresh state and the hardened state [30]. Based on the results obtained, concrete slabs were produced using five types of permeable concrete mixtures. The slabs can be applied as a final coating on soils with permeable profiles. For the production of permeable concrete specimens, five mixtures were considered: (I) 100% coarse natural aggregate – AGN, (II) 100% coarse aggregate from demolition waste – AGD, (III) 100% coarse aggregate from construction waste – AGC, (IV) 50% AGN and 50 % of AGD, (V) REF – fine and natural aggregate. Test specimens were moulded with each of the five mixtures to perform the tests of compressive strength, tensile strength by diametrical compression, and tensile strength in flexion and to produce permeable concrete slabs.

Considering that one of the objectives of this work is to evaluate some of the mechanical properties of permeable concretes produced with recycled aggregates from construction and demolition waste, the following response variables were defined: 1) Air content incorporated into the concrete [31]; 2) Workability measured by the concrete slump rate [32]; 3) Resistance to axial compression [33]; 4) Tensile strength by diametrical compression [34]; 5) Tensile strength in flexion [35].

Selection and characterisation of materials

The water used in making the concretes, mortars, and pastes came from the supply system of the city of Rio de Janeiro – Companhia Estadual de Água e Esgoto (CEDAE). For the production of mortars, this work opted to use Portland Cement Common CPII E-32. The choice for this type of cement was made due to the similarity of the present study with research work on mortar with recycled ceramic waste aggregate, which was in progress in the laboratory. The use of the same type of cement allows for future comparisons between studies, considering the difference in the kind of waste recycled used. The aggregates used in this study were obtained from the disposal of construction waste from the new Building Materials Testing Laboratory at the Polytechnic School of the Federal University of Rio de Janeiro (LAMAC). The laying of the ceramic floor generated the construction waste (RC), composed solely of ceramic waste and the demolition of the concrete base of the old cyclic loading test machine for concrete elements, which in turn gave rise to the demolition waste (RD), composed only of concrete waste as shown in Figure 2.

Figure 2. Construction waste (a) and demolition waste (b)

Coarse aggregates were produced in the structure laboratory (LabEST-COPPE / UFRJ), after collecting the waste samples, where there was no need for processing, as there was a very small amount of contaminants, such as cardboard, glass, plaster, wood, plastic, earth, among others, probably due to the finishing stage that the work was in. The jaw crusher, model Queixada 200, was used for crushing the waste. The equipment was regulated for the production of coarse aggregates, with average dimensions of the No. 1 gravel. The adjustment was made by successive attempts based on tactile-visual analysis of the aggregates produced (**Figure 3a**). After completing the calibration of the equipment, the waste was crushed using different procedures for each type of waste. After crushing, parts of the materials were bagged for the characterisation of recycled construction and demolition aggregates (**Figure 3b**). A part was stored in 200-litre PVC containers (**Figure 3c**) as raw material for the production of the specimens for testing the mechanical properties of permeable concrete, as well as for moulding slabs of that concrete. Table 1 presents a schematic summary encompassing all parameters of the experiment execution, including the number of specimens and their respective tests.

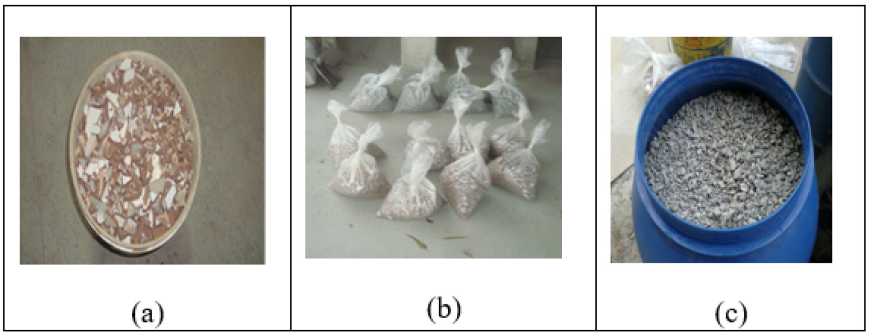


Figure 3. Coarse aggregate selected (a), coarse aggregate after separate grinding for characterisation (b), and coarse aggregate after grinding for making the plates (c)

Table 1. Schematic summary of the variables studied in the experiment, number of specimens and tests performed

