ENGLISH VERSION..........

Factibilidad en la fabricación de ladrillos no estructurales, a partir del reciclaje de las colillas de cigarrillo

Practicability in the manufacture of non-structural bricks, from the recycling of cigarette butts

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Abstract

Cigarette butts are one of the most common waste worldwide. The toxic and non-biodegradable components make cigarette butts a hazardous waste and one of the causes of pollution. This paper presents some of the results of a study on the re-cycling cigarette butts in the manufacture of clay bricks. Four mixtures were made, these include a control clay brick, with a clay content of 100% (LADRICOL 0%) and three additional mixtures incorporating cigarette butts in different percentages by weight (LADRICOL 2.5%, LADRICOL 5.0% and LADRICOL 7.5%). The mixtures were fired at different temperatures and these were tested to determine the physical and mechanical properties of the bricks. The results showed that the samples incorporating 2.5% cigarette butts content and fired at 850 °C are in compliance with the standard normative for this type of product (NTC 4205-2). Furthermore, this brick can improve the environmental quality and can reduce energy consumption during firing, by 19.75%.

Keywords: *Cigarette butts, clay bricks, physical properties, mechanical properties, energy saved*

Resumen

Las colillas de cigarrillo son uno de los residuos más comunes a nivel mundial. Sus componentes tóxicos y no biodegradables hacen de este un residuo peligroso y una de las causas de contaminación ambiental. Este artículo presenta los resultados de una investigación en la que se estudió la alternativa de incorporar colillas de cigarrillo en la fabricación de ladrillos de arcilla. Se elaboraron cuatro mezclas dentro de las que se incluye una mezcla patrón con contenido de 100% arcilla (LADRICOL 0%) y tres adicionales con colillas de cigarrillo en diferentes porcentajes en peso (LADRICOL 2,5%, LADRICOL 5% y LADRICOL 7,5%). Estas mezclas fueron cocidas a diferentes temperaturas y se sometieron a los ensayos respectivos para determinar propiedades físicas y mecánicas del producto terminado. Los resultados obtenidos, demostraron que, con la adición de colillas de cigarrillo en un 2,5% y una temperatura óptima de cocción de 850°C, se pueden fabricar ladrillos no estructurales tipo M, cumpliendo con los estándares establecidos en la NTC 4205-2, generando impactos positivos en el medio ambiente y reduciendo el consumo energético durante la cocción del ladrillo, en un 19,75%..

Palabras clave: Colillas de cigarrillo, ladrillos de arcilla, propiedades físicas, propiedades mecánicas, ahorro energético

1. Introduction

Cigarette butts are undoubtedly the most common type of waste dumped on the streets. At present, approximately 6 trillion cigarettes a year are consumed worldwide, of which 4.5 trillion are dumped into the environment once consumed (De Granada et al., 2016).
The high rates of waste dumped into the soil and water sources without control have become one of the causes of pollution, not only by the high volume of cigarette butts dumped but also by the toxic substances present in these products.

The materials used to make cigarette filters include cellulose acetate, a non-biodegradable material that can take between eighteen months and ten years to decompose depending on the environmental conditions to which it is exposed. Although the sun rays can break the filter down into small pieces, this material never disappears; instead, it passes into the soil and water sources, causing environmental pollution (Novotny and Slaughter, 2014) and (Mohajerani et al., 2016).

Besides cellulose acetate, the cigarette comprises about 4,000 chemical substances such as ammonia, nitrogen oxide, hydrogen cyanide, pesticides and some toxic metals such as cadmium and nickel that are part of the numerous chemicals considered carcinogenic (Castañeda, 2011) and (Monzonis, 2011). It is also composed of other toxic substances such as nicotine and tar, which are trapped in the cigarette butts. Only one cigarette can contaminate up to 50 liters of water (Guevara, 2010) and (Lozano et al., 2015).

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Despite the risks that cigarette butts represent for the environment, it is frequent to see smokers throwing them on the ground, parks, bridges, streets and many other public places where they accumulate and become a source of danger for domestic animals, fish, birds, turtles, among others, which can ingest them causing their death due to their toxicity (Castañeda, 2011 and (Rath et al., 2012).

In Colombia, 12.9% of the population over the age of 18 is a current consumer of cigarettes. This figure is equivalent to just over 3 million smokers in the country. (Gobierno Nacional de la Republica de Colombia, 2014). On the other hand, (Lozano et al. 2015) indicated that the number of cigarettes consumed in Colombia ranges from 412 to 600 cigarettes per smoker. This is why the country generates approximately 1,236 to 1.8 billion cigarette butts per year.

On the other hand, among the most used construction materials worldwide are clay bricks. During its manufacture, this material generates negative impacts on the environment due to the amount of energy it requires. Bricks are made from clay and are subjected to high temperatures during firing. Therefore, it is estimated that they contain approximately 2.0 kWh of incorporated energy and release around 0.41 kg carbon dioxide (CO_2), among other gases released into the atmosphere during their manufacture, such as carbon monoxide (CO), sulfur dioxide (SO_2), ammonia (NH_3), chlorine (Cl_2) and fluorine (F) (Zhang, 2013); (Abdul et al., 2015).

For this reason, this article presents the results of an investigation where cigarette butts were recycled by including them in the manufacture of clay bricks, evaluating the effect of the firing temperature on the physical and mechanical properties of the bricks, as well as its effect on the possible reduction of energy costs associated with their manufacture.

The properties of the bricks were compared with the Colombian regulations for seismic-resistant construction (From the Spanish Reglamento Colombiano de Construcción Sismo Resistente, NSR-10) and the mandatory Colombian standards such as NTC 4017 and NTC 4205-2.

2. Materials y Methods

2.1 Preparation of the mixtures and processing of the specimens

The raw materials used were mainly clay and cigarette butts. In the case of cigarette butts, these were collected from streets and common areas such as bars, universities and business buildings. Additionally, a previous adaptation of these materials was carried out by grinding them using a domestic mill (Figure 1).

