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ORIGINAL ARTICLE

Study of the potentiality of murumuru husk ash, an amazonian agroindustrial waste, as a filler to structural concrete

Estudo da potencialidade da cinza da casca do murumuru, um resíduo agroindustrial amazônico, como filler ao concreto estrutural

Milleno Ramos de Souza[a]
Marcelo Rassy Teixeira[a]
Luciana de Nazaré Pinheiro Cordeiro[a]
Fernanda dos Santos Sousa[a]
Andrey da Costa Gonçalves[a]
Arudá Gomes Vieira Filho[a]

[a]Universidade Federal do Pará – UFPA, Núcleo de Desenvolvimento Amazônico em Engenharia, Programa de Pós-graduação em Engenharia de Infraestrutura e Desenvolvimento Energético, Tucuruí, PA, Brasil

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Abstract: This research paper focuses on the use of murumuru husk ash (MHA), an agro-industrial waste generated specifically in the Amazon region, as partial replacement of cement in structural concrete. It also evaluates the physical, chemical and mineralogical characteristics of the ash to act as filler in concrete and its properties in the fresh and hardened states in concrete. To this end, the MHA performed physical-mechanical characterization tests, such as specific mass, pozzolanic activity with Portland cement, pozzolanic activity with lime, and BET test, also performing the mineralogical and chemical analysis of the ash. The results showed that there is technical feasibility with partial replacement of 6% of MHA in cement using plasticizer additive to improve workability, thus showing an improvement in the physical-mechanical and durability properties of the concrete.

Keywords: waste, concrete, filler, ash, murumuru.

Resumo: O estudo objetiva pesquisar o uso da cinza da casca do murumuru (CCM), um resíduo agroindustrial gerado especificamente na região amazônica como substituição parcial do cimento no concreto estrutural e avaliar as características fisicas, químicas e mineralógicas da cinza para atuação como *filler* no concreto, além de suas propriedades no estado fresco e endurecido no concreto. Com esse intuito, o CCM passou pelos ensaios de caracterização físico-mecânicas como o de massa específica, atividade pozolânica com cimento Portland, atividade pozolânica com a cal e ensaio de BET, realizando-se também as análises mineralógicas e químicas da cinza. Os resultados mostraram que existe uma viabilidade técnica com substituição parcial de 6% de CCM no cimento, utilizando-se aditivo plastificante para melhorar a trabalhabilidade, mostrando uma melhora nas propriedades físico-mecânicas e de durabilidade do concreto.

Palavras-chave: resíduo, concreto, filler, cinza, murumuru.

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Corresponding author: Milleno Ramos de Souza. E-mail: millenoramos@gmail.com
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1 INTRODUCTION

The diminishing natural resources and inadequate final disposal of residues has raised concerns in the technical scientific environment, thus driving the search for sustainable solutions.

Increasing concerns about environmental problems caused by aggregate production and destruction, and by insufficient storage area for the generated waste, have led many countries to consider waste reuse and recycling, and many studies have been conducted on these topics [1].

This growing global concern with energy and material consumption in the construction industry has sparked increased interest in the use of organic-based materials in recent years. In addition to that, organic-based building materials can provide several advantages, such as improved thermal insulation, remarkable improvement of concrete mechanics, weight reduction in regular building structures, besides being environment-friendly with respect to waste reuse [2].

The construction sector is one that most uses natural resources, with precious resources being reduced every year, in addition to the environmental damage caused by the extraction of said resources. The construction industry is also responsible for generating a great amount of solid waste, the so-called construction waste, many times with inadequate final disposal [3].

The agricultural sector produces a vast number of different wastes, which can be studied for the application in the construction industry. One such waste, considered in the herein paper, the murumuru husk ash (MHA), can serve as filler material in concrete.

It is expected that this waste can act as a filler material in the concrete by improving the properties in the fresh and hardened states. This paper reports the analyses of the physical, chemical, and mineralogical characteristics of the MHA, and how this waste material can contribute positively when mixed into concrete.

2 LITERATURE REVIEW

The relevant topics of the literature review are presented. Initially, the materials traditionally used as a partial substitute for cement in concrete production are described. Then, the concepts of using agro-industrial wastes in concrete mixes and their effects are assessed. Finally, tests used to characterize other materials and agro-industrial wastes are described, which are also adopted to characterize the murumuru husk ash (MHA) reported herein.

2.1 Materials added as a substitute for cement in the production of concrete

The cement industry strives to mitigate CO_2 emissions from cement materials. The most common strategy to reduce the environmental impact of concrete is to reduce the clinker content in the cement by incorporating filler during the grinding of Portland clinker, which results in decreased energy consumption and greater conservation of natural resources.

Various supplementary cementitious materials, whether natural pozzolans or those derived from industrial by-product waste materials such as silica fume, fly ash, and blast furnace slag, have been used for many years to develop blended cements not only to reduce environmental damage but also to improve concrete durability [4].

To ensure that cement-based concrete is a sustainable competitive material, it is necessary, in the near future, to make use of new sustainable materials in cement [5].

2.2 The effect of agricultural waste on concrete performance

Concrete performance varies according to what is added to the mixture. Each addition can induce properties that are beneficial to its performance as well as undesirable characteristics. Several concrete mixtures were evaluated with agro-industrial residues, such as rice husk, sugar cane bagasse, sawdust, banana fiber, among other residues, incorporated as ashes or fibers.

Among the residues from biomass combustion, rice husk ash is the topic of a large amount of research related to mechanical strength and durability of concrete [6]. The study by Qureshi et al. [7] showed that rice husk residue, along with silica fume, improves the rheological properties of concrete by reducing the demand for admixtures and reduces the water requirement to achieve the desired workability. It is reported that rice husk residue showed a higher filler effect when compared to fly ash, which means that rice husk residue can improve the packing density of the binder better than fly ash. Reference [8] relates the high reactivity of rice husk residue to its high specific surface area compared to that of fly ash. They also reported that rice husk residue showed a better filler effect than fly ash, which means that rice husk residue can improve the packing density of the binder better than fly ash.

