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Improving Thermal Insulation and Mechanical Properties of Building Bricks made from Moroccan Clay

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Abstract. This study aims to improve the thermal of insulation properties of fired bricks based on clay from the Drâa-Tafilalet region (Es-sifa), using coffee waste without losing mechanical properties. Samples were produced on a laboratory scale by shaping, similar to a feasible industrial production technique. The raw material was first characterized using various analytical techniques such as XRD and TGA/DTA. Secondly, we optimized the main parameters affecting the properties of the bricks, such as particle size, aging time, drying time, final sintering temperature and the percentage of agent porosity. These parameters are assessed by mechanical strength and porosity tests. Examination of results the optimization following results: the particle size is less than 180 µm, the aging time and the drying time are three and four days respectively, while the sintering temperature is 1050 °C and the percentage of coffee waste used as a porosity agent is 4%. Introducing coffee waste to the brick reduces weight and improves thermal and acoustic properties by creating pores during firing. These results are very promising for exploiting these materials as base materials in the manufacture of building bricks with important properties.

Introduction

The construction sector is a vital component of the worldwide economy. The demand for eco-friendly building materials has prompted researchers to investigate alternative solutions that can diminish environmental impact and construction expenses, all while delivering mechanical strength, thermal insulation, and acoustic properties. Consequently, the significance of local and traditional materials has increased, driven by their economic advantages, ease of transportation, and environmentally friendly characteristics. This trend persists even with the presence of contemporary materials such as concrete, fiberglass/resin composites, steel, and plastics [1] clay brick remains a popular choice for wall blocks. This is because it is easy to produce, uses readily available raw materials, is affordable, resists fire and rotting, has a long lifespan, and is recyclable [2].

Numerous investigations have been conducted to mold composite bricks and assess their mechanical, physical, and thermal attributes. Thermal insulation is essential in building bricks. It helps to reduce energy consumption, improve performance and prevent heat exchange between the external and internal environments. An interesting approach to thermal insulation is to improve bricks porosity. Incorporating specific waste materials into the raw clay results in the formation of the pore structure, thereby enhancing the thermal insulation properties of clay bricks. Several studies have been conducted in the literature on the topic of waste materials that can be used for various purposes. Some examples of such materials include mahogany sawdust [3,4], limestone and sawdust[5], kaolinitic sand waste[6,7], waste pomace from the wine industry[8], rubber[9], rice husk ash[10], recycled paper processing residues[11], cigarette butts[12], residues from biodiesel production[13], olive mill waste[14,15], Kraft pulp[16], and tea waste[17].

In this work, during the elaboration of bricks from a paste of clay and different percentages of organic additive (coffee waste), we discussed the effectiveness of optimizing certain parameters such as particle size, water volume, mixing time, aging time, drying time and sintering temperature of the properties of the bricks such as porosity and mechanical strength.

Experimental study

Raw Materials

In this work the raw material used is clay (sampled in the Es-sifa district (Morocco)). During firing, porosity decreases due to sintering. To maintain this important property, we used coffee waste as the organic material. The organic additive used is not characterized because it decomposes entirely by combustion during heat treatment.

Characterization of the raw clay

The analytical techniques employed for characterizing the raw clay under investigation were as follows: X-ray diffraction, TDA/GTA thermal analysis.

The XRD pattern was acquired using a X'PERT MPD-PRO wide-angle X-ray powder diffractometer, employing a diffracted beam monochromator and Ni-filtered CuKα radiation (λ=1.5406 Å). The scanning of the 2θ angle ranged from 4° to 30° with a step size of 0.01 /s;

With a simultaneous LABSYS/evo TGA/DTA thermal analyzer, TDA/GTA analyses were realized in an air atmosphere Subjected to linear heating at a rate of 10°/min, within the temperature range from room temperature to 1000°C.

Brick Shaping

Before the bricks can be shaped, a plastic paste must first be prepared. Fig.1, shows the different stages involved in obtaining fired bricks. A good-quality formulation is obtained after several trials, taking into account a number of parameters such as the granulometry of the raw clay, which affects pore size in the ceramic part, during sintering, the aging time (t_v), the drying time (t_s) and the sintering temperature (T_f)[18,19].

