# STUDY OF THE INFLUENCE OF AGRICULTURAL WASTE ON THE POROSITY OF CLAY BRICK

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***Resume***

This paper deals with the influence of two organic residues on the porosity of clay bricks. The insulation capacity of the brick increases with increasing the porosity. Combustible organic additions are often used to form pores. The formation of the more homogenous porous structure is favourably impacted by using the crushed rough olive stones containing oil. Plasticity, bulk density and mechanical properties were studied. The additions of organic residues have proved successful to form pores while maintaining the mechanical properties in the limits of the Algerian norms.

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## 1. Introduction

Accumulation of unmanaged industrial or agricultural solid waste especially in developing countries has resulted in an increased environmental concern. Recycling of such wastes as a sustainable construction material appears to be viable solution not only to pollution problem but also an economical option to design of green buildings [1]. Today, the recycle of waste and the economy of energy are also very important researches. For example of solution envisaged for those problems, we cited the big importance that has the recycle of agricultural waste to increase porosity in clay bricks. These materials are referring to bricks lighter than traditional bricks and aim at especially better insulation ability. In this research, several organic wastes are expertise like sawdust, coal, paper sludge, straw and spent grain [2, 3]. In another study paper mill residue and rice husk ash were used for development of sustainable construction material [4]. Rimpel and Scmedders (1996) show the possibility of utilization of straw and reed in the production of building bricks (cited by Demir) [5]. Demir used waste tea for the same purpose [2]. Demir and Orhan Baspinar expertise the spent grain [3]. Demir used grass, tobacco residue and sawdust [5]. Sawdust and cherries seeds, thanks to their organic substances content, during their combustion, bring an energetic support in the bricks firing phase and act as pore forming agent [6].

It's in this type of materials where is situated the brick with additions of olive stones and hay, the subject of our study. Their judicious use is desirable not only from the technical benefits but also for the national environmental. The olive stones are very abundant in Algeria and they are discharged into rivers and coastal waters. This situation conduces to the pollutions which can have negative impacts on human health and the environment.

## 2. Experimental methods

X-ray analysis, thermal analysis and Soxhlet extractor are three sophisticated methods that will give a good indication of the use potential of raw material (agricultural wastes and clay).

Mineralogical analysis by X-ray diffraction is used to identify the mineralogical composition of a material. X-rays interact with the atoms in a crystal. W. L. Bragg explained this result by modeling the crystal as a set ofdiscrete parallel planes separated by a constant parameter d. It was proposed that the incident X-ray radiation would produce a Bragg peak if their reflections of the various planes interfered constructively. The interference is constructive when the phase shift is a multiple of 2π. This condition can be expressed by Bragg's law:

$$n\lambda = 2d\sin\theta \quad (1)$$

where n is an integer, λ is the wavelength of incident wave, d is the spacing between the planes in the atomic lattice, and θ is the angle between the incident ray and the scattering planes. The test was carried out on Siemens instrument D5000.

The differential thermal analysis (DTA) and the differential thermal gravimetric (DTG) were employed for measuring the thermal stability and phase transformation of agricultural wastes at a heating rate of 15 °C/min, the temperature ranged from 30 °C up to 1000 °C under the air atmosphere. The test was carried out on a Netzsch instrument STA 409 PC Luxx.

The analysis of the fatty substances in the agricultural wastes is carried out with an apparatus of Soxhlet. It is an apparatus for extracting components from a solid. The agricultural wastes used are placed in a thimble made of thick filter paper and this is held in a specially designed reflex condenser with a suitable hexane solvent. The chamber holding the thimble fills with warm solvent and this is led back to the source via a side arm. The apparatus can be operated for long periods, with components concentrating in the source vessel.

## 3. Characterisation of the materials

Based on the results of X-ray diffraction the main crystalline phases found in the clay are (Fig. 1): calcite, chlorite, dolomite, kaolinite, quartz and mica minerals.

The clay used comes from the city of Bejaia in Algeria [7, 8]. The chemical composition of the clay is given in Table 1.

It is possible to observe a high content of silica $SiO_2$ and a smaller proportion of $Al_2O_3$, $CaO$, $SO_3$, $Na_2O$, $K_2O$, $MgO$, $Fe_2O_3$, $MnO$, $TiO_2$ and $P_2O_3$.

