Contemporary Engineering Sciences, Vol. 11, 2018, no. 92, 4581 - 4591
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2018.89501

Porous Covering Compound

of Clay Matrix and Coal Ashes

Gabriel Peña-Rodríguez[1,*], C.X. Díaz Fuentes[2] and J. Lemus T.[2]

[1] GIFIMAC Research Group, Francisco de Paula Santander University (UFPS)
Av. Gran Col. 12E-96, Colombia
[*]Corresponding author

[2] GRAMA Research Group, Francisco de Paula Santander University (UFPS)
Av. Gran Col. 12E-96, Colombia

Abstract

Here are presented the elaboration and characterization of a composite material with an atomized ceramic paste and flying ashes product of the coal combustion. The samples consist of prismatic tiles of 10x5x1 cm, formed by uniaxial pressing at 30 bars, made for mixes with a percentage weight of 90-10, 80-20, 70-30, 60-40 and 50-50, where the majority phase corresponds to the atomized ceramic paste. The drying process was conducted at room temperature for 12 hours and then in drying oven at 110 ° C for 24 hours. The sintering was carried out in gradient electric muffle at a maximum temperature of 1150 °C. According to the porous morphology and mechanical properties found for samples, this can be used as ceramic coatings with thermal isolation qualities for edifications in tropical weather like the metropolitan area of Cucuta, North Santander (Colombia)

Keywords: Envelop ceramic, compose material, atomized ceramic paste, flying ashes

1. Introduction

Since a global scale of the cities is growing up with an accelerated rhythm, whereby the demand for the material consume for the construction is growing too, allowing that sector to be one with the biggest industrial development [1]. By the other hand, the densification of the urban centres is letting an ecologic print that will take generation to recover, where the natural resources will turn scarcer and more expensive, so that the architecture, the science and the material engineering will have to face against new dares in innovation tasks.

Cúcuta is the capital city of North Santander, which one is located at the north east area of the Andean region in the Republic of Colombia, over the oriental mountain range between the geographic coordinates 06°56’42” and 09°18’01” north latitude; 72°01’13” and 73°38’25” west longitude. It’s bounded at north and east with the Bolivian Republic of Venezuela, at south with the Boyacá and Santander provinces, and at the west with Santander and Cesar Provinces. The territorial extension is about 22.367 km^2, counts with 40 municipalities representing the 1.9% of the national territory. The population is 1’355.723 habitants (According to population projection 2006-2020 of DANE). In North Santander is a climate variety conditioned for the topographic reliefs, which goes from warm weathers (50 m above the sea) to temperate climates (3.600 m above the sea). The Cucuta city is located on the north latitude 7°54’ and the west longitude 72°30’, with an average altitude of 320 m above the sea. Has a warm weather sub-humid isothermal, with irregular rain seasons, the average temperature is 26.9°C reaching the minimum average temperature of 22.5°C and a maximum average of 31.8°C, with relative humidifies of 68% and precipitations of 816,4 mm according to IDEAM.

The reflections on which this work is based are: The need to diversify the offer of local products and their use in building, recognizing the area of North Santander in Colombia as the first producer and exporter of red ceramics without enamel at national level, mainly tile and brick [2, 3]. The growing synergy between the academy, the companies and the government through agreements has allowed enlarge the discussion about the needs of new products for the building, able to offer more efficient constructive solutions and at the vanguard of the business needs [4]. In this way and according to what is stated in the PECDTI Departmental Strategic Plan for Science, Technology and Innovation 2014-2024, the ceramic industry of North Santander, is projected to the next 10 years, as an industrial sector highly equipped in technology, with qualified human resource and national and international recognition, in the matter of project initiatives and products that will position it as reference cluster for the ceramic industry of the Colombian industrial area [5]. Those discussions have strengthened the actives research lines inside the research group in matter of architecture and alternative materials linked to the architecture program, urbanism and Ceramic Materials Investigation Center CIMAC as a propelling institution of investigation and development, both belonging to Francisco de Paula Santander University at in Cucuta, Colombia.

