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Incorporation of spent bleaching earth and glass sediment as an alternative raw material for the manufacture of eco-products based on fired clay

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ABSTRACT: This study explores the use of two industrial residues: spent bleaching earth (SBE) and glass sediment (GS), as alternative raw materials in the production of ceramic materials from fired clay. The mixtures incorporating 0%, 10%, 30%, and 50% by weight of these residues, were examined. The impact of quantity and type of waste on product properties (density, water absorption, compressive strength, and thermal conductivity) was assessed against NTC 4205 standards. Incorporating 50% SBE reduced thermal conductivity by 35%, but increased porosity affected compressive strength. Glass sediment incorporation increased thermal conductivity but surpassed pure clay in mechanical behavior. The triphasic mix (20% GS, 10% SBE with lime) demonstrated optimal mechanical performance, meeting fired clay masonry unit standards. An eco-product prototype based on this mix was successfully manufactured, affirming that industrial waste is a viable alternative raw material, yielding ceramic materials with properties meeting or surpassing Colombian construction industry standards.

KEY WORDS: Spent bleaching earth; Glass sediment; Clay; Industrial waste; Eco-product.

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RESUMEN: *Incorporación de tierras de blanqueo gastadas y sedimento de vidrio como materia prima alternativa para la fabricación de ecoproductos a base de arcilla cocida.* Este estudio reporta el uso de dos residuos industriales: tierra de blanqueo agotada y sedimento de vidrio, como materias primas alternativas en la producción de materiales cerámicos a partir de arcilla cocida. Se analizaron mezclas que incorporaban 0%, 10%, 30% y 50% en peso de estos residuos. Se evaluó el impacto de la cantidad y tipo de residuos en las propiedades del producto (densidad, absorción de agua, resistencia a la compresión y conductividad térmica) en comparación con la norma NTC 4205. La incorporación del 50% de tierra de blanqueo redujo la conductividad térmica en un 35%, pero el aumento de la porosidad afectó la resistencia a la compresión. La incorporación del sedimento de vidrio aumentó la conductividad térmica, pero el comportamiento mecánico fue superior que en la arcilla pura. La mezcla trifásica (20% de sedimento de vidrio, 10% de tierra de blanqueo con cal) demostró un rendimiento mecánico óptimo, cumpliendo con las normas de unidades de albañilería de arcilla cocida. El eco-producto cerámico cumple las propiedades exigidas en las normas en Colombia, lo cual demostró que estos residuos industriales son una materia prima alternativa viable.

PALABRAS CLAVE: Tierra de blanqueo; Sedimento de vidrio; Arcilla; Residuos industriales; Ecoproducto.

1. INTRODUCTION

Due to its high demand for natural resources, the construction sector is one of the least sustainable sectors worldwide and is characterized by following a linear economy model. It accounts for 60% of lithosphere extraction, 36% of global energy consumption, and 40% of solid waste generation as well as being responsible for large quantities of greenhouse gas emissions (1–3). One of the subsectors with an important participation in construction is the clay sector. This industrial sector is made up of companies that manufacture, and market products made with clay, in particular the production of bricks, blocks, slats, and tiles. The productive growth of this industry, and its importance in the civil construction sector, has generated a global shortage of clay, a scarce non-renewable resource that is difficult to replace (4, 5).

In contrast to other sectors, the ceramic sector can reuse around 99.5% of the waste generated during production. Fragments of fired and unfired tiles, sludge from different stages, or waste from the grinding phases can thus be reincorporated into the production process, thereby avoiding the extraction, transportation, and use of tons of raw materials such as clays, feldspars or oxides, with the consequent fuel savings and reduction of emissions of carbon dioxide (CO_2) (6). Not only the waste generated during the production process can be reused to obtain ceramic products: the use of other solid waste or byproducts from related industrial sectors further reduces dependence on using non-renewable natural sources and encourages recycling. Depending on the type of waste employed, it is possible, for example, to save energy in the manufacturing process, reduce water requirements by improving the plasticity of the mixture, reduce costs by facilitating the supply of alternative raw materials, and even improve certain properties of ceramic products (4, 7–9).