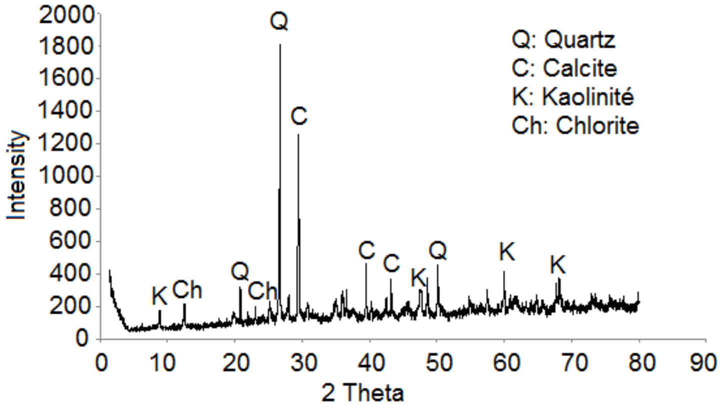


*Fig.1. X-ray diffraction of the clay.*

*Table 1*

*Chemical composition of clay (oxide wt. %).*

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ | MnO | $TiO_2$ | $P_2O_3$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 48.60 | 12.80 | 4.15 | 16.70 | 1.87 | 0.57 | 0.91 | 0.48 | 0.26 | 1.15 | 0.19 | 12.32 |

*Table 2*

*Clay fractions.*

| sandy fractions (f > 20 µm) | dusty fractions (2 µm < f < 20 µm) | clay fractions (f < 2 µm) |
|---|---|---|
| 12.49 % | 71.79 % | 15.54 % |

*Table 3*

*Chemical composition of additions.*

| | Rough olive stones (ROS) | Shell of olive stone (SOS) | Hay |
|---|---|---|---|
| **Lignin (%)** | 22.61 | 25.17 | 34.65 |
| **Cellulose (%)** | 33.42 | 41.15 | 30.24 |
| **Hemicellulose (%)** | 15.12 | 18.33 | 07.59 |
| **ash (%)** | 2.41 | 0.62 | 4.25 |
| **fats matters (%)** | 3.47 | 1.60 | 0.62 |

According to the analysis, the clay used in the experimental studies is typical carbonate clay. The loss on ignition value for clay is a measure or indication of carbon content.

Noted that the clay of Bejaia consists of sandy grains, clay particles and grains of carbonates (Table 2).

The olive stones and hay come from the city of Bejaia (Algeria). The olive stones are the reject of modern machine for extracting oil. They were dried for a few days in the air to facilitate the separation of the shell. Part of this residue is so sieved to separate the shell from the pulp.

Therefore we have to incorporate to the clay three types of additions.

- Rough olive stones (ROS)
- Shell of olive stone (SOS)
- Hay

Carried out with an apparatus of Soxhlet, the chemical analysis of agricultural waste used shows that olive stones and hay are composed mainly of cellulose, lignin and hemicellulose and a small amount of ash (Table 3). They contribute to the strength gain of bricks at the raw state (before firing).

We also done thermal analysis on raw materials used (clay, residues, clay + 5 % of each residues) to predict with more precisions how they will behave while the firing of the brick’s samples. Fig. 2 shows in particularly by differential thermal analysis (DTA) that all series analysis with additions emits more heat than the control sample.

This shows that adding organic matter helps to increase temperature in the furnace by the influence of the heat given off.

Fig. 3 shows the state of development of weight loss in samples with 5 % additions of organic matter (ROS, SOS and hay) compared with the control sample (0 % of additions).

The first peak for all samples shows the weight loss caused by the loss of moisture. The second peak corresponds to the loss of plant material between 190 °C and 340 °C (organic matter). This is verified by thermal gravimetric analysis of each addition, which confirmed that the loss in mass on the same interval of temperature (Fig. 4)

It is clear that the samples with additions show a considerable loss in weight compared with the control sample. The last peak of loss in weight is attributed to the decomposition of carbonates between 600 °C and 780 °C.