In the study by Arif et al. [9], bagasse ash has dominant filler effect in concrete from a greatly reduced pozzolanic activity because of the polymorphic phase changes from quartz to α-quartz, rather than the often reported a-crystallite to bagasse-derived silica. The sugarcane bagasse ash used as filler in concretes provided substantial improvements in compressive strength also up to 20%. Reference [10] also shows that the addition of sugar cane ash improved concrete properties, such as the mechanical properties, decrease of pores and so on.

Processing of the açaí stone residue with the Blaine specific surface and the appropriate unit mass and a good grinding time, provides a physical action that optimizes the concrete produced with this addition. Grain shape and/or variation in particle size typically provide greater compactness where the finer residue particles tend to fill the voids between the larger fractions, thus optimize grain packing [11].

When using cashew nut residue in concrete, the slump decreases as more of this residue is added. This effect is due to the fine particles, smaller particle size and specific weight, and high specific surface area of the cashew nut shell residue compared to regular Portland cement. These properties increase water demand due to a larger volume. The result is a highly cohesive and impermeable concrete, thus reducing the slump on the fresh concrete [12].

Reference [13] reports the analysis of fresh state concretes by incorporating the mixture of saturated and dry eucalyptus bark, whereby the mixture with saturated bark shows a slight increase in its slump of 8 cm, compared to the reference concrete with 7-cm slump. However, this value is within the allowable range of variation and, therefore, is not necessarily associated with the added fiber. On the other hand, the incorporation of dry fiber showed no variation in relation to the reference concrete, i.e. with the slump within acceptable limits for a concrete.

2.3 Murumuru

The murumuru palm is abundant in the Amazon Region, growing preferentially in periodically flooded areas, especially on islands and lowlands along the rivers, throughout the Amazon River estuary and its tributaries, extending to the border with Bolivia and Peru [14].

Currently, the cosmetic and pharmaceutical markets have been responsible for most of the consumption of this raw material, and the production of Amazonian oils is developing rapidly. Andiroba and cupuaçu seeds and murumuru and buriti pulp are, for example, generating income for native communities and feeding national and multinational industries [15].

Despite its economic potential, the species is poorly exploited commercially, probably due to the difficulty in handling it, since it has many thorns. Currently, there are products on the market that use oils extracted from its fruits as raw material [16].

3 MATERIALS AND EXPERIMENTAL PROGRAM

3.1 Materials

The cement used in this research was Portland Cement CP-II-F 32 agglutinant because it is widely used in the region and its physical properties presented in Tables 1 and 2. The fine aggregate used is washed quartz sand. Table 3 shows the methods adopted in the characterization of the sand. The coarse aggregate is a granite gravel, with properties shown in Table 4. The admixture used to produce the concretes was a plasticizer based on liquid. The murumuru husk ash was incorporated as a partial substitute for cement.

Table 1 - Physical Properties – CP II-F-32

CP II-F 32									
Physical tests	**Blaine (cm^2/g)**	**Initial setting time (h:min)**	**End setting time (h:min)**	**Sieve fineness # 200 (%)**	**Sieve fineness # 325 (%)**	**Hot expandability (mm)**	**Normal consistency (%)**	**7-day compressive strength (MPa)**	**28-day compressive strength (MPa)**
Provided	–	$\geq$1	$\leq$12	$\leq$8.0	–	$\leq$5.0	–	$\geq$20.0	$\geq$32.0
Standards	NBR NM 76	NBR NM 65	NBR NM 65	NBR 11579	NBR 9202	NBR 11582	NBR NM 43	NBR 7215	NBR 7215

Table 2 - Chemical Composition-CP II-F-32

CP II-F 32										
Chemical Tests	**Loss on Ignition (%)**	**Insoluble residue (%)**	**Sulfur trioxide – SO_3 (%)**	**Free calcium oxide – CaO Livre (%)**	**Magnesium oxide – MgO (%)**	**Aluminum oxide – Al_2O_3 (%)**	**Silicon oxide – SiO_2 (%)**	**Iron Oxide – Fe_2O_3 (%)**	**Calcium Oxide – CaO (%)**	**Alkaline equivalent (%)**
Provided	≤4.5	–	≤4.0	–	≤6.5	–	–	–	–	–
Standards	NBR 5743	NBR 5744	NBR 5745	NBR 7227	NBR 9203	NBR 9203	NBR 9203	NBR 9203	NBR 9203	–

Table 3 - Physical characteristics of natural and standard washed sand IPT

Testing	Method	Results	
		Washed sand	Standard sand IPT
Maximum diameter (mm)	NBR 17054 (2022)	1.19	-
Fineness modulus	NBR 17054 (2022)	2.11	-
Specific mass (g/cm^3)	NBR 16916(2021)	2.67	-
Unit mass (g/cm^3)	NBR 16972(2021)	1.58	-
Water absorption (%)	NBR 16916(2021)	0.27	-
Silica content (%)	NBR 7214 (2014)	-	96.4
Granulometry-Fraction 16 – 2.4 mm e 2.0 mm (%)			6
Granulometry-Fraction 16 – 2.0 mm e 1.2 mm (%)	NBR 7214 (2014)	-	92
Granulometry-Fraction 30 – 1.2 mm e 0.6 mm (%)	NBR 7214 (2014)	-	98
Granulometry-Fraction 50 – 0.6 mm e 0.3 mm (%)	NBR 7214 (2014)	-	97
Granulometry-Fraction 100 – 0.3 mm e 0.15 mm (%)	NBR 7214 (2014)	-	97
moisture (%, in mass)	NBR 7214 (2014)	-	0
Organic matter	NBR 7214 (2014)	-	< 100 ppm

Table 4 - Physical characteristics of the coarse aggregate gravel

Testing	Method	Results
Maximum diameter (mm)	NBR 17054 (2022)	19.00
Fineness modulus (%)	NBR 17054 (2022)	6.87
Specific mass (g/cm^3)	NBR 16917(2021)	2.80
Water absorption (%)	NBR 16916(2021)	0.47
Unit mass (g/cm^3)	NBR 16972(2021)	1.51

3.2 Methods

3.2.1 Beneficiation of the waste

The murumuru husk ash was obtained by calcination in a bakery oven, which reaches an average temperature of 200°C without burning control. This is a practice adopted in the region in order to reduce the volume of waste.

