CORN COB LIGHTWEIGHT CONCRETE FOR NON-STRUCTURAL APPLICATIONS

Jorge Pinto[a,1], Barbosa Vieira[a], Hélder Pereira[a], Carlos Jacinto[a], Paulo Vilela[a], Anabela Paiva[a,2], Sandra Pereira[a,2], Vítor M.C.F. Cunha[a,3], Humberto Varum[b]

[a] Engineering Department, School of Science and Technology, University of Trás-os-Montes e Alto Douro, Vila Real, Portugal

[b] Civil Engineering Department, University of Aveiro, Aveiro, Portugal

[1] Associate Laboratory I3N, Aveiro, Portugal

[2] C-MADE, University of Beira Interior, Portugal

[3] ISISE, Institute for Sustainability and Innovation in Structural Engineering, University of Minho, Portugal

KEYWORDS

Corn cob, lightweight concrete, thermal insulation, agricultural waste, sustainability

ABSTRACT

A light weight concrete using granulated of corn cob (without corn) as aggregate is proposed in this research work. Taking into account that corn cob, after extracting the corn, is generally considered an agricultural waste, an interesting economic and sustainable benefit may result by using it as a building material. Therefore, it can be an alternative sustainable lightweight aggregate solution in comparison to the most current applied ones such as expanded clay, particles of cork, particles of expanded polystyrene (EPS), among other. The density, the compressive strength and the thermal insulation properties of a corn cob concrete were experimentally quantified. An expanded clay concrete was also studied as reference. The obtained main results are presented and discussed indicating that the proposed corn cob concrete may have the adequate material properties required for a lightweight concrete for non-structural application purposes.

1. INTRODUCTION

The continuous search for more sustainable and economic processed solutions has been an important investigation topic of a broad research community worldwide. The resulting solutions can therefore be adapted by the industry thus leading to a more sustainable society. The building industry is not immune to this reality and huge efforts have been done in order to find alternative sustainable building materials and low technology methods, which result in a more sustainable and affordable construction complemented with the comfort standards required nowadays. The CO2 emissions to the atmosphere, energy and water consumptions are some parameters that have significant impact in this equation. Reusing, opting for green building materials (which must be renewable, local, and abundant), retrofitting, choosing low technology methods and techniques are some practices that have given good results in this context [1-3].

The main scope of this research work consists on analyzing the potential use of corn cob granulate (without containing any corn, i.e. an agricultural waste) as a sustainable aggregate solution of lightweight concrete and as an alternative of common applied products such as: expanded clay, particles of expanded polystyrene (EPS), particles of cork or other lignocellulose wastes [4]. Since corn cob is generally considered an agricultural waste, an interesting economic and sustainable benefit may be achieved through this proposed technological solution. Within the authors' knowledge the utilization of corn cob in concrete is quite novel, and is only known the use of corn cob ash in blended cement concretes [5-7].

Recently, different research works have been done focused on applying biological materials or different types of wastes within distinct building applications. Several authors [8-13] have already proposed using different agricultural product wastes such as bagasse, cereal, straw, corn stalk, corn cob, cotton stalks, kenaf, rice husks, rice, straw, sunflower hulls and stalks, banana stalks, coconut coir, bamboo, durian peel, oil palm leaves among others for product processing such as particleboard, hardboard and fiber board, and focusing on their thermal insulation ability. Others authors have been studying the technical potential of using others types of residue such as newspaper [14], honeycomb [15] or polymeric wastes [16] in the processing of different building components.

The lightweight corn cob concrete, presented in the present paper, was designed mainly for using it on regularization layers of pavements. Some of the expected requirements of a regularization layer building solution are: lightweight, insulation capacity (thermal and/or acoustic), and durability and economic are. Therefore, the density, the compressive strength and the thermal insulation performance were the material properties assessed of the proposed corn cob concrete within this research work. In order to evaluate and compare the performance of corn cob concrete, in parallel, was developed and tested a conventional lightweight concrete using expanded clay.

This paper is structured as follows, firstly, some possible lightweight concrete applications are presented and also some common lightweight aggregates are identified. Secondly, the compressive strength of corn cob and expanded clay concrete samples are assessed. The sample preparation and used equipment are described, and the obtained experimental results are presented and discussed. Thirdly, an alternative expedite experimental setup for thermal insulation performance assessment of light weight concrete samples is proposed. The inherent facility, the sample preparation, the used equipment and the test preparation are presented and described in detail. The obtained experimental results are presented, analyzed and discussed, whereas the thermal transmission coefficient of the two light weight concrete samples are quantified. Finally, the main conclusions of this research work are drawn.

