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Porous red ceramic bricks made from mixtures of clay and pine sawdust

Ladrillos porosos de cerámica roja a partir de mezclas de arcilla y aserrín de pino.

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Juan Pablo Pasquini
Universidad Tecnológica Nacional, Facultad Regional San Nicolás, Grupo de Estudios Ambientales, Colón 332, San Nicolás, Buenos Aires, Argentina.
jpasquini@frsn.utn.edu.ar

Gisela Guadalupe Pelozo
Universidad Tecnológica Nacional, Facultad Regional San Nicolás, Departamento de Ingeniería Industrial, Grupo de Estudios Ambientales, Colón 332, San Nicolás, Buenos Aires, Argentina.
gpelozo@frsn.utn.edu.ar

Nancy Esther Quaranta
Universidad Tecnológica Nacional, Facultad Regional San Nicolás, Grupo de Estudios Ambientales, Colón 332, San Nicolás, Buenos Aires, Argentina.
nquaranta@frsn.utn.edu.ar

Abstract

The objective of this study is to examine the effects of incorporating pine sawdust into clay mixtures utilized in the production of ceramic materials. In particular, the research aims to assess the impact of these aggregates on the physical and mechanical properties of the resulting bricks. The production conditions were as follows: uniaxial pressure at 25 MPa from clay-sawdust mixtures, with additions of 5% to 30% by volume and 8% of water, in 70 mm x 40 mm molds, resulting in thicknesses of approximately 15 mm. The samples were heat treated at 1000°C for a period of 3 hours. The products obtained exhibit a homogeneous reddish coloration and a well-defined structure, with no evidence of shelling. The properties of the ceramic pieces are within the required values for their intended use as building brick. The porosity of these ceramic bricks increases in proportion to the amount of pine sawdust incorporated into the mixtures. The pore sizes were analyzed with consideration of the distribution of aggregate particle sizes, resulting in the determination of a ratio between pore size and particle size of 60-70%.

Keywords: Biomass, Residues, Sawdust, Ceramics

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Resumen

El objetivo de este estudio es examinar los efectos de la adición de aserrín de pino a mezclas arcillosas utilizadas en la fabricación de materiales cerámicos. En particular, la investigación analiza la influencia de estos agregados sobre las propiedades físicas y mecánicas de los ladrillos obtenidos. Las condiciones de producción fueron: presión uniaxial a 25 MPa de mezclas arcilla-aserrín, con agregados de 5% al 30% en volumen y 8% de agua, en moldes de 70 mm x 40 mm, resultando espesores de aproximadamente 15 mm. Las muestras fueron tratadas térmicamente a 1000°C durante 3 horas. Los productos obtenidos presentan una coloración homogénea rojiza y una estructura bien definida sin desgranamientos. Las propiedades de las piezas cerámicas se hallan dentro de los valores requeridos para su uso como ladrillo de construcción. La porosidad de estos ladrillos cerámicos aumenta proporcionalmente a la cantidad de aserrín de pino agregada en las mezclas. Los tamaños de poro se analizaron teniendo en cuenta la distribución de tamaños de partícula agregada, determinando una relación entre tamaño de poro y tamaño de partícula del 60-70%.

Palabras claves: Biomasa, Residuos, Aserrín, Cerámicos

Introduction

Agro-industrial waste is defined as residual material generated in productive activities that is not of direct interest. Typically, these discarded biomasses are retained on the premises of the companies that produce them, until they are sent for final disposal, or are destined for other uses such as energy production.

The term biomass defines organic matter that has originated from a natural or induced process and can be used as a source of energy, that is, residual material that can be used as fuel. This source of energy has several notable advantages, including its contribution to the economic and social development of the regions where it is produced, the reduction of waste materials and the decrease in emission. However, it does present one significant drawback: the generation of a new waste product consisting of ashes, albeit in a much smaller volume, with greater feasibility of use (Agrela et al., 2019).

The source of biomass for energy purposes can be natural, agricultural, industrial or urban. The utilization of residual biomass represents a promising way for investigation, offering a significant advantage in the form of decontamination when it is eliminated, in addition to the generation of energy. The direct combustion of lignocellulosic materials can be carried out in a variety of devices, which exhibit notable differences in terms of their degree of technological sophistication, processing capacity, energy efficiency, level of emissions, and investment costs. In Argentina, several companies are engaged in the production of energy from agricultural waste, including peanut shells, corn cobs, rice husks, etc.

In addition to their use in biomass-energy processes, a considerable number of residual biomasses have been the subject of investigation with a view to their potential applications in other uses. To illustrate, pistachio shells have been employed as catalyst supports (Akti, 2022). Rice husks, pine sawdust and corn cobs have been demonstrated to be effective as adsorbent materials for heavy metals present in liquid effluents, which are then immobilized in ceramic matrices (Simón et al., 2019; Romano et al., 2020). The adsorption of Pb and Ni has been investigated using a range of biomaterials, including sugarcane bagasse, coffee waste,

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rice husks, and others, as biosorbents (Saxena et al., 2017; Alhogbi, 2017; Bulgariu & Bulgariu, 2018; Ezeonuegbu et al., 2021).