Then the residue was grinded and the ash sieved through a 75 µm mesh, drying, obtaining in the process a little more than 3kg of residue for the analyses.

3.2.1 Characterization of murumuru husk ash

Because murumuru husk ash (MHA) is a residue not previously studied as a filler, the specific mass was determined for its application in cementitious matrices, in addition to other physical, chemical, and mineralogical analyses.

3.2.2.1 Physical-mechanical characterization

To determine the physical and mechanical characteristics of murumuru husk ash the tests presented in Table 5 were performed, following the normative recommendations and the methodologies recommended in the literature.

Table 5 - Adopted Physical Tests

	Testing	No. of samples	Methods	Objective
Physical-mechanical characterization of the MHA	Specific mass	1 sample analysis.	NBR 16605	For use in determining the Pozzolanicity indices, in the preparing the trace and to see the degree of density of the waste.
	Specific surface	1 sample analysis	Nitrogen adsorption (BET)	Determine the porosity that can affect the expected performance.
	Pozzolanic Activity Index (PAI) with cement at 28 days	6 specimens for each control	NBR 5752	Indicate, by mechanical testing, the degree of Pozzolanicity of the residue, at 28 days for mixtures with cement and 7 days for lime mixtures.
	Pozzolanic Activity Index (PAI) with lime at 7 days	3 specimens by sample.	NBR 5751	

3.2.2.2 Morphological, mineralogical and chemical characterization

Morphological analysis was performed using the Scanning Electron Microscopy (SEM) technique for high magnification with high image resolution together with Energy Dispersive Spectroscopy (EDS) for accurately determining the chemical composition of the ash. In the mineralogical analysis, the X-ray diffractometry (XRD) technique was used, which has a qualitative and/or quantitative character based on the identification of the crystalline phases contained in the analyzed material. For chemical analysis, the ashes were submitted to the X-ray Fluorescence Spectrometry (XRF) assay for the identification and quantification of the chemical elements present in a semi-quantitative way in the form of oxides. The chemical analysis of loss on fire and carbon content was also performed.

All these analyses are summarized in Table 6. These procedures are similar to normative recommendations and methodologies used in other studies with ash of agroindustrial residues.

Table 6 - Morphological, mineralogical and chemical tests adopted

	Testing	No. of samples	Methods	Objective
Chemical, mineralogical and morphological characterization	Chemical analysis	1 sample analysis	XRF	Determine the elementary composition of the material.
	Mineralogical analysis	1 sample analysis	XRD	Identify and quantify crystalline phases in the analyzed sample.
	Morphological analysis	1 sample analysis	SEM/EDS	Make a semi-quantitative analysis to allow identifying the chemical elements present in the ash.
	Morphological analysis	1 sample analysis of each ash concrete content.	SEM	Make a semi-quantitative analysis to allow identifying the chemical elements present in the concrete with and without ash.
	Chemical analysis	1 sample analysis	Loss on ignition by IT LAB 17 e 162	Determine mass loss when subjected to heating thermal cycle.
	Chemical analysis	1 sample analysis	Carbon content by ASTM E 1019	Evaluate the amount of carbon not burned.

3.2.3 Concrete Mixing and Production

This study aimed to design a concrete mix for structural use. Based on Sousa (2019), the reference mix ratio of 1:1.6:2.4 (by mass) was used, with a w/c ratio of 0.43 and a characteristic strength of 30 MPa. The study aims to analyze the effect of ash replacement in the behavior of this concrete. The replacement levels adopted were 6%, 9%, and 13%. These amounts were chosen based on previous research with agroindustrial residues that showed satisfactory performance in mechanical terms for this type of concrete, proportions based on cashew nut shell studies [12], of açaí stone as an addition in concrete [11] and of sugarcane bagasse ash in concrete [17].

The mixtures were made in a tilted-shaft concrete mixer with a capacity of 80 L. The order of mixing the materials started with coarse aggregate, part of the water already with the admixture, mixing them in the concrete mixer for 3 minutes, then resting the mixer for 3 minutes, then adding the fine aggregate, then placing the cement previously mixed with MHA residue (for mixes with ash contents), and lastly adding water remaining with plasticizer additive, fixing the mixing time. Table 7 presents the quantities of materials used in the specimens with and without MHA in kg/m^3.

Table 7 - Nomenclature of the mix and composition of concrete with MHA by mass

MHA content	0%	6%	9%	13%
Designation concrete mix	**S-MHA-0**	**S-MHA-6**	**S-MHA-9**	**S-MHA-13**
Cement (kg / m^3)	485.16	470.61	460.90	451.20
Total water (kg / m^3)	208.62	208.62	208.62	208.62
Water / cement (w/c)	0.43	0.43	0.43	0.43
MHA (kg / m^3)	0	7.79	12.99	18.19
Sand (kg / m^3)	776.26	776.26	776.26	776.26
Gravel (kg / m^3)	1164.40	1164.40	1164.40	1164.40
1% additive content in relation to cement mass.	4.85	4.71	4.61	4.51

3.2.4 Evaluation of the effect of MHA on fresh concrete properties

For the study of concrete in the fresh state, with the ash and ash-free contents, the tests presented in table 8 were performed, following the recommendations and the methodologies recommended by the literature. These tests are performed right after the concrete has been made in the concrete mixer.

