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Characterization of briquettes made of cassava stalk

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Abstract: *Biomass is one of the mains means of exploiting renewable energy. The growth in heavy fuel use increases around 8% per year and the market for this fuel had a growth forecast of 40 to 50 million tons in 2020. In this scenario, the study of the different biomasses, it is necessary to show new waste for use in energy production. For the densification process, it is necessary to know about variables like pressing time, granulometry and compression force. This work aimed to characterize briquettes made from the cassava stalk biomass (Manihot esculenta Crantz). The waste was dried at 12% humidity, ground and sieved with 16 mesh e 42 mesh granulometry. It was made 24 briquettes equally divided into 12 briquettes of 16 mesh and 12 briquettes of 42 mesh. Two forces were applied to form the briquettes, one force was 10.000 kgf, and another was 20.000 kgf; for pressing time for 1 and 2 minutes. The bulk density was 0.14 g.cm-3 (for 16 mesh) and 0.11 g.cm-3 (for 42 mesh). It obtained a high heat value (HHV) of the cassava of 17,81 MJ.kg-1. The immediate analysis for cassava stalk obtained 22.43 ± 0.09%, 73.25 ± 0.05% and 4.33 ± 0.06% for ash, volatile and fixed carbon. To mechanical resistance, it was obtained for treatment 42 mesh with a force of 20000 kgf and pressing time of 2 minutes, the highest mechanical resistance being 1,61 MPa. All briquettes were resistant to stacking, showing values above 20 m in height. ANOVA statistical analysis showed that the applied pressure and granulometry used for the experiment were significant. Cassava stalk is a good material for burning and energy production, presenting an excellent high heat value.*

Keywords: *Bioenergy, Energy, Cassava stalk, Fuel, Mechanical resistance.*

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I. INTRODUCTION

The use of energy sources from coal, oil, and natural gas has grown linearly to meet population growth and energy demand. The use of fossil fuels has led to an increase in greenhouse gases, creating the need for studies on renewable energy sources, demonstrating that biomass is a viable alternative because it is clean, less aggressive to the environment and highly available worldwide (Obi et al., 2016).

The world energy consumption will grow by 56% from 2010 to 2040. Due to environmental and economic impacts, there is a growing demand for renewable energies, and in particular solid fuels have an ever increasing market since 2012, around 300% (Bajwa et al., 2018).

Biomass crops generate a significant amount of waste, either in the field, during the harvest phase (agricultural waste), or in the processing phase in agro-industries (agro-industrial waste), where they are generally used as animal feed or soil fertilization. We can cite as an example of biomass, bagasse cane, cassava, rice, cobs in which have proved widely used for energy densification processes (Souza et al.,2016; Eddine et al., 2012).

On a global scale, more than 3 billion people are deprived of access to modern energy alternatives. These people live in developing countries and rely on traditional biomass resources to meet their basic energy needs. Therefore, the central premise of the global energy strategy aims to shift away from using high-cost fossil fuels and minimising environmental damage to cost-effective renewable energies obtained from renewable resources (biomass, wind, hydro and solar) (Guta et al.,2012; Baqir et al., 2018).

Cassava is produced in the tropics for the production of roots. It is considered the most Brazilian of crops because it originated in Brazil and is cultivated throughout the national territory. Its production generates a large yield of biomass and being resistant in environments that other species would not survive. The aerial part of the plant is formed by thick and thin stalks, petioles and leaves, and the lower part consists of roots and seeds. (Veiga et al., 2016; Embrapa, 2014).

According to the Brazilian Institute of Geography and Statistics (IBGE) (2020), analysing data from the 2019 crop, the area planted with cassava was 1.4 million per hectares, and harvested area reached 1.2 million per hectares, with average productivity of 18.9 t/ha. The states with the highest yields are in the Southeast (São Paulo), South (Paraná and Santa Catarina) and Northeast (Sergipe, Alagoas and Bahia) regions (IBGE, 2020)

Studies developed in recent decades expose the intention to reduce firewood use as an energy source, encouraging the use of plant biomass waste. These studies can be used directly as an energy source or, still, transformed into briquettes, serving as fuel for ovens in bakeries, pizzerias, among other purposes showing the feasibility of briquetting from agroindustrial waste. There is not a variety of works focusing on cassava waste, which justifies this experiment's relevance to analyze and evaluate the cassava stalk for the process of energy densification given the high productivity of culture in Brazil (Paula et al., 2011).

