Characterization of corn cob as a possible raw building material

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A R T I C L E    I N F O
Article history:
Received 4 September 2011
Received in revised form 6 January 2012
Accepted 23 February 2012

Keywords:
Corn cob
Raw building materials
Sustainable building materials
Agriculture waste materials
Material properties

A B S T R A C T

Usually, the corn cob is considered an agriculture waste. This natural and organic waste material may be used in the industry, in general, and in the building industry, in particular. The work presented in this paper was developed in order to give a contribution to the knowledge of this material, by attempting to describe and assess its macrostructure and microstructure, elementary chemical composition, density, water absorption, fire resistance and thermal insulation capacity. These properties of the corn cob were compared with the corresponding ones of the most common thermal insulation products applied in the Portuguese building industry, which are extruded polystyrene (XPS), expanded polystyrene (EPS), cork and expanded clay. Several similarities were found when comparing the properties of these materials, in particular between the corn cob and the cork, which suggests that the corn cob may be used as a raw material to process thermal insulating products, light partition walls, ceiling coating, indoor doors and furniture, among other possible applications. The obtained results can also contribute to a more environmentally friendly building industry.

1. Introduction

Huge efforts have been done by the research community worldwide, in order to find alternative sustainable building materials and low technology methods, which result in a more sustainable and affordable construction complying with the comfort standards required nowadays. Adopting green building materials is a good option to converge to this goal. Therefore several authors have already proposed the use of different agriculture products 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. Among the agriculture products identified above, corn cob has an additional advantage, in terms of its possible application as an alternative processed product, because it does not collide with the worldwide food stock and it is generally considered as an agriculture waste. Recent research works have given particular emphasis to its application in the industry.

In a perspective of applying corn cob as a raw or as a processed building material such as a particleboard or a sandwich panel product it is relevant and fundamental to know its properties previously. So the main goal of this paper is to give a contribution to the knowledge of this natural and organic material by attempting to describe and to assess some of its properties. The macrostructure and microstructure, the elementary chemical composition, the density, the water absorption, the fire resistance and the thermal insulation capacity properties were studied. These material properties were compared with the corresponding ones of the most frequently applied thermal insulation products in the Portuguese building industry, which are extruded polystyrene (XPS), expanded polystyrene (EPS), cork and expanded clay. Several material property similarities between the analyzed products were found, in particular between the corn cob and the cork, which suggests that the corn cob may be used as a raw material for the process of thermal insulating products, light partition walls, ceiling coating, indoor doors and furniture, among other possible applications.

This paper is structured as follows: firstly, the corn plantation and production scenarios in the last years in Portugal and in the major corn producer countries are briefly introduced; secondly, the macrostructure and the microstructure of the corn cob are presented and described as well as the macrostructure of XPS, EPS, cork and expanded clay. The microstructures of these products are then compared. Plus, their elementary chemical compositions are also presented and compared; thirdly, the density, the water
absorption and the fire resistance of the corn cob are assessed and discussed. The inherent experimental procedures applied are also explained in detail. When possible, a property comparative analysis of the above products is also done; fourthly, the potential thermal insulation capacity of the corn cob is evaluated by estimating the thermal transmission coefficient and the thermal conductivity of a specific corn cob particleboard processed for this purpose. The adopted experimental set up, to assess these measures, is also described; finally, the conclusions are drawn and the potential use of the corn cob in the industry is highlighted.

2. Corn plantation in Portugal and other countries

The corn plant, Zea mays, was introduced in Portugal in the mid 16th century and, ever since it has been part of the Portuguese agricultural panorama. According to ANPROMIS [13], the overall land area of the corn plantation in Portugal mainland has been facing a decreasing trend. In fact, a 53% decrease of the corn plantation land area occurred from 2004 to 2010. Meanwhile, the corn plantation land areas are basically in the north and center of Portugal mainland, corresponding approximately to 69%, of the plantation area. The south and the Portuguese islands are responsible for 31% of the overall corn plantation area.