Table 8 - Fresh concrete testing

	Testing	No. of samples	Methods	Objective
Testing fresh concrete properties	Concrete cone slump (Slump test)	1 analysis by MHA content in cement	NBR 16889	Analyze the consistency and workability of concrete.
	Specific mass	1 analysis by MHA content in cement	NBR 9833	Evaluate the specific mass of concrete without and with ash content.

3.2.5 Evaluation of the effect of MHA on concrete properties in the hardened state

In the study of concrete in the hardened state with and without ash, the tests presented in Table 9 were performed. After molding, the specimens were cured in the humid chamber, while observing the number of days for each type of test, according to the related standard method.

Table 9 - Concrete testing in the hardened state

	Testing	No. of samples	Methods	Objective
Testing concrete properties in the hardened state	Specific mass	3 specimens for each concrete mix	NBR 9778	Evaluate the specific mass of concrete without and with ash content.
	Compressive strength	3 specimens for each concrete mix	NBR 5739	Check the maximum stress that the concrete will resist before rupturing.
	Tensile strength by diametral compression	3 specimens for each concrete mix	NBR 7222	Check and measure the load for which cracking of the concrete occurs.
	Absorption by capillarity	3 specimens for each concrete mix	NBR 9779	Analyze the degree of porosity of the concrete.
	Modulus of Elasticity	3 specimens for each concrete mix	NBR 8522	Analyze the concrete deformation, observing the degree of deformation.

4 RESULTS AND DISCUSSIONS

4.1 Characterization of waste

4.1.1 Physical-mechanical characterization

In Table 10, the physical-mechanical test results are presented and compared with the properties of the cement to be partially replaced. These parameters are important to analyze the potential of MHA in structural concrete.

Table 10 - Result of the physical-mechanical tests

	Testing	MHA Result	Results for CP II-F Cement
Physical-mechanical characterization of the MHA	Specific Mass (g/cm³)	1.50	2.80
	Specific surface BET (cm²/g)	616,620	13,920
	Pozzolanic Activity Index (PAI) with cement at 28 days	**MHA Result**	**NBR 12653**
		96.72%	≥90%
	Pozzolanic Activity Index (PAI) with cement at 28 days	0.09 MPa	6 MPa

As presented in the table above, the value of the actual specific mass of the MHA is lower than some agricultural residues previously researched, such as sugarcane bagasse ash 2,720 kg/m³ [10] and rice husk ash 2,400 kg/m³ [18] and also lower than that of the survey cement, which is 2,800 kg/m³, meaning the production of lighter concretes.

It can be seen that the BET surface area of the MHA particles resulted in higher values compared to the partially replaced cement (CP-II F 32), which has a BET surface area of 1.39 m²/g. This explains the higher water demand and the loss of workability the higher the ash content in the concrete, which demonstrates the need for plasticizer admixtures to improve workability in concrete.

The values presented in the pozzolanic activity with Portland cement show that this ash has pozzolanic activity according to the NBR 12.653 standard, where it must have at least 90% of the total of the reference mixture at 28 days. This can positively influence the strength of concrete and its durability, by increasing impermeability.

As for the result presented for pozzolanic activity with lime, where it was possible to demold without disintegration of the specimens, the result of the average tensile strength of the specimens showed a low resistance, well below the 6.00 MPa required by NBR 12653, considering a non-pozzolanic material for this aspect.

4.1.2 Morphological Analysis (SEM-EDS) of the MHA

In Figure 1, it can be seen that the particles vary in size with a more porous and lamellar appearance, and this should influence the workability of concrete by decreasing this property, thus increasing the demand for water, which was noticed during the development of the research.

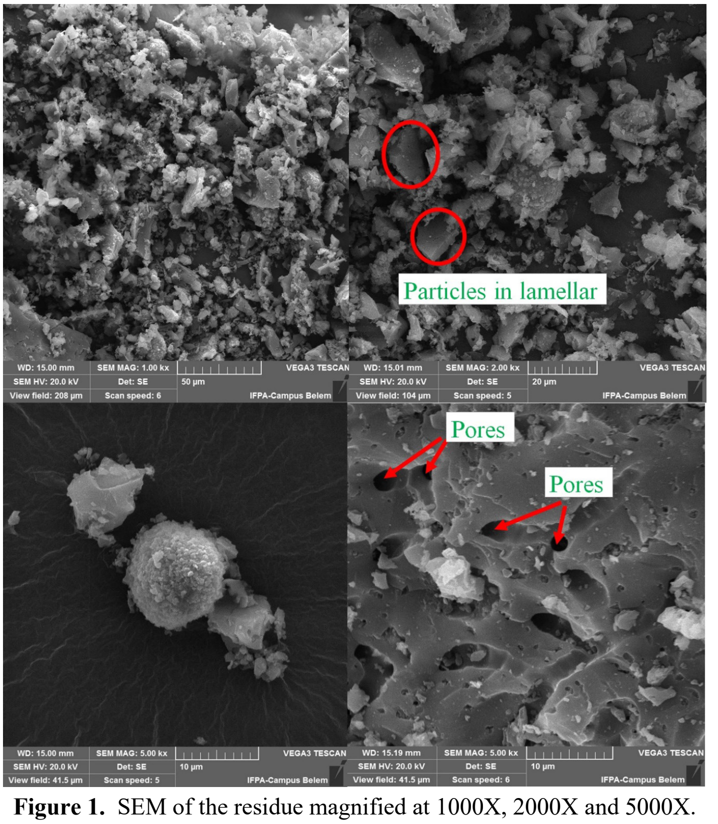

Figure 1. SEM of the residue magnified at 1000X, 2000X and 5000X.

