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ANALYSIS OF THE EFFICIENCY OF RECYCLED CONCRETE IN CIVIL CONSTRUCTION

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ABSTRACT

Sustainability has become a partner in matters involving civil engineering considering that the generation of construction waste produces similar amounts in Brazil to the industrial sector, where, moreover, most cannot be ruled out in any way, because they are harmful to the environment, some of which are irreparable. The emergence of techniques and ways to build sustainably has created ideas and new destinations for construction waste. Recycled concrete is one of the solutions adopted to reduce costs with new materials and appropriate treatment to waste generated by the civil council. The objective of this work was to make a comparison between tensile strength and compression of recycled concrete, analyzes the structural viability, using the same proportions of materials as a conventional concrete. The tests were carried out based on specimens of cylindrical shapes of 150 mm in diameter and 300 mm in height, following the imposed ratio of the height/diameter ratio required by the standard in force in the country. The result to traction was considered low, both for recycled and conventional concrete. However, concrete using 100% recycled material presented a higher "fck" than conventional. The two proportions used of recycled materials in two of the three concretes under study, showed whether the quantity of this is adequate and does not interfere with the result of the characteristic compressive strength of the concrete.

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INTRODUCTION

Civil Construction is an activity of great importance for economic and social development, generating jobs, improving infrastructure, income, enabling housing, among other positive socioeconomic impacts (LINTZ *et al*., 2012). On the other hand, disordered growth, high consumption of natural resources, large generation of waste and landscape modification make it an activity that generates negative environmental impacts (BRASILEIRO & MATOS, 2015). The unbridled generation of waste, associated with an inadequate disposal, has the result of pollution of the environment. Gradually, environmental awareness extends to companies in the sector, but slow (LINS *et al*, 2020). The generation of Construction Waste (CCR) is usually due to losses of construction materials, through waste during the execution process and improper use, as well as the remains of materials that are lost due to damage in the receipt, transportation, and storage. They are generally best known for debris and are technically defined as the tailings of all material used in the execution of stages of the works, and can be generated from infrastructure works, demolitions, renovations, restorations, repairs, new constructions, among others, such as a set of fragments or remains of boulders, sands, ceramic materials, mortar, steel, wood and others (FERREIRA *et al*, 2014). The use of recycled construction material is originates in Europe in the 1940s, as it had large amounts of debris resulting from the bombings. The use of debris for the construction of new civil works became a reality where most of the debris was ceramic materials (tiles, sanitary ceramics), natural stone material, plastics, and rubbers (HOFFMANN *et al*, 2012; KULAKOWSKI *et al*, 2012) and concrete; which subsequently received additions such as slag, fly ash, active silica (GONZÁLEZ-FONTEBOA *et al*, 2009). To minimize the impacts generated by climate change and environmental pollution, the Kyoto Protocol, which entered into force in 2005, began. The protocol determined that developed countries at least initiate policies to reduce the volumes of pollutants into the atmosphere, which also constitutes a heritage of all (ALONSO *et al*, 2007) either through reuse, reduction or seeking recycling alternatives (VALDÉS *et al*, 2009). Studies conducted in the European Union (ETXEBERRIA *et al*., 2007) where countries with scarcity in deposits of standing can determine the feasibility of reusing concrete from construction as granular material. Research showed that the physical and mechanical properties of recycled concrete, composed of additions of recycled aggregates in its matrix, can guarantee its strength and mechanical performance (TOPCU, 1997; TOPCU & SENGEL, 2004).

The use of pozzolan waste indirectly solves the accumulation of other solid waste that contaminates and occupies spaces, in addition to adding silicoaluminates to recycled concrete that increases mechanical performance with other mixtures. Using this mineral, it is also possible to increase the protection of the reinforcement by densify, reducing the attack by carbonation in concrete (PÉREZ-QUIROZ *et al*., 2014). The results of the physical and mechanical properties obtained with the additions, substitutions and additives used in the new mixtures of concrete and mortar base cement and lime, in the fresh and hardened state, show the veracity of these statements (MARTINEZ *et al*, 2015; BERNABÉ, 2015; JACOBO, 2014). Therefore, the objective of this work was to smooth the behavior of concrete based on the use of recycled aggregates of civil construction and demolition, based on tests that define its compressive and traction strength, analyzing its viability in constructions that require a more requesting load application than that necessary when used for road paving.