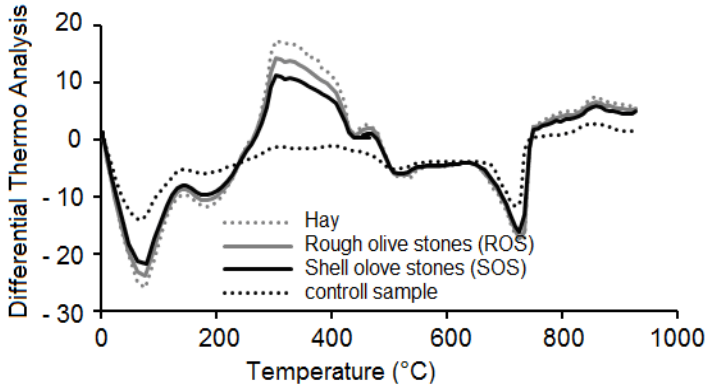


*Fig. 2. Comparison between differential thermal analysis (DTA) of different sample containing 5 wt. % of additions with the control sample.*

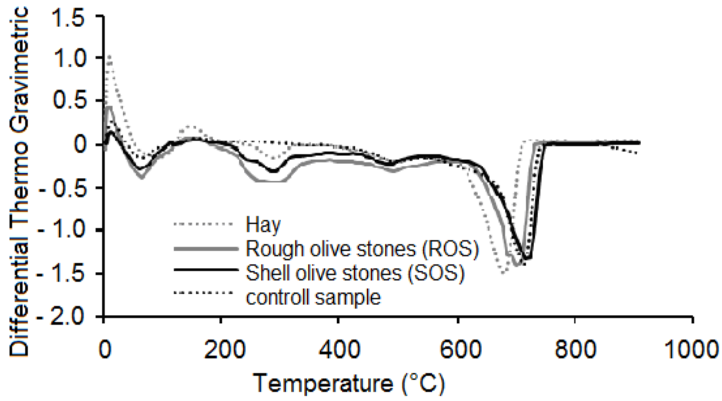


*Fig. 3. Speed reduced mass of the samples containing 5 wt. % additions by differential thermal gravimetric (DTG) compared with the control sample.*

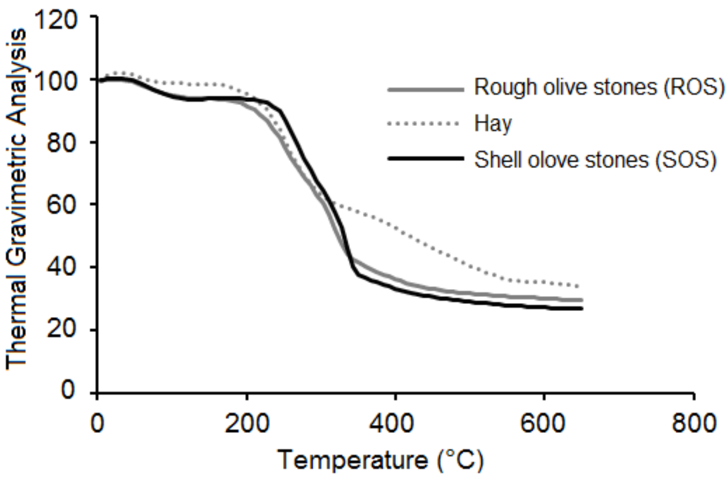


*Fig. 4. Thermal gravimetric analysis (TGA) of the different additions.*

**4. Preparation of the bricks samples**

Seven series of samples were prepared for testing according to the residue additions percentage. Serie 1 is the standard brick clay (0 % additions) as a control sample. Series 2, 3, 4, 5, 6 and 7 contain residue's additions of 1 %, 2 %, 3 %, 4 %, 5 %, 10 % respectively. For hay, the percentage was arrested at 3 % because of its lightness. If the percentage is higher, the clay will be drowned in the hay.

According to NF P 94-051 [9], the clay and the agricultural wastes have been mixed, water was added and mixed until to have the plastic limit of the mixture. For each sample, the water content was determined. The results are given in Table 4.

Therefore the samples formed were air-dried in laboratory for 72 hours then they were dried again in an oven at 105 °C until the weight will be constant. The bricks samples were fired using the follow cycle: up to 600 °C with a heating rate 2 °C /min (proceed by slow cook at the beginning in order to assure the incineration of organic substances without inflammation) then 5 °C/min until 900 °C. The samples were naturally cooled to room temperature in the furnace.

