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Mechanical characterization of spent- coffee-grounds briquettes

Caracterización Mecánica de Briquetas de Borra de Café

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Abstract

This article provides an overview of the manufacture of briquettes by mixing spent coffee grounds (SCG) and recycled newsprint (RNP), with some established compositions. Hollow cylindrical briquettes were used as samples for mechanical characterization for the research project "Characterization of type 2 biomass briquettes as solid fuel alternative to firewood and coal in kitchens, restaurants and small businesses, based on the Colombian Technical Standard 2060" carried out at the University of America in Bogotá, Colombia. Initially, the process of design and construction of a Peterson type press for the manufacture of briquettes was carried out. A universal testing machine was used for the mechanical compression tests. The shatter resistance was evaluated by launching the samples in free-fall from a height of 1 m several times until they got broken. Finally, and the abrasion resistance was measured using a ball-mill adapted to the proposed briquette size. All these tests were carried out to identify which of the proposed briquettes compositions has suitable mechanical properties to keep the shape, size and density in the actual processes of transport, handling and storage.

Briquettes, Spent coffee ground, Solid biomass, Solid biofuels

Resumen

Este artículo ofrece una visión general de la fabricación de briquetas mediante la mezcla de borra de café y papel de periódico reciclado, con algunas composiciones establecidas. Se utilizaron briquetas cilíndricas huecas, como muestras para la caracterización mecánica para el proyecto de investigación "Caracterización de briquetas de biomasa tipo 2 como combustible sólido, alternativo a la leña y al carbón vegetal en cocinas, restaurantes y pequeños negocios, con base en la Norma Técnica Colombiana 2060" realizado en la Universidad de América en Bogotá, Colombia. Inicialmente se realizó el proceso de diseño y construcción de una prensa tipo Peterson para la fabricación de briquetas. Para el ensayo de compresión mecánica se utilizó una máquina universal de ensayos, mientras que la resistencia al impacto se realizó sometiendo las muestras en caída libre desde una altura de 1 m varias veces hasta que se fragmentaban. Por último, resistencia a la abrasión se midió utilizando un molino de bolas adaptado al tamaño de briqueta propuesto.Todas estas pruebas se llevaron a cabo para identificar cuál de las composiciones propuestas de briquetas, tiene propiedades óptimas mecánicas para conservar su forma, el tamaño y densidad en procesos reales de transporte, manejo y almacenamiento.

Briquetas, Borra de café, Biomasa sólida, Biocombustibles sólidos

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Introduction

Fossil fuels cause greenhouse gases and global warming. In developing countries, mainly in Africa and Asia, the only available energy source for people is the wood obtained from forests and jungles. [1]. Colombia undergoes this problem in several rural areas, mainly in Amazonian region [2]. Besides deforestation, its combustion produces respiratory pathologies such as asthma, emphysema and chronic obstructive pulmonary disease (Nijhuis 2017) [3]. These pathologies bring similar consequences to those produced by tobacco consumption [4]. Therefore, it is necessary for rural communities to look for clean, inexhaustible, and highly competitive renewable energies such as biofuels.

In this project, briquette production from spent coffee grounds (SCG) mixed with renewable newsprint (RNP) as a binder is studied as an alternative to firewood and coal, due to availability of these feedstocks, and ease to elaboration.

The physical-chemical and mechanical properties of briquettes guarantee adequate performance as fuel. Also, they offer optimal integrity and appearance in transport, storage, and distribution. To a large extent, these features are obtained through an adequate pressing process. For these reasons, several experiences needed to be evaluated before constructing the machine.

The briquetting press is a device that produces samples in the form of briquettes (usually as a cylindrical block) to evaluate their mechanical and physicochemical properties such as compression strength, shatter and abrasive resistance, heating value, combustion gases, among others. These devices are made to compress briquettes from raw material that generally has a high moisture content. Therefore, this water must be drained while compressing.

Design variables and operation conditions were identified to evaluate the mechanisms and size the machine, applying characterization of materials and manufacturing process concepts. The main objective is to characterize mechanically briquettes of SCG and RNP in order to have an approximation to actual condition of transport, handling and store were their integrity and shape must be guaranteed.

1. Experimental Methodology

1.1 Design and construction of a Peterson type briquetting press

Following steps were carried out to design and build the briquette press:

– Review of similar projects that entail different models of briquetting machines assembled for diverse materials. Once the review was completed, the most practical, cheap, and easy-to-build device was chosen to adjust it to project requirements, adapting it, or improving some of its mechanisms.