2. CONTEXT

In order to guaranty the architectural design performance of a pavement, it is often used a regularization layer (detail 3 in Figure 1) as a technological building solution. In most of the cases, a cement mortar or a light weight concrete are the materials used in this regularization layer. This situation may occur on the pavements located on the ground floor (Figure 1.a), intermediate floors (Figure 1.b) or at the top floor (i.e. terraces), Figure 1.c. Associated to the regularization layer another layer of a thermal or / and acoustic insulation material is also commonly applied (see detail 4 in Figure 1). In the Portuguese context, thicknesses between 3 cm and 10 cm of the regularization layer are the most common solutions. This thickness depends on the location of the pavement, the type of the expected building floor utilization, among other factors. Lightweight, insulation capacity, durability and economic are some of the expected requirements for this constructive system (i.e. regularization and insulation layers).

Alternative solutions of the abovementioned constructive systems have been proposed and successfully applied. Some of those solutions employ lightweight aggregates such as expanded clay, particles of cork or particles of expanded polystyrene (EPS). This research work intends to propose another alternative solution of the above described system and focused on analyzing the potential of using particles of corn cob, Figures 2.a and 2.b, as lightweight aggregate for concrete. An expanded clay (Figure 2.c) concrete is adopted as reference. The analyzed material properties are the density, the compressive strength and the thermal insulation capacity.

3. MECHANICAL BEHAVIOR ASSESSMENT

At this stage, the compressive strength was the mechanical property analyzed because it is the more required for this context. Meanwhile, good compressive strength is also an indicator of good impact and abrasion capacities.

3.1. Sample preparation and test equipment

The compressive strength of both corn cob and expanded clay concrete was assessed with cubic specimens of 15 cm edge length. In both cases, a weight ratio of 6:1:1 (i.e. lightweight aggregate: Portland cement: water) was adopted. This is a current applied ratio for regularization layer of expanded clay concrete applications in the Portuguese context. Figure 3 exemplifies some steps of the corn cob concrete sample processing such as adding the components (Figure 3.a), curing process (Figure 3.b) and the unmoulding step (Figure 3.c). Figure 3.b also indicates the corn cob concrete sample type used in the compression test (I, Figure 3.b) and the corn cob concrete sample type used in the thermal insulation performance test (II, Figure 3.b) related to section 4. On the other hand, Figure 4 features the same steps of the expanded clay concrete sample processing. In both cases, the curing occurred under controlled thermal and hygrometric conditions.

At the age of 28 days, the samples were tested in terms of compression. Previously, they were measured and their mass was assessed by using a digital weighing-machine HP-20K. An ALPHA 3-3000D compression testing rig with an ultimate carrying capacity of 3000 kN was used, as depicted in Figure 5.

3.2. Experimental results and discussion

The mass, density, ultimate compression load and the compressive strength were the material properties evaluated during the compressive test. The values of these properties are presented in Tables 1 and 2 for the corn cob and the expanded clay concrete specimens, respectively.

The average evaluated density of the corn cob concrete samples (ratio 6:1:1) was 382.2 kg/m^3 which is lower than the respective material property of the expanded clay concrete samples (ratio 6:1:1), 576.3 kg/m^3, see Tables 1 and 2. Since a low specific weight is probably one of the most important qualities for a regularization layer, i.e. without any special needs in terms of mechanical resistance (for a non-strucutural application), this experimental result corroborates the potential use of this agricultural waste product as a natural lightweight aggregate within concretes for regularization layers. The compressive strength of the expanded clay concrete (average value of 1360 kN/m^2, Table 2) is clearly higher than the correspondent property of the corn cob concrete (average value of 120 kN/m^2, Table 1). The fact that the corn cob concrete samples were not yet completely dried at the age of 28 days, and that the granulometry of the corn cob particles may require improvements in terms of range of dimensions and weight proportions; and the adopted corn cob concrete components ratio may be inadequate, may justify the above discrepancy. In order to figure out the impact of the corn cob concrete component ratio, four additional samples were casted (ratio 3:1:1) and tested under compression at the age of 28 days. The respective obtained experimental results are presented in Table 3. The compressive strength increased nearly 220% (from 120 kN/m^2, Table 1; to 392.2 kN/m^2, Table 3) associated to the fact of reducing the amount of corn cob particles in relation to the binder content (from 6:1:1, Table 1, to 3:1:1, Table 3). However, the improvement on the compressive strength is still unsufficient to reach the strength obtained with the expanded clay concrete (392.2 kN/m^2, Table 3; against 1360 kN/m^2, Table 2). At the same time, it was verified that there was a significant increment of the density (from 382.2 kg/m^3, Table 1, to 777.8 kg/m^3, Table 3). It is worth to underline that the corn cob concrete samples processed with the ratio of 3:1:1 were also not completely dried at the age of 28 days.