Utilizing industrial waste as raw materials in the ceramic industry can significantly mitigate the issues of landfill disposal and the depletion of non-renewable natural resources (10). In this study, waste glass and spent bleaching earth were used. Waste glass is a 100% recyclable material rich in silica and calcium with considerable amounts of sodium oxide (a material widely known as flux). Global glass production was estimated at 130 million tons in 2018, and its waste volume was around 79%, which highlights the need to find alternatives for using this waste that currently ends up in landfills. (11). Waste glass can be used as a raw material in various applications, including the production of abrasives, flux material in the ceramic industry, coarse aggregates in asphalt or concrete mixtures, and as a pozzolan in blended cements, among other uses (12). In Colombia, the manufacture of glass and glass products is distributed in several departments, and the Valle del Cauca participates with approximately 11% of this production, according to data reported for the year 2016. The analysis of the volumes reported in the Environmental Registry –RUA – for the manufacturing sector, show that the volume of glass waste generated in 2019 and 2020 by companies in Valle del Cauca was 7,510 and 5,090 tons per year (equivalent to 625.8 and 424.2 t/ month), respectively, where 86.6% correspond to container glass and 10.68% to waste from glass transformation processes. Although there is no precise statistical data on the total volume of glass waste generated in Colombia, the recycling of glass waste is considered less than 15% of the total generated, and its common use is in the production of new glass containers and flat glass. Spent bleaching earth (SBE), typically acid-activated montmorillonite/bentonite clays with high surface areas are the primary solid waste generated in the edible oil refining process (13). SBE can be repurposed in various products, including roof tiles (14), ceramic membranes (15), bricks (1), adsorbent material, concrete and asphalt (13).

The effect of incorporating glass waste into clay brick mixtures have been studied, obtaining in all cases a microstructure with higher densification and lower porosity levels, and therefore improved mechanical performance (16-19). Although the use of filtration of earth waste or spent bleaching earth from the filtration of fats and oils for the manufacture of clay-based products, unlike glass waste, is limited, it is a potentially useful and valuable by-product (20). Eliche-Quesada and Corpas-Iglesias (1) investigated the potential of incorporating filtration earth waste and spent bleaching earth as a pore-forming agent and using silica precursors in bricks in proportions between 5 to 30% by weight. The results showed that an increase in the proportion of these wastes caused an increase in porosity and a decrease in mechanical resistance, although, in addition to 20% of these wastes, the mechanical resistances obtained were within the ranges established by the standards for bricks. The balance in properties such as apparent density, mechanical resistance, and thermal conductivity was achieved with a percentage of 10% by weight of these wastes compared to the 100% clay bricks. Elsewhere, Heidari and Jalili Ghazizade (10) studied the use of spent industrial soil (SIS) in the manufacture of clay bricks in proportions between 5-25% by weight, the results showed that the use of these wastes increases water absorption, and reduces the density of the brick samples due to the increase in porosity in the brick structure. The mechanical strength however was not strongly influenced by porosity, which was associated with the fact that the proportion of SIS increases the content of amorphous and glassy phases in the samples, thus causing a decrease in the pore size (10).

Although progress in waste management has been notable in recent times, waste production remains very high (1). In Colombia, the waste management model is mainly based on the economic model of linear production and consumption. By 2030, waste generation in both urban and rural areas is projected to reach 18.74 million tons per year. Of this total, 14.2 million tons annually will need to be disposed of in landfills that lack adequate capacity. This shortfall in landfill capacity is expected to lead to significant environmental problems due to the improper management of solid waste, adversely affecting water, soil, and air quality, and posing health risks to nearby communities (21-23). In the particular case of glass waste, given its non-biodegradable nature, serious environmental pollution is generated and although statistically there is no clear information on the total global amount of this waste, it is estimated that 7% of solid waste corresponds to glass waste (24). Meanwhile, the residue of filtration earth or spent bleaching earth from the filtration of fats and oils is a waste generated by the vegetable oil refining industries in the order of 2 million tons worldwide, which is disposed of directly into landfills, a procedure that is also expensive and unfriendly to the environment. Its restricted use is mainly associated with the high oil content, which poses both a fire hazard and an environmental problem. However, it is a potentially useful and valuable byproduct that can be incorporated into the production of construction materials (20).

When the use of waste for the manufacture of new ceramic products does not adversely affect, and on the contrary improves, the properties of a material, such as ceramic clay for civil construction, align with contemporary principles of sustainable development, which promote not only a decrease in pollution but also the safeguarding of clay as an important natural resource (2, 16). Various strategies that can be applied to improve resource efficiency include dematerialization of goods and services, eco-design, life cycle thinking, prevention of waste production, extension of product life cycle, and industrial symbiosis (9). These considerations necessitate shifting from the traditional linear economy model to a circular economic model, which is more efficient and strategically aimed at fostering a prosperous, modern, competitive, and environmentally neutral economy (23). Based on the above, this research proposes the use of two Colombian non-hazardous industrial wastes – spent bleaching earth and glass sediment (fine powder resulting from the glass polishing process)- as a solution to the recycling of this type of waste in Colombia, using them in the manufacture of a sustainable, environmentally friendly ceramic product. It is worth mentioning that the simultaneous use of these two wastes in the production of ceramic materials has not been investigated.

2. MATERIALS AND METHODS

2.1. Materials

In this study, the following were selected as raw materials: commercial clay, two spent bleaching earth (SBE and SBC) from the bleaching process in the refining of oils and fats of animal and vegetable origin from a food product manufacturing company, and glass sediment from a safety glass processing and transformation company for architecture, located in the Department of Valle del Cauca in Colombia. These materials can be seen in Figure 1. The adaptation of the clay was carried out in a jaw crusher and subsequently, a grinding process was carried out, using a ball mill for a period of two (2) hours. The glass sediment (GS) was also subjected to a grinding process in a ball mill, and in the case of the spent bleaching earth maceration process was carried out in a porcelain mortar, until obtaining a particle size passing through sieve No. 100 (<0.149 mm).