Figure 1. *Mill and ground cigarette butts*

The clay was supplied by a local brick company and subjected to a milling and sieving process for its respective adaptation. Also, Atterberg limits were determined according to Colombian standards INV-E 125-13 and INV-E 126-13. Similarly, granulometry (INV-E 213-13) and density (INV-E 128-13) tests, as well as thermogravimetric (TGA) and thermo-differential (TDA) analyses were carried out at a heating speed of 10 ºC/min, from room temperature to 1000 ºC, in air atmosphere at a flow rate of 100 ml/min, chemical composition (X-ray fluorescence [XRF]), and mineralogical composition (X-ray diffraction [XRD]), scanned in the range of 2 = 5 - 80° at a scanning speed of 0.02 sec/step, using Cu Kα radiation at 45 kV and 40 mA.

Four mixtures were made, including a standard mixture with 100% clay content (LADRICOL 0%) and three additional mixtures in which cigarette butts were incorporated in different percentages by weight, in relation to the clay content (LADRICOL 2.5%, LADRICOL 5% and LADRICOL 7.5%).

For the production of the specimens, these mixtures were molded into prismatic specimens of 150 x 50 x 25 mm. They were subsequently pressed with a Shimadzu machine at an average compaction pressure of 0.92 MPa.

The specimens were dried in an oven at 105 - 110 °C for 48 hours. The firing was carried out at 800 °C, 850 °C and 900 °C to identify the optimum temperature at which the brick obtained the best physical and mechanical properties.

2.2 Determination of physical and mechanical properties

At the end of each of the molding, drying and firing phases, weights and dimensions of each specimen were recorded to determine important physical and mechanical properties of the brick and to determine the practicability of its manufacture and use as non-structural type M masonry, compliant with the requirements of NTC 4205-2. Considering non-structural type M masonry those units without perforations and those in which the perforations represent less than 25% of the total volume of the unit (Instituto Colombiano de Normas Técnicas y Certificación, 2019).

The firing shrinkage, volumetric density, water absorption percentage, and initial absorption rate were determined within the physical properties. In the case of the mechanical properties, the compressive strength and flexural strength of the finished product were evaluated, taking into account the methods described in NTC 4017. The reported results correspond to the average of three specimens tested in each mixture.

To determine the compressive strength of the finished product, it was previously submitted to capping to parallel the load faces and achieve a uniform distribution of the load on the specimen to be tested (Sanchez and Mejía, 2009). The calculation of this property was made as established in NTC 4017, and as shown in (Equation 1):

$$C = \frac{W}{A} \qquad (1)$$

Where
C= Compressive strength, in MPa.
W= Maximum breaking load, in N.
A= Specimen area, in mm^2.

The flexural strength of the specimens was determined using a Shimadzu universal testing machine by using the maximum load that can be supported. The test was performed at a speed of 1.3 mm/min, and the modulus of rupture of each specimen was calculated according to the Colombian technical standard NTC 4017, and as described in (Equation 2):

$$MOR = {3W\left(\frac{L}{2} - x\right)}\Big/{bd^2} \qquad (2)$$

Where
MOR= Modulus of rupture or flexural strength, in MPa
W= Maximum load, in N
L= Distance between support stands (center to center measurement), in mm.
X= Average distance from the fault level to the center of the part, in mm.
b= Net width (face-to-face distance) of the sample in the fault level, in mm.
d= Depth, distance from the top of the sample to the support level, in mm.

Finally, X-ray diffraction (XRD) tests were carried out on the conventional brick and the brick in which 2.5% of cigarette butts were incorporated to know the mineralogical phases present in each of them.

2.3 Energy saving

The assessment of energy costs associated with the production of each brick was carried out. Subsequently, with this information, the respective comparisons to determine the possible reduction in energy consumption were made.

To calculate the energy cost of the conventional brick, the average national energy consumption was taken as a reference, which is 2,405 MJ for each ton of bricks produced (Unidad de Planeación Minero-Energética, 2001). With this information and the average value of the kWh for the non-residential sector, the energy cost associated with the firing of the brick was determined.

Concerning the energy consumption for the manufacture of the brick in which cigarette butts were incorporated, the calculation was made taking into account the clay mass and the percentage of cigarette butts incorporated, as well as the calorific value of the cellulose acetate, which corresponds to 19 MJ kg^{-1} (Mohajerani et al., 2016).

To determine the energy saving generated by incorporating the cigarette butts, the energy used in the manufacture of the conventional brick was calculated (Equation 3.1) as well as the energy used in the brick with 2.5% cigarette butts (Equation 3.2). Finally, the energy saving percentage was calculated using (Equation 3.3), as mentioned by (Mohajerani et al., 2016).

Energy used in LADRICOL 0%,

$$\boldsymbol{Q_1 = q \cdot m_1} \qquad \textbf{(3.1)}$$

Energy used in LADRICOL 2,5%,

$$\boldsymbol{Q_2 = q \cdot m_2 - CV \cdot m_3} \qquad \textbf{(3.2)}$$

Energy saving,

$$\Delta \boldsymbol{E}(\%) = \frac{\boldsymbol{Q_1 - Q_2}}{\boldsymbol{Q_1}} \boldsymbol{X\ 100}\% \qquad \textbf{(3.3)}$$

Where:
q = *energy consumption in LADRICOL 0% (2,405 MJ/kg)*
m_1 = *clay mass in LADRICOL 0% (kg)*
m_2 = *clay mass in LADRICOL 2.5% (kg)*
m_3 = *cigarette butt mass in LADRICOL 2.5% (kg)*
CV = *calorific value of cellulose acetate (19 MJ kg-1)*
$\Delta E(\%)$ = *energy saving*

3. Results y Discussion

3.1 Physical and chemical properties of clay

(Table 1) shows the physical properties of the clay used for the manufacture of the specimens.

Table 1. *Physical composition of clay*

Physical Property	Result
Liquid Limit (%)	34
Plastic Limit (%)	18
Plasticity Index (%)	16
Apparent Density (g/cm^3)	0,97
Natural Moisture (%)	3,65

(Figure 2) shows the granulometric distribution curve of the clay used.

