Energy and Buildings 80 (2014) 17–22

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Development of better insulation bricks by adding mushroom compost wastes

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ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form 5 May 2014
Accepted 6 May 2014
Available online 15 May 2014

Keywords:
Lightweight bricks
Thermal conductivity
Compressive breaking stress
Spent mushroom compost
Waste revalorization

ABSTRACT

This paper studies the application of spent mushrooms compost (SMC), as a new additive to produce bricks with better insulation and in a more sustainable way. The aim is to determine how SMC adding varies properties of fired clay bricks (FCBs), specially the thermal behavior, and whether it is a viable solution for recycling SMC. Clay was mixed with different percentages of SMC (0–17 wt.%) and formed by pressing. Samples were fired at the facilities of the partner's factory up to 950 °C. The influence of SMC on FCBs was related to its thermal conductivity (TC), compressive strength (CS), water absorption (WA), bulk density (BD), linear shrinkage (LS), apparent porosity (AP) and weight losses during firing (WL). As a result, a blend of clay with up to 17% SMC, limited by minimal CS and WA, may be used for masonry works with an enhancement on thermal behavior. Addition of 17% of SMC leads to a 26.17% decreasing in TC compare to those without SMC, achieving a minimum TC of 0.55 W/m K. This implies a reduction of 10% on the equivalent thermal transmittance, that means a better insulation of the buildings and thus this is an important energy saving.

1. Introduction

Lately engineers have been searching mainly for both enhancement properties of materials and new ways of reuse, reduce and recycling wastes (the so called 3R). It has been shown the use of these wastes in brick manufacturing as an optimal method to achieve those purposes [1–7]. In special, ceramic sector can incorporate different residues in a large amount due to the high temperatures in firing process through tunnel kiln [8–10]. Researches include the use of ash from the combustion of rice husk [11], sugarcane bagasse [12], etc., the addition of sludge from waste water treatment plants [13,14] or the mixing with different organic matter as sawdust, wine pomace, paper pulp, sawdust, coke, among others [15–20].

One of these residues is the spent mushroom compost (SMC). The production of mushrooms (*Agaricus bisporus*) involves growing them on a substrate. Once the mushrooms have been harvested, this substrate layer (the so called SMC) constitutes the main waste produced by mushroom producers.

The behavior and composition of SMC depends on its raw materials. Commonly SMC is made with water, straw (mainly from wheat), poultry manure (as an organic source of nitrogen), regulators such as ammonium nitrate or urea and gypsum minerals. This mixture ferments, with the mesophilic microorganisms being replaced by thermophilic fungi and bacteria by means of different temperature gradients. The next step involves pasteurizing and conditioning the compost in order to remove possible competitors of *A. bisporus* and *Agaricus bitorquis* (the main varieties grown). Also ammonia residues and simple carbohydrates are removed and thermophilic flora is deactivated, turning it into nutrient for mushroom [21].

Management of SMC supposes a challenge that has given rise to several projects. Its use as a fuel has been analyzed in depth in previous publications and its technical feasibility has been proven [22–24] however the profitability is still low [25].

Other solutions involve its use as fertilizers [26–28], as a covering for the recovery of landfills [29], as the basis of animal feed [30].

Related to bricks manufacturing SMC has been investigated as an additive for FCBs [31]. In this reference samples, made by adding

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http://dx.doi.org/10.1016/j.enbuild.2014.05.005
0378-7788/

Table 1
Elemental analysis of the clay used.

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	LOI
48.32%	0.83%	19.75%	5.07%	2.30%	7.71%	0.79%	2.93%	16.08%

only 3% of SMC were formed by pressing and then fired at 950 °C. Several properties were tested but thermal conductivity (TC) for fired samples has not been yet addressed.

In order to contribute to the further development of this way of SMC recycling, in this paper, different percentages of SMC were used for FCBs manufacturing. Special attention was paid to the TC in order to determine if SMC addition may improve thermal insulation of FCBs. From this point of view, SMC addition might be not only a sustainable way of recycling but an element which increases the thermal insulation for buildings. Therefore FCBs made by using SMC will provide lower wall thermal transmittance and thus an energy saving. In order to comply requirements abide by settled law for structural clay bricks [32] compressive strength (CS) and water absorption (WA) have been tested to determine the maximum percentage of SMC that can be added.

2. Preparation of the samples

The clay was provided by factory from the homogenization pit, in the so-called aging pit, where it is stored for two or three months before manufacturing. In this stage clay becomes homogeneous. This raw material was sent to Laboratorio Cerámico Sebastián Carpi [33] to determine dilatometric (see Fig. 1) and chemical composition (see Table 1).

