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# Investigation on fired clay bricks by replacing clay with recycled glass and sludge ash

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**Abstract.** Depositing the solid waste generated by wastewater treatment in landfills presents an environmental problem due to the leaching of nitrogen and subsequent eutrophication and contamination of aquifers. Glass is a material with a wide array of uses which is often disposed of after completing its use. This study evaluates an alternative to the production of bricks by replacing clay for recycled glass and sludge ash in proportions of 10% and 20%. The physical properties of the fabricated bricks (compressive strength, water absorption, and the initial rate of absorption) were then measured. The temperature used in the firing process was 950 °C. The fabricated bricks utilizing the proposed mixtures complied with the Colombian technical code for structural and non-structural brick exceeding 20 MPa. This alternative method of brick fabrication reduces the environmental impact of glass and solid waste on the ecosystem and reduce freshwater contamination. It will also solve the issue of the sludge waste produced by wastewater treatment plants.

## 1. Introduction

Wastewater treatment plants (WWTP) are designed to clean the wastewater generated in homes, industries, supermarkets, etc. before being discharged back into the ecosystem. Decontamination is performed through various physical, chemical, and biological processes which generates a biosolid as a by-product of these processes as defined in decree 1287 of 2014 [1]: "Products resulting from the stabilization of the organic fraction of the sludge generated in the treatment of municipal wastewater, through physical, chemical, and microbiological characteristics may be used for alternative purposes."

These biosolids generate environmental problems due to four types of fundamental pollutants: 1) metals, due to their potential for bioaccumulation and biomagnification in human tissues; 2) nutrients and organic matter due to their potential for eutrophication of ground and surface waters; 3) organic pollutants due to their possible toxicological impact on the soil-plant-water ecosystems and 4) pathogens due to the presence of bacteria, viruses, protozoa, trematodes, cestodes, and nematodes [2].

Glass is an inorganic product that arises from the mixing and melting at high temperatures of sand, soda, dolomite, feldspar, minor aggregates, and cullet (recycled glass (RG)). This mixture becomes rigid after solidification without the formation of crystals [3]. This study utilized recycled industrial glass bottles, which is primarily made of silica, sodium oxides, and calcium oxides. Silica is part of the basic raw material while sodium oxides provide an ease of fusion, and calcium oxides provide chemical



stability [4]. The material used was collected from the waste generated at the Universidad Santo Tomás Tunja, in Boyacá, Colombia.

The study aims to generate an added value to materials which are contaminants and are being generated in large quantities. This is the result at El Salitre, a WWTP in the city of Bogotá, Colombia where more than 4500 tons of biosolids are produced per month. This proposal aims at being an alternative waste management method to reduce the negative environmental impact that may be generated.

## 2. Materials and methods

Clay (CL) from the Oasis company was used to make the bricks at the Ladrillera de Boyacá in Colombia. The biosolids were collected from the El Salitre WWTP in Bogotá, Colombia, and the sludge ash (SA) was obtained by burning the biosolids at temperatures above 550 °C, in an oven. The recycled glass (RG) was obtained from the Universidad Santo Tomás in Tunja, Boyacá and was crushed for the mixture. To determine the chemical composition of the clay, a JEOL model JSM 5910 LV scanning electron microscope (SEM), was used with an energy-dispersive detector (EDS) attached. The analysis for the biosolid ash was performed using the quant-express method with a Bruker model S8 tiger in the range of sodium (Na) and uranium (U) with a sequential spectrum of X-ray fluorescence. The analysis of the chemical characteristics of the glass was carried out through a bibliographic review corresponding to industrial soda lime glass.

The mineralogical characterization of the biosolid ash was carried out in a Bruker Model D8 Advance with DaVinci geometry X-ray diffractometer. The qualitative analysis of the different phases were carried out by comparing the observed profile with the diffraction profiles reported in the database of the International Center for Diffraction (ICDD). The quantitative analysis of the phases were carried out by refining the Rietveld Method. The glass was analyzed with a Phillips X'pert Pro Panalytical diffractometer with Bragg-Brentano geometry using sweeping steps of 0.5s per step between 10 and 80 degrees on the 2Theta axis. A radiation generator with a cobalt empyrean tube for the detection of angles was utilized and analyzed through the X'pert High Score plus program using references from the diffraction patterns in the inorganic crystal structure database (ICSD).