The chemical composition was determined by X-ray fluorescence (XRF). The results can be seen

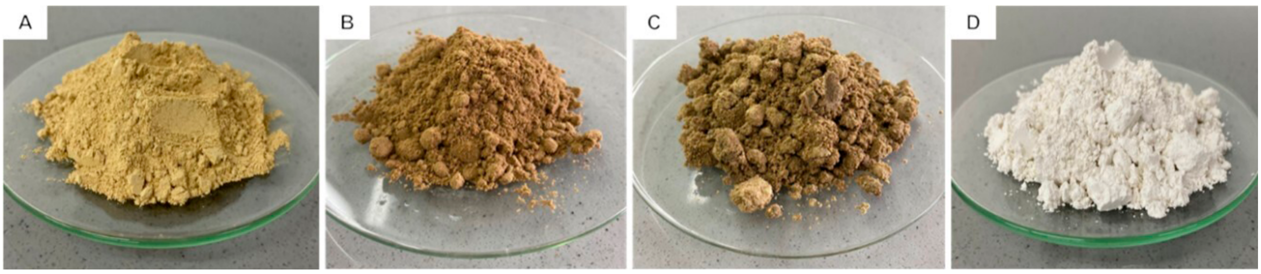

Figure 1. a) Clay (C), b) Spent bleaching earth (SBE), c) Spent bleaching earth with lime (SBC), and d) glass sediment (GS).

in Table 1. In general, the solid waste contemplated in this study reported significant amounts of SiO_2. In the case of the spent bleaching earth (SBE), the MgO content was greater than 16%, the CaO in the spent bleaching earth with lime (SBC) and in the glass sediment (GS) meanwhile exceeded 9% by weight, while the Al_2O_3 was around 3 % in the spent bleaching earth. As reported by Eliche-Quesada et al. (26), the presence of oxides such as K_2O, Na_2O, Fe_2O_3, CaO, and MgO favor vitrification and are considered fluxes, so they can influence the densification behavior of the ceramic materials during firing and therefore help reduce the process temperature, thereby improving the properties of the ceramics. It is noteworthy that the spent bleaching earth had a high loss on ignition (L.O.I.), greater than 25%, associated mainly with the presence of organic compounds, in this case from the oil. However, waste that contains fuel also contributes to saving energy in firing, while waste containing oxides improves the ceramic properties (27).

The density of the powders was determined in an Anton Paar Ultrapyc 3000 helium pycnometer according to the ASTM C329 standard (ASTM International 2016). Table 1 shows that the glass sediment has a higher density (2.53 g/cm^3) compared to the spent bleaching earth. A modular particle size analyzer with Mastersizer 2000 laser diffraction technology that includes a Hydro 2000MU accessory was used to determine the particle size of the clay and the glass sediment, obtaining an average particle diameter of 8.558 µm and 36.994 µm, respectively. The granulometry results revealed that for the glass sediment, 90% of the sample remained below a particle size of 63.716 µm, whereas for the clay, it was 24.040 µm. Differential thermal analysis was carried out in a TA Instruments V2.5H universal equipment (SDTQ 600) at a heating rate of 10 °C/min. in airflow of 100ml/min up to a maximum temperature of 1100 °C for the clay and 1000°C for the spent bleaching earth and the Infrared Spectroscopy analysis was carried out on the PerkinElmer Spectrum 100 FTIR equipment with the KBr tablet preparation procedure.

2.2. Production of material from fired clay

The manufacture of fired clay masonry involves four basic steps, summarized as: a) Selection and

Table 1. Chemical Composition and Physical properties of raw materials.

		SBE	SBC	GS
Chemical Composition (wt%)	SiO_2	45.01	41.99	71.95
	Al_2O_3	3.60	3.42	1.59
	CaO	1.78	9.35	11.38
	Fe_2O_3	1.30	1.27	0.09
	MnO	0.02	0.02	
	K_2O	0.71	0.65	0.51
	MgO	17.13	16.16	0.26
	P_2O_5	0.55	0.46	0.02
	Na_2O	0.42	0.36	13.77
	SO_3	0.34	0.35	0.26
	SrO	0.02	0.02	-
	TiO_2	0.18	0.18	0.07
	V_2O_5	0.01	0.02	-
	CuO	-	-	0.04
	SnO_2	-	-	0.02
	ZrO_2	-	0.01	0.01
	CI	0.03	0.03	-
	CdO	0.03	0.03	-
	PtO_2	0.02	0.01	-
	L.O.I.	28.9	25.7	-
Physical Properties	Density (g/cm^3)	1.81	1.86	2.53
	Particle Size (µm)	< 149	< 149	36.99

