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MECHANICAL ANALYSIS OF CONCRETE PRODUCED WITH CDW AGGREGATES ASSOCIATED WITH THE USE OF BAMBOO

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ABSTRACT

In the current scenario, it is necessary to develop sustainable constructive practices. The use of Construction and Demolition Waste (CDW) is an alternative to minimize the environmental impacts caused by civil construction, because, in addition to exploiting many resources, this industry generates a lot of waste. In contrast, it is observed that there is a decrease in the compressive strength of concretes produced with CDW. In this sense, bamboo appears as a possibility to mitigate these losses, in view of its high mechanical resistance. In this way, this research had as general objective to analyze the influence of the use of bamboo on the compressive strength of concrete produced with CDW aggregates as coarse aggregate. A bibliographic research was done, followed by an experimental research, being molded and submitted to the compressive strength test concrete and bamboo specimens filled with concrete, both with the following variations in the substitution ratio of CDW aggregates: 0% (reference concrete), 25%, 50%, 75% and 100%. Bamboo samples were also submitted to the test without adding concrete. The main results of the research point to the gradual loss of compressive strength of the concrete, but the use of recycled aggregate for concrete production up to the percentage of 25% has proved feasible. In turn, the association of concrete with CDW to bamboo was insignificant, since the bamboo culm without concrete showed superior resistance. In addition, in the samples filled with concrete, there were no relevant variations in resistance according to the CDW content incorporated into the concrete.

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INTRODUCTION

The environmental issue is worrying more and more due to climate change and scarcity of natural resources. Civil construction is an industry that has a great impact in this regard, considering that it exploits many natural resources, as well as generates a significant amount of waste. According to Soto (2017), waste from civil construction represents around 50% of urban solid waste. Reusing these residues, that is, reinserting them in the production chain, is an alternative to minimize environmental impacts. To regulate the disposal of these residues in Brazil, there is the Resolution nº 307 of the National Council for the Environment - CONAMA (2002). It determines the proper disposal of Construction and Demolition Waste (CDW), establishing that these residues cannot be disposed of inurban solid waste landfills, in "throw away" areas, empty lots, on slopes, water bodies or in places protected by law. Recycled aggregates can be used to partially or completely substitution natural aggregates. However, the substitution of natural aggregate for recycled aggregate influences the strength of concrete, an extremely important property. According to Soutsos*et al.* (2004 *apud* SOTO, 2017), to maintain the strength of concrete with CDW identical to that of a conventional concrete, it is necessary to increase the consumption of cement. This is not feasible from both a financial and an environmental point of view, since in the cement production carbon gas (CO_2) is released. In view of this probable loss of resistance, the use of bamboo appears as a possible alternative to compensate for this deficit. Bamboo is a versatile material, which can be used in various ways, and has as its main characteristic its high mechanical resistance, essential for use in civil construction. The great advantage of the bamboo is its quick growth, reaching its ideal strength in a few years (AKINYEMI; OMONIYI, 2020). Given this context, the main objective of the research is to analyze the influence of the use of bamboo on the compressive strength of concrete produced with CDW aggregates as coarse aggregate. As specific objectives, it was sought: characterize the compressive strength of concrete according to the substitution content of natural aggregate for concrete recycled aggregate; define the percentage of substitution of CDW aggregate that presents the best mechanical performance; and evaluate the behavior of concrete with CDW associated with bamboo. For this, a bibliographic research was done on the study materials (CDW and bamboo), and following an experimental research, where CDW aggregates were made for molding and testing of concrete and bamboo specimens filled with concrete.

