Addition of polymeric wastes as pore formers in ceramic lightweight bricks

N. Quaranta[1], M. Caligaris[1], H. López[1], M. Unsen[1], N. Lalla[1],
M. L. Franzoy[2], M. F. Carrasco[2], J. Citroni[2] & M. Avendaño[2]
[1]Universidad Tecnológica Nacional, F. R. San Nicolás, Argentina
[2]Universidad Tecnológica Nacional, F. R. Santa Fe, Argentina

Abstract

In the Argentine littoral region, ceramic brick masonry is generally used, with common bricks of 0.15 m thick for walls constituting the exterior of homes. This thickness is insufficient to achieve adequate hygroscopic and thermal isolation conditions because this area requires that such walls provide a minimum thickness of 0.30 m, considering the brick and plaster on both sides.

The objective of this work is to develop alleviating bricks, decreasing their density by the incorporation of macroscopic pores in the mass of the fired brick through solid wastes consumed during heat treatment, using conventional manufacturing procedures. In this way, the thermal insulation capacity will increase, without risky reductions in the resistance to compression or excessive increases in costs, and the amount of natural land use will be reduced.

Samples of 24 cm x 12 cm x 5 cm were obtained, from mixes of clays, like those used in traditional brick production (soil), with the addition of different waste materials: cinder and crushed expanded polystyrene of two different granulometries.

The utilized raw materials were characterized by several techniques: particle size analysis, optical and scanning electron microscopies and X-ray electron dispersion analysis. From the sintered bodies, parameters such as density, porosity, thermal conductivity and compression resistance were determined. A better behavior was observed when polymeric waste was used in respect of cinder utilization: greater resistance to compression and less thermal conductivity.
Keywords: wastes, ceramics, construction.

www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/ARC100381

1 Introduction

In the Argentine littoral region, ceramic brick masonry is generally used, with common bricks of 0.15 m thick for wall cladding and the exterior of homes. This thickness is insufficient to achieve adequate hygroscopic and thermal isolation conditions because this area requires that such walls provide a minimum thickness of 0.30 m, considering the brick and plaster on both sides.

For that reason, this work attempts to develop alleviating bricks, decreasing density by incorporating macroscopic pores in the mass of the fired brick through solid wastes consumed during heat treatment, using conventional manufacturing procedures.

Different combustibles and organic compounds have been used as pores formers in the commercial brick industry [1, 2]. Ducman and Kopar [3], for example, have carried out essays on clay bricks with 30% in volume of sawdust and paper industry mud as porosity generators. The bricks obtained, with a heat treatment of 920°C, resulted in structural ceramic materials, highly porous and with good properties for their specific use.

In previous works [4, 5], experiences that helped to determine the feasibility of incorporation of wastes into the brick structure, yielding a material with characteristics similar to commercial bricks were presented. In these experiments the possibility of incorporating up to 61% of waste, such as crushed expanded polystyrene and cinder, without significant changes in manufacturing procedures applied in local brickworks was determined.

One of the utilized wastes, expanded polystyrene (EPS), is a petroleum by-product that is usually applied in the construction industry for lightweight concrete, improving its characteristics in terms of thermal insulation, or as fuel for electricity generation or heating. While the EPS can be arranged in landfills without risk of contamination of soil or groundwater, this alternative disposal has the serious problem of generating excessive volumes. Another important source of polystyrene waste is from commercial or home use as protective packaging, both compact or pellets, and all the material that emerges in the process of cutting plates.

The cinder, on the other hand, is the disposal of furnace production of charcoal that is precariously sieved or shaken in brickworks, in order to separate the fraction of coal used as fuel to burn in the oven between layers of adobes. This separation is carried out with a metal mesh with an opening of about half an inch. This waste is available in abundant quantities and without charge. The cinder incorporation emerged from observing the techniques of assembling the oven, because it is used between layers of adobes to achieve a uniform temperature. The incorporation of these wastes allowed in all cases, to obtain bricks with increased porosity and reduced bulk density, which resulted in increasing the capacity of thermal insulation [4]. There were, also, reductions in resistance to compression, which can be explained by the relationship between this property and the porosity for brittle materials such as ceramics [6].