preparation of the mixture, b) Molding, c) Drying, and d) Firing (7). In the first stage, the quantities of residue added to the mixes were established (0, 10, 30, and 50% by weight). Table 2 shows the compositions by weight of each of the mixes. The amount of water added was 30% by weight, an amount corresponding to the plastic limit of the clay determined by the ASTM D4318 standard (ASTM International, 2018). Once the compositions were established, experimental units were prepared in the form of 2x2x2 cm cubes in an artisanal manner, where the molding was carried out manually. It is important to highlight that in the mixes with the incorporation of spent bleaching earth (SBE), the workability was superior. The samples were subjected to a drying process for 24 hours. Finally, the heat treatment of the samples was carried out in an electric oven at 1000 °C, for 3 h.

Table 2. Compositions by weight of each of the mixes.

Mixture ID	Dosification (wt%)			
	C	SBE	SBC	GS
C	100%	-	-	-
CSBE1	90%	10%	-	-
CSBE3	70%	30%	-	-
CSBE5	50%	50%	-	-
CSBC1	90%	-	10%	-
CSBC3	70%	-	30%	-
CSBC5	50%	-	50%	-
CGS2	80%	-		20%
CSBC1GS2	70%	-	10%	20%

The heat treatment of the samples involved four stages: 1) Preheating to 300 °C and elimination of water physically bound to the clay, 2) Heating up to 700 °C, in which the water chemically bonded to the clay is eliminated, 3) Maturation of the product at 1000 °C, and 4) Tempering of the piece, cooling in an oven. At this stage, it is important to consider the firing interval, that is, the temperature range between the beginning of vitrification (formation of the glassy phase) and the beginning of deformation since the characteristics of the paste depend on it and must be as wide as possible. The optimal firing temperature must be within this range, not too close to the beginning of vitrification so that the material is not too porous, and not too close to the beginning of deformation so that the piece is not deformed (28). The appearance of the samples after the firing process is evident in Figure 2, where a color change is observed with the incorporation of residues compared to the 100% clay sample (C). The samples with the presence of glass sediment (GS) presented a reddish appearance.

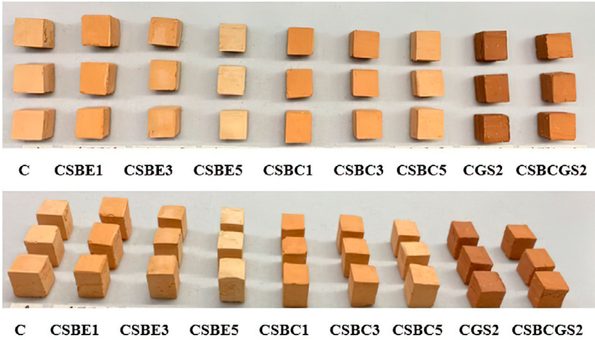

Figure 2. Appearance of the samples after the firing process.

The methodology used to determine the physical and mechanical properties of fired clay pieces was taken from the Colombian regulations NTC 4017, Methods for sampling and testing of masonry units and other clay products, where the selection and preparation of the sample procedures are set out (ICONTEC, 2018), a modified adoption of ASTM C67:2017, Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile. The compressive strength of the brick was evaluated in a Universal Testing Machine: INSTRON 3369 with a 50 KN compression capacity. For this test, three specimens of each mixture were taken with measurements of 20x20x20 mm. All specimens were subjected to a progressively increasing normal stress, applying a centered load with a speed of 1 mm/min. The physical characteristics (apparent density (ρa), water absorption (A24h), and volume of permeable pores (Vpp)) of the samples were determined according to the provisions of the NTC 4017:2018 standard (29) and were complemented by the technique with the ASTM C642-13 standard (30). Finally, the thermal conductivity measurement was carried out by the transient plane source (TPS) method by the ISO 22007-2 Standard in a Hot Disk Thermal Constants Analyzer model TPS 500 S from Thermtest - Thermal conductivity instruments.

3. RESULTS AND DISCUSSION

3.1. Characterization of the raw material

The results of the thermal analysis carried out on the clay and spent bleaching earth are reported in Figure 3, where a total mass loss for the clay of 10% was observed. In the case of the spent bleaching earth, the mass losses were 35% for spent bleaching earth with lime (SBC) and 37.97% for spent bleaching earth without lime (SBE).

The DTA curves of the clay show endothermic peaks at 56 °C and 243 °C that can be related to its dehydration. The peak at 508 °C can be associated with a dehydroxylation process (31, 32). Around 900 °C, several exothermic effects are observed attributable to the crystallization of high-temperature phases (25). The DTA curve of the spent bleaching earths is typical of a solid fuel. In the DTA curve of the waste, two weight losses are observed between 335 and 457 ºC associated with the combustion processes of the organic matter, which coincides with that reported by Eliche-Quesada and Corpas-Iglesias (1). The endothermic reaction between 656 and 850 °C may be attributed to the thermal decomposition of the carbonate present in the sample (25). The importance of thermal analyses of a clay material lies in the fact that they reveal the behavior of the sample as the temperature changes. Through the thermal profile, it is therefore known how to implement a firing curve or propose a heating program appropriate to the sample characteristics. By controlling the firing curve, it can be ensured that the sintering processes are carried out in a controlled manner and the greatest densification of the pieces is achieved, achieving products that meet the quality standards demanded by the market (33).