Figure 3. *Granulometric curve*

In the tests of thermogravimetric (ATG) and thermo-differential (ATD) analyses, a loss of weight and an endothermic peak ranging from 25 ºC to 110 ºC could be observed, which is possibly attributed to the loss of water from moisture. At approximately 520°C, structural water loss from kaolinite occurs (Figure 3). This is in line with authors such as (Joshi et al. 1994) and (Isel et al. (2017), who indicate that the dehydroxylation of this mineral generally occurs between 400 °C and 600 °C.

Regarding the chemical properties, (Table 2) shows the results obtained in the X-ray fluorescence (XRF) analysis, where it can be noted that the most present components are silica (SiO_2) and alumina (Al_2O_3). As mentioned by authors such as (Barranzuela 2014) and (Santos et al. 2009), these are the two most essential components in the composition of clays. Therefore, they are usually the most abundant in this material, while others, such as iron, are usually found in lower percentages.

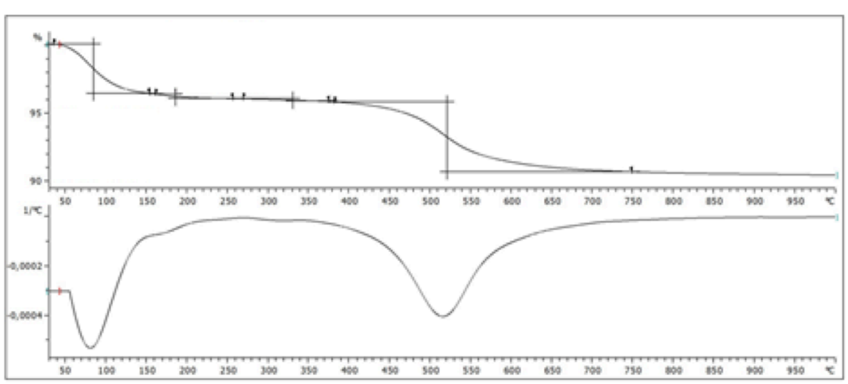

Figure 3. *ATG and ATD curves of clay*

Table 2. *Chemical composition of clay (FRX)*

Component	Content (%)
SiO_2	62,65
Al_2O_3	20,28
Fe_2O_3	4,26
TiO_2	0,97
CaO	0,38
K_2O	1,29
SO_3	0,54
MgO	0,95
Na_2O	0,27
Loss on ignition	8,17

Also, the content of SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MgO and Na_2O s very similar to those clays used by (Sánchez et al. 2009), (Mohajerani et al. 2016) and (Fuentes et al. 2017) in the manufacture of bricks containing cigarette butts, biosolids and fly ash.

In the case of the mineralogical composition, (Figure 4) shows the diffractogram of the clay used in the study, evidencing characteristic mineralogical phases of clays such as quartz (SiO_2) at angles of 21.1794°; 26.9496°; 36.8383°; 39.7578°; 42.7379°; 50.4242°; 60.2280° and 68.4041° (reference code 01-083-2469 and 00-003-0427), and kaolinite ($Al_2Si_2O_5(OH)_4$) at angles 12.6776° and 25.1782° (reference code 00-003-0058) (Joshi et al., 1994); (Gonzalez et al., 2014); (Ruge-Guerrero et al., 2016).

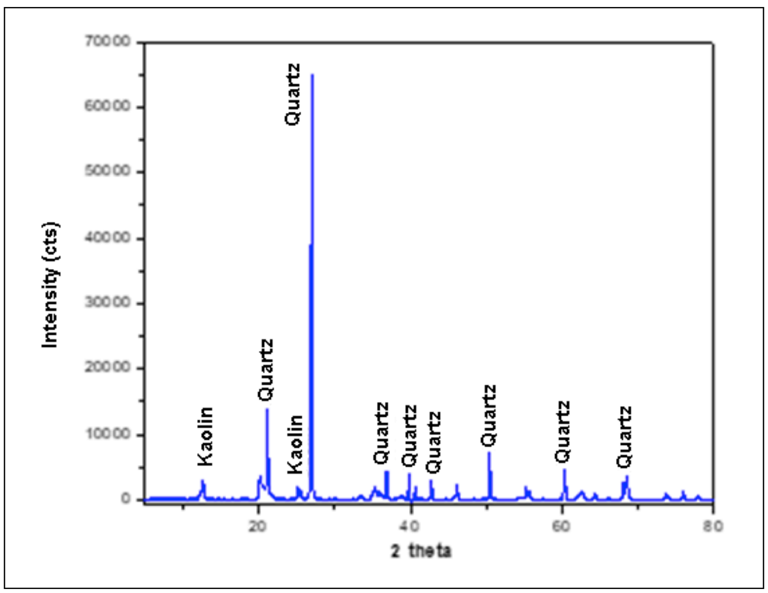

Figure 4. *X-Ray Diffraction pattern of clay*

3.2 Physical properties of fired bricks

The physical properties of the four mixtures (LADRICOL: 0%, 2.5%, 5% and 7.5%), fired at temperatures of 800 °C, 850 °C and 900 °C, are shown in (Figure 5), (Figure 6), (Figure 7), (Figure 8), (Figure 9), (Figure 10), (Figure 11), (Figure 12) and (Figure 13).

The apparent density results show that this property increases in direct proportion to the firing temperature, as observed in (Figure 5), (Figure 6), (Figure 7) and (Figure 8); although, it decreases when the amount of cigarette butts incorporated increases.

