

# REVISTA AIDIS

de Ingeniería y Ciencias Ambientales:  
Investigación, desarrollo y práctica.

## INCORPORATION OF TANNERY WASTE AND SUGARCANE BAGASSE ASH IN SOIL-CEMENT BRICKS

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Recibido el 24 de septiembre de 2020. Aceptado el 12 de abril de 2021

### Abstract

*Seeking to use wastes disposed in the environment by incorporating them into low environmental impact materials, the study aimed to analyze the effect of using sugarcane bagasse ash and leather dust generated in tanneries in soil-cement brick mixtures. The experiment involved the characterization of used soil mixtures in various ratios, brick molding, and the analysis of performance parameters after an assessment of the material microstructure and heavy metal leaching (chromium). The comprehensive strength against compression decreased with an increasing ratio of waste in the mixtures, where mixtures containing 5.56% ash ratio reached a maximum of 2.52 MPa, and those with leather dust reached 3.69 MPa for the same ratio. Microscopically generated images with a scanning electron microscope indicated differences in the internal structure of the bricks, where ash joined the soil-cement structure whereas the leather dust remained inert and separated from the soil cement composite. Leached hexavalent chromium values were below 0.06 mg.L<sup>-1</sup> for up to 20% waste, which, according to the NBR 10005 standard, does not pose any health risks. Following the acceptable standards, up to 7.14% by volume of sugarcane bagasse ash can be incorporated into bricks without any harm in relation to the standards. Leather dust indicated usage potential of up to 14.29% in the analyzed mixtures.*

**Keywords:** waste; sustainability; construction materials.

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## Introduction

Inadequate solid waste management is one of the elements contributing to pollution in developing countries. The poor disposal and handling of rejected material cause ecosystem degradation and compromise the population's health and well-being (Saha, 2013). According to Świąder *et al.* (2010), cities constantly face economic and environmental problems, and better waste management could contribute positively to the environment, improving health and generating income for the population.

In the same vein, civil construction activities also affect the environment and directly or indirectly contribute to its deterioration. Methods that cause less environmental impact have been developed in this regard, seeking to promote sustainable development (Umar *et al.*, 2012).

The leather industry has a high polluting potential owing to the generation of solid waste and wastewater, and the release of gases produced during the tanning stage (Santos *et al.*, 2015a). The tanning process involves addition of chemical substances to improve the durability and physical characteristics of the leather products (Matos *et al.*, 2014). The most commonly used additive in such cases is chromium basic sulfate, used in approximately 80-90% of tanneries (Teixeira *et al.*, 2015a). These chromium III salts used as mineral additives result in wet blue leather, which is the name given to leather that contains chrome (Cassano *et al.*, 2003).

The solid waste generated in the leather making process comes from various chemical discharges, large pieces of leather cuttings, trimmings, and fleshings. Therefore, the proper management of this waste is a worldwide concern, owing to its possible chromium toxicity (Pavin *et al.*, 2017). Most waste elimination methods involve disposal or incineration, which negatively affect the environment. In an environmentally aware era, development of processes that enable the reuse of tannery waste is of great importance (Shouhui *et al.*, 2018).

Sugarcane production is also in the spotlight when discussing waste generation, as 140 kg of bagasse is produced for each ton of processed sugarcane (Melati *et al.*, 2017). The bagasse produced from sugarcane cultivation is a lignocellulosic waste and quite prevalent in Brazilian farming. Cultivation occurs principally for extracting sucrose, which is then used as raw material for sugar and ethanol production. Brazil is the world's largest sugarcane producer, followed by India, China, and Thailand.

Sugarcane bagasse, the leftover fibrous matter from sugarcane milling, can be used for energy production. The use of agricultural and organic waste for energy production is a strategy with great potential for generating renewable energy, and reducing waste disposal and environmental pollution (Teixeira *et al.*, 2015b). However, a few residues, such as the ash generated, when not applied to the soil, is a residue that requires suitable disposal.

The goal of using sustainable development to provide a safe environment for the population can be achieved by using ecological construction materials. Research on the use of sustainable materials in construction seeks alternative methods for the reuse of diverse wastes, aiming to reduce noxious gas emissions and propose affordable housing for low-income populations (Al-Jabri *et al.*, 2017).

The use of soil–cement bricks is one of the technologies that can preserve the environment and avoid the scarcity of natural resources. When combined with waste use, it helps reduce disposed materials, as well as the cost of construction (Reis *et al.*, 2018). Soil–cement bricks are composed of soil, Portland cement, and water (ABNT, 2012a), with soil as the main component that exerts a large influence on the strength and durability of the constructed blocks.