The clay used was sieved through different sieves to obtain powders of different granulometries such as:

250 µm < Φ_1< 315 µm
180 µm < Φ_2< 250 µm
160 µm < Φ_3< 180 µm
Φ_4< 315 µm
Φ_5< 250 µm
Φ_6< 180 µm

The clay paste ought to be homogeneous, cohesive, hard, and plastic. These characteristics will be obtained, for an adjusted composition, by the mixing time, the volume of water, and the aging time[20] Each prepared dough is preserved in a refrigerator for aging. The porosity agent used in this work is coffee grounds in varying percentages from 2 to 20%.

The pastes are then moulded in laboratory moulds. The size of the bricks depends on the dimensions of the mould used: in our case, we used a mould of length L= 70 mm, width l= 30 mm and thickness e=10mm. The shaped bricks are air-dried and then sintered at a sintering temperature (T_f= 800, 850, 900, 950, 1000, and 1050°C).

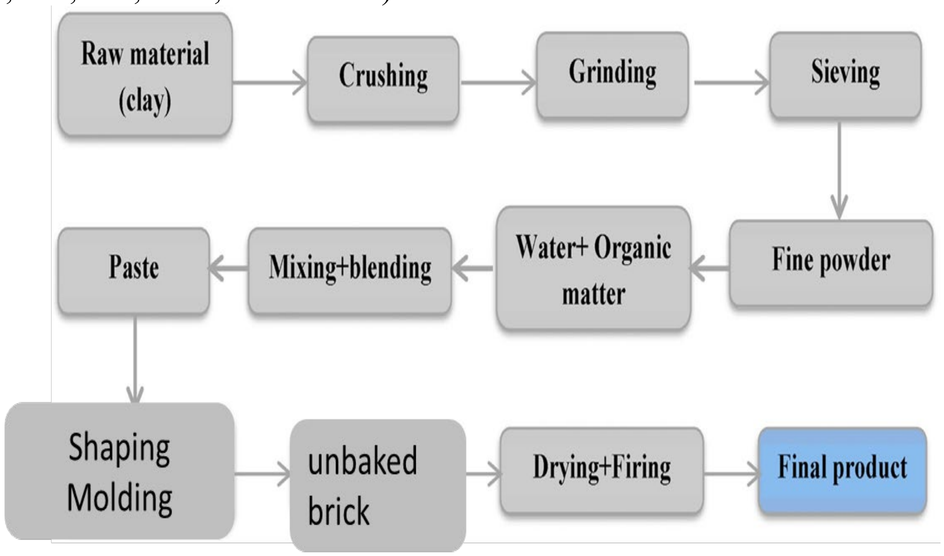

Figure 1: Brick manufacturing process

Thermal treatment

The thermal program we drew up in Fig.2, takes account of the results of differential thermal and gravimetric analysis (DTA - GTA). The temperature was raised slowly to avoid cracking the bricks. The bricks were fired in a programmable Nabertherm electric kiln.

