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Evaluation of the replacement of commercial coarse aggregate by *Attalea funifera Martius* (Piaçava) in concrete manufacturing

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Abstract

In recent decades, technological advances and increased urbanization have instigated remarkable growth in the construction industry, and consequently an increase in environmental impacts both in obtaining raw materials and in the disposal of construction waste. Some studies are being carried out in Brazil for the application of natural fibers as a reinforcing element to produce concrete. According to these facts, the focus of this work is to comparatively evaluate the mechanical strength of commercial concrete with concrete produced with piaçava fiber sludge. Attalea funifera Martius, commonly known as piaçavas, is a solitary, thornless, erect, caulescent palm from the Aracaceae family. It reaches an average height of 8 to 15 meters with a stem diameter of 20 to 25 cm, having 8 to 10 leaves, each 9 meters long. Ten specimens were produced to carry out compression tests. Water, common Portland cement (CP I), sand, gravel and piassava obtained in the municipality of Barcelos-AM were used in the preparation. After curing the specimens, compression tests were carried out until the specimens ruptured. We also observed that the most resistant specimens were those produced with the addition of crushed stone, since the resistance of the specimen with crushed stone was approximately 22 MPa against 19 MPa of piaçava concrete. The main conclusions verified is that with the use of piaçava in the concrete mixture there is a drop in mechanical resistance, despite being a material *that presents resistance to cracks, it does not have the same capacity as concrete with gravel as a coarse aggregate.*

Keywords: Concrete, coarse aggregate, piassava, gravel, fiber, cement.

1. Introduction

In recent decades, technological advances and increased urbanization have instigated a remarkable growth in the construction industry, and consequently an increase in environmental impacts both in obtaining raw materials and in the disposal of construction waste [1].

It is estimated that civil construction consumes approximately 40% of electricity, 29% of raw materials from renewable and non-renewable sources, 25% of water, 16% of land and is responsible for about 30% of atmospheric emissions [2].

The concern with this exacerbated exploitation of natural resources and with the preservation of the environment, has been increasingly the agenda for research and development of new materials and techniques, with the reuse of waste from renewable, non-renewable sources, industrial, urban and waste even the civil construction itself [1].

According to [2], the intelligent use of natural resources by civil construction can solve, minimize or even mitigate the negative impacts generated by this sector. By reusing waste from plant extraction, reusing construction waste, replacing minerals with plants, among others.

As stated by [1], some studies are being carried out in Brazil for the application of natural fibers as a reinforcing element in the production of concrete. Among the fibers already researched, coconut fiber, sisal, sugarcane bagasse, bamboo and piaçava stand out. It should be noted that some studies carried out by the Federal University of Bahia demonstrate that piaçava has properties of high mechanical resistance, which make the fibers excellent options for reinforcing materials for various applications, bringing improvements to their properties and a higher level of safety, in its use.

Attalea funifera Martius, commonly known as piaçava (Figure 1), is a solitary, thornless, erect, caulescent palm from the *Aracaceae* family. It reaches an average height of 8 to 15 meters with a stem diameter of 20 to 25 cm, having 8 to 10 leaves, each 9 meters long. Piaçava, as it is popularly known, is a plant native to the southern region of Bahia, and can also be found in other regions of Brazil and the world. Its name originates from the Tupi language which means 'fibrous plant' [4].

Figure 1. Piaçava.

Source: Author, 2022.

Piaçava receives different names throughout its development. Until the age of 3, it is called Patioba; from 3 to 12 years old, it is called banana tree and it is at this time that piaçava fiber production begins (Figure 2); from 12 to 15 years, young coconut tree, where it reaches its maximum in height, making it difficult to extract the fiber; and after 15 years it is called old coconut tree, and in this phase the production of the fiber begins to gradually decrease, however up to 50 years it is still possible to extract it [4].

Figure 2. Young piaçava.

Source: Author, 2022.