Mixture	Water / Cement Factor	Coarse Construction Aggregate (%)	Coarse Demolition Aggregate (%)	Natural Coarse Aggregate (%)	Natural Fine Aggregate (%)	Number of Specimens (Tests) Cylindric	Prismatic
Conventional Natural Coarse Aggregate	0.5			50	50	12 (1)	4 (2)
Crushed Stone 1 Permeable	0.37			100		12 (1)	4 (2)
Coarse Demolition Aggregate (100%)	0.39		100			12 (1)	4 (2)
Coarse Construction Aggregate (100%)	0.48	100				12 (1)	4 (2)
Coarse Construction Aggregate (50%) and Demolition (50%)	0.46	50	50			12 (1)	4 (2)

RESULTS OF THE ASSESSED PROPERTIES OF PERMEABLE CONCRETE

The properties of permeable concrete with recycled aggregate in the fresh state were evaluated by determining the workability and incorporated air. In the hardened state, the evaluated properties were resistance to axial compression, deformation module, tensile strength by diametrical compression, and strength for flexural traction. The required data were obtained through tests of specimens performed at COPPE / UFRJ Laboratories.

Incorporated air content – fresh state

Air incorporated into concrete is defined as air introduced intentionally by means of an appropriate agent. This air must be clearly distinguished from accidentally trapped air; the types of air differ by the dimensions of the bubbles, with those of embedded air having a diameter of about 0.05 mm, while those of accidental air usually form larger bubbles, some as large as the common surface flaws of concrete [31].

The control of the content of incorporated air is fundamental to the control of the quality of the concrete, either to verify maximum and minimum desirable limits of incorporated air or to identify the contents of voids of air in the concrete. The air content in concrete is, therefore, a topic of utmost importance to its final quality. The control of the percentages of air in fresh concrete allows the measurement of the dosages, the additions of additives, and, as a consequence, the guarantee of the quality of the material. Air values above those predicted in the material dosage indicate that the concrete may suffer mechanical damages, such as reductions in compressive strength and modulus of elasticity, or aesthetic ones, such as the formation of surface macro bubbles [36].

Conventional concretes contain in their interior, even without the use of air-incorporating additives, 1 to 3% of their volume in trapped air due to the mixing process and its consistency. In the case of concrete produced in plants and transported by concrete mixer trucks, this percentage can reach the order of 4%. Percentages of incorporated air above 5% can damage the mechanical performance of the material [37].

In Brazil, NBR NM 47/02 – Fresh Concrete – Determination of Air Content by the Pressometric Method, is the test used to obtain the value of air incorporated and/or trapped in concrete [38]. Figure 4 shows the device used to measure the air content in concrete, which consists of a hermetically sealed container filled with fresh concrete. Water and air under pressure are injected through the holes in the cover to expel the air contained in the fresh concrete. The pressure gauge detects the pressure loss and indicates the equivalent percentage in the mixture.

Figure 4. Built-in air meter

The air content is calculated by the difference between the actual volume of concrete (volume considering air) and the theoretical volume (without considering air and calculated based on the specific masses of the components), expressed as a percentage of the actual volume. The accuracy of the obtained value will depend on the precision of the density values of the components. The results are shown in **Table 2**. It can be reported, observing the results of the test as mentioned above, that the values found were very close to the mixtures of conventional concrete and permeable concrete with natural aggregate (gravel No. 1), with an average variation of a little more than 10%. These values are below the maximum limit of 3% of air incorporated into conventional concrete [38]. Air values above those predicted in the material dosage indicate that the concrete may suffer mechanical damage, such as reductions in compressive strength and modulus of elasticity, or lowered aesthetics, such as the formation of surface bubbles [40].

Table 2. Results of the test of air content incorporated into the concrete

Concrete Mixtures	Air incorporated into concrete [%]
Conventional	2.00
Natural Coarse Aggregate – Crushed Stone 1	1.80
Large Demolition Aggregate (100%)	1.60
Large Construction Aggregate (100%)	2.00
Large Construction Aggregate (50%) and Demolition (50%)	2.20

Workability – fresh state

There is unanimity in stating that concretes with recycled aggregates have a lower Consistency Index than mixtures executed with natural aggregates of the same trait. This statement is justified by the greater porosity presented by the recycled material, a fact that ends up increasing the water absorption of the same and decreasing the amount of free water of the mixtures. Also, the more angular shape of the recycled aggregates can cause a decrease in the workability of the concretes produced with this material [40]. The cone trunk slump test is the test that will be used in this study, considered a qualitative index of the stability and fluidity of the concrete mixture in the fresh state, being the most widely used for uniformity control of concrete production worldwide [37].