Silva *et al.* (2014) studied the incorporation of ceramic waste into soil–cement bricks. Their experimental results indicated that its addition was promising and fulfilled the standard requirements for use in non-structural masonry. The best values in the compressive test were achieved with 12% cement and 4% waste incorporation. Paschoalin Filho *et al.* (2016) developed soil–cement bricks by adding polyethylene terephthalate (PET) flakes and after testing the samples in terms of comprehensive strength against compression and water absorption, obtained comprehensive strength values lower than the minimum recommended standards and water absorption rates close to the established Brazilian standards. Contributing to the sustainability of the construction and foundry industries, Leonel *et al.* (2017) analyzed the viability of incorporating discarded foundry sand into soil–cement brick manufacturing. They assessed bricks prepared with 10% cement, 0% to 65% foundry sand, 0% to 25% commercial sand, 25% to 60% clay, and 15% to 30% gravel dust. The results indicated acceptable rates in bricks with the addition of foundry sand combined with gravel dust, which reduced the water absorption and maintained their comprehensive strength.

Moreover, modern material science has retained its focus on the properties-microstructure relation. The progress in this field resulted in the establishment of the principle that properties originate in the internal microstructure, and that relation influences strength, dimensional stability, and durability (Mehta and Monteiro, 2008). Quantification is one of the several methods to evaluate the durability of a material, by testing its mass loss and dimensional variation. A dimensional analysis is essential to verify that the incorporation of the residue does not affect the standard measures of brick production, that is, the quality and durability is maintained, without breaking, cracking, crumbling, etc. De Macêdo Reis *et al.* (2018) and França *et al.* (2018) performed these analyses, unlike several other researchers; however, it is important to include them with studies that researched the addition of residues.

Another important point is to evaluate whether the use of waste, such as from tanneries, in soil–cement brick production, ends up causing the leachate of toxic composites from the generated waste to reach the population in different addition ratios (Juel *et al.*, 2017).

In light of the foregoing, in the present study, we sought to evaluate the effect of using sugarcane bagasse ash and leather dust in soil–cement bricks. For this investigation, we included the dimensional analysis of the produced material, with an analysis of the composite microstructure and heavy metal (Cr), to promote its reuse as an alternative and add value to the waste.

### Materials and method

The study was conducted using wastes such as sugarcane bagasse ash and leather dust and incorporating them into soil–cement bricks. The waste materials were used in different proportions and tested according to the Brazilian standards.

The laboratory analyses in this study followed those performed by Barbosa *et al.* (2019), which also used Brazilian standardization (NBRs from the Brazilian Association of Technical Standards (ABNT)) to assess the soil–cement bricks with the incorporated waste. The evaluation performed for the bricks containing sugarcane bagasse ash and leather dust also included the dimensional analysis of the produced material, the investigation of the composite microstructure and heavy metal (Cr).

#### Materials

Soil was collected in Campo Grande/MS, and Portland CP V-ARI cement - NBR 16697 (ABNT, 2018), was used as the binder, based on the reference values of Uliana *et al.* (2015), utilizing the chemical composition provided in Table 1.

**Table 1.** Chemical composition of the soil.

Component	SiO <sub>2</sub>	CaO	MgO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Loss on ignition
Percentage	18.65%	63.72%	0.75%	4.91%	2.97%	0.80%	3.84%

The sugarcane bagasse ash was sourced from burnt sugarcane in a mill located in the vicinity of the Costa Rica/MS municipality. It was used in mixtures with the parcel size passing through a 4.75 mm mesh sieve. The mineralogical composition of the sugarcane bagasse ash was obtained with X-ray refraction, as shown in Table 2.

**Table 2.** Chemical composition of the sugarcane bagasse ash according to Schettino and Holanda (2015).

Component	SiO <sub>2</sub>	CaO	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	MnO
Percentage	85.55%	4.05%	0.20%	2.29%	1.21%	2.28%	3.01%	0.08%

Wet blue leather dust sample was sourced from a tannery located in Campo Grande/MS. The chemical characterization of wet blue leather was performed by Oliveira *et al.* (2008) and is presented in Table 3.

**Table 3.** Chemical composition of wet blue leather dust according to Oliveira *et al.* (2008).

Component	Unit	Value
N	%	10.40
P	%	1.00
K	mg kg <sup>-1</sup>	0.15
Ca	mg kg <sup>-1</sup>	0.60
Mg	mg kg <sup>-1</sup>	0.44
S	mg kg <sup>-1</sup>	12.00
Fe	mg kg <sup>-1</sup>	133.00
Mn	mg kg <sup>-1</sup>	2.00
Zn	mg kg <sup>-1</sup>	5.00
Cr	mg kg <sup>-1</sup>	27,150.00

#### Characterization of soil, sugarcane bagasse ash, and leather dust

Soil samples were prepared according to NBR 6457 (ABNT, 2016a), with natural drying and subsequent grain dimension reduction. The granulometric analysis was performed following the procedure described in NBR 7181 (ABNT, 2016d), and was implemented by sieving with sedimentation.