In conjunction with scanning electron microscopy (SEM) analysis, specific chemical analysis by energy dispersive spectroscopy (EDS) was performed. In Figure 2, it is possible to have a semi-quantitative analysis of the elements contained in the ash, noting the important elements in the residue for concrete, such as Silicon (Si), Calcium (Ca), Oxygen (O), Iron (Fe), among other elements.

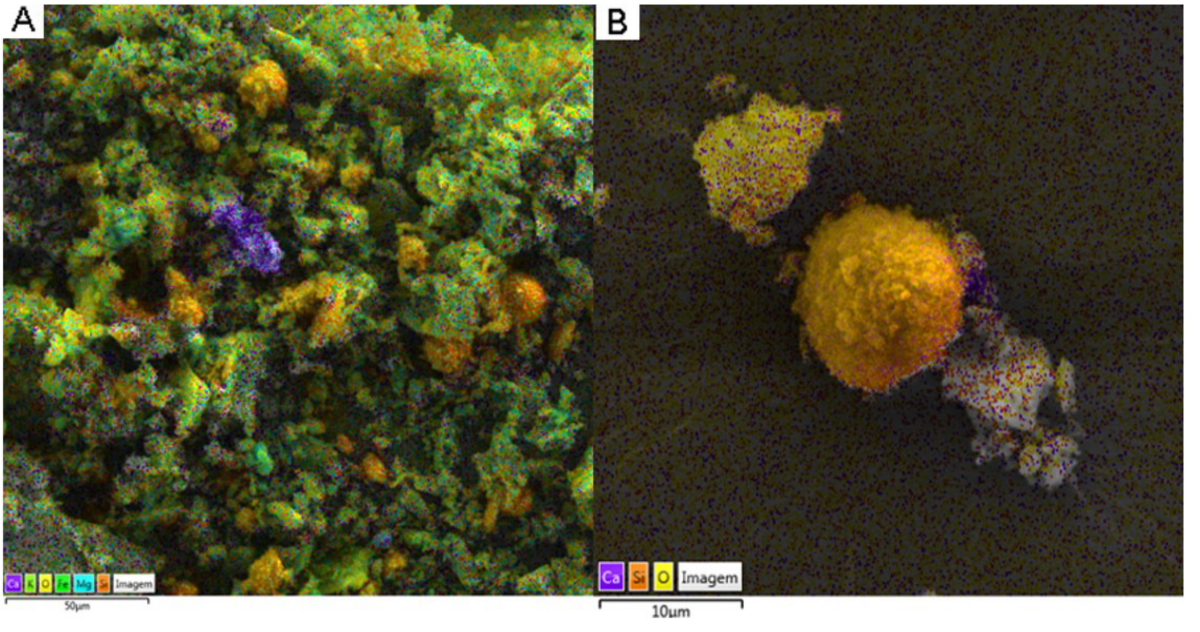

Figure 2. SEM of the murumuru husk ash at two distinct points (A) and (B) by EDS.

4.1.3 X-Ray Fluorescence Analysis

The chemical analysis was done by X-ray fluorescence, showing the oxide percentages of all the components contained in the samples, in addition to the verification of the carbon content and loss on ignition. The results can be found in Table 11.

Table 11 - X-Ray Fluorescence, Carbon Content and Loss on ignition results

Oxides/Elements	SiO_2	CaO	K_2O	P_2O_5	Fe_2O_3	Al_2O_3	SO_3	MgO	SnO_2	MnO	CuO	Cr_2O_3	C	PF
Values (%)	59.9	11.1	10.3	5.1	3.9	2.8	2.4	2.2	0.77	0.5	0.3	0.3	89.5	96.2

The MHA test resulted the amount of SiO2 + Al2O3 + Fe2O3 to be 66.74%, which characterizes this material within the requirement of NBR 12653 for class E. This result is mainly by the fact of containing silica in the composition, which reacts with Ca(OH)2 and form C-S-H, that is directly related to the mechanical strength of concrete.

The loss on carbon content is high, but already expected due to the uncontrolled burning process which is caused by losses in the ignition process and in the process of incomplete combustion. The values recommended by NBR 12655 for loss on fire is a maximum of 6% in class E and the residue is ten times higher than the recommended value.

4.1.4 X-ray diffraction

Figure 3 shows the diffractogram of the MHA. The data indicate that it is a partially crystalline material, which exhibits, in the interval between 38º and 45º, an amorphous halo demonstrating a disorder in the atomic arrangement of the material. These indications corroborate the presence of reactivity in the material.

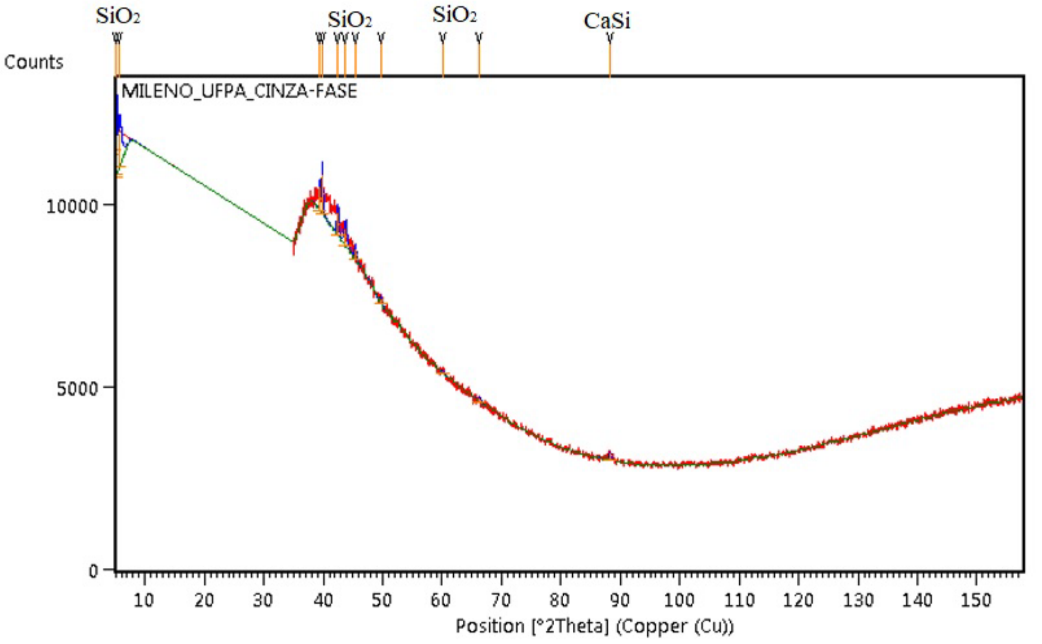

Figure 3. X-ray diffraction from MHA.