On this way, it was relevant to study the attributes conferred on the design of ceramic pieces for the façade that offer facilities of installation, reparability, low weight, among other qualities, that allow to obtain a remarkable decrease of costs for transport, maintenance and artificial climatization, configuring systems highly attractive for short-term moments in the building sector and thus in the economy of the region, getting closer to the promulgated guidelines by the national ministry of Colombian housing through national politics of sustainable construction and the action plan about projects of innovation and actualization of technology, fabrication process of building material and constructive systems. Therefore, it's presented the results of the first phase of this project, which ones correspond to the development and characterization of wraparound ceramics made using atomized ceramic paste and flying ashes of the coal combustion, raw materials of the North Santander area, whose were supplied by Ceramica Italia S.A. and Termotasajero S.A companies, respectively. Later the possibilities about the use of the material developed in the first phase will be evaluated, starting with bioclimatic criteria for the intention of a constructive solution with special attributes in the tropical weather use [6], that can represent a challenge for the local enterprises once industrially validated.

2. Materials and methods

Because of the composition and pozzolanic properties, the flying ashes of the coal combustion have been used in the cement industry and can be incorporated in the elaboration of ceramic materials [7-9]. In the table 1, it´s presented the mixtures used for the prismatic tiles elaboration of 10x5x1 cm (Figure 1 a, b), using the process of conforming by uniaxial pressing at 30 bars, with humidity between 6 and 7% through a hydraulic trademark Gabrielli®. This forming process was chosen, because there are not studios in the region where products are made based on clay and coal flying ashes in this method, there are regional studios where the method of conformed by extrusion was used [10,11]. The ceramic paste powders, as the flying ashes ones, wasn´t submitted to a pre-grinding process, because their size of particles was inside the marge used in work processes at regional level. The amount of material used for every test was 100.0 grams.

Table 1. Mixtures used on the elaboration of the ceramic tiles

Mixtures	Weight-percentage relation
M1	100% Ceramic paste
M2	90% ceramic paste - 10% Flying coal ashes
M3	80% ceramic paste - 20% Flying coal ashes
M4	70% ceramic paste - 30% Flying coal ashes
M5	60% ceramic paste - 40% Flying coal ashes
M6	100% Flying coal ashes

The drying process was made first at room temperature for 12 hours, later in circulation drying oven trademark Gabrielli®, at 110 ± 5°C, for 24 hours. On the other hand, the sintering of the samples was made using a gradient electric muffle trademark Gabrielli®, with a firing curve (figure 2) at maximum temperature of 1150°C.

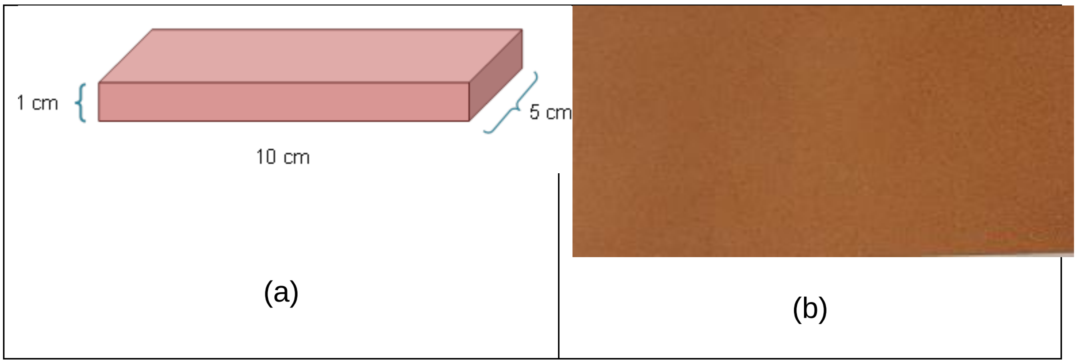


Figure 1. (a) Dimensions of the prismatic samples, (b) Digital picture of the prismatic specimen.

