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A chemical, morphological and mineralogical study on the interaction between hemp hurds and aerial and natural hydraulic lime particles: Implications for mortar manufacturing

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HIGHLIGHTS

- Microstructure at the interface between hemp hurds and lime in mortars.
- Delayed hardening of the lime due to the presence of hemp.
- High amount of vaterite after three months due to lack of water for the matrix.
- Need of further studies on the reactions between $Ca(OH)_2$ and hemp organic compounds.

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ABSTRACT

Mixing hemp with aerial or natural hydraulic lime gives rise to mortars with improved flexibility and insulation but with peculiar microstructure compared to lime-aggregate mortars. The chemical–mineralogical and morphological investigation carried out here shows that hemp absorbs most of the water present in the matrix, causing superficial deposition and scarce adhesion of the lime to the hemp. This also delays the hardening process, as demonstrated by the high content of portlandite, vaterite and calcium silicates found after three months of curing. Some modifications to the production and curing procedures are suggested to improve the microstructure and final performance of hemp-lime mortars.

1. Introduction

Mortars are among the most used and diffused building materials in new and old constructions all over the world. Although only three basic components (i.e. binder, aggregate and water) are needed to produce this composite material, a huge variety of mortar types are possible, due to the existence of binders and aggregates with different chemical, mineralogical and textural features. The variability of properties and characteristics typical of composite materials, achieved by adjusting the component types and proportions, is a distinctive feature of mortars, for example compared to natural stone. As a consequence, mortar is a versatile composite material with multiple uses in construction.

Furthermore, mortars are often made with additional components, called additives and admixtures, which modify the properties or improve already existing characteristics of the material [1]. The use of admixtures is an ancient practice in the field of construction, as indicated by Vitruvius in *De Archirectura libri decem* (15 BC). In particular, the addition of fibres (e.g. animal hairs, vegetable fibres) to mortars is an ancient and effective method of improving flexibility, adhesion and strength of mortars [2].

With a world production of 214,000 ton [3], hemp is one of the 10 major primary plants grown as source of bast fibres (i.e. fibres obtained from the exterior part of the stem) and hurds (i.e. inner woody part of the stem, also called shives), used for various

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industrial purposes, such as: textiles, cordage, panelling, biofuel, paper, plastic composites and building materials. In particular, the hemp hurd, which in the past was discarded (only fibres and seeds were used [4]), is now of great interest for the unique properties that confers to building materials. For example, the use of hemp-based mortar leads to a reduction of 12–17% in energy consumption in buildings [5]. Hemp-based mortars are also efficient CO_2-sequestering agents, thanks to the ability of both hemp bast fibres [6] and lime of absorbing CO_2 from the atmosphere (during crop and hardening, respectively). Furthermore, the use of hemp in the place of a stone aggregate allows the production of mortars with a very low bulk density (i.e. lightweight mortar), which makes them suitable for specific building applications (e.g. filling, rendering, etc.).

However, the formulation of a mortar composed of only lime and hemp hurds involves important changes of the main characteristics (i.e. chemistry, mineralogy, texture) and properties (i.e. hygric and mechanical behaviour, durability) of a typical mortar. In recent decades, the importance of studying hemp-lime-based mortars to understand the influence of the presence of hemp both at microscopic and macroscopic level is being taken into consideration. The hygric, mechanical and thermal properties of hemp-based blocks have been investigated [5,7–10]. However few studies relate the macroscopic properties of these peculiar composite materials with the microstructural characteristics at the interface between the matrix and the vegetable fibre [11–13] and still many unanswered questions remain about the interaction between such different components when they are mixed together.

In this work, we have studied the interaction between hemp hurds and three types of lime (natural hydraulic and aerial in form of powder and as a putty) from chemical, morphological and mineralogical perspectives. Morphological and chemical investigations of both fresh and dry hemp hurds were carried out to evaluate the differences between these two hurds, depending on the initial amount of water. Moreover, investigations on the lime particle size distribution and specific surface area and microscopical observations of the mixes have been performed to evaluate the adhesion of the lime particles to the hemp hurds. Finally, a mineralogical study has been carried out to evaluate if the contact of the matrix with hemp hurds somehow modifies the hardening process of the limes (mineral phases consumed and formed).

2. Materials and methods

2.1. Materials

The hemp, whose commercial name is Cannhabitat®, is produced by AgroFibre, Euralis (Cazeres, France) and was supplied by the Cannabric enterprise (Guadix, Granada, Spain; www.cannabric.com). Plants are usually collected at the end of summer and dried on site. The hemp hurd, which is the part of the plant used for construction purposes, is cut to elongated and flat particles of size in the range of 2–25 mm (Fig. 1). Both fresh (i.e. green, not dried) and dry hurd particles were investigated although only the dry hemp hurds were mixed with lime, as usual in construction.