In the specific case of the lignocellulosic material under investigation in this work, namely pine sawdust, its potential applications have been examined. The most prevalent use of pine sawdust is the production of pellets for utilization as a solid fuel. This can be used as standalone biomass source (Rashid et al., 2017), or in combination with other lignocellulosic materials such as algae (Hosseinizand et al., 2018; Carneiro et al., 2017), oat husks (Murillo et al., 2021), corn cobs and coconut shells (Kamga et al., 2024).

The adsorption of heavy metals, organic compounds, and other substances, has been investigated using sawdust, both ground and in its forms of activated carbon and biochar. The analysis of these works demonstrates that, in the majority of cases, the most effective form for the removal of contaminants is biochar. The efficacy of adsorption processes for hexavalent Cr (Zhang et al., 2018), Cu (Orozco et al., 2023), Cd (Hashem et al., 2020), and for the adsorption of gases such as CO_2 and CH_4 (Durán et al., 2022; Patel et al., 2023), has been demonstrated.

The potential of various types of sawdust, including pine and eucalyptus has been studied for the production of load-bearing panels in the construction industry. Nunes de Oliveira et al. (2023) have produced ecological panels with excellent mechanical properties, starting from ground residual materials such as sawdust and chamotte (a granular material derived from the pulverized bricks), through a pressing with resin and curing process at 80°C. Rojas-Herrera et al. (2024) have developed materials for use as thermal insulation in sustainable construction from residual sawdust.

This biomass material has been the subject of study with a view to its potential use as a pore former in the manufacture of advanced ceramics, including microporous and mesoporous membranes. Bose & Das (2015) have produced designer membranes using various biomass functionalization conditions, with a particular focus, on the selection of the sawdust particle size added to the original ceramic mixture, which primarily comprises kaolin, feldspar and quartz. The same materials, when added to suitable ceramic mortars, have been used by these authors as a matrix in mixtures with ground sawdust of known particle distribution, for the production of low-cost, tubular-shaped porous ceramic membranes (Bose & Das, 2013).

A number of studies have been identified in the literature which make use of sawdust as a porogen in fired clay materials. Some of these focus on the production of artisanal bricks (Deulofeuth Carrera & Severiche Hernández, 2020; Delgado, 2022). The parameters employed in these cases, such as the temperatures attained in the selected samples, are not well defined or controlled. It is acknowledged that in an artisanal kiln, the firing of bricks occurs in different sections under varying conditions with regard to temperature, air pressure and other factors. These are not systematic studies with the scientific rigour required in such cases to achieve reproducible results and valid conclusions.

In the field of red clay production, some manufacturers have experimented with the incorporation of sawdust from various tree species as a porosity modifier. Although some process parameters such as temperature or pressing pressure are controlled, these are not systematic studies that lead to the control of the final product porosity. Cultrone et al. (2020) studied the production of lightweight bricks from clayey earth and sawdust from carpentry workshop waste. In this study, they used aggregates of up to 10% sawdust and treatment temperatures ranging from 800°C to 1100°C. The samples were handmade using an artisanal process, even though the vast majority of industrially produced bricks today are manufactured by extrusion or pressing.

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The present research is original because it is a meticulous, systematic study that analyses a wide range of residual biomass aggregates (sawdust) as the sole variable in the process. Other parameters that are subject to control are moisture content in the mixtures, compression pressures used, drying temperatures of the pieces, firing temperature and time, etc. These are the same used for obtaining all ceramic pieces. The study's originality also lies in the characterization of the pores formed, in relation to the characteristics of the aggregated sawdust particles. Through this analysis, the sizes and shapes of the pores formed in the final products have been examined.

The objective of this work is: i) to study the incorporation of pine sawdust as a porosity former in ceramic matrices, ii) to evaluate the properties of the resulting products and ascertain their suitability for the market requirements and iii) to characterize the shape and size of the pores produced, in relation to these parameters of the pine sawdust aggregate particles.

Materials and methods

The pine sawdust used in this process is sourced from a sawmill located in the town of Villa Constitución, Santa Fe Province, Argentina, where the wood is processed. The commercial clay used comes from quarries located in the central area of the Buenos Aires Province and was supplied by a ceramic industry in the region. Both raw materials were subjected to a grinding, drying and sieving process.

The materials were characterized by a variety of techniques, including optical microscopy (OM) and scanning electron microscopy (SEM), energy dispersive X-rays spectroscopy (EDS), particle size distribution, weight loss on ignition (LOI), differential thermal and thermogravimetric analysis (DTA-TGA), and X-ray diffraction (XRD). The ceramic products obtained were characterized with techniques such as: porosity, water absorption, permanent volumetric variation (PVV), weight loss on ignition (LOI), flexural and compressive strength.