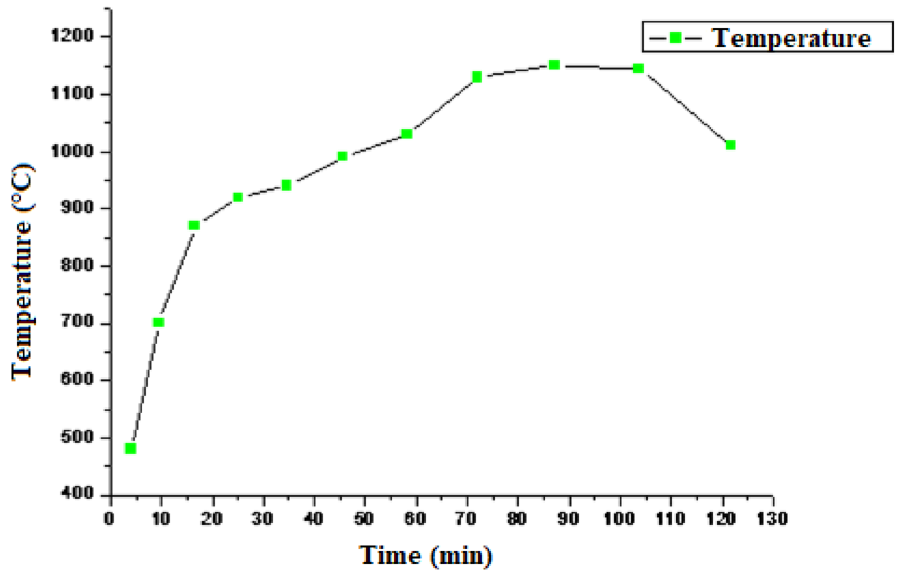


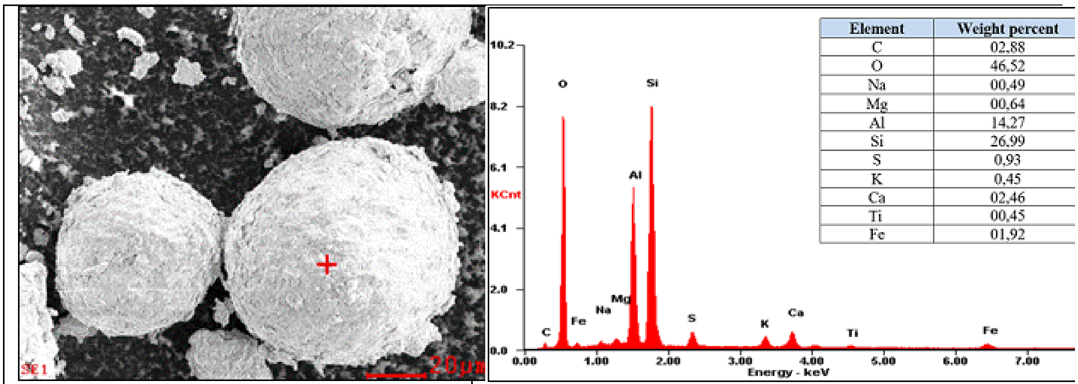
Figure 2. Firing curve for thermal treatment of the samples

The water absorption percentage and the mechanic resistance to the flexion was made according to the standard ISO 10545-3 and 10545-4 respectively. Those parameters are useful for the ceramic industry for two purposes, the first one is to infer about the degree of material vitrification (the lower the absorption, bigger the vitrification degree), and the second one to classify the material according to the international standard to determinate the possible application field [12,13]. The morphology of the raw materials and the samples was studied by scanning electronic microscopy (SEM) and microanalysis (EDS), through the SEM FEI Quanta FEG 650.