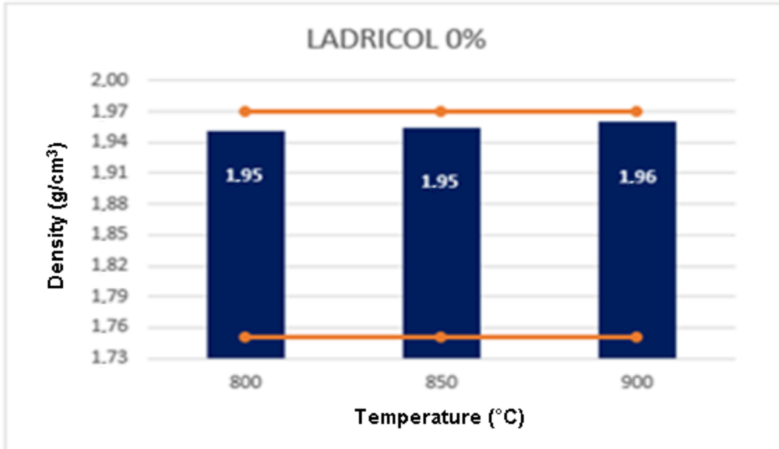

Figure 5. *Density of LADRICOL 0%*

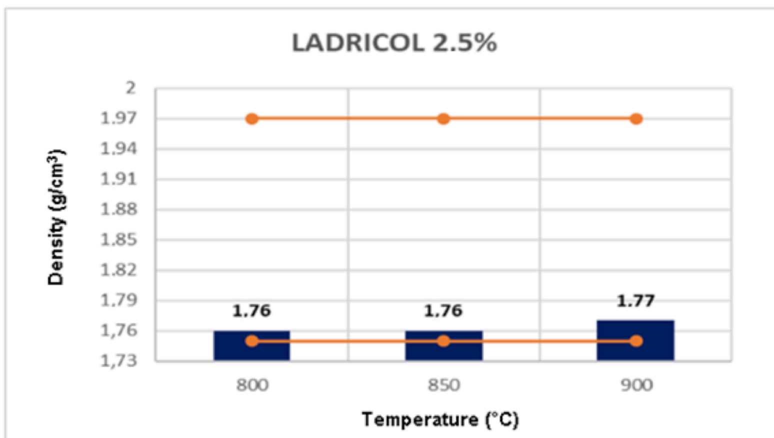

Figure 6. *Density of LADRICOL 2,5%*

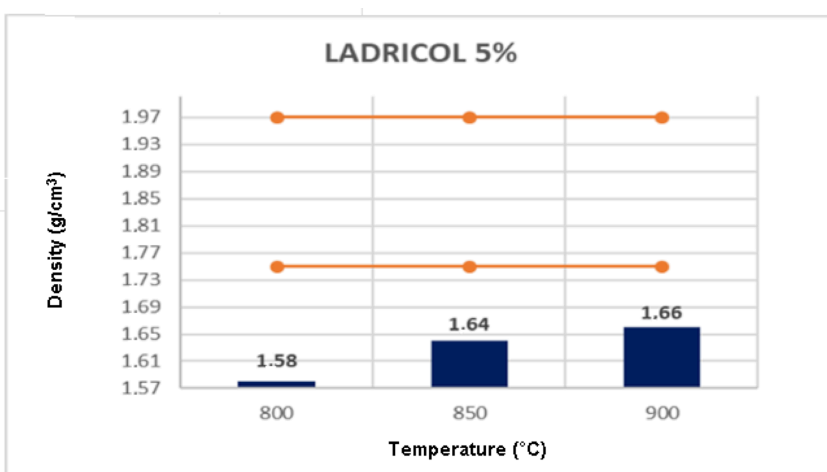

Figure 7. *Density of LADRICOL 5%*

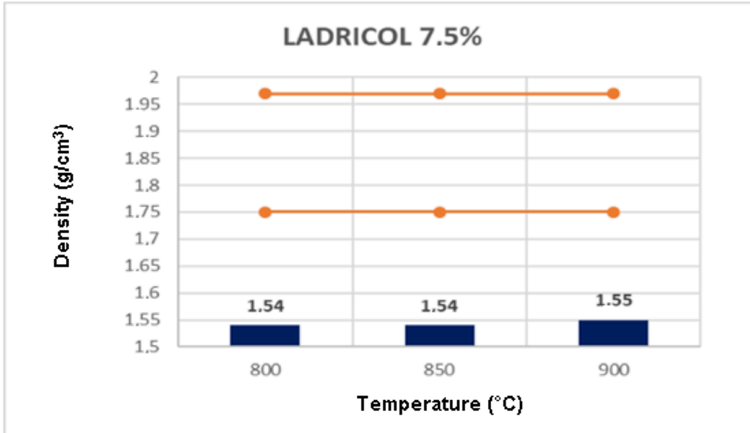

Figure 8. *Density of LADRICOL 7,5%*

Regarding water absorption, this relationship is inversely proportional, as shown in (Figure 9), (Figure 10), (Figure 11) and (Figure 12). In these cases, water absorption decreases as the firing temperature increases. However, it is directly proportional to the addition of cigarette butts since in LADRICOL 5% and 7.5% mixtures the absorption is higher than in the conventional mixture and in the mixture with 2.5% butts. This behavior is attributed to the increase in the brick porosity since the bricks in which the butts were added presented a greater porosity in their interior and consequently greater water absorption.

For a common brick, the apparent density in firing is usually between 1.75 – 1.97 g/cm^3 (Delgado, 2015); (Lozano and González, 2016). Concerning water absorption, for non-structural type M masonry, the NTC 4205-2 establishes a maximum result of 20% for each brick unit. Taking into account these reference values, 850 ℃ was selected as the optimum temperature since, as shown in (Figure 5) and (Figure 6), this temperature allowed adequate densities to be reached (1.95 g/cm^3 and 1.76 g/cm^3 in the conventional brick and the brick with 2.5% butts, respectively).

800 ºC and 900 ºC were ruled out since despite having very similar properties to 850 ºC, the former generates greater water absorption, which represents lower product quality, and the latter (900 ºC) represents a higher energy cost for the manufacture of the brick.