– Determination of necessary parameters of briquettes: basic physical-chemical characteristics of the material to be briquetted (coffee residue and newsprint binder), compression force, size, weight, and shape of the briquette, among others.

– Draft of the previous press design.

– Detailed sketches of the components and parts of the machine.

– Acquisition of materials of the structure or body.

– Acquisition of cylinders to obtain the diameter and dimensions of the briquettes.

– Calculations of the compression system to be applied by the press.

– Design of the drainage system, separation, and extraction of briquettes.

– General drawings of the machine and detailed plans of its parts with the calculated measurements.

– Final assembly of its components and mechanisms, as shown in figure 1.

Figure 1 Briquetting machine
Source: Own Elaboration

Table 1 shows all the specifications of the briquetting machine.

Briquette Machine Features	
Denomination	**Value**
Maximal compaction force (kgf/cm²) – (kN/m²)	69.299 – 6796
Dimensions (mm)	22 x 10 x 95
Weight (kg)	9.87
Nominal production (briquettes/test)	3
Average product density (g/cm3)	0.36
Briquetting process performance	Manual and intermittent
Dimensions of hollow cylinder briquette	Diameter = 64.4 mm, thickness = 21.34 mm, and average height = 49 mm

Table 1 Briquetting machine specifications
Source: Own Elaboration

1.2 Manufacture of briquettes

1.2.1 Mixture preparation

Initially magazine, bond and newspaper, were tested as a binder for SCG after several tests. It was determined the magazine is difficult to cut and shred, besides, to be less soluble in water. Between bond paper and newspaper, the second was chosen since the briquettes made with this binder became more compact. Therefore, it was left as the only binder to make the different SCG-compositions

To evaluate the mechanical properties, SCG-RNP compositions of 50-50, 70-30 and 80-20 by weight were elaborated. The preparation of the mixture was made by dissolving manually, 1 kg of RNP cut into fine pieces in 4 liters of water. Then it was left to soak for 24 hours (Figure 2).

The next day, the soaked paper was weighed for manual mixing with the SCG in compositions SCG-RNP as follows.

Composition 50-50: 0.5 kg of SCG, 0.50 kg of RNP

Composition 70-30: 0.70 kg of SCG, 0.30 kg of RNP

Composition 80-20: 0.80 kg of SCG, 0.20 kg of RNP

Figure 2 Preparation of mixture
Source: Own Elaboration

Once the mixtures were made, they were compacted in the Peterson-type briquetting press.

1.2.2 Compaction of mixture

Briquettes use experiences in countries such as Spain, Ukraine, Russia, and the United Kingdom, were analyzed. In rural areas, the lack of conventional heating is supplied with chimneys and biomass-based boilers. These systems employ biofuels from different biomass such as sawdust, shavings, branches, stems, shells, grains, among others, to produce briquettes or pellets.

In the case of briquettes, Peterson presses are used. These machines are composed of a metallic sheets and wood frame, a hydraulic jack, a drainage system, and a press-molding device. The manually operated hydraulic jack puts the mixture under pressure of 6.796 MPa. The average dimensions obtained for the selected compositions are shown in figures 3 and 4, together with table 2.

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Figure 3 SCG-RNP briquettes dimensions
Source: Own Elaboration

Figure 4 Batch of briquettes made to be tested
Source: Own Elaboration

Composition	Height (mm)	Thickness (mm)	Diameter (mm)
50:50	48.70	22.48	64.08
70:30	49.75	22.05	64.55
80:20	50.23	22.33	64.65

Table 2 Average dimensions for different SCG.RNP compositions
Source: Own Elaboration

1.2.3 Drying process

Briquettes made in the Peterson press are exposed directly to sunlight to ensure suitable moisture removal and to give them compaction properties.

1.3 Mechanical characterization of briquettes

1.3.1 Compression strength test

The compression test for briquettes was applied on the SHIMATZU E-50 Universal Testing Machine for eight samples of each composition as shown in figure 5.