In Portugal, the corn plantation process starts by the end of the winter (i.e. March) and can be carried out until the end of the spring (i.e. May), the harvest process takes place during the summer (i.e. between June and September). Generally, in the Portuguese context, the corn plant and the corn cereal are used for cattle food and baking industry. In contrast, the corn cob does not have any significant specific application, being occasionally used for heating, and, therefore, it is mainly considered as an agriculture waste, which is often burnt contributing consequently and unfortunately to the increase of the amount of CO2 in the atmosphere. Finding innovative applications for this agriculture waste may result in an alternative affordable and sustainable product. The impact of this possible benefit may be relevant taking into account the overall amount of corn cob produced worldwide per year. In Fig. 1 a flowchart related to the corn production of the USA, China and Brazil, from 2003 to 2009 is presented [14]. The amount of corn produced per year has been increasing in these countries, in contrast with the Portuguese situation. Therefore, using corn cob as a possible raw building material seems opportune. Meanwhile, this fact may also reverse the decreasing trend in corn production that Portugal has been facing recently.

3. Microstructure and elementary chemical composition

As it was stated above, there are already some recent research works highlighting the potential of the application of corn cob as an alternative sustainable raw building material. A set of ancient Portuguese buildings studied by Pinto et al. [6], had corn cob applied in external walls. The microstructure, the macrostructure and the elementary chemical composition of this natural organic material and also of the extruded polystyrene (XPS) was studied by these authors. An attempt to compare these two materials in terms of thermal insulation performance was also performed. They came to the conclusion, that the corn cob can have a satisfactory thermal insulation performance, based on a comparative analysis with the XPS and due to the existing microstructure and elementary chemical composition similarities, between these two materials. The XPS was chosen in that research work, because it has been one of thermal insulation materials most frequently applied in the buildings’ external walls, in the Portuguese context. The corn cob is composed by three different layers (I, II and III, Fig. 2), clearly perceived by their color, texture, shape and density, as illustrated in Fig. 2a. In terms of microstructure, the three layers also have different characteristics. The internal layer (Layer I) presents a regular alveolar microstructure in which the alveoli have an interesting regular geometric shape, taking into account that it is a natural organic material. The alveoli have thin walls and are filled with air, Fig. 2b. This alveolar microstructure type tends to dissipate from the inside to the outside of the corn cob (from Layer I to Layer II). Furthermore, Layer II seems to have a higher density than the other two layers and also seems to have a strength capacity similar to a soft wood.

In order to complement the information reported by Pinto et al. [6], the microstructure of other thermal insulation materials frequently applied in Portugal such as expanded polystyrene (EPS), cork and expanded clay was identified. All of these materials have an alveolar microstructure and this microstructure is similar to the corn cob which improves the possibilities of using it as a building material, raw or processed. A material with low density is usually associated to this type of microstructure. It is important to underline that among these insulation thermal materials only the cork and the corn cob are natural and organic. This fact adds important relevance to this paper, taking into account that there is a multipurpose established cork industry in which Portugal is leader worldwide, which does not occur for the corn cob that is mainly an agriculture waste. In Fig. 3 the microstructure of granulated cork and expanded clay is presented.

The microstructure and the elementary chemical composition of the above materials were identified by performing a Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM/EDS) analysis. The most relevant chemical elements identified in each thermal insulation material studied and also the corresponding percentages are identified in Table 1. The identified chemical elements are aluminum (Al), calcium (Ca), chlorine (Cl), fluorine (F), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), oxygen (O), silicon (Si) and titanium (Ti).

Generally, the most relevant identified chemical elements are O, Al and Si. None of the materials present all the identified chemical elements in their chemical elementary composition. Among the studied materials, the corn cob, the expanded clay and the XPS are the ones showing more similarities in terms of the chemical elementary composition.