Optical microscopy observations were performed using Zeiss-Axiotech equipment with a Donpisha 3CCD camera and image digitizer. SEM and EDS analyses were performed using an FEI Inspect S50 scanning electron microscope with an energy dispersive analyzer (EDAX-Phoenix). Particle size distribution was conducted on a Zonytest vibrating bench, with superimposed sieves of standardized mesh sizes (ASTM standard).

X-ray diffraction (XRD) patterns of powdered samples were recorded using PANalytical X'Pert PRO equipment with CuKα radiation (α = 1.5406 nm) under operating conditions of 40 kV and 40 mA. Thermal behavior tests on biomasses (DTA-TGA) were performed using Shimadzu DTA-50 TGA-50 equipment with TA-50 WSI analyzer, at heating rates of 1°C/min, in air atmosphere, in the temperature range from ambient to 1000°C. The diffraction patterns obtained were analyzed using the HighScore program (version 3.0b-3.0.2, 2011). The results will be reported according to the program's reference codes (RC).

The porosity and water absorption of the bricks obtained were determined in accordance with the standards in ASTM C20-00. The PVV and LOI values were obtained from the difference between the weight and volume of the green pieces and those of the fired pieces. The mechanical properties, specifically flexural and compressive strength, were determined using a DIGIMESS 600KN universal testing machine (model WDW 600S). The flexural test was conducted at a speed of 0.5 mm/min, according to IRAM 11827 standard, while the compression test was performed at a speed of 0.6 MPa/min, in accordance with the IRAM 12586 standard.

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The ceramic pieces were obtained from mixtures of commercial clay and pine sawdust in proportions of 5, 10, 15, 20, 25 and 30% by volume, with the addition of 8% by weight of water, in 70mm x 40mm molds, resulting in thicknesses of approximately 15mm, using a uniaxial pressure of 25 MPa.

The compacts obtained were dried at room temperature and in an oven at 100°C, followed by heat treatment at 1000°C for 3 hours. This was done in accordance with firing curves that are commonly employed by the ceramic industry for this specific material. The heat treatment was conducted using a TecnoDalvo electric furnace with a Dhacel TD101 programmable temperature controller. In order to achieve reproducible results, five bricks of each composition have been obtained.

For comparison, a sample of commercial clay without added residue was prepared. The samples produced are identified as follows:

A0: commercial clay sample with no sawdust added.

A5: commercial clay sample with 5% by volume of sawdust

A10: commercial clay sample with 10% by volume of sawdust

A15: commercial clay sample with 15% by volume of sawdust

A20: commercial clay sample with 20% by volume of sawdust

A25: commercial clay sample with 25% by volume of sawdust

A30: commercial clay sample with 30% by volume of sawdust

Results and discussion

The semi-quantitative chemical composition of the raw materials, pine sawdust and clay, has been determined by EDS, and is presented in Table 1 where it is expressed as percentage by weight of its elements.

	C	O	Na	Mg	Al	Si	P	K	Ca	Fe
Sawdust	71.2	23.1	-	0.1	0.3	0.7	4.3	--	0.3	--
Clay	15.6	40.7	1.1	1.3	8.7	23.8	--	2.0	1.3	5.5

Table 1. EDS chemical analysis of raw materials used.

As can be observed, the biomass contains, in addition to carbon and oxygen, a majority proportion of P and, in much smaller proportions, elements such as Mg, Al, Si and Ca. The clay exhibits a composition that is consistent with that of commercial clays, with significant proportions of Si and Al, as well as other elements such as Fe, Mg, Ca, K and Na. If the results are expressed in the form of oxides, it is evident that the composition of the clay shows is dominated by Si (61.2%), Al (20.7%) and Fe (8.4%) oxides.

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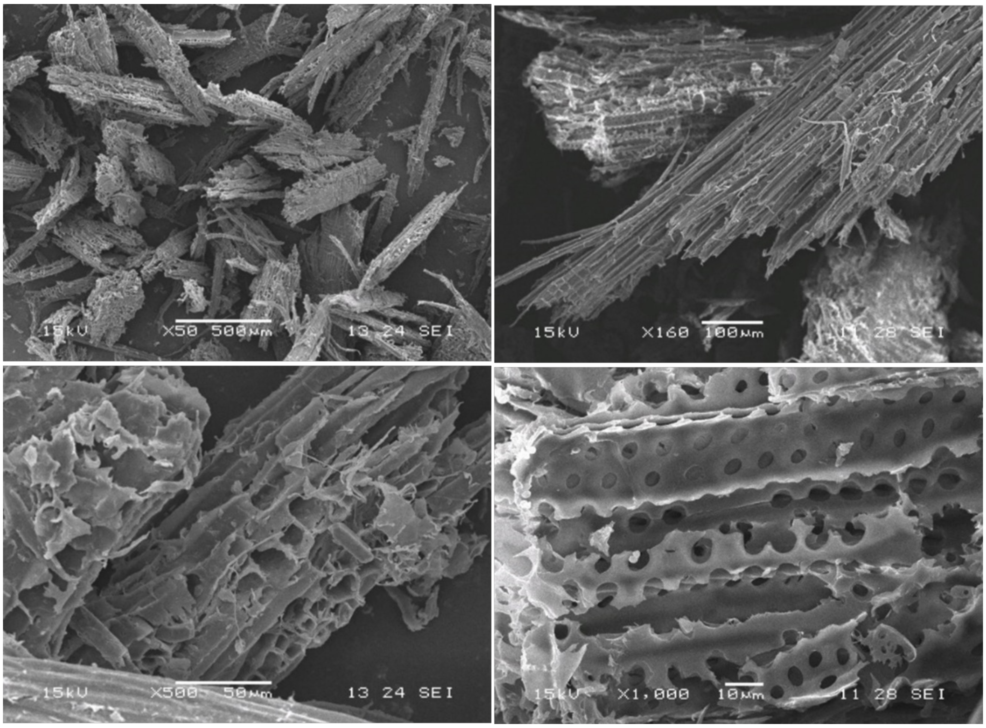