3. Results and Discussion

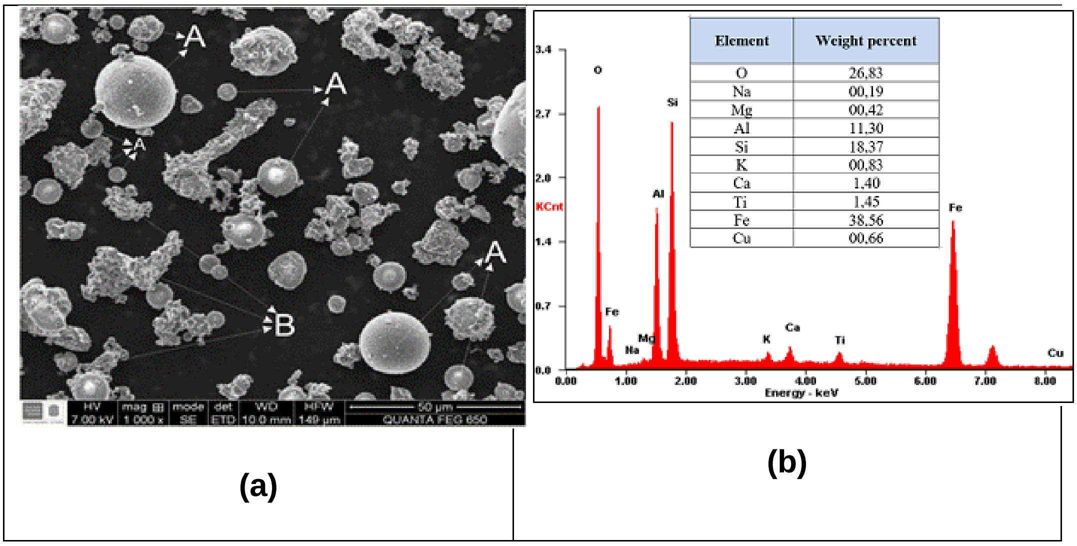
In the figures 3 and 4 are presented the morphology and microanalysis of the atomized ceramic paste powders (ACP) and of the flying ashes particles (FA) respectively. From this is inferred that the morphology of the ACP, is partially spherical, whit a major concentration of silica, followed by aluminum, reporting a relation Si/Al=1,9. The micrograph of FA powders, allow us to observe the FA spherical particles and some agglomerated little unburned coal particles. Also, from the microanalysis is appreciated a relation of Si/Al=1,6. Comparing the found values for the Fe, is appreciated that the FA have a high concentration of this chemical element, which is because of the hematite concentration present on the FA [14]. From the values of the Si/Al relations, both for the powders of FA and ACP, it can be affirmed that those raw materials can be integrated on the sintering process.

An image of the sintering samples is shown in the figure 5, there is appreciated how as the concentration of FA powders increases, the samples color changes, going from scarlet red to orange, it is also observed that the corresponding sample to 100% of FA (M6), present a small fracture on the top right corner, what is due to the fragility because of the low mechanic resistance.



(a) (b)

Picture 3. (a) Morphology and (b) Chemical composition (microanalysis) for the atomized ceramic paste powders using SEM and energy dispersed spectroscopy (EDS).



Element	Weight percent
O	26,83
Na	00,19
Mg	00,42
Al	11,30
Si	18,37
K	00,83
Ca	1,40
Ti	1,45
Fe	38,56
Cu	00,66

Figure 4. (a) Morphology and (b) chemical composition (microanalysis) for the flying ashes powders using SEM and energy dispersed spectroscopy (EDS). (A) spherical shape of the flying ashes particles, (B) Coal particles (unburned).

Figure 5. Digital image of the samples.

The density values, the water absorption percentage, as the mechanic resistance to flexion are reported on the table 2. This shows how the samples density decrease as the FA concentration increase, coherent behavior according to the values found for the water absorption percentage (porosity) which increase, this result is reaffirmed for the flexion mechanic resistance values, being lower as more FA concentration on the sample. Is evident, that the FA addition doesn't favor the vitrification process, evidencing on the decrease of mechanic resistance, and on the porosity increase. The explanation to this trend can be occasioned for some factors, the first one has to be with the more quartz and mullite addition, which are presented on the FA [15-17], and whose thermic stability result very high to reach a complete sintering at 1150°C of temperature. The second aspect is the possible porosity formation [18], occasioned due to the gases detachment product of the coal waste combustion (unburned) presented on the FA.