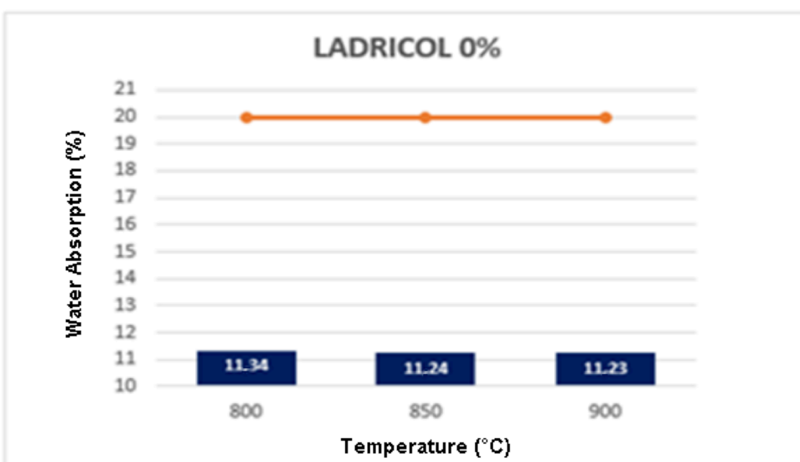

Figure 9. *Water absorption of LADRICOL 0%*

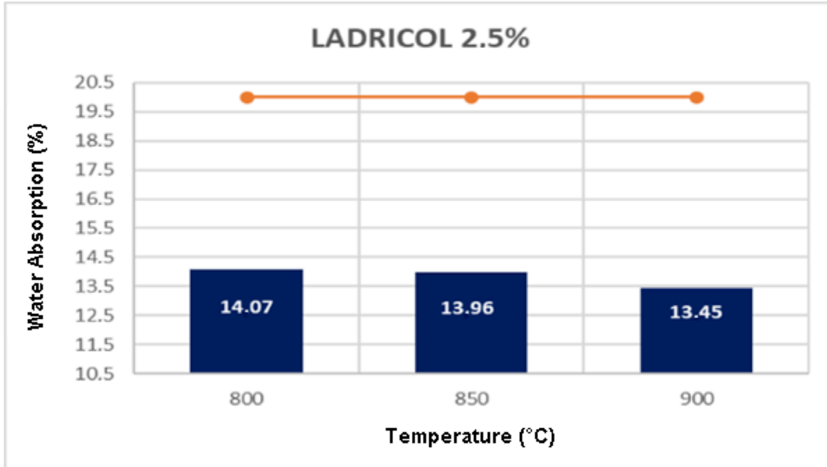

Figure 10. *Water absorption of LADRICOL 2,5%*

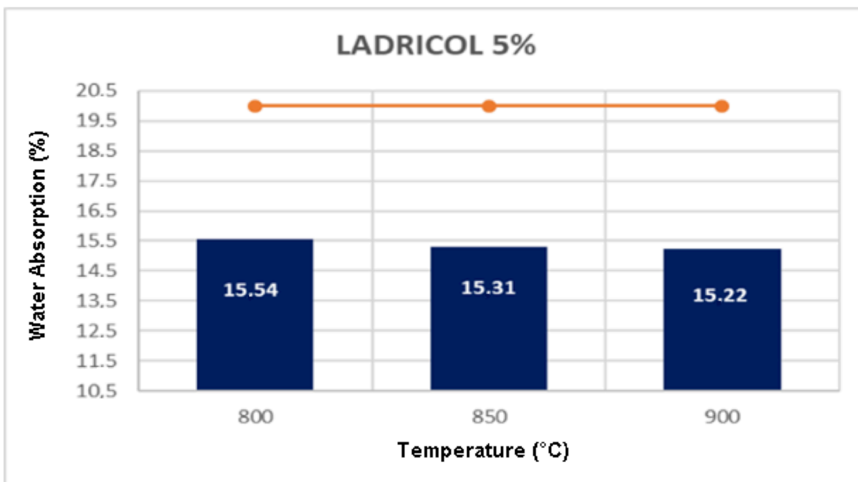

Figure 11. *Water absorption of LADRICOL 5%*

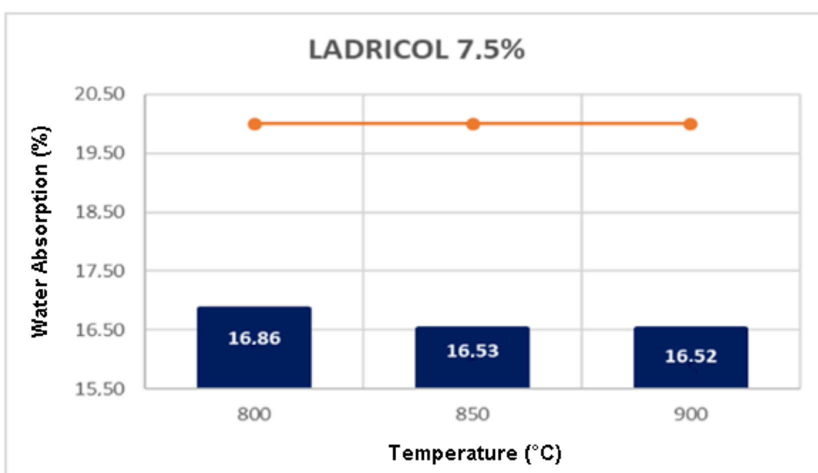

Figure 12. *Water absorption of LADRICOL 7,5%*

In addition, the mixtures LADRICOL 5.0% and LADRICOL 7.5% were rejected, as they did not comply with the usual minimum density. In both cases, the densities did not exceed the minimum value of 1.75 g/cm^3, thus affecting the strength of the material.

Based on the results shown above, the mixtures LADRICOL 0% and LADRICOL 2.5%, fired at a temperature of 850 °C, were chosen as suitable for the manufacture of non-structural type M masonry. The initial absorption rate was evaluated on these mixtures, obtaining the results shown in (Figure 13).