The properties of the ceramic elements are dependent on the size and distribution of particles in the raw materials. Granulometry affects properties such as: plasticity, porosity, specific gravity, homogeneity, permeability, and penetrability [5]. The raw materials (CL-SA-RG) were subjected to a reduction process; selecting particles between 70µm and 1 mm (material passing sieves No. 18 - No. 200). The dosage of the materials in the mixtures was carried out by weight. These waste materials were substituted for the clay in increments of 10% and 20% in the bricks then fired at 950°C. In total, 90 ceramic bricks were created using a factorial design. There were three factors with three sub-factors each, and each sub-factor consisting of 10 replicas. The clay elements were shaped based on what is established in the Colombian technical code NTC 296 (modular dimensions of clay bricks) [6], rectangular in shape with a length of 10.0 cm, a width of 5.0 cm, and a height of 5.0 cm, using the uniaxial pressing technique, applying a force of 60 kgf/cm<sup>2</sup>.

A drying cycle composed of three stages was performed in three phases. The first phase was performed at room temperature for 12 hours; the second phase at 60 °C for 12 hours; and the final phase at 105 °C for 12 hours. (The drying cycle is based on the construction of Bigot curves for each of the mixtures tested in the study). Three temperature profiles were utilized each with an increase of 5 °C/min until the desired firing temperatures are reached 950 °C [7]. The physical properties (compressive strength, water absorption and the initial rate of absorption) were determined based on the Colombian technical code NTC 4205 [8] according to the methodology established in the Colombian technical code NTC 4017 [9].

### 3. Results and discussion

#### 3.1. Characterization of raw materials

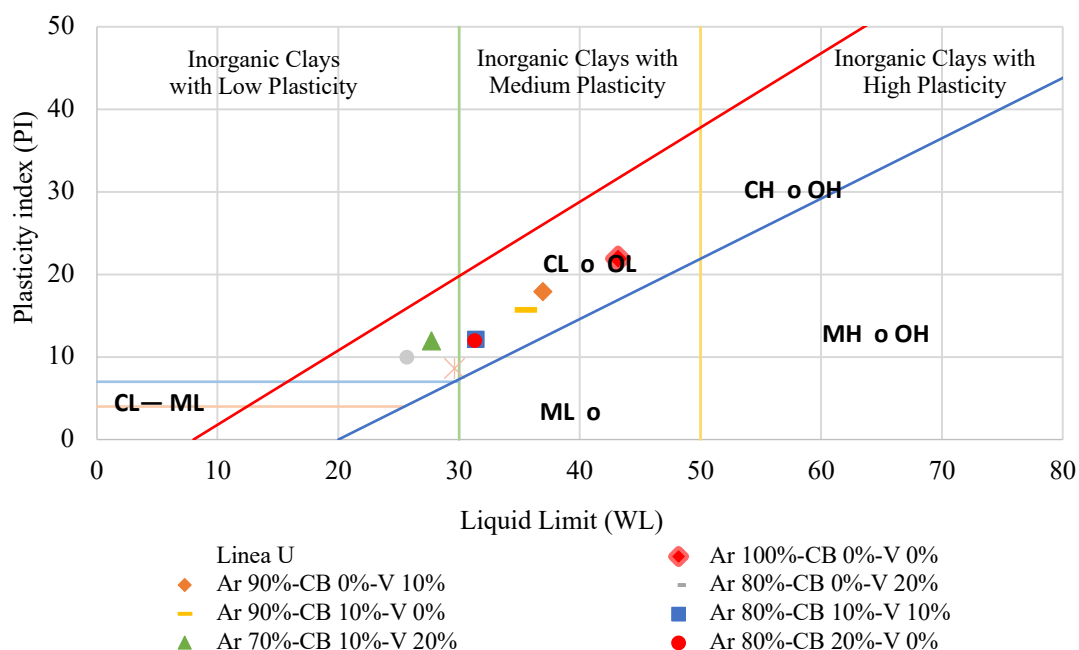
**3.1.1. Chemical composition.** The most abundant element found in the clay was Silicon (Si) with 38.72%. In the biosolid ash; calcium (Ca) was the most abundant element with 27.64%, a value attributable to the high macronutrient content. In the glass, silicon oxide ( $\text{SiO}_2$ ) commonly known as silica made up 75% of the glass. This is expected since sand is the basic raw material for obtaining glass [10]. The greater the  $\text{SiO}_2$  content, the greater its chemical, thermal, and mechanical resistance [11] see Table 1.