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The Fourier transform infrared (FTIR) spectroscopy results are reported in Figure 4. As can be seen, the spectra of the spent bleaching earth with and without lime are similar. The difference lies mainly in small shifts and the intensity of the bands in each of the spectra, in addition to the presence of a band at 872 cm^{-1} for the spent bleaching earth sample with lime.

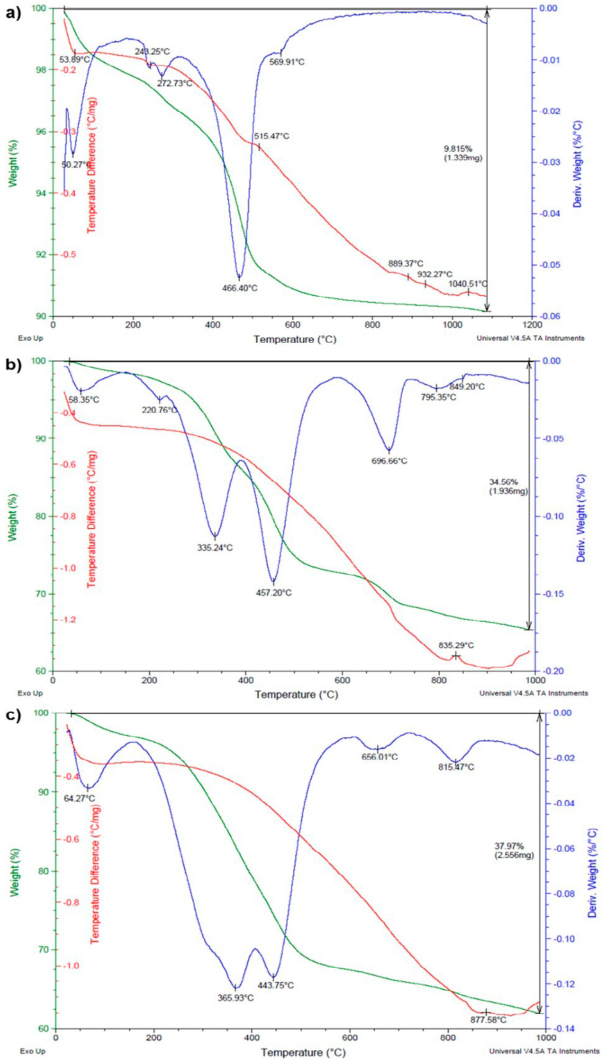

Figure 3. DTA-TG and DTG curves: a) Clay, b) SBC, and c) SBE.

The bands between 3698 and 3621 cm^{-1} for the clay and spent bleaching earth are associated with the stretching of the O-H bond, which according to Chaisena and Rangsriwatananon (34) occurs due to the presence of kaolinite, bands 3433 and 3473 cm^{-1}, corresponding to the stretching of the O-H bond of water (H_2O) present in the samples, and around 1635 cm^{-1} to the bending of H_2O. In the clay spectrum, the band at 1115 cm^{-1} corresponds to the Si-O-Si stretching. The peaks that appear at 911 and 872 cm^{-1} for the spectrum of clay and spent bleaching earth with lime, respectively, correspond to the stretching of Si-OH and/or bending of Al-Al-OH (kaolinite) inter tetrahedral. The bands between 780 and 798 cm^{-1} belong to the stretching of the Si-O-Al, (Al, Mg)-O-H bond and the stretching of the Si-O-(Mg, Al) bond. Finally, the bands between 471-694 cm^{-1} were associated with the bending of the O-Si-O bond, while the bands between 536-546 cm^{-1} of the clay and spent bleaching earth spectra correspond to the bending of the Si-O-Al bond (33-36).