In this context, to affirm and indicate that a given material is a good energy generator, it is necessary to characterise it is using physical-chemical analyses, which will show the product's viability (Marozzi et al., 2012).

This work analysed the biomass of the cassava stalk concerning the pressing time. The force applied for the confection of briquettes also made the immediate chemical analysis, volumetric variation over time, mechanical strength test, storage capacity and statistical analysis of significance ANOVA

II. EXPERIMENTAL PROCEDURE

1.1 Bulk Density and Moisture Content

The cassava stalk used was collected in the settlement Porto Maria located in the region of Rosana - SP with the coordinates 22°25'37.80" S; 52°48'22.11" O and underwent a pre-treatment which consisted in drying the material. The moisture content was measured using a moisture balance (Figure 1), obtaining a value of 11.71%, and the cassava was milled.

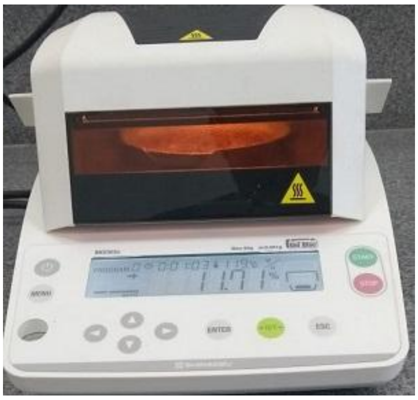

Figure 1: Moisture measuring scale

The desired grain sizes were obtained by grinding and separating the material through the sieving process and chose the particle size of 16 mesh and 42 mesh. We used DIN EM 17828 standard for bulk density analysis. To determine the volume, we use a 250 ml beaker and an analytical balance to determine the mass for each particle size of 16 mesh and 42 mesh, and we made three measurements. Equation (1) shows how to calculate the bulk density.

$$d = \frac{m}{v} \qquad (1)$$

where d (g cm^3) is the density, m is the mass of the briquette (g) and v is its volume (cm^3).

It used a hydraulic piston press (Figure 2) with cylindrical stainless steel mould (Figure 3) for energy densification to produce briquettes. It made twelve briquettes from 16 mesh and 42 mesh. For built each briquette, it used 20 g of cassava stalk. The material was pressured in the cylindrical mould with two forces: 10000 kgf and 20000 kgf, at intervals of 1 minute and 2 minutes.

Figure 2: Hydraulic piston press

Figure 3: stainless steel mould

1.2 Volumetric expasion

After making the briquettes, the dimensions were measured at time intervals of 1, 3, 5, 7, 24 and 48 hours so that the volumetric expansion rate of the briquette could be determined over time, using Equation (2).

$$EV = \frac{Vol2 - Vol1}{Vol1} 100 \quad (2)$$

where EV (%) represents the rate of volumetric expansion of briquettes, Vol1 (cm^3) is briquette volume immediately after compaction and Vol2 (cm^3) is briquette volume 48h after compaction.

1.3 Proximate analysis

It performed the proximate analysis of the material following the NBR 8112 standard, where the contents of volatile materials, ash and fixed carbon were determined.

The volatile content, ash and fixed carbon have used the Equation (3), Equation (4) and Equation (5), respectively.

$$TV = \frac{m2 - m3}{m} 100 \quad (3)$$

where TV (%) is the volatile material content, m2 (g) is the initial mass of crucible + sample, m3 (g) is the final mass of crucible + sample and m (g) is the mass of the sample.

$$TZ = \frac{mcf - mci}{m} 100 \quad (4)$$

where TZ (%) represents the ash content, mci (g) is the initial mass of the crucible, mcf (g) the final mass of the crucible + residue and m (g) is the mass of the sample.

$$TCF = 100 - (TV + TZ) \quad (4)$$

where TCF (%) is the fixed carbon content, TV (%) is the volatile material content and TZ (%) is the ash content.

1.4 Statistics

Statistical analysis was performed using the ANOVA test at 95% significance level, analysing whether the factor granulometry, pressure and pressing time was significant for the experiment.

