Corn's cob as a potential ecological thermal insulation material

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1. Introduction

The environmental issues are gaining an increasing interest worldwide. The world’s population is much more aware of the importance of sustainability and the need for a proper conduct to protect the environment. This is now reflected positively in our lifestyle [1].

In the industry, there has been a huge effort to find new solutions which protect the environment, are economical and guaranty the present requirements of comfort, health and quality standards. The construction industry is not excluded from this reality [2]. The authors believe that there is a lot to learn from ancient building practice to design modern sustainable buildings.

Recently, the authors have been studying [3–5] the traditional Portuguese building technique called tabique in Trás-os-Montes e Alto Douro region, which is in the northeast part of Portugal. An interdisciplinary team composed of civil, forest, mechanical and chemical engineers and architects has been participating in this research. The tabique constructions are spread over a vast area and they present specific characteristics associated with the climatic conditions, soil, local natural materials, etc. At this stage, the research work has included a field work for surveying the characteristics inherent of this type of buildings and an experimental work for the identification/characterization of the traditionally used building materials.

The importance of this research work is further justified because many existing tabique buildings are in an advanced stage of deterioration. In fact, many of them have been demolished or replaced by new ones using reinforced concrete. At the same time, there is still a lack of scientific work on this subject which is required in order to technically support future conservation/renovation actions.

Since the majority of existing tabique construction was basically built in the XVIII and XIX centuries, it is obvious that the respectively used materials are mainly natural and local [5]. The applied building techniques associated to the tabique are very likely to be sustainable. Thus, understanding this traditional building technique will have the additional advantage of identifying sustainable concepts and solutions which may be applied in modern building solutions.

The specific objectives of this paper are (i) to introduce an unusual ancient Portuguese building technique related to the tabique construction which uses corn’s cob as a building material and (ii) to examine this natural and biological material as a sustainable alternative solution for thermal insulation. In the context of
the Portuguese building industry nowadays, extruded polystyrene (XPS) is the most common thermal isolation building material. There are others research works [6–9] which have focused on the study of using solid and agricultural waste materials such as straw, durian peel, coconut coir, corn peel, corn cob, bagasse, rice hull, oil palm leaves, among others, for thermal insulation purposes. They have analysed possible ways of developing new composite boards with low-thermal conduction and achieving some physical and mechanical properties of those composite materials. Meanwhile, Hasse et al. [10] have studied honeycomb panels filled with paraffin for short-term heat storage. Furthermore, an investigation on thermal conductivity of newspaper sandwiched aerated lightweight concrete panels was done in [11].

The paper is structured as follows firstly, the current research work into the study of the existing tabique construction in the Trás-os-Montes e Alto Douro region in the northeast part of Portugal [3] is being carried out. This type of construction is not exclusive of this region. However, its density is undoubtedly higher in the north of Portugal.

Tabique construction is one of the most expressive traditional Portuguese building techniques that use earth as a building material. Other traditional Portuguese building techniques based on earth, as adobe masonry and rammed earth were not developed and used in this region [12].
Tabique walls have an internal timber structure filled and covered on the both sides with earth. The tabique component materials, timber and earth, are both natural and locally available. This aspect is extremely relevant concerning the current trends in construction research which are searching for environmental friendly building solutions.

The structural arrangement of tabique elements is very simple. It consists of thick vertical clapboard timber elements connected to the pavements and connected to each other by smaller sized horizontal timber elements. The connection between vertical and horizontal timber elements is materialized by metal nails. Each horizontal timber element usually connects more than three vertical timber clapboard elements [5].

In the Portuguese context, the tabique building technique had its boom in terms of application during the XVIII and XIX centuries, before the massive introduction of the reinforced concrete framed structural solutions.

Based on the research work already done in this project which included a survey of 120 buildings (about 50% of the region), it is possible to state the following:

- The most common types of tabique buildings are dwellings of two storeys (ground and first storey), as shown in Fig. 1. Usually, the ground floor is used as a storage room or for business and the first floor is used for housing.
- The tabique technique is used mainly to build interior walls. However, it is also possible to find exterior load-bearing tabique walls in Trás-os-Montes e Alto Douro region. Interestingly, chimneys built using this technique were also found.
- It is very rare to find tabique building components at the ground floor level in this region.
- In general, the existing tabique constructions show an alarming deterioration due, basically, to the lack of conservation actions. This can be justified by the age and limited financial resources of...
the owners. Most of the *tabique* buildings surveyed are already in ruin, some had even been demolished during this research project which is still on-going. This is more common in the interior (rural) areas which has been suffering progressively with human desertification.

The earth based mortar in the *tabique* building components revealed to play an important role, protecting the internal timber structure from decaying.

3. Ancient *tabique* elements incorporating corn’s cob

During the field work in two sub-regions of Trás-os-Montes e Alto Douro, namely Terra Quente do Nordeste Trasmontano and Terra Fria do Nordeste Transmontano, a set of isolated cases of ancient *tabique* buildings, located in three different places Alfândega da Fé (Fig. 2a), Mirandela (Fig. 2b) and Izeda (Fig. 2c), present the unusual particularity of having a mixture of corn’s cob and earth as a filling material of the timber elements in the *tabique*.