Figure 5 Compression strength test in universal testing machine
Source: Own Elaboration

1.3.2 Shatter resistance test

Bhavsar´s work showed, the briquettes shatter resistance was evaluated, dropping them in free fall from a height of 1 m as shown in figure 6 [5]. This essay was also recommended by Law and Asamoah respectively[6] [7]. Repetitions were made until the briquette got completely broken in pieces. The initial weight of the entire briquette and the weight of the largest piece were measured and compared to obtain this index with the equation 1.

$$\% shatter\ resistance = \left(1 - \frac{w_1 - w_2}{w_1}\right) \times 100 \quad (1)$$

Where w_1 corresponds to the weight of the complete briquette before impact and w_2 is the weight of the biggest piece after impact.

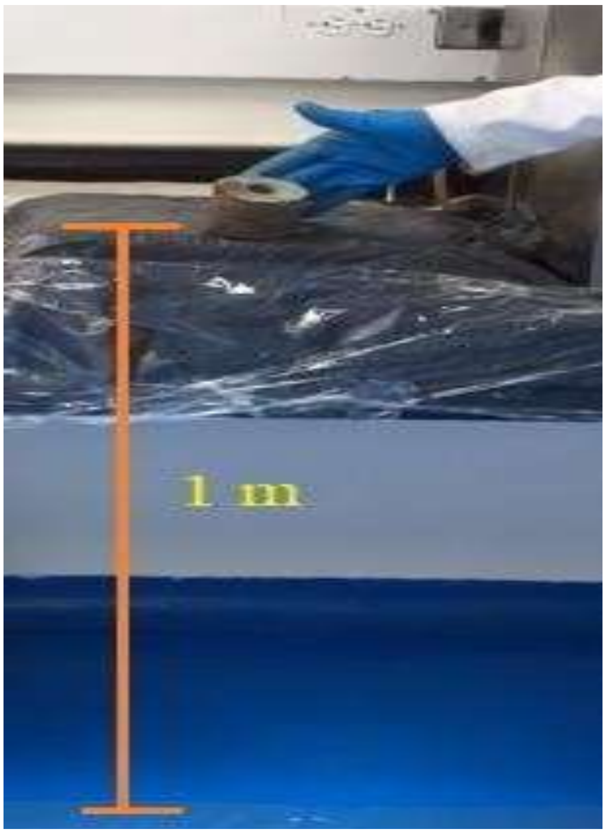

Figure 6 Shatter resistance test
Source: Own Elaboration

1.3.3 Abrasive resistance

According to the stipulations of the EN 15210-2 standard, six samples of briquettes of each composition were subjected to a rotating drum of 20 cm in diameter, 30 cm in length, for 5 minutes by rotating it at 25 rpm. [8]. The Armfield CEN-MKII-11 didactic ball mill was selected and adapted to the size of the manufactured briquettes as shown in figure 7.

Figure 7 Armfield CEN-MKII-11 didactic ball mill
Source: Own Elaboration

Instead of placing a flat dividing plate on the drum, a sheet of sandpaper 100 was placed on the inner walls to provide the abrasive medium. The weight of each briquette was measured before and after the test with a precision electronic balance. The abrasion resistance was determined using the final mass in percent after rotation as an indicator, employing the equation 2.

$$\%abrasive\ resistance = \left(1 - \frac{w_1 - w_2}{w_1}\right) \quad (2)$$

Where w_1 and w_2, correspond to the weight of the briquette before and after rotation in the drum respectively.

2. Results and discussion

The values obtained from the mechanical tests were compared and analysed, with stipulated parameters in the Colombian Technical Standard NTC 2060 and other standards, together with the experiences of different authors who carried out similar tests [9]

2.1 Compression strength tests

Figure 8 shows the state of the briquette after the compression test.

Figure 8 Final appearance of briquette after compression test
Source: Own Elaboration

For all the compositions, there was a characteristic deformation in the radial direction. But, as the percentage of RNP binder in the mix decreased, a greater detachment of material took place. Table 3 show the results of this test for the tested briquettes and graphic 1 shows the disposition and trend of the data obtained.