The liquid limit (LL) was established through a laboratory test following NBR 6459 (ABNT, 2016b) standards, using a liquid limit determination device. The plasticity limit was determined with the execution technique exposed in NBR 7180 (ABNT, 2016c) and its determination is fundamental to obtain the plasticity index (PI).

The LL is defined as the moisture content equivalent to 25 strokes represented in the mean straight, identified as 32%. As the plasticity rate is the difference between the two limits, we obtained a PI of 10%, considering a 22% plasticity limit. The LL satisfied the NBR 10833 standard requirement (ABNT, 2012c), which recommends soils with LL lower than or equal to 45%. The plasticity rate also showed values in accordance with NBR 10833, where the PI must be lower or equal to 18%.

The compaction experiment was performed with a Proctor cylinder based on NBR 7182 (ABNT, 2016e). We determined the optimum moisture, which is described in percentage and represents the quantity of water to be added to the mixture of soil–cement bricks. The meeting point of tangent straights with the curve resulted in an optimum moisture equivalent to 18.10%. Although there may be certain changes in optimum moisture, a suitable trace was used for the soil in the region, and only the percentage of incorporation of the residues varied. In practice, this facilitates the manufacturing. Even though it is possible to find the optimum moisture for each mix, technically this can cause manufacturing errors with another variable in the process. This variation is shown later (Table 4), where the control was 1/6 and 1/8, with the cement proportion maintained constantly at 1 and the proportion of the soil decreased (5.5, 5.0, 4.5), and the remainder was the added residues (bagasse ash and leather dust). This process was adopted based on practice and the methodology of Barbosa *et al.* (2019).

The soil met the granulometric parameter established by NBR 10833, which recommends using soils with 100% particles passing through a 4.75 mm mesh sieve and 10-50% passing through a 0.075 mm sieve.

For the soil used in our experiment, 100% and 43.23% grains passed through the 4.75 mm and 0.075 mm mesh sieves, respectively, and the soil was classified as clayey silty sand.

Similarly, 100% and 0.9% leather particles passed through the 4.75 mm and 0.075 mm mesh sieves, respectively. Furthermore, 100% and 97.2% of sugarcane bagasse ash also passed through the 4.75 mm and 1.18 mm meshes, respectively.

#### Manufacture and cure of bricks

Standard ratios were used, and residues were incorporated into the soil parcel in different percentages, according to Table 4. Preliminary studies were performed for the soil used, and a base ratio from 1/6 to 1/8 was found. The waste incorporation was based on an appropriate proportion range that satisfied the Brazilian normative parameters.

**Table 4.** Variables assessed for soil–cement bricks manufacture with sugarcane bagasse ash and leather dust.

		Cement + Soil (CS)					
Variable 1		CS 16			CS 18		
Ratio		1/6			1/8		
Dry mass (kg)		0.4/2.6			0.3/2.7		
		Cement + Soil + Sugarcane bagasse ash (CSB)					
Variable 2		CSB 61	CSB 62	CSB 63	CSB 81	CSB 82	CSB 83
Ratio		1.0/5.5/0.5	1.0/5.0/1.0	1.0/4.5/1.5	1.0/7.5/0.5	1.0/7.0/1.0	1.0/6.5/1.5
Dry Mass (kg)		0.4/2.4/0.2	0.4/2.1/0.4	0.4/1.9/0.7	0.3/2.5/0.2	0.3/2.4/0.3	0.3/2.2/0.5
		Cement + Soil + Leather dust (CSL)					
Variable 3		CSL 61	CSL 62	CSL 63	CSL 81	CSL 82	CSL 83
Ratio		1.0/5.5/0.5	1.0/5.0/1.0	1.0/4.5/1.5	1.0/7.5/0.5	1.0/7.0/1.0	1.0/6.5/1.5
Dry mass (kg)		0.4/2.4/0.2	0.4/2.1/0.4	0.4/1.9/0.7	0.3/2.5/0.2	0.3/2.4/0.3	0.3/2.2/0.5

The brick manufacturing process followed the specific requirements provided in NBR 10833 (ABNT, 2012c), and the soil–cement mixture was created manually. Cement was added to the previously prepared soil, harrowed and sieved, and mixing was performed after adding water until homogeneity was obtained.

Eco Premium 2600 CH MA (Eco Máquinas) machine was used for brick production. The mixture was inserted into the machine compartment immediately after preparation and pressed. After pressing, the bricks were placed in a humid chamber to guarantee the necessary cure recommended by NBR 10833 (ABNT, 2012c).

