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Physical and mechanical behavior in soil matrix materials due to residues addition and burning temperature

Comportamento físico e mecânico em materiais da matriz do solo devido à adição de resíduos e temperatura de queima

Comportamiento físico y mecánico en los materiales de la matriz del suelo debido a la adición de residuos y la temperatura de combustión

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Abstract

The building construction is responsible for the largest industrial sectors in the world, with high energy demand and use of natural resources. Given the scarcity of natural resources and the energy crisis, the use of waste in building materials becomes a target. Therefore, this study aimed to evaluate different treatments with pine sawdust and coffee husk additions, both at 10% by mass and also evaluated in drying and burning. The treatments were evaluated by bulk density, linear shrinkage and compressive strength. In the treatments without burning, it was possible to verify that the addition of 10% of residue reduces the mechanical resistance of the material considerably but improves the physical properties. In the burned materials, it was observed that the addition of residues is unsatisfactory due to the high temperature, carbonizing them, increasing the porosity, thus destabilizing the material, negatively affecting the physical and mechanical properties.

Keywords: Pine sawdust; Coffee husk; Waste in construction; Compressive strength; Ceramic materials; Adobe.

Resumo

A construção civil é responsável pelos maiores setores industriais do mundo, com alta demanda de energia e uso de recursos naturais. Dada a escassez de recursos naturais e a crise energética, o uso de resíduos em materiais de construção passa a ser alvo de pesquisas. Portanto, o presente trabalho teve como objetivo avaliar diferentes tratamentos com adições de serragem de pinus e casca de café, tanto a 10% em massa quanto avaliados no processo de secagem e de queima. Os tratamentos foram avaliados quanto à densidade do solo, retração linear e resistência à compressão. Nos tratamentos sem queima, foi possível verificar que a adição de 10% de resíduo reduz consideravelmente a resistência mecânica do material, mas melhora as propriedades físicas. Nos materiais queimados, observou-se que a adição de resíduos é insatisfatória devido à alta temperatura, carbonizando-os, aumentando a porosidade, desestabilizando assim o material, afetando negativamente as propriedades físicas e mecânicas.

Palavras-chave: Serragem de pinho; Casca de café; Resíduos de construção; Resistência à compressão; Materiais cerâmicos; Adobe.

Resumen

La edificación es responsable de los sectores industriales más importantes del mundo, con alta demanda energética y aprovechamiento de recursos naturales. Dada la escasez de recursos naturales y la crisis energética, el uso de residuos en materiales de construcción se convierte en un objetivo. Por tanto, esta investigación tuvo como objetivo evaluar diferentes tratamientos con adiciones de aserrín de pino y cascarilla de café, tanto al 10% en masa como también evaluados en secado y quemado. Los tratamientos se evaluaron por densidad aparente, contracción lineal y resistencia a la compresión. En los tratamientos sin quemar, se pudo comprobar que la adición de 10% de residuo reduce considerablemente la resistencia mecánica del material, pero mejora las propiedades físicas. En los materiales quemados, se observó que la adición de residuos es insatisfactoria debido a la alta temperatura, carbonizándolos, aumentando la porosidad, desestabilizando así el material, afectando negativamente las propiedades físicas y mecánicas.

Palabras clave: Aserrín de pino; Cascarilla de café; Residuos de construcción; Resistencia a la compresión; Materiales cerámicos; Adobe.

1. Introduction

The quality of any building is directly linked to the quality and knowledge of the materials used. Research contributes to technical standards that present safety in projects and constructions. Therefore, the understanding of materials is a reason for study.

The scarcity of natural resources and the energy crisis, the search for materials with lower energy coefficients and the use of waste are being the focus of several current researches, aiming to combine construction and sustainability.

Coffee is a product with a high commercial value, considered as commodities being a growing culture in several countries mainly in South America (Associação Brasileira Da Indústria Do Café - ABIC, 2017). In coffee processing, one of the wastes generated and representing a large part of the total volume is the coffee husk. The use of coffee residues such as husk, parchment, fibers, ashes and powders and other agricultural by-products has been studied (Ornamet al., 2017; Khurshid et al., 2018; Alzukaimi & Jabrah, 2019). Therefore, the interest in coffee waste in materials is due to the high volume and the presence of lignin, which provides greater cohesion in materials.

Another large-scale agricultural and industrial waste is from wood processing (chips, sawdust and dust). The interest in the use of sawdust is due to the high volume generated as well as the physical and mechanical properties of the wood, being several studies on composites from these residues (Csicsely et al., 2009; Vilane, 2010; Malaiskiene, MacIulaitis, & Kicaite, 2011; Marques et a., 2014; Corrêa et al., 2015; Badea & Dan, 2016; Christoforou et al., 2016; Muñoz et al., 2016; Jokhio, Syed Mohsin, & Gul, 2018; Khurshid et al., 2018).

Adobe is a building material made of soil and water and when necessary natural or synthetic fibers are added (Galán-Marín et al., 2010). Adobe is a material with low energy coefficient compared to ceramic due to the nonoccurrence of burning in its manufacture, significantly reducing its energy cost (Gandia et al., 2018). Adobe presents some challenges such as destabilization in contact with water and low mechanical resistance, but it is a material with excellent thermal comfort. Several works are presented using natural and synthetic residues as well as stabilizers to improve such properties (Corrêa et al., 2006; Galán-Marín et al., 2010; Corrêa et al., 2014; Danso et al., 2015; Nakamatsu et al., 2017; (R.M. Gandia et al., 2019); Gandia et al., 2019).

Ceramic materials are defined as inorganic, non-metallic substances consisting of metallic and non-metallic elements, have hardness, but are fragile, with low toughness and ductility and the increase of mechanical resistance is directly related to the type of burning (temperature and time) (Bauer, 2015). Clays have the function of binder in soil matrix materials; therefore, they are fundamental for the cohesion effect and consequently directly interfere with the physical and mechanical properties of the materials. The most important properties of clays are plasticity, shrinkage and the effect of heat. Natural and synthetic wastes, fibers and stabilizers are also studied to improve the properties of ceramic materials (Menezes et al., 2005; (Pérez-Villarejo et al., 2012; Barbieri et al., 2013; Bories et al., 2015; Velasco et al., 2015; Kazmi et al., 2016; Bonet-Martínez et al., 2018).

Research shows that the influence factor of stabilizers in improving the properties of soil matrix composites is related to several factors such as: residue origin, concentration, particle size (particles) or aspect ratio (fibers). Such factors promote mechanically resistant materials, lightweight, well-defined geometry after drying / burning (linear or volumetric shrinkage), water-resistant, longer durability, better thermal conductors or insulators and other properties.

Among the largest energy expenditures in masonry building materials is the expense due to the firing process characterized by the firing of ceramic materials. Comparing the energetic value of adobe and ceramic solid brick, the author noted that adobe has up to eight times lower energy in production than ceramic brick (R.M. Gandia et al., 2018).

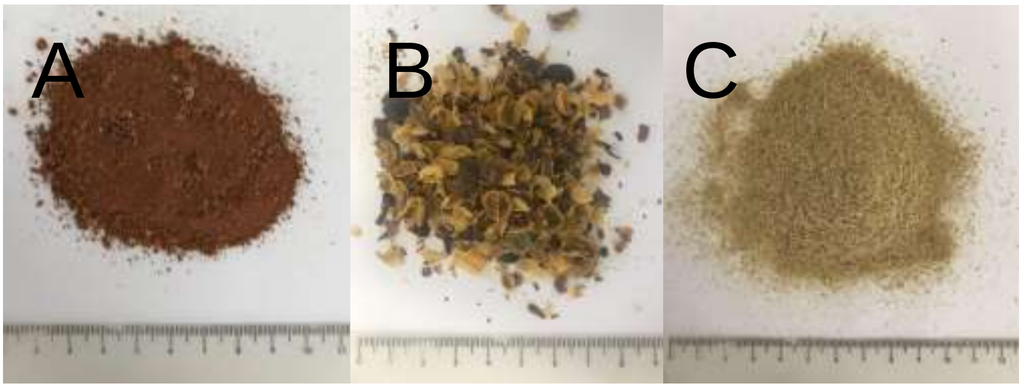
Therefore, the objective of this work was to evaluate the physical and mechanical properties of burning (ceramic) and non-burning (adobe) soil matrix materials according to the incorporation of coffee husk and pine sawdust.