The SMC used was provided by the Mushroom Technology Research Center of La Rioja. SMC composition varies highly, depends on several parameters [34]. Thus, Table 2 shows the results from years, carried out by this Mushroom Technology Research Center of La Rioja.

SMC were oven-dried at 110 °C until constant weight was achieved. Mean moisture content was recorded in order to determine, on a dry basis, the amount of SMC added. It should be noted that SMC was supplied with a suitable grain size, controlled by screening, guaranteeing a maximum size of 1.5 mm × 1.5 mm. However the granulometric fractions were not controlled.

Different percentages of SMC were added, ranging from 0% to 17%. These percentages extend prior studies ranges [31]. The dry-weight percentages of the SMC, added into the blend, are shown in Table 3.

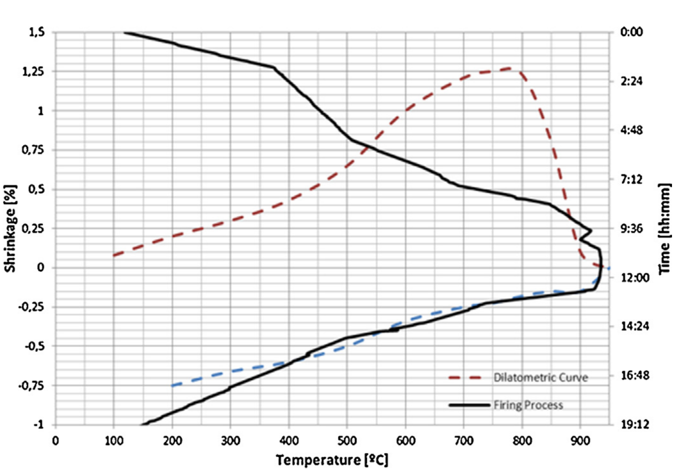

Fig. 1. Dilatometric curve (discontinuous line) and firing process (continuous line).

Due to the high financial cost and unnecessary environmental impact that involves the minimum clay load, settled by factory process (approx. 300 ton), samples were mixing and formed in the University facilities. At least 10 specimens for each group were molded using a uniaxial press machine, compressing blend under 25 MPa. This pressure is the same that take place in the manufacturing extrusion process. The mold was made taking into account that after firing process, test specimens did not shrink below 300 mm in any side. This requirement was settled due to the accuracy of the thermal measurement instrument. Samples shall fit perfectly inside the hot guarded plate to guarantee an accurate thermal conductivity measure.

Once samples were demolded, they were carried to bricks factory and inserted in the drying line and then automatically undergone to the firing process in a tunnel kiln. Stages of firing process can be seen in Fig. 1.

Before drying and after firing specimens dimensions were measured by using a caliper of ±0.01 mm and weighted in a balance ±0.1 g. according to EN 772-16:2011 [35]. Therefore linear shrinkage and weight losses may be carried out by calculations.

3. Characterization of the bricks

TC was determined by the normalized guarded hot-plate and flow meter method [36], using the WL-376 device manufactured by GUNT [37].

The samples had a surface of 300 mm × 300 mm, which fitted the area of both hot and cold plates perfectly. Thickness was on the range from 20 to 30 mm. Before testing, specimens were drying in a muffle furnace at 110 °C until constant weight was measured, as it is indicated per standard EN 1745:2002 [38].

TC was obtained at three different temperatures, once steady flow was established. The mean value of each sample was determined by linear regression extrapolating data for 10 °C as it is indicated by standard UNE-EN 12664 [39].

Table 2
Summary of elemental analysis of SMC.

	Mean	Maximum	Minimum
Moisture [wet weight percentage]	58.94	68.78	42.30
Ash [dry weight percentage]	43.56	67.73	32.28
Total nitrogen [dry weight percentage]	2.43	3.06	1.60
NH_4 [percentage of dry matter]	0.05	0.13	0.00
pH	6.91	8.50	6.29
Conductivity	6.75	8.35	4.27
Organic matter [dry weight percentage]	56.44	67.72	32.27
Carbon–nitrogen ratio	14.57	17.86	12.54
Gross heating value [kcal/kg]	2424.72	3058.30	2029.20

Table 3
Doses used in each series (d.w.c. is dry-weight of clay).

	AA00	AC05	AC11	AC17
Clay [g]	10,000.0	10,000.0	10,000.0	10,000.0
Additive [g]	–	500.0	1100.0	1700.0