LITERATURE REVIEW

Construction and Demolition Waste (CDW): According to the Resolution nº 307 (CONAMA, 2002), Construction and Demolition Waste (CDW) is defined as the waste arising from construction, demolition, reforms, as well as those resulting from the movement and excavation of land. So, in general, it is the rubble/shrapnel of the works, as it is commonly called. The composition of the CDW, according to Mymrin*et al.* (2014), is approximately 49% concrete, 23% mortar, 26% brick and block sealing components and 2% deleterious materials (heavy metals, asbestos, paper, plastics, etc.). According to Rangel (2015), this heterogeneous characteristic of the CDW makes difficult its reuse of considerable form, complicating its transformation into recycled aggregates aiming at the partial or total replacement of natural aggregates for the concrete production. So, it is essential to start the process of transformation of the CDW from the construction site, making the correct sorting of the waste. According to Amario (2015) and Soares *et al.* (2014), irregular accumulation of the CDW can generate considerable environmental impacts, such as silting and clogging of water courses (rivers and lakes); constant flooding (due to the obstruction of water courses); waste of valuable materials; visual pollution and development of vectors harmful to public health. In addition, the absence of recycling of these wastes contributes to the depletion of natural resources, since, if the wastes were reused, the demand for new raw materials would be reduced.

Concrete with recycled aggregate: According to NBR 15116 (ABNT, 2004), recycled aggregate is the granular material derived from the recycling of construction waste, presenting technical characteristics for application in building and infrastructure works, among other engineering works. However, the production of concrete with recycled aggregates requires care, mainly due to the heterogeneity of the components of the CDW, which influences the properties of the concrete. The granulometric composition of the aggregates is an important variable that interferes at other properties of the concrete, such as water absorption, permeability, workability and mechanical resistance, besides to be fundamental for the concrete dosing. The CDW aggregates have a more irregular granulometry and a rougher texture, resulting in a lower concrete slump value, which, in turn, makes it necessary more cement paste to obtain concretes with good workability. This is due to the fact that there is a greater packaging between the particles of the recycled aggregates, in relation to the natural aggregate (LEITE, 2001 *apud* MOREIRA, 2010). Porosity is one of the properties that most differentiates CDW from natural aggregate. According to Andrade (2018), recycled aggregates are more porous than natural aggregates and, consequently, are more absorbent. According to Gómez-Soberón (2003 *apud* WERLE, 2010), for concrete CDW aggregates, the diameter of their pores is up to 40% larger than the pores of natural aggregates. Bravo *et al.* (2015) explains that water absorption is also related to the aggregate granulometry, and as the size of recycled aggregates decreases, absorption increases. Another factor inherent toabsorption is the substitution content of the aggregates, where a directly proportional relationship is observed, that is, the absorption is greater the higher the substitution content. Thus, due to the high absorption capacity of the CDW aggregates, some authors recommend that they be previously saturated, in order to prevent the aggregate from absorbing part of the water from the paste. Specific mass is also affected. According to Rangel (2015), recycled aggregates have a lower specific mass than natural aggregates, since the RCD has a more porous constitution. Because of this, consequently, concrete with recycled aggregate also has a lower specific mass, if compared to concrete with natural aggregate. About the compressive strength, there is an inversely proportional relationship between porosity and mechanical resistance. Dilbas, Şimşek and Çakir (2014) explain that the compressive strength of concrete with recycled aggregate decreases as the proportion of substitution of natural aggregates for recycled aggregates increases. Replacing 100% of natural aggregates for CDW aggregates can result in a loss of resistance of 20% to 30%, however, for a substitution content less than or equal to 20%, the resistance loss is low, around 5% (BARBUDO *et al*., 2013; VÁSQUEZ; HENDRIKS; JANSSEN, 2004 *apud* SOTO, 2017). Then, for the use of CDW in the concretes production it is necessary to pay attention to the loss of resistance. That said, this work analyzes concrete produced with CDW associated with bamboo, material discussed below.