Table 2. Density, water absorption and samples flexion resistance

Samples	Density(g/cm^3)	Water Absorption (%)	Mechanic resistance (N/mm^2)
M1	2.17 ± 0.02	7.2 ± 1.0	27.3 ± 4,0
M2	2.05 ± 0.02	10.1 ± 0.8	17.6 ± 1.9
M3	2.05 ± 0.01	10.6 ± 1.7	16.6 ± 3.3
M4	1.67 ± 0.02	19.7 ± 2.7	3.7 ± 1.4
M5	1.45 ± 0.02	24.8 ± 1.8	2.5 ± 0.8
M6	1.13 ± 0.01	45.7 ± 1.4	1.3 ± 0.6

Source: CIMAC-UFPS.

When comparing mechanic flexion resistance of the samples, with the reported in literature, it's found that M2 and M3 meet the requirements for the wall ceramic tiles [19, 20], and are higher values than those reported for A. P. Carvalho et.al. [21] for Portuguese tiles who found a mechanic resistance of 9,7 N/mm2. On the other hand, it is observed that the samples M2 and M3 report a mechanic resistance of 64,5% and 60,8% regarding the sample without FA (M1). Of the above, it is concluded that according to the sintering temperature and pressure used, the samples conformed with 10% (M2) and 20% (M3) of FA can be used as wall ceramic tiles or porous ceramic covering with bioclimatic benefits, in places without presence of climatic seasons (winter), as is the case of Cúcuta, meanwhile the samples M4 and M5 due to their porosity and mechanic resistance, can be used in other technologic applications, like the addition of amendments on soils bioremediation.

4. Conclusions

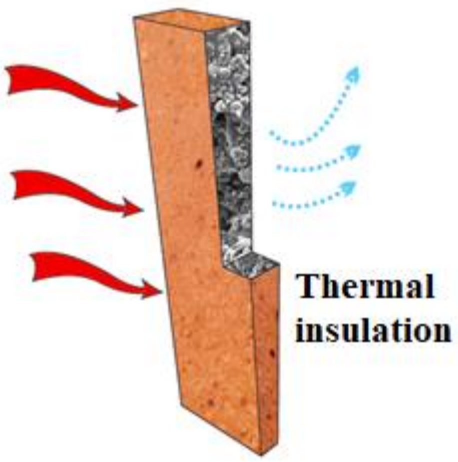


Figure 6. Section of the porous ceramic piece. Evaporative cooling.

According to the results, it is found that the mixtures with a FA weight percentage of 10% and 20%, meet the requirements of the industrial sector to be used as wall ceramic tiles, which allow us the possible application as porous ceramic covering with thermal isolation attributes (figure 6), as the porosity favors the energy efficiency conditions where is used the water evaporation as semi-passive system taking advantage of evaporative cooling potential for air humidification, when passing through the material permanently wet to create comfort inside the habitat coated with this material, assuming that the enthalpy is constant because the water needs latent heat to evaporate, which is obtained from the air descending [22].