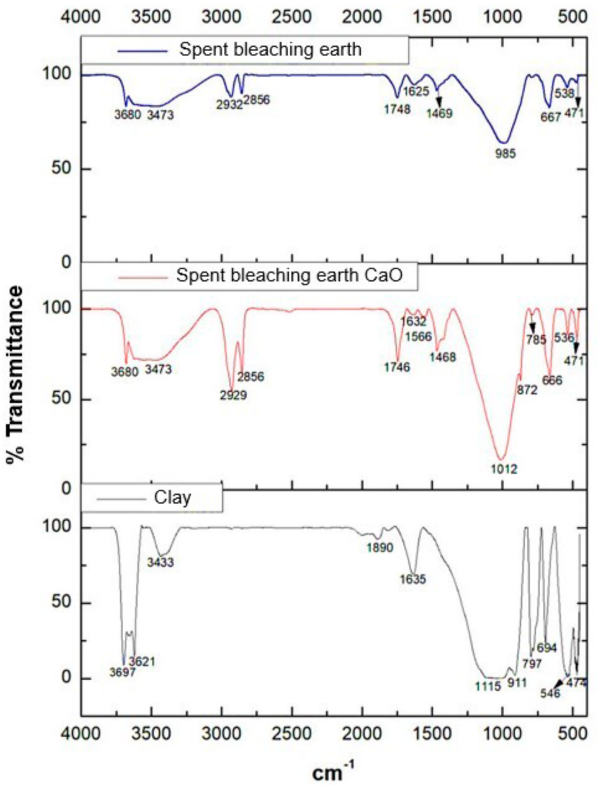

Figure 4. Fourier transform infrared (FTIR) spectroscopy curves.

3.2. Water absorption, porosity, and apparent density tests

The results of the water absorption, porosity, and apparent density tests are reported in Figure 5. According to the provisions of the NTC 4205-2: 2009 standard, the maximum requirements for immersion in water for 24 hours that fired clay masonry units must meet should be 20%. If the samples exceed this value, the standard suggests determining whether or not the firing temperature was sufficient to form stable ceramic phases through differential thermal analysis tests of the raw material (37). As seen in Figure 5, only the 100% clay samples and those with the addition of glass sediment (GS) had an absorption within the parameters established by the standard, unlike the samples with the incorporation of spent bleaching earth. This is associated with the high content of organic matter present in the spent bleaching earth (>34% by weight), where it was expected that during the firing process, due to the combustion of the oil present in the samples, there would be an increase in the porosity of the ceramic pastes as the percentage of addition of the residue in the mixture increased (27). The lower water absorption of bricks with glass sediment is the result of a greater amount of local liquid phase at high temperatures, which contributes to an increase in the density of the fired brick and a decrease in the volume of open and closed pores (16, 18, 38).

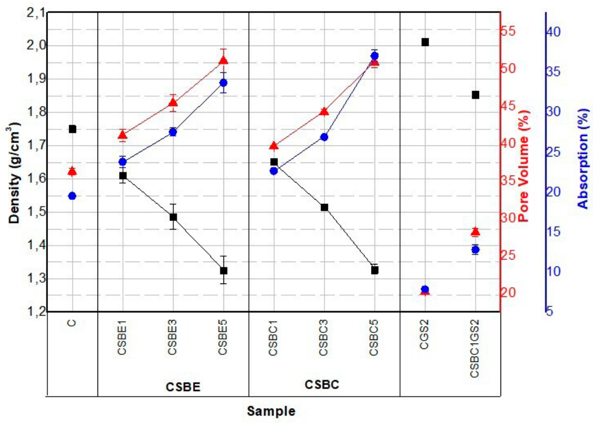

Figure 5. Apparent density (black), porosity (red) and water absorption (blue) results.

The degree of porosity of the ceramic bricks depends on the nature, properties, and processing of the initial clay. The highly porous materials can produce lower mechanical performance, and higher water absorption, although the thermal insulation is improved (18, 25, 39). In this case, the organic nature of the spent bleaching earth, in addition to contributing to the ceramic firing process by saving energy in manufacturing and fuel consumption, can give rise to a more porous microstructure, which can contribute to improving the thermal insulation capacity of the final product.

3.3. Compressive strength

Compressive strength is a crucial quality for bricks to be of use in the construction sector, as these materials primarily experience compressive loads; in contrast, flexural strength and tensile strength are typically assessed in porcelain samples (38, 39). As established in NTC 4205-2 (ICONTEC, 2009), the minimum compressive strength that non-structural masonry units must meet is 10 MPa per unit, and in the case of structural masonry according to NTC 4205-1: 2009, the minimum suggested strength is 15MPa. Considering what is reported in Figure 6, the fired clay samples and the clay mixtures with the incorporation of 10% of spent bleaching earths (CSBE1 and CSBC1), exceed the values established for structural masonry units, while the CSBE3 sample that has an incorporation of 30% of lime-free spent bleaching earth exceeds the value established only for non-structural masonry units. In general, the incorporation of spent bleaching earth reduces the compressive strength, compared to the standard fired clay sample, which may be associated with the increase in porosity, coinciding with what was reported by Singh and Chandel (38) who associate the decrease of the compressive strength to the firing of the organic materials present in the mixtures that give rise to porous structures.