Moreover, shrinkage, weight loss on drying and after firing and the water absorption coefficient were determined. Water absorption coefficient was determined as described in NA 1957 [10]. The water absorption coefficient of brick can be expressed by the follow equation (2):

$$C = \frac{M}{S\sqrt{t}}100 \qquad (2)$$

Where M is the mass in grams of water absorbed by the brick from the beginning of immersion, S is the surface of the submerged face expressed in $cm^2$ and t is the time in minutes elapsed from the start of immersion. Under the conditions of the test (t = 0 minutes).

One major surface of each test sample is placed in contact with liquid water. The samples are stored in stainless steel containers during (the test of 10 minutes). On the container bottom a 5 mm high spacer is arranged to support the sample and to guarantee a defined thickness of water layer between the test surface and the container. Water is maintained at (22 ± 1) °C. Table 5 illustrates the values of water absorption coefficient.

*Table 4*

*Water content, dry shrinkage and total shrinkage after firing of samples.*

| | **Water content (%)** | | | **Dry shrinkage (%)** | | | **Total shrinkage after firing (%)** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample** | **ROS** | **SOS** | **Hay** | **ROS** | **SOS** | **Hay** | **ROS** | **SOS** | **Hay** |
| **0%** | 20.76 | 20.76 | 20.76 | 4.38 | 4.38 | 4.38 | 4.63 | 4.63 | 4.63 |
| **1%** | 20.90 | 21.89 | 21.15 | 4.56 | 4.81 | 4.69 | 4.69 | 4.94 | 4.75 |
| **2%** | 21.73 | 22.67 | 21.91 | 4.69 | 4.94 | 4.88 | 4.75 | 5.13 | 5.00 |
| **3%** | 22.12 | 23.43 | 22.34 | 4.81 | 5.19 | 5.06 | 4.94 | 5.31 | 5.19 |
| **4%** | 22.75 | 24.07 | - | 5.06 | 5.44 | - | 5.19 | 5.56 | - |
| **5%** | 23.01 | 24.67 | - | 5.38 | 5.63 | - | 5.38 | 5.63 | - |
| **10%** | 25.13 | 26.71 | - | 6.00 | 6.38 | - | 6.19 | 6.50 | - |

*Table 5*

*Absorption water coefficient of samples.*

| | **Absorption water coefficient of samples (%)** | | |
|---|---|---|---|
| **Sample** | ROS | SOS | Hay |
| **0%** | 28.01 | 28.01 | 28.01 |
| **1%** | 27.27 | 27.51 | 27.28 |
| **2%** | 25.91 | 26.30 | 26.07 |
| **3%** | 25.18 | 25.54 | 25.31 |
| **4%** | 24.45 | 24.61 | - |
| **5%** | 23.72 | 23.95 | - |
| **10%** | 18.83 | 19.05 | - |

*Table 6*

*Total mass loss after firing of samples.*

| | Total mass loss after firing (%) | | |
|---|---|---|---|
| **Sample** | **ROS** | **SOS** | **Hay** |
| **0%** | 14.33 | 14.33 | 14.33 |
| **1%** | 15.01 | 14.91 | 14.85 |
| **2%** | 15.69 | 15.15 | 15.39 |
| **3%** | 16.37 | 16.06 | 15.90 |
| **4%** | 17.03 | 16.64 | - |
| **5%** | 17.67 | 17.21 | - |
| **10%** | 20.61 | 20.03 | - |

*Table 7*

*Apparent density and total mass after kilning.*

| | Apparent density ($g/cm^3$) | | | Total mass loss after firing (%) | | |
|---|---|---|---|---|---|---|
| **Sample** | ROS | SOS | Hay | ROS | SOS | Hay |
| **0%** | 1.69 | - | - | 28.01 | - | - |
| **1%** | 1.58 | 1.6 | 1.56 | 27.27 | 27.51 | 27.28 |
| **2%** | 1.54 | 1.55 | 1.52 | 25.91 | 26.3 | 26.07 |
| **3%** | 1.49 | 1.51 | 1.48 | 25.54 | 25.18 | 25.31 |
| **4%** | 1.46 | 1.48 | - | 24.45 | 24.61 | - |
| **5%** | 1.42 | 1.44 | - | 23.72 | 23.95 | - |
| **10%** | 1.32 | 1.34 | - | 18.83 | 19.05 | - |