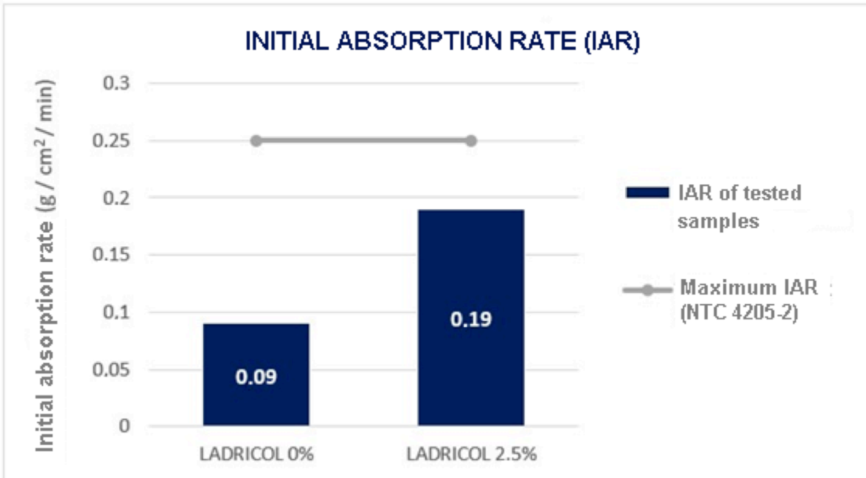

Figure 13. *Initial Absorption Rate (IAR)*

The result of the initial absorption rate increased for the mixture containing cigarette butts. This is mainly due to the porosity generated by the butts inside the brick, which in turn generates a higher initial absorption rate. However, this value does not exceed the 0.25 g/cm^2/min established in NTC 4205-2.

3.3 Mechanical properties of fired bricks

The average result of the compressive strength for the mixtures LADRICOL 0% and LADRICOL 2.5% was 19, 03 ± 4.33 MPa and 18.85 ± 1.10 MPa, respectively. See (Figure 14). This is compliant with NTC 4205-2, which establishes a minimum compressive strength for non-structural type M masonry of 10 MPa. This result also complied with the Colombian regulations for seismic-resistant construction (NSR-10 title D, Table D.10.3-1), where a minimum compressive strength of 15 MPa is established for clay bricks to be used in confined masonry walls, which are widely used in Colombia.

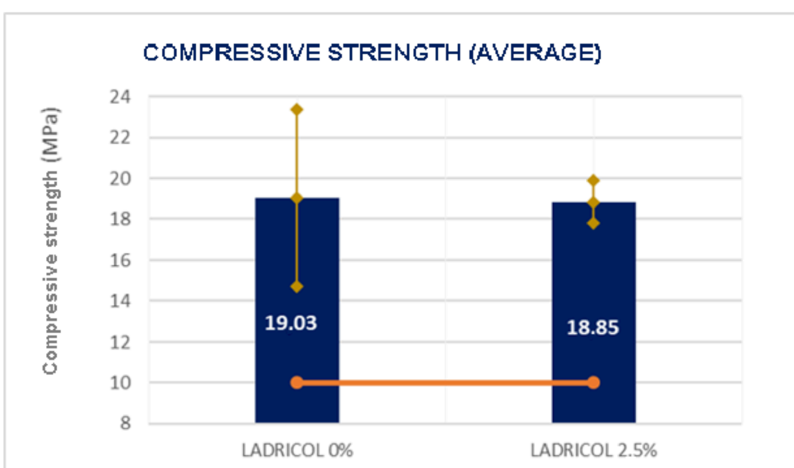

Figure 14. *Compressive strength*

Regarding flexural strength, the result obtained was 3.39 ± 0.24 MPa for the mixture LADRICOL 0%, and 1.28 0.24 MPa for the mixture LADRICOL 2.5%, as shown in (Figure 15).

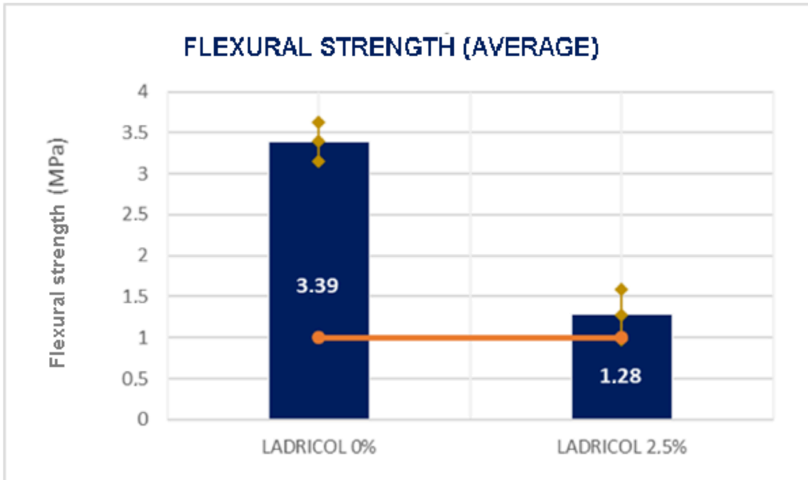

Figura 15. *Flexural strength*

There is a slight reduction in the physical and mechanical properties of the bricks containing cigarette butts (LADRICOL 2.5%). This reduction is associated with an increase in the porosity of the interior of the fired brick. The brick porosity increases in proportion to the percentage of butts added, as shown in (Figure 16).

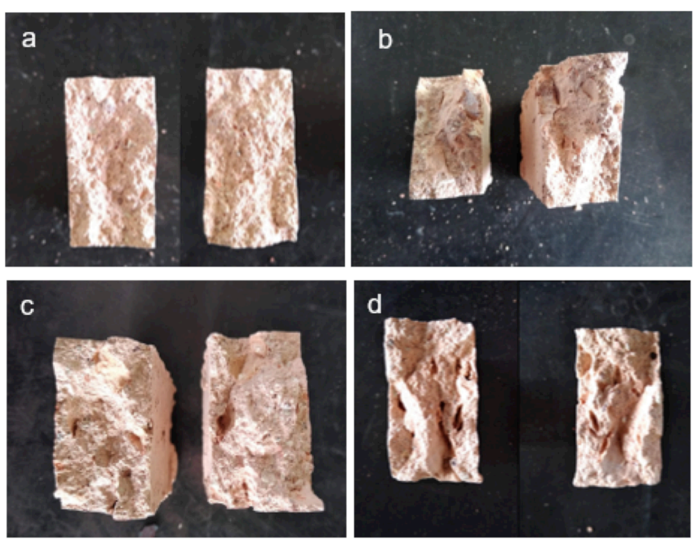

Figure 16. *Bricks with 0% (a), 2.5% (b), 5% (c) and 7.5% (d) cigarette butts*

On the other hand, the X-ray diffraction patterns of the conventional bricks (LADRICOL 0%) and those incorporating 2.5% cigarette butts (LADRICOL 2.5%) showed that there are no different mineralogical phases between them. See (Figure 17). The mineralogical phase present is quartz (SiO_2) at angles of 21.1794°; 26.9496°; 36.8383°; 39.7578°; 42.7379°; 50.4242°; 60.2280° and 68.4041° (reference code 01-083-2469 and 00-003-0427), which comes from the conventional raw material, i.e., clay.

