

Quality study of ceramic bricks manufacture with clay and ashes from the incineration of municipal solid wastes

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Estudio de calidad de la fabricación de ladrillos de cerámica con arcilla y cenizas procedentes de la incineración de residuos sólidos urbanos

Estudi de qualitat de la fabricació de maons de ceràmica amb fang i cendres procedents de la incineració de residus sòlids urbans

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RESUMEN

Este artículo presenta los principales resultados del análisis y caracterización de los ladrillos fabricados con una mezcla de barro y cenizas en las siguientes proporciones: 100:0, 99:1, 95:5, 90:10, 80:20 y 60:40 y calcinados a una temperatura que oscila desde 50 hasta 1100 °C. Las cenizas que se utilizan en este trabajo se obtuvieron a partir de la parte inferior y los gases de salida de un horno de ladrillos de tipo Hoffmann en Tabio, Cundinamarca, Colombia. Cuando el consumo de carbón típico fue sustituido, en parte, con la incineración de residuos sólidos urbanos (co-incineración). Los ladrillos de arcilla y cenizas se caracterizaron físico químicamente mediante las siguientes pruebas: difracción de rayos X (DRX), fluorescencia de rayos X (FXR), Espectroscopía de Infrarrojo (IRS), termogravimetría (TG), Análisis Térmico Diferencial (DTA), Espectroscopía de Absorción Atómica (AAS), Microscopía Electrónica de Barrido (SEM) y el procedimiento de lixiviación característico de toxicidad (TCLP) las pruebas de lixiviación que se realizaron de acuerdo al método de la EPA de 1311 para la determinación de metales pesados. Las pruebas de absorción Porosimetría, frío, carga de rotura y resistencia se llevaron a cabo para determinar la calidad de los ladrillos. Los resultados muestran que el grado y la carga de rotura aumentan ligeramente con la adición de cenizas hasta la proporción 90:10 y disminuciones en las superiores, mientras que la absorción de agua aumenta en todas las mezclas. El estudio revela que el producto final, fabricado con arcilla y ceniza cumple con todos los estándares de calidad exigidos en Colombia.

Palabras clave: Ladrillos, co-incineración, residuos sólidos municipales, cenizas volátiles.

SUMMARY

This paper presents the main results of the analysis and characterization of bricks manufactured with a clay and ashes mixture in the following proportions: 100:0, 99:1, 95:5, 90:10, 80:20 and 60:40 and calcined at a tempera-

ture ranging from 50 to 1100°C. The ashes used for this study were obtained from the bottom and the outlet gases of a Hoffmann-type brick furnace in Tabio, Cundinamarca, Colombia. When the typical coal consumption was substituted in part with incineration of municipal solid wastes (Co-incineration). The clay and ashes bricks were physical and chemical characterized with the following tests: X-Ray diffraction (XRD), Fluorescent X-Ray (FXR), Infra Red Spectroscopy (IRS), Thermogravimetry (TG), Differential Thermal Analysis (DTA), Atomic Absorption Spectroscopy (AAS), Scanning Electronic Microscopy (SEM) and Toxicity Characteristic Leaching Procedure (TCLP) lixiviation tests that were performed according to the EPA 1311 method for the determination of heavy metals. Porosimetry, Cold Absorption, Breaking Load and Strength tests were also carried out to determinate the quality of the bricks. The strength and the breaking load slightly increases with the addition of ashes up to the 90:10 proportion and decreases in the higher ones, whereas the water absorption increases in all the mixtures. This study show that the finished product, manufactured with clay and ashes comply with all the quality standards required in Colombia.

Key words: Bricks; Co-Incineration; Municipal Solid Wastes; Volatile Ashes.

RESUM

Aquest article presenta els principals resultats de l'anàlisi i caracterització dels maons fabricats amb una barreja de fang i cendres en les següents proporcions: 100:0, 99:1, 95:5, 90:10, 80:20 i 60:40 i calcinades a una temperatura que oscil·la des de 50 fins a 1100 °C. Les cendres que es fan servir en aquest treball s'obtenen a partir de la part inferior i els gasos de sortida d'un forn de maons del tipus Hoffmann, a Tabio, Cundinamarca, Colòmbia. El consum típic de carbó va ser substituït, en part, amb la incineració dels residus sòlids urbans (co-incineració). Els maons

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de fang i cendres es van caracteritzar físic químicament mitjançant les següent proves: difracció de raigs X (DRX), fluorescència de raigs X (FXR), Espectroscopia d'Infraroig (IRS), termogravimetria (TG), Anàlisi Tèrmic Diferencial (DTA), Espectroscopia de Absorció Atòmica (AAS), Microscopia Electrónica d'Escombratge (SEM) i el procediment de lixiviació característic de toxicitat (TCLP). Les probes de lixiviació es van realitzar d'acord amb el mètode de la EPA de 1311 per la determinació de metalls pesats. Les probes d'absorció, porosimetria, fred, càrrega de trencament i resistència es van portar a terme per determinar la qualitat dels maons.