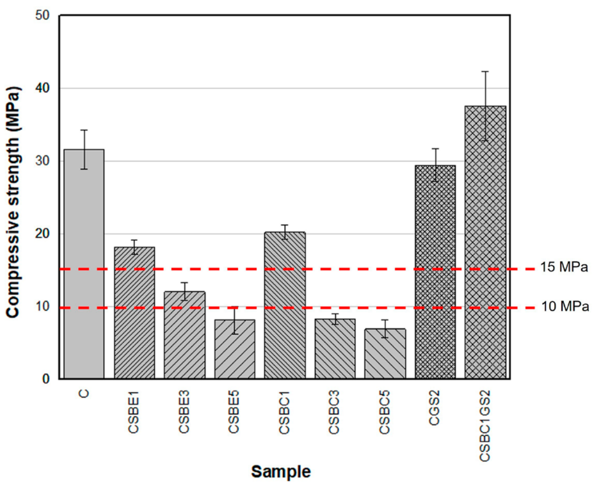

FIGURE 6. Compressive strength results.

Noteworthy is the best performance achieved by the samples with the incorporation of glass sediment in percentages of 20% (CGS2), showing compressive strengths greater than 29 MPa, exceeding 93% of the minimum value established in NTC 4205 for structural masonry. This coincides with what was reported by Mohammad et al. (4) and is attributed to the fact that the incorporation of glass reduces the distance between particles, leading to greater cohesion of the developed composite. The mix with the incorporation of 10% of the SBC and 20% of GS (CSBC1GS2) increases the compressive strength and even exceeds the values obtained in the reference sample (C) by up to 19%. This increase could possibly be associated with the formation of crystalline phases between the calcium of the SBC and the glass.

3.4. Thermal properties

Figure 7 reports the results of thermal conductivity, thermal diffusivity, and specific heat of the eco-products. The average thermal conductivity of the samples with 100% clay content (C) was 0.55 W/mK. With the increase in the percentage of addition of SBE, a trend is evident in the decrease of up to 35% in the thermal conductivity of these samples compared to the control sample (C). This trend is also observed in the properties of thermal diffusivity. The incorporation of glass sediment (CGS2), for its part, increases the thermal conductivity values (0.97 W/mK) by 77%. This coincides with what was reported by Xin et al. (19) who found that the incorporation of glass waste in percentages of 5, 10, and 15% in the bricks increased by 46%, 50%, and 56% respectively, with the increase in the addition percentage, compared to the average thermal conductivity of the brick (0.63 W/mK). When the glass sediment is incorporated with spent bleaching earth with lime (CSBC1GS2), the value obtained for conductivity (0.75 W/mK) is 36% higher compared to the fired clay sample, but there is a decrease of up to 29% compared to the sample with the incorporation of only glass sediment (CGS2). The increase is also observed in the specific heat for the samples with the incorporation of glass sediment, although the incorporation of SBE in the CSBC1GS2 sample decreases the thermal diffusivity concerning sample C.

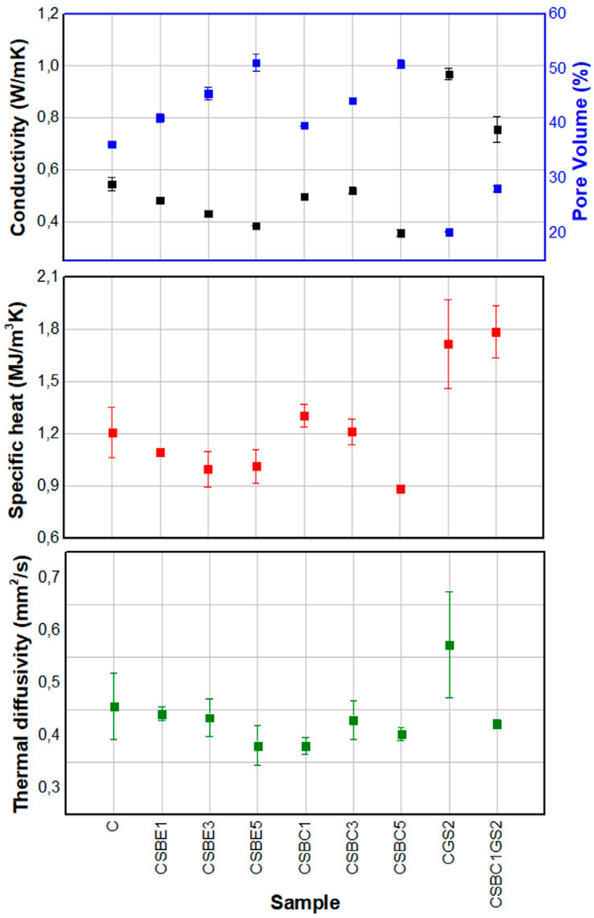

FIGURE 7. Thermal properties of the products.

The increase in conductivity is mainly associated with the increase in apparent density, which in turn leads to a decrease in the total porosity of the samples as observed in the first graph of conductivity versus pore volume. In the particular case of bricks with the incorporation of glass waste, the formation of a glassy phase helps to reduce porosity and therefore there is an increase in density and thermal conductivity (19). It is important to highlight that the thermal conductivity of brick products is influenced by the characteristics of the pore system, the mineralogical composition, and the microstructure because certain crystalline phases demonstrate higher thermal conductivity compared to some amorphous or glassy phases (1, 39).

