Construction and Building Materials 147 (2017) 185–193

Contents lists available at ScienceDirect

Construction and Building Materials

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

Environmental characterisation of coffee chaff, a new recycled material for building applications

P. Ricciardi [a,*], F. Torchia [a], E. Belloni [b], E. Lascaro [b], C. Buratti [b]

[a] Department of Civil Engineering and Architecture, University of Pavia, Via Ferrata, 1, 27100 Pavia, Italy
[b] Department of Engineering, University of Perugia, Via G. Duranti, 67, 06125 Perugia, Italy

HIGHLIGHTS

- A new recycled material for building application is proposed: coffee chaff.
- Different sample thicknesses were produced and tested by means of impedance tube.
- Porosity and flow resistance were experimentally investigated.
- LCA was carried out for environmental analysis.
- Primary embodied energy and greenhouse gas emissions were determined.

ARTICLE INFO

Article history:
Received 27 November 2016
Received in revised form 12 April 2017
Accepted 13 April 2017
Available online 28 April 2017

Keywords:
Recycled sustainable materials
Life Cycle Assessment
Coffee chaff
Acoustic characterization

ABSTRACT

Coffee is one of the most frequently consumed drinks in the world. Coffee chaff, being the dried skin of the coffee bean, the husk, which comes off during the roasting process, is the only by product produced during the coffee beans roasting process. However, methods for the effective utilization of coffee chaff have not been developed. Reuse of coffee chaff, which is the primary residue from the coffee industry, is important for the environment and economy. Recently there have been some attempts to reuse the coffee chaff for energy production, biological materials, and as a nutrient source for solid-state fermentation. The purpose of this work is to propose coffee chaff as sound insulation and absorption material for the building industry. The experimental evaluation of the acoustic absorption properties of new samples made of coffee chaff was carried out. Different sample thicknesses were produced and tested by means of impedance tube, according to ISO 10534-2, showing a good behaviour at middle high frequencies. Porosity and flow resistance were also experimentally investigated. In order to highlight the environmental benefits, Life Cycle Assessment was carried out in terms of primary embodied energy and greenhouse gas emissions, considering a "cradle-to-gate" approach.

1. Introduction

In the European Union, the building sector is responsible for over 40% of overall energy consumption [1–4]. The reduction of carbon emissions due to the building sector is nevertheless mandatory [4]. New policies have been promoted all over the world to construct sustainable buildings and hence to reduce CO_2 emissions. Various studies showed that effective building insulation alone will save over one hundred times the impacts of carbon foot print from material usage and disposal [5,6]. At the same time, noise pollution is increasingly getting more attention amongst the construction industry as it is a major health concern [7] and demand for better noise insulating materials is increasing. The widely used insulation materials in the construction industry are the glass fibre based, which are derived from silica sources or other synthetic fibres derived from petroleum. Glass fibre based materials are known to have carcinogenic effects [8]. With new regulations and increasing demand alternative materials, development of materials which can provide both thermal and sound insulation will become a sustainable alternative. Recently new insulating solutions with recycled and discard materials are becoming more common on the market [9–13].

* Corresponding author.
E-mail address: paola.ricciardi@unipv.it (P. Ricciardi).

http://dx.doi.org/10.1016/j.conbuildmat.2017.04.114

The growing environmental awareness throughout the world has triggered a shift towards developing environmentally friendly materials from renewable resources. This work is focused on the acoustic and environmental characterization of coffee chaff, the dried skin of the coffee bean, which comes off during the roasting process. Coffee is one of the most widely consumed beverages [14] and with a production of 8 million metric tons per years represents one of the most important food products traded [15]. About 60 tropical and subtropical countries produce coffee extensively, being for some of them the main agricultural export product [16]. Economic importance of coffee is mainly due to the coffee brew or beverage and infusion prepared from the roasted and ground beans. Most coffee beverage consumed around the world is produced by the species Coffee Arabica (Arabica) and Coffee canephora (Robusta) [17]. Coffee plants belong to the botanical family Rubinaceae, which includes approximately 80 species. Two major coffee species are cultivated for drinking. Arabica coffee accounts for approximately 75% of global coffee production and Canephora, known as robusta coffee, accounts for approximately 24% of global coffee production. Coffee beans are roasted using dry heat at temperatures between 200 °C and 300 °C, with constant agitation to ensure oven heating. Industrial processing causes the removal of the husks, including the pericarp, outer mesocarp, pectin layer, endocarp, and part of the coffee chaff, from green coffee beans. During the roasting processes the residual coffee chaff is completely removed and the ground roasted coffee beans are finally used for coffee beverage production. Coffee chaff, given the volumes of crude coffee processed at present, is an industrial waste readily available in large amounts and in need for a definition of its potential value-added uses.