1.5 Mechanical Test

It carried out the test of resistance to traction by diametral compression described in the norm ABNT NBR 7222. The briquette was compressed with a speed of 3.0 mm min-1 in the radial direction because it is the position that presents less resistance of materials with cylindrical forms. For each treatment, it made five repetitions. The maximum strength and deformation were obtained with equation (6) (Chrisostomo, 2011).

$$\sigma_{Tx} = 2 * \frac{F}{(\pi * \emptyset * l)} \quad (6)$$

where σ_Tx (MPa) represents the tensile strength by diametrical compression, 2 is a dimensionless constant, F (kN) is the applied force, ∅ (mm) is the diameter of the briquette and l (mm) is the length or height of the briquette.

1.5.1 Número de amostras empilhadas

The number of vertically stacked samples (N_emp) serves as a basis for determining the maximum amount of stacked pieces that treatment may handle during storage or transportation. It was calculated by the maximum breaking force (F_Mrup), a safety factor (f_s) with an average sample mass of 20 g. The compaction test provides F_Mrup. The f_s was considered to be 300%, i.e. it decreases the F_Mrup by three times. Equation (7) shows such an analysis (Silva et al., 2015).

$$N_{emp} = \frac{F_{Mrup}}{f_s * 0{,}020} \quad (7)$$

1.5.2 Stacking height

In the test of several stacked samples (N_emp), it is possible to calculate the stacking height (H_emp), which allow us to analyze the maximum heigh that the briquettes can be stacked so that they do not suffer rupture in their dimensions. Given that the samples' diameter is, on average, 3.5 cm, the height is given by Equation (8) (Silva et al., 2015).

$$H_{emp} = \frac{N_{emp} * 3{,}5}{100} \quad (8)$$

III. RESULTS AND DISCUSSIONS

3.1 Bulk Density

It carried out three measurements of the material's bulk density. Table 1 shows the average of the results.

Table 1: Material’s Bulk density.

MATERIAL	MASS (g)	DENSITY (g/cm^3)	DENSITY (kg/m^3)
Cassava stalk (16 mesh)	34,61±1,27	0,14±0,01	138,43±5,09
Cassava stalk (42 mesh)	27,13±3,11	0,11±0,01	108,51±12,43
Sugar cane bagasse	-	0,16 (Fernandez et al. 2017)	150,00 (Ribeiro, 2012)
Rice Husk	-	-	135,00 (Omoniyi, 2016)
Pinus	-	0,17 (Fernandez et al. 2017)	-

In comparison analysis, Ribeiro (Ribeiro et al., 2012determined that the density of sugarcane bagasse is around 150.00 kg/m3. The average values found in the cassava stalk were 138.43 kg/m3 for granulometry of 16 mesh and 108.51 kg/m3 for the granulometry of 42 mesh.

Also, on a relative level, Omoniyi and Igbo (Omoniyi, 2016) obtained in their analysis a density value for rice husk of 135.00 kg/m3; the numerical value differs from the crude due to the low density of rice husk.

Fernandez et al. (Fernandez et al. 2017)obtained the value of 0.16 g/cm3 density for sugar cane bagasse and 0.17 g/cm3 for pine, values close to those found for cassava stalk.

So, cassava stalk presented a lower value in bulk density when compared to sugarcane bagasse, rice husk and pine (Ribeiro, 2012; Omoniyi, 2016; Fernandez et al. 2017).

3.2 Volumetric expasion

It produced twenty-four units of briquettes being 12 in the granulometry of 16 mesh and 12 in the granulometry of 42 mesh. It made briquettes applying the pressure and pressure time, as showed in Table 2. After this process, it carried the height and volume measure to analyse the volumetric expansion in the times of 0h, 1h, 3h, 5h, 7h, 24h and 48h (Figure 4 and Figure 5)

Table 2: Numbering and corresponding treatments.

NUMBERING	TREATMENT
1	16 MESH 10 TONELADAS 1 MINUTO
2	16 MESH 10 TONELADAS 2 MINUTOS
3	16 MESH 20 TONELADAS 1 MINUTO
4	16 MESH 20 TONELADAS 2 MINUTOS
5	42 MESH 10 TONELADAS 1 MINUTO
6	42 MESH 10 TONELADAS 2 MINUTOS
7	42 MESH 20 TONELADAS 1 MINUTO
8	42 MESH 20 TONELADAS 2 MINUTOS

The volumetric expansion measured was performed with a digital pachymeter. It can be observed in Figure 4 and Figure 5 the behaviour of the briquettes over time. The expansion can be seen, in terms of percentage, in Table 3.