Furthermore, an interesting resilience capacity of the corn cob concrete was noticed while carrying out the compression test.

4. THERMAL PERFORMANCE ASSEMENT

In order to evaluate the thermal properties (e.g. the thermal transmission coefficient, U, or the thermal conductivity, λ) of materials or building component systems, a thermal test cell is currently applied, which is a laboratory device. In this research work, an alternative experimental procedure based in [17] was applied since it can be applied in situ and also because it allows evaluating thermal properties of real scale building component systems. The facilities, the sample preparation, the equipment and the test procedures are crucial for the success of this adopted experimental setup. Therefore, in the context of this paper, these aspects will be explained in detail within the following sections.

4.1. Facility and sample preparation

A confined room with 4.00 m × 3.00 m × 2.54 m (length × width × height) was used as an alternative expedite solution of a thermal test cell, Figure 6.a. This room must have windows preferentially orientated to north in order to avoid the direct sunshine incidence on the samples. In this case, there are five windows in the northeast façade of the confined room, Figure 6.a.

Corn cob and expanded clay concrete samples were specifically produced for this test. These samples were sized 40 cm × 20 cm × 5 cm (width × height × thickness) as illustrated in Figure 3.b (detail II) for the corn cob concrete samples. Meanwhile, the XPS panel was 76 cm × 64 cm × 5 cm (width × height × thickness) (detail a, Figure 6.b). The size of the XPS support panel (i.e. width and height) is similar to the size of the existing windows of the confined room. In this case, the windows identified as I and II in Figure 6 were used. A hole was done in the central part of the XPS panel with the same shape and dimensions of the samples. The corn cob (detail b, Figure 6.b) and the expanded clay (detail c, Figure 6.b) concrete samples were then placed in the hole of the XPS panel and both materials were connected by polyurethane foam. The set (i.e. sample and XPS) replaced a window and was also fixed by polyurethane foam, (detail d, Figure 6.b). All these experimental procedures require additional care in order to avoid any undesirable insulation voids, thermal bridges, uninsulated headers and other faults which may compromise the feasibility of the final results.

4.2. Equipment and test preparation

In this research work two heat transfer systems (i.e. one for each sample), two thermo hygrometric devices and a domestic heater device were adopted as the main equipment. Each heat transfer system included two heat flux measurement sensors (detail f, Figure 6.b), four superficial temperature sensors (detail e, Figure 6.b), a data logger and a computer. The heat flux measurement sensors allow measuring the heat flow across a sample. A heat flow occurs when there is a significant thermal gradient between the two surfaces of a sample (i.e. indoor and outdoor surfaces). In this case, this gradient results from the existing thermal gradient between indoor and outdoor temperatures. The superficial temperature sensors were used as a complement and as reference of the heat flux measurement sensors, and in order to evaluate the inner surface temperature of the samples. It was adopted two superficial temperature sensors by heat flux measurement sensor and as Figure 6.b shows. One thermo hygrometric device was placed indoor and another one was placed outdoor. The heat transfer and the superficial temperature sensors were fixed on the inner face of the samples by adhesive tape, Figure 6.b. This procedure is extremely important taking into account the rugosity of the surface of the two tested samples types, which were corn cob concrete samples (ratio 6:1:1, aged 60 days) and expanded clay concrete samples (ratio 6:1:1, aged 60 days). It is imperious to guaranty a perfect contact between the surfaces of the heat flux measurement sensor and the inner face of the samples, and to avoid any possibility of the sensors coming off during the test performance. According to [17], the test duration is related to the thermal inertia of the building component under study. For a high thermal inertia building component a minimum of fourteen days test duration is recommended. On the other hand, for a low thermal inertia building component a minimum of 3 days of test duration is recommended. In this case, five days test duration was considered assuming that the both type of light weight concrete samples under study had low thermal inertia.