*Table 8*

*Compressive and flexural strength of samples.*

| | Compressive strength (no fired samples) (MPa) | | | Compressive strength fired samples) (MPa) | | | Flexural strength (fired samples) (MPa) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample** | ROS | SOS | Hay | ROS | SOS | Hay | ROS | SOS | Hay |
| **0%** | 4.88 | - | - | 24.06 | - | - | 8.62 | - | - |
| **1%** | 4.97 | 5.02 | 5.02 | 22.68 | 23.36 | 22.37 | 7.86 | 8.16 | 7.62 |
| **2%** | 5.32 | 5.44 | 5.39 | 22.14 | 22.69 | 21.63 | 7.15 | 7.45 | 6.98 |
| **3%** | 5.75 | 5.83 | 5.80 | 21.69 | 22.13 | 20.64 | 6.63 | 6.92 | 6.52 |
| **4%** | 5.98 | 6.14 | - | 21.27 | 21.59 | - | 6.18 | 6.59 | - |
| **5%** | 6.15 | 6.28 | - | 20.46 | 20.86 | - | 5.59 | 6.04 | - |
| **10%** | 6.88 | 7.05 | - | 15.11 | 15.85 | - | 3.83 | 4.62 | - |

## 5. Test results and discussions

All technological properties: shrinkage after drying and weight loss after firing increase with increasing percentage of organic additions (Table 4 and 6)

The shrinkage has a small increase because of the water content which increased in proportion to additions (Table 4). The total mass loss of samples studied varies between 14 and 21 % (Table 6). The values found are still in the norm (< 25 %) [11].

When brick's samples are fired the plant materials are driven off. The test results of Bouaziz and Rollet were carried out on thermal analysis and proved the loss of plant materials [12]. Fig. 4 illustrates the weight loss between 200 °C and 500 °C of the agricultural wastes.

The results of physic-mechanical properties are given in Table 7 and 8.

Increasing the percentage of organic waste has caused a reduction in apparent density. The main reason is the burning of these residues.

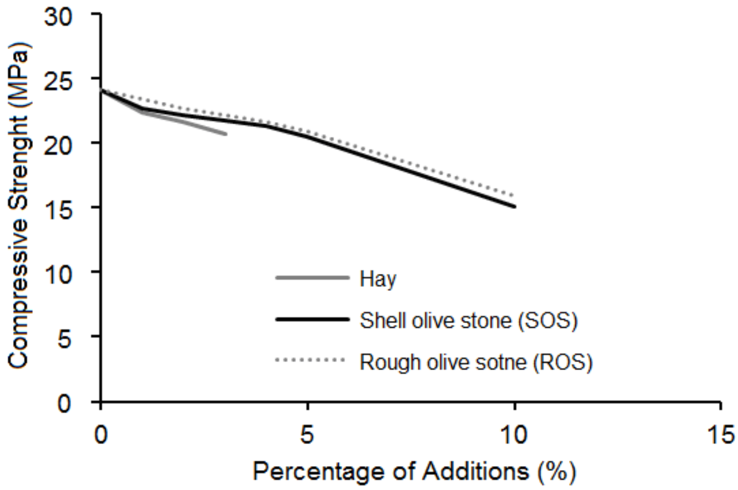


*Fig. 5. Compressive strength according to the percentage of additions.*

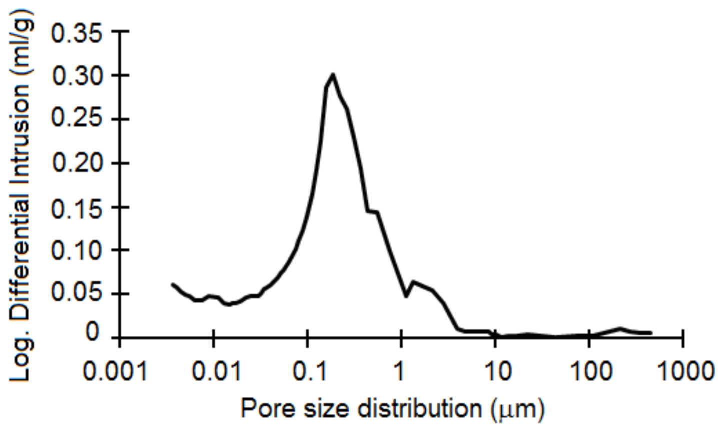


*Fig. 6. Pore size distribution of the control sample (without addition).*

Compressive strength of brick's samples at raw state has increased proportionally to the percentage of organic wastes. These organic wastes contained in clay are as a binding agent of the brick's structure before firing. This increase is useful to reduce the falls due to the displacement of the bricks. Table 8 illustrates this for various ROS, SOS and hay in %.