According to Kharun and Svintsov (2017), comprehensive strength against compression depends on not only the quantity of cement in the mixture, but also the temperature and moisture conditions of the cure.

Tests were performed with ten bricks according to NBR 8491 (ABNT, 2012a). Then, seven, three, and all ten specimens were subjected to a compression test, water absorption test, and dimensional analysis, respectively, as per NBR 8492 recommendations (ABNT, 2012b).

### Characterization of soil–cement bricks

#### **Dimensional analysis, comprehensive strength to compression, and water absorption**

We performed a dimensional analysis on ten bricks, in consonance with NBR 8491, with the aid of a digital caliper. Three determinations were performed at distinct points on each face, one at each extremity, and one at the center.

A simple compression test was performed according to NBR 8492. The machine used for the compression test (Forney hydraulic press, F-502F-CPILOT model) applied  $500 \pm 50$  N/s uniform load, which was gradually increased until rupture.

The water absorption percentage was determined as stated in NBR 8492. The three test objects were tested by placing them in a  $105 \pm 5$  °C temperature greenhouse for preliminary moisture removal. The moisture-free samples were first weighed and then immersed in an immersion tank for the second weighing, which represents the mass of soil–cement + water bricks after saturation, for a pre-set period of 24 h.

The entire calculation procedure is described in NBR 8492. The results of dimensional analysis are expressed in millimeters (mm), simple compression tests in megapascals (MPa), and water absorption in percentage (%).

#### **Analysis of microstructure**

A microstructure analysis of soil–cement bricks with the incorporation of sugarcane bagasse ash and leather dust was conducted with a scanning electron microscope (JEOL, JSM-6380LV model), fabricated in Tokyo, Japan, belonging to Multilam INFI/UFMS.

In scanning electron microscopy, the target region is irradiated with a small beam of electrons to obtain its topographic, morphological, and surface composition information (Choudhary and Malik, 2017).

Because the material was not conductive to the electric current, the brick samples were first treated to allow them to be analyzed with SEM. Finally, through images generated during the process, the microstructure of soil–cement bricks (CS) and those with waste, CSB, and CSL, were analyzed by comparing their constituent parcels and identifying their structural organization.

#### **Analysis of hexavalent chromium**

Total chromium and  $\text{Cr}^{+6}$  (hexavalent) in the the soil–cement brick test objects incorporated with 10% and 20% tannery waste (leather dust) was determined in agreement with the NBR 10005 methodology (ABNT, 2004). The technically feasible percentages for incorporating these residues vary between 10% and 20%; therefore, by applying these two values allows us to know if it exceeds the limit and is safe for those using this material. The experiment entailed leaving the waste immersed in distilled water for 24 h. During this

period, pH was maintained at  $5.0 \pm 0.2$ . Afterwards, the aqueous phase was filtered in  $0.45 \mu\text{m}$  glass fiber membrane, and for sample preservation, concentrated nitric acid was used. A flame atomic absorption spectrometer (Varian, AA 220FS) was used to determine the concentrations of total chromium and  $\text{Cr}^{+6}$ .

## Results and Discussion

### Comprehensive strength, dimensional analysis, and water absorption

Table 5 presents the results obtained in the dimensional analysis tests.