METHODOLOGY

To ensure the resistance of recycled concrete for use in structures with requesting loads, standardized tests were carried out in the country to proveits strength. It is emphasized that andsses tests aim to make the quality control of concrete and according to the specifications of the standard. The most important of these tests is axial compression, since the concrete has a high compressive strength, having little traction.

Materials Used: The cement used was CP-II Z, Portland cement composed with the addition of pozzolone, for both types of concrete, to better compare the results in relation to their tensile and compression strengths. The kid aggregate used in conventional concrete was of quartz origin, with particle size distribution presented in Table 1, in the chapter of Results and Discussion. The large aggregate, also used in conventional concrete, was of basaltic origin, and with granulometric distribution visualized in Table 2, in the chapter of Results and Discussion. In recycled concrete, the aggregate granulometry was measured, and the aggregate was the same as the conventional concrete. The granulometry of the recycled aggregate, replacing the large aggregate, which originates from construction and demolition debris and from concrete debris is presented in Table 3.

Dosage of Materials: The ratio used to make both types of concrete, both conventional and recycled, was 1:2:3 (cement: sand: gravel). In the manufacture of recycled concrete, between 50 and 100% of the aggregate was replaced by the recycled aggregate. For this study, a total of 31 specimens were performed, cylindrical and in accordance with NBR 5738:2007, with dimensions 10 x 20 centimeters. 15 specimens of conventional concrete were molded to test their compressive and tensile strength and calculate their modulus of elasticity. For recycled concrete, it was replaced between 50 and 100% of the total aggregate by recycled under the same conditions of mixing, densification and curing of conventional concrete, thus being able to better compare the results of the two concretes. They were carried out 8 specimens exchanging 50% of the aggregate for the recycled aggregate and 8 specimens exchanging 100% of the aggregate for the recycled aggregate. To carry out the tests, the specimens were molded and placed in a tank provided by the university, so that the curing process could be done, and after 33 days, the tests were performed to determine the resistance of recycled concrete for structural works.

Compressive Strength: To measure the actual strength and know if certain concrete can be used for a given construction, it was determined from the compressive strength. For the performance of this assay, the recommendations, and definitions of NBR 5738:2003 and 5739:2007 were used, using cylindrical specimens, with a height equal to twice the diameter. The test was completed when it reached the rupture of the test body. Before the test, the specimens were rectifiedina company specialized in tests and preparations to determine the strength of the concrete.

Compression test on conventional concrete: After being cured for 33 days, the specimens were rectified, and the resistance tests continued. The axial compression resistance assay was carried out in the laboratory of civil construction materials of the Catholic University of Pernambuco, Brazil, and 8 specimens were tested to obtain the average of the resistances found. According to Table 1, it can be observed the loads applied on the specimens.

Table 1. Load applied in compression test

Test Body	Applied Load (KN)
First	182,71
2nd	200,22
Third	183,72
4th	205,34
5th	187,11
6th	191,04
7th	184,87
8th	185,97

Source: The Authors (2021).

It was still necessary to calculate the standard deviation of the samples. This deviation was calculated by the following steps:

- Calculates the average resistance (fcm) of the samples by the formula:

$$fcm = \sum_{i=1}^{n} \frac{fci}{n} \qquad (1)$$

- After the calculation of the resistance, a plot was calculation, which will help in the definition of the standard deviation:

$$(\boldsymbol{fci - fcm})^{\boldsymbol{2}} \qquad (\boldsymbol{2})$$

- To finish the calculation of the standard deviation, we found the variance (V), calculated by the formula:

$$V = \frac{\sum_{i=1}^{n}(fci - fcm)^2}{n-1} \qquad (3)$$

- After all these calculations is made the final calculation of the standard deviation (Sd):

$$Sd = \sqrt{V} \qquad (4)$$

- With the calculated standard deviation, it was possible to discover the fck of the concrete under study, using the following formula:

$$fck = fcm - 1{,}645xSd \qquad (5)$$

Compression test on 50% recycled concrete: After performing the tests related to conventional concrete, the concrete compression was performed with50% recycled aggregate. In this concrete, 50% of gravel was used as a big aggregate and 50% of recycled aggregate. The paste was maintained, and the type of aggregate was also the same as conventional concrete. Eight specimens were performed, replacing the recycled aggregate, and 4 of them were tested in the test the axial compression according to Table 2.