Fig. 3a–c give detailed views of these *tabique* buildings incorporating corn’s cob. It is very likely that the original intention of the use of the corn’s cob was to simplify and to economize the building process. Corn’s cob being an agricultural waste was used as a filling material as a substitute for earth in the earth based mortar. A gain in thermal insulation property was probably unintentional.

The above finding stimulated the authors of this paper to study the potential of corn’s cob as a possible ecological and sustainable alternative of thermally insulating buildings. Therefore, a new research line focussing on the study of the physical properties of corn’s cob and exploring its potential use in thermal insulation products is in progress.

In this study, the XPS has been used as a reference thermal insulation material, since it is the most common material used for thermal insulation walls in the Portuguese building industry context.

4. Corn’s cob versus XPS

4.1. SEM/EDS

At this stage, samples of corn’s cob, Fig. 4a and b, and XPS, Fig. 4c, have been experimentally analyzed by SEM/EDS in order to compare their microstructure and the elementary chemical composition. This experimental work has been performed at the Electronic Microscopy Laboratory of the Trás-os-Montes e Alto Douro University. SEM/EDS analysis have been successfully used for this purpose in the study of others materials [5] and [13–15].

Fig. 4b illustrates a cross-section of a corn’s cob in order to understand the macrostructure of this natural material. Three different layers are identified, clearly perceived by their colour, texture, shape and density. Due to its nature, it is recalled that the corn’s cob is a heterogeneous material. In contrast, the XPS is a homogeneous material, Fig. 4c.
Fig. 5a–c shows the microstructure of the layers I, II and III of the corn’s cob material, respectively, and Fig. 6 shows the same feature for the XPS.

Comparing the two materials, one natural and the other processed, in terms of its microstructure it is possible to find similarities since they both have a closed cellular structure type. As expected, the XPS has a much more regular and uniform shape of its closed cellular structure contrasting with the corn's cob material. However, this difference dissipates when comparing the microstructures of layer I of the corn’s cob (Fig. 5a) with the XPS material (Fig. 6). This gives the first insight in the potential use of the corn’s cob material for thermal insulation products, since it is a natural and biological material, in contrast with the XPS material which is an industrially processed product.

Apart from the study on the microstructures, illustrated in Figs. 5 and 6, the SEM/EDS analysis also allows to identify the elementary chemical composition of the two materials under study. The results obtained are presented in Fig. 7, from which it can be observed that the most expressive elementary chemical elements identified are: oxygen (O), magnesium (Mg), aluminium (Al), silicon (Si), potassium (K), calcium (Ca) and iron (Fe).

Based on the experimental results presented in Fig. 7 it is possible to state that the elementary chemical composition of the two materials tested are quite similar; they have the same chemical elements although in different proportions.

4.2. Thermography

A corn’s cob panel sample of 0.25 m × 0.25 m was fabricated using as molding an XPS panel, of 0.76 m × 0.64 m, Fig. 8a. Both panels had a thickness of 0.05 m. The panels replaced a window of a room sized 3.00 m × 4.00 m × 2.54 m (width × length × height) in which the temperature was constant of 21.6 °C. In these conditions, the panels worked as an exterior wall. This model was then tested in terms of thermal behaviour using thermography. Fig. 8b shows a thermogram obtained in the interior side of the panels for the following thermal-hygrometric conditions: interior temperature of 21.6 °C; exterior temperature of 10.7 °C; relative humidity of 46% (interior and exterior).

The thermogram of Fig. 8b shows that both materials have a similar superficial temperature. This expeditious experimental procedure and its result indicate that it is very likely that the corn’s cob may have adequate thermal properties (i.e. thermal conductivity) and its application for building purposes may be promising.
4.3. Discussion

The identified similarities in terms of microstructure, elementary chemical composition and superficial temperature between the two studied materials, lead to the conclusion that the use of corn's cob based material in the building sector is a promising field. Particularly, it can be used as a thermal insulation material in future conservation actions performed in existing tabique constructions thus also reducing the amount of the CO2 emissions and the energy consumption.

Furthermore, these experimental results also give guidance and inspiration for additional future research work focused on developing biological and sustainable thermal insulation materials and products for construction and other applications.

5. Conclusions

A set of clusters of ancient tabique buildings located in the Trás-os-Montes e Alto Douro region has revealed the application of corn's cob as a building material in tabique walls.

The analyses of those buildings also suggest that the earth based mortar conserves biological materials such as timber and corn's cob, since the building system is not in direct contact with the ground and also the earth covers all the faces of those biological materials, protecting them from the rain and biological attack.

The corn's cob presents three layers which are different in terms of shape, texture, density and colour. The corn's cob material is heterogeneous, in contrast to common thermal insulation building materials, which is related to its origin being a natural biological material.

SEM/EDS's results indicate that there are some interesting similarities between the corn's cob and the extruded polystyrene (XPS) materials. These similarities are related to the closed cellular microstructure type, as well as to the presence of the same chemical elements.

These findings suggest that the use of corn's cob, taking simultaneously a role of filling material and a thermal insulation material, is very likely a lost ancient building technique/solution.

Furthermore, these findings give guidance for future conservation/renovation actions of existing tabique constructions.

An expeditious experimental procedure for comparing the thermal behaviour of corn's cob and XPS was presented. Thermography results indicate that the corn's cob may have adequate thermal properties for building purpose. Further research is required to assess fundamental thermal properties such as thermal conductivity of this biological material.

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