2. Methodology

Introduction and experimental plan

The experiment was conducted at the Federal University of Lavras (UFLA) in the Engineering department. The materials used in the production of composites (Figure 1) were: soil, coffee husk and pine sawdust. All materials were collected at the university. The materials were characterized before the manufacture of the specimens. The reason for the use of this waste was due to the high volume of waste generated in the region and worldwide. To avoid energy expenditure on processing, the wastes were used on the way it was found.

Figure 1. Materials used in the production of treatments.



A). Soil. B) Coffee husk. C) Pine sawdust. Source: Authors.

The specimens were conducted for analysis of compressive strength, bulk density and linear shrinkage. Table 1 shows the quantities of soil, coffee husk and pine sawdust, as well as the burning temperature. The amounts given are related to dry materials (0% humidity).

Table 1. Treatments and compositions.

Treatment	Soil (%)	Coffee husk (%)	Pine sawdust (%)	Water (%)	Burn (°C)
ControlA	70.5	0.0	0.0	29.5	0
ControlB1	70.5	0.0	0.0	29.5	550
ControlB2	70.5	0.0	0.0	29.5	950
B12	70.5	0.0	0.0	29.5	550+950
ACH	60.2	10.0	0.0	29.8	0
B1CH	60.2	10.0	0.0	29.8	550
B2CH	60.2	10.0	0.0	29.8	950
APS	60.2	0.0	10.0	29.8	0
B1PS	60.2	0.0	10.0	29.8	550
B2PS	60.2	0.0	10.0	29.8	950

Source: Authors.

Materials characterization

Soil

The soil was collected at 1.3 meters depth and is characterized as very clayey red latosol (EMBRAPA, 2013). The soil was characterized by texture, consistency limits, specific mass, granulometry and X-ray diffraction.

The texture test was according to NBR 7181 (Associação Brasileira de Normas Técnicas - ABNT, 2016c). The consistency limits test was according to NBR 6459 (Associação Brasileira de Normas Técnicas - ABNT, 2016a), NBR 7180 (Associação Brasileira de Normas Técnicas - ABNT, 2016b), NBR 7183 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - ABNT, 1982). The specific mass of the soil was according NBR NM 52 (Associação Brasileira de Normas Técnicas - ABNT, 2009). Results are presented in Table 2.

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Table 2. Soil properties.

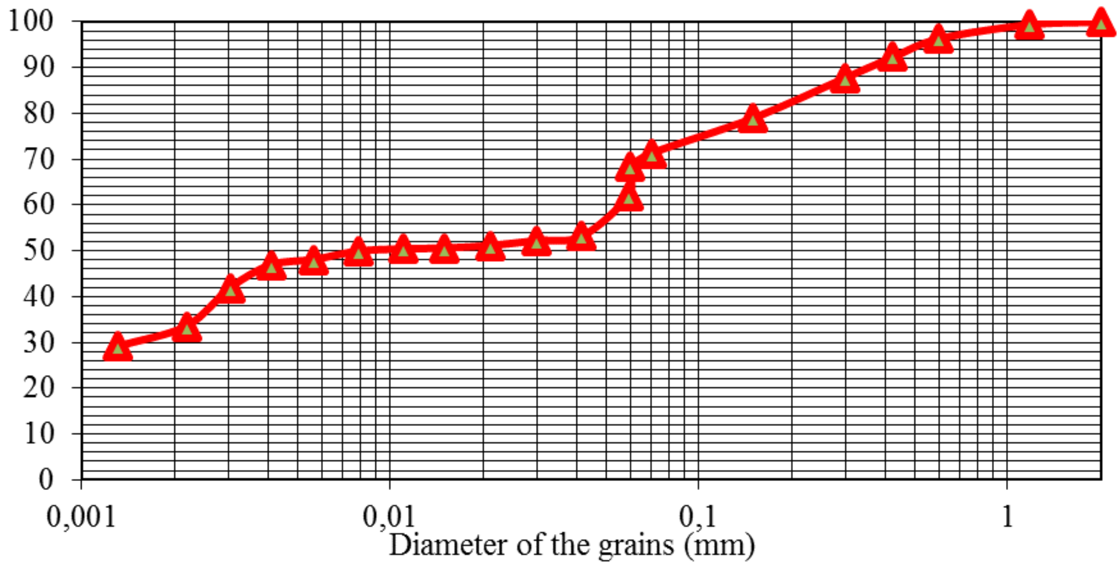
Assay		Soil
Texture (%)	Clay	66
	Silt	6
	Sand	28
Consistency limits (%)	LL	40
	PL	30
	CL	17
Especific mass (g cm⁻³)	-	1.98

LL: liquid limit, PL: plastic limit, CL: contraction limit. Source: Authors.

The ideal amount of water in the composition of the adobe is larger than the PL and smaller than the LL to give workability to the earth mass and limit the amount of water, thus avoiding both large linear shrinkage in the drying process and cracks (Gandia et al., 2019).

The particle size test was according to NBR 7181 (Associação Brasileira de Normas Técnicas - ABNT, 2016c).

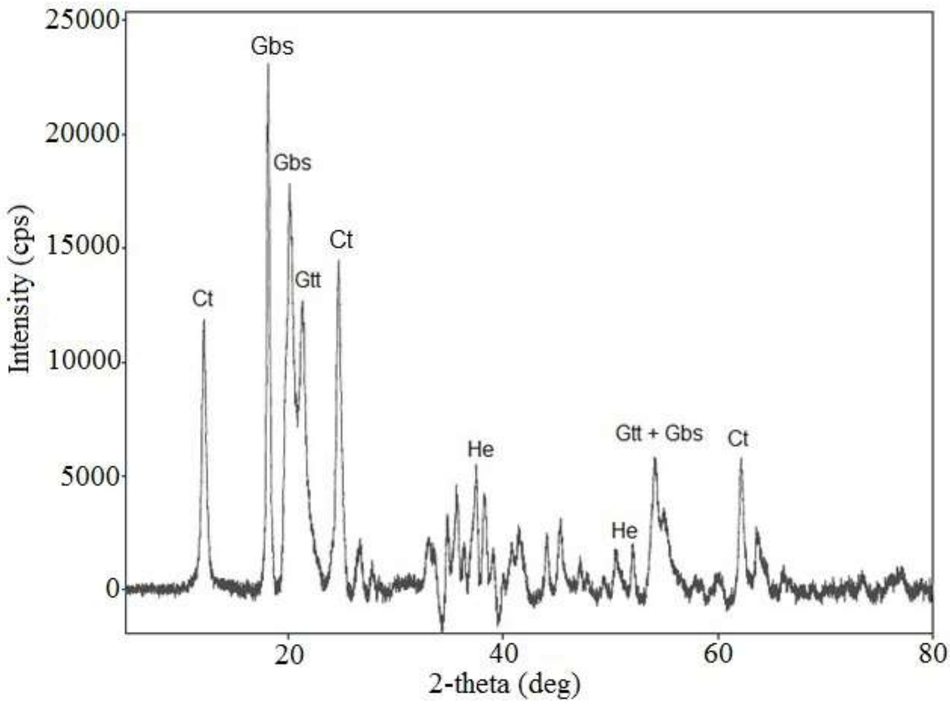
Figure 2. Granulometric curve of the soil.



Source: Authors.

For the X-ray diffraction analysis (Resende et al., 2005), the soil clay separation was done by sieving, which involved separating the organic matter, sand and coarse silt, performing sedimentation by pH difference to remove the fine silt, and using a siphoning process to separate all the clay. The clay was dried in an oven. The X-ray diffraction of the soil shown in Figure 3 indicates the presence of kaolinite. A Rigaku Miniflex 600 was used with a scan range of 5–80° and angular variation of 0.01° 2 theta.

Figure 3. Diffractogram of the clay fraction of soil.



Ct (kaolinite), Gbs (gibsite), Gtt (goethite) and He (hematite). Source: Authors.