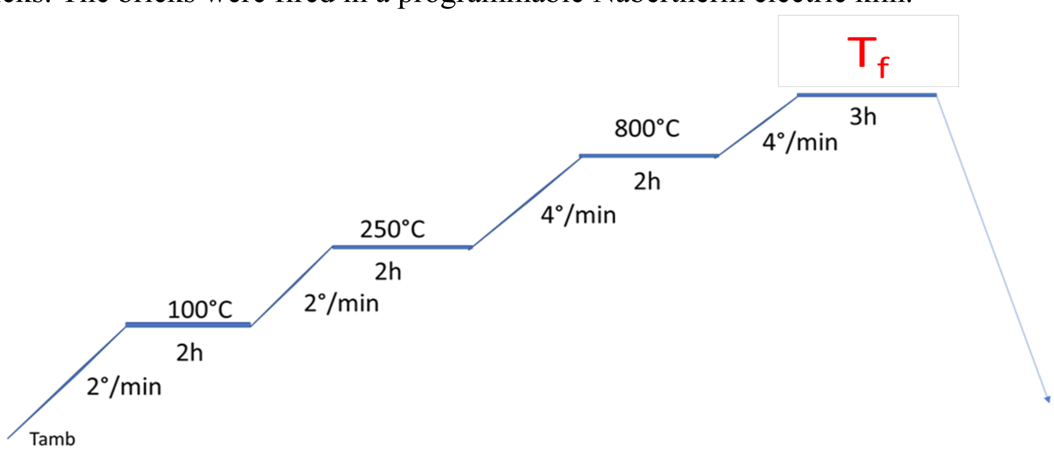

Figure 2: Thermal program drawn up

Bricks characterization

In order to shape bricks with high mechanical strength and porosity, it is necessary to meet the requirements for shaping them from a clay paste. This formulation is obtained after a many tests, taking into consideration a number of parameters for example the granulometry of the powder, the percentage of porosity agent, the aging time (t_v), the drying time (t_s), and the sintering temperature (T_f)[19,20] In this work we studied the variation of porosity and mechanical strength as a function of these parameters.

Test of porosity
Porosity is determined using the water impregnation method as per ISO 10545-3. The calculation of porosity is performed through equation1[21].

$$P = \frac{M_{sat} - M_{sec}}{M_{sat} - M_h} * 100\ (\%) \qquad (1)$$

With
M_{sec}, M_h and M_{sa} are respectively the dry mass, the wet mass, and the saturated mass.

Compressive strength
The mechanical strength was determined using the three-point flexural method. The equipment used in the laboratory allows a force F to be applied to the brick placed on two supports (two points) until it breaks, then the rupture force is recorded in Newton. The stress of the breaking is calculated from the equation(2) [22].

$$\sigma = \frac{3 * F * d}{2 * l * e^2}\,(\text{Mpa}) \qquad (2)$$

With:
F: intensity of load applied at fracture (N)
d: distance between the two supports (mm)
e: sample thickness (mm)
l: sample width (mm)

Results and Discussion
Characterization the raw clay
XRD
Upon conducting a mineralogical study of the raw clay (shown in Fig. 4) using X-ray diffraction, several crystalline phases were observed. Quartz, which is considered to be a vital phase, was identified through the 2θ diffraction peaks at 20.84, 26.72, 39.38, and 50.1° [23]. Additionally, the diffraction diagram showed other peaks at 12.39, 29.51, and 31° which characterize kaolinite, calcite, and dolomite, respectively[24–27].

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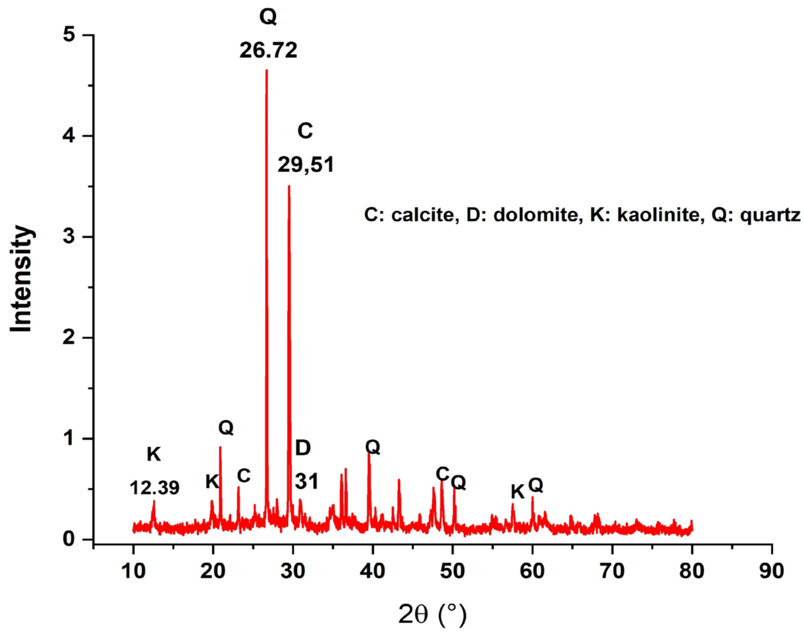

Figure 3: XRD diffractogram of Clay

DTG/DTA

The results of the TGA DTA analysis are shown in Figure 4. The peak identified at 104°C corresponds to the evaporation of moisture and is concomitant with a mass reduction. The peak detected at 332°C is associated with the elimination of organic substances, coinciding with a decrease in mass. The peak low intensity detected at 485°C shows that the clay studied is poor in kaolinite. The peak at 577°C is linked to the conversion of quartz from α to β. The endothermic peak detected at 803°C corresponds to carbonate decomposition. The peak identified at 892 °C attributes the transformation of the meta kaolinite into a spinel aluminium-silicon and the amorphous silica[28,29].