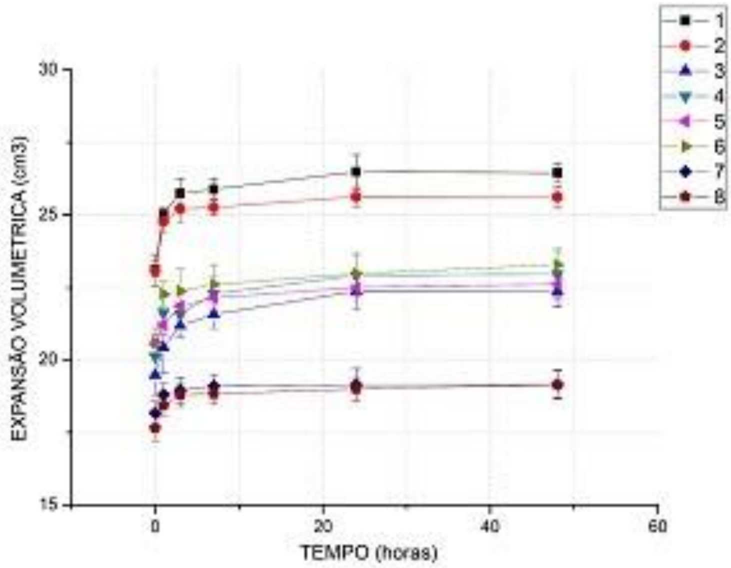

Figure 4: Volumetric expansion of briquettes considering all times.

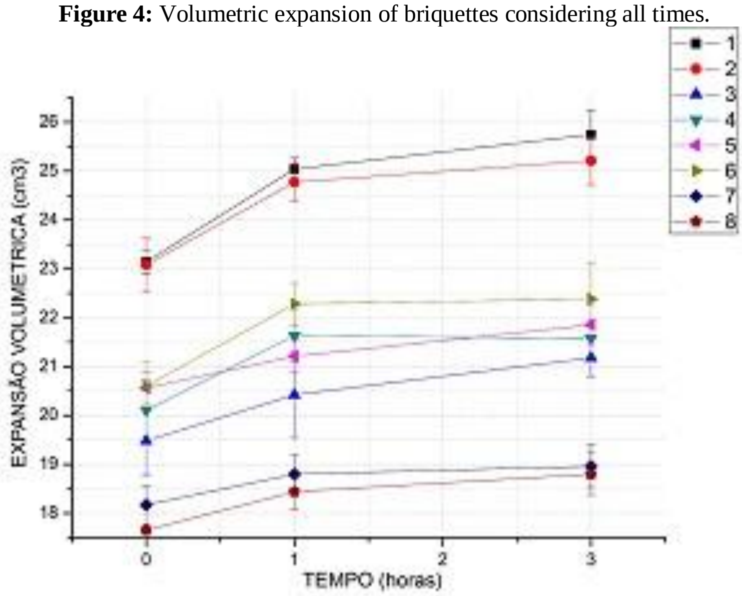

Figure 5: Volumetric expansion of briquettes considering the initial three hours.

Table 3: Volumetric Expansion

NUMBERING	VOLUMETRIC EXPANSION ($\Delta V(\%)$)
1	14,30
2	10,96
3	14,78

4	14,12
5	9,97
6	13,01
7	5,39
8	8,50
Casca de Eucalyptus	1,56 [17]

According to Sette Junior et al., (Sette et al., 2018), a volumetric expansion in the bark of Eucalyptus uro-grandis was 1.56%. This study's lowest value was 5.39%; this difference is due to the biomass's composition in question.

Rahaman and Salam (Rahaman et al., 2017) analyzed a volumetric expansion considering the pressure in different moulds and biomass particles' sizes. For the briquettes used with separation of 9.50 mm, pression of compaction of 48.30 MPa, the volumetric expansion found after 24 hours was 81.90%. The largest volumetric expansion was 14.78% for treatment 3. Treatment 3 had a force of 20000 kgf applied during 1 minute for the granulometry of 16mesh.

The lower volumetric expansion of the cassava stalk briquettes indicated an excellent grouping between the particles. It is believed that the volumetric expansion of the material is related not only to the granulometry but also with the characterization and constituents of its fibres (**Fernandez et al. 2017)**.

3.3 Proximate Analysis

It performed the proximate analysis and the analysis of high heat value (HHV). For the cassava stalk, it obtained for HHV the value 17.81 MJ / kg.