Les resultats mostren que el grau i la càrrega de trencament augmenten lleugerament amb l'addició de cendres fins a la proporció 90:10 i disminueix en les superiors, mentre que l'absorció d'aigua augmenta en totes les mescles. L'estudi revela que el producte final, fabricat amb fang i cendra compleix amb tots els estàndards de qualitat exigits a Colòmbia.

Mots clau: maons, co-incineració, residus sòlids municipals, cendres volàtils.

INTRODUCTION

Since long time ago the man has used calcined clay bricks for construction. China for example restricts the used of this bricks, because of the high consumption and scarcity of this material. Ashes encapsulation has been studied as a replacement material in concrete blocks and structures but the ashes humidity difficult the forging process and decrease the final product quality.

The encapsulation of bottom and fly ashes produced during the co-incineration of MSW, in clays mixture used in bricks-making, arise as a solution for the proper disposal of these ashes and as a replacement material [1-4].

Bricks are classified as *solid* (less than 25% perforations by volume), perforated (containing a pattern of small holes through the brick removing no more than 25% of the volume), cellular (containing a pattern of holes removing more than 20% of the volume, but closed on one face), or hollow (containing a pattern of large holes removing more than 25% of the brick's volume).

The application of each type of unit and the respective physical characterization must be in accordance to the calculations and requirements established in the local seismically-resistance regulation - NSR-98 and guarantee the stability of a structure constructed with these bricks [5-7]

MATERIALS AND METHODS

Ten units of 200 grams each for each of the following proportions: 100:0, 99:1, 95:5, 90:10, 80:20 and 60:40 are made. Then, the units are calcined in a laboratory's furnace following the same temperature pattern of the brick furnace. For testing and determination of the optimum proportion of clay: ashes mixtures, three bricks from each proportion were picked randomly from each batch.

The characterization tests can be classified in two groups, the first one indicates the stabilization and solidification of the ashes into the clay and the second group determine the quality of the bricks.

The following tests are carried out to measure the stability of the ashes into the clay.

- **Scanning Electronic Microscopy (SEM)** Allows the morphologic study of the surfaces. The SEM explores point by point the surface of the image and produces realistic tridimensional images of the object's surface. Knowing the material's surface enables to have an idea of the atoms arrangement in a molecular scale, as well as the arrangement's degree.

- **X Ray Diffraction (XRD)** This technique is used to determine the crystalline structure of an atom or molecule. The X ray diffraction or X ray crystallography consists in passing one X ray beam through one crystal of the substance been analyzed. The X ray's wave length does not vary, but diffraction figures are formed. It is possible to work with mono crystals or mono crystalline powders.

The metals arrangement inside the crystalline net and the changes that the clay could suffer during the stabilization process is also determined.

- **Fluorescent X-Ray (FXR)** Allows to find the chemical composition of a sample, determinates the quantity of refractory elements as Si, Ti, V, Ge, Ba, W, Y, Zr, Hf, U, Th, Nb, Sr, Cr, Ga, Ta, Te, Se, Bi, Sb, and from the platinum group (Pt, Pd, Rh, Os, Ir).

- **Atomic Absorption Spectroscopy (AAS)** Is used to determine the elements in an analytic sample. To start it is necessary to disaggregate the sample; this is done with the acid and alkaline method.

As well as with the FXR test, it is possible to identify the elements that compose the analyzed material. The tests were applied to the clays, the ashes and the bricks with the purpose of finding differences, establishing changes and some way or another quantify the effectiveness of the stabilization process.

- **Thermal Analysis**

- **Differential Thermal Analysis (DTA)** The continuous study of the difference in temperature between a sample and a reference material, both submitted to a thermal change under controlled work conditions. The heat that is involved during the change of phase is invested in changing the temperature of one of the substances (sample) while the other one (reference substance), stable, remains at room temperature. These differences in temperature are perceived by the thermocouple whose signal is then interpreted by the temperature differential measure device, which allows a double reading of temperature and the variation in temperature during the process in terms of time.

- **Thermal Gravimetric Analysis (TGA)** The continuous study of the variation in mass of a sample submitted to a thermal change under controlled work conditions.

Differential Scan Calorimetry (DSC) Provides a quantitative measure of the changes in enthalpy experienced by a sample in terms of temperature.