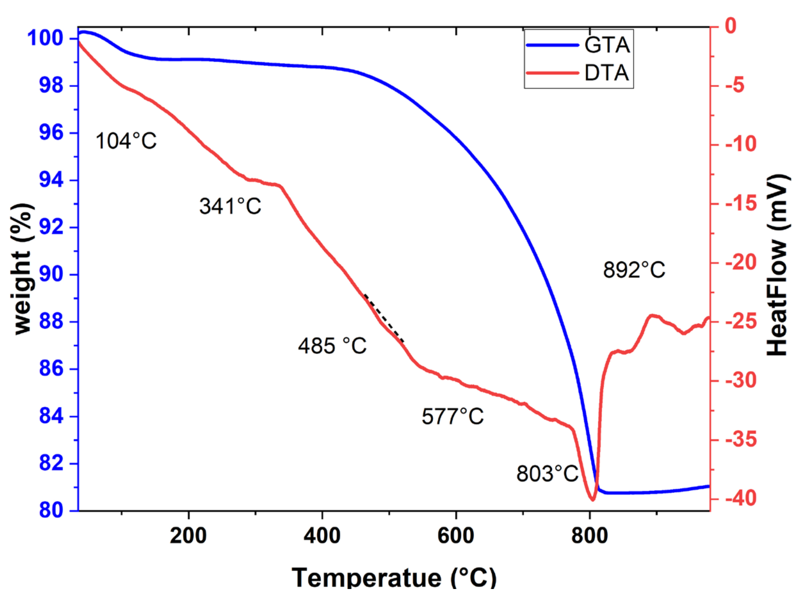

Figure 4: TGA/DTA of raw Clay

Characterization of bricks

Particle size optimization

The distribution of particle sizes in the clay raw materials utilized in brick manufacturing significantly influences the behavior of bricks throughout the drying and firing processes. Additionally, it impacts various properties of construction materials, such as mechanical characteristics [30]. Figure 5 depicts the fluctuations in porosity and mechanical strength of the manufactured bricks concerning particle size. The results obtained show two aspects.

The first aspect is that the mechanical strength for the grain size. Φ_1, Φ_2 and Φ_3 is low compared to that obtained for Φ_4, Φ_5 and Φ_6, unlike the porosity, which is due to the particle size distribution of the fractions Φ_1, Φ_2 and Φ_3, which is narrow compared to that of the fractions Φ_4, Φ_5 and Φ_6 fractions, on the other hand, is large, in the latter case the apparent density increases because the interstices between the larger particles are filled with In the context of ceramics and metallurgy, it is observed that smaller particles exhibit accelerated sintering kinetics at a given temperature. Consequently, they can be sintered effectively at lower temperatures compared to their larger counterparts[31].

The second aspect is that mechanical strength increases with decreasing grain size, whereas porosity decreases. This can be explained by the contact surface, i.e. the smaller the grain size, the greater the contact surface, which favours the various physicochemical transformations during firing and, consequently, the formation of ceramic bonds, resulting in a denser ceramic part with greater mechanical strength[32]. It can be seen from these results that the optimum particle size for maximum mechanical strength (11.05 MPa) and acceptable porosity (36.5%) is less than 180 µm, which is the size chosen for the rest of our work.