Figure 1: Photograph of the oven used for firing bricks in the study.

Bricks studied at different stages of this research were fired in traditional brickworks ovens, which are called “anthill” and which are formed by stacking of the bricks to be fired. Figure 1 shows a photograph of an assembled oven for firing the samples under study. Depending on where the mud is placed in the oven, the bricks acquire different tones: those from the top are clearer and more prone to collapse, those in the middle are of better quality and the bricks in the bottom are burned by excess heat and appear glued, twisted, dark color and are used for stuffing or grinding.

This work attempts to determine the influence of the incorporation of waste and the heat treatment, on the morphological and structural characteristics and mechanical properties of bricks made in pilot scale.

It is important to take into account, from the environmental point of view, that during the fire process of these mixtures, particulate and gaseous emissions from organic compound combustion can occur.

The emissions characterization from polystyrene combustion was carried out by S. Durlak et al [7]. They established that an important number of organic species are formed, when this material is heat treated in the range of 800°C to 1200°C, besides the expected combustion products such as CO, CO_2, and particulate matter. They also observed that there was an exponential decrease in the total number and mass of these organic species with the temperature increase.

In this work, the emission products (gas and particulate matter) produced during the heat treatment of clay and polystyrene mixtures were analyzed.

2 Experimental

Three samples were prepared using three different aggregates: polystyrene, milled polystyrene and cinder with average particles sizes of 2.5 mm, 0.5 mm and 30 μm. Mixtures of clay and aggregates were obtained with a dose volume of clay aggregation like 1:0.60, 1:0.65 and 1:0.95, respectively. Bricks without addition of any waste were also produced to be taken as patterns. The samples are identified as follows:

B: brick without aggregates

BC: brick with cinder addition.

BPc: brick with polystyrene with average grain sizes of 2.5 mm addition.

BPf: brick with polystyrene with average grain sizes of 0.5 mm addition.

The procedure of preparing the clay, molding and firing the bricks is described in a previous work [1]. All the bricks were shaped in the usual measures of commercial bricks of the area, which is 24 cm x 12 cm x 5cm.

During the firing of the bricks with waste incorporation, it was necessary to reduce the amount of wood burned in furnaces, because an excessive amount of stuck and twisted bricks was detected in places where usually bricks with acceptable characteristics were found. After this reduction, the bricks showed no major superficial defects, but in the interior of some of them, dark zones, indicative of high temperature firing, were still observed.

The powders to be used as raw material for the compact bodies' production and the fired samples obtained were characterized by several techniques: optical and scanning electron microscopies (SEM), particle size analysis, and Vickers microhardness measurements, among others. The samples granulometries were determined by optical and scanning electron microscopies.

Physical and mechanical properties of the bricks such as resistance to compression (IRAM 12586), apparent density and porosity (IRAM 12510), and thermal conductivity were evaluated on the obtained bricks.

The SEM analyses were carried out through a Phillips 515 scanning electronic microscope with an X-ray detector (EDAX-Phoenix).

The optical observations were made with Zeiss-Axiotech equipment with a Donpisha 3CCD camera and an image scanner.

The microhardness analyses were made with a Vickers indenter in a HMV-2000 Shimatzu equipment, using loads of 100 g during 10 sec in all cases.

The firing processes were characterized in relation to the possible gases and particulate matter emissions. This characterization was carried out in a lab oven analyzing the air quality in the superior exit of it, in the range of room temperature to 1100°C.

For this, air quality analyzer equipment, with laser technology for particulate matter analysis and electrochemical sensors for gases was used (XILIX-EPA 2001). It was located so that the emissions were analyzed a few seconds after they were produced. The contaminants determined were hydrocarbons in general (HC), carbon monoxide (CO), and particulate matter with particle size inferior to 10 μm (PM10). The HC sensor detects all present hydrocarbons and calculates the concentration on the basis of four carbons in the molecule.

3 Results and discussion

In Figure 2 waste materials used as aggregates for obtaining the alleviating bricks, cinder and expanded polystyrene, are observed.