There are three native species of piaçava in the Amazon, *Apandra natalia occurs* in the Juruá Valley (Acre, Brazil), in Peru and Ecuador; *Attalea funifera Mart*, is endemic to the Atlantic Forest biome, occurring on the coast of Bahia-BA, and *Leopoldinia piassaba Wallace*, endemic to the Amazon [5].

Piaçava fiber is the main product extracted from the piaçava tree. This material is collected only once along the year. An experienced extractivist can collect up to 45 Kilograms of piaçava per day, which is equivalent to approximately 30 Kilograms of clean material. A single foot yields 8 to 10 Kilograms of fiber per year. Depending on the species, piaçava fibers can reach up to 4 meters in length, with an impermeable, smooth, rigid texture and an average diameter of 1 millimeter [4].

After extraction, the process of combing the fibers is carried out, where all types of impurities are removed, such as dry branches, insects, cobwebs, brittle fibers, etc. After being combed, the fibers are tied into bales and shipped for sale, these bales are called by the extractivists as piraíbas (Barcelos region - AM) and weigh about 60 Kilograms. The material left over from the combing process is called dregs and can be sold to local artisans to make basketry and ornaments, and the rest is discarded (Figure 3) [5].

(A) (B) (C)

Figure 3. (A) Piaçava dregs; (B) Piraíbas after the combing process; (C) Piraíbas ready for sale.
Source: Author, 2022.

According to [4], the first records about piaçava date back to the 18th century in letters-reports made by Caminha, during his passage through Brazilian territory, in the region where Bahia is today, the place of origin of this palm tree.

However, even before the arrival of Portugal to Brazil, the native Indians of the region already used piaçava fiber to cover their houses, in ornaments and tools, but the use that most attracted the attention of the Portuguese people was the production of ropes made for navigation that did not degrade easily in salt water. Because they observed that piaçava fiber was a material with great mechanical rigidity, impermeability and resistance to saline water. In this way, fiber became one of the main exported products to Portugal between the years 1757 to 1860 [6].

With the great demand for this material and the incorrect management of the palm, in the 19th century, there was a significant drop in the production of piaçava. Thus, there was a drop in exportations, opening up space for other types of fiber to enter the market, yet the local market remained quite heated with the use of piaçava in the production of brooms, ropes and handicrafts. It was then from 1940 onwards that there was a gradual increase in the production of piaçava from 5,000 tons, reaching up to 60,000 tons in 1980. This shows that the largest consumer of piaçava is the domestic market [4].

Piaçava has been widely explored in civil construction due to its properties of high mechanical resistance, good thermal insulation and low density. In addition, piaçava can be used to replace synthetic fibers that cause great environmental impacts, allowing excellent performance in both structural and non-structural applications [7] [8].

In addition, piaçava has a high lignin and cellulose content, which gives it the characteristic of great resistance to water absorption, making the composite more resistant and an excellent solution for places with a tropical climate with a high incidence of rainfall [9], since it the composite becomes less prone to waterlogging and erosion processes [4].

Thus, the objective of this study is to evaluate the replacement of concrete with commercial coarse aggregate by piaçava composite concrete in civil construction, focusing on the mechanical resistance of commercial concrete with concrete produced with piaçava fiber sludge, from samples of concrete tested using commercial coarse aggregate and piaçava composite concrete with different concentrations, in addition to performing physical, mechanical and weathering tests of the concrete test specimens, evaluating the performance of different concentrations of the piaçava composite and scaling the viability of the cost-effectiveness of using piaçava composite in concrete for civil construction.

2. Materials and Method

All the procedures described in this topic were developed at the Construction Technology Laboratory (TECON) at the Faculdade Estácio do Amazonas. Ten specimens were produced to carry out compression tests. Table 1 shows the compositions of the prepared mixtures. Water, common Portland cement (CP I), sand, gravel and piaçava sludge were used in the preparation (Figure 4). We also used buckets for weighing the raw materials, a digital scale for weighing the material, an electric mixer for mixing, a cylindrical mold for drying the specimens and a hydraulic press for the compression tests (Figure 5).