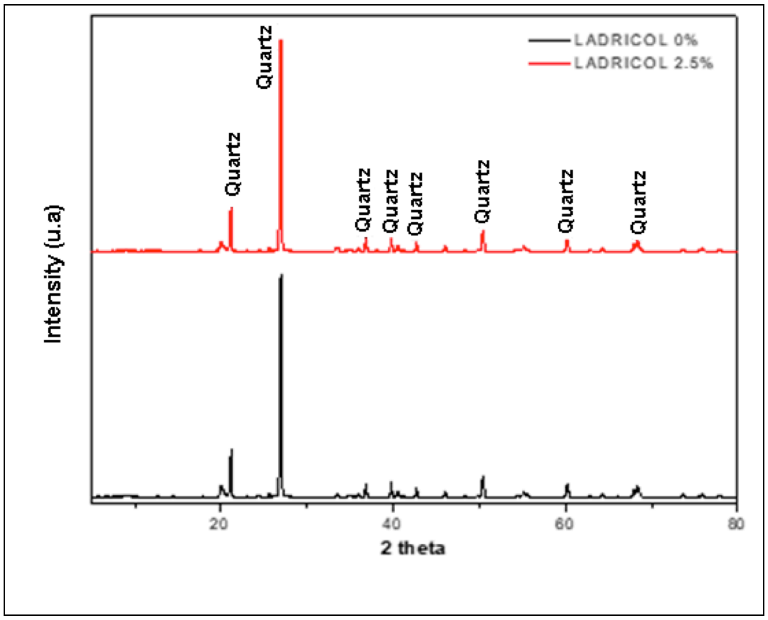

Figure 17. *DRX of LADRICOL 0% and LADRICOL 2.5%*

3.4 Energy consumption

To calculate the energy consumption required for firing the mixture LADRICOL 0% and LADRICOL 2.5%, (Equation 3.1) and (Equation 3.2) were used. (Table 3) shows the results and reflects a higher energy consumption in the conventional brick (0.9160 MJ) than in the brick with 2.5% cigarette butts (0.7351 MJ).

With respect to the percentage of energy saving, the result reflects a saving of 19.75% by incorporating cigarette butts in the manufacture of the brick. This is mainly due to the cellulose acetate present in the cigarette butts, as it is organic matter, and when mixed with the clay, it contributes positively to the firing process, allowing the concentration of heat; thus reducing the amount of energy required for the firing of the brick (Jackson and Dhir, 1996) and (Mohajerani et al., 2016).

Table 3. *Energy saving associated with the firing of LADRICOL 2.5%*

Energy Consumption q ***(MJ)***	***Clay Mass LADRICOL 0% y 2,5%*** m_1 and m_2 ***(kg)***	***Cigarette Butt Mass*** m_3 ***(kg)***	***Energy Used in LADRICOL 0%*** Q_1 ***(MJ)***	***Energy Used in LADRICOL 2.5%*** Q_2 ***(MJ)***	***Energy Saving %*** ΔE ***(%)***
2.405	*0.38091*	*0.0095*	*0.9160*	*0.7351*	*19.75*

4. Conclusions

This study determined the practicability of using cigarette butts as a raw material in the manufacture of bricks. The results obtained show the possibility of incorporating up to 2.5% cigarette butts in relation to the weight of clay used, allowing to obtain bricks with values of density (1.76 g/cm^3), water absorption (13.96%), compressive strength (10 MPa) and IAR (0.19 g/cm^2/min) according to the standards established by the Colombian regulation NTC 4205-2 for non-structural type M masonry.

On the other hand, the diffraction patterns (XRD) of the bricks with 2.5% cigarette butts showed no different mineralogical phases than those present in the bricks of the standard mixture (LADRICOL 0%). Additionally, incorporating this residue in such a percentage reduces the energy consumption due to the cellulose acetate, which allows the concentration of heat, resulting in a saving of 19.75% of the energy consumed.

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6. References

Abdul Kadir, A.; Mohajerani, A.; Roddick, F.; Buckeridge, J. (2015). Effect of heating rate on gas emissions and properties of fired clay bricks and fired clay bricks incorporated with cigarette butts. Applied Clay Science, 104, 269-276. https://doi.org/10.1016/j.clay.2014.12.005.

Barranzuela, J. (2014). Proceso productivo de los ladrillos de arcilla producidos en la región Piura. Tesis de pregrado en Ingeniería Civil. Universidad de Piura. Facultad de Ingeniería. Programa Académico de Ingeniería Civil. Piura. Perú.

Castañeda Espitia, S. (2011). Transformación de las colillas de cigarrillo a medios creadores de vida, para mitigar el impacto ambiental. Tesis de pregrado en Diseñador Industrial. Pontificia Universidad Javeriana. Facultad de Arquitectura y Diseño. Programa Académico de Diseño Industrial. Bogotá D.C.

De Granada-Orive, J. I.; Girón-Matute, W.; López Yepes, L. (2016). Cigarette butts: The collateral effects of cigarettes on humans, animals and the environment. Arch Bronconeumol. 2016; 52:285.