**Table 1.** Chemical composition of raw materials.

Sample	Element									
	O	Al	Si	Fe	K	Ca	C	$\text{SiO}_2$	Na	Mg
Clay	49.2	8.8	38.7	6.6	-	-	-	-	-	-
Sludge ash	-	3.6	6.4	1.4	1.1	27.6	-	-	0.2	1.9
Glass (soda lime)	-	3.0	-	-	1.0	14.0	-	75.0	18.0	4.0

Oxygen (O), Silicon dioxide ( $\text{SiO}_2$ ), Sodium (Na), Magnesium (Mg), Aluminum (Al), Silicon (Si), Iron (Fe), Potassium (K), Calcium (Ca), Carbon (C).

**3.1.2. Plasticity.** From the Atterberg limits (liquid limit, plastic limit, and shrinkage limit) it is possible to determine if the plasticity of the mixtures is low, medium, or high. Figure 1 shows a tendency towards lower plasticity in mixtures containing SA and RG. This is due to the large amount of silica present in the material making it a raw material which is rigid and unmalleable. An increase in the amount of SA and RG was found to decrease the plasticity index of the mixtures. This results in a positive effect during the drying stage.



**Figure 1.** Casagrande diagram.

In Table 2, the impact of SA and RG on the plasticity index of the ceramic paste can be seen. Mixtures with a plasticity index greater than 10% indicating that they would be appropriate for use in the

fabrication of ceramic materials for construction [12]. The results obtained demonstrate the degreasing nature of the residues studied.

**Table 2.** Plasticity index (PI).

Mixture %CL-%SA-%RG	Plasticity index (IP)
100 – 0 – 0	21.9
90 – 0 – 10	17.9
80 – 0 – 20	11.9
90 – 10 – 0	15.7
80 – 10 – 10	12.1
70 – 10 – 20	11.9
80 – 20 – 0	12.0
70 – 20 – 10	8.6
60 – 20 – 20	10.0

*3.1.3. Mineralogical composition.* Table 3 demonstrates that a sample of clay corresponds to a material with a high quartz and kaolinite content. This makes clay the ideal material for the manufacture of traditional brick and other ceramic pieces within the construction field such as bricks, tiles, and masonry blocks. The content of iron oxides (Goetite) is low and results in a clay that tends to turn a light brown color as evidenced by the bricks manufactured during this study.

**Table 3.** Mineralogical compositions detected from samples of raw materials.

Mineral	Chemical formula	Clay (%)	SA (%)
Quartz	SiO <sub>2</sub>	74.0	11
Hematite	Fe <sub>2</sub> O <sub>3</sub>	–	8.7
Kaolinite 1	Al <sub>2</sub> Si <sub>2</sub> O <sub>5</sub> (OH) <sub>4</sub>	11.0	–
Calcium magnesium phosphate	(Ca <sub>2.589</sub> Mg <sub>0.411</sub> )(PO <sub>4</sub> ) <sub>2</sub>	–	14.4
Goetita	FeO(OH)	2.0	–
Calcium and sodium aluminosilicate	Ca <sub>85</sub> Na <sub>14</sub> Al <sub>1.83</sub> Si <sub>2.16</sub> O <sub>8</sub>	–	33.3
Kaolinite 2	Al <sub>2</sub> (Si <sub>2</sub> O <sub>5</sub> )(OH) <sub>4</sub>	13.0	–
Cristobalita	SiO <sub>2</sub>	–	23.3
Magnetite	Fe <sub>3</sub> O <sub>4</sub>	–	N. C
Iron silicate	Fe <sub>2</sub> (SiO <sub>4</sub> )	–	2.3

\*Not quantifiable due to low concentration.