Thus, the results suggest that the fine grinded ash presents a partially amorphous and crystalline arrangement.

4.2 Effect of MHA on fresh concrete properties

Table 12 shows the test results on the concrete in the fresh state, showing that the replacement of cement by murumuru influenced concrete behavior.

Table 12 - Test results for fresh concrete

Mixtures	Slump (mm)	Specific mass fresh state (kg/m^3)
S-MHA-0	220	2,909
S-MHA -6	122	2,930
S-MHA -9	90	2,888
S-MHA -13	89	2,901

When checking the consistency, it was noted that the workability of the concrete reduces with the increase of the replacement content. For S-MHA-6 there was a reduction in the slump by approximately 45%, compared to S-MHA-0. The difference in slump reduction is even greater for S-MHA-9 and S-MHA-13 than that of the reference, which is close to 60%. This fact is due to the larger surface area of the MHA, when compared to Portland cement, exposed in the BET result, and also to the lamellar shape of the ash. Comparing to other studies, such as [9] in sugar cane ash and [19] in rice husk ash, it is possible to conclude that the slump increases with increasing the cement replacement content by vegetable ash residue.

In relation to the specific mass, it was verified that the concretes with and without waste showed similar specific mass in the fresh state. Since the residue has a lower specific mass than the cement, from a deductive analysis the concrete will have a lower fresh state specific mass.

4.3 Effect of MHA on concrete properties in the hardened state

Table 13 summarizes the results of the concrete in the hardened state. Like in the results in the fresh state, it is possible to conclude that the replacement of cement by murumuru also influenced the behavior of concrete in the hardened state.

Table 13 - Test results for concrete in the hardened state

Mixtures	Specific mass hardened state (kg/m³)	Average compressive strength at 28 days (MPa)	Average tensile strength (MPa)	Average Modulus of Elasticity (GPa)	Absorption by capillarity at 72 h	
					C (g/cm²)	h (cm)
S-MHA-0	2,286	28.33	3.17	43.04	0.54	5.2
S-MHA -6	2,330	28.75	3.47	47.72	0.23	0.4
S-MHA -9	2,265	18.36	2.99	48.69	0.22	0.2
S-MHA -13	2,277	23.03	3.08	38.54	0.26	0.1

- Specific mass in the hardened state

As can be seen in the table above, a small increase for S-MHA-6 compared to S-MHA-0 can be observed in the specific mass result. As for S-MHA-9 and S-MHA-13, there was a slight reduction in specific mass, practically equal to concrete S-MHA-0. The reduction in specific mass in general occurs by the sum of the specific masses of the materials, with an increase in the substitution content of cement for waste.

- Compressive strength

The results of the compressive strength at 28 days of concrete with and without MHA are presented. The chart in Figure 4 also shows the resistance of the 0%, 6%, 9%, and 13% mixture at 28 days. The resistance marginally increased only for the 6% mixture.

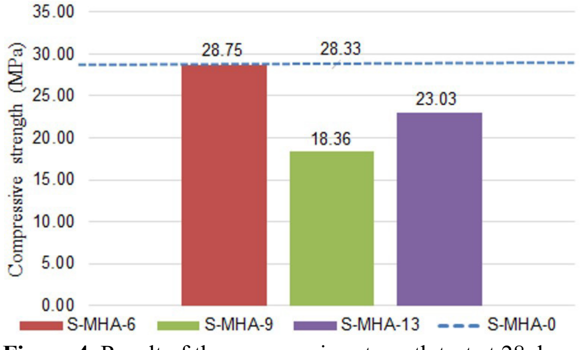

Figure 4. Result of the compressive strength test at 28 days.

The study demonstrated with the partial replacement of cement by MHA in the mixture of 6% is the one that presents the best result with similar compression strength when compared to the reference concrete.

- Tensile strength

The results of the tensile strength by diametrical compression are shown in Table 13. Note that the 6% substitution content of MHA was the only one that showed higher strength than the reference concrete, which was expected due to the filler effect that tends to increase the internal cohesion of the concrete particles. The chart in Figure 5 shows a 9% increase in tensile strength of the 6% substitution concrete when compared to the reference mixture.

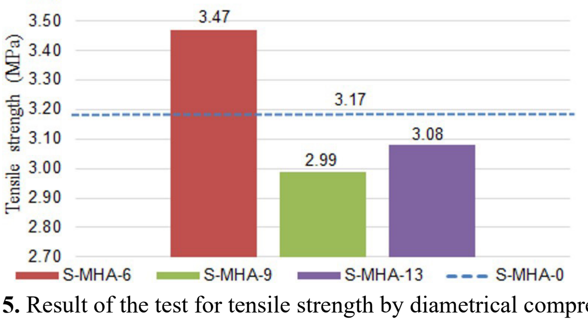

Figure 5. Result of the test for tensile strength by diametrical compression.

• Modulus of Elasticity

The chart in Figure 6 also shows that through the increase in the incorporation of MHA in the mixtures of 6% and 9% substitution percentages. There is an increase in the values of elastic modulus. The 13%-mixture, on the other hand, showed a lower elasticity modulus in relation to the reference mixture.