4. Some properties of the corn cob

As it was stated above, in a perspective of applying corn cob as a raw or as a processed building material such as a particleboard or a sandwich panel product it is relevant and fundamental to know its properties. Therefore, the density, the water absorption and the fire resistance of the corn cob were determined. The variability associated to a natural and an organic product, such as the corn cob, increased the difficulty of this task and, therefore, the achieved
experimental results in this research work have to be considered as reference. On the other hand, the corn cob material itself is irregular and heterogeneous, which increases this difficulty. In order to obtain representative corn cob samples, Fig. 4a, they were collected near Amarante, a city which belongs to the Douro Litoral region and near Viana do Castelo, a city which belongs to the Minho region. Both regions are situated in the north of Portugal which is one the parts of the country where the corn plantation activity is more intense, according to the stated earlier.

4.1. Density

Ten corn cob samples were picked up randomly and dried. Their mass (dried mass) was measured (Table 2, column 2). Afterwards, each corn cob sample was submersed in distilled water (Fig. 4b) and the resulting additional water volume was quantified (V1). Since the corn cob floats, it was necessary to use a simple device linked to the corn cob sample. The volume of this device (V2)
and 350 kg/m³. Among the above traditional Portuguese thermal insulation materials, the cork are similar. The density of the cork varies between 100 and 350 kg/m³. Meanwhile, the densities of the XPS and EPS which are 25–40 kg/m³ and 10–25 kg/m³, respectively [13]. Most of these materials are processed (i.e. XPS, EPS and expanded clay). Only the corn cob and the cork are natural and organic materials which may lead to the conclusion that the corn cob has acceptable water resistance for certain building applications. The fact that a set of ancient Portuguese buildings present corn cob applied in exterior walls [9] gives strength to this conclusion.

4.2. Water absorption

In order to figure out the water absorption capacity of the corn cob an expedite experimental test was performed, which consisted basically on putting dried corn cob samples in a recipient filled with distilled water until the samples became saturated. Ten corn cob samples selected randomly, as explained before, were used. This test was performed under controlled thermo hygrometric conditions in the laboratory, in order to prevent undesirable water evaporation. The experimental results of this test are presented in Table 3.

According to the results presented in Table 3, the corn cob seems to have an impressive water absorption capacity. Meanwhile, samples of XPS, EPS, granulated cork and expanded clay were also tested and the respective values of water absorption were 13%, 34%, 244% and 36%. These experimental results also converge to the assumption that corn cob and cork may have interesting property similarities. Furthermore, this test also made it possible to verify that the corn cob requires over 15 days to become saturated (corresponding to the testing stage in which the corn cob sets down on the base of the recipient), depending on the size of each sample. This fact indicates that the corn cob has a progressive saturating process due to its microstructure and material composition which implies a capillary net existence and a water permeability tendency. On the other hand, at the end of this test, all the 10 samples of corn cob showed material integrity, which may lead to the conclusion that the corn cob has acceptable water resistance for certain building applications.

4.3. Fire resistance

Fire resistance is a very important property required for the building materials. Therefore, at this stage of the research, an expedite fire resistance test was performed using samples of the above traditional Portuguese thermal insulation materials in order to establish a very simple comparison between their performance, when exposed to a fire scenario. Flaming, combustion, gas emission and the time consumption for total combustion were the data collected during this test. The samples were exposed to a direct flame during 5 min, which was the maximum test duration considered. The obtained experimental results through this test are summarized in Table 4 and the combustion level faced by corn cob, cork and expanded clay is illustrated in Fig. 5.

Among the tested materials, the expanded clay was the only one whose integrity was kept intact after 5 min of direct exposure to a flame, there was no combustion phenomenon. The corn cob and the cork granulate showed similar fire resistance. They faced a slow progressive combustion process characterized by flame and a black gas emission. In contrast, the XPS and the EPS showed

