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Influence of the Type of Mixture and Concentration of Different Binders on the Mechanical Properties of “Green” Charcoal Briquettes

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The application of biomass to generate energy has been highly studied as an alternative to fossil fuels. In Brazil, there is a large production of orange juice, and their solid waste (bagasse) has as its main destination the production of food for ruminants. Therefore, there is an interest among the industries to transformed this waste into a by-product with higher benefit. In this way, this work has as main objectives, the use of a new type biomass to produce “green” charcoal and the application of three different types of binders (industrial cornstarch, pectin with high degree of esterification and pectin with low degree of esterification) using three different proportions (5, 10 and 15%) and two types of mixtures in way to verify which briquette has the lowest friability index a better compression resistance. To determine the friability index, the tumbling method was applied. The compressive strength of the briquettes was also determined. The binder that brought better characteristics to the charcoal briquettes, and therefore would be chosen for a production line is the industrial cornstarch. For this binder, the briquettes showed higher mechanical strength when applied the second mixing method. In this case, the briquette with a composition of 10 % of industrial cornstarch, presented characteristics as non-friable and withstand a pressure of 4.093 MPa in the compression tests. The choice of this binder is also because it is cheaper among the three tested ones.

1. Introduction

The search for new alternatives for power generation has been intensified in the scientific community. In this context, there is an increased interest in the use of biomass waste as an energy source. Biomass is any organic material of vegetable origin that has energy available for burning, such as wood and forest wastes, livestock and agricultural wastes. Among the agricultural wastes, the solid waste from processing of orange juice (orange’s bagasse) can be highlighted (Yaman, 2004; Carvalho and Poppe, 2010; Alho, 2012). So, the development of researches for the use of these wastes as by-products becomes interesting. Orange solid wastes were collected in local restaurants. In this way, “green” charcoal particles, a wood charcoal substitute, has been obtained by carbonization process of those wastes. The particles were then processed to become fines and an agglomeration step was necessary to facilitate the combustion and transport of the briquettes. The charcoal briquettes production demands a binder to mix with the charcoal fines, since the charcoal by itself does not have a good cohesive property among particles. Many materials can be used as binders; however it is necessary that it does not harm the energy characteristics of the briquette, either reducing the calorific yield or increasing volatile and ash content. Thus, the choice of type and amount of binder is the most critical point on the briquettes production, which is the most sensitive stage to process costs. The search for new binders has been increasing, as long as it provides the necessary requirements of a high-quality briquette, for example, presents high mechanical strength, such as a low friability index and a high resistance to compression.
The compressive strength is a significant parameter in the evaluation of the briquette to its storage (De Melo, 2010). In order to evaluate the influence of the forces applied in the energetic densification stage, the

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resistance of the briquettes to the compression is going to be determined in order to predict their mechanical behavior when subjected to a given load or effort, considering their storage position.

The friability of a material is the property that it has to be turned into powder. In the case of charcoal, friability is understood as the property that it has to generate fines when handled or during its storage and transport. The lower the capacity of generation of fine, more resistance has the briquette (Gomes and Oliveira, 1980; Tumuluru et al., 2011).

In this way, in this study, three different types of binders were tested (industrial corn starch, pectin with high esterification degree and pectin with low esterification degree) in three different proportions (5, 10 and 15 % w/w) and two ways of mixing in order to verify the mechanical resistance (compression and friability) at the produced charcoal briquettes.

2. Material and Methods

The orange's bagasse was kindly provided by local restaurants. It was chopped into 1 cm² pieces, dehydrated in an oven at 105 °C for 24 hours approximately, to remove free moisture. After this first drying, the orange's bagasse (dried) went through the carbonization process. This step was carried out at a temperature of 450 °C (for 1 hour), with a rate of 10 °C/min. After carbonization, the obtained charcoal was grinded (TE 633, Tecnal) and the charcoal particles (*ca*. 2.0 mm to 4.0 mm) were sent to the energetic densification step.

The process of energy densification is necessary to have a concentration of the energy supplied by the coal in the briquette. In this step, it is need the addition of a binder, since the charcoal particles by itself do not shown molecules cohesion. The binders used were industrial cornstarch, pectin with high esterification degree (Pec-1) and pectin with low esterification degree (Pec-2). As a novelty the two different pectin were used as binders. Therefore, cornstarch was applied for comparison, since its use as a binder has already been elucidated in literature.

Three different proportions between the charcoal particles and binders were applied (5, 10 and 15 % $w_{binders}/w_{charcoal}$) and two types of manual mixtures were prepared.

- In the first one, the binder and charcoal were mixed, and to this mixture was added water. Only for the industrial cornstarch that this mixture still underwent a heating, so the activation of the starch could occur.
- In the second mixture, the binders were first mixed with water (heated in the case of cornstarch), and then the charcoal particles were added into this mixture.