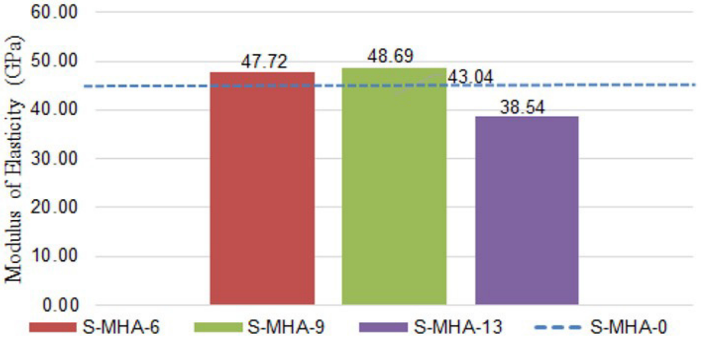

Figure 6. Static modulus of elasticity test result.

• Absorption by capillarity

The results of water absorption by capillarity and the maximum height that the water reached inside the specimens of the samples analyzed at 72h are shown in Table 13. From Figure 7, it can be seen that the more MHA is added to concrete, the lower is the capillary absorption, thus demonstrating the filler effect of the residue in concrete at all levels, which consequently would positively demonstrate better protection to reinforced concretes.

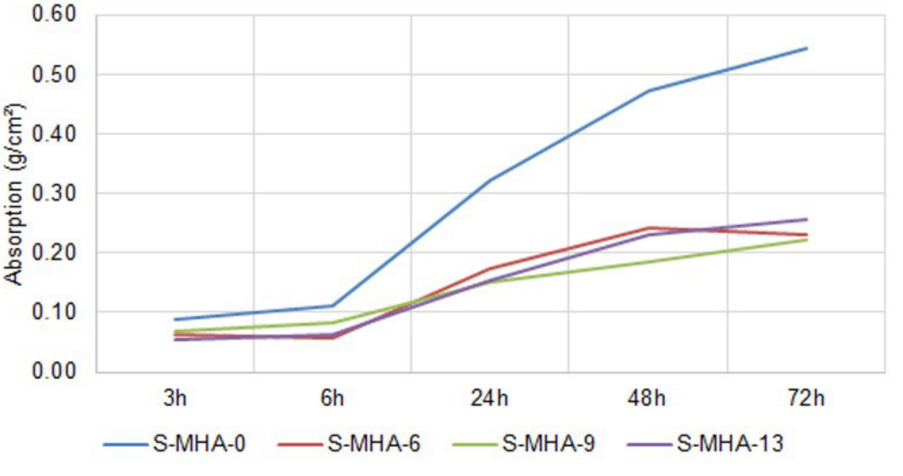

Figure 7. Water absorption by capillary suction (g/cm^2).

• Microstructure of Concrete

After the compression test at 28 days, the failed specimens were submitted to a microstructural analysis by scanning electron microscopy (SEM), aiming to analyze the cementitious matrices. Figure 8 shows the microscopy for S-MHA-0.

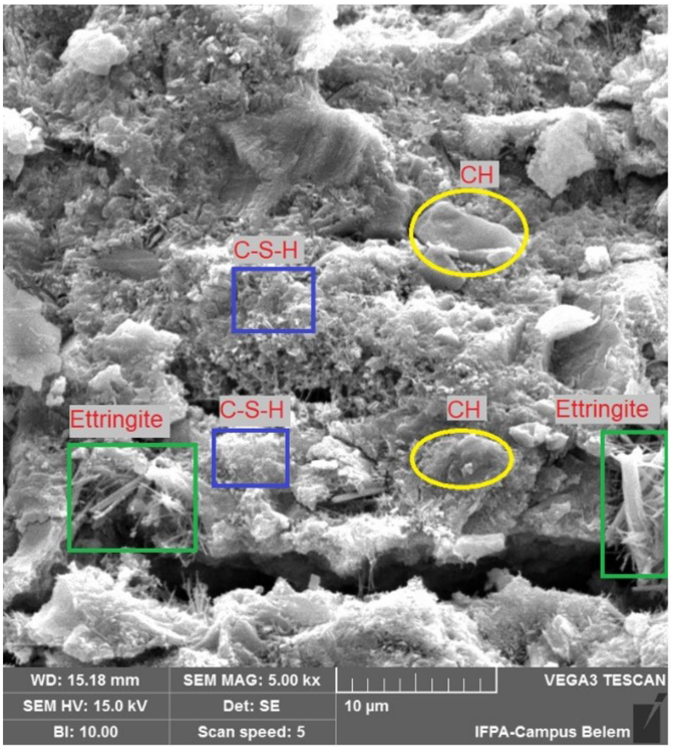

Figure 8. SEM of S-MHA-0 with 5k X

In the Figure above, the phases of the hydrated cement paste, such as Ettringite, Calcium Hydroxide Hydrate (CH), and Calcium Silicate Hydrate (C-S-H) can be seen.

Figures 9 and 10 show the SEM of S-MHA-6 in two distinct regions. The morphological analysis shows that the concretes had the main element of mechanical strength, which is C-S-H, and indicated morphologically the presence of MHA particles seen in darker gray in the images, as it has a lower specific mass than cement, also showing its lamellar shape.