Figure 1. SEM micrographs of the pine sawdust particles.

SEM observations of the ground residual material (Figure 1) at low magnifications (up to 200X) show that these are elongated particles with a fibrous structure and a higher proportion of average sizes within the range selected for the study. Both selected raw materials are composed of particles smaller than 1 mm. At higher magnifications, 500X and 1000X, it is observed that these are open grooved structures, which in principle suggests a greater interaction between the biomass and the clay particles during the formation of the mixtures.

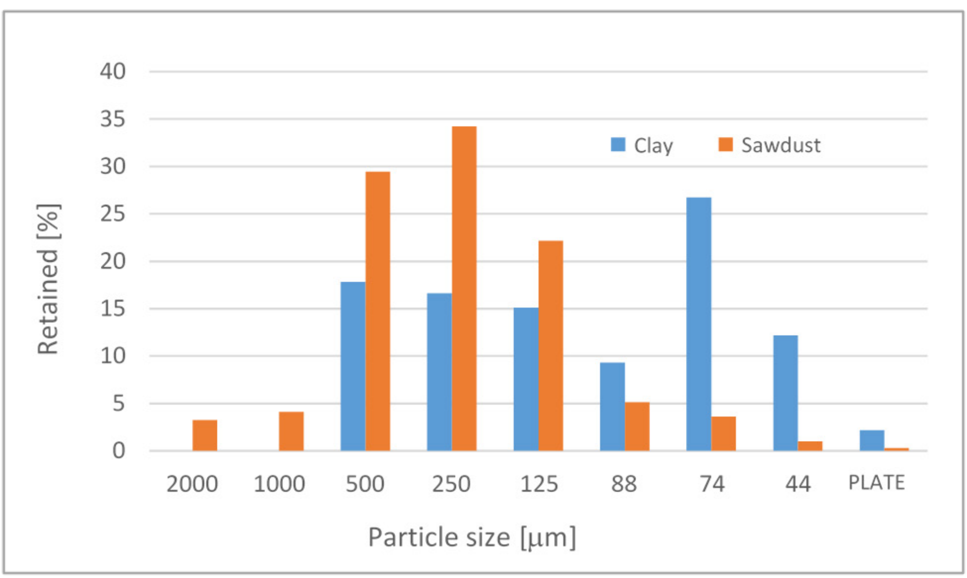

Figure 2. Particle size distribution of raw materials.

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Figure 2 illustrates the particle size distribution of the original raw materials. The clay is mainly constituted of particles with an average size within the range 125µm-500µm, exhibiting a notable prevalence of smaller particles (44µm-88µm). Pine sawdust also exhibits a high percentage of particles within the 125µm-500µm range, while the percentage of fine particles (≤ 88µm) and coarse particles (≥ 1mm) is notably low. This distribution characteristic is highly advantageous in the development of the designed mixtures to obtain more homogeneous compacts, which subsequently lead to more compact and durable ceramic matrices. The particle sizes selected for this study were those that passed through a 1mm mesh, in accordance to the particle size distributions observed in the figure.

The mineralogical analysis by X-ray diffraction of the used clay material shows the presence of feldspars in greater proportion. The labradorite phase has been identified. The presence of quartz and hematite peaks is also observed.

The main peaks, along with their corresponding crystallographic planes for the aforementioned phases and the RCs used by the program for their identification, are presented below.

-Labradorite: 39.4° (-3,-3,2); 40.2° (-2,-2,6); 42.4° (2,-4,2); 45.7° (0,6,2); 50.1° (0,-4,6). (RC 01-083-1417).

-Quartz: 20.8° (1,0,0); 26.6° (0,1,1); 36.5° (1,1,0); 39.4° (1,0,2); 42.4° (2,0,0); 45.7° (2,0,1); 50.1° (1,1,-2); 55.0° (0,2,2); 59.9° (2,1,-1); 68.2° (0,3,1); 73.2° (1,0,4); 75.7° (3,0,2). (RC 01-078-1252).