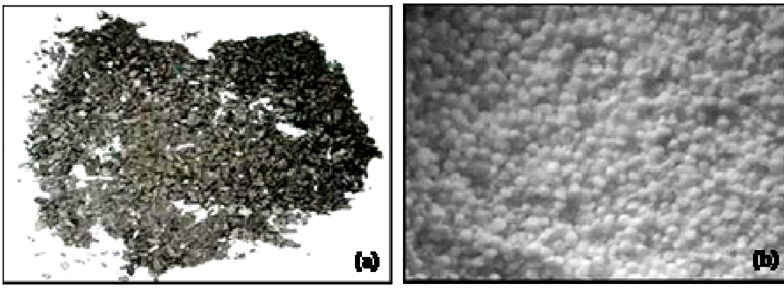


Figure 2: Photographs of the aggregates: (a) cinder (b) polystyrene.

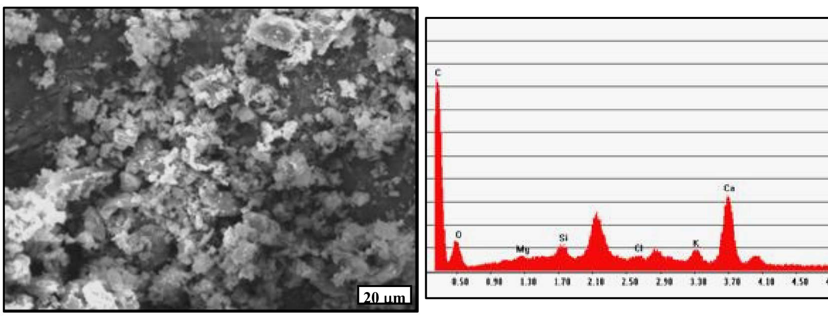


Figure 3: SEM photograph and EDS analysis of cinder.

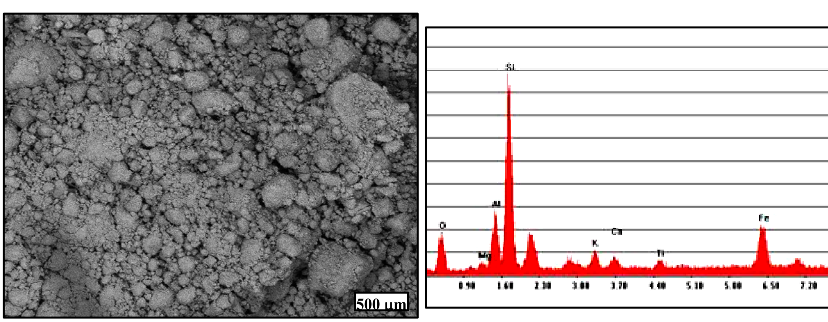


Figure 4: SEM photograph and EDS analysis of the used soil.

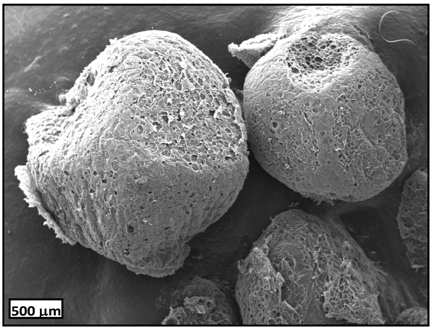
SEM and EDS analysis of the starting materials including the used clay (soil) are presented in Figures 3 and 4 and in Table 1.

As noted in these studies, the cinder material has approximately 70% of C, component that is removed during the firing of the brick, generating porosity in the resulting product. The remaining components will be incorporated into the brick structure in the great majority as oxides during the firing process.

It is observed that the base material used, is a common silicoaluminous soil, with a significant content of Fe, and smaller quantities of Mg, Ca, K and Ti. The high content of Fe gives intense reddish to the fired brick.

Table 1: EDS analysis of raw materials used: cinder and soil.