The amount of water used for the Pec-1 and Pec-2 binders was 50 % water/coal. However, for the industrial cornstarch was used the ratio of 100 % water/coal. These amounts were defined in previous assays. In order to the charcoal briquettes be produced, a cylindrical mold and a uniaxial manual hydraulic press were used (Figure 1). The briquetting time was 1 min with a 5-tf application (2.0 cm² area each piece).

After obtaining the charcoal briquettes, they were dehydrated in an oven at a temperature of 80 °C for about 12 hours, so that the briquettes moisture was around 10 %. After this drying, the mechanical strength tests were performed.

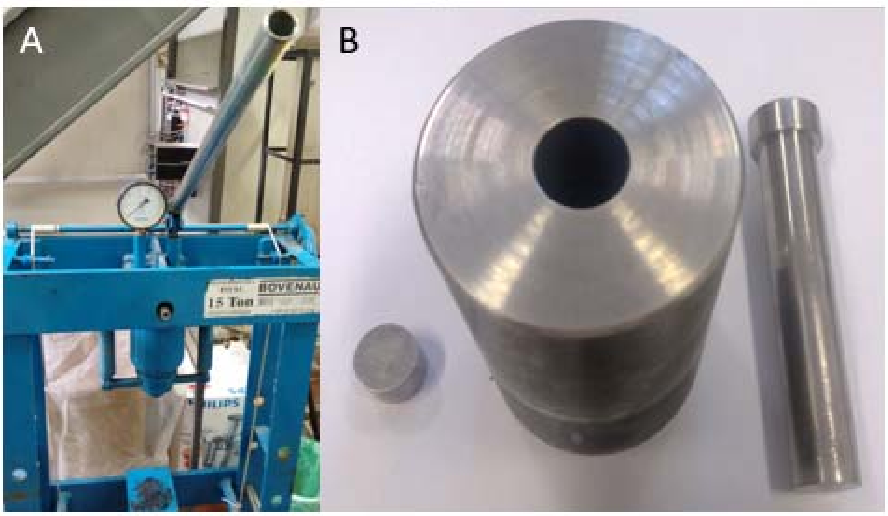

Figure 1: A: Manual uniaxial press; B: Cylindrical mold.

2.1 Friability Index

The friability test was performed using the tumbling method. For this, a friabilometer was used (300, Ethik®) in which the charcoal briquette was subjected to 500 rotations. The ratio between the final and the initial mass provides the friability index. According to the amount of mass lost during the test, the charcoal briquette can be classified (Oliveira and Almeida, 1982), as shown in Table 1.

Table 1: Charcoal classification

Loss Mass (%)	Classification
≥ 30	Extremely friable (EF)
25 - 29	Fairly friable (FF)
15 – 24	Medium Friability (MF)
10 – 14	Slightly Friable (SF)
< 10	Non-Friable (NF)

2.2 Compression Test

The hardness was measured by the compression test in a universal test machine (MTS). The parameters used were pre-test velocity, velocity test and post-test velocity (all of 0.3 cm / min) and contact load (10 kN). In the test, the briquette was subjected to continuous pressure until its rupture, as shown in Figure 2. The values of the velocities test were based on the work of Quirino (1991).