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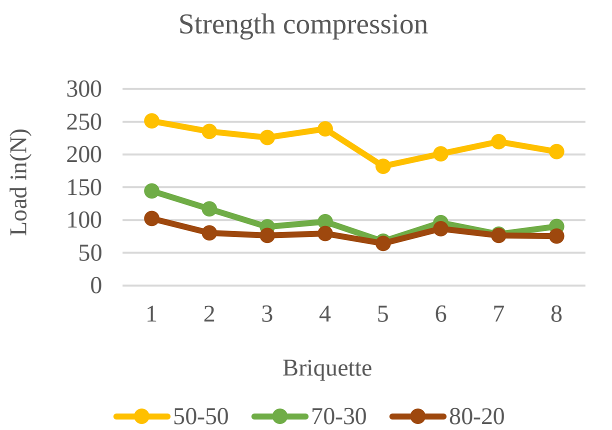
Briquette Composition	Average load (N)	Standard deviation
50:50	219,78165	22,7965282
70:30	97,683925	23,8226605
80:20	80,269138	10,9332847

Table 3 Strength Compression in (N) for briquettes SCG-RNP
Source: Own Elaboration



Graphic 1 Graphic behaviour of Strength Compression of Briquettes SCG-RNP
Source: Own Elaboration

According to the NTC 2060 standard, the strength compression for biomass briquettes weighing more than 40 g should not be less than 588.23 N or 60 kgf. In the present project, the samples had weights between 48 and 61 g. The 50:50 composition samples showed better crush resistance when loaded on the universal testing machine [9]. On average, they supported a load of 219.78 N, alike the values of 97.683 and 80.27 (N) registered by those of 70:30 and 80:20 respectively. The values obtained do not fulfil this requirement, but in similar studies carried out on batches of briquettes with different binders, it is evident that they do not reach this value either. The study carried out by Cubero et obtained average fault load values 538.93 N [10]. Balseca´s work registered an average failure load of 237.74 N [11]. Lisowskis´ test calculated the resistance to crushing stress for SCG pellets at 1.75 MPa, compared to the 68.148 kPa obtained in the present project for the 50-50 composition. However, the value of this last reference would be below that established by this standard [12]. These values are lower than those stated in Standard NTC 2060, because it takes coal as a pattern. According to the graphic 1, a marked difference is evident in terms of compressive strength based on the amount of RNP contained. Therefore, it proves that this binder has a notable impact on the increase in resistance to this load condition.

Although the minimum compression or crushing load was under standard requirement, these briquettes would support many briquettes established in table 4 based on their weight and the load held.

Composition	Maximum load on top (N)	Briquettes stacked on top
50:50	219.780	443
70:30	97.683	153
80:20	80.270	137

Table 4 Number of Briquettes help on top
Source: Own Elaboration

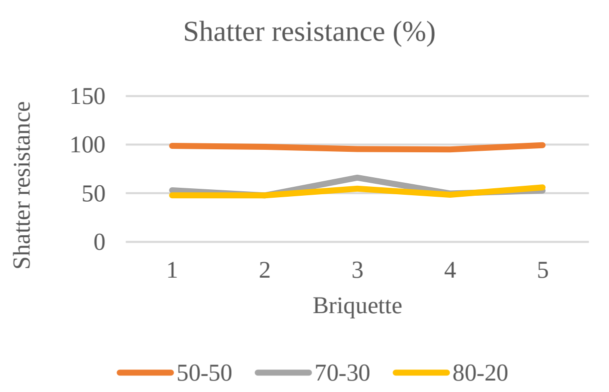
2.2 Shatter resistance tests

Table 5 show the results of this test for the evaluated briquettes and graphic 2 shows the disposition and trend of the data obtained.

Note that the number of launches is not the same for each composition, because that is when the total disintegration of the briquette occurs.

Briquette Composition	Average values (%)	Standard deviation	Number of launches in the free fall
50:50	97,347	1,93143794	20
70:30	53,909	7,12501966	7
80:20	51,069	4,04252242	4

Table 5 Shatter resistance in (%) for SCG-RNP briquettes
Source: Own Elaboration



Graphic 2 Graphic behaviour of shatter resistance of briquettes SCG-RNP
Source: Own Elaboration

The newspaper as a binder improves the compaction of the mixture and prevents the briquettes from collapsing when thrown in free-fall. In the experiment, at a large amount of paper, more launches are needed to fragment the briquette.

By decreasing its proportion, the briquette becomes more brittle. Bargazan, suggest as suitable values for this indicator those greater than 56% [13]. Law´s test found that coffee grounds develop high impact resistance when agglomerated with rice husk [6]. Approximately 96% was this indicator, while when mixed in different proportions with sugar cane bagasse, this was of almost 100% [6]. Brunerova´s study, found that this indicator improves in SCG briquettes agglomerated with wood shavings or sawdust, but does not give a suitable response to compression [14].