X-ray diffraction is important for identifying the type of mineral clay present in the soil to know its behavior. Junior & Kämpf (2005) analyzed the soil in the same region and found the predominant presence of kaolin in the clay part of the soil using X-ray diffraction analysis.

Kaolinite – Ct (1–1) has strong bonds and prevents the adsorption of water with no significant expansion upon water contact, reducing the cracks in the drying process (Corrêa et al., 2006).

Wastes

The GFRP residue after processing was analyzed according to aspect ratio, specific mass, chemical composition, and thermogravimetry. The particles after were analyzed with

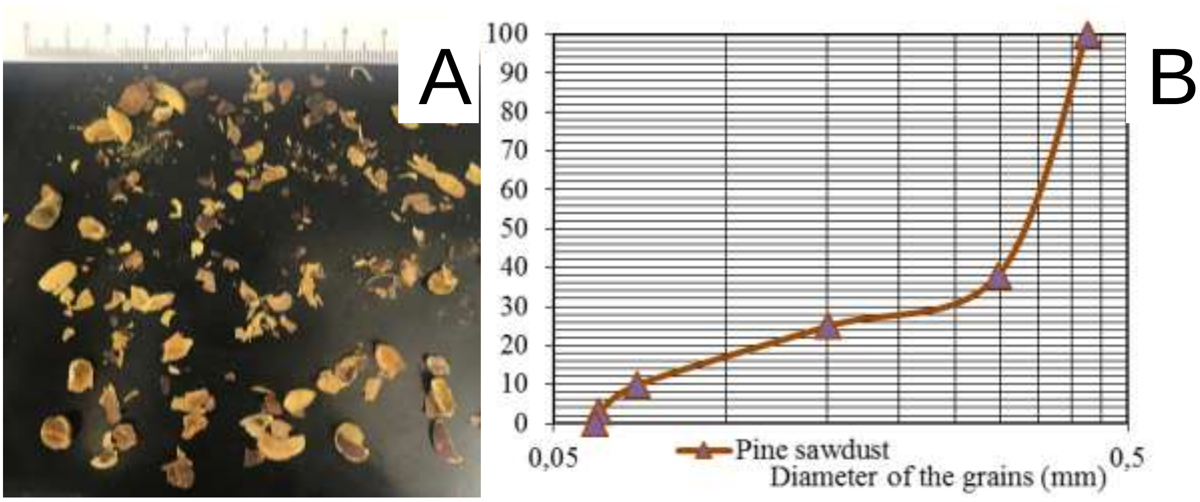
ImageJ software (Figure 3A). Were selected 100 samples of random fibers, finding an average length of 10.507 ± 0.439 mm and an average diameter of 0.04404 ± 0.008 mm. The aspect ratio (L / D) was 238.58.

The sawdust comes from pine wood and the coffee husk comes from arabica coffee. Both materials were characterized by granulometry (for sawdust pinus), aspect ratio (for coffee husk), specific mass, thermogravimetric analysis and chemical analysis.

The particles of coffee husk were analyzed with ImageJ software (Figure 4A). Were selected 100 samples of random particles, finding an average length of 5.958 ± 0.736 mm and an average diameter of 2.027 ± 0.614 mm. The aspect ratio (L / D) was 2.939.

Figure 4B shows the particle size curve of the pine sawdust. About 30% of the particles are in the range of 0.05 to 0.25 mm and 70% of the particles are in the range of 0.25 to 0.4 mm.

Figure 4. Particles of coffee husk and granulometric curve of sawdust pine.



Source: Authors.

The determination of chemical analysis and immediate chemical analysis (Table 3) were performed according to NBR 14853 (Associação Brasileira de Normas Técnicas - ABNT, 2010), NBR 7989 (Associação Brasileira de Normas Técnicas - ABNT., 2010) e NBR 8112 (Associação Brasileira de Normas Técnicas - ABNT., 1986). Holocellulose content was obtained by difference in relation to the other chemical and mineral constituents.

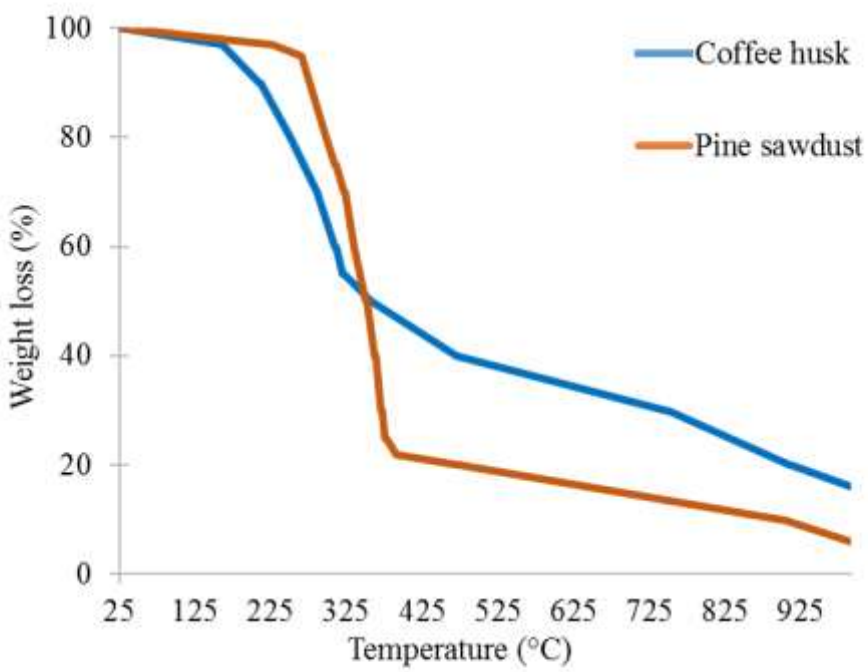
Table 3. Chemical composition of materials.

Analysis		Coffee husk (%)	Sawdust pine (%)
Chemical analysis	Ashes	6.3	1.4
	Extractives	48.2	12.0
	Holocellulose	14.8	62.3
	Total Lignin	30.7	24.3
Immediate chemical analysis	Ash content	8.5	1.2
	Fixed carbon content	24.3	17.6
	Volatile materials	67.2	82.4

Source: Authors.

To determine the composition of the residues, thermogravimetric analysis (ASTM, 2014) was performed (Figure 5). A Shimadzu-DTG 60H analyzer was used. The scans were performed between 25 and 992 °C with a rate of 10 °C min^{-1} under an inert atmosphere of O_2 and flow of 50 $mL.min^{-1}$. It was done in triplicate and the intermediate value was used. The initial weight of both sample was 5.836 mg.

Figure 5. Thermogravimetric graph of coffee husk and sawdust pine.



Source: Authors.

In short, the residues presented three ranges of mass loss: close to 100 ° C, generally attributed to water loss; 250-350ºC, regarding the degradation of hemicelluloses and part of the cellulose and the range between 350 and 500ºC, regarding the degradation of cellulose and lignin (Ouajai & Shanks, 2005).

Pine sawdust has lower thermal stability than coffee pods. Coffee husk showed around 56% of mass loss at 400ºC, while pine sawdust presented around 80%. The reason is attributed to the higher percentage of lignin and fixed carbon present in the coffee husk (Table 3), since lignin is the one that presents higher molecular weight and higher thermal stability due to carbon-carbon bonds between the monomeric units of phenyl-propane (Shafizadeh, 1985).