These techniques allow having some knowledge regarding the thermal behavior of the materials. The different volatile elements are determined and also the temperatures at which transitions occur or the different changes in state of such materials, allowing to see the possibility that at a given time, a dismembering of the molecules from the tested bricks may occur. Molecules dismembering may affect the physical, mechanical or environmental performance of these bricks.

- **Infra Red Spectroscopy (IRS)** Permits to identify the existing links at the interior of a molecule. This technique is applied in order to get to know the different types of interactions between the elements that compose the material, the relationships between these elements, through which is possible to determine in a qualitative manner how strong can the links inside the molecule get to be.
- **Mercury Intrusion Porosimetry [8]** It is mainly used for the study of macro porosity ($d > 50\text{nm}$), although, depending on the equipment you can reach pore sizes of up to 1,8 nm in radius.
- The N_2 adsorbing techniques and Hg porosimetry are complementary in the study of every range of pores.
- **Thermal Programmed Reduction[8](TPR)** This procedure shows us the possibilities in reduction of the element groupings inside the materials, in order to go, in this case, to the active phase of the process. The Thermal Programmed Reduction technique determines the numbers of reducible species present in a catalyzer and it reveals the temperature at which the reduction occurs.

Table 1 lists the equipment used for the XRD, FXR, DTA, and AAS tests, which were performed in the Chemistry laboratories at Los Andes University.

Table 1. Equipment used for the XRD, FRX, ATD, and AAS tests

ANALYSIS	EQUIPMENT	MODEL	CHARACTERISTICS
XRD	RIGAKU	MINIFLEX	2 – 70° (c/0.02°), 2°/min
FRX	PHILLIPS	PW 1400	Tube XR, anode de Rh, Collimat HR.
DTA	NETZSCH	STA 409 PC LUX	30 – 1100°C, 15°/min
AAS	PERKIN ELMER	AANALYST 300	

The lixiviation tests TCLP were performed at the “Environmental Engineering Research Center” of the Innovation Center and Technology Development - CITEC and the Chemistry Department of Los Andes University, following the standard method EPA SW-846 (1311), TCLP extraction equipment was used according to the specifications in regulation EPA 1311.

The following heavy metals are specifically studied for their importance to human health: Arsenic (As), Barium (Ba), Cadmium (Cd), Chrome (Cr), Mercury (Hg), Silver (Ag), Lead (Pb) and Selenium (Se). The mercury porosimetry analysis and the TPR are performed at the “Surface Science and Pore Mediums Laboratory” of the San Luis Nacional University in Argentina, and the SEM tests are performed at the “Tests and Research Center” of the National University of Colombia.

In order to measure the quality of the clay/ash units of mixture, the following tests were performed:

- **Water Absorption:** It is the capacity that the unit of masonry has of exerting attraction over the water that it is in contact with, and the capacity to allow the water to penetrate it. The measurement was performed according to local regulation NTC 4017 and its international equivalent ASTM C67.
- **Mechanical Resistance to Compression:** It is the stress to which a unit is exposed by the action of opposing forces that tend to reduce or change its vol-

ume. For each type of structural unit, different ways to determine this property are established. The tests are performed according to local regulation NTC 4017.

- **Initial Absorption Rate:** It is the capacity of the dry structural unit for capillary absorption; it is a factor that affects the quality of the link between the brick and the mortar. It is used in brick standards to recommend masonry reinforcements. The tests are performed according to local regulations NTC 4017, NTC 4205 and its international equivalent ASTM C 43-02.
- **Appearance:** When the unit of masonry demands to have a particular color, texture, finishing, uniformity, or boundaries in the grid, or any other imperfection that may decrease the appearance of the unit. The units that have been colored superficially with glazed smalts or any other application during the ceramic process should not present discoloration or changes in tone when submitted to 600°C for a period of 2 hours. The tests are performed according to local regulation NTC 4205 and its international equivalent ASTM C 216.
- **Surface Defect Boundaries:** This test corresponds to the finishing, and it refers to surface defects such as cracks, overflows and distortion of the faces or axis. On top of this, the units must be free of other imperfections such as laminations, blisters, craters and deformations that may interfere with the proper placement on the wall, or may affect their resistance, stability or durability, or that may degrade their view from a distance of 5 m.
- **Efflorescence:** The units must meet the depreciable parameter when tested by the described method in the local regulation NTC 4017 which corresponds to the international standard ASTM C 67.

The properties previously described may have additional requirements and special design and quality characteristics because of acoustic, thermal, fire resistance, architectural or building demands, but they must maintain their water absorption and compression resistance requirements for their primary use (interior, exterior or structural). The architectural finishing units may have shapes, textures and free finishing, but likewise, they must maintain the pertinent requirements for their main application.