The bamboo: As a plant, bamboo belongs to the family of Grasses (*Graminae* in Latin), as well as corn, and to the subfamily *Bambusoideae*. With regard to genus and species, according to Soares (2013), there are more than 90 genus and more than 1300 species around the world, most of which are located in tropical and subtropical locations, with the exception of Europe. Bamboo stands out for having an accelerated growth, being considered the fastest growing vegetable. Bamboo grows around 30% faster than most tree species, which guarantees a much higher yield than wood (VÉLEZ, 2001 *apud* SILVA, 2007). Throughout history, various materials have been used in civil construction, especially those easily found in nature. According to Silva (2005 *apud* PEIXOTO, 2008), in Asia, there are records of the bamboo use of approximately 5000 years, while in South America this application is more recent, a little more than 500 years. Chung and Yu (2002) and Lima Jr. *et al.* (2010) report that bamboo has been widely used for scaffold and platform assembly in Southeast Asia, mainly in Hong Kong and southern China, being able to exceed 20m in height. The first bamboo scaffold is believed to have been assembled about 5000 years ago (YU; CHUNG; CHAN, 2005). As for its properties, bamboo has as one of its main characteristics the high mechanical resistance, being able to overcome resistances of 60 MPa in compression and 250 MPa in traction, depending on the species, and allied to this it has low specific weight, about 850 kg/m³ (LIMA JR. *et al.*, 2010). In relation to the shear parallel to the fibers, the resistance increases from the bottom to the top, as well as the parts without knot present a higher resistance than those with knot. According to Ghavami and Marinho (2005), the average shear strength is 2.02 MPa. However, this shear strength parallel to the fibers is much lower than traction and compression. One of the most questioned factors about the use of bamboo is the question of durability. When the material is not treated correctly, many buildings made of bamboo and wood degrade in 2 to 3 years, however, there are constructions where bamboo has been applied to reinforce raw earth walls, which had a durability of more than 100 years (LOPEZ, 1974 *apud* LIMA JR.; WILLRICH; FABRO, 2005).According to López (1978 *apud* PEIXOTO, 2008), the insects that generally deteriorate and impair the resistance and durability of bamboo are *Dinoderusminutus F.*, called woodworm, and *Rhinastuslatisternus C.*, known as the bamboo borer. Thus, it is necessary to treat bamboo so that it presents a greater durability. But, this need for treatment is also common to other materials, such as steel (subject to oxidation) and concrete (requires waterproofing). Bamboo presents itself as an alternative raw material for civil construction, mainly due to the need to seek sustainable development, keeping in mind that it is a fast-growing renewable material with good mechanical properties. In addition, it is a versatile material, which can be used in isolation and/or associated with other materials.According to Peixoto (2008), combining bamboo with concrete, for example, is a way of providing greater stability and reduce the risk of crushing parts at strategic points, such as in the mooring/connection places, considering that the bamboo culm is hollow. From this point of view, this research focuses on analyzing the behavior of a concrete composite material produced with CDW aggregates and bamboo.

METODOLOGY

The experimental part was divided into 5 stages. First, bamboo and old concrete specimens were collected to make the CDW aggregate. The second stage consisted of crushing and screening of the waste, in addition to preparing the bamboo culms. The third was dedicated to the analysis of the CDW, carrying out granulometric and absorption tests. In the fourth stage, concrete and bamboo specimens filled with concrete were molded, both with substitution ratio of 0% (reference concrete), 25%, 50%, 75% and 100%. Finally, in the fifth stage, were done tests of compressive strength and analysis of the results.

Materials: For the production of concrete specimens with CDW aggregate and bamboo filled with concrete, the following materials were used: coarse natural and CDW aggregate; fine aggregate; Portland cement; water and bamboo. The natural coarse aggregate used in this research was obtained at a building material store in the city of Itaíba-PE, being classified as coarse aggregate nº 1. The recycled coarse aggregate, in turn, was obtained by crushing specimens collected in a construction in the city of Garanhuns-PE, which have an average compressive strength of 20 MPa, bearing in mind that the construction in question uses the construction method of concrete walls. The specimens were collected and transported to the materials and weighing laboratory of the Autarchy of Higher Education of Garanhuns (AESGA), where the crushing was done manually, trying to reduce the fragments of CDW to a granulometry close to that of the natural aggregate. After crushing, the material obtained (Figure 1) was sieved, being used for concrete production only the fraction passing through the sieve with a 25 mm opening and retained in the sieve with a 4.75 mm opening.