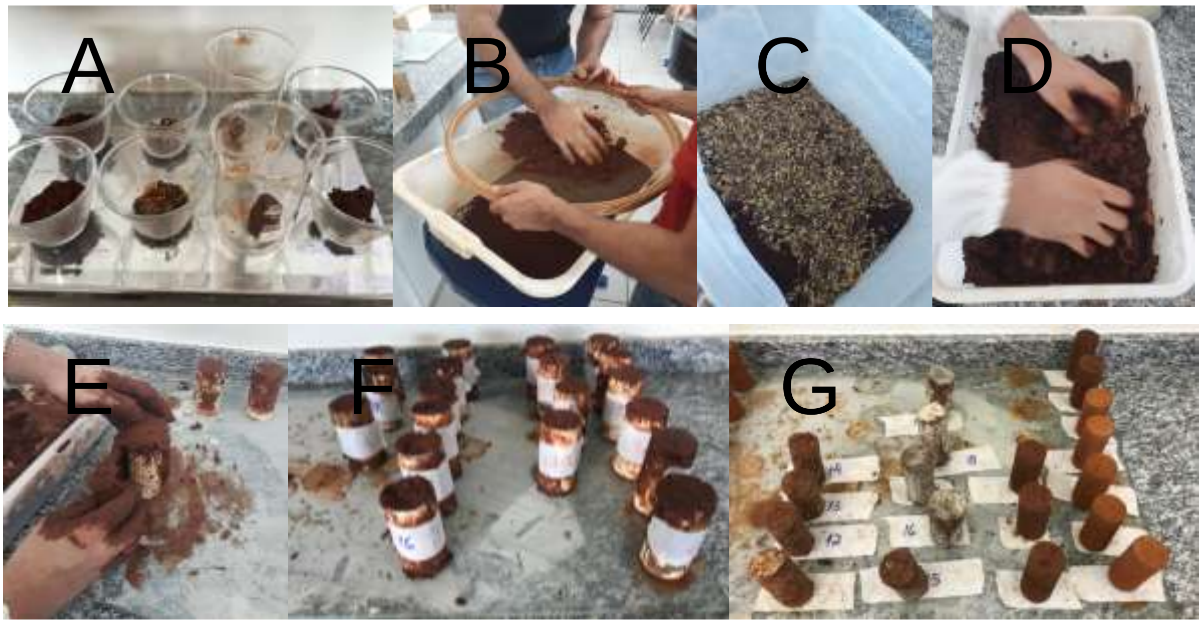
From 400ºC, the mass loss increases continuously and slightly. For coffee husk, there is more significant loss of mass that can be attributed to the release of minerals and salts that are very common in this material (Cimò et al., 2014). It was also observed that pine sawdust presented greater mass loss between 250 and 350ºC (second zone of mass loss) attributed to the high percentage of holocellulose present in these materials (Table 3).

The determination of the specific mass of the residues were made in triplicate (Associação Brasileira de Normas Técnicas - ABNT, 2009). The values obtained were 0.142 ± 0.009 $g.cm^{-3}$ and 0.093 ± 0.006 $g.cm^{-3}$ for coffee husk and sawdust pine respectively. Do Vale et al. (2007) found 1.39 ± 0.02 $g.cm^{-3}$ for coffee husk and Garcez, Santos & Gatto (2013) found .016 $g.cm^{-3}$ for sawdust pine, the specific mass varies depending on the manufacturing and disposal process of each company.

Production of specimens

Before and after production, samples of the materials and specimens (Figure 6A) were collected for laboratory analysis and placed in an oven for 24 h at 103 ± 2 °C for moisture calculation. The soil was air dried and then sieved using a 4.5 mm mesh sieve (Figure 6B). The soil was mixed separately with each residue and using water in the ratio between the liquid limit and then homogenized using the hands (Figure 6C and Figure 56D). The specimens were molded into cylindrical shapes (Figure 6E and Figure 6F). After one week the forms were removed from the specimens for better drying. Subsequently, the specimens were dried and burned (Figure 6G).

Figure 6. Production stages.



Source: Authors.

The cylindrical molds of the specimens have average dimensions of 45.1 mm in diameter and 99.9 mm in height (Associação Brasileira de Normas Técnicas - ABNT, 2015).

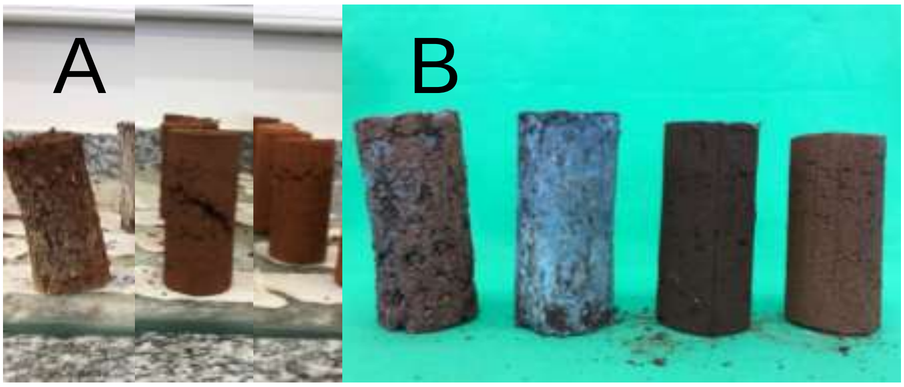
The treatments without burning went through only one step: drying. The drying period was 23 days and was protected from the sun and maintained at ambient temperature until material moisture stabilization (less than 2%) (Corrêa et al., 2015; Gandia et al., 2019).

Burning treatments went through two stages: drying for 23 days; Burns in muffle for 2 hours. The temperature range was divided into 550 and 950 ° C.

Only the "B12" treatment went through four stages: drying for 23 days; burns at 550 ° C; rest for 24 hours; burns at 950 ° C.

After drying and burning, specimens that visually showed large cracks or cracks were discarded. It is noteworthy that most of the samples that were burned and used the waste were discarded (Figure 7).

Figure 7. Visually discarded samples.



Source: Authors.

Specimen Tests

All tests were performed in the same period. Statistical analysis was partially performed using Sisvar software version 5.6 (Ferreira, 2014). The results of each test were statistically analyzed in a single completely randomized design. The Tukey test was used to analyze the significant differences at 5%. Results were plotted using standard deviation within each treatment.

Micro structural visualization was done using an SMZ 1500 epifluorescence (Nikon) stereoscope microscope. The samples were from the specimen fragments after the compressive strength test to visualize and interpret the interaction between the matrix (soil) and the residues (coffee husk and pine sawdust).

The bulk density test was done with 3 randomly chosen specimen. Four measurements were made, two for height and tow for diameter using a 20 cm digital scaling device. The mean of each dimension was calculated by Eq. (1). The mass was determined using a digital scale in grams.

$bd = \frac{m}{v}$ where:

bd is the bulk density in g cm^{-3},
m is the mass in grams (g), and
v is the volume in cubic centimeters (cm^3).

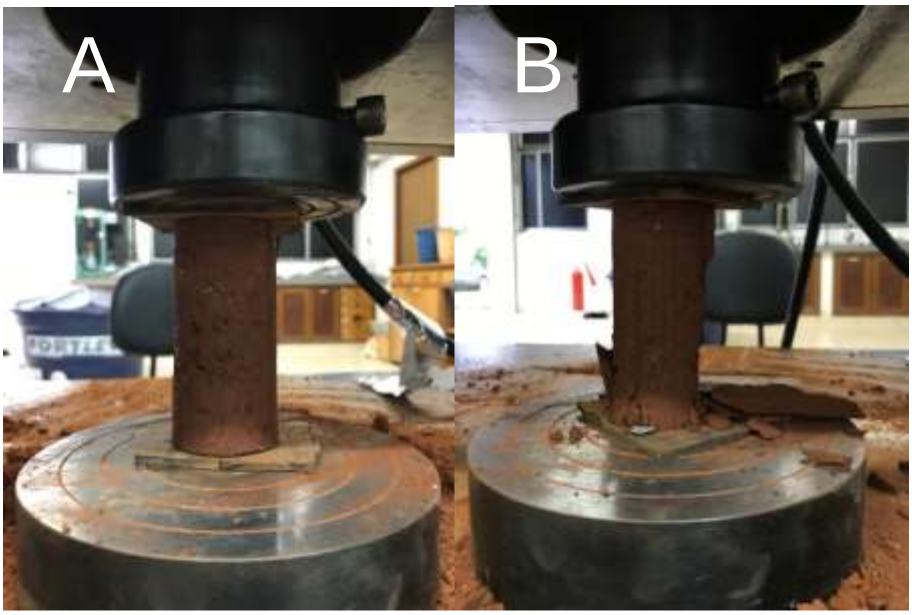
The linear shrinkage test was done with 3 randomly chosen specimen. Two measurements were made on the upper and lower diameter of each sample using a 20 cm digital scaling device. The mean diameter of each sample was calculated. The linear shrinkage was calculated by Eq. (2).