RESULTS AND DISCUSSION

The composition of the clay and the ashes used, which come from the co-incineration of the MSW with coal, is presented in Tables 2 and 3. It is determined by the performance of the FXR and AAS tests, which show a possible affinity between the clay and the ashes. It is possible to find a high content of inorganic matter in the ashes that corresponds to oxides from different metals.

The content of silica in the clay is low, the rate silica:alumina is close to 2.4:1, the content of potassium is meaningful, which is why it is possible that it is an illitic clay. The SiO_2 in the ashes (41%) is lower than that in the clay, as well as the level of Al_2O_3 .

Table 2. Chemical Composition of the Clay and Ashes

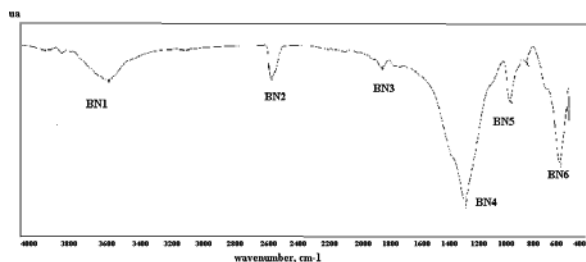
CLAY		ASHES	
Substance	%	Substance	%
SiO ₂	58.5	SiO ₂	41
Al ₂ O ₃	24.7	Al ₂ O ₃	16
CaO	0.5	CaO	12.5
MgO	0.3	MgO	2.5
Fe ₂ O ₃	4.8	Fe ₂ O ₃	8.6
P ₂ O ₅	0.5	P ₂ O ₅	8.4
TiO ₂	0.9	TiO ₂	1.1
K ₂ O	1.5	K ₂ O	0.8
MnO	0.8	MnO	0.7
		N ₂ O ₅	3.5
		CaCO ₃	2.5
		Fe ₂ SiO ₄	0.4
Humidity	7.5	Humidity	2

The ashes have an acceptable heavy metal concentration in terms of governmental regulations [9-13].

Table 3. Heavy Metals found in the ashes. 'Maximum accepted in lixiviation tests.

METAL	CONCENTRATION (mg/L)	
	ASHES	MAXIMUM*
Arsenic (As)	1,120	5
Barium (Ba)	2,260	100
Cadmium (Cd)	0,430	1
Chrome total (Cr)	3,450	5
Copper (Cu)	1,560	-
Mercury (Hg)	0,023	0,2
Magnesium (Mg)	4,720	-
Nickel (Ni)	3,370	-
Lead (Pb)	1,230	5
Silver (Ag)	0,083	5
Selenium (Se)	0,021	1

The infrared analysis presented some identical absorption bands for the different proportions of clay and ash, indicating that there is no formation of new compounds as a result of the reaction between ash and clay. Although there is formation of new structures and the modification with the ashes which generates a loss in the definition of the characteristic bands in the tetrahedral layer as well as the octahedral layer, due to the calcinations of the sample the corresponding bands are softened, some of these calcinations correspond to the deformation of the Si-O-Si link. We can see the alteration of the structure of the starting clay by the disappearance of some of the bands and the widening and displacement of most of these. The IR for the 90:10 samples is shown next, as well as an analysis of the bands which are repeated through out all the IR analysis performed.

**Figure 1. IR performed on the 90:10 clay:ash mixture. % Transmittance vs Wave Number [cm⁻¹].**

Band No. 1. oscillates around 3600, it is wide, of medium intensity, attributed to the O-H stretching, related to the

water absorption caused by the tension vibrations of the hydroxyls associated by hydrogen bridges between the interlaminar water, meaning close to the change cations.

Band No. 2. oscillates around 2600, of variable intensity, characteristic of the Si-H de SiH, SiH₂ vibrations.

Band No. 3. oscillates around 1300, it is weak, characteristic of the water's H-O-H link deformation.

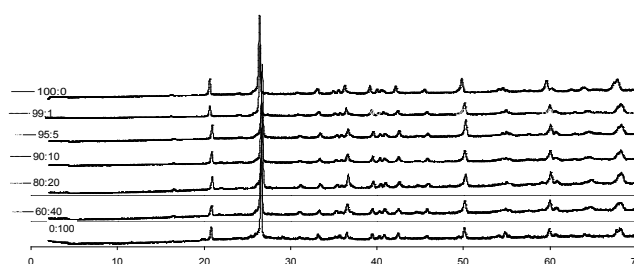
Band No. 4. oscillates around 1084.2, it's strong, it corresponds to the Si-O stretching of the tetrahedral layer. You can distinguish a spike attributed to the vibration of the Al-O link of the octahedral layer. From 1000 cm⁻¹ it's complex because of the blowing of the OH deformation absorption bands of the octahedral and tetrahedral layers.