Three different types of lime were selected for this study: a hydrated lime in the form of dry powder (CL90S [14]) produced by ANCASA (Seville, Spain); a hydrated lime in the form of putty stored under water for 2 years (CL90S PL), produced by ComCal (Barcelona, Spain); and a natural hydraulic lime (NHL3.5 [14]) produced by Socli, Italcementi Group. The lime:hemp:water dosage by volume was 3:5:2.5 for the limes in the form of a powder (CL90S and NHL 3.5). This dosage was chosen with the objective of producing suitable mixes for application as rendering materials. In the case of the lime putty (CL90S PL) the same volume of lime but a lower amount of water were used, since this lime already has 6% wt. of supernatant water. The difference in the water content was calculated considering the differences in the bulk density between the powdered (~540 g/L) and the putty (~1205 g/L) lime. In total, 30 samples of 4 × 4 × 16 cm were cured for three months under average conditions of T = 17 °C and RH = 75%. The mixes were named as: AL-dh (aerial lime CL90S + dry hemp); AP-dh (aerial lime putty CL90S PL + dry hemp); NHL-dh (natural hydraulic lime NHL 3.5 + dry hemp).

2.2. Study of the limes

X-ray fluorescence (XRF) was used to analyse the chemical composition of major and minor elements of the limes, by means of a Bruker S4 Pioneer X-ray fluorescence spectrometer with wavelength dispersion, equipped with a goniometer that analyses crystals (LIF200/PET/OVO-55) and a Rh X-ray tube (60 kV, 150 mA). Measurements were performed in a vacuum with a rotating sample. Semiquantitative scanning spectra were obtained using Spectraplus® software. Before the analysis, the lime powders (~5 g) were dispersed in KBr, deposited in an aluminium cup and then pressed at 10 ton to obtain a pressed pellet (40 mm sample disc).

The mineral phases of the three lime types were identified by X-ray diffraction (XRD) analysis, using a Panalytical X'Pert PRO MPD diffractometer, with automatic loader. Analysis conditions were: radiation Cu Kα (λ = 1.5405 Å), 3–60° 2θ explored area, 45 kV voltage, 40 mA current intensity and goniometer speed using a Si-detector X'Celerator of 0.01° 2θ/s. The identification and semi-quantification of the mineral phases (portlandite, calcite and calcium silicates) was performed using the X-Powder© software [15]. In particular, the identification of calcite indicates that a partial transformation of the lime occurred; therefore XRD analysis was used not only to identify mineral phases in the limes but also to control their prior carbonation during sample preparation.

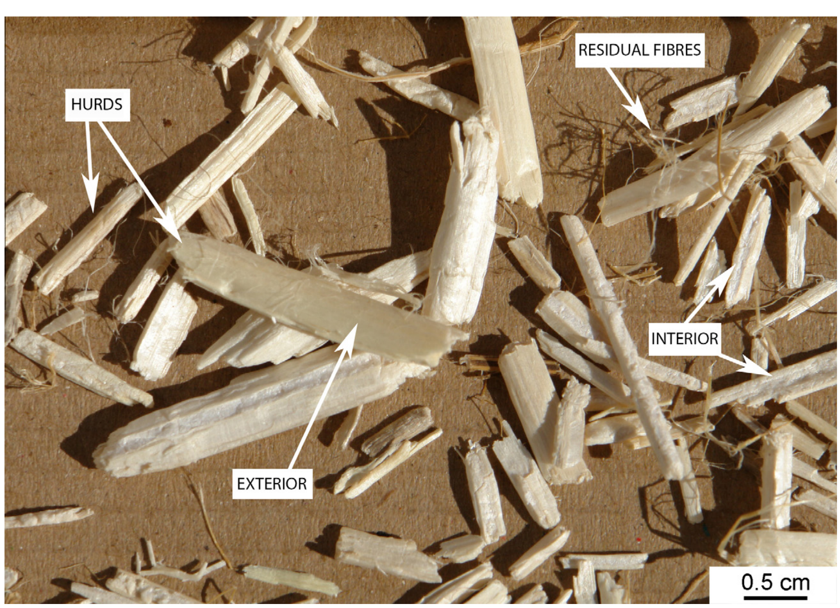

Fig. 1. Dry hemp hurds. Interior and exterior indicate the concave and convex surfaces of the hemp hurds, respectively.