$ls = \frac{md - da}{md} 100$ where:

ls is the linear shrinkage in percentage %,
md is the mold diameter in millimeter (mm), and
da is the diameter after drying/burning in millimeter (mm).

The compressive strength test was done with 3 randomly chosen specimen. The test was performed on a Universal Mechanical Testing Machine with loading load of 0.30 ± 0.06 MPa / min. The loading load was proposed by Faria et al. (2008) and Neves and Faria (2008) who based the project Brazilian standard of adobe (in the process of approval - final phase for approval), the methodology was used by Gandia et al. (2019) and verified the correlation with the results with the NTE E.080 (Norma Técnica de Edificacion - NTE, 2000). The number and name of the project of the standard is: ABNT PN 002:123.009-001 Adobe – Terminology, requirements, production, execution of masonry and test methods (*Adobe – Terminologia, requisitos, produção, execução de alvenaria e métodos de ensaio*). To level the specimens, a rubber was used at both ends of the samples. Figure 8A and Figure 8B show a sample before and after the assay.

Figure 8. Compressive strength test.



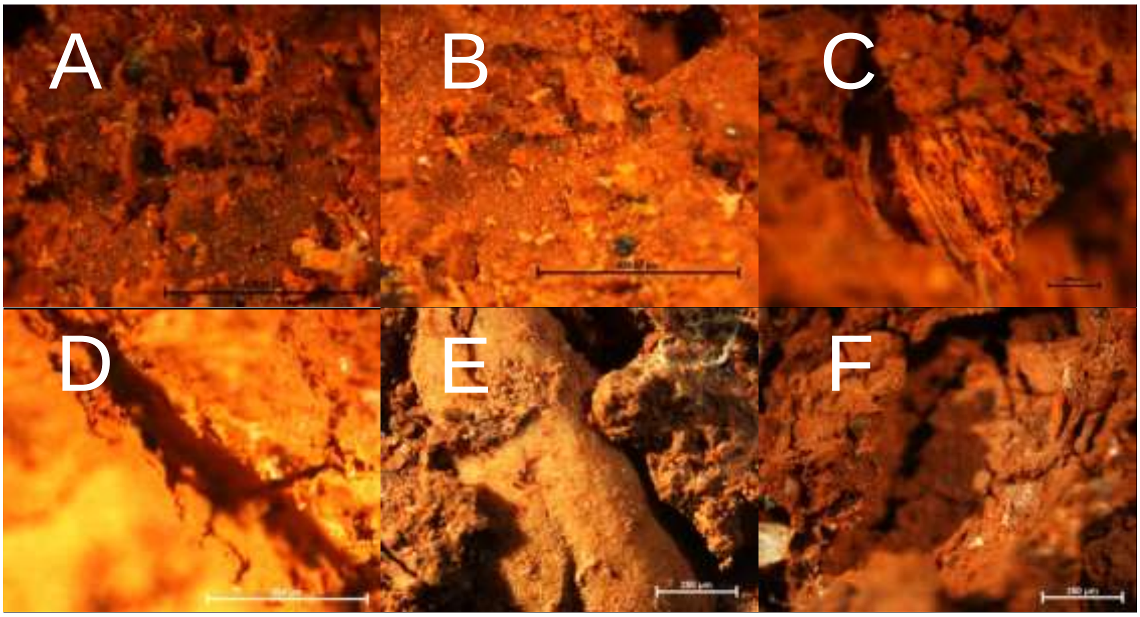
Source: Authors.

3. Results and Discussion

Microstructure

The microstructural interaction between the soil matrix with and without residues after drying and burning is observed using stereoscope microscope is observed in Figure 9.

Figure 9. Fracture surface of specimens microstructure.



A) Adobe. B) Cerâmico. C) Adobe + pine sawdust. D) cerâmico + pine sawdust. E) adobe + coffee husk. F) cerâmico + coffee husk. Source: Authors.

Figure 9A and Figure 9B show the difference between the number and size of pores. Figure 6A shows more pores due to non-burning compared to the vitrified structure in Figure 9B by the burning process.

Figure 9C and Figure 9D show the only dry and burned pine sawdust composite respectively. The non-burning composite shows pine sawdust tied to the soil matrix surrounded by fragile points (pores). The burnt composite presents the pore generated by the pine sawdust due to carbonization, leaving the material with large pores and therefore fragile.

Figure 9C and Figure 9D show the composite with pine sawdust dried and burned respectively, clearly showing pores due to the carbonization of the material. The same occurred with the coffee husk, shown in Figure 4E and Figure 4F, visually the presence of larger pores due to the larger grain size of the coffee husk.

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In the burned treatments, it was visually observed the coarse and non-symmetrical deformation in the geometry of the specimens that were added the residues. This deformation is caused by the high burning temperature that completely charred the waste (observed in Figure 9D and Figure 9F), readjusting the dimensions of the specimens.

In the treatments that were added the residues and only dried, it was visually observed smaller shrinkage in all the geometry. The residues formed a mesh (observed in Figure 9C and Figure 9E) that made it difficult for soil particles to move during water loss. Another reason was due to the interaction of the soil matrix with the residues that accommodated and homogenized, resulting in the packaging of the residues in the soil particles.

Bulk density

Bulk density analysis showed two groups of results variations: waste addition and burning process.

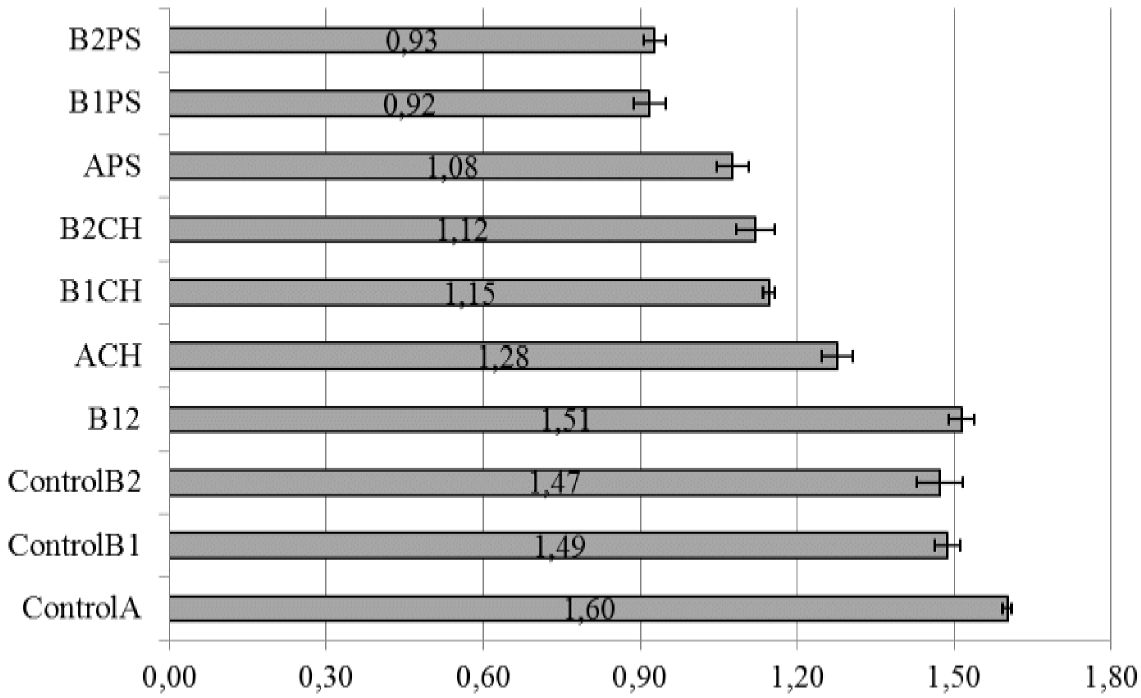
The first group referred to the decrease in bulk density due to the addition of natural residues. Pine sawdust composites had the lowest values followed by coffee husk composites. The composites without the addition of fibers presented the highest values of bulk density.

The second group was represented by the decrease of bulk density due to the burning process, and the composites that underwent the burning process presented the lowest bulk densities.