Table 3

<table>
<thead>
<tr>
<th>Sample</th>
<th>Dried mass (g)</th>
<th>Saturated mass (g)</th>
<th>Water absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.4</td>
<td>88.5</td>
<td>278</td>
</tr>
<tr>
<td>2</td>
<td>21.2</td>
<td>95.0</td>
<td>348</td>
</tr>
<tr>
<td>3</td>
<td>18.2</td>
<td>89.5</td>
<td>392</td>
</tr>
<tr>
<td>4</td>
<td>21.8</td>
<td>91.7</td>
<td>321</td>
</tr>
<tr>
<td>5</td>
<td>20.5</td>
<td>94.0</td>
<td>359</td>
</tr>
<tr>
<td>6</td>
<td>23.8</td>
<td>101.7</td>
<td>204</td>
</tr>
<tr>
<td>7</td>
<td>22.2</td>
<td>95.6</td>
<td>331</td>
</tr>
<tr>
<td>8</td>
<td>24.5</td>
<td>100.7</td>
<td>311</td>
</tr>
<tr>
<td>9</td>
<td>22.3</td>
<td>105.6</td>
<td>374</td>
</tr>
<tr>
<td>10</td>
<td>26.7</td>
<td>95.7</td>
<td>258</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>327</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Material</th>
<th>Flaming</th>
<th>Combustion</th>
<th>Gas emission</th>
<th>Time for total combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn cob</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>5 min</td>
</tr>
<tr>
<td>XPS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Few seconds</td>
</tr>
<tr>
<td>EPS</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Few seconds</td>
</tr>
<tr>
<td>Cork granulate</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>5 min</td>
</tr>
<tr>
<td>Expanded clay</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>N/A</td>
</tr>
</tbody>
</table>
an insignificant fire resistance because both lost their complete integrity (melted) after few seconds of direct exposure to a flame. The combustion process faced by the XPS was characterized by the occurrence of a flame and the emission of a black gas. Meanwhile, the combustion process of the EPS did not include any visible flame or gas emission. Based on these results, it is possible to conclude that the corn cob has an acceptable fire resistance when compared with the other thermal insulation materials.

5. Thermal performance of the corn cob

Attempts to evaluate the thermal insulation capacity of the corn cob were made by Pinto et al. [6] and Dowling and Mathia [9]. Pinto et al. used the thermography analysis and Dowling and Mathia a special laboratory experimental set up, to compare the insulation capacity of materials. In this paper, a heat fluxmeter system was applied, as an alternative experimental procedure for measuring the thermal insulation capacity of a corn cob based product, following the prescribed by Santos and Matias [15], Paiva et al. [12] and in ISO 9869 [16]. At this stage, the thermal insulation capacity of a single corn cob was not measured. In fact, the measurement of this material property is very important, but in the buildings context it is more important to determine the thermal insulation capacity of a product based on the above materials. Therefore, a sample of particleboard of corn cob with dimensions 0.25 m × 0.25 m × 0.05 m (height × width × thickness) was specially processed for this purpose, using an XPS panel sized 0.64 m × 0.76 m × 0.05 m (height × width × thickness) as a frame. The corn cob was previously granulated and wood glue was used as a binder. The panel system (XPS and corn cob particleboard) replaced a window of a confined room, working in this way as an external der. The north of Portugal. The thermal transmission coefficient (U) was measured continuously (10 min timing interval) using two heat fluxmeters placed indoor and outdoor, respectively. The heat flow through the particleboard (q1(n) and q2(n)) was measured during seven consecutive days (n).

The measured temperatures and heat flow are shown in the graph of Fig. 6. The peaks of the heat flow through the particleboard sample of corn cob are in accordance with the peaks of the differential between indoor and outdoor temperatures (ΔT), which is the temperature range at this time of the year in the north of Portugal. The thermal transmission coefficient (U) can be quantified applying Expression (1), in which all the variables are defined in the caption of Fig. 6. The value obtained for the particleboard sample of the corn cob was 1.89 W/m²°C. Furthermore, the thermal conductivity (λ) of the sample was also estimated based on the experimental results, the value obtained was 0.139 W/m°C. The value of XPS is 0.037 W/m°C [15], so there is a significant difference in terms of thermal insulation capacity between these two materials. XPS insulation is more than the particleboard sample of corn cob used in this research work. According to ISO 9869 [15], the thermal conductivity of a conventional industrialized thermal insulation product must be less than 0.065 W/m°C, which happens with XPS and does not happen with the particleboard sample of the corn cob. This sample cannot be considered an insulation material, according to ISO 9869, but the proposed handmade corn cob particleboard is neither conventional nor industrialized and its thermal conductivity is very low when compared with other construction materials and has the advantage of being a natural and organic material.