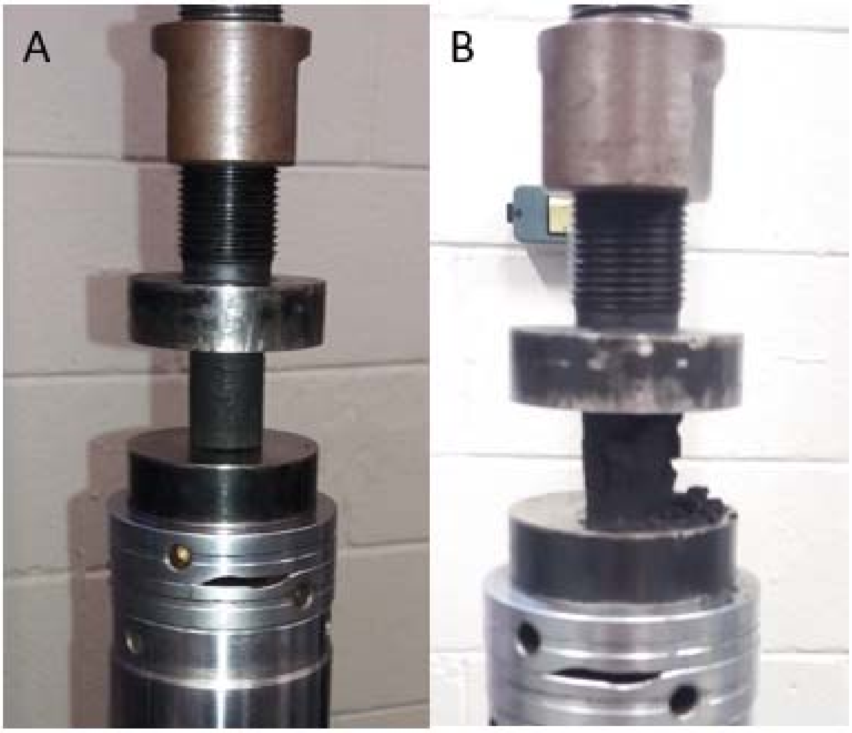

Figure 2: Charcoal briquette before (A) and after (B) the compression test

3. Results and Discussions

3.1 Friability Index

The run results of the friability test for the charcoal briquettes obtained with the three binders and the two ways of mixing are shown in Table 2, as well as the briquettes classification according to their loss mass. The friability index graphical representation is shown in Figure 3.

Table 2: Friability index results and charcoal classification

Amount of binder	Mixture 1	Mixture 2	Classification Mixture 1	Classification Mixture 2
Cornstarch 5 %	31.461 ± 3.312	14.090 ± 2.064	EF	SF
Cornstarch 10 %	4.320 ± 0.310	3.403 ± 0.806	NF	NF
Cornstarch 15 %	3.811 ± 0.852	2.705 ± 0.054	NF	NF
Pectin-1 5 %	42.442 ± 1.294	59.058 ± 1.677	EF	EF
Pectin-1 10 %	13.822 ± 0.900	16.207 ± 2.921	SF	MF
Pectin-1 15 %	10.177 ± 1.082	10.248 ± 1.995	SF	SF
Pectin-2 5 %	27.488 ± 2.211	26.388 ± 4.569	FF	FF
Pectin-2 10 %	16.911 ± 0.792	7.797 ± 0.476	MF	NF
Pectin-2 15 %	14.032 ± 1.358	6.958 ± 0.730	SF	NF

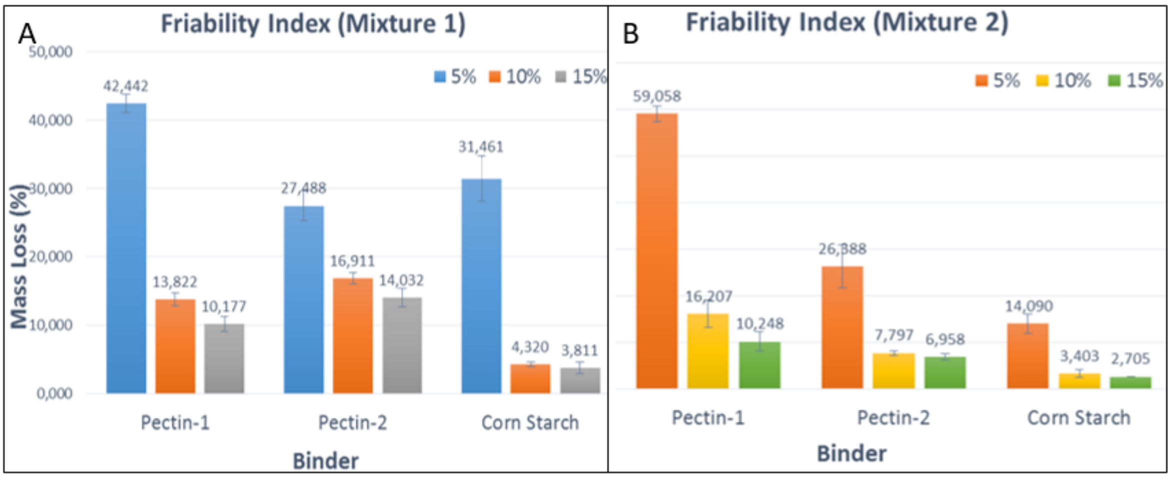

Figure 3: Friability index results. Illustration 'A' brings the results for mixture 1, while "B" brings the results for mixture 2

Analyzing the data of the friability index presented previously, we can observe that as a greater the amount of binder is added, the less friable the charcoal briquette becomes. This fact is expected due to the fact that with the addition of the binder there is a greater adhesion between the coal particles. Despite there is a large difference between the proportions of 5 and 10 % of binder on the results, there is no such notable difference when there is an increase from 10 to 15 % in the ratio between the charcoal and the binder.

Regarding the type of mixture, it is noticed that there is a decrease in the friability of the charcoal briquette when it was elaborated with the second mixing technique, except to Pec-1 as a binder. To this fact, it is believed that when there is initial the mixing between the binder and the water, there is a better homogenization of these two compounds, and when the charcoal is added, that mixture (binder and water) reaches the pores of the charcoal particles. This effect do not happened when the first form of mixing is applied. Similar results are reported in the literature for the use of the Pec-1 as binder. Concentino et al. (2016) produced charcoal briquettes applying 3 minutes of compression during the briquetting step and, verified the same influence as saw in this work on the proportions of binder in the final product.