In the Portuguese context and, in particular, in the northeastern region of this country, it is convenient to perform this test during the winter or the summer because it is easy to assure the desirable uniform high thermal gradient between indoor and outdoor spaces. A uniform high thermal gradient between indoor and outdoor is desirable because it corresponds to the ideal condition to allow a significant heat flow across the sample. During the winter, this condition can be achieved by using a simple domestic heater device placed indoor and able to keep the room constantly warm. In contrast, during the summer, an air conditioner can be able to keep the room constantly cool. In this case, the test was performed during the winter, namely, in February of 2011. Therefore, a uniform high thermal gradient between indoor and outdoor was achieved by placing a common domestic heater device in the confined test room.

4.3. Experimental results and discussion

The two types of light weight concrete samples were tested in parallel. A continuously data acquisition was carried out during the test (in-between 10 minutes intervals (n)). That acquired data comprised the values of the heat flow across the corn cob concrete sample (q`1(n) and q`2(n), measured by the two used heat flux measurement sensors placed on this sample) and the values of the heat flow across the expanded clay concrete sample (q1(n) and q2(n), measured by the two used heat flux measurement sensors placed on this sample). It also included the interior and the exterior temperatures (Ti(n) and Te(n)), and the relative humidity. Figure 7 depicts graphically the abovementioned registered data.

In this case, it was necessary almost 48 hours (Δt stabilizing, Figure 7) to stabilize the interior temperature at 20ºC of the confined room. Meanwhile, the exterior temperature had shown its natural and expected swing in a day time (e.g. ΔTnight and ΔTday, Figure 7). For that period of the year, in the north region of Portugal, the exterior temperature was always lower than the interior temperature. Therefore, adequate thermal gradients were guaranteed (e.g. details I and II, Figure 7).

According to [17], the thermal transmission coefficient (*U*) can be quantified by:

$$U(ntotal) = \frac{\sum_{n=1}^{ntotal} q(n)}{\sum_{n=1}^{ntotal} (Ti(n) - Te(n))} \qquad (1)$$

where, *U* is the thermal transmission coefficient, *q(n)* is the heat flow across the sample in the moment *n*, *Ti(n)* and *Te(n)* are the interior and the exterior temperature at the moment *n*, respectively; *ntotal* is the total number of moments in which the data was registered.

Taking into account that two heat flux measurement sensors were used by each sample, corresponding to *q1(n)* and *q2(n)*, it was possible to estimate two thermal transmission coefficients for each sample, *U1(ntotal)* and *U2(ntotal)*, by applying Eq. 1. Thus, the thermal transmission coefficient of each sample (*U`(ntotal)*) can be the average value of *U1(ntotal)* and *U2(ntotal)* and according to Eq. 2.

$$U`(ntotal) = \frac{U1(ntotal) + U2(ntotal)}{2} \qquad (2)$$

Where, *U`(ntotal)* is the thermal transmission coefficient of the sample, *U1(ntotal)* and *U2(ntotal)* is the thermal transmission coefficient related to the data registered by the heat flux measurement sensor 1 and 2, respectively.

Based on the prior experimental data (Figure 7) and applying the previous expressions the thermal transmission coefficient of each light weight concrete sample can be estimated. These coefficients are presented in Table 4.

The results of Table 4 evidence the thermal insulation performance benefits of using corn cob particles as an aggregate of lightweight concrete when comparing to a lightweight concrete with expanded clay.

5. CONCLUSIONS

Granulate of corn cob, without containing any corn, is proposed as an alternative natural aggregate of light weight concrete. Generally, corn cob is considered an agricultural waste. Using it as an alternative to expanded clay, cork, EPS, among other possibilities may have an interesting economic and sustainable benefit. At this stage, the obtained experimental results indicate that corn cob concrete processed according to ratio of 6:1:1 (corn cob granulate:Portland cement:water) may have acceptable material properties. For instance, the density and the thermal performance properties are in accordance with the respective material properties of an expanded clay concrete. However, the studied corn cob concrete has shown low compression strength when compared to the expanded clay concrete. Aspects related to the granulometry of the corn cob particles, the ratio of components and the curing time may justify the above vulnerability. Nevertheless for non-structural application purposes, such as pavement's regularization layers may be suitable. Further research will be carried out to solve the abovementioned low concrete strength.