-Hematite: 24.1° (0,1,2); 33.2° (1,0,4); 35.6° (1,1,0); 40.9° (1,1,3); 49.5° (0,2,4); 54.1° (1,1,6); 57.5° (0,1,8). (RC 00-024-0072)

In XRD diffraction studies (XRD), biomass materials may present a number of distinctive diffraction peaks, some of which are attributed to the crystalline phase of one of the biopolymers present, namely cellulose. In the case of the pine sawdust used in this work, the obtained diagram exhibits five peaks within the range of 2θ between 10° and 80°, as can be seen in Figure 3.

Three peaks are observed at diffraction angle 2θ= 16.1, 22.4 and 34.7, which are corresponding respectively to (1,1,0), (2,0,0) and (0,0,4) lattice planes of cellulose I [Mayta Paucara et al., 2023; Shaheen & Emam, 2018; Kumar et al., 2014; Zhao et al., 2007]. Additionally, a peak can be identified at 2θ=26.5°, corresponding to the most intense peak of quartz phase of silica (SiO_2), previously described. The peaks observed at 31.6° (1,0,4) and 45.3° (2,0,2) are assigned to the calcium and magnesium carbonate ($MgCa(CO_3)_2$) [Chen et al., 2023]. These elements are naturally in small quantities in this type of tree biomass, but can be found in XRD-detectable amounts because they can be absorbed from soil.

The Full Width at Half Maximum (FWHM) was calculated from XRD pattern of sawdust. It is important to note that a comparison of FWHM values is only possible if the peak intensities are equal. This is not the case in the presence instance, which is the reason why the corresponding maximum height (Hmax) ascertained in each peak in conjunction with the 2Θ value is specified in brackets. Both FWHM and Hmax are expressed in mm. The results of the study are as follows: 6.3 (2θ 16.1, Hmax 15.9); 8.8 (2θ 22.4, H_{max} 51.0); 1.7 (2θ 26.5, H_{max} 32.0); 1.7 (2θ 31.6, H_{max} 32.0); 4.0 (2θ 34.7, H_{max} 12.8) and 1.7 (2θ 45.3, H_{max} 15.5).

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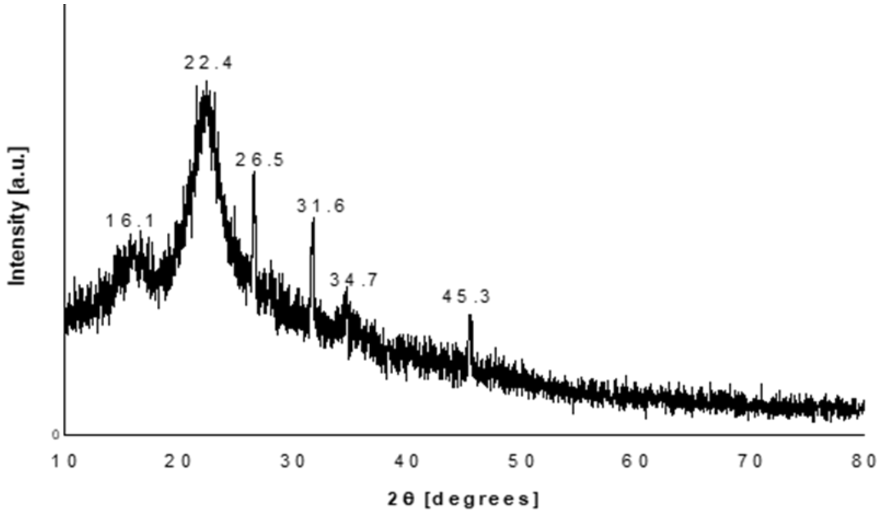

Figure 3. XRD diagram of ground pine sawdust.

The differential thermal analysis (DTA) and thermogravimetric analysis (TGA) of agro-industrial biomasses typically exhibit up to three characteristic peaks that can be attributed to the decomposition-combustion reactions of the main biopolymers present, namely hemicellulose, cellulose and lignin. These peaks appear in a specific order, with hemicellulose exhibiting the earliest peak, followed by cellulose and then lignin, as the temperature increases. The analysis of ground pine sawdust (Figure 4) revealed the presence of two exothermic peaks, occurring at 327°C and 448°C, respectively. The first was well-defined and intense, while the second was broader, probably due to the coexistence of the cellulose and lignin peaks. The TGA curve records the weight losses that occur during the combustion of the biopolymers. It is observed that there are staggered weight losses, whereby, in the case of sawdust, on the one hand, the combustion of hemicellulose can be identified, and on the other hand, at higher temperatures, a region of joint combustion of cellulose and lignin. This is in agreement with the observed DTA peaks.