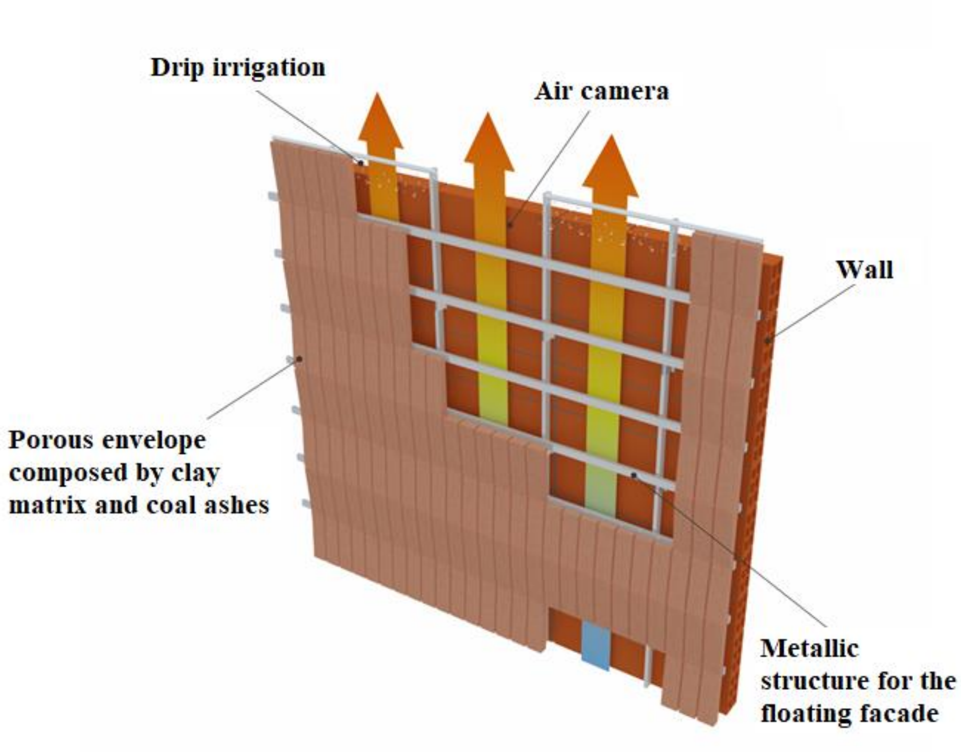


Figure 7. Porous ceramic covering. Constructive solution east to west.

Because of the increased porosity when increasing the FA concentration in the samples, it´s allowed to infer that the use of this kind of materials is not recommended on environments with presence of climatic seasons, specially because of the frozen water expansion on winter time, property known as low resistance to the frost cycles, nevertheless it should be noted that we have focused on the possibilities of the use of this material in tropical weather, finding this humidity absorption quality as an favorable aspect through the earthenware effect, able to cool the air as a consequence of the water evaporation [23]. Starting of this quality it is posed as a possible application the configuration of semi-passive systems of cooling (indirect evaporative) from incorporating humidity in the air through the ceramic ventilated facade generating a cloak of fresh air between the covering and the wall, which is configured as a constructive solution needs the installation of an irrigation system in the facades with more solar radiation according to the orientation as is shown in the figure 7.

References

[1] Carlos Alberto Torres Tovar, Calidad de vida: realidad y percepción, *Revista Bitácora Urbano Territorial*, **17** (2010), no. 2, 7-12.

[2] J. Sánchez, *Diagnóstico De La Situación De Los Artesanos De La Arcilla Del Área Metropolitana De Cúcut*a, Grupo GITEC. Universidad Francisco de Paula Santander, Cúcuta, 2004.

[3] J. Sánchez, *Conformación E Implementación Del Clúster De La Cerámica De Norte De Santander*, Grupo de investigación en tecnología cerámica, Universidad Francisco de Paula Santander, 2008.

[4] *OCyT. Indicadores* de Ciencia y Tecnología. Observatorio Colombiano de Ciencia y Tecnología, 2012.

[5] PEDCTI, 2014-2024. Plan estratégico departamental de ciencia, tecnología e innovación. Gobernación de Norte de Santander, Colciencias. 5.6. Plan de acción clúster industria cerámica en Norte de Santander, 1468.

[6] R. Velasco, D. Torres, Diseño de eco-envolventes - Modelo para la exploración, el diseño y la evaluación de envolventes arquitectónicas para climas tropicales, *Revista de Arquitectura*, **13** (2011), 92-105.

[7] M. Dhaval, Bhavsar J. Vaviya, P. Jayesh, Bricks with total replacement of clay by fly ash mixed with different materials, *National Conference on Recent Trends in Engineering & Technology*. India, (2011).