Table 1. Preparation of specimens.

SAMPLES	DESCRIPTION	DIMENSIONS	CONCRETE COMPOSITION	CURING TIME
A B C D E	Concrete aggregated with gravel	10 cm diameter x 20 cm high	1 of Cement 2 of Sand 3 of Gravel 0.5 of water	30 days
F G H I J	Concrete aggregated with piassava	10 cm diameter x 20 cm high	1 Cement 2 Sand 2 Piaçava 0.5 of water	30 days

The piaçava sludge (Figure 4D) used was obtained from the city of Barcelos in the state of Amazonas, after manual extraction and combing of the fiber, about 5 Kilograms of sludge was collected, formed by pieces of fiber that break in the combing process and are also trimmed in the preparation of piraíbas, or that have flaws and are normally not marketed (Figure 3A).

First, all materials were weighed (Figure 5A) in separated buckets according to the proportions from Table 1, then the materials were added to the mixer (Figure 5C) and left stirring for 10 minutes for complete homogenization. After that, they were transferred to the cylindrical molds (figure 5B) and tapped a few times for better compaction of the aggregate and removal of air bubbles. The specimens were left to rest inside the mold for 30 days at room temperature until complete cure.

(A) (B) (C) (D)

Figure 4. (A) Sifted sand; (B) Brita; (C) CP I cement; (D) piaçava.
Source: Author, 2022.

(A) (B) (C)
(D)

Figure 5. (A) Digital scale; (B) Mold for specimen; (C) Electric concrete mixer; (D) Hydraulic press.
Source: Author, 2022.

After curing the specimens, compression tests were carried out (Figure 5D) until the specimens ruptured. The maximum pressure results now of rupture and the time until rupture was collected. For processing the results, Excel was used to calculate the mean and standard deviation (SD) and relative standard deviation (RSD) and to create graphs.

3. Results and Discussion

The results obtained in the compression test of the specimens are presented in Table 2. We can observe that the compression results as well as the time until the rupture of the specimens were approximate, which shows us the reproducibility of the test.

Table 2. Compression Results.

SAMPLES	TIME (s)	COMPRESSION (MPa)	AVERAGE (MPa)	SD	RSD (%)
A	8	21,32	21,82	0,5	2,1
B	9	22,45			
C	9	21,57			
D	9	21,63			
E	9	22,12			
F	6	17,56	18,83	1,1	5,8
G	7	19,76			
H	8	20,03			
I	7	18,90			
J	7	17,89			

As mentioned in Table 1, the specimens named from A to E were produced identically with a cementitious matrix aggregated from gravel and we obtained an average compression result of 21.82 MPa. The specimens named from F to J were prepared with the same composition, but piaçava was added instead of gravel, in this case, we observed a greater difference in the results with a relative standard deviation (RSD) of 5.8%, which indicates that the specimens prepared with piaçava were more unstable in terms of compressive strength. We can also verify that the average compression that the specimens with piaçava reached was 18.83 MPa, a result lower than that obtained with the tests of the specimens aggregated with gravel.

In figures 6 and 7 we can easily observe the compression results obtained for each group of specimens. The specimens that most resisted compression were B (aggregated with gravel) and H (aggregated with piassava), which presented, respectively, compression results of 22.45 MPa and 20.03 MPa. These results are very close, which indicates a great possibility of using piaçava sludge as a more profitable option for replacing commercial aggregates.