Oxide	Cinder [%]	Soil [%]
C	70,88	---
O	21,5	33,75
Mg	0,75	2,75
Si	1,03	32,04
Cl	0,46	---
K	0,87	2,29
Ca	4,5	1,68
Al	---	10,51
Fe	---	15,47
Ti	---	1,5



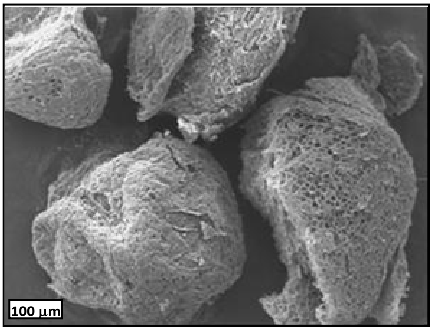


Figure 5: SEM photographs of the EPS particles of two different granulometries.

The other aggregate, polystyrene, was added in two different granulometries, average particle sizes of 2.5 mm and 0.5 mm. The larger aggregates have rounded homogeneous shape, while the smallest are heterogeneous in shape, as broken spheres, because of the milling process made for further use. This can be seen in the photographs of Figure 5, which presents the SEM analysis of both materials. The internal porous structure of both wastes is similar, and can be seen in Figure 6.

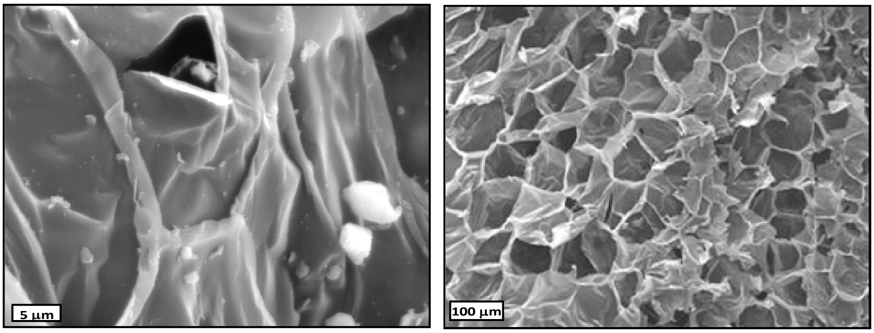


Figure 6: SEM photographs of the internal structure of polystyrene particles.

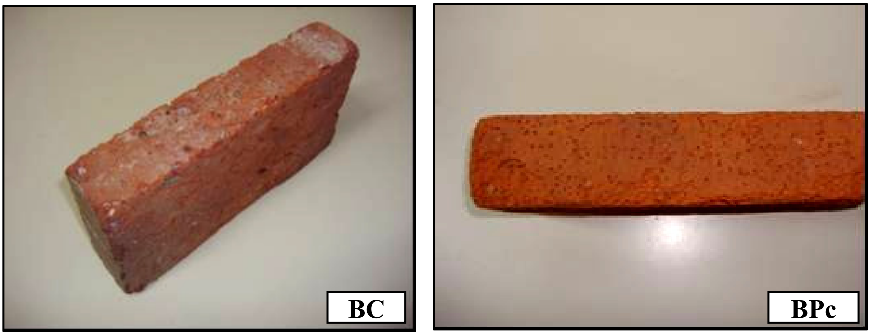


Figure 7: Brick obtained with cinder (BC) and polystyrene (BPc) aggregates.

Obtained bricks (Figure 7) have good external characteristics, with defined edges, without losing edges or corners. The bricks with the addition of polymers have an intense reddish coloration while those with added cinder have a more uneven coloration with darker areas.

These samples were cut for microscopic observation in order to determine differences in the morphology, distribution and internal structures of the pores formed.

Figure 8 shows SEM photographs taken in the three samples of bricks BC, BPc and BPf. As it can be seen, the samples BP have pore sizes according to the size of the added material, which suggests the idea of base structure densification simultaneously or before the combustion of the material, because otherwise, if the densification were later this would lead to a decrease in pore sizes and hence a shrinkage of the final product. For the BC sample, the internal morphology obtained is similar to those seen in common bricks without aggregates, with the presence of irregular pores.

By comparing the fine structure of the bricks, it can be detected in both samples of bricks BP, areas with different sintering degrees of the material which could be mainly grouped into two regions, those analyzed in the internal walls of the pores, and those studied in the rest of the brick, on the dense areas of the material.