**Table 5.** Dimensional analysis (7 days).

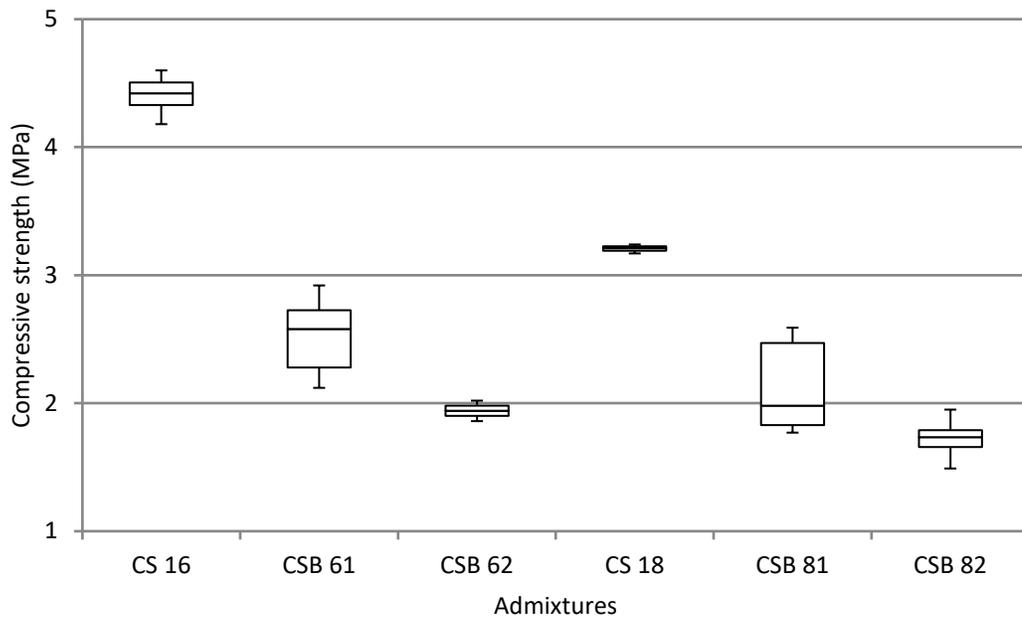
Trace	Dimensional analysis (mm) + SD*		Trace	Dimensional analysis (mm) + SD*	
CS 16	Width	$125.63 \pm 0.05$	CS 18	Width	$126.13 \pm 0.07$
	Height	$62.16 \pm 0.06$		Height	$58.24 \pm 1.25$
	Length	$250.74 \pm 0.12$		Length	$251.51 \pm 0.29$
CSB 61	Width	$125.52 \pm 0.18$	CSB 81	Width	$126.35 \pm 0.09$
	Height	$62.10 \pm 0.16$		Height	$54.15 \pm 0.82$
	Length	$250.59 \pm 0.20$		Length	$251.16 \pm 0.31$
CSB 62	Width	$126.12 \pm 0.11$	CSB 82	Width	$126.09 \pm 0.18$
	Height	$60.17 \pm 0.56$		Height	$52.98 \pm 0.73$
	Length	$251.31 \pm 0.13$		Length	$251.02 \pm 0.08$
CSL 61	Width	$126.51 \pm 0.09$	CSL 81	Width	$126.54 \pm 0.24$
	Height	$56.05 \pm 1.80$		Height	$56.19 \pm 3.27$
	Length	$251.29 \pm 0.27$		Length	$251.44 \pm 0.36$
CSL 62	Width	$126.51 \pm 0.06$	CSL 82	Width	$126.73 \pm 0.13$
	Height	$54.88 \pm 1.29$		Height	$57.05 \pm 1.32$
	Length	$252.03 \pm 0.55$		Length	$251.61 \pm 0.13$
CSL 63	Width	$128.62 \pm 0.46$	CSL 83	Width	$127.87 \pm 0.52$
	Height	$62.94 \pm 0.03$		Height	$61.89 \pm 0.24$
	Length	$254.79 \pm 0.58$		Length	$254.12 \pm 0.16$

Note: \*SD refers to Standard Deviation

The manufacturing device produced soil–cement bricks with dimensions of 125 mm width, 62.5 mm height, and 250 mm length. Averages obtained in all manufacturing lots satisfied the limits stipulated by NBR 8491 (ABNT, 2012a), which allows deviations of  $\pm 1$  cm in any test object dimension.

Notably, brick heights varied depending on the ratios, a difference that was not considered harmful to performance, because it was still below the maximum standard deviation determined by NBR 8491.

NBR 8491 stipulates that the comprehensive strength against axial compression tests, carried out as defined in NBR 8492, must not show an average value lower than 2.00 MPa or an individual value lower than 1.7 MPa, respectively at seven days of aging. The comprehensive strengths of base ratios of soil–cement and mixtures containing sugarcane bagasse ash against axial compression, corresponding to an age of seven days as per the NBR 8491 requirement, are depicted in Figure 1.