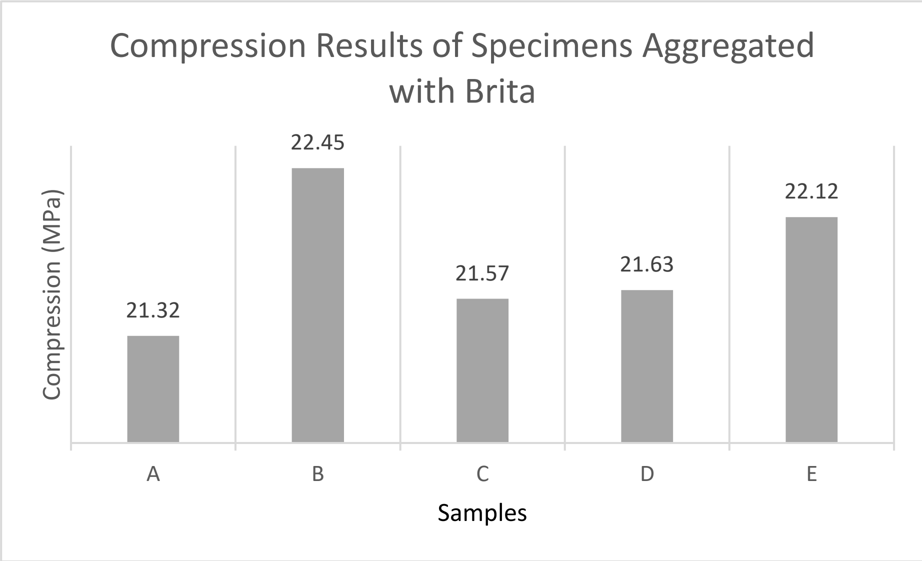

Figure 6. Compression results of aggregated concrete with gravel.

However, during the compression tests, we observed that the specimens prepared with piaçava had a much lower quality of appearance compared to the specimens prepared with gravel. We can visualize such characteristics in Figure 8, where we see that the specimen on the right (piaçava aggregate) presents a brittle appearance, empty spaces and deformities in its structure, while the specimen on the left (gravel aggregate) presents its structure complete and without flaws or voids.

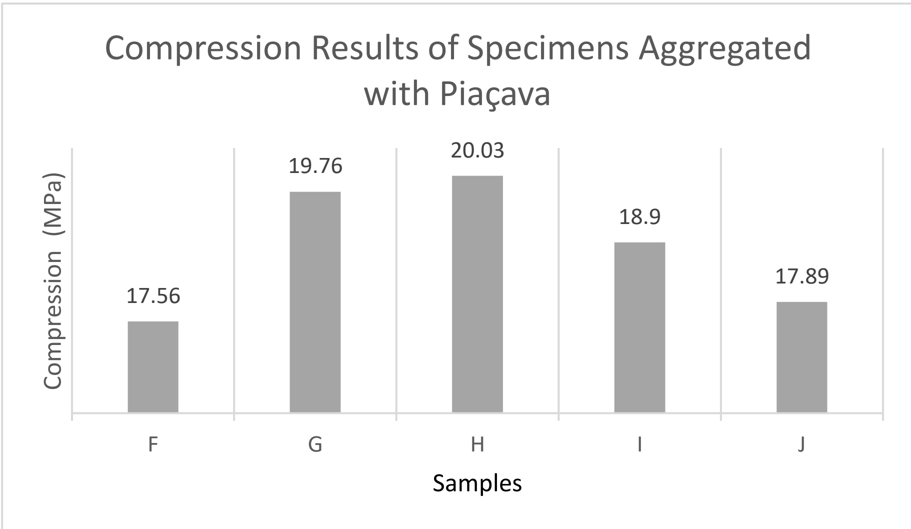

Figure 7: Compression results of aggregated concrete with piaçava.

According to that, we can attribute that the lower compression results for the specimens prepared with piaçava are due to the fact that the structure of the specimen presents structural flaws, deformities and failure in the adherence of the fiber in the cementitious matrix (Figure 8). Similar behavior was obtained in studies using fiber and reinforcement of industrial residues of copolymers such as EVA (ethylene-vinyl acetate) [1].
[10] we see that this characteristic of fragility of the material plus natural fibers is repeated, also affecting the results of resistance to tension and elongation and we can also notice that the amount of fiber added is again

an important factor in the evaluation of the composite strength. Due to this fact, it is suggested the execution of a physical-chemical treatment of the fiber before the preparation of the composite, which, as evidenced by [11], changes the properties of the fiber and improves the structure and appearance of the composite.