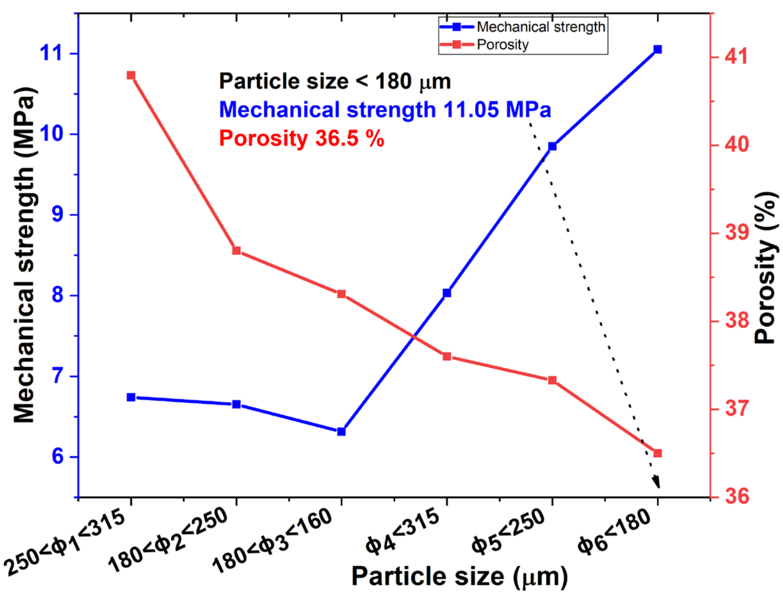

Figure 5: Optimization of the particle size of the bricks are treated at 1000°C/3h.

Optimizing aging time

Aging is an operation that consists of homogenizing the paste, and the migration of organic additives and water leads to an improvement in the quality of the final ceramic part[19], which is the objective of this section. In order to optimize the aging time, we set the drying time at three days and the particle size at less than 180µm in the production of the bricks. Fig.6 illustrates the variation in porosity and mechanical strength as a function of aging time. It can be seen that porosity decreases with aging time, while mechanical strength increases with aging time. This is quite normal, since the homogeneity and hardness of the paste increase with aging time[20]. Examination of the results also shows that after three days the increase in mechanical strength and the decrease in porosity are not significant, so three days is considered the most adequate aging time.

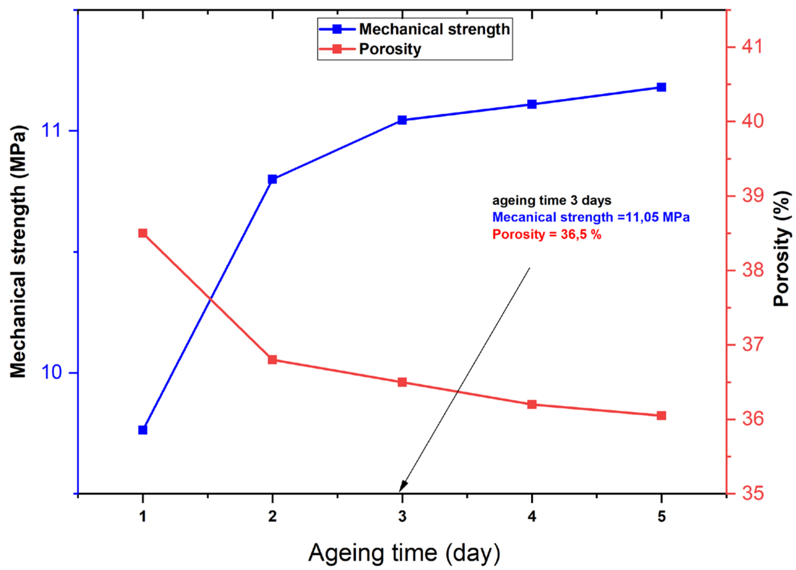

Figure6: optimizing aging time

Optimization of drying time

The purpose of drying shaped products is to eliminate moisture water. This is a delicate and important phase in the manufacturing process, which must be carefully controlled to avoid cracking, significant differential shrinkage and distortion of the ceramic products. Drying is carried out progressively by controlling two parameters, temperature and humidity [33,34] and this stage requires significant energy input. The need to reduce energy consumption and CO_2 emissions has led to the development of new technologies for more efficient drying for this reason, in this work we carried out open-air drying at ambient temperature and the drying time varied from one to five days. The aging time was set at three days and the particle size was less than 180µm. To optimize this parameter, we studied the mechanical strength and porosity as a function of the drying time in Fig.7. During the drying process, we noticed that the bricks contracted and strong volume shrinkage took place. The evacuation of the water caused a contraction of the solid structure, directly linked to the mechanical properties of the material. Figure 9 explains the drying process, with a large quantity of interstitial water evaporating. This leads to the hardening of cured bricks[35].