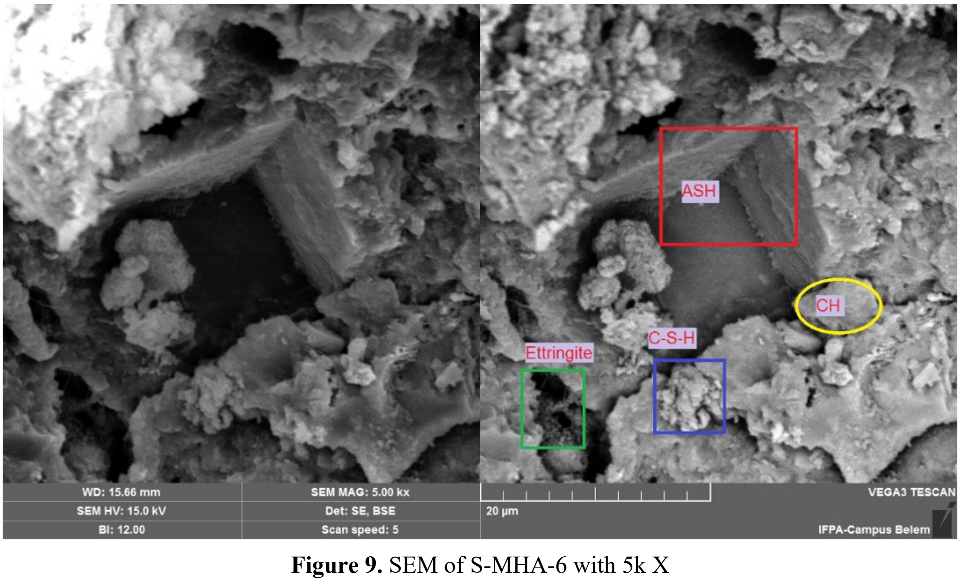

Figure 9. SEM of S-MHA-6 with 5k X

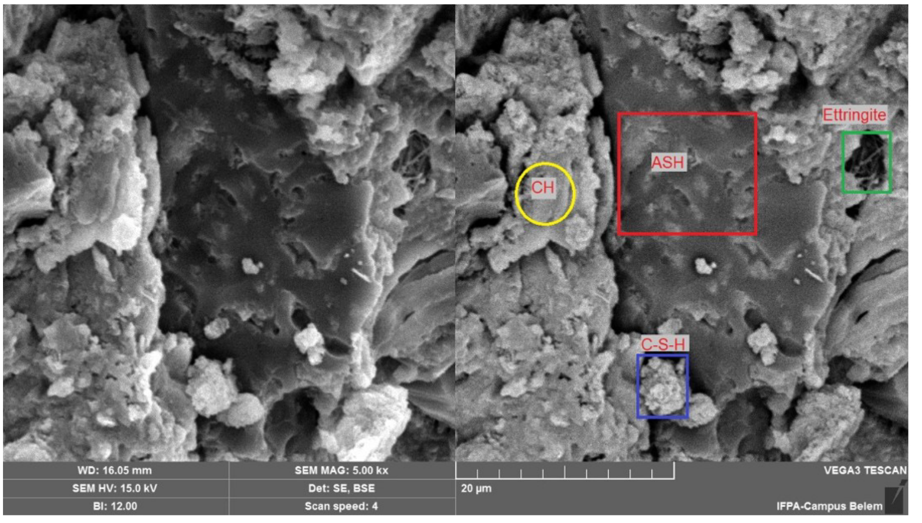

Figure 10. SEM of S-MHA-6 in a different region at 5k X

These constituent elements and particles in the 28-day concretes prove that the material also has a filler effect, with no reaction with the anhydrous substances, functioning to increase the packing of the composite.

5 CONCLUSIONS

The murumuru residue, whether in the form of husk or ashes, is currently disposed of in dumps, landfills, and open air burning, or burned ovens. Adding it to the cement matrix, in the concrete industry, is one opportunity to increase environmental responsibility and to improve the performance characteristics of concrete.

From the results reported hereby, it can be concluded that the incorporation of murumuru ash and partial replacement of cement modifies the mechanical behavior of the analyzed concretes. The results of this research of partial replacement of Portland cement by MHA in concrete provided an analysis of the influence of agro-industrial ash on the properties in the fresh and hardened states of concrete.

In the ash analysis, it influenced properties such as a specific mass lower than that of the cement, which allow for producing lighter concretes. The specific surface area BET was high for the ash, denoting a loss of workability of the concrete, requiring the use of a plasticizer admixture. In the pozzolanic activity, the ash showed a good result, fitting as pozzolanic for the normative study involving the cement, already the XRF allowed to verify the oxides present in the chemical composition of the MHA, which influence the pozzolanic character of the waste and in the hydration reactions of the concrete, while in the XRD analysis crystalline phases in the ash, mainly quartz, were observed, but also showing amorphous. Through the SEM for microstructural analysis, it is concluded that the ash has a lamellar format and presents (quartz), which provides a better packing of the particles, thus increasing the impermeability of the concrete.

The addition of natural ash influenced the consistency of the concrete while reducing workability. This can be justified by the fact that the ash is lamellar and has a high specific surface area higher than the Portland cement used. The specific mass of the concrete in the fresh state was within the range of dense concretes.

Regarding the properties of concrete in the hardened state, the specific mass of concrete with ash showed values close to the reference. The analysis of water absorption indicated much lower values for samples with MHA compared to S-MHA-0, noting the decrease in concrete porosity, and increasing durability due to good filler characteristics. The concrete with replacement content of 6% showed an increase in the compression and tensile strength. Regarding the modulus of elasticity, S-MHA-6 and S-MHA-9 yielded lower deformability than the reference mixture, but S-MHA-13 showed the lowest modulus of all, consequently a higher deformability. Through SEM analysis of the concretes, the hydration compounds in the cement matrix, such as calcium hydroxide (CH), ettringite, and calcium silicate hydrate (C-S-H), which are important components for concrete strength, were observed.

Based on the results in this research, it can be concluded that the murumuru husk ash has good physical-mechanical, chemical and mineralogical characteristics and demonstrates technical viability for partial replacement of cement for the content of S-MHA-6, where it showed the best results within the tests in the fresh and hardened states submitted in the research, acting as a filler material.

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