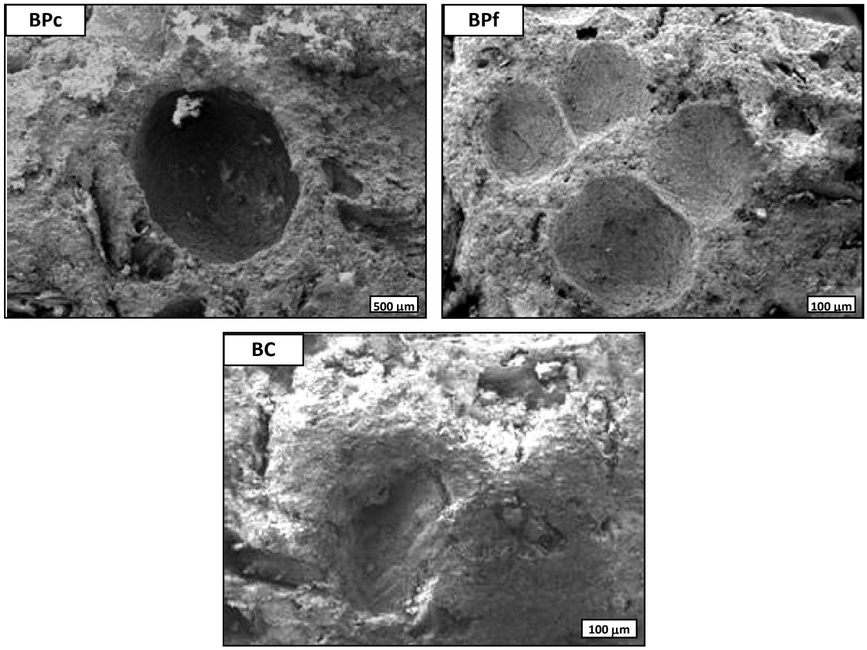
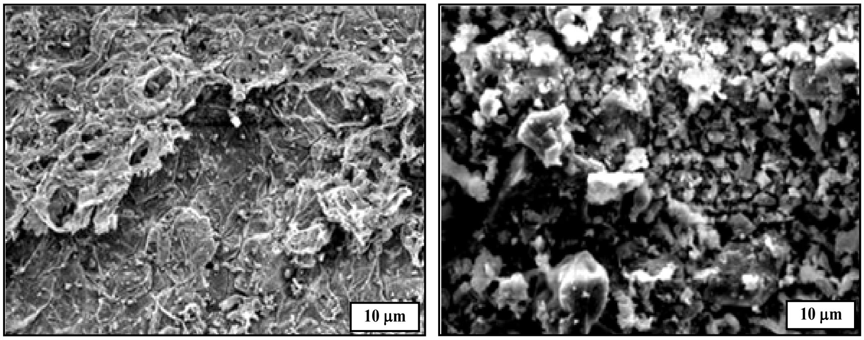


Figure 8: SEM photographs of the morphologies in samples BPc, BPf and BC.



(a) (b)

Figure 9: Analysis of the sintering degree of different regions of BP bricks. (a) Pores internal surface. (b) Dense material area.

Figure 9 shows the sintering characteristics found in these two regions. A higher degree of sintering in the internal areas of the pores is determined, which indicates the probable presence of higher temperatures in these regions. The internal surface of the pores presents the same aspect as the surface of EPS particles, like a superficial replica. This reinforces the mentioned idea that the clay matrix sintering is a previous step to the complete burning of EPS particles.

The tests carried out to determine the properties of the obtained bricks are shown in Table 2. This table summarizes the average results obtained for each of the specimens tested. These results are very encouraging because density was reduced from 1.50 g/cm^3 in common bricks to 1.03 g/cm^3 in BC bricks and for bricks including polystyrene densities of 1.09 and 1.15 were determined.

The local IRAM 12566 standard defines various categories of bricks according to their resistance to compression. For common bricks the value of compressive strength between 3.5 and 9.0 MPa classifies them as type 2, between 9.1 and 15.0 MPa as type 3 and type 4 corresponds to values greater than 15 MPa. Therefore BP bricks, according to this, are classified as type 2.