Band No. 5. oscillates around 900, weak band, harmonic for Si-H of SiH, SiH₂ and SiH₃ vibrations.

Band No. 6. oscillates between 550, Si-O-Si links associated to amorphous silica, it corresponds to octahedral vibrations, in this band and in the one found close to 3720nm⁻¹ it is reflected for the di-octahedral hydroxyls which confirms that we're dealing with a 2:1 trilaminar structure material, probably illitic.

In the X ray diffraction analysis, some of the phases were identified. The movement of the peaks indicates modifications in the diffractogram and therefore in the phases that were found. The peaks were compared and analyzed based on the charts reported by the "Joint committee on powder diffraction Standards" for 1995 and the database from the "International Centre for Diffraction Data" version 2.16 in Newton Square PA 19073 U.S.A. Clear presence of silicates and aluminates, as well as typical minerals like quartz were found. The identified phases in the clay at 1100°C were: mullit and quartz in a higher proportion. In the ashes, at 1100°C also, mullit was identified as the main phase, followed by quartz and a low proportion of cristobalit. The diffractograms of concentration of ash lower than 20% have a similarity with those of pure clay, the diffractograms of the higher ash concentration mixture are closer to those of ash.

According to the literature, at elevated temperatures, quartz is modified into cristobalit and the illit changes into mullit, which is precisely what the performed XRD tests show. The phases of cristobalit and mullit are more stable phases than those of illit and quartz. The fact that modifications in the DRX exist implies a change in the crystalline structure of the clay, during these modifications, it is possible that some of the heavy metals from the ashes may have been introduced into the clay's [Clay-Ash 60:40 @ 800°C] it's Cationic Interchange Capacity (CIC), which although it was not measured, it is known that this clay has a CIC where some of the metals present in the interlaminar layers come out of it allowing the entrance of other cations that are found around the matrix. The spect[Clay-Ash 60:40 @ 1100°C]

**Figure 2. Overlapped Diffractograms for the Clay:Ash Mixtures**

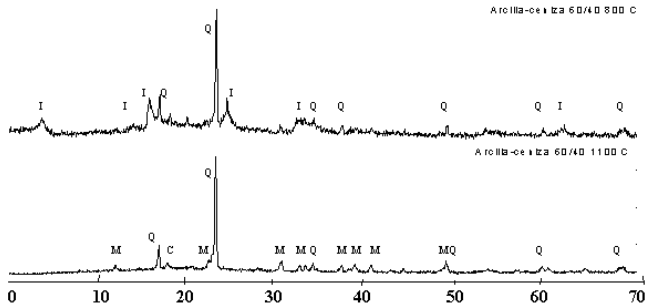


Figure 3. Diffractograms for the 60:40 clay:ash mixture (Illit, Mullit, Quarz)

The previous analyses confirms some of the aspects announced by Sun et al [14-15]. where it was mentioned that the process of stabilization is developed in two stages; the first one consists in an “encapsulation” where the clay forms a physical barrier around the metal preventing its lixiviation. However if the clay matrix breaks, the material may emerge into the environment. The second stage starts with an absorption process and ends with the incorporation of the metal into the ceramic matrix. The result is the formation of a chemical link with the clay becoming part of the matrix and eliminating the metal’s possibility of lixiviation. The first stage occurs at low temperatures, and it is due to an ionic interchange where the metals are attracted towards the crystalline structure’s surface layers of the negatively charged clay, this is known as external adsorption.

As clay is mostly illit, it is possible that not only external adsorption may present but also internal adsorption since you can find interlaminal cations in its structure that may be replaced by the surrounding heavy metals. At temperatures close to 1100°C we can see that the illit present in the clay begins to turn into mullit. This way, the metals that had been initially absorbed by the illit are incorporated into the new mullita matrix.

Figures 4 and 5 show some of the microphotographs (SEM) where quartz may be identified as a series of big-sized grains, as well as another phase which corresponds to the clay’s mineral.