Based on the results obtained, it was verified that the application of the binders Pec-1 and Pec-2 is not feasible when compared to the use of cornstarch, due to the cost of these binders and the presented resistance.

Based on this test, the application of 10 % (w/w) of the cornstarch binder to the production of charcoal briquettes and the use of the second way of mixture for its production is indicated.

This is because the briquette presents as non-friable (loss of mass of 3.403%), according to the classification presented in Table 1.

3.2 Compression Test

The stress values required for the rupture of each briquette as well as the elongation (strain) that each briquette showed are presented in Table 3. The uniaxial mechanical compression graphical results are shown in Figure 3.

Table 3: Compression test results

Amount of binder	Stress (MPa) Mixture 1	Strain (%) Mixture 1	Stress (MPa) Mixture 2	Strain (%) Mixture 2
Cornstarch 10 %	3.243 ± 0.418	9.753 ± *	4.093 ± 0.232	11.563 ± *
Pectin-1 10 %	2.188 ± 0.256	10.266 ± *	1.414 ± 0.057	9.417 ± *
Pectin-2 10 %	1.776 ± 0.068	9.207 ± *	2.063 ± 0.159	11.636 ± *

*Value not computed by the equipment.

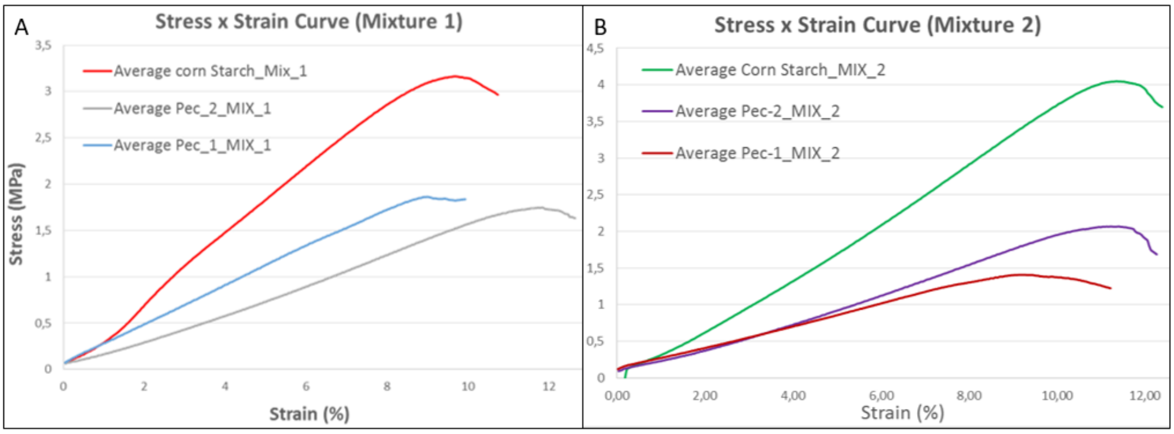

Figure 4: Compression tests results. Illustration 'A' brings the results for mixture 1, while "B" brings the results for mixture 2

For these analyzes the briquettes whose composition had 10% binder were used. It is verified that the results of the mechanical compression tests are in agreement with the results of the friability index, with respect to the type of mixture. That is, the briquettes produced by the second type of mixture were more resistant to compression, except for the briquette produced with Pec-1.

As there was a significant increase in the value of the compressive strength (26.21%) when the cornstarch was used as binder and the second way of mixing was applied, again, this binder would be the suitable one for the production of charcoal briquettes.

Similar results are found in the literature, however, for this, there was a need to use a larger amount of binder than the one used in this study, as is the case of the papers presented by Rubio et al (1999) and Habib et al (2013). Zanella et al. (2015), Worked with the production of charcoal briquettes using orange's bagasse and commercial cornstarch, obtaining as best result for mechanical compression the value of 2.177 MPa, for a proportion of 15 % of binder. In this way, the study of the type and amount of the binder becomes interesting for future works.

It is also observed by the Stress x Strain curves and by the Strain values, presented in Table 3, that all briquettes presented a similar elongation value until its rupture. This indicates that there is a uniformity in the shape and size of the briquettes during the production process and therefore they behave in similar ways, regardless of the type of mixture and the binder applied.

4. Conclusions

The data obtained in this work indicate that solid orange wastes can be used for thermal conversion in the manufacture of charcoal. It also indicates that the use of 10 % (w/w) of industrial cornstarch as a binder in the energetic densification step becomes interesting for the production of charcoal briquettes, with satisfactory characteristics regarding their mechanical resistance. Given this, charcoal briquette made from the use of orange's bagasse and cornstarch becomes an alternative to the use of fossil fuels.

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