The experimental program included the study of the workability of recycled concrete. It was decided to avoid using plasticizers or superplasticizers for production of permeable concrete at a lower cost and to evaluate the workability of concrete without the use of additives [38].


(a)


(b)

Figure 5. Slump of conventional concrete with natural aggregates (a) and slump of concrete with recycled aggregate from demolition (b)

The workability of the permeable concretes produced was determined by measuring the reduction of the cone trunk according to the prescription of NBR NM 67 for the determination of consistency by cone slumping in conventional concrete, with natural aggregates (a) and slumping of concrete, with recycled aggregate from demolition (b), as shown in **Figure 5**. The values of the measurements of the cone trunk slumping of the concrete mixtures carried out in this research, defined in the experimental study, are shown in **Table 3**.

Table 3. Measurement of the slump in the cone of concrete mixtures

Permeable Concrete Mixtures	Cone Trunk Abate Measurement [cm]
Natural Gravel Aggregate 1 Permeable	19.50
Large Demolition Aggregate (100%)	19.80
Large Construction Aggregate (100%)	12.00
Large Construction Aggregate (50%) and Demolition (50%)	14.00

Regardless of the slump values obtained for concrete with recycled aggregates, the greater or lesser ease with which they can be compacted is what can be considered as a parameter to limit their use **[41]**. Based on the studies cited, the porosity of recycled coarse aggregates and their heterogeneous and angular shape are the properties that can most influence the characteristics of concrete in its fresh state.

Some important aspects were observed in the measurements of the cone trunk slump. The content of substitution of natural coarse aggregate for recycled coarse aggregate had a significant effect on the permeability of the permeable concrete, where there was a very large variation between the mixtures. the smallest difference between the abatements of the concrete with recycled aggregates and conventional concrete occurred in the concrete with 100% recycled aggregate from the construction waste, reaching 118% greater. However, the most significant difference occurred in the concrete with 100% recycled aggregate from demolition waste, reaching 260%. The recycled aggregates, because they are more porous, incorporate a greater amount of air into the mixtures and, despite the greater roughness given to the concrete, and the physical properties of the aggregates, which favor the locking of the mixtures and the reduction of the abatement value, these are present more workable, because the greater the amount of trapped air, the lower the resistance to densification **[42]**.

The results obtained in the cone slump test for the concrete mixtures studied indicate that some procedures can minimise the adverse effects of recycled aggregates on the consistency of the concrete. One can increase the amount of water in the mix by a value equal to part of the total absorption of the aggregate or pre-wetting it before starting the mix. Another option is increased consumption of cement, which will result in the modification of the w/c ratio. Other procedures include using plasticizing additives or increasing their dosage, alternatively using less porous (that is, denser) coarse aggregates with less water absorption.

Axial compression strength test – hardened state

The mechanical properties concern the potential of the permeable concrete to resist the stresses that are requested. Among the properties analysed, compressive strength is most frequently used on all study fronts, given the relative ease of carrying out the tests **[40]**.

The strength of a material is defined as the ability to withstand stress without breaking. In concrete, therefore, strength is related to the stress required to cause rupture, defined as the maximum stress that the concrete sample can withstand. In compression, the specimen rupture occurs even if there are no visible signs of external fracture, but the internal cracks are in such an advanced state that the specimen will not withstand a greater load. Strength is generally considered to be the fundamental property of concrete. It gives a general indication of concrete quality because it is directly related to the structure of the hardened cement slurry **[43]**.

A Shimadzu servo-controlled press, model UF-F 1000 kNI (**Figure 6**), as prescribed to NBR 5739/2007, with a loading speed of 0.0075 mm/min **[38]**, was applied in the evaluation of the compressive strength. The rupture tests used cylindrical concrete specimens with dimensions of 10 cm in diameter and 20 cm in height.

Figure 6. Servo-controlled Shimadzu press to perform the tests of resistance to axial compression

The characteristics of stresses versus strains were measured using electrical sensors in the specimens to measure longitudinal displacements. The specimens had irregular upper and lower surfaces in such a way that they impaired the application of the loads during the test. To solve this problem, these surfaces were regularised with a layer of sulfur as can be seen in **Figure 7**.