Figure 1. CDW Coarse aggregate

After making the CDW aggregate, granulometric tests were performed on the coarse aggregates, according to the recommendations of the standards NBR 7211 (ABNT, 2019) and NBR NM 248 (ABNT, 2003). In addition to the granulometric test, the coarse aggregate samples were also subjected to the absorption test, according to NBR NM 53 (ABNT, 2009). In relation to the fine aggregate, washed sand collected in the township of Itaíba-PE was used. As was done with the coarse aggregates, a granulometric test was also carried out with the fine aggregate, according to the recommendations of the standards NBR 7211 (ABNT, 2019) and NBR NM 248 (ABNT, 2003). For concrete production, Portland cement CP II-F-32 was used, which contains added of limestone filler, often used in the region, being a type of cement for general application. The water, in turn, came from the public supply network.

The bamboo used in the research was collected on the margins of the PE-177, in the township of Canhotinho-PE. During the collection, the culms were selected with diameters of approximately 10 cm (usual measurement of a concrete specimen). After collection, the bamboo culms were transported to the city of Garanhuns, where they were sawn at a height of 20 cm, excluding knots (Figure 2). Several specimens were obtained, however, for the experiment were selected 18, looking for the most similar, being 3 specimens to be analyzed without concrete and 15 with concrete, varying the substitution ratio of CDW aggregate.

Figure 2. Sawn bamboo culms

After these procedures, the bamboo was transported to AESGA's materials and weighing laboratory, where they went through a curing process, staying in the stove for about 50 minutes, at a temperature of approximately 100ºC.

Production of specimens: Concrete and bamboo specimens filled with concrete were made, both with variations in the substitution ratio of CDW aggregates. The following substitution ratio have been adopted: 0% (reference concrete), 25%, 50%, 75% and 100%. In the Table 1 is presented the number of specimens according to the percentage of CDW and material.

Table 1. Number of specimens

Material \ % Subst.	0% (REF)	25%	50%	75%	100%
Concrete	3	3	3	3	3
Concrete + Bamboo	3	3	3	3	3
Bamboo	3	-	-	-	-

Source: Authors (2020)

Before preparing the concrete, the trace was defined according to the IPT/EPUSP method. According to Leite (2001 *apud* MOREIRA, 2010), due to the more irregular and rougher granulometry of the CDW, concretes with this type of aggregate present a lower slump value, demanding a higher mortar contentmortar. Considering the dry material ratio of 1:6 and mortar content of 57%, the trace presented the following configuration: 1 : 2,99 : 3,01 : 0,66 (cement: sand : coarse aggregate: w/c). The CDW aggregates were previously saturated in water for about 10 minutes, since these aggregates tend to absorb a lot of water in the initial minutes, but this water was not considered in the water/cement ratio. In order to check the consistency and workability of the concrete, was made the concrete slump test. According to specifications of the NBR NM 67 (ABNT, 1998), the slump should be 100 mm ± 20 mm. The molding of the specimens was performed according to NBR 5738 (ABNT, 2015). Concrete specimens are 10 cm in diameter and 20 cm in height. Bamboo ones, in turn, have a variable diameter. In the case of bamboo specimens filled with concrete, the bamboo culms themselves functioned as a mold for the concrete. In the Figure 3 is showed the molded specimens.