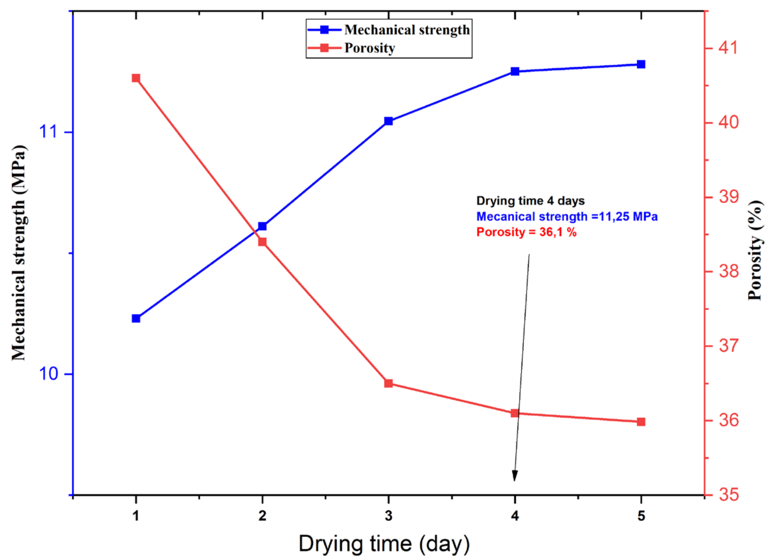

Figure 7: optimizing of drying time.

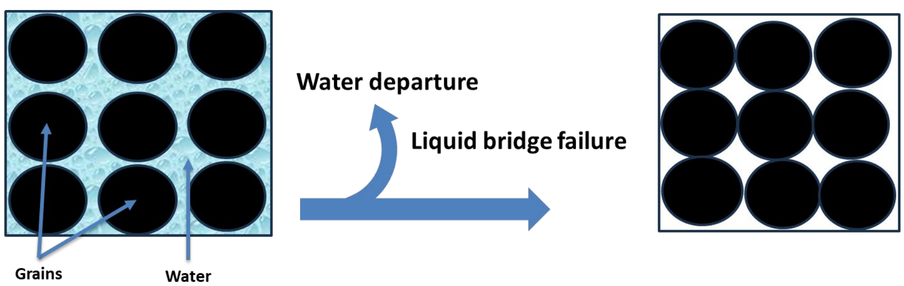

Figure 8: diagram explaining the drying process.

Optimization of sintering temperature

Figure 9 displays how porosity and mechanical strength change with temperature. The findings indicate that the mechanical strength rises proportionally with the increase in sintering temperature, reaching its maximum (11.74 MPa) at 1050°C. On the other hand, the porosity decreases from 39 to 35.27 %, which can be explained, on the one hand, by The porous structure becomes more compact, and the grains aggregate more as the sintering temperature increases [19]. Secondly, the appearance of a glassy phase, as the clay contains large quantities of (sodium oxide, potassium oxide and magnesium oxide) [36], which is confirmed by the appearance of the yellow color after heat treatment in Fig.10 As can be seen from the figure, the bricks are homogeneous and without any kind of macro-defects or breaks. They retain the same parallelepiped shape and the color of the bricks changes from a brick-red hue to a deep yellow as the sintering temperature increases. is increased from 800 to 1050 ◦C. The color change in bricks after thermic treatment is caused by the oxidation of iron oxide.[37,38]. Given the obtained results, selecting 1050°C as the optimal sintering temperature for the remaining part of our study is a judicious choice.