Figure 7. Capping of the upper and lower surfaces of the specimens

The axial compressive strength of concrete is one of the most important properties when evaluating the performance of a structure [44]. Resistance is linked to the ability of materials to withstand stresses without breaking. Broadly speaking, resistance is closely related to the porosity of materials. The more porous these are, the lower their resistance tends to be. In concrete, in addition to the porosity of the cement matrix and coarse aggregate, the porosity of the transition zone between the matrix and the aggregate must be considered. In the study of the strength of concrete with natural aggregates, generally, the use of dense and resistant aggregates causes this property to be influenced basically by the porosity of the matrix and the transition zone. However, when experimentally studying the strength of concrete with recycled material [44], it is believed that the porosity of the aggregate will play an important role in determining the strength of the concrete. The authors of [44] compared, in their study, the compressive strength of permeable concrete composed of recycled aggregates with permeable concrete composed of natural aggregates. They found that this strength directly decreases probably due partly to the reduction of the cement interface and the recycled aggregate and partly to the increase in the number of concrete voids. The axial compression strength is calculated by **Eq. (1)** [38].

$$fc = \frac{4 \times \mathrm{F}}{\pi \times \mathrm{d}^2} \tag{1}$$

Where: fc – compressive strength [MPa], F – maximum load obtained in the test [N], and d – diameter of the specimen [mm].

The tests of the specimens were performed as established by NBR 5739/2007 and the results obtained are listed in **Table 4**. It appears that the results of compressive strength are within the limits, lower and upper, for the compressive strength of permeable concrete with natural coarse aggregates varies from 7 to 14 MPa **[40]**. The cases where sharp reductions have occurred show the negative influence of the porosity of coarse CDW aggregates on their own strength and on the strength of the concrete. Concrete mixtures composed of recyclable aggregates, both 50% replacement and 100% aggregate replacement, had their axial compression strength around 26% less than the mixture of concrete with crushed stone No. 1.

Table 4. Results of tests of resistance to axial compression

Permeable Concrete Mixtures	Axial Compression Resistance [MPa]
Natural Gravel Aggregate 1 Permeable	10.72
Large Demolition Aggregate (100%)	7.05
Large Construction Aggregate (100%)	8.74
Large Construction Aggregate (50%) and Demolition (50%)	7.85

Tensile strength test by diametrical compression – hardened state

Although the tensile strength of concrete is a secondary characteristic, since concrete does not resist well to tensile stresses, however, as porous concrete consisting of recycled coarse aggregate still has a small number of research, it is necessary to study this mechanical property **[45]**. In the tests of tensile strength by diametrical compression, the concrete specimens were subjected to compression loads along two axial lines that are opposed. The load must be applied continuously at a constant speed within a range of 0.7 to 1.3 MPa, until the specimen ruptures **[44]**. The test was carried out according to NBR 7222/2010 - Mortars and Concrete: Determination of tensile strength by diametrical compression, for cylindrical specimens, with dimensions of 10 cm in diameter and 20 cm in height and aged 28 days. The tests were performed on the Shimadzu press, model UF-F 1000 kNI. The test was carried out on 06 (six) specimens, for each of the 05 (five) mixtures established in the experimental project **[38]**. **Figure 8** shows the permeable concrete specimen positioned in the press.

Figure 8. Test specimen positioned in the press to perform the diametrical compression test

The tensile strengths obtained by diametrical compression were compared with conventional concrete and with permeable concrete with natural coarse aggregate (crushed stone 1). The diametrical compression values (ft,D), found through the test described in NBR 7222/2011, at 28 days of cure are shown in **Table 5**.

Table 5. Result of tensile tests by diametrical compression

Permeable Concrete Mixtures	Tensile strength by diametrical compression [MPa]
Natural Gravel Aggregate 1 Permeable	1.63
Large Demolition Aggregate (100%)	1.79
Large Construction Aggregate (100%)	1.76
Large Construction Aggregate (50%) and Demolition (50%)	1.79

The tensile strength by diametrical compression is calculated by **(Eq. 2) [38]**, as follows:

$$ft,D = \frac{2.\mathrm{F}}{\pi \times \mathrm{d} \times \mathrm{l}} \qquad \text{(Eq. 2)}$$

Where;
f t,D: tensile strength by diametrical compression [MPa], to the nearest 0.05
F: maximum load obtained in the test
d: diameter of the specimen
l: specimen height

It was found that all permeable concrete mixtures had lower stresses than conventional concrete. The results of mixtures with recycled aggregates were slightly higher, but very close to the result of mixing with natural aggregate, around 8%, even with different water/cement factors, that is, this factor did not change the tensile strength by compression diametral. The angular and lamellar shape, as well as the rough surface of the aggregates, contributed to this result.