Table 4 presents data on the ash content, volatile content and fixed carbon content.

Table 4: Proximate Analysis

MATERIAL	ASH (%)	VOLATILE CONTENT (%)	FIXED CARBON (%)
Cassava stalk	22,43±0,09	73,25±0,05	11,53±0,06
Pterocarpus indicus	10,10 (Anggono et al.,2018)	67,90 (Anggono et al.,2018)	-
Sugarcane bagasse	-	84,00 (ALÓ et al., 2017)	
Sugarcane	39,55 (Anastaya et al.,2019)	57,72 (Anastaya et al.,2019)	-
Bamboo	-	81,00 (Brand et al., 2019)	16,40 (Brand et al., 2019)
Cassava Rizhome	4,13 (Sen et al., 2016) 14,45 (Granado et al. 2021)	59,65 (Sen et al., 2016) 72,50 (Granado et al. 2021)	24,43 (Sen et al., 2016) 13,10 (Granado et al. 2021)

According to Anggono et al. (Anggono et al.,2018), analysing Pterocarpus indicus twigs was found an ash value of 10.10%. In comparison, the value found for ash content to cassava stalk averaged 22.43%. The data showed high values, probably because the cassava stalk was not washed. In this study, this step was dispensed with, resulting in a percentage of the soil in the residue, causing a higher content of mineral elements.

Aló et al (ALÓ et al., 2017)] found, for sugarcane bagasse, a percentage of the volatile content of approximately 84.00%, while Anggono et al. (Anggono et al.,2018) found 67.90%. The value found in this work (73.25%) shows to be adequate, resulting in an accelerated burning process.

Anatasya, Umiati and Subagio (Anastaya et al.,2019)] found for sugar cane briquettes, values of ash, volatiles of 39.55% and 57.72%, respectively. In contrast, in our work, these values were 73.25% for the volatile content and 22.43% for the ash content. Thus, we found that the cassava stalk is better concerning the beginning of burning because it has a high volatile content. However, it has a high ash content; the cassava stalk still presents a value lower than that obtained by Anatasya, Umiati and Subagio (Anastaya et al.,2019), so that the burning of cassava stalk is possible.

According to Brand et al (Brand et al., 2019)], bamboo briquettes' burning rate will be high due to the low amount of residual carbon in these compounds, which makes the compound burn more slowly. The value of fixed carbon for bamboo, Bambusa species, was 16.40% and value of 81.00% for volatiles, while for cassava stalk presented 11.53±0.06% and 73.25±0.05%, respectively.

In comparison with the same type of biomass used, Sen, Wiwatpanyaporn and Annachhatre (Sen et al., 2016)

identified cassava rhizome values of ash content, volatile content and fixed carbon content of respectively 4.13%, 59.65% and 24.43%, while Granado et al. l (Granado et al. 2021)obtained the values of 14.45%, 72.50% and 13.10% respectively for ash content, volatile content and fixed carbon. It observed that the cassava stalk finds values close to those obtained for cassava rhizome both for volatile content and fixed carbon, getting only different value for ash content. This difference is due to not washing the residue, leaving it with much soil and many minerals, contributing to no small ash.

3.4 Mechanical Test

In the tests of resistance to traction by diametrical compression, the capacity of the material to support pressures and static loads was verified.
Figure 6 and Figure 7 show the results.

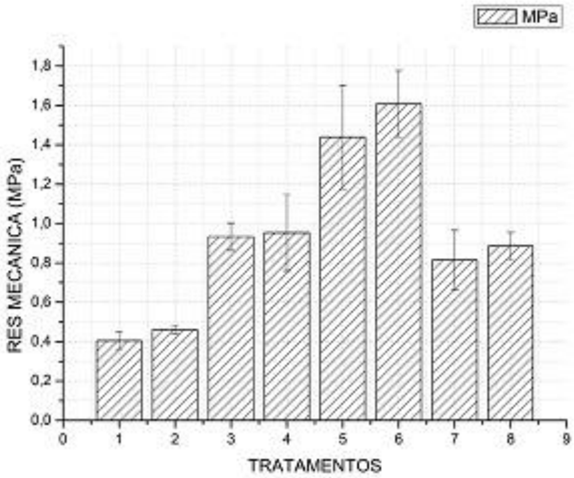

Figure 6: Resistance to traction by diametrical compression (MPa)

Regarding the mechanical strength, it is possible to verify that the briquette with the treatment of 42 mesh with a pressure of 20000 kgf and time of 2 minutes showed the highest value, 1.61 MPa of strength. According to Aló et al. (ALÓ et al., 2017)], the highest value found was 1.10 MPa, which shows a value found close to cassava stalk. Sen, Wiwatpanyaporn and Annachhatre (Sen et al., 2016) found 0.02 MPa (not adding binders) and obtained a maximum value of 1.47 MPa (considering the addition of binders). Thus, the cassava **stalk** showed a higher value than what was found in the literature, offering significant compaction and strength.