Table 2. Load applied in compression test

Body of proof	Load Applied (kN)
First	174,73
2nd	201,47
Third	181,52
4th	190,61

Source: The Authors (2021).

Compression test on 100% recycled concrete: Finally, the tests were carried out for concrete with 100% recycled aggregate, where the entire large aggregate was replaced by recycled aggregate, to obtain a result with the total exchange of the aggregate. As in the other two concretes, the paste was maintained and the type of aggregate kid as well. Eight specimens were performed, replacing the recycled aggregate, and 4 of them were tested in the test for axial compression, according to Table 3.

Table 3. Load applied in compression test

Body of proof	Load Applied (kN)
First	185,92
2nd	186,16
Third	196,16
4th	182,86

Source: The Authors (2021).

Tensile strength: In addition to the compression test, other tests were performed to better determine the parameters of comparison between conventional concrete and recycled concrete. The tensile test was based on NBR 7222:2010, and performed in the laboratory at the University, by diametrical compression. After positioning the test body in the machine that was used, the force was applied constantly until it ruptured.

The calculation of tensile strength is not done in the same way as compression, it will be done using the following formulas:

$$fctd = \frac{fctk,inf}{\gamma c} \quad (6)$$

Γc is the coefficient of reducing the strength of the concrete, being equal to 1.4 and the fctk, in f = 0.7 fctm, with the fctm equal to the mean tensile strength of the concrete, which is calculated from the following formula:

$$ctm = 0{,}3\sqrt[3]{fck^2}, \text{ if the} \leq 50 \text{ Mpa} fck \quad (7)$$

Traction test on conventional concrete: When the curing process was completed, which lasted 33 days, the conventional concrete was submitted to a diametric compression tensile test. The tensile strength test was carried out in the laboratory of civil construction materials of the Catholic University of Pernambuco, and 7 specimens were tested, finding the applied load and the tensile rupture resistance. TheTable4displays the applied loads.

Table 4. Load applied to diametriccompression tensile assay in conventional

Body of proof	Load Applied (kN)
First	93,08
2nd	86,95
Third	88,29
4th	80,69
5th	68,17
6th	69,16
7th	60,6

Source: The Authors (2021).

Traction test on recycled concrete at 50%: Following the same curing procedure of conventional concrete, the recycled concrete at 50%, passed 33 days, after its molding to be carried out the tests, one of which was traction by diametrical compression. The tensile strength test was carried out in the laboratory of civil construction materials of the University and 4 specimens were tested, finding the applied load and the tensile rupture resistance.

Table 5. Load applied to diametric compression tensile assay in conventional

Body of proof	Load Applied (kN)
First	59,36
2nd	45,97
Third	55,39
4th	45,49

Source: The Authors (2021).

Traction test on 100% recycled concrete: With the cure performed in the same 33 days of the previous concretes, the recycled concrete at100% was taken to perform the tests, one of which was traction by diametric compression. The tensile strength test was performed in the laboratory of civil construction materials of the University and 4 specimens were tested, finding the load applied according to Table 6.

Table 6. Load applied to diametric compression tensile assay in conventional

Body of proof	Load Applied (kN)
First	63,1
2nd	54,19
Third	45,73
4th	43,72

Source: The Authors (2021).

Modulus of Elasticity: After the compression and traction tests were performed to analyze the strength of a concrete, the calculation of the quality of elasticity of conventional concrete was performed, with 50% recycled aggregate and 100% recycled aggregate.

Modulus of elasticity of the concretes studied: According to the standard it is **possible to calculate the** modulus of elasticity of each concrete under study, using the fck found in previous calculations.

RESULTS AND DISCUSSION

Compression and tensile tests were performed for the three types of concrete, which is conventional concrete, (used in structural works) with certain cement and aggregate dosages; The concrete with 50% recycled aggregate, having the same proportion of cement paste and for the operation of kid aggregate, having been replaced only 50% of large aggregate; the concrete with 100% of a big aggregate, with the same characteristics as the other two concretes. The three concretes were submitted to the same procedures, curing, molding, storage as seen in the methodology. Table 7 shows the results of the compression and traction tests and modulation of the elasticity of the three concretes.