Therefore, Figure 10 shows five statistically equal results ranges, at 5% confidence by the tukey test, in increasing order of bulk density:

- Burnt sawdust composites (B1PS, B2PS);
- Burned coffee husk and unburnt sawdust composites (B1CH, B2CH, APS);
- Unburnt coffee husk composite (ACH);
- Burnt composites (ControlB1, ControlB2) and
- Unburnt composite (Control).

Figure 10. Mean values of bulk density (g. cm^{-3}).



Source: Authors.

The reason for the decrease in bulk density due to the addition of residues is due to the difference in specific mass between materials. The soil has the highest specific mass (1.98 g.cm^{-3}), followed by coffee husk (0.142 g.cm^{-3}) and pine sawdust (0.093 g.cm^{-3}). Therefore, as the same amounts of coffee husk and pine sawdust (10% by dry weight) were added. The pine sawdust composite had the lowest bulk density, followed by the coffee husk composite and, subsequently, the highest bulk density was the non-addition of residue.

The decrease in bulk density due to the burning effect is explained both by the loss of water (± 120 ° C), the material is completely dry, and also by the higher burning temperature (550 to 950 ° C), the natural waste burns, significantly reducing their mass. It is observed that the coffee husk composites present higher values to pine sawdust even when burned at the same temperature and increased in the same amount, this result is explained by the higher content of fixed carbon and lignin (Table 3) present in the coffee husk.

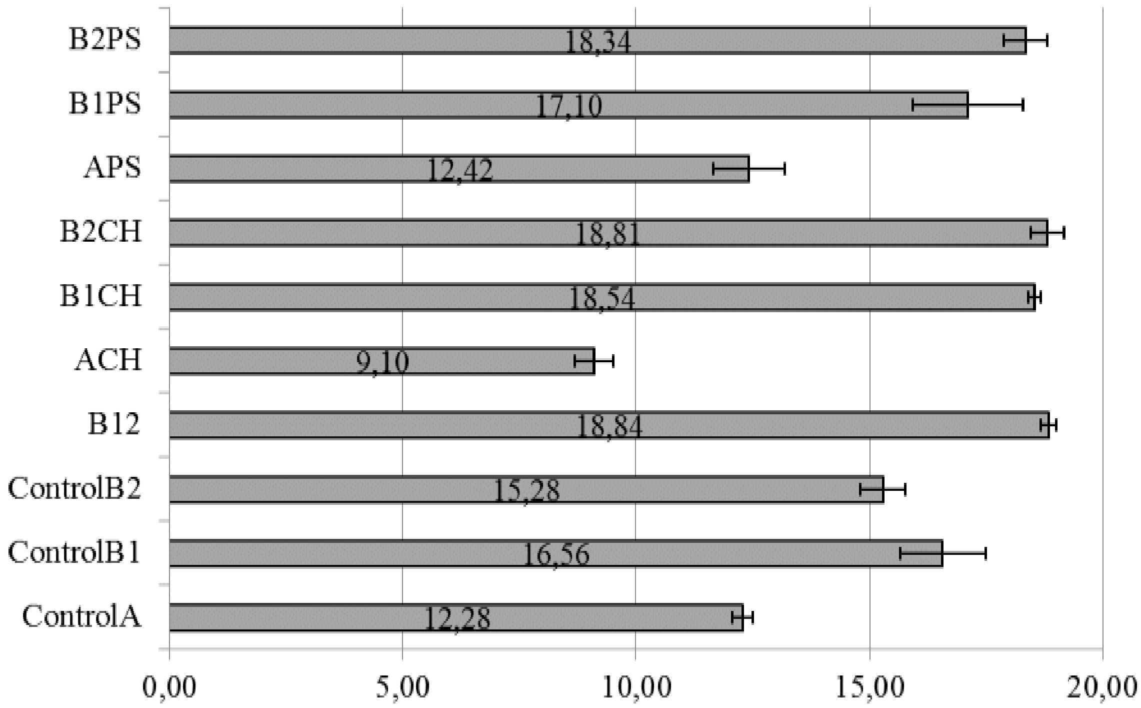
Therefore, the treatment "ControlA" presented the highest bulk density and the treatments "B1PS" and "B2PS" presented the lowest bulk density.

In non-burning materials the use of residues of lower specific mass than the matrix was verified the gradual reduction of bulk density according to the largest addition of the residue (Corrêa et al., 2015; Danso et al., 2015; Gandia et al., 2019). In burned materials, even using ash residues, a small reduction in bulk density was observed according to the addition of the residues (Pérez-Villarejo et al., 2012; Barbieri et al., 2013).

Linear shrinkage

Figure 11 shows the linear shrinkage values, it is observed that the values are inversely proportional to those of bulk density, and may associate that the more the material shrinks the smaller the bulk density.

Figure 11. Mean values of linear shrinkage (%).



Source: Authors.

It was observed that the “ACH” treatment presented the lowest linear shrinkage, since the coffee bark has larger particles than the pine sawdust, allowing a greater reinforcement of the composite, resulting in less linear shrinkage even after the loss of water due to drying.

It is also possible to observe that all treatments burned with residues and “B12” are statistically equal and presented the largest shrinkage. This larger shrinkage is a consequence of the loss of a large amount of mass during the burning process, so the composites realigned themselves in the waste occupied voids (Figure 9D and Figure 9F), explaining the grotesque geometric (Figure 7A) deformation of some specimens. For the treatment “B12”, Bauer

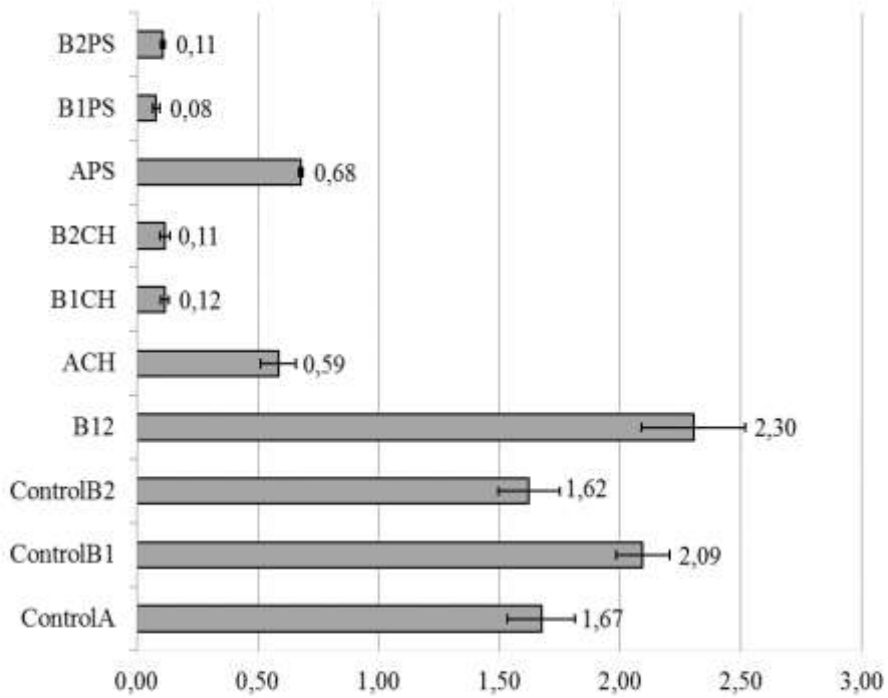
(2008), explains that in the first stage of burning (550 ° C) the material compaction process occurs adhering the soil particles and in the second stage of burning (950 ° C) the vitrification process that fixes the glaze occurs, because of this greater compaction and vitrification the material undergoes a greater linear shrinkage.

In the treatments without burning, the same was observed using natural residues in soil matrix, the decrease of linear shrinkage (Corrêa et al., 2015; Danso et al., 2015; Gandia et al., 2019). In burned materials, the use of ash residues by other authors showed an opposite result, decreasing linear shrinkage according to the addition of ash from the residue (Pérez-Villarejo et al., 2012; (Bories et al., 2015); Velasco et al., 2015; Kazmi et al., 2016; Bonet-Martínez et al., 2018). In this work, as the residue without burning was used, the shrinkage effect was opposite, drastically increasing the linear shrinkage.

