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Use of raw rice husk as natural aggregate in a lightweight insulating concrete: An innovative application

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HIGHLIGHTS

- Design of a lightweight insulating concrete based on lime and whole rice husks.
- Comparison of our new developed building material with hemp concrete.
- Rice husk concrete can compete with hemp concrete in terms of thermal insulation.
- Compressive strength of 0.33 MPa for 60 days old rice husk concrete with a density of 640 kg m^{-3}.

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ABSTRACT

As the building sector presents major impacts on the natural environment, the development of eco-friendly concrete materials using plant aggregates has emerged as a high priority. This kind of concrete allows moving towards a low carbon material with good thermo-physical properties. This is the case of hemp concrete made out of hemp hurd mixed with a lime-based binder. Hemp concrete is aimed at replacing usual systems based on concrete blocks and mineral wool. In this way, it can qualify as a multifunctional material which takes a clear position regarding the energy efficiency and the optimization of building envelopes.

This study deals with the development of an innovative insulating concrete having the same application than hemp concrete one but using rice husks.

Having examined physical and structural characteristics of plant aggregates, specimens made out of whole rice husks and a lime-based binder were manufactured by mixing and mechanical tamping. Both thermal and mechanical properties of the final concrete materials were studied in comparison to hemp concrete designed with the same process. The effects of an outdoor exposure of the specimens on the mechanical strength are discussed and the binding matrix mineral phases considered.

It is established that for a same binder on aggregates mass ratio, the target dry density of rice husk concrete is necessarily higher than those of hemp concrete due to the different physical and morphological properties of rice husks. Thermal measurements show that rice husk concrete can compete with hemp concrete in terms of thermal insulation with a dry thermal conductivity ranging from about 0.10 W m^{-1} K^{-1} to 0.14 W m^{-1} K^{-1} depending on the mix proportioning. Compression test results on a defined mixture intended to be used as a filling material in a wall timber frame highlight lower mechanical performances for rice husk concrete with an average compressive strength of 0.33 ± 0.03 MPa at 60 days compared to 0.48 ± 0.02 MPa for hemp concrete.

1. Introduction

Nowadays, the main challenges facing the building sector are focused on the improvement of its energy efficiency and the reduction of its environmental impact. In this context, eco-friendly materials using renewable and local resources are in full development. Over the last years, a significant increase of various research activities about eco-materials using vegetable resources has been reported. Examples of studied materials are hemp [1–3] and bagasse fibres [4], flax shives [5,6], hemp hurds [7–10] or sawdust [11,12].

This paper refers to lightweight insulating concretes using vegetable aggregates and mineral binders. Many works have been

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carried out on the combination of hemp hurd aggregates which correspond to the woody core of the hemp stem and alternative lime-based binders [7–10]. The resulting material is called Lime and Hemp Concrete (LHC). As it is fundamental to select carefully the raw materials to design sustainable and more comfortable low-carbon buildings, it makes sense to create interesting links between agriculture and building industry. The use of plant aggregates like hemp hurds benefits from a low energy required to transform the agricultural crops into hurds. Add to that, their neutral carbon footprint. The fact is that plants store carbon during their growth as a result of photosynthesis and the carbon remains locked within the plant material until it decays. Moreover, the absorption of CO_2 by lime partially offsets its release during the production of the binder. In this way, the association of plant-derived particles with a lime-based binder allows to design a carbon negative building material [13]. Furthermore, using lime helps regulate temperature and humidity within building because it is moisture permeable [11,14].

With a very low thermal conductivity generally less than 0.2 W m^{-1} K^{-1} [9] depending on the mix formulation, LHC meets the thermal requirements becoming increasingly demanding. This excellent thermal behaviour is due to the interconnected network of porosity which characterizes this material. Indeed, three levels of porosity are mentioned, that of the binder (nanometric), inside hemp particles (on average 10 μm) and the intergranular macroporosity that can reach up to several millimeters [9,15]. LHC is mainly used in individual housing as a filling material and it is often cast around load-bearing wooden structures for wall application. The corresponding mixture (called Wall mixture) has a dry density of about 450 kg m^{-3} [9] and a binder on aggregates mass ratio of 2. It is a compromise between thermal conductivity and compressive strength, which does not exceed 0.5 MPa after 60 days when the material is placed with a reasonable compaction load [9,16]. It seems clear that the mechanical properties of these plant-based concretes may be considered as the main weakness point. Indeed, hemp based concretes cannot be used as load-bearing materials.