3.5. Number of stacked samples

The number of samples and the maximum stacking height is in Table 5.

Table 5: Stacking values

NUMBERING	FORCE (N)	N_{emp}	H_{emp}(m)
1	612,95±50,34	1041,67	36,46
2	680,89±30,62	1157,21	40,50
3	1186,81±69,45	2017,00	70,60
4	1219,85±210,39	2073,17	72,56
5	1583,31±228,50	2690,83	94,18
6	1766,78±135,16	3002,50	105,09
7	1074,07±147,00	1825,33	63,89
8	1160,95±82,70	1973,00	69,06
Sugarcane bagasse	-	-	20,00[10]

It is possible to verify that the briquette presented the lowest mechanical strength and elasticity value and showed a minimum height of stacked samples (H_emp) of 36.46 m.
According to Silva et al. (Silva et al., 2015), analyzing the sugarcane bagasse, the lowest value calculated for the height of stacked samples was 20 m. This difference can be explained by handling and storing this material, which shows that both values proved ideal for storage.

3.6 ANOVA

The ANOVA statistical test was performed varying the pressure, granulometry and pressing time, as shown in Table 6.

Table 6: ANOVA statistical test

TEST	F	$F_{tabelado}$	CONCLUSION
1 – 3	137,13	7,71	SIGNIFICANT
5 – 7	72,36	7,71	SIGNIFICANT
1 – 5	113,36	7,71	SIGNIFICANT
3 – 7	37,90	7,71	SIGNIFICANT
1 – 2	5,16	7,71	NO SIGNIFICANT
3 – 4	1,69	7,71	NO SIGNIFICANT
5 – 6	3,45	7,71	NO SIGNIFICANT
7 – 8	6,10	7,71	NO SIGNIFICANT

In Table 6, the calculated value for F is higher than the same table for both pressure and particle size, which allows concluding that the variation in pressure and particle size in the experiment are significant. For the pressing time, the calculated F is lower than the tabulated, concluding that this parameter's variation in the investigation is not significant.

The particle size parameter analysis is significant for the manufacture of briquettes because there are smaller particles in the material, thus facilitating the filling of the remaining spaces during its manufacture (Gonçalvez et al., 2013).

According to Chin and Siddiqui (Chin et al., 2018), the pressure variation is directly related to the stability and expansion of the produced briquette and, consequently, with the formed briquette's mechanical strength. Such experimental statements support the significance of pressure variation in the energy densification process.

IV. CONCLUSION

- ✓ The cassava stalk became feasible for the briquetting process, presenting good chemical analysis and physical analysis values. It proved superior to other materials that already have a more consolidated study in the literature.
- ✓ The mechanical test of traction by diametral compression allows data to be obtained to store this material. With the results, it was possible to get the maximum height that can stack these briquettes in a shed, allowing a stacking height of up to 105.09 m, solving biomass storage.
- ✓ Analysing the mechanical resistance test, the treatment that presented the highest value was the briquettes produced with a force of 10000 kgf with a particle size of 42 mesh and pressing time of 2 minutes was 1.61 MPa. For the elastic modulus, the same treatment presented the highest value of 57.77 MPa.
- ✓ In the volumetric expansion test, the most significant variation was in treatment number 3, representing a granulometry of 16 mesh, the pressure of 20 tons and pressing time of 1 minute, presenting an expansion of 14.78%. The lowest variation was in treatment number 7, with a volumetric increase of 5.39%.
- ✓ The statistical test ANOVA studied the influence of pressure, granulometry and pressing time for the experiment. The variation of each interferes in the final result, showing that the variation of pressure and granulometry is significant for the investigation, but not the pressing time.
- ✓ The best pressure and particle sizes are 10000kgf and 42 mesh, repectively.

Conflict of interest

There is no conflict to disclose.

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