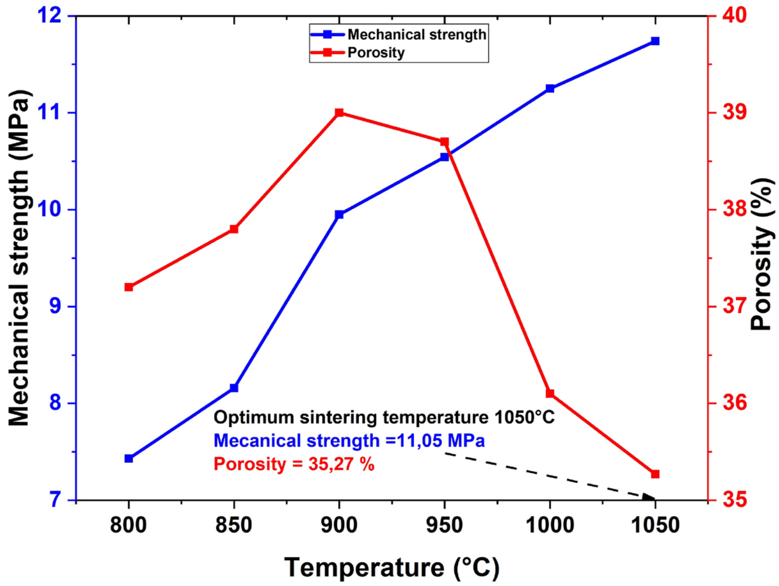

Figure 9: Optimization of sintering temperature

Figure 10: sintered bricks at different temperatures

Optimization of pore-forming agent percentage

The porosity of the bricks is a property that must be taken into account, as it improves the thermal and acoustic insulation of the bricks and increases their lightness, which affects transport costs. In order to increase porosity, coffee waste was added to the mixture in percentages ranging from 0 to 20%. Fig.11, Shows how compressive strength and porosity changes with varying proportions of coffee waste.

Analysis of the results shows that porosity and compressive strength are inversely proportional; in our case, porosity increases and mechanical strength decreases as a function of the quantity of coffee waste. This phenomenon is elucidated by the formation of pores resulting from the combustion of coffee waste during the sintering procedure [39]. The quantity of pores corresponds directly to the percentage of the added material. Combustion of the coffee waste is primordial in energy saving, as combustion is exothermic. The presence of pores leads, on the one hand, to a reduction in the thermal conductivity, on the other hand, to a reduction in density, so the bricks become lighter, which reduces transport costs. The third role affects sound insulation...

The composition that provides favorable porosity without compromising the flexural strength of the produced bricks is 4%, sintered at 1050°C.

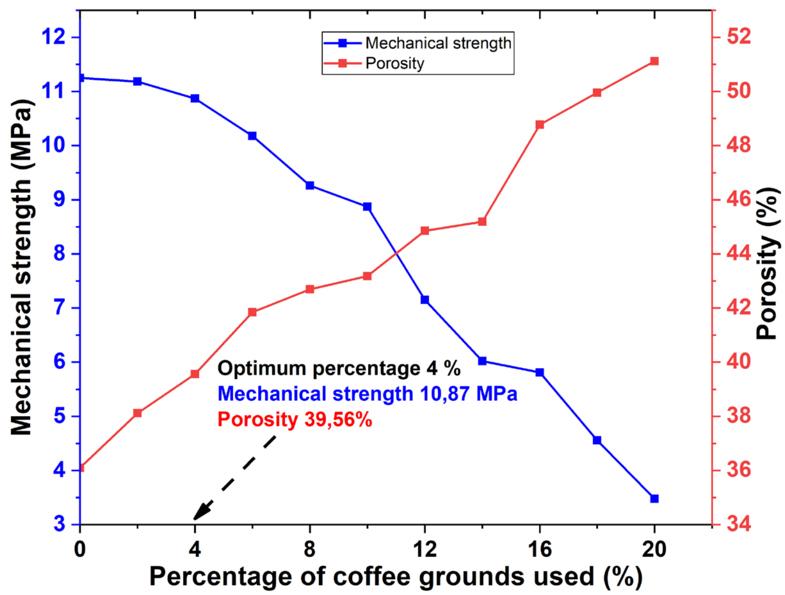

Figure 11: optimization of the organic additive

Conclusion

The use of used coffee grounds as an organic additive in the elaboration process of fired bricks is very important due to the following reasons: it leads to improved mechanical, thermal and acoustic properties and reduced brick weight, as well as additional environmental and economic benefits. This work provides the characterization and development of fired building bricks based on low-cost local raw materials. Optimization of the main parameters in the manufacturing process revealed the following results: the particle size is less than 180 µm, the aging time is three days, the drying time is four days, the sintering temperature is 1050°C and the percentage of coffee waste used as a porosity agent is 4%. The exothermic nature of coffee grounds combustion saves energy during the sintering process.

the incorporation of coffee grounds creates pores in the final product, which increases the porosity and therefore improves the thermal and acoustic insulation and lightness of the bricks. Up to 4% of coffee grounds does not significantly reduce the bending strength of the bricks. Coffee grounds can therefore be used as a good pore-forming additive in clay bodies without any adverse effect on the other properties of the bricks.

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