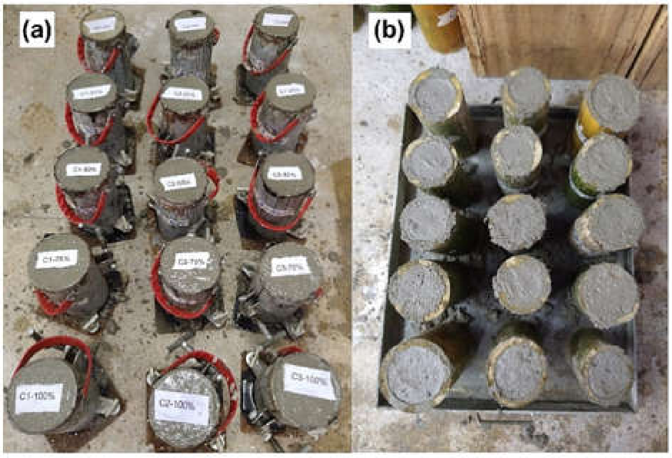

Figure 3. Specimens of (a) concreteand (b) bamboo filled with concrete

Before being filled with concrete, the molds were weighed for later determination of the specific mass of the concrete obtained. After filling, the molds were weighed again, the mass of the concrete being the difference between the mass of the filled mold and the mass of the empty mold. The concrete specimens were kept in moist curing until the day of the rupture, performed at 28 days.

Test methods: Seeking the objective of the work, which is to analyze the influence of the use of bamboo on the compressive strength of concretes produced with CDW aggregates as coarse aggregate, the main test performed was that of compressive strength, according to NBR 5739 (ABNT, 2018). But, as previously described, granulometric and absorption tests were also performed, according to standards NBR NM 248 (ABNT, 2003) and NBR NM 53 (ABNT, 2009), respectively.

RESULTS AND DISCUSSION

The granulometric and absorption tests were carried out with the aggregates before molding the specimens. During molding, the concrete molds were weighed for later determination of the specific mass of the concrete obtained according to the substitution content of CDW aggregate. In addition, the consistency of the concrete was evaluated by the slump test. Finally, the results for the compressive strength test are presented.

Granulometric test: The granulometry test was performed with fine and coarse aggregates. According to NBR 7211 (ABNT, 2019), the Maximum Characteristic Dimension corresponds to the sieve opening, in millimeters, where the aggregate has an accumulated retained percentage equal to or immediately below 5%. Thus, the Maximum Dimension of the fine aggregate was 2.36 mm, since in this sieve there was an accumulated retained percentage of 1.48%, and in the next sieve this value is already higher than 5%. The Fineness Module, in turn, is the sum of the accumulated retained percentage in the sieves of the normal series (in this case, the 6.3 mm sieve is excluded), divided by 100. So, the fineness module of the fine aggregate was 2.43, which characterizes it as an average sand, within the optimal zone (2.20 to 2.90), according to NBR 7211 (ABNT, 2019). In the Figure 4 is presented the granulometric curve of the fine aggregate. For comparison purposes, the inferior and superior limits defined by the NBR 7211 (ABNT, 2019) are also shown. As shown in Figure 4, in the initial sieves (with larger opening mesh) the fine aggregate was found within the usable zone. Soon afterwards, it followed the trend of the optimal zone, as confirmed by the Fineness Module. The non-occurrence of mass retained in the first sieves of the set can be attributed to the fact that a preliminary sieving of the sand was done, in order to eliminate the stones and possible impurities that were in it. For a better characterization of the materials used, coarse aggregates were also submitted to granulometric analysis. The CDW coarse aggregate presented a Maximum Diameter of 19 mm, because, in this sieve, it presented an accumulated retained percentage of 2.42% (immediately below 5%). Another information obtained was the Fineness Module, corresponding to 2.87. The natural coarse aggregate also presented a Maximum Diameter of 19mm, presenting, in this sieve, accumulated retained percentage of 4.05%. Already the Fineness Module corresponded to 2.93. The results of the granulometric test of coarse aggregates (CDW and natural) are summarized in Figure 5, where there are also the granulometric zones established by the NBR 7211 (ABNT, 2019).