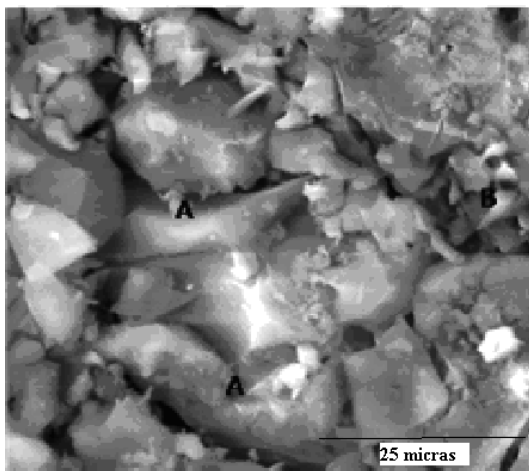


Figure 4. SEM 1. Sample 100:0, where A=quartz y B=mullit

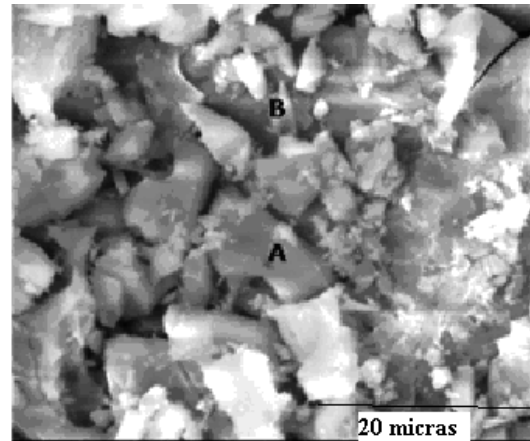


Figure 5. SEM2. Sample 95:05, where A=quartz y B=mullit

As the ash concentration increases in the final mixtures, structural changes and grain size distribution difference can be observed in the SEM images (figure 4 and 5). The amount of larger grains decreases as the presence of smaller grains becomes evident at higher ash proportions. At higher clay quantity (> 70%), the size distribution difference is not very meaningful, but becomes evident when comparing SEM with higher ash mixtures.

The previous paragraph leads to believe that there doesn’t exist a good distribution of the ashes in the clay for higher concentrations of ash. The XRD for every sample are very similar, except for 60% and 0% clay, in these a higher quantity of metals can be identified in the analyzed section. At this point, a relatively high quantity of potassium is found, confirming the clay’s illitic character.

Through the thermal analyses performed, a good thermal stability of the materials was observed. The change in the quantity of mass during the time of heating is very low, lower than 1%, this small variation is presented at the beginning of the analysis, it is mainly attributed to the liberation of remaining water in the material, then the quantity of matter remains practically constant during the rest of the trial, showing a great stability with temperature. Having good stability with temperature is a much appreciated characteristic for this type of material given it is intended to be in contact with high temperatures and it is not desired for the material to generate any type of substances, weaken or deform.

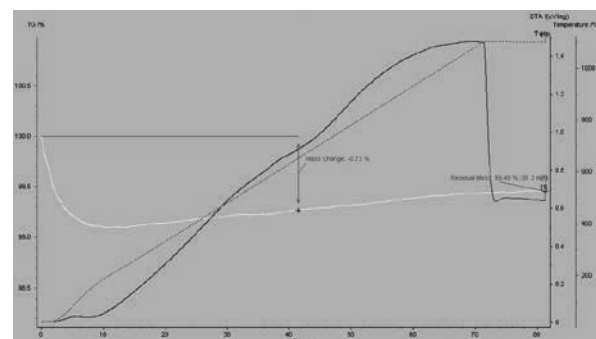


Figure 6. Thermograms obtained in the thermal analysis of a 95:5 mixture.

In the TDA in figure 6, show the mass behavior at different temperatures, of which at 110°C approximately, a sign that corresponds to the loss of water inside the material was found. About 500°C and 700°C a slight curvature, that

does not imply any modification in the amount of matter. It is found that this curvature may possibly imply some small modification or transition between the phases of the material, as metals exchange occurring at the interior of the matrix. Close to 900°C an endothermic signal is noted, where it is considered that the material suffers a transition from one phase to another one of higher stability, it possibly corresponds to the change from the illitic phase to the mullitic one, however not all the clay is transformed. According to figure 7, the incorporation of ashes affects the formation of pores. The clay presents a pore size close to 2µm and a low quantity of pores with respect to the other samples. Incorporating 10% of ash increased the amount of pores, lowering the medium diameter to 1.5µm. When increasing the quantity of ash, the medium diameter and the total porosity increase.

The material has pores of great size (macro pores), between 0,1 - 8 µm. When having pores of elevated size, different substances can penetrate the interior of the solid matrix, stay inside and remain there until it is attacked by dragging substances that may act as intra particle and lixiviated washers, the dragging is presented unless they are strongly attached or part of the solid matrix. In the lixiviation trials it was found that the substances employed did not displace great amounts of metals, the percentage of lixiviated heavy metals was low. It can be said that it is likely that the stabilization inside the clay's matrix was presented in a very strong hold manner, indicating that not only physical stabilization indeed took place but also a chemical and a structural.