Figure 8. Specimen Models.
Source: Author, 2022.

In Figure 9, we have the comparison of the average of the compression results obtained for each evaluated composite, we can see, in this way, the disparity of the compression results. In fact, the most important aspect in the results obtained was the structural deformation suffered by the composite added with piassava. We can discuss the need to carry out future studies with the evaluation of different composition proportions of piaçava as well as the possibility of chemical treatments of the fiber surface that allow a better adhesion at the fiber/matrix interface, such as, for example, the study carried out by [11].

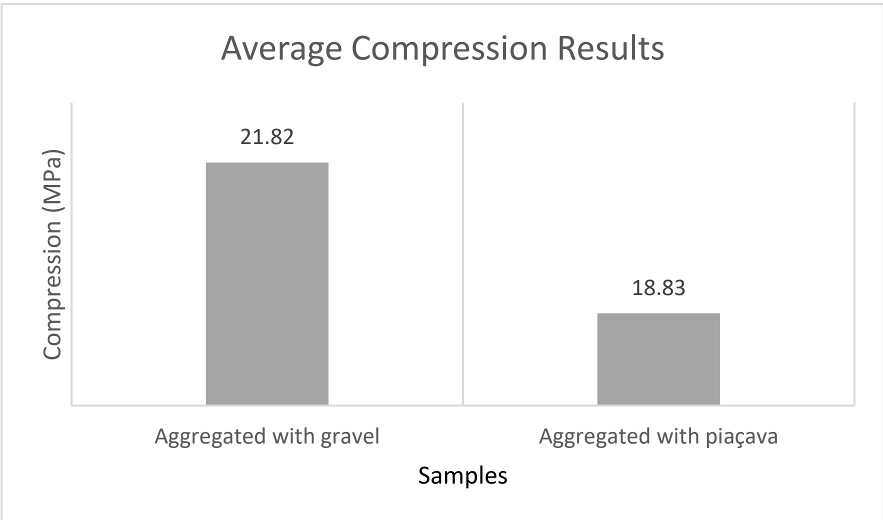

Figure 9: Comparison of the average compression results of the two types of concrete.

We can also mention other variables that interfere with the results obtained, such as the drying temperature, since it is a determining factor for the drying time and the ambient humidity, that is, temperature variations can increase or decrease the drying time composite, so the curing time also becomes a determining factor in the quality of the results. In addition, piaçava is a normally hygroscopic lignocellulosic fiber that can resist adherence in the cementitious matrix, which in most cases is hydrophobic.

4. Conclusion

Based on the process shown, we conclude that with the addition of piaçava sludge in the concrete composite there is a significant reduction in the mechanical resistance to compression due to structural failures presented by the specimen after curing. However, piaçava is a well-explored material and it is already known that it has high mechanical resistance and does not degrade easily with humidity. In addition to the tests carried out, we saw that the time until failure was approximate in comparison with the two verified compositions, which shows that piaçava can be used as an aggregate, for purposes where less demand is made on concrete in terms of compression.

We also concluded that the tests showed high reproducibility since the relative standard deviation was low and, therefore, the results were approximated for each composition group analyzed. However, as previously mentioned, the specimens prepared with piaçava sludge showed deformations and structural failures, which caused the results to have a higher relative standard deviation.

Thus, we suggest in future works the performance of compression tests with specimens that have different concentrations of fiber in the composite preparation, to verify which combinations of this material presents better resistance results. We also suggest the previous physical-chemical treatment of the fiber to improve its adhesion at the interface of the cementitious matrix.

We can emphasize the need for research for the development of new cementitious composites composed with piaçava fibers based on the potentialities presented in this study, in this way being able to reach its maximum potential, in terms of properties, resistance and degradation to humidity that must be brought to the construction civilian in modernity.

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