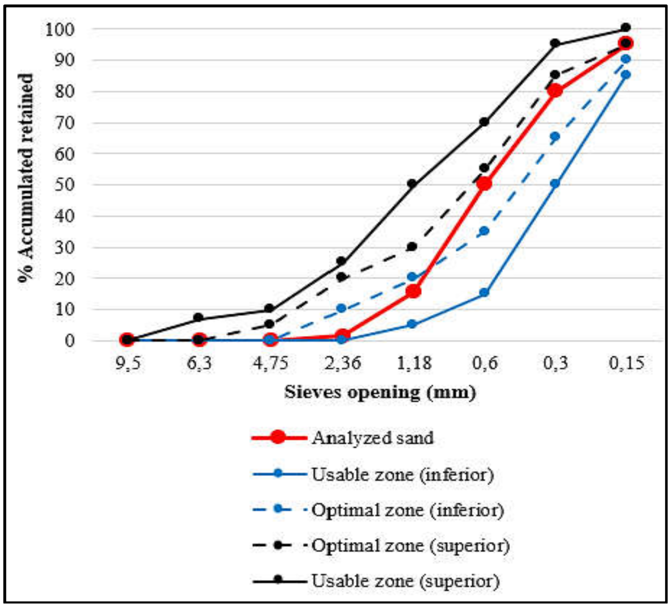

Figure 4. Fine aggregate granulometric curve

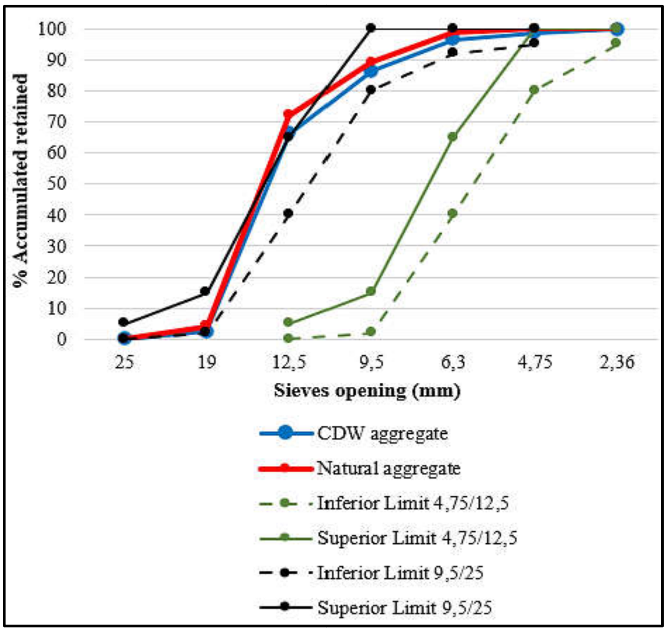

Figure 5. CDW and natural coarse aggregates granulometric curves

Based on Figure 5, it is observed that the two types of aggregates presented similar granulometries. Both followed the trend of the second granulometric zone d/D (9,5/25), expressing that the coarse aggregates have, mainly, diameters from 9.5mm to 25mm.In this way, these aggregates are classified as coarse aggregate nº 1.

Absorption test: The absorption test was performed with coarse aggregates, aiming to compare the natural aggregate with that of CDW. The results of the absorption of both are presented in Table 2.

Table 2. Absorption ratio of CDW and natural coarse aggregates

Aggregate	Absorption (%) in 24 hours
CDW	5.16
Natural	0.25

Source: Authors (2020)

Through Table 2, it is evident that the CDW has a high absorption content, if compared to the natural aggregate. Despite this, the CDW aggregate remained within the limit defined by NBR 15116 (ABNT, 2004), where the recycled coarse aggregate for the production of non-structural concrete must have an absorption equal to or less than 7%. In this research, the CDW absorption ratio was 5.16%. Andrade (2018) explains that recycled aggregates are more porous and have a greater specific surface area than natural ones and, consequently, have greater water absorption. For this reason, some authors recommend that the CDW aggregates be previously saturated, avoiding the absorption of water from the cement paste.

Slump Test: In the Figure 6 are shown the results for the concrete slump test.