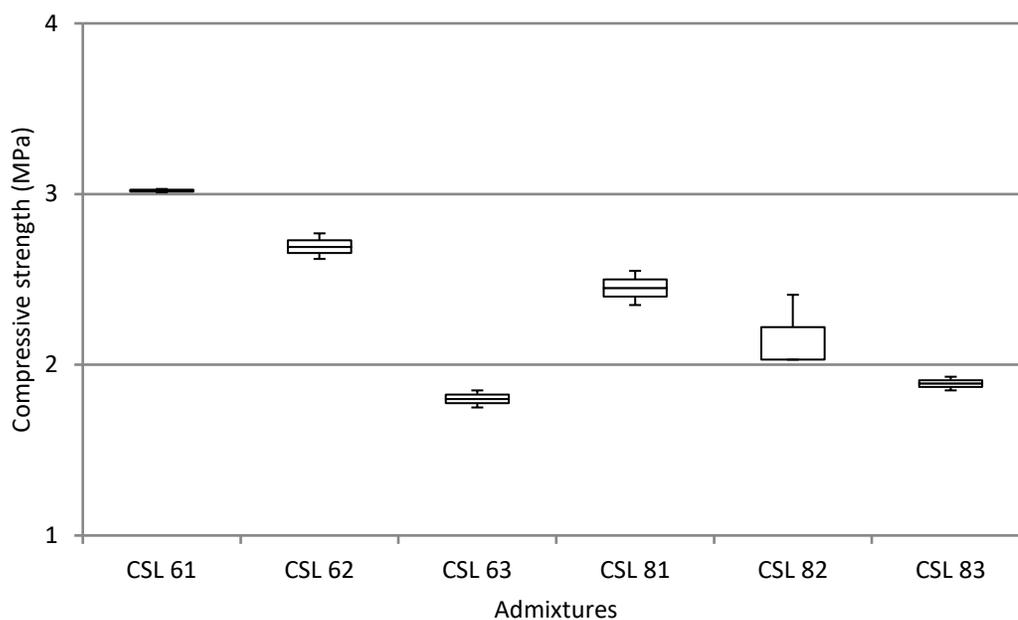


**Figure 1.** Comprehensive strength of soil–cement and mixed with sugarcane bagasse ash.

Among the analyzed ratios, the highest possible percentage of sugarcane bagasse ash used was 7.14%, corresponding to the CSL 61 ratio, which reached 2.52 MPa after seven days of aging.

Eko and Riskowski (2001) added *in natura* sugarcane bagasse to the mixture, and the compressive strength was 1.03 MPa for samples containing bagasse treated at 20% ratio. Valenciano and Freire (2004) partially replaced cement with CSB, reaching the compressive strength required by standards at 60 days for certain ratios employed. Both studies were considered inappropriate according to Brazilian standards.

The compressive strengths of specimens for mixtures containing leather dust is shown in Figure. 2. These values correspond to the age of seven days as per the NBR 8491 requirement.



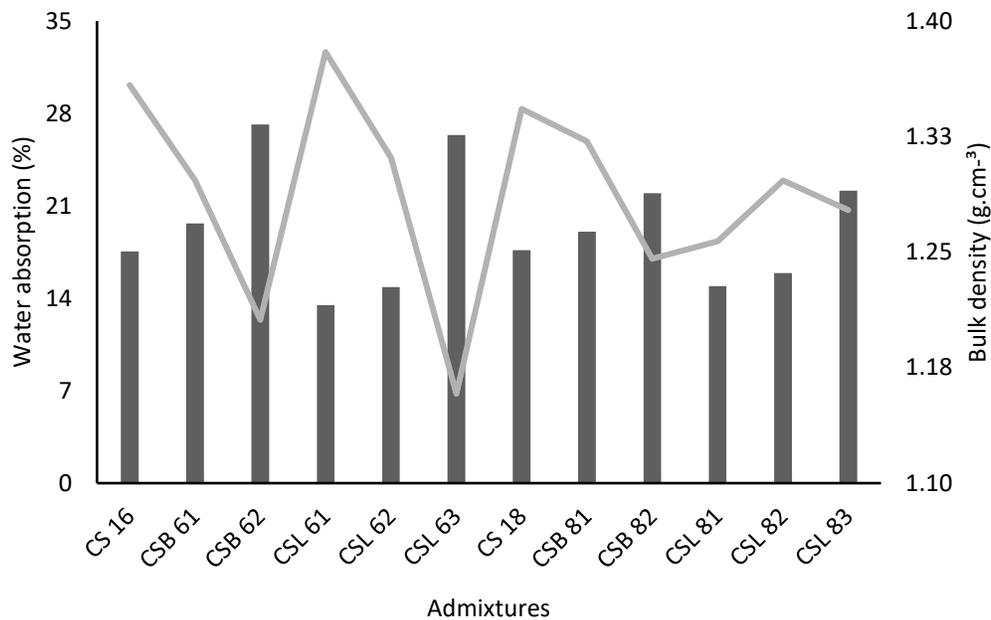
**Figure 2.** Compressive strength against simple compression in mixtures of soil–cement and leather dust.

The simple compression test results demonstrated satisfactory values up to 14.29% leather incorporation at seven days. Santos *et al.* (2015b) incorporated 10%, 15%, 20%, and 30% leather dust volume into soil, and obtained satisfactory results of 2 MPa only for the specimen with 10% of the waste.

The ratios CS 16, CSB 61, CSL 61, and CSL 62 fulfill the Brazilian standardization requirements and are adequate for use in axial compression. The mixtures CSB 62, CSB 82, CSL 63, and CSL 83 did not qualify the minimum resistance standards required by NBR 8491.