REFERENCES

[1] John Perez-Garcia, Bruce Lippke, David Briggs, James B. Wilson, James Bowyer, Jaime Meil, The Environmental Performance of Renewable Building Materials in the Context of Residential Construction, *Journal of Wood and Fiber Science*: 37 (2005) 3-17.

[2] Azra Korjenic, Vít Petránek, Jiří Zach, Jitka Hroudová, Development and performance evaluation of natural thermal-insulation materials composed of renewable resources, *Energy and Buildings*: 43 (2011) 2518-2523.

[3] Oscar Ortiz, Frances Castells, Guido Sonnemann, Sustainability in the construction industry: A review of recent developments based on LCA, *Construction and Building Materials*: 23 (2009) 28-39.

[4] S.R. Karade, Cement-bonded composites from lignocellulosic wastes, *Construction and Building Materials*: 23 (2009) 28-39.

[5] D.A. Adesanya, A.A. Raheem, Development of corn cob ash blended cement, *Construction and Building* Materials:23 (2009) 347-352

[6] D.A. Adesanya, A.A. Raheem, A study of the workability and compressive strength characteristics of corn cob ash blended cement concrete, *Construction and Building Materials*: 23(2009) 311-317.

[7] D.A. Adesanya, A.A. Raheem, A study of the permeability and acid attack of corn cob ash blended cements, *Construction and Building Materials*: 24 (2010) 403-409.

[8] J. Younquist, B. English, H. Spelter, P. Chow, Agricultural fibers in composition panels, Proceedings of the 27th International particleboard/composite materials symposium, 1993 March 30-31, Pullman, WA. Pullman, WA: Washington State University, 1993: 133-152.

[9] P. Chow, Dry formed composite board from selected agricultural residues. World consultation on wood based panels. Food and Agriculture Organization of the United Nations. New Delhi. India (1974).

[10] P. Lertsutthiwong, S. Khunthon, K. Siralertmukul, K. Noomun, S. Chandrkrachang, New insulating particleboards prepared from mixture of solid wastes from tissue paper manufacturing and corn peel, *Bioresource Technology*: 99 (2008) 4841-4845.

[11] J. Khedari, N. Nankongnab, S. Fotios, Agricultural waste materials as thermal insulation for dwellings in Thailand: preliminary results, in: PLEA 2008: 25th Conference on Passive and Low Energy Architecture, Dublin, 22nd to 24th October 2008, 2008.

[12] N. Stone, Thermal performance of straw bale wall systems, Ecological Building Network (EBNet) (2003) 1-7.

[13] J. Pinto, A. Paiva, H. Varum, A. Costa, D. Cruz, S. Pereira, L. Fernandes, P. Tavares, J. Agarwal, Corn`s cob as a potential ecological thermal insulation material, *Energy and Buildings*: 43 (2011) 1985-1990.

[14] N. Soon-Ching, L. Kaw-Sai, Thermal conductivity of newspaper sandwiched aerated lightweight concrete panel, *Energy and Buildings*: 42 (2010) 2452-2456.

[15] C. Hasse, M. Grenet, A. Bontemps, R. Dendievel, H. Sallée, Realization, test and modeling of honeycomb wallboards containing a phase change material, Energy and Buildings: 43 (2011) 232-238.

[16] N. Quaranta, M. Caligaris, H. López, M. Unsen, N. Lalla, M. Franzoy, M. Carrasco, J. Cotroni, M. Avendaño, Addition of polymeric wastes as pore formers in ceramic lightweight bricks, in: S. Hernandez, C. A. Brebbia, W.P. De Wilde (Eds.), ECO-ARCHITECTURE III, Harmonisation Between Architecture and Nature, WIT Transactions on Ecology and the Environment, vol. 128, 2010, pp. 447-458, ISBN: 978-1-84564-430-7, ISSN: 1723-3541 (on-line).

[17] ISO 9869. Thermal insulation – Building elements – In–situ measurement of thermal resistance and thermal transmittance, International Organization for Standardization (ISO), 1994.