Table 7. Results of the tests and calculations of the concretes under study at 33 days

Concrete	Compressive Resistance (fck)	Tensile Resistance (fctd)	Modulus of Elasticity
conventional	22,4	1,20	26504
50% recycled	22,1	1,18	26326
100% recycled	22,7	1,20	26680

Source: The Authors (2021).

Therefore, it is found or whether the concretes in this study are classified as structural concrete or not. For this, it was necessary to compare with the structural concrete classes, given by the legislation in force. According to NBR 8953:2015, concrete can be classified according to its compressive strength into two groups, group I and group II. In addition, the standard also states that concretes with fck less than 20 Mpa are not considered structural and, if used, should follow NBR 6118/2014 and NBR 12655/2015.The Table 8 features the concrete class as well as its compressive strength. With this, it was possible to observe that the fck, which determines the characteristic compressive strength, is higher in concrete with 100% recycled aggregate, surpassing even conventional concrete, already tested in several other tests, to ensure its structural use.

The lowest was concrete with 50% recycled aggregate. Thus, the three concretes of this work, the conventional, the concrete at 50% and the concrete at 100% are classified in class I of structural concrete, according to the norm, being its fck greater than 20 Mpa. The result to traction was considered low, both of recycled concrete and of conventional concrete. These results to traction do not bring great news, since the lack of strength of concrete to traction is already known by several authors (BALBO, 2013; VIEIRA & MOLLIN, 2011), being improved with the implementation of steel bars.

Table 8. Structural concrete strength classes

Resistance Class Group 1	Characteristic compressed resistance (Mpa)	Resistance Class Group 2	Characteristic compressed resistance (Mpa)
C20	20	C55	55
C25	25	C60	60
C30	30	C65	70
C35	35	C70	80
C40	40	C75	90
C45	45	C80	100
C50	50		

Source: The Authors (2021).

According to TENÓRIO (2007), it is difficult to measure the compressive strength of recycled aggregates, because of the size for tests, thus being measured through the compressive strength of the concrete, performed with certain aggregates. Also according to the author, if the recycled concrete has lower compressive strength and if at the time of rupture, many grains appear ruptured, it is concluded that the aggregate strength is lower than the compressive strength of the same concrete. Regarding the modulus of elasticity, TENÓRIO (2007), says that it depends on the modulus of elasticity of the aggregate. In comparison with LIMA (1999), which presents different values, because its parameters and proportions of materials differ from the study of this study, it can still be concluded that, in general, recycled concretes have compressive strength less than or equal to that of conventional concrete, having the same cement consumption, being medium or high. With low cement consumption, it can present higher compressive strength than conventional ones. The author states that the difference between the two resistances will depend on the type of aggregate used, their quality and the consumption of cement. The author then divides the types of recycled aggregates into two large groups, those from ceramic recycled and those from recycled concrete.

CONCLUSIONS

The performance of this study allowed knowledge about the mechanical properties of concrete with recycled aggregates of construction and demolition waste. The two proportions used of recycled materials in two of the three concretes under study, showed whether the quantity of this is adequate and does not interfere, with much difference, the result of the characteristic strength to the compression of the concrete. Conventional concrete, widely used in structural works, has reached an expected result, with the appropriate proportions used, and the type of procedure. The recycled concrete at 50%, presented a fck lower than the conventional, but still, to be considered a structural concrete, according to the norm, having a fck greater than 20 Mpa. The recycled concrete at 100%, reached a fck higher than the conventional concrete, and a modulus of elasticity greater. According to the tests and calculations performed, it is noticed that the three concretes under study in this study obtained characteristic compressive strength greater than the limit to be considered structural concrete, fck greater than 20 Mpa. About tensile strength, it is already known that the concrete does not have a good result, being on average 10% of the characteristic compressive strength. In this case, the three concretes showed exceptionally low tensile strength, having to be combined with some other material, so that it can improve its traction performance, which is a reason for further studies, to know if the recycled aggregate would react well with steel intended to help in the tensile strength of concrete. Depending on the compressive strength of concrete, they can be used in structural works, requiring some additional studies to determine their total use in civil construction as structural concrete.

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