Modulus of elasticity – hardened state

The modulus of elasticity of concrete depends on the porosity of its phases (paste, aggregate and transition zone). In the case of the aggregate, its maximum dimension, shape, surface texture, granulometry and mineralogical composition can also influence the modulus of elasticity by influencing the microcracking of the transition zone. However, porosity is more important by virtue of being linked to its rigidity, and strength.

Based on the characteristics that influence the deformation modulus, it can be said that the deformation modulus of recycled aggregates is very close to the modulus values presented by the cement slurry matrix, since the composition of construction and demolition waste is basically from cementitious base materials (concrete mortars, coating and masonry execution) and very porous ceramic components. In this way, as the porosity of the aggregate is what controls the restriction of the deformation of the matrix, in the case of recycled aggregate the concrete produced will be more deformable, since this control is incipient. Matrix and aggregate of recycled concrete are much more porous when compared to concretes produced with natural aggregates. The decrease in the specific mass of recycled concretes also leads to reductions in modulus values. There remains only the influence of the transition zone which may have had an improved adhesion, as already seen previously, but which alone is not sufficient to raise the modulus values of the recycled concretes **[46]**. The modulus of elasticity (Ec) found at 28 days of curing were compared with permeable concrete with natural coarse aggregate (brita1) and are shown in **Table 6**.

Table 6. Modulus of elasticity

Permeable concrete mixtures	Modulus of elasticity [GPa]
Aggregate grade natural-Brita 1	12.61
Demolition grade aggregate (100%)	9.46
Construction grade aggregate (100%)	11.94
Construction grade aggregate (50%) and Demolition grade aggregate (50%)	10.19

The modulus of elasticity was calculated by **(Eq. 3)**, which follows below.

$$Ec = \frac{\sigma b \ - 0{,}5}{\mathcal{E}\mathrm{b} - \mathcal{E}\mathrm{a}}\ 10^{-3} \qquad \text{(Eq. 3)}$$

Where;
Ec = modulus of elasticity [GPa].
σb = the greater stress in MPa (σb = 0,4fc).
0,5 = the basic stress in MPa.
Ɛb = medium specific deformation, under greater stress [mm]
Ɛa = average specific strain, under the basic stress of 0,5 MPa [mm]

Observing the graph shown in **Figure 9**, it can be seen that all permeable concrete mixtures with recycled coarse aggregates had lower moduli of elasticity than those of permeable concrete mixtures, composed of natural aggregates.

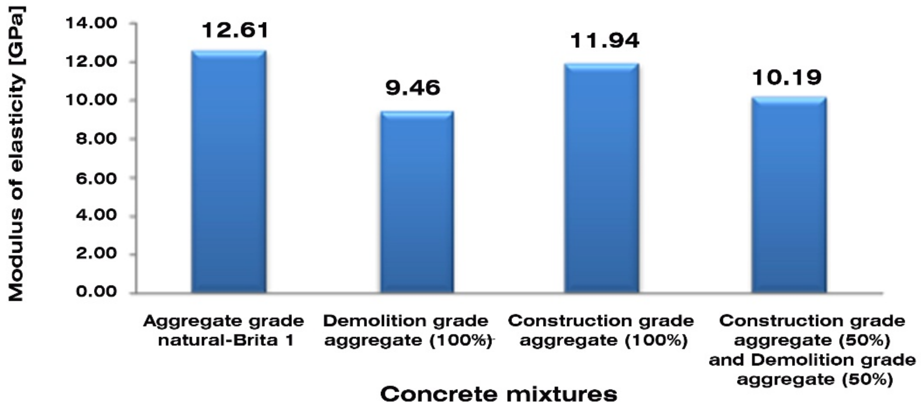


Figure 9. Test result graph-elasticity module

The greater the amount of dense aggregates in a concrete mixture, the higher the modulus values obtained. Thus, the statement that the increase in the amount of porous aggregates in concrete mixtures decreases the modulus of elasticity, is also valid. It is believed that this is one of the characteristics of concrete with recycled aggregates, where the decrease in the modulus of elasticity occurs as the type of CDW is replaced, and the concrete residue is more porous than the ceramic.