LIST OF TABLES

Table 1: Compression test results of the corn cob concrete samples (ratio 6:1:1)

Sample	Mass (kg)	Density (kg/m^3)	Ultimate load (kN)	Compression strength (kN/m^2)
1	1.21	358.5	2.0	88.9
2	1.46	432.6	5.1	226.7
3	1.22	361.5	1.9	84.4
4	1.27	376.3	1.8	80.0
Average	1.29	382.2	2.7	120.0

Table 2: Compression test results of the expanded clay concrete samples (ratio 6:1:1)

Sample	Mass (kg)	Density (kg/m^3)	Ultimate load (kN)	Compression strength (kN/m^2)
1	2.04	604.4	38.7	1720.0
2	1.87	554.1	24.5	1088.9
3	1.86	551.1	24.0	1066.7
4	2.01	595.6	35.2	1564.4
Average	1.95	576.3	30.6	1360.0

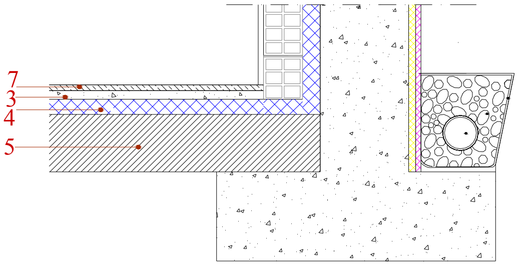
Table 3: Compression test results of the corn cob concrete samples (ratio 3:1:1)

Sample	Mass (kg)	Density (kg/m^3)	Ultimate load (kN)	Compression strength (kN/m^2)
1	2.3	681.5	6.3	280.0
2	3.2	948.1	11.5	511.1
3	2.5	740.7	8.6	382.2
4	2.5	740.7	8.9	395.6
Average	2.6	777.8	8.8	392.2

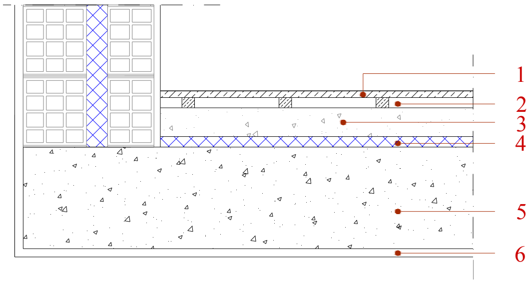
Table 4: Thermal transmission coefficient (*U`(ntotal)*) of the two lightweight concretes

Sample	*U`(ntotal)* (W/m^{2o}C)
Corn cob concrete	1.99
Expanded clay concrete	2.72

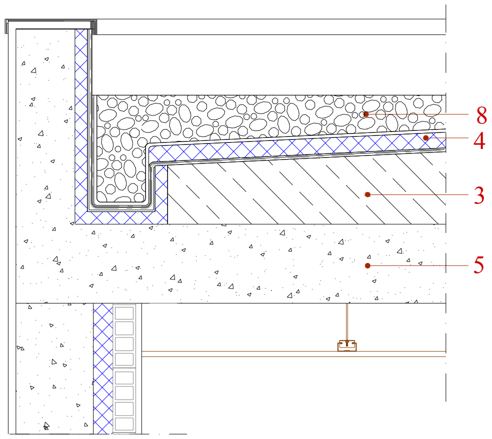
LIST OF FIGURES



a) Ground floor



b) Upper floor



c) Terrace

Key: 1 – Wood floor; 2 – Air layer; 3 – Regularization layer; 4 – Extruded polystyrene (XPS); 5 – Pavement; 6 – Plaster; 7 – Ceramic tiles; 8 - Pebble

Figure 1: Examples of applications of regularization layer

a) Corn cob (without corn)

b) Granulate of corn cob

c) Expanded clay

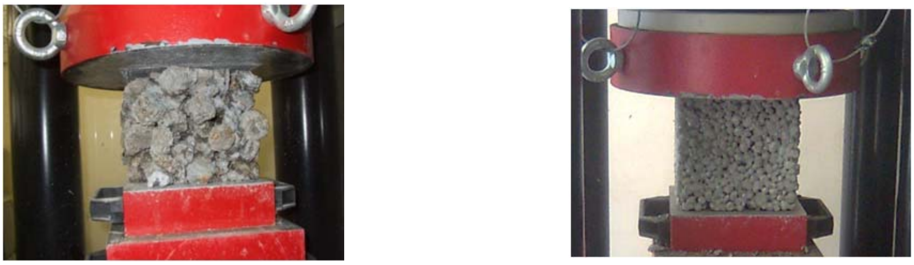
Figure 2: Expanded clay *vs* Corn cob (without corn)