Since more than 50% of the coffee fruit is not used for production of the commercialized green coffee and, therefore, is discarded during processing, it should be interesting to find applications for these by-products. Up to now most progress has been achieved in their use for industrial purposes other than the building construction industry, such as energy production [18,19], adsorption of compounds [20] and manufacturing of industrial products, such as particleboards, ethanol, gibberellic acid, and α-amylase [21–23]. Nevertheless, it has been poorly investigated in the past and has been almost invariably used only as combustible or fertilizer. Few reports about coffee chaff have been published in the scientific Literature and it could become a potential candidate as a new sustainable materials for the building construction industry. Sustainable materials are products that provide environmental, social, and economic benefits while protecting the environment over their entire life cycle, from the extraction of raw materials until the final disposal. The whole life cycle of a material includes the extraction, the production process, the in-situ installation, the maintenance, and finally the disposal or the recycling procedures. Both natural materials and recycled ones could be considered eco-friendly materials: the first types derive directly from raw materials, such as wood, hemp, clay, pumice; the second ones are produced from discard waste materials or components and they represent an excellent alternative from an environmental point of view, allowing the reduction of the quantity of waste to be treated. Therefore, coffee chaff could have both the properties: it is a natural material and produced by the waste of the coffee. The importance of its applicability is also due to its thermal and acoustic properties: in particular materials with high porosity, such as coffee chaff, are very interesting because they can absorb the sound that enters their matrix and can be dissipated.

The novelty of this work is the proposal of the use of coffee chaff as sound insulation and absorption material for the building industry, since methods for the effective utilization of coffee chaff have not been developed. Four types of coffee chaff samples were produced: loose, glued, cold and hot pressed. In order to verify the samples resistance to high temperature Thermal Gravimetric Analysis (TGA) was carried out. Their acoustic absorption properties were investigated in the frequency range 100–5000 Hz. Different thicknesses were tested by means of impedance tube. Porosity and flow resistance were also experimentally tested by means of measurement set-ups, that were especially realised for this work. Being coffee chaff an industrial waste, Life Cycle Assessment was carried out in terms of primary embodied energy and greenhouse gas emissions, considering a "cradle-to-gate" approach, in order to highlight its environmental benefits.

2. Materials and methods

2.1. Description of the samples

In Fig. 1 the structure of the fruit of the coffee tree is showed. The coffee cherry is oval and approximately 10 mm in size. Coffee fruit is a drupe with an outer skin, or pericarp, usually green in unripe and red-violet or deep red in ripe fruits (even yellow or orange in particular cultivars). The pericarp covers a soft yellowish, fibrous, and sweet pulp (outer mesocarp), a highly hydrated layer of mucilage (the pectin layer), and a thin endocarp (the parchment). Finally, the so called "coffee chaff" covers each hemisphere of the endosperm, which represents the common coffee seed.

Green coffee beans are generally produced via two processes, purification and thresh process. The outer skin, pulp, pectic adhesive layer, and parchment are completely removed from the green coffee beans in these two processes. However, a portion of coffee chaff remains with the green coffee beans after their treatment.

Coffee chaff still remains attached to the green coffee beans and it is removed during roasting.

The samples investigated in the present paper were made of coffee chaff derived as the waste of the roasting process of an industry from the north of Italy (Pavia). Coffee chaff has been tested loose (Fig. 2a) and assembled by means of three different methodologies:

- glued coffee chaff (Fig. 2b);
- cold pressed coffee chaff (Fig. 2c);
- hot pressed coffee chaff (Fig. 2d).

The samples, realised in laboratory, are cylindrical disk with diameter of 29 mm e 100 mm and thickness variable from 1 to 4 cm, suitable to be tested in the impedance tube, in compliance with ISO 10534-2 [24].

For the realization of the glued samples showed in Fig. 2b, a cold-water-based polyurethane glue was used, having a density of 1.000 kg/m^3 and a glue percentage of 5,5% of the total weight of the sample. The cold press used for the realization of

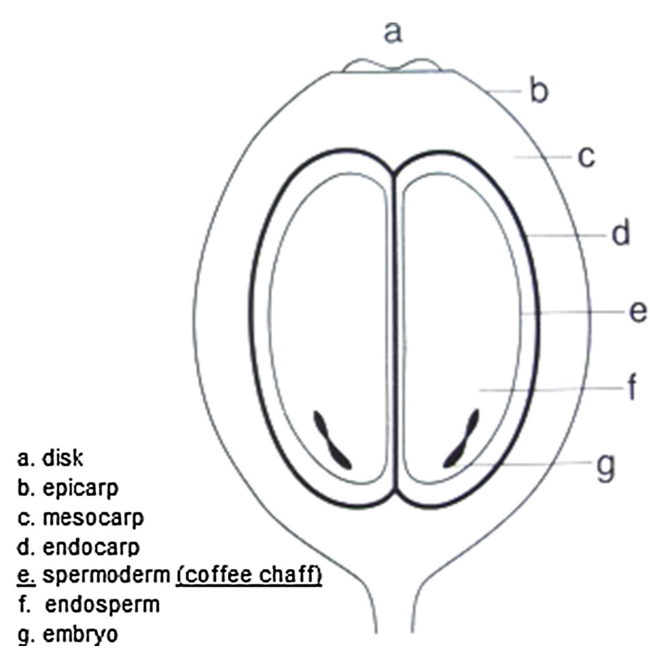

Fig. 1. Coffee fruit structure.