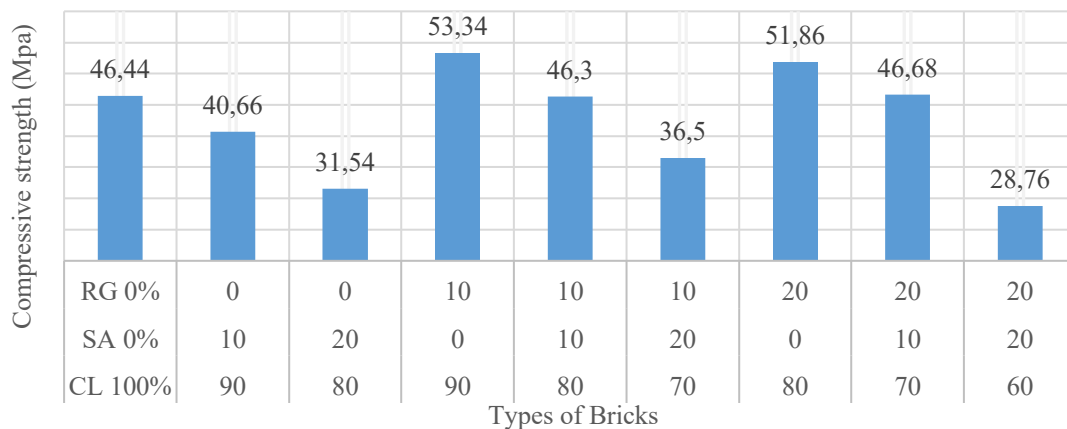
The results of X-ray diffraction indicate that the SA has a high content of calcium and sodium aluminosilicate (CaNaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub>) (33.3%). The presence of these minerals generates the necessary plasticity for molding, improves the mechanical and suspension properties, and provides the components necessary for the formation of liquid and crystalline phases during firing [4]. (See Table 2). Among the identified crystalline compounds that were detected was silicon dioxide, commonly known as silica. The presence of this mineral results in decreased plasticity and therefore reduced shrinkage [13]. Iron oxides (ferric oxide Fe<sub>2</sub>O<sub>3</sub> and ferrous oxide Fe<sub>3</sub>O<sub>4</sub>), calcium, and magnesium were also detected. Iron oxides often act as pigments, however in the SA the content is low resulting in no effect on the color of the manufactured elements. The X-ray diffraction analysis performed on the glass sample revealed a presence of a completely amorphous compound in its structural ordering since it does not reflect any diffraction signal in the diffractogram.

### 3.2. Quality of fabricated materials – physical properties

*3.2.1. Compressive strength.* In Figure 2, resistance to compression vs percentage (CL – SA – RG), it is evident that the recycled materials have an impact on the resistance to compression. As the RG is raised the SA is decreased. The fabricated brick with a combination of 90% CL, 0% SA, and 10% RG had the

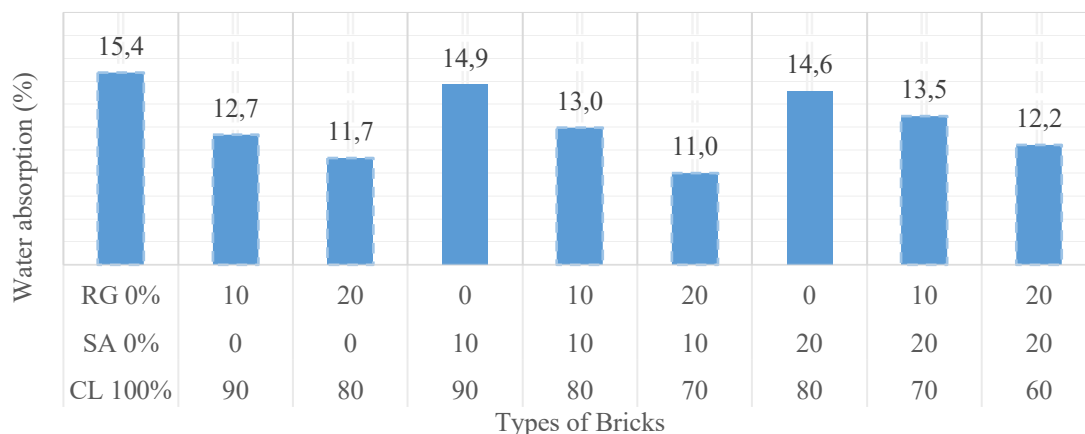
highest resistance at 53.34 MPa. The best mixture had CL content of 70%, an SA content of 10%, and an RG content of 20%. However, all the proposed mixtures comply with the minimum standards required by the Colombian technical code NTC 4205 [8] (14 MPa for non-structural bricks and 20 MPa for structural bricks).