Compressive strength

As noted, the treatment that presented the greatest linear shrinkage was “B12” due to two burning processes, consequently to the greater compaction and fixation of the glaze, resulting in greater particle adhesion and greater structure of the material, therefore a higher compressive strength, shown in Figure 12.

Figure 12. Mean values of compressive strength (MPa).



Source: Authors.

The treatments with the lowest compressive strength were the burnt composites with residues. The reason is due to the carbonization of the residue at high temperatures, subsequently increasing the porosity of the material, losing the cohesion between the particles and the structure.

It can be said that two-step burn is essential for the higher quality production process. Treatments "B12" and "ControlB2" were elevated at the same burn temperature and there was a significant difference in the analysis of compressive strength. The difference is due to the one-time rise in temperature (ControlB2) which decreases the quality of the burnt material, as Bauer (2015) explains. When the material is raised to two burn stages, with a cooling period between the stages, it can go through two distinct stages, compressing and fixing the glaze better (Bauer, 2015).

Treatment "ControlB1" (fired at 550 ° C) showed a statistically superior result than treatment "ControlB2" (fired at 950 ° C), stating once again that raising the temperature to 950 ° C at once interferes negatively with the final quality of the material. Making an economic and energy analysis, it can be stated that the ControlA treatment (without burning) statistically equals treatment "B2Control" (burned at 950 ° C), stating the feasibility of using adobe in construction and showing the economy of energy and cost by the firing process and still showing the importance of two-step firing in ceramic materials.

Most research with ceramic materials is used ashes of natural waste or synthetic fibers. In this work it is observed that the compressive strength presents insignificant values. In treatments without burning, the results are also unsatisfactory, it is observed that the compressive strength is reduced by up to 25% of the value without residue.

4. Final Considerations

The replacement of coffee husk and pine sawdust in 10% of the soil matrix interferes with the physical and mechanical properties of unburnt and burnt composites. As well as drying, temperature range and two-step burning also interfere with such properties.

In the case of compressive strength, the replacement of coffee husk and pine sawdust in 10% of the soil matrix negatively affects the materials. In ceramic composites, such interference is due to burning of waste and appearance of pores. Being indicated lower dosages or using residues with higher combustion temperature. In non-burning composites, the viability of using natural waste is restricted to the dosage and size / aspect ratio of the waste. For future research, the use of coffee husk ash is indicated.

Analyzing the physical properties, the replacement of coffee husk and pine sawdust in 10% of the soil matrix interferes positively, decreasing bulk density and linear shrinkage. The composites became lighter and with well-defined edges and geometries. Enabling better workability, better transport logistics and helping in the laying of mortar in masonry.

It was also possible to conclude that the burning process will only be effective and improve the properties of the materials if it is done in two steps, in a controlled manner, positively interfering with the final quality of the material, increasing its mechanical resistance.

References

Alzukaimi, J., & Jabrah, R. (2019). The preparation and characterization of porous alumina ceramics using an eco-friendly pore-forming agent. *International Journal of Applied Ceramic Technology*, *16*(2), 820–831. https://doi.org/10.1111/ijac.13126

Associação Brasileira Da Indústria Do Café - Abic. (2017). *Tendências Do Mercado De Cafés EM 2017*. http://abic.com.br/estatisticas/pesquisas/pesquisa-tendencias-de-consumo/

Associação Brasileira de Normas Técnicas - ABNT. (2010). *NBR 7989. Pulp and wood - Determination of acid-insoluble lignin. Rio de Janeiro, 6 p.* 6.

Associação Brasileira de Normas Técnicas - ABNT. (1986). *NBR 8112. Carvão vegetal - Análise imediata - Método de ensaio. Rio de Janeiro, 5 p.* 5.

Associação Brasileira de Normas Técnicas - ABNT. (2010). *NBR 14853. Wood - Determination of soluble matter in ethanol-toluene and in dichloromethane and in acetone. Rio de Janeiro,*. 3.

Associação Brasileira de Normas Técnicas - ABNT. (2015). *NBR 5738. Concrete - Procedure for molding and curing concrete test specimens, Rio de Janeiro,*. 9.

Associação Brasileira de Normas Técnicas - ABNT. (2016a). *NBR 6459. Soil - Liquid limit determination. Rio de Janeiro, 5p.* 5.

Associação Brasileira de Normas Técnicas - ABNT. (2016b). *NBR 7180. Soil — Plasticity limit determination. Rio de Janeiro, 3 p.* 3.

Associação Brasileira de Normas Técnicas - ABNT. (2016c). *NBR 7181. Soil - Grain size analysis. Rio de Janeiro,. 12*. 12.

Associação Brasileira de Normas Técnicas - ABNT. (2009). *NBR NM 52. Fine aggregate - Determination of the bulk specific gravity and apparent specific gravity. Rio de Janeiro, p. 06*. 6.

Associação Brasileira De Normas Técnicas - ABNT. (1982). *NBR 7183. Determinação do limite e relação de contratação de solos. Rio de Janeiro. 3 p.* 3.

ASTM. (2014). *ASTM E1131. Standard Test Method for Compositional Analysis by Thermogravimetry. ASTM International, West Conshohocken, PA*.

Badea, C., & Dan, S. (2016). Unburned clay bound building materials for masonry. *Materiale Plastice*, *53*(4), 681–684.

Barbieri, L., Andreola, F., Lancellotti, I., & Taurino, R. (2013). Management of agricultural biomass wastes: Preliminary study on characterization and valorisation in clay matrix bricks. *Waste Management*, *33*(11), 2307–2315. https://doi.org/10.1016/j.wasman.2013.03.014

Bauer, F. A. F. (2015). *Materiais De Construcao - Volume 2 (5a ed.)*, LTC.

Bonet-Martínez, E., Pérez-Villarejo, L., Eliche-Quesada, D., Sánchez-Soto, P. J., Carrasco-Hurtado, B., & Castro-Galiano, E. (2018). Manufacture of sustainable clay ceramic composite with composition SiO2-Al2O3-CaO-K2O materials valuing biomass ash from olive pomace. *Materials Letters*, *229*, 21–25. https://doi.org/10.1016/j.matlet.2018.06.105

Bories, C., Aouba, L., Vedrenne, E., & Vilarem, G. (2015). Fired clay bricks using agricultural biomass wastes: Study and characterization. *Construction and Building Materials*, *91*, 158–163. https://doi.org/10.1016/j.conbuildmat.2015.05.006

Christoforou, E., Kylili, A., Fokaides, P. A., & Ioannou, I. (2016). Cradle to site Life Cycle Assessment (LCA) of adobe bricks. *Journal of Cleaner Production*, *112*, 443–452. https://doi.org/10.1016/j.jclepro.2015.09.016

Cimò, G., Kucerik, J., Berns, A. E., Schaumann, G. E., Alonzo, G., & Conte, P. (2014). Effect of heating time and temperature on the chemical characteristics of biochar from poultry manure. *Journal of Agricultural and Food Chemistry*, *62*(8), 1912–1918. https://doi.org/10.1021/jf405549z

Corrêa, A. A. R., de Paula Protásio, T., de Lima, J. T., Tonoli, G. D., & Mendes, L. M. (2014). Mechanical Properties of Adobe Made with Sugar Cane Bagasse and “Synthetic Termite Saliva” Incorporation. *Key Engineering Materials*, *634*, 351–356. https://doi.org/10.4028/www.scientific.net/kem.634.351

Corrêa, A. A. R., Mendes, L. M., Barbosa, N. P., De Paula Protásio, T., De Aguiar Campos, N., & Tonoli, G. H. D. (2015). Incorporation of bamboo particles and “synthetic termite saliva” in adobes. *Construction and Building Materials*, *98*, 250–256. https://doi.org/10.1016/j.conbuildmat.2015.06.009

Corrêa, A. A. R., Teixeira, V. H., Lopes, S. P., & Oliveira, M. S. de. (2006). Avaliação Das Propriedades Físicas E Mecânicas Do Adobe (Tijolo De Terra Crua) Evaluation of physical and mechanical properties of adobe bricks. *Scielo*, *30*(3), 503–515. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1413-70542006000300017

Csicsely, Á. O., Józsa, Z., & Sajtos, I. (2009). Analysis of Adobe-Clay as an Envorinmental-Friendly Structural Material. *Materials Science Forum*, *537–538*, 17–24. https://doi.org/10.4028/www.scientific.net/msf.537-538.17

Danso, H., Martinson, D. B., Ali, M., & Williams, J. B. (2015). Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres. *Construction and Building Materials*, *101*, 797–809. https://doi.org/10.1016/j.conbuildmat.2015.10.069

do Vale, A. T., Gentil, L. V., Goncalez, J. C., & da Costa, A. F. (2007). Caracterização Energética e Rendimento da Carbonização de Resíduos de Grãos de Café e de madeira Duke.