According to Forcelini *et al.* (2016), soil bricks show higher compressive strength for lower quantities of cement and lower voids ratios, and its stabilization occurs at 14 days.

Figure 3 shows the mean values of water absorption results for the respective ratios at seven days, according to NBR 8491's requirement.



**Figure 3.** Results for water absorption of the specimens.

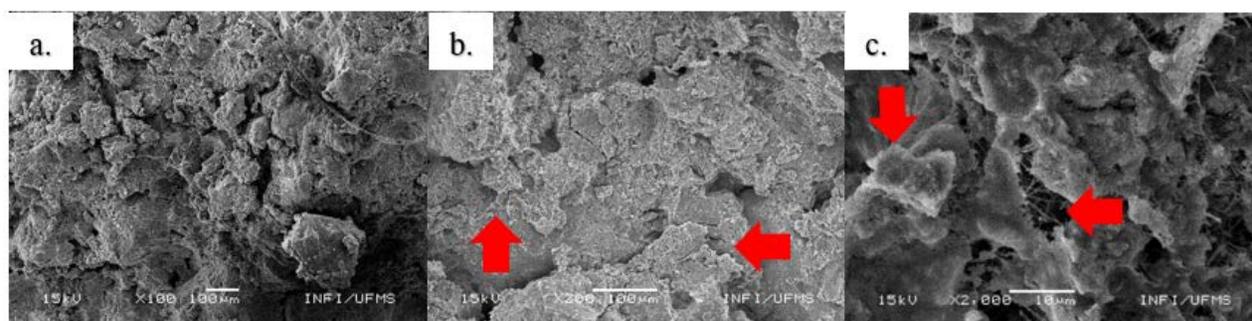
It was observed that ratios containing sugarcane bagasse ash demonstrated higher water absorption than those with leather dust. According to NBR 8491, water absorption must be lower than or equal to 20% (ABNT, 2012a). Ratios with 11.11% and 14.29% ash showed higher values, failing in the water absorption normative criterion. Bricks with incorporated leather dust failed when the waste percentage in the total mixture was 16.67% and 21.43%, according to normative parameters. The other percentages for the specimen were within the normative parameters.

James *et al.* (2016) detected a higher water absorption in 10% cement content in the soil and reported that the addition of CSB is more effective at lower cement content.

Further, similar to the experimental results of Barbosa *et al.* (2019), it can be verified that the greater the incorporation of residues, the greater the absorption of water, the lower the density, and the lower the resistance to compression. This phenomenon is possibly because the void rate increases and favors the entry of water, as verified by Santos *et al.* (2018).

#### Analysis of microstructure

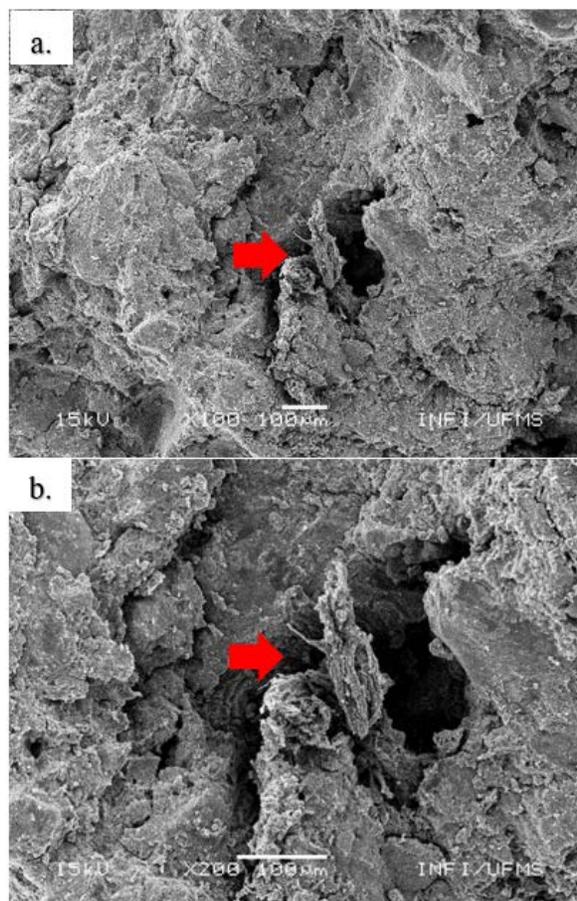
For the control structure (Figure 4a) obtained from the tests of CS 18 trace brick samples, we noted a calcium silicate hydrate mass structuring the soil–cement composite.



**Figure 4.** a: Sample CSB 81, 100× amplification; b: sample CS 18, 200× amplification, and c: sample CSB 81, 2000× amplification.