In contrast to the physical and mechanical properties, the thermal conductivity and diffusivity of fired clay bricks have traditionally garnered minimal attention, but, with the rising global emphasis on energy saving, these thermal properties have gained increasing recognition in recent years (39). Therefore, reducing the thermal conductivity of bricks is pivotal for realizing potential energy savings in buildings, as its improvement facilitates the efficient storage and absorption of heat, resulting in cooler interiors during summer and warmer spaces in winter. Consequently, occupants benefit from reduced energy consumption for air conditioning (19). One of the most effective ways to reduce the thermal conductivity in traditional ceramics is by increasing their porosity, which is possible to achieve by incorporating different pore-forming organic fuels. However, one of the resulting disadvantages is a deterioration in the mechanical properties (1). The thermal conductivity of the standard brick (C), and those that had an incorporation of up to 30% of SBE, as reported by (19), are within the range established for bricks of fired clay: 0.4 W/mK to 0.7 W/mK.

With the use of waste such as SBE, not only a considerable decrease in thermal conductivity would be achieved, but also the valorization of waste for the manufacture of environmentally friendly ceramic products with a decrease in their manufacturing costs. Another important factor in using waste materials for manufacturing fired clay masonry elements is specific heat, since due to the high organic matter content in SBE waste releases a substantial amount of heat during combustion, significantly aiding the ceramic firing process (27).

3.5. Development of an eco-product prototype

The CSBC1GS2 mix had the highest compressive strengths and lowest water absorption, complying with the standards established in the Colombian regulations for fired clay masonry. The good mechanical behavior was associated with the contribution of the glass sediment in the densification of the clay matrix, in addition to the reinforcing action of this residue as particulate material in the matrix. It was therefore selected as the optimal composition for the manufacture of a larger-scale eco-product prototype in the form of a decorative brick (facade). The manufacturing process was similar to that used for the 20x20x20 mm experimental units. The final product is seen in Figure 8. Its properties are: Compressive strength 37.59 MPa, Absorption 12.82%, Thermal conductivity 0.75 W/ mK.

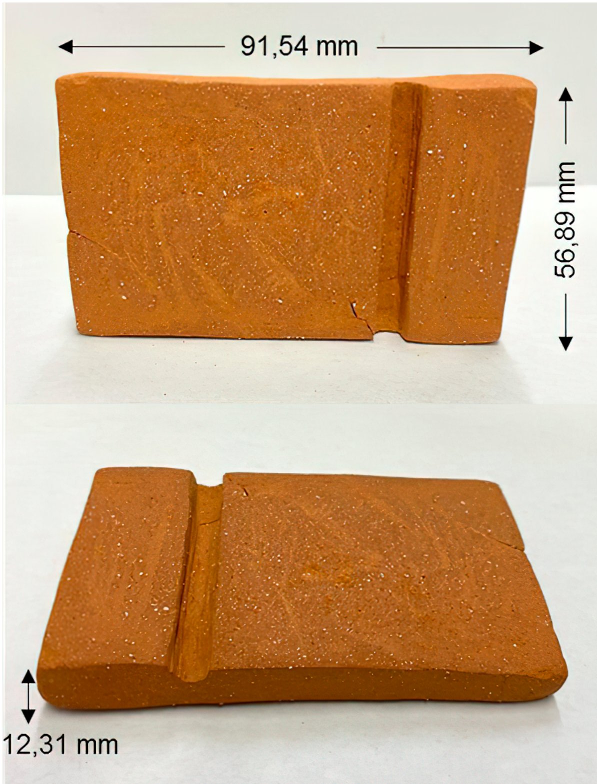

Figure 8. Prototype obtained with CSBC1GS2.

4. CONCLUSIONS

The results demonstrate the feasibility of producing ceramic materials using up to 30% of non-hazardous industrial waste, while maintaining physical and mechanical properties that meet or exceed Colombian standards for fired clay masonry. The use of spent bleaching earth can decrease mechanical strength and increase water absorption, whereas glass sediment enhances strength and reduces water absorption. However, the incorporation of spent bleaching earth leads to a decrease in thermal conductivity, suggesting its potential as pore-forming agents for obtaining fired clay pieces with low thermal conductivity, meeting minimum strength requirements for non-structural masonry elements.

The combination of clay, glass sediment, and 10% spent bleaching earth with lime yielded the optimal balance of mechanical strength, water absorption, and thermal conductivity. This supports the viability of sustainable development in the clay industry through the utilization and valorization of various non-hazardous industrial wastes as alternative raw materials to produce fired clay masonry elements.

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Authorship contribution statement

Estefanía Montoya-Quesada: Conceptualization, Formal analysis, Investigation, Methodology, Writing - original draft, Visualization.

Ruby Mejía-de-Gutiérrez: Conceptualization, Funding acquisition, Methodology, Validation, Project administration, Resources, Supervision, Writing - review & editing.

Declaration of competing interest

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

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