The parameters presented in Table 2 indicate that the compressive strength is lower in the bricks with the addition of wastes, while the porosities obtained are quite superior. It succeeded in getting brick with lower density, and hence the definition of “alleviating”.

Table 2: Properties of the studies samples.

Brick	**Apparen t density** [g/cm^3]	**Resistance to compression** [MPa]	**Thermal conductivity** [Kcal/hmºC]	**Porosity** [%]	**Hv** [Kg/mm^2]
B	1,50	10,4	0,568	26,5	---
BC	1,03	1,9	0,355	59,7	180
BPc	1,15	3,8	0,420	52,5	248
BPf	1,09	3,8	0,469	53,3	260

The macropores generated by the cinder calcination, as seen in the SEM analysis, show an angular and irregular shape, and branched cracks occur at the ends, that weaken the area. These angular shapes may also be a major focus of stress. On the contrary, in the case of macropores resulting from the calcinations of crushed expanded polystyrene, the cells have a regular spherical shape, with well defined boundaries and without cracks.

In the Vickers microhardness tests, well-defined indentations, without cracks, have been obtained, indicating the presence of tough structures [5]. In the case of sample B, cracks developed around the Vickers indents are observed, and it was impossible to determine a reproducible microhardness value. The obtained values show behavior consistent with the resistance to compression determined in the samples.

In relation to the thermal conductivity, the standard brick without wastes presents the higher value, and the lesser one corresponds to BC sample. The bricks BP show intermediate values. These values are in inverse correspondence with porosity values obtained.

The air quality analyses were carried out during heat treatments of samples obtained in the same conditions as the original bricks studied, but in pieces of small sizes. Figure 10 shows the results of PM10, CO and HC analyses, in two probes, one corresponds to sample B (soil) and the other corresponds to BPc sample. The highest levels of contaminants for sample containing EPS waste are observed, as it is expected. In the case of HC pollutant the maximum concentrations were determined in the range 470°C – 680°C. The observed values don´t reach in any case the standard legal values for these substances [9].

It is important to mention that the average levels of these compounds in the lab environment, without heat treatment process in course, are habitually 0.05 mg/m^3, 0.02 ppm and 0.1 ppm for PM10, CO and HC respectively.

Taking into account the results of these studies, it is possible to conclude that the incorporation of discarded EPS in clay mixtures, in the studied proportion, leads to obtaining alleviating ceramic bricks, with an adequate porosity, improving the superficial hardness and heat conductivity properties in relation to bricks obtained in the same experimental conditions but without wastes.