Delgado, M. C. (2015). Recursos naturales: Arcillas de uso cerámico, la sepiolita. Trabajo fin de grado en Química. Universidad de Jaén. Facultad de Ciencias Experimentales. Programa Académico de Química.

Fuentes Molina, N.; Isenia León, S.; Ascencio Mendoza, J. (2017). Biosólidos de tratamiento de aguas residuales domésticas, como adiciones en la elaboración de ladrillos cerámicos. Producción + Limpia. 12 (2): 92-102. DOI: 10.22507/pml.v12n1a8.

Gobierno Nacional de la Republica de Colombia. (2014). Estudio Nacional de Consumo de Sustancias Psicoactivas en Colombia 2013. Bogotá D.C.

Gonzalez Clemente, O. J.; Bezada Díaz, M.; Millán Boadas, Z. D.; Carrera, J. M. (21 de 01 de 2014). Caracterización de las arenas y arcillas minerales de los depósitos de canal y planicie de inundación del río portuguesa, Venezuela. Investigaciones geográficas, n.85, pp.18-32. doi:dx.doi.org/10.14350/rig.35291.

Guevara Lizano, A. (Noviembre de 2010). Sistema para el adecuado desecho de colillas de cigarrillo. Tesis de pregrado en Ingeniería en Diseño Industrial. Instituto Tecnológico de Costa Rica. Escuela de Ingeniería en Diseño Industrial. Cartago.

Instituto Colombiano de Normas Técnicas y Certificación. (30 de 11 de 2005). NTC 4017 Métodos para muestreo y ensayos de unidades de mamposteria y otros productos de arcilla. Bogotá.

Instituto Colombiano de Normas Técnicas y Certificación. (18 de 11 de 2019). NTC 4205-2 unidades de mamposteria de arcilla cocida. Ladrillos y bloques cerámicos. Parte 2: Mampostería no estructural.

Isel, V.; Sánchez, J.; Chaparro, A. (19 de Julio de 2017). Evaluación de arcillas caoliniticas-illiticas provenientes de la formación guayabo del Área Metropolitana de Cúcuta, Norte de Santander, Colombia. Revista ION, Vol. 30 Núm. 1. doi:http://dx.doi.org/10.18273/revion.v30n1-2017009

Jackson, N.; Dhir, R. (1996). Civil engineering materials (Fifth edition ed.). Palgrave.

Joshi, R.; Achari, G.; Horfield, D.; Nagaraj, T. (1994). Effect of heat treatment on strenght of clays, Journal of Geotechnical Engineering, Volume 120 Issue 6, 1080-1088.

Lozano Ortiz, M. M.; González Peláez, S. (2016). Uso de residuos cerámicos en la producción de ladrillos de arcilla cocidos del sector alfarero de candelaria. Tesis de pregrado en Inigeniería Industrial. Pontificia Universidad Javeriana. Facultad de Inigeniería. Programa Académico de Ingeniería Industrial. Santiago de Cali. Colombia.

Lozano Rivas, W. A.; Bonilla C., R. A.; Salinas C., A.; Flórez R., L.; Campos V. M. P.; Manrique R., A.; Jaimes R., Á. (Noviembre de 2015). Quantification of Cigarette Butts Littered to the Streets and Sidewalks in Dance Clubs and Pub Areas in Bogota D.C., Colombia. International Journal of Research Studies in Science, Engineering and Technology, Volume 2, Issue 11, 69-78.

Mohajerani, A.; Abdul Kadir, A.; Larobina, L. (2016). A practical proposal for solving the world's cigarette butt problem: Recycling in fired clay bricks. Waste Management. 52, 228-244. https://doi.org/10.1016/j.wasman.2016.03.012.

Monzonis Marco, J.; González Romero, J. (2011). Estudio para la minimización del residuo de colillas de tabaco y su posible reutilización. Tesis de grado. Universidad Politécnica de Valencia. Gandia.

Novotny, T. E.; Slaughter, E. (2014). Tobacco Product Waste: An Environmental Approach to Reduce Tobacco Consumption. 1, 208-2016. DOI 10.1007/s40572-014-0016-x

Rath, J. M.; Rubenstein, R. A.; Curry, L. E.; Shank, S. E.; Cartwright, J. C. (2012). Cigarette Litter: Smokers' Attitudes and Behaviors. Environmental Research and Public Health. 9, 2189-2203. doi:10.3390/ijerph9062189.

Ruge-Guerrero, O.O.; Martínez-Ovalle, S.A.; Diaz-Lagos, M. (2016). Evolución de fases magnéticas presentes en arcillas de Boyacá sometidas a altas temperaturas. Revista Ingeniería Investigación y Desarrollo, 16 (2), pp. 84-93

Sánchez Molina, J.; Corpas Iglesias, F.; Rojas Suarez, J. (2019). Cenizas volantes de una planta termoeléctrica como materia prima para la fabricación de materiales cerámicos de construcción: Efecto de la temperatura de cocción sobre las propiedades del material. Información tecnológica, 30 (1), 285-298. https://dx.doi.org/10.4067/S0718-07642019000100285.

Sanchez, A. Y.; Mejia, F. Y. (2009). Análisis de los esfuerzos de compresión en unidades de mampostería estructural y muretes E-9, E-11 y E-14 de una empresa ladrillera de Santander. Tesis de pregrado en Ingeniería Civil. Universidad Pontificia Bolivariana Seccional Bucaramanga. Programa Académico de Ingeniería Civil. Bucaramanga.

Santos, J. D.; Malagón, P. Y.; Córdoba, E. M. (2009). Caracterización de arcillas y preparación de pastas cerámicas para la fabricación de tejas y ladrillos en la región de Barichara, Santander. DYNA, Vol. 78 Núm. 167. 0012-7353.

Unidad de Planeación Minero-Energética. (2001). Determinación de la eficiencia energética del subsector industrial del ladrillo, vidrio y cerámica. Republica de Colombia Ministerio de Minas y Energía. Colombia.

Zhang, L. (2013). Production of bricks from waste materials - A review. Construction and Building Materials, 47, 643-655. https://doi.org/10.1016/j.conbuildmat.2013.05.043.