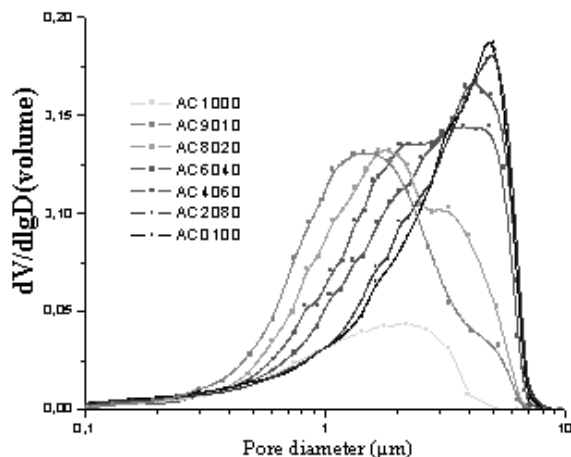


Figure 7. Mercury Porosimetry of the bricks.

The ashes contain a series of metals, which, in general, after thermal treatment are transformed into oxides; A study with the thermal programmed reduction may provide information about the interaction of these oxides with the clay's matrix. The TPR profiles are shown in Figure 8. In every case the reduction temperature is high, higher than 500°C, indicating a strong reaction with the support, this concurs with what was found in terms of the incorporation of metals to the structure. The clay presents a higher resistance to the reduction with a temperature of 800°C. As the content of ash increases, the medium temperature of hydrogen consumption decreases, implying that at a higher quantity of ash a higher quantity of metallic oxides is exposed at the reduction. The latter concurs with the porosity study, where the ash's components are respon-

sible for the porosity, probably forming the pore's walls, and remaining exposed to the action of the hydrogen.

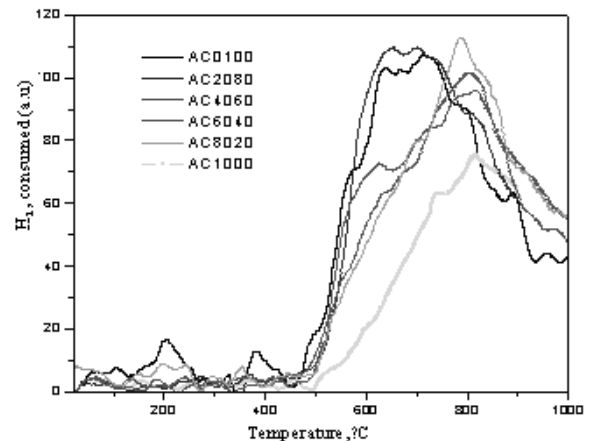


Figure 8 TPR results for the bricks obtained with different mixtures

The standard characterization tests for masonry bricks indicate that the quality of the bricks is within local standards. The absorption, at cold temperatures, increases as the content of ashes increases as well, due to the increase in porosity. The load/rupture and the resistance behave the same way when changing the quantity of ash. For quantities of ash of 5 and 10% absorption increases, but it decreases significantly with higher quantities of ash, this can be explained since the pores at 5 and 10% are smaller in size than in other samples. Furthermore, with high quantities of ash, pores are not completely integrated to the matrix being left dispersed through out the brick, generating points of lower resistance. The absorption of water increases with the increase of the concentration of ash in the blocks; this is not favorable because it reduces stability overtime given the use for these bricks. With 40% of ash content the local regulation is not met, the maximum permitted is exceeded; this fact is also attributed to the increase in the material's porosity as the proportion of ash in the mixture increases.

Table 4 Compression and absorption trial for blocks manufactured with a clay/ash mixture.

Sample No.	Test Date	Sample Identification	Absorption in Cold	Load rupture	Resistance		
					%	(Kg.)	Kg./cm ²
1	04-Nov	AC 100-0	12,44	14300	39,95	568,69	3,92
2	04-Nov	AC 99-1	12,74	14180	39,63	564,22	3,89
3	04-Nov	AC95-5	13,06	16260	45,43	646,79	4,45
4	04-Nov	AL 90-10	13,22	16480	46,07	655,84	4,52
5	04-Nov	AL 80-20	13,50	12160	33,93	483,05	3,33
6	04-Nov	AL 60-40	14,88	10780	30,16	429,39	2,96
Regulation Limit Value			14		14	26	3,00

According to the findings resulting from this analysis, the samples that present higher advantages with respect to the specific tests for bricks, are concentrations with less than 10% ash, where the resistance and load/rupture properties are maximized although the absorption in a cold environment is relatively high with respect to the minimum

concentrations, it is important to highlight that the local regulation is met; hence 90:10 mixtures could be used with increased the ashes consumption at maximum the bricks properties.

CONCLUSIONS

The results obtained in the metals lixiviation tests accomplish the registered values for Potable Water Regulation, Basic Surety (RAS 98) and EPA. Metals concentration reductions are observed in the lixiviates of the calcined clays and ashes mixtures, between a 70 and a 99% in relation to the concentration measured in the lixiviation tests done before been calcination.