The manufacture of bricks based on the formulations (90%CL – 0%SA – 10%RG) and (80%CL – 0%SA – 20%RG) demonstrated the highest values of compressive strength. These formulations had 0% sludge ash added but had an increase in compressive strength due to the amount of recycled glass added. Since glass is mainly composed of elements which provide strength to the material, compressive strength increases with the addition of these substances.



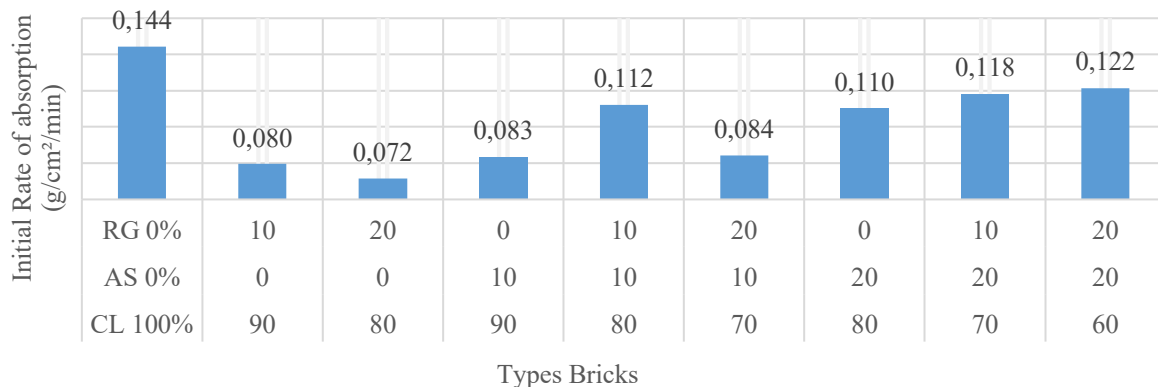
**Figure 2.** Compression resistance versus percentage (CL-RG-SA).

**3.2.2. Water absorption.** According to Figure 3 the rate of adsorption decreases with an increase in the percentage of SA and RG. RG provides a greater influence on this rate due to its liquid condition when heated allowing it to occupy the pores in the ceramic matrix and decrease the amount of empty spaces. Based on these results the structural elements fabricated under these combinations meet the maximum percentage of adsorption established for non-structural bricks for interior use. They are found to be under the 17% established by the Colombian technical code NTC 4205 for exterior use. Only material with an adsorption rate of less than 13% can be used both on the inside and outside of buildings. The impact that recycled materials have on the percentage of adsorption in the bricks is positive. Keeping in mind that high adsorption values indicate that the bricks are more permeable translating into significant volumetric changes, discolorations, and reduced durability of the brick [14].



**Figure 3.** Water Absorption versus percentage (CL-RG-SA).

3.2.3. *Initial rate of absorption.* In Figure 4 a decrease in the initial rate of water adsorption as a result of the addition of SA and RG. All the fabricated products and their respective mixtures were below the  $0.25\text{ g/cm}^2/\text{min}$  recommended by the respective technical code allowing them to be considered as low suction bricks. The recycled material generates a positive impact due to their low initial adsorption rate allowing them to be more resistant to environmental conditions [14].



**Figure 4.** Initial Rate of Absorption versus percentage (CL-RG-SA).

#### 4. Conclusions

The chemical, physical, mineralogical characterization, as well as the effects observed in the drying process of the elements conclude that SA and RG can be used in the manufacture of bricks. Their ability to diminish the plasticity of the clay and minimize the risks of fissures and deformations in the brick during the drying process is an added benefit.

While an increase in SA resulted in a lower resistance to compression, an increase in the use of RG resulted in an increase in the compressive strength of the masonry.

From a technical aspect both SA and RG can be utilized as a raw material in the manufacture of clay bricks while complying with the requirements of the Colombian technical standard for structural and non-structural masonry.

Further studies can research the preparation of bricks whose firing temperature is lower than those utilized in this study. This may be made possible by utilizing a higher quantity of glass in the mixture to increase the compressive strength that may be achieved.

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