[8] M. Ahmaruzzaman, A review on the utilization of fly ash. *Progress in Energy and Combustion Science*, **36** (2010), 327-363.
https://doi.org/10.1016/j.pecs.2009.11.003

[9] A. Zimmer and C.P. Bergmann, Fly ash of mineral coal as ceramic tiles raw material, *Rev. Waste Management*, **27** (2007), no. 1, 59-68.
https://doi.org/10.1016/j.wasman.2006.01.009

[10] L. Balaguera and J. Carvajal, *Estudio Para Producir Bloque Aligerado A Partir De Mezclas De Arcilla, Cenizas Volantes Y Poliestireno Expandido En La Empresa Cerámicas Támesis*, S.A., PhD Tesis, Cúcuta, Colombia: Universidad Francisco de Paula Santander, 2004.

[11] S. Mora and R. Monroy, *Estudio Para Producir Bloque Termoarcilla A Partir De Arcilla*, Poliestireno y cenizas. PhD Tesis, Cúcuta, Colombia: Universidad Francisco de Paula Santander, 2005.

[12] ASCER. Retrieved 28 de Noviembre de 2013 from Asociación Española de Fabricantes de Azulejos y Pavimentos Cerámicos. Cerámica para la arquitectura - fundamentos. España, (2013).
http://www.ascer.es/verFotoHD.ashx?id=36

[13] J. Navarro. Retrieved 28 de Noviembre de 2013 from Requisitos técnicos de baldosas cerámicas para usos concretos. Qualicer 94. Castellón,España, (1994).
http://www.qualicer.org/recopilatorio/ponencias/pdf/9411060s.pdf

[14] J. N. Akhtar, J. Alam and M.N. Akhtar, Bricks With Total Replacement Of Clay By Fly Ash Mixed With Different Materials, *International Journal of Engineering Science and Technology,* **3** (2011), no.10, 7338-7346.

[15] L. Santaella, Caracterización física química y mineralógica de las cenizas volantes, *Ciencia e Ingeniería Neogranadina*, **10** (2001), 47-62.
https://doi.org/10.18359/rcin.1379

[16] M. Villar, L. Gago and R. García Comportamiento de mullitas a alta temperatura: Estudio mediante difracción de rayos x, *Boletín de la Sociedad Española de Cerámica y Vidrio*, **43** (2004), no. 2, 35-137.
https://doi.org/10.3989/cyv.2004.v43.i2.485

[17] J. Anggono, Mullite Ceramics: Its Properties, Structure, and Synthesis, *Jurnal Teknik Mesin*, **7** (2005), no. 1, 1-10.

[18] Jamasri Subarmono, M.W. Wildan and Kusnanto, *Effect of porosity on mechanical properties of aluminum fly Ash composite.* Palembang: Seminar Nasional Tahunan Teknik Mesin (SNTTM) ke-9, 2010.

[19]http://www.ceramicaitalia.com/inf/images/stories/WebPageFiles/FichaTecnicaRV.pdf consulted July 12, 2018

[20] https://alfa.com.co/consulted July 12, 2018.

[21] A. P. Crvalho, M. F. Vaz, M. J. Samora, J. Pires, Characterization of ceramic pastes of Portuguese ancient tiles, *Materials Science Forum*, **514-516** (2006), 1648-1652. https://doi.org/10.4028/www.scientific.net/msf.514-516.1648

[22] L. Carlos Herrera, Estrategias de bioclimatización: reducción del consumo de agua en equipos de enfriamiento evaporativo, Infonavit, Redalyc, 46-48.

[23] F.J. Terrados-Cepeda, L. Baco-Castro, D. Moreno-Rangel, Patio 2.12: Vivienda prefabricada, sostenible, autosuficiente y energéticamente eficiente. Participación en la competición Solar Decathlon Europe 2012, *Informes de la Construcción*, **67** (2015), no. 538, eo88. https://doi.org/10.3989/ic.13.138

Received: October 2, 2018; Published: November 5, 2018