The weight loss resulting from the calcination of this powder sample can be calculated from the graph in Figure 4, by determining the point of intersection with the TGA [mg] axis. This value represents the amount of ash produced in the sawdust combustion process. In this case, a value of 0.90% is obtained.

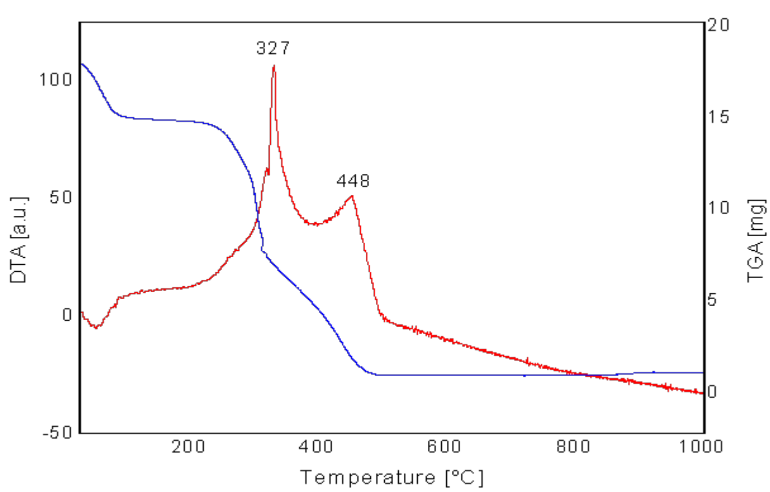

Figure 4. DTA-TGA of the ground biomass.

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The result of this thermal behavior analysis is important because the fact that this biomass has a wide range of combustion temperatures allows to infer that when it is incorporated into the clay mixtures, cracks will not occur during the sintering process of the ceramic products. This is in contrast to the potential occurrence of such cracks when the biomass burned in a very limited temperature range.

The DTA-TGA characterization of the clay shows a DTA curve without the presence of peaks that indicates phase transformations or other reactions, while the weight loss of the sample is recorded continuously from approximately 200°C to 800°C. This indicated that the only reactions occurring at the test temperatures are the loss of surface-adsorbed water, structural water, and dehydroxylation processes common in silicoaluminates.

Figure 5 shows the bricks obtained with commercial clay with and without added residue. It can be observed that the products exhibit a homogeneous reddish coloration and a well-defined structure. No spalling is observed at the corners or edges. The color observed is attributed to the Fe content of the clay and is consistent across all samples, irrespective of the initial content of pine sawdust.

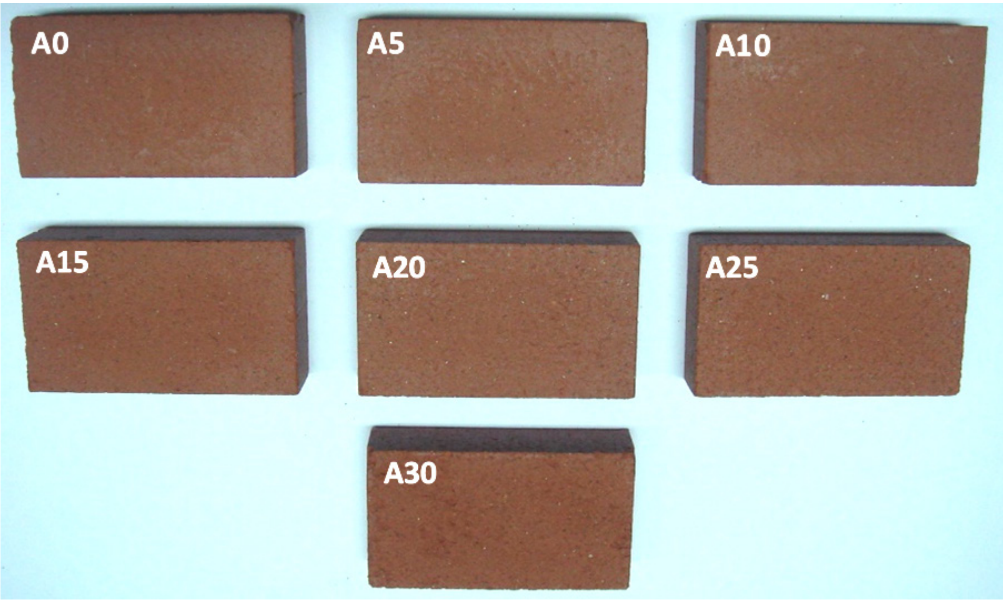

Figure 5. Ceramic bricks obtained with clay and pine sawdust mixtures.

The distinctive properties of the bricks produced with varying proportions of residual biomass added, in comparison to the reference sample comprising solely clay (A0), are shown in Table 2. It can be observed that the values of the permanent volumetric variation (PVV), which in this case are the percentages of shrinkage, demonstrate a tendency to decrease as the sawdust content in the samples increases. However, this tendency is lost in the samples with higher proportions, with values fluctuating around 5.4 ± 0.5 %.