As shown in Figure 4a, there is an alteration in the microstructure of calcium silicate hydrate in the CSB 81 specimen. After magnifying the image to 2000× (Figure 4c), it was noted that the mass of low crystallinity is in fact formed by acicular “striped” structures that are part of the mixture. This occurrence may stem from a possible reaction between the sugarcane bagasse ash pozzolan and calcium silicate hydrate. Figure 5a presents images of the CSL 81 sample containing leather dust. Notably, there was no microstructure alteration in the mixture compared with that in the independent materials, that is, soil and leather dust alone.

A leather dust fiber immersed in the mass of calcium silicate hydrate and soil is visible in the figure. The sample fiber was observed under 200× magnification. As seen in Figure 5b, the fiber possesses chemical inertness with regard to the CSH soil, while the fiber in the soil–cement composite is visible and does not show any microstructure alteration.



**Figure 5.** a: Sample CSL 81, 100× amplification; b: sample CSL 81, 200× amplification.

*Analysis of total and hexavalent chromium in test objects incorporated with leather dust fiber*

Table 6 presents the results of total chromium (total Cr) and hexavalent chromium ( $\text{Cr}^{+6}$ ) analyses in test objects incorporated with leather dust fibers.

**Table 6.** Concentration of chromium in leached extract

	10%	20%	NBR 10005 (ABNT, 2004)
Total Cr ( $\text{mg.L}^{-1}$ )	$1.76 \pm 0.48$	$2.42 \pm 0.46$	5.00
$\text{Cr}^{+6}$ ( $\text{mg.L}^{-1}$ )	< 0.06	< 0.06	0.06

It was observed that the total chromium and hexavalent chromium in the soil–cement brick samples containing 10% and 20% tannery waste “leather dust” were below the limits established by NBR 10005. For environmental classification, the maximum allowable limit is  $5.0 \text{ mg.L}^{-1}$  and  $0.06 \text{ mg.L}^{-1}$  for total Cr and  $\text{Cr}^{+6}$ , respectively. In the present study, the soil–cement bricks were classified as non-hazardous; hence, they are considered safe for manufacture and application in civil construction. Wu *et al.* (2012) evaluated the replacement of incinerated ash in Portland cement production and found that heavy metals such as chrome, plumb, cadmium, zinc, and nickel did not pose a leaching risk for the environment. According to Al-Fakih (2019), several studies have concluded that the use of waste materials can contribute to the production of sustainable construction materials and eco-friendly construction products.

### Conclusions

The soil used in our study fulfilled the requirements mandated by NBR 10833 and was considered appropriate for use in soil–cement mixtures for brick pressing.

Compressive strength against axial compression declined depending on the waste ratios. Bricks containing 5.56% and 7.14% sugarcane bagasse ash demonstrated satisfactory values (higher or equal to 2 MPa), according to NBR 8491. The leather dust ratio showed higher incorporation potential and showed satisfactory values with up to 14.29% waste in relation to the mixture.

In terms of water absorption, a few mixtures fulfilled the approved established limits for compressive strength against axial compression. Samples such as 11.11% CSB and 16.67% CSL did not satisfy NBR 8491.

The dimensional analysis showed variation in brick height among the analyzed ratios. The standard deviation did not exhibit a linear variation behavior, which can be justified by the pressing strength and the water absorption potential of the mixture at the moment of brick molding.

Soil–cement bricks exhibited good results for soil replacement with sugarcane bagasse ash for up to 7.14% content. Leather dust can be used without harm to normative reference parameters up to a 14.29% maximum incorporation and with hexavalent chromium leaching values lower than  $0.06 \text{ mg.L}^{-1}$ . Hence, the incorporation of both wastes separately is viable in percentages used for the studied traces.

Scanning electron microscopy images exhibited differences in internal structures of the different specimens. The brick fragment with leather dust did not show variation in relation to the control sample microstructure, and it was possible to infer that the fiber had chemical inertia when

compared with the other component mixtures. The alteration occurred only in the specimen microstructure of the sample with sugarcane bagasse ash, where there was possible sugarcane bagasse ash pozzolan reaction with the calcium silicate hydrate in the soil–cement composite structure.

According to the cited Brazilian standardization parameters, the reuse of sugarcane bagasse ash and leather dust as aggregates in soil–cement bricks is technically viable. Conventional soil–cement bricks have already adapted to ecological alternatives in construction to reduce impacts stemming from the extraction of raw material from the environment. Moreover, our method does not require any burning during the manufacturing process. The possibility of incorporating the studied waste maximizes the product sustainability, reducing the environmental impact caused by improper disposal.

### Acknowledgements

*We are grateful to the Coordination for the Improvement of Higher Education Personnel (CAPES) and to the National Council for Scientific and Technological Development (CNPq), Brazil.*

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