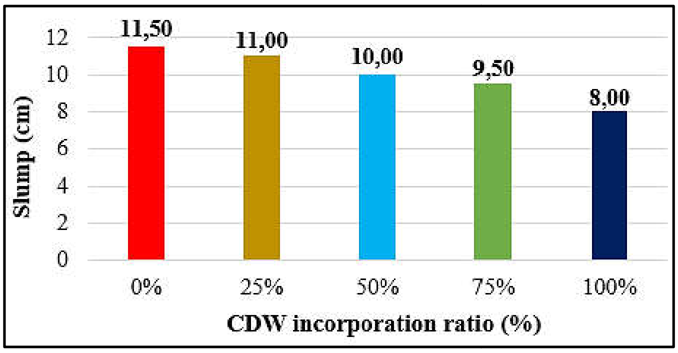

Figure 6. Concrete slump

Analyzing the graph of Figure 6, it can be seen that as the CDW aggregate substitution ratio increased, the concrete slump decreased. This behavior was expected, because, according to Leite (2001 *apud* MOREIRA, 2010), CDW aggregates present a rougher texture, leading to a lower concrete slump value. Thus, a higher mortar content is necessary to obtain concrete with good consistency and workability.

Specific mass of the concrete: The results of the specific mass of the concrete obtained as a function of the substitution content of recycled aggregate are shown in the graph of Figure 7.

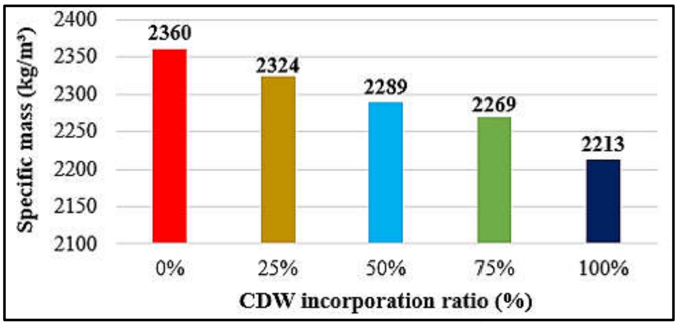

Figure 7. Specific mass of the concrete obtained

Through Figure 7, it is noted that there was a decrease in the specific mass of the concrete as the substitution content of CDW aggregate increased. The concrete with 100% of CDW had a specific mass about 6.2% lower than the reference concrete. According to Rangel (2015), recycled aggregates have a lower specific mass than natural ones, because CDW has a more porous constitution. This, consequently, reflects on the specific mass of the concrete produced with recycled aggregates. It should be noted that these values may vary, depending on the origin of the waste.

Compressive strength test: The results of the compressive strength of concrete and bamboo specimens filled with concrete are shown in the graph of Figure 8.