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Sample	PVV [%]	LOI [%]	Porosity [%]	Water Absorption [%]
A0	6.45	8.34	19.1	9.1
A5	6.75	9.63	19.8	9.6
A10	6.83	10.70	22.4	11.1
A15	4.87	11.55	23.9	12.0
A20	5.84	12.25	26.6	14.0
A25	4.90	13.53	27.3	14.7
A30	5.60	15.28	30.4	16.8

Table 2. Properties of the obtained ceramic products.

The weight loss on ignition (LOI) values show an increase with the incorporation of sawdust into the samples. A loss of 8.34% is observed in the clay brick sample, which is in accordance with expectations given that biomass combustion occurs under heat treatment conditions. Consequently, the remaining samples show elevated values in proportion to the biomass content.

The porosity values obtained for the samples studied demonstrate an increase in accordance with the sawdust content, indicating that during the combustion of the biomass, the structure of the brick matrix is either maintained or exhibits minimal variation, resulting in the generation of pores within this space. This may account for the variation observed in the PVV values at high sawdust contents. In the event that this were not the case, a disproportionate contraction of the piece with the formation of structural cracks would be observed. The A30 sample, in particular, exhibits an increase of approximately 60% in porosity relative to the control sample.

Figure 6 shows the results of the mechanical properties of the bricks: flexural strength expressed in terms of the modulus of rupture (MOR) and compressive strength (CS). Although the IRAM standards used to perform these tests do not specify minimum required values, the values established by the ASTM C62-04 standard for the compressive strength of building bricks (structural and nonstructural masonry) are usually used, which specifies the following minimum required values: 8.6 MPa for individual pieces, and 10.3 MPa as the average value of 5 bricks tested. The Argentine Regulations for Masonry Structures (CIRSOC, 2007) establish a compressive strength value of 5.0 MPa, which can also be used as the required value in the local market. The compressive strength values of all samples exceed these required values.

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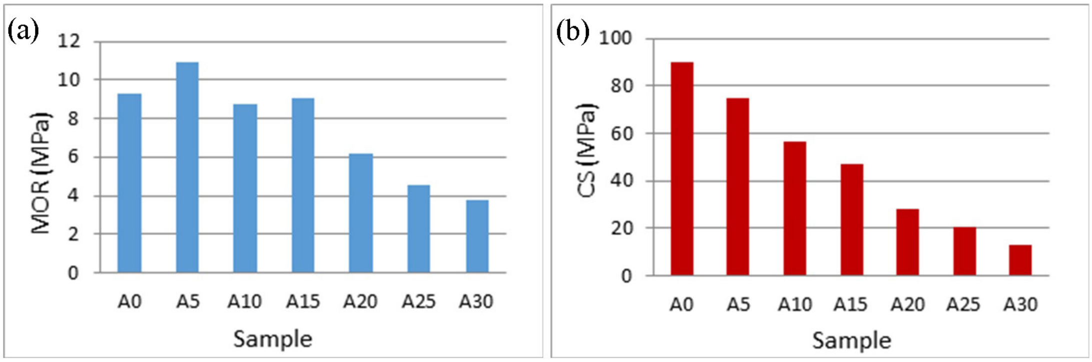

Figure 6. Mechanical properties of the obtained ceramic bricks: (a) modulus of rupture (MOR) (b) compressive strength (CS)

In the case of the modulus of rupture (flexural strength), the samples with added residue are analyzed according to the minimum values established by the ASTM C410-60 standard for bricks for industrial floors, which are: 5.2 MPa for single pieces and 6.9 MPa as an average value of 5 bricks tested. As can be seen in Figure 6, the samples tested have higher values than those mentioned up to aggregates of 15% sawdust. The use of ceramic products in industrial floors represents an application with higher requirements in terms of flexural strength than when they are used in masonry. In this case, CIRSOC 501 (2007) gives values of 0.7 MPa and 1.3 MPa, measured perpendicularly or parallel to the joints, respectively.

The general reduction in mechanical properties observed in this type of material can be attributed to two primary factors: increased porosity and the presence of microscopic imperfections or cracks, both internal and superficial. These imperfections act as stress points, leading to a deterioration in the material´s overall strength and durability. The MOR values in ceramic bricks are influenced by various parameters including porosity, PVV, LOI and the presence of internal microcracks. The combination of these factors determines the level of resistance of the material, and in the case of these samples, the observed differences in mechanical properties may be attributed to the specific combinations of the parameters present. For instance, sample A5 exhibits greater resistance than sample A0, while sample A15 presents slightly higher values than sample A10.

The morphology and dimensions of the pores generated in the ceramic bricks were examined through optical microscopy. It was determined that the shape of the pores is similar to that of the sawdust particles that gave rise to them, regardless of the proportion of biomass added to the sample. However, the amount of pores formed in them is influenced by the biomass proportion. With regard to pore size, although there is heterogeneous, it was observed that the most abundant size present corresponds to 60% of the most abundant particle sizes, as illustrated in Figure 1 (250µm-500µm). The largest observed pores correspond to 70% of the largest aggregate particle size, which in this case was 1 mm, though their presence is extremely scarce.