Flexural tensile strength test – hardened state

Although the tensile strength of concrete is a secondary feature, since concrete does not resist tensile stresses, however, as porous concrete consisting of recycled coarse aggregate still has a small number of research, it is necessary to study this mechanical property **[44]**. The prismatic specimens were marked and tested as prescribed by NBR 12142/2010 - Concrete: Determination of the tensile strength in flexion in prismatic specimens - Test method, with dimensions of 10 cm x 10 cm x 40 cm (**Figure 10**), aged 28 days, loaded at a speed of 0.8 to 1.2 MPa / min **[38]**.

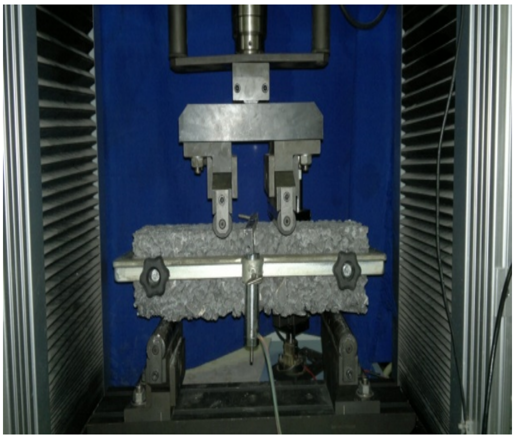


Figure 10. Positioning of the specimen for the flexural tensile test.

This test was performed on the Shimadzu press, model UF-F 1000kNI, as shown in **Figure 11**.

Figure 11. Shimadzu press, model UF-F 1000kNI.

The tensile strength in the permeable concrete bending (fctM) can be determined in two different ways, depending on the location where the rupture occurs. The standard NBR 12142/1991 establishes two equations for the calculation of resistance, one if the rupture of the traction surface occurs in the middle third of the span length and another if this rupture occurs outside the middle third, but less than or equal to 5 % of span length. The tensile surfaces of the specimens tested in this study broke in the middle third, so the resistances were calculated using **(Eq. 4) [38]**.

$$f\,ctM = \frac{\mathrm{P\,.\,L}}{\mathrm{b\,.\,d^2}} \qquad \text{(Eq. 4)}$$

Where;
f ctM: flexural tensile strength [MPa]
P: maximum load obtained in the test [N]
L: span length [mm]
b: specimen width [mm]
d: specimen height [mm]

The results found after the ruptures of the specimens, with 28 days of curing, are listed in **Table 7**. The conventional concrete test was not presented, as there was a significant loss in the acquisition of its data.

Table 7. Result of flexural tensile tests

Permeable Concrete Mixtures	Flexural tensile strength [MPa]
Natural Gravel Aggregate 1 Permeable	2.40
Large Demolition Aggregate (100%)	2.44
Large Construction Aggregate (100%)	1.86
Large Construction Aggregate (50%) and Demolition (50%)	1.79

The results tended to be higher, the lower the water / cement factors. The mixtures of concrete with demolition aggregates and gravel No. 1, had the results of tensile strength in flexion greater, around 25%, than the results of mixtures with 100% construction aggregates and the mixture with 50% demolition aggregates and 50% construction. The results of the tensile strength tests in this research reached higher values in mixtures of permeable concrete with 100% natural aggregate and 100% recycled construction aggregate, 2.40 MPa and 2.44 MPa respectively, probably due to the cubic shape and rough surface texture of these aggregates [38], where it is inferred that the shape and surface texture of the aggregates have a considerable influence on the strength of the concrete. The tensile strength indexes are slightly lower for concretes with recycled coarse aggregate when compared with conventional concretes [41].

MOLDING OF RECYCLED PERMEABLE CONCRETE PLATES

After carrying out the experimental testing stage, the step of molding permeable concrete plates, produced with studied recycled aggregates, was passed. The dosage and traces of the concrete were the same established, for each of the five mixtures used for the molding of the specimens. The recycled concrete slabs were molded at the COPPE / UFRJ Structure Laboratory, in eight square PVC shapes, 45 cm by 45 cm and 5 cm thick, for each of the five recycled concrete mixes established, being in the process of being cure for 28 days in a humid chamber. Figure 12 shows PVC mold for the production of recycled concrete (a) and 05 mixtures surveyed PVC molds (b).