Cerne, *13*(4), 416–420.

EMBRAPA. (2013). *Brazilian system of soil classification* (3rd ed.).

Faria, O. B., Oliveira, B. M. de, Tahira, M., & Battistelle, R. A. G. (2008). Realização Do Programa Interlaboratorial Proterra. *TerraBrasil*, 1–12.

Ferreira, D. F. (2014). Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*, *38*(2), 109–112. https://doi.org/10.1590/s1413-70542014000200001

Galán-Marín, C., Rivera-Gómez, C., & Petric, J. (2010). Clay-based composite stabilized with natural polymer and fibre. *Construction and Building Materials*, *24*(8), 1462–1468. https://doi.org/10.1016/j.conbuildmat.2010.01.008

Gandia, R.M., Campos, A, T., Corrêa, A, A, R., & Gomes, F, C. (2018). Energy costs comparison of masonry made from different materials. *THEORETICAL AND APPLIED ENGINEERING*, *2*(1), 1–8. http://www.taaeufla.deg.ufla.br/index.php/TAAE/issue/view/5/R1023

Gandia, R.M., Gomes, F. C., Corrêa, A. A. R., Rodrigues, M. C., & Mendes, R. F. (2019). Physical, mechanical and thermal behavior of adobe stabilized with glass fiber reinforced polymer waste. *Construction and Building Materials*, *222*, 168–182. https://doi.org/10.1016/j.conbuildmat.2019.06.107

Gandia, Rômulo M, Corrêa, A. A. R., Gomes, F. C., Marin, D. B., & Santana, L. S. (2019). PHYSICAL, Mechanical And Thermal Behavior Of Adobe Stabilized With " SYNTHETIC TERMITE SALIVA ". *Engenharia Agrícola*, *39*(2), 139–149. https://doi.org/http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v39n2p139-149/2019 PHYSICAL,

Garcez, Mônica, R., Santos, T., & Gatto, Darci, A. (2013). Avaliação Das Propriedades Físicas E Mecânicas De Concretos Pré-Moldados Com Adição De Serragem Em Substituição Ao Agregado Miúdo. *Science & Engineering Journal*, *22*(2), 95–104.

Jokhio, G. A., Syed Mohsin, S. M., & Gul, Y. (2018). Two-fold sustainability - Adobe with sawdust as partial sand replacement. *IOP Conference Series: Materials Science and Engineering*, *342*(1). https://doi.org/10.1088/1757-899X/342/1/012069

Junior, A. V. I., & Kämpf, N. (2005). Variabilidade De Goethita E Hematita Via Dissolução Redutiva Em Solos De Região TropicaL E SUBTROPICAL. *Revista Brasileira de Ciência Do Solo*, *29*(6), 851–866.

Kazmi, S. M. S., Abbas, S., Saleem, M. A., Munir, M. J., & Khitab, A. (2016). Manufacturing of sustainable clay bricks: Utilization of waste sugarcane bagasse and rice husk ashes. *Construction and Building Materials*, *120*, 29–41. https://doi.org/10.1016/j.conbuildmat.2016.05.084

Khurshid, I., Ahmad, S., Nawaz, R., Arshad, M., Dar, M. E. U. I., Imran, M., Aslam, F., Nasir, R., Shah, G. M., Ahmad, N., & Naeem, M. A. (2018). Development of fire bricks from organic waste: An eco-friendly energy solution. *Applied Ecology and Environmental Research*, *16*(4), 3919–3932. https://doi.org/10.15666/aeer/1604_39193932

Malaiskiene, J., MacIulaitis, R., & Kicaite, A. (2011). Dependence of ceramics physical-mechanical properties on chemical and mineralogical composition. *Construction and Building Materials*, *25*(8), 3168–3174. https://doi.org/10.1016/j.conbuildmat.2010.12.047

Marques, M. L., Silva, E. J., Velasco, F. G., & Fornari Junior, C. C. M. (2014). Potencialidades Do Uso De Resíduos De Celulose (Dregs/Grits) Como Agregado Em Argamassas. *Revista Brasileira de Produtos Agroindustriais*, *16*(4), 423–431. https://doi.org/10.15871/1517-8595/rbpa.v16n4p423-431

Menezes, R. R., Ferreira, H. S., Neves, G. A., Lira, H. de L., & Ferreira, H. C. (2005). Use of granite sawing wastes in the production of ceramic bricks and tiles. *Journal of the European Ceramic Society*, *25*(7), 1149–1158. https://doi.org/10.1016/j.jeurceramsoc.2004.04.020

Muñoz V., P., Morales O., M. P., Letelier G., V., & Mendívil G., M. A. (2016). Fired clay bricks made by adding wastes: Assessment of the impact on physical, mechanical and thermal properties. *Construction and Building Materials*, *125*, 241–252. https://doi.org/10.1016/j.conbuildmat.2016.08.024

Nakamatsu, J., Kim, S., Ayarza, J., Ramírez, E., Elgegren, M., & Aguilar, R. (2017). Eco-friendly modification of earthen construction with carrageenan: Water durability and mechanical assessment. *Construction and Building Materials*, *139*, 193–202. https://doi.org/10.1016/j.conbuildmat.2017.02.062

Neves, C., & Faria, O. B. (2008). Programa Interlaboratorial Proterra . Ensaios De Adobe. *TerraBrasil*, *2*(1), 1–10.

Norma Técnica de Edificacion - NTE. (2000). *NTE E.080. Reglamento nacional de construcciones.*

Ornam, K., Kimsan, M., Ngkoimani, L. O., & Santi. (2017). Study on Physical and Mechanical Properties with Its Environmental Impact in Konawe - Indonesia upon Utilization of Sago Husk as Filler in Modified Structural Fly Ash - Bricks. *Procedia Computer Science, 111*(2015), 420–426. https://doi.org/10.1016/j.procs.2017.06.043

Ouajai, S., & Shanks, R. A. (2005). Composition, structure and thermal degradation of hemp cellulose after chemical treatments. *Polymer Degradation and Stability*, *89*(2), 327–335. https://doi.org/10.1016/j.polymdegradstab.2005.01.016

Pérez-Villarejo, L., Eliche-Quesada, D., Iglesias-Godino, F. J., Martínez-García, C., & Corpas-Iglesias, F. A. (2012). Recycling of ash from biomass incinerator in clay matrix to produce ceramic bricks. *Journal of Environmental Management*, *95*(SUPPL.), S349–S354. https://doi.org/10.1016/j.jenvman.2010.10.022

Resende, M., Curi, N., Ker, J. C., & Rezende, S. B. (2005). *Mineralogia de solos brasileiros: interpretação e aplicações* (UFLA (ed.)). UFLA.

Shafizadeh, F. (1985). Pyrolytic reactions and products of biomass. In: Fundamentals of Biomass Thermochemical Conversion. *Elsevier*, 183–217. https://doi.org/10.1007/978-94-009-4932-4_11

Velasco, P. M., Ortiz, M. P. M., Giró, M. A. M., Melia, D. M., & Rehbein, J. H. (2015). Development of sustainable fired clay bricks by adding kindling from vine shoot: Study of thermal and mechanical properties. *Applied Clay Science*, *107*, 156–164. https://doi.org/10.1016/j.clay.2015.01.017

Vilane, B. R. T. (2010). Assessment of stabilisation of adobes by confined compression tests. *Biosystems Engineering*, *106*(4), 551–558. https://doi.org/10.1016/j.biosystemseng.2010.06.008

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