On the other hand, the thermal insulation performance of the corn cob particleboard may be improved by refining its manufacturing process or increasing its thickness. Furthermore, these experimental results express the interesting thermal insulation potential of corn cob.

\[ U = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} (T_i - T_e)} \]  

(1)

6. Conclusions

In spite of the registered decrease of the corn plantation intensity that has taken place in the last years, this activity is still relevant in the Portuguese agricultural panorama. Corn and corn stalk have different uses but the corn cob is in general treated as an agriculture waste which requires to be burnt. Unfortunately, this option does not contribute to a better environmentally friendly world. Finding fields in which corn cob can be used will help solve this problem and also stimulate small industrial activities using low technology methods which may contribute simultaneously to the social and economical development of certain interior and rural regions of the north of Portugal. This possible benefit can also easily be achieved worldwide by adopting the
same procedure. At the same time, the recent figures related to the amount of corn produced in USA, China and Brazil, indicates that this agriculture waste is considerably abundant.

The building industry is one of those fields in which the corn cob can have an important role as an alternative sustainable raw building material. Substantial economic and environmental benefits can result from the adoption of this solution. Therefore, it is fundamental to undertake further research, in order to increase the knowledge of the properties of the corn cob and its processed products.

In terms of macrostructure, the corn cob presents three main differentiated layers clearly perceived by their color, texture, shape and density. In terms of microstructure, those layers are also different. The central layer has a regular alveolar microstructure in which the alveoli have an interesting regular geometric shape of thin walls filled with air. This alveolar microstructure type tends to dissipate from the inside to the outside of the corn cob. The microstructure of the most traditional Portuguese applied thermal insulation building materials (i.e. XPS, EPS, cork and expanded clay) were also delivered in this paper. A comparative analysis of the microstructure of the above materials made it possible to figure out that there are enormous similarities, which highlights the possible potential thermal insulation capacity associated to the corn cob. Moreover, it was also concluded that there are also interesting similarities in terms of the elementary chemical composition of the above materials, which reinforces this potential.

In order to study new sustainable building materials, based on corn cob, it is necessary to know in advance their properties, such as density, water absorption, fire resistance and thermal insulation capacity. Therefore, in this paper, an attempt at studying these properties was made. Samples of corn cobs picked up in the north of Portugal were used in the experimental work. The average value of the density of the corn cob was 212.11 kg/m³, with a variation of 5%.

In terms of water resistance behavior, corn cob and cork seem to have expressive water absorption. Due to its microstructural and material composition, which implies a capillary net existence and a water permeability tendency, the saturating process of the corn cob is gradual and progressive. The corn cob samples tested required over 15 days to become saturated. On the other hand, corn cob keeps its material integrity after being in contact with water for several days. Among the different tested materials in terms of water resistance behavior, corn cob and cork seem to have interesting similarities. Furthermore, the corn cob has a slow progressive combustion process characterized by the existence of flame and a black gas emission which contrasts with the low fire resistance capacity of the XPS and the EPS. Meanwhile, corn cob and cork seem to have similar fire resistance. An alternative experimental set up was applied in this research in order to estimate the potential thermal insulation capacity of the corn cob. A specific particleboard based on corn cob granulate was processed to this purpose, as an alternative solution for testing a single corn cob.

The experimental results show that the estimated value of the thermal transmission coefficient and of the thermal conductivity of the corn cob are 1.89 W/m² °C and 0.139 W/m °C, respectively, which are significantly higher than the corresponding values for the most common processed thermal insulation materials (i.e. XPS and EPS). However, the evaluated thermal insulation capacity is still adequate for building application purposes.

Further research is still required, in order to consider a more representative corn cob sample, to perform some of the above tests according to established standards (in particular the fire resistance test) and to study other properties such as the mechanical ones. However, the preliminary achieved properties suggest that corn cob may be an interesting raw building material. The several similarities found between corn cob and cork reinforces this idea. The corn cob can be used as raw material to produce thermal insulation products, light partition walls, ceiling coating, indoor doors and furniture.

References