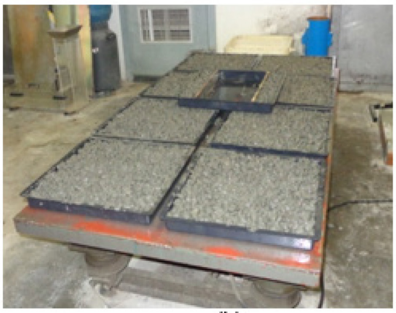

(a)

(b)

Figure 12. PVC mold (a) and PVC molds for the production of recycled concrete slabs, composed of the 05 mixtures surveyed (b)

Figure 13 shows the curing of recycled concrete plates (a) and concrete plates (b).

(a) (b)

Figure 13. Curing of recycled concrete plates (a) and concrete plates

CONCLUSION

In order to increase knowledge about recycled concrete, this research sought to evaluate the behavior of this concrete, produced with different amounts of coarse aggregates, from the recycling of construction and demolition waste, as well as also evaluating some physical properties of this type of concrete. The use of recycled bulk aggregates to replace natural aggregates was studied in five different mixtures; (I) 100% coarse natural aggregate - AGN, (II) 100% coarse aggregate from demolition waste - AGD, (III) 100% coarse aggregate from construction waste - AGC, (IV) 50% AGN and 50 % of AGD, (V) REF - fine and natural aggregate. For these mixtures, the influence of its composition on the properties of the concrete in its fresh state - incorporated air content and workability - and in its hardened state - resistance to axial compression - tensile strength by diametrical compression and tensile strength in the flexion.

In parallel to this study, an economic feasibility of the process should be made, considering that mechanical tests are required to prove the technical feasibility of recycled concretes compared to conventional concretes.

The absorption rates of coarse construction and demolition aggregates were high, 6.82% and 7.37% respectively, so there was a need to compensate them during the production of permeable concrete mixes, to avoid reducing free water, where the density and workability of the mixture could be compromised. The high absorption of recycled aggregates did not have to be fully compensated, it being only necessary to adjust the amount of water between 40 and 50% of the absorption rate of the aggregates. The time interval sufficient for this compensation must be determined by the absorption curve of the recycled aggregates used. In this study, the recycled aggregates were pre-humidified 10 minutes before the concrete mix production process. The specimens and permeable concrete plates were satisfactorily shaped, demonstrating that the workability of the concrete mixtures was adequate, even without the use of plasticizer or superplasticizer additives and with the increase of the water / cement factor, the workability of the mixtures studied concrete, demonstrate to be easy to be molded.

The porosity of the recycled aggregates and the water / cement factor negatively impact the resistance of the recycled permeable concrete, considerably decreasing the resistance to compression, traction and the modulus of elasticity. The recycled permeable concretes showed a reduction in the relationship between tensile strength and compressive strength, which is identical to conventional concrete, but the reduction in this relationship is greater in recycled permeable concretes. The air content incorporated to the recycled permeable concrete was found on average 2%, demonstrating that this characteristic of this concrete did not contribute to the reduction of the strength of the recycled concrete.

According to the results obtained, in comparison with conventional concrete, it is considered that permeable concrete mixtures composed only of coarse aggregates, negatively influenced the mechanical properties of these concretes, mainly the compressive and tensile strength.

Some limitations, difficulties and doubts were observed in the course of this research, and due to this analysis, suggestions for future scientific research are presented. Conduct further study on the procedures for measuring the workability of recycled concrete To survey the cost of using recycled aggregate for the production of recycled concrete, referring to the various stages of the production process, especially waste management, implementation of programs for recycling construction and demolition waste. Deepen the study with the addition of plasticizer additives to compare the results in relation to the strengths of recycled concrete. Conduct a study on the behavior of compressive and tensile strengths, as well as wear resistance and durability of concrete slabs, composed of recycled construction and demolition aggregates, when applied as floor coverings in urban environments. Carry out specific studies and tests on the permeability of slabs produced with coarse CDW aggregates to assess the viability of their application as a permeable pavement. To evaluate the effects and results of permeable concrete slabs, produced with RCD, when used as a compensatory measure to mitigate the problems arising from urban drainage.

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