Regarding this indicator (20 launches in the free- fall), the 50:50 composition will guarantee the physical integrity of the briquettes if they undergo an unforeseen fall.

The variation in the graph of the compositions 70:30 and 80:20, refers to the fact that in some briquettes a kind of cracking was initially observed on them.

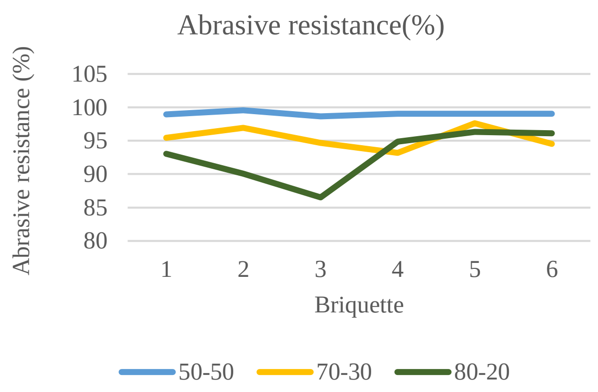
2.3 Abrasive resistance tests

Table 6 shows the results obtained in the abrasion test and graphic 3 shows the disposition and trend of the data obtained. According to requirements of NTC 2060, this test must be applied to a batch of 100 briquettes in a rotating drum with a diameter of 1.0 m. The reference for this test was the Standard EN 15210-2 [8] [6].

A smaller number of samples are allowed to be subjected to rotation and to evaluate the detachment of material. A sheet of sandpaper 100 was placed on the walls of the drum, rather than a flat barrier inside the drum. In this study 5 tests were performed with each composition. [8].

Briquette Composition	Average values (%)	Standard deviation
50:50	99,0436833	0,29385645
70:30	95,4105000	1,65221905
80:20	92,8270833	3,86789073

Table 6 Abrasive resistance in (%) for SCG-RNP briquettes
Source: Own Elaboration



Graphic 3 Graphic behaviour of abrasive resistance of briquettes SCG-RNP
Source: Own Elaboration

The test showed the newspaper maintains the physical integrity of the briquettes, detaching less than 2% of material after undergoing the rotation of the drum, the impact between them and the contact with the sandpaper wall. Law carried out the abrasion test or also called durability, for the briquettes of rice husk and mud, obtaining values between 96% and 100%. This resistance increased as the amount of SCG was added. The combination of cane bagasse and SCG remained very close to 100% regardless of composition [6]. Brunerova´s study evidenced the abrasion resistance is high in briquettes whose composition consists of 100% sawdust or sawdust - erased in 50-50 or 75-25.

On the other hand, this study verified that the resistance of wood chip briquettes had a low resistance to abrasion (below 50%). [14]. The results of this test obtained in the present study suggest that the combination of SCG with RNP makes the briquette highly resistant to abrasion. In practical applications these briquettes would not present significant material detachment, when colliding with each other as would happen in transportation. Their integrity, presentation and performance in the combustion process would not be affected.

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Conclusions

The machine can work with different granulated or powdered products, like those already studied in this article, as it offers a wide range of compacting forces. In the whole design process, it was used the highest number of easily available materials and standardized screws. The production of briquettes based on biofuels aids the creation of articles that substitute wood and hydrocarbons and encourages research for clean and renewable energy sources.

Despite not having reached the compressive strength limit, the briquettes showed high axial load support values. In practice these briquettes can support a considerable quantity of briquettes stacked on top of each other. This result ensures that they will not be disintegrate when arranged in boxes.

Briquettes, whose composition was 50-50, showed a high resistance to impact. They required several launches to show material detachment which was less than two percent. This composition would guarantee that in the event of accidental falls such as those that can occur in loading and transport processes, its integrity or shape will not be affected. As the binder content gets reduced, they become more brittle.

The 50-50 composition showed good abrasion resistance when rotated against sandpaper covered walls. Detached material was less than two percent, unlike compositions with less binder. In practice, this behavior showed the fact that the contact between briquettes or the friction between them would not produce material losses when packed in boxes. It is not necessary to put cardboard or separation divisions inside, which would save costs for this concept.

These mechanical tests showed that RNP, contributes significantly to improve mechanical properties of briquettes based on coffee grounds. In addition to being a readily available material.

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