The quality verification tests show that the bricks with low ashes content support higher loads and have higher resistance than those bricks made of pure clay. This happens for ashes concentrations near the 10% were the properties are maximum. When the ashes content is increase to 20 or 40% the properties decrease respect with the ones without or lower ashes content . The decline of the properties is very significant, for example in terms of resistance, in the unit with 20% this decreases up to a 15% and in the ones with 40% this decreases up to a 24%. All of this agree with the porosity, at higher quantity of pores, lower the resistance is and higher the adsorption of water. In the 90:10 proportion the quantity of pores reduces but their size lightly increases, whereas in the other proportions the number of pores increases as well as their size.

Based in the stability and the quality tests and comparing the results with the current local regulation, is possible to have clay and ashes calcined units, the optimum proportion is 90% of clay with 10% of ashes.

REFERENCES

1. García-Ubaque C., Fajardo R. and Moreno-Pirajan J. *Modification and Use of Hoffman Brick in the Incineration of Urban Solid Wastes and Evaluation of their Polluting Emissions*. Instrumentation Science & Technology. Vol 32, Nov 2004, pp. 669 – 680.
2. García-Ubaque C., Sanchez F. and Moreno-Pirajan J. *Simulation and Flow Analysis for a Brick Furnance*. Electronic Journal of Environmental Agricultural and Food Chemistry. Vol 5, May 2006, pp. 1500 – 1508
3. García-Ubaque C., Moreno-Pirajan J., Giraldo L. and Sapag K. *Stabilization & Solidification of Ashes in Clays used in the manufacturing of Ceramic Bricks* . Waste Management & Research. Vol 25, Mar 2007, pp. 1 – 11.
3. Xu L., Guo W., Wang T., Yang N. *Study on fired bricks wit replacing clay by fly ash in high volume ratio*. Construction and Building Materials, Vol 19, Jul 2004, pp 243 – 247.
4. La Grega, Michael D., Buckingham, Phillip L., Evans, Jeffrey C., 1994. *Hazardous Waste Management*, Ed Mc Graw Hill Inc.
5. Dyer, J. R. *Applications of Absorption Spectroscopy of Organic Compounds*. Prentice Hall. Englewood Cliffs. New York. 1965
6. Charles H. K. Lam, Alvin W. M. Ip, John Patrick Barford and Gordon McKay, *Use of Incineration MSW Ash: A Review*, *Sustainability* 2010, 2, 1943-1968.
6. Banar, M.; Zkan, A. Characterization of the municipal solid waste in Eskisehir City, Turkey. *Environ. Eng. Sci.* **2008**, *25*, 1213-1219.
7. Moy, P.; Krishnan, N.; Ulloa, P.; Cohen, S.; Brandt-Rauf, P.W. Options for management of municipal solid waste in New York City: A preliminary comparison of health risks and policy implications. *J. Environ. Manag.* **2008**, *87*, 73-79.
8. Johannessen, K.M. The regulation of municipal waste incineration ash: A legal review and update. *J. Hazard. Mater.* **1996**, *47*, 383-393.
9. Ecke, H.; Sakanakura, H.; Matsuto, T.; Tanaka, N.; Lagerkvist, A. State-of-the-art treatment processes for municipal solid waste incineration residues in Japan. *Waste Manag. Res.* **2000**, *18*, 41-51.
10. Sakai, S.I. Municipal solid waste management in Japan. *Waste Manag.* **1996**, *16*, 395-405.
11. Jung, C.H.; Matsuto, T.; Tanaka, N.; Okada, T. Metal distribution in incineration residues of municipal solid waste (MSW) in Japan. *Waste Manag.* **2004**, *24*, 381-391.
12. Okada, T.; Tojo, Y; Tanaka, N.; Matsuto, T. Recovery of zinc and lead from fly ash from ash-melting and gasification-melting processes of MSW—Comparison and applicability of chemical leaching methods. *Waste Manag.* **2007**, *27*, 69-80.
13. Li, M.; Xiang, J.; Hu, S.; Sun, L.S.; Su, S.; Li, P.S.; Sun, X.X. Characterization of solid residues from municipal solid waste incinerator. *Fuel* **2004**, *83*, 1397-1405.
14. Sawell, S.E.; Chandler, A.J.; Eighthy, T.T.; Hartln, J.; Hjelmar, O.; Kossou, D.; Van Der Sloot, H.A.; Vehlow, J. An international perspective on the characterisation and management of residues from MSW incinerators. *Biomass Bioenerg.* 1995, *9*, 377-386.
15. Vieira, C.M.F.; Monteiro, S.N., Incorporation of solid wastes in red ceramics – an updated review, *Revista Matéria*, v. 14, n. 3, pp. 881 – 905, 2009.