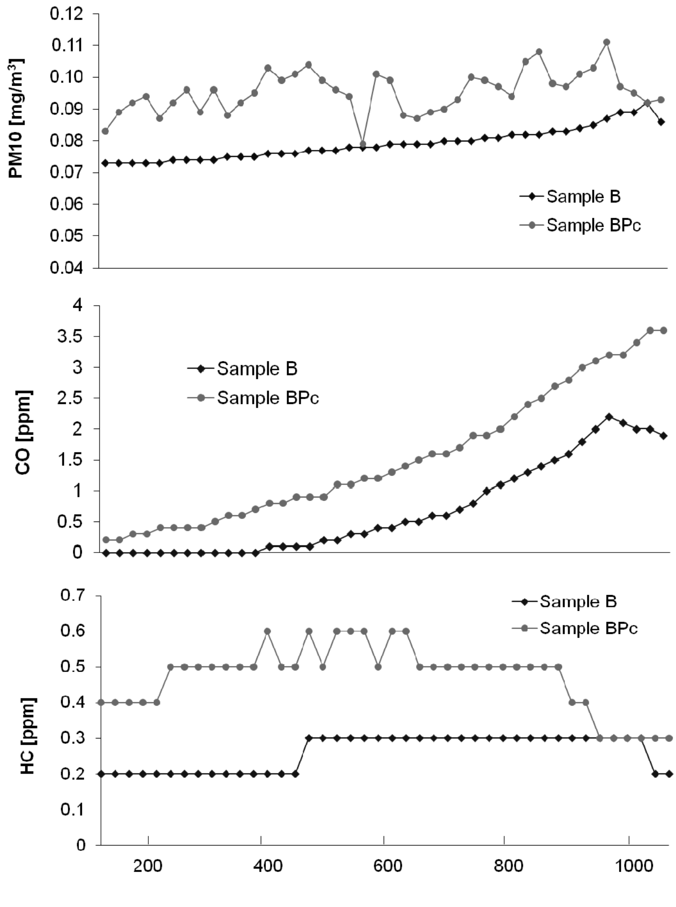


Figure 10: Air quality analyses during samples' heat treatment.

4 Conclusions

Alleviating bricks have been produced, by incorporating discarded cinder and wastes of expanded polystyrene in two different granulometries to ceramic bricks. The bricks obtained with addition of polymers show better characteristics than the bricks with carbon addition, due to the spherical shape of the macropores formed within the brick and the absence of cracks in its perimeter.

In order to determine the sintering degree of the material, the internal structures present on the bricks have been studied. A clear difference between the inner surfaces of the pores, with higher sintering degrees, in relation to the characteristics of the dense areas of the material, with less degrees of sintering is observed, suggesting the development of higher temperatures in regions where the burning of the waste material took place.

The addition of discarded EPS in clay mixtures during standard bricks production leads to obtaining alleviating ceramic bodies, with the formation of pores in an adequate proportion to improve the toughness, hardness and heat conductivity in relation to bricks without waste incorporation. The porosity values obtained classifies this material as ceramic bricks type II (local standard). The resistance to compression is lower than the standard products but its value is in the required commercial range.

The emissions of gases and particulate matter during the firing processes were characterized and they are below the standard legal values for these substances established in local norms.

Acknowledgements

The authors wish to thank the Commission of Scientific Researchers of Buenos Aires Province, Argentina, and National Agency of Technological and Scientific Promotion, Argentina, for the financial supports received for this work.

The fulfillment of this work was also possible thanks to the collaboration of the company LADRIMAR S.C. - Mr. Marinoni (Recreo City, Santa Fe Province, Argentina).

References

[1] Turgut P. and Algin H., Limestone dust and wood sawdust as brick material, *Building, and Environment* **42**, pp. 3399-3403, 2007.

[2] Demir I., Effect of organic residues addition on the technological properties of clay bricks, *Waste Management* 28**,** pp. 622-627, 2008.

[3] Ducman V. and Kopar T., Sawdust and paper making sludge as pore-forming agents for lightweight clay bricks source, *Industrial Ceramics* 21 **[2]**, pp. 81-86, 2001.

[4] Citroni J., González A., Carrasco M.F., Avendaño M., Botterón A., “Ladrillos cerámicos alivianados elaborados a partir de la utilización de residuos” en *VIII Congreso Latinoamericano de Patología de la Construcción y X Congreso de Control de Calidad en la Construcción*

(CONPAT 2005), Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de las Construcciones (ALCONPAT), (2005): pp. III.221 a III.227, Asunción. Paraguay.
[5] Citroni J., Rodríguez M., Carrasco M.F., Avendaño M., Sota J.D., Franzoy M.L. y Baldó E. "Desarrollo de ladrillos cerámicos alivianados a partir de la utilización de residues". *En IV Reunión PROCQMA.* San Rafael, Mendoza. ISBN 950-42-0056-7.
[6] Mindess S. and Young J. *Concrete*. Prentice. Hall, inc. Englewood, Cliffs. New Jersey. (1981) pp. 194-197.
[7] Durlak S., Biswas P., Shi J. and Bernhard M. *Environ. Sci. Technol.* (1998) 32, pp. 2301-2307.
[8] McColm I. Cracked Indent – Friend or Foe? Their Use in Toughness and Brittleness Characterization (Chapter V). *Ceramic Hardness, Ed. I. McColm,* Ed. Plenum Press, pp. 145-207, 1990.
[9] Environmental Polity Secretary *Decree 3395/96, Law 5965*, modified by *Resolution 242/97*. Argentina.