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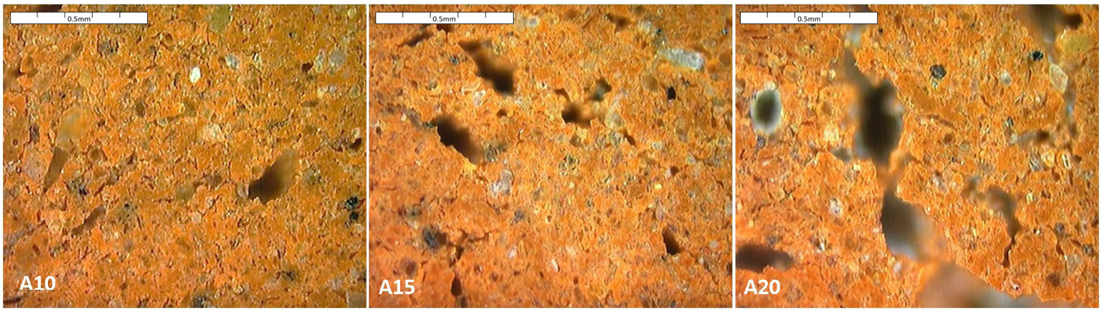

Figure 7. OM micrographs of the samples A10, A15 y A20. Magnification 100X.

Figure 7 shows three micrographs corresponding to samples A10, A15 and A20, which exhibit intermediate biomass contents within the addition range used. It can be observed that as the percentage of biomass added is higher, the presence of pores increases. In the case of samples with biomass contents equal to or greater than 20%, the presence of areas with pores of larger sizes than expected based on the sizes of the aggregated particles was observed. This is illustrated in Figure 7 for sample A20.

This can be interpreted as a function of the high biomass content of these samples, which probably hinders homogeneity in the mixing process during the formation of the pastes. This results in the formation of pores that are actually produced from two or more agglomerated sawdust particles. Similarly, in the samples with higher sawdust contents, areas of aligned pores linked together by small microcracks or channels, akin to a "chain of pores" have been detected (sample A20, Figure 7). These areas may be responsible for the observed decline in the mechanical properties.

In previous works using analogous experimental conditions, studies have been conducted on porous ceramic materials where the pore formers were peach pits (Quaranta et al., 2020) and pistachio shells (Quaranta et al., 2023), and the treatment temperatures were 1000°C and 950°C, respectively. In such instances, it was determined that the proportion of aggregated biomass that generates the optimal characteristics and properties in the final product is 10%, as determined in this work for the case of sawdust. It has been demonstrated that, up to these compositions, the pores obtained have the shape of the original biomass particles, and their sizes correspond to approximately 60% of the original aggregate size. This is similar to the results obtained for the sawdust in this work.

Conclusions

In this study, ceramic bricks have been produced incorporating significant volumes of pine sawdust (up to 30% by volume) as a porosity-forming material. This biomass has suitable characteristics that determine a good distribution in the clay-sawdust mixtures, and enable combustion at a wide range of temperatures. It is therefore anticipated that during the sintering process, the bricks will not develop internal cracks or splits due to extreme volumetric variations.

The resulting ceramic pieces exhibit a uniform coloration and well-defined, sustained structures, demonstrating no tendency to crumble at angles or edges. The porosity of the bricks increases in proportion to the original sawdust content, indicating that the structure

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of the brick matrix is sustained when biomass is burned, thereby containing the generated pores. The mechanical properties of the obtained bricks tend to decrease with higher percentages of added sawdust. However, for contents of up to 15%, both the compressive and flexural strength meet market demands.

The analysis of the produced pores indicates that their shapes are similar to those of the original sawdust particles, while their sizes correspond to 60%-70% of the aggregate particle sizes (60% of the most abundant size and 70% of the largest aggregate size). In samples with contents greater than 20%, pores of significantly larger sizes have been observed. These pores are interpreted as the product of two or more agglomerated or joined particles that have not been separated during the mixing process, likely due to the quantity of sawdust present.

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Authors contribution

	Academic collaboration													
Author surname and first name	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Juan Pablo Pasquini	x		x	x	x		x	x		x	x			x
Gisela Guadalupe Pelozo	x	x	x	x	x	x	x	x	x			x	x	
Nancy Esther Quaranta	x	x		x	x	x	x	x	x			x	x	x

1-Project administration, 2-Funding acquisition, 3-Formal analysis, 4-Conceptualization, 5-Data curation, 6-Writing - review and editing, 7-Research, 8-Methodology, 9-Resources, 10-Original draft, 11-Software, 12-Supervision, 13-Validation, 14-Visualization.

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This research was conducted as part of a PhD in Engineering with a specialization in Materials at the San Nicolás Regional Faculty of the National Technological University, Argentina.