This study deals with the use of rice husks to design a lightweight insulating concrete in the same way as for LHC. In research studies, the vast majority of lignocellulosic particles associated with a mineral binder come from plant stems, as it is the case of hemp hurds. Rice husks come from a totally different part of the plant since they correspond to the protective shell of the rice grain.

The growing of rice in France is limited to the Camargue area. Rice husks can be considered as agro-industrial by-products coming from the rice hulling. These crop residues represent about 20 wt% of the whole grain paddy rice harvested on spikelets [17]. Hence, rice farming produces nearly 20,000 tons per year of rice husk in France.

Currently, the use of rice husks is highly limited, these latter being regarded as waste materials often buried in the ground or used as a fuel. Indeed, rice husks can be consumed for electricity generation because of their high calorific value. However, the incineration process is dangerous to human health and to the environment. Therefore, rice husks cause critical problems in rice growing areas because significant volumes are generated and not used in a beneficial way [18].

The use of raw and whole rice husks in concrete materials without any burning has rarely been investigated. Few studies have examined the association of whole rice husks with hydraulic Portland cement. Most of the time, concrete materials are designed with a very small volume fraction of rice husks and sometimes even with sand. In these works [18,19–24], specimens are essentially studied in terms of mechanical performances. The density of the mortars and concretes is most of the time higher than 800 kg m^{-3}. Therefore, these materials are not really insulating but halfway between insulating and light structural according to some authors [22,24] who have proposed a classification of concretes depending on the density and the compressive strength (Table 1).

The approach of this paper is quite original since cereal husks are used in a lightweight insulating concrete designed with an identical way as for LHC. In this regard, rice husks will be considered as natural aggregates like hemp hurd ones and re-used as raw products.

Using rice husks in Languedoc-Roussillon to design an eco-friendly concrete like LHC is particularly relevant since rice husks are produced in Camargue, a natural area located in the heart of the region. This provides a perspective to design an innovative building material using a locally available agricultural waste.

Rice husks present many substantial advantages. They do not flame or smolder easily because of their peculiar silica–cellulose structural arrangement [23]. Moreover, given that husks do not biodegrade or burn very easily, they are sometimes free-of-charge. Add to that the availability of rice husks throughout the year because most farms store rice and process it on a daily basis. This is not the case of hemp which is grown as a break crop and harvested after 4 months [25]. Furthermore, hemp hurds result from an industrial grinding process to separate hurds from the fibres whereas rice husks are used as they stand, requiring no shredding.

The first objective of this work was to investigate the main key characteristics of rice husks, namely their physical and structural characteristics. Secondly, specimens made up of rice husks and a lime-based binder were designed on the basis of mix proportions used for LHC. This study aims at developing a husk-based insulating concrete with a dry density less than 800 kg m^{-3}. Then, the experimental program pays particular attention to the macroscopic properties of this innovative building material. As for the characterization of the raw particles, macroscopic properties were experimentally compared with those of a hemp based-concrete. Thermal properties were investigated on specimens designed in various mix proportions by changing the binder on aggregates mass ratio whereas compressive strength tests were conducted on the wall timber frame mixture previously stated.

To the best of our knowledge, only the study of Arnaud and Gourlay [9] examined the influence of different established relative humidity on the mechanical behaviour of LHC in laboratory conditions. In the present paper, the influence of two kinds of curing conditions on the mechanical behaviour was studied. Some specimens were kept inside, in a climate-controlled room and some were kept outside until compressive tests after 30 and 60 days that is to say these specimens were exposed to temperature and humidity variations.

2. Materials and methods

2.1. Raw materials

2.1.1. Natural particles

Two different crop by-products were used for this work.

- The first one was a commercial hemp hurd and it was taken as reference as it is already used in association with a lime-based binder and marketed for individual housing construction.
- Rice husk was selected as a local resource, coming from a nearby rice field (Biosud, Arles). In the present paper, rice husks were regarded as new lignocellulosic aggregates. The variety corresponds to natural husks, which means that they have not undergone any parboiling.

2.1.2. Mineral binder

The binder used in this study was a 50/50 wt% combination of natural hydraulic lime NHL3.5 and hydrated calcic lime CL90 (EN459-1 standard). The material density values are presented in Table 2.