a) Adding b) Curing c) Unmoulding

Figure 3: Processing of the corn cob concrete samples for the compression test

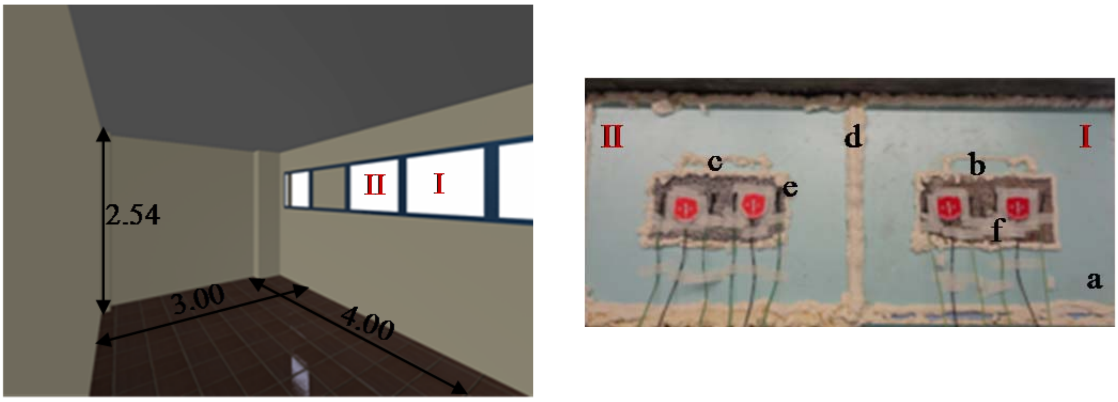
a) Adding b) Curing c) Unmoulding

Figure 4: Processing of the expanded clay concrete samples for the compression test



b) Corn cob concrete sample c) Expanded clay concrete sample

Figure 5: Compression test procedure



a) Confined room (m) b) Set up

Key: a – XPS; b – Corn cob concrete sample; c – Expanded clay concrete sample; d - Polyurethane foam; e - Superficial temperature sensor; f - Heat flux sensor

Figure 6: Facility and sample setting up

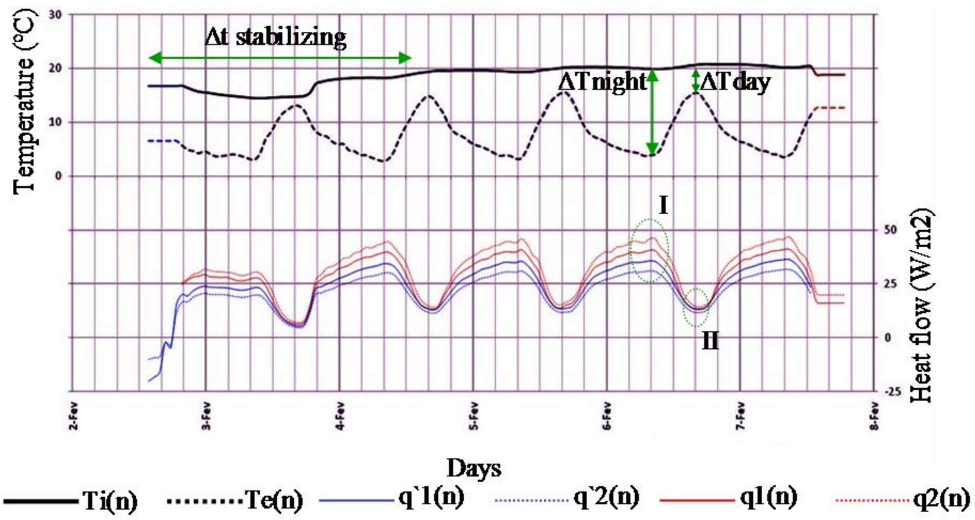


Figure 7: Interior (Ti(n)) and exterior (Te(n)) temperatures. Heat flow across the corn cob (q`1(n) and q`2(n)) and the expanded clay (q1(n) and q2(n)) concrete samples. February (Fev) of 2011