As against, the compressive strength of fired samples has decreased with the increase of additions percentage (Fig. 5)

However, the values are still higher than that required by the Algerian norm which requires a brick's compressive strength between 10 and 40 MPa for use in construction [13]. The percentage of the decrease compared to the control sample reached 37.2 % for an organic addition of 10 %.

The absorption water coefficient has decreased with increasing additions. The values are illustrated in Table 5. Bricks with additions absorb less water from the mortar. This characteristic is an advantage because the bricks without additions absorb much of the mortar's water and causes its crumble implying a poor bond. According to NA 1957 [10], the optimum value of water absorption coefficient is considered to be less than 30 %.

The additions of residues at different percentages were efficient to increase the pores in the structure of samples with acceptable compressive strength. We can however recommend the percentage of additions until 5 % to limit the drop in compressive strength.

The pore size distribution (in the 0.01 – 1000 µm range) was determined by mercury

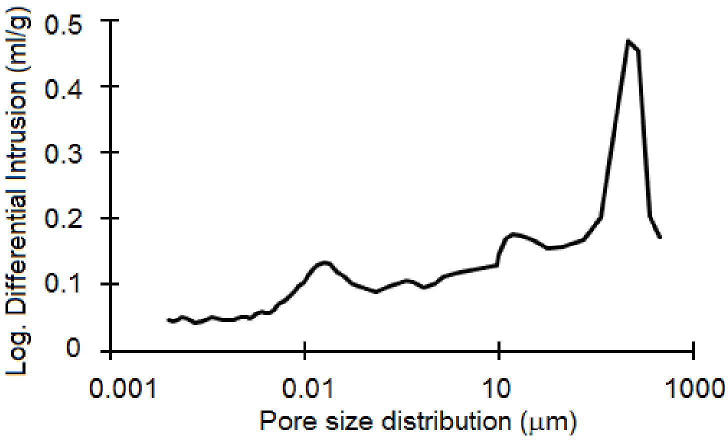


*Fig. 7. Pore size distribution of the sample with 5 % addition.*

intrusion porosimetry (Thermo Finnigan Pascal 140/240) with an experimental uncertainty of about 1 % relative. The pore structure of the clay brick made from pure clay (control sample) consists mainly of pore with the size of 0.06 to 1 μm (Fig. 6).

These pores must be appearing due to the decomposition of carbonates (calcites and dolomite), which content in the clay, according to chemical analysis, is reaching up to 21.6 %. The reason for reduction in the rate of pore from 0.06 to 1 μm in Fig. 7 is that the 5 % of clay was substituted by the crushed olive stone.

As is shown on Fig. 7, the porous structure of the clay brick with 5 % crushed rough olive stones has been fully developed.

The pore size is between100 and 500 μm. The rough olive stone was ground leading to a mean particle diameter of 200 μm. Most of the pores have a diameter of 200 μm which correspond to the mean particle diameter of the crushed olive stone. Formation of the more homogenous porous structure is favourably impacted by using the crushed olive stones containing oil.

## 6. Conclusions

The use of olive stone and hay in the manufacture of bricks will be inscribed in an approach of sustainable development and it has the advantage of using a renewable raw material as opposed to aggregates quarries that's their resources are becoming.

We showed in this study that the addition of agricultural waste which burn during the firing have reduced the apparent density of the brick. The bricks in this effect become lightweight and help to reduce the dead load in buildings. The use of light brick can also reduce transportation's expenses and the cost of the walls. Besides, this kind of bricks can be used as thermal or noise insulator.

Organic residues are easily consumed during the firing and with their combustion, they contribute to increase the temperature in the furnace. This allows economic use of the energy needed for firing. Also the additions of organic materials which burn while firing create pores in the finished product. The high porosity is a characteristic sought after today in order to save energy. The presence of pores in the materials helps to reduce the thermal conductivity and increases therefore its isolation [14, 15].

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