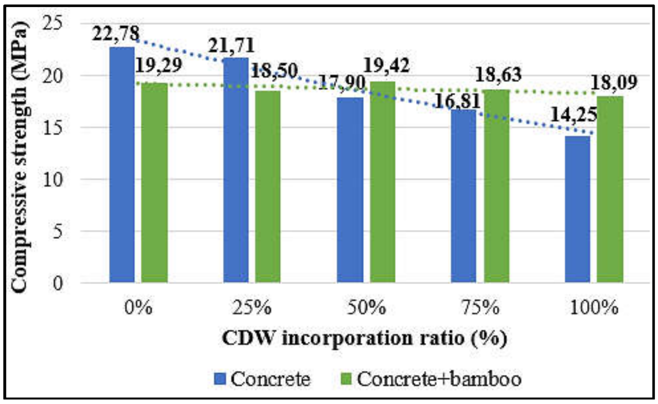

Figure 8. Results of the compressive strength test at 28 days

According to Figure 8, it is observed that as the CDW aggregate substitution content increased, the compressivestrength decreased. The replacement of 100% of the natural aggregate by CDW resulted in a decrease in strength of approximately 37%. However, the substitution of 25% resulted in a loss of strength of only 4.5%, proving to be viable the replacement of the natural aggregate by recycled up to this percentage. It was also evident that the addition of CDW to the concrete associated with bamboo was irrelevant, because there were not considerable variations in compressive strength according to the CDW content. In addition to the results of the concrete and bamboo specimens filled with concrete shown in Figure 8, 3 bamboo specimens were tested without adding concrete, presenting an average strength of 46.05 MPa, while in the bamboo-concrete composite material the greatest strength verified was 19.42 MPa. Therefore, the compressive strength parallel to bamboo fibers was greater than that of bamboo associated with concrete. Based on the analysis by Lima Jr. *et al.* (2010) on mixed bamboo-concrete pillars, it is observed that this behavior occurs due to the lateral expansion caused by the crushing of the concrete, since it presented reduced resistance compared to bamboo. In the Figure 9 is presented the ruptures of the bamboo culms without and with concrete filling, where it is possible to check details of the failure of the specimens.

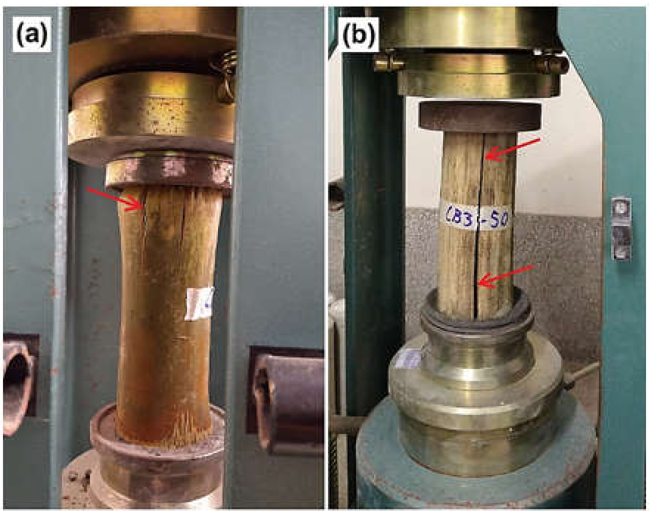

Figure 9. Rupture of (a) bamboo without concrete and (b) with concrete filling

Analyzing Figure 9, it is observed that in the bamboo culm without concrete, fissures parallel to the fibers appeared. In the bamboo with concrete filling, a larger longitudinal fissure appeared, going from one end to the other, characterizing a complete opening of the bamboo culm by the lateral expansion of the concrete. Then, in relation to compressive strength, the use of bamboo without concrete proved to be more efficient and economical.

CONCLUSIONS

Throughout this work, the need for research on sustainable construction materials and techniques was observed, bearing in mind that civil construction causes large environmental impacts by exploiting resources and generating a lot of waste. A viable way to reduce these impacts is to reuse the CDW for concrete production, in partial substitution of the natural aggregate. Based on granulometric tests with fine and coarse aggregates, it was verified that these aggregates presented granulometric compositions according to the limits determined in standard, showing that the CDW aggregate made in laboratory was similar to the natural one, in terms of granulometry. However, the absorption test showed the main difference between recycled and natural aggregates. While the natural aggregate had an absorption content of 0.25%, in the CDW this percentage was 5.16%. This is a consequence of the high porosity and greater specific surface area of the recycled aggregate. This high porosity also interfered with the specific mass of the concrete, because as the CDW incorporation ratio increased, the specific mass reduced. Concrete with 100% of CDW had a specific mass around 6.2% lower than that of conventional concrete. Regarding the compressive strength test, gradual loss of strength has been proven as the CDW substitution content has been increased. This loss of strength is also associated with the porosity of the recycled aggregate. Despite this, the concrete production with a percentage of recycled aggregate of up to 25% proved to be viable, since the resistance reduction was not high, staying around 4.5%. On the other hand, the substitution of 100% caused a significant loss, of approximately 37%. The use of concrete with CDW associated with bamboo, in turn, proved to be irrelevant, if the compressive strength obtained is considered, because, regardless of the substitution content of the CDW aggregate, the highest strength values were found in bamboo culms without concrete. It is suggested to analyze other variables linked to the bamboo-concrete composite material, such as shear and crush strength, as well as assessing the durability of these materials when combined.

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