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Optimization of lime and clay-based hemp-concrete wall formulations for a successful lime rendering

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HIGHLIGHTS

- Drying time of compacted-hemp concrete blocks is increased by the presence of clay.
- 2-weeks-rendered blocks show more intense pigmentation and microbial colonization.
- Lime putty maintains higher RH underneath the render than natural hydraulic one.
- Aragonite on lime putty render is an evidence of the higher RH and organic content.

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ABSTRACT

Different pathologies may arise on a wall finish if this is applied on a hemp-based rammed wall that is not completely dry. By simulating uneven drying and early-rendering of load-bearing and non-load-bearing hemp concrete blocks (made with natural hydraulic lime only or a mix of lime with clay) and studying them by means of chromatic, microbiological, textural and morphological investigations, we found that: it is advisable to wait at least ten weeks before rendering; adding clay to hemp concrete delays drying, leading to more intense deterioration of the render; natural hydraulic lime is the preferred binder for rendering hemp concrete.

1. Introduction

1.1. Hemp-based building materials

Hemp is a fast-growing, renewable and carbon sequestrating plant [1] that is crop annually for several industrial applications [2], such as food, bio-fuels, packaging, pharmaceutical products, automobiles and building materials [3], among others. To obtain a composite building material made with hemp, the inner part of the hemp stem is cut into pieces or particles (called shiv or hurds) that are mixed with a binder (or a mix of different binders, e.g. lime + cement, lime + clay) and water in different dosages according to the intended function in the building. The resulting product, called hemp concrete, shows high water vapour permeability and flexibility, little shrinkage and is effective in improving thermal and acoustic insulating properties and in regulating relative humidity in the building [4,5].

When in the fresh state (i.e. right after mixing), the hemp-lime concrete can be either moulded or sprayed in conjunction with timber frame for wall insulation and finish, casted in prefabricated panels and blocks to build solid walls or used as infill [4], or even compacted to build rammed earth walls. The fabrication of cast blocks and rammed walls can vary in cost as their composition may differ according to their function as load-bearing or non-load-bearing materials. In the former, indeed, more binder or a small aggregate is added to increase mechanical strength [6]. Besides, cast and rammed hemp concretes show different performances in the building compared to sprayed hemp concretes, as the former are denser and heavier and therefore provide lower thermal insulation [4]. In particular, the hygrothermal properties of hemp concrete change depending on the application process,

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as sprayed concrete lead to faster drying time in comparison to compacted processes; furthermore, intense compaction increases the material density and drying time [7,8]. The drying kinetics of this peculiar material will therefore depend on three main factors: water dosage, application method and exposure conditions (RH, T, solar radiation and wind pressure, providing protection against rainfall).

Estimating the drying time of hemp concrete is fundamental in the view of applying a wall finish, which ideally would be a lime render or plaster. Bevan and Woolley [4] suggested to let cast and rammed hemp concretes dry out for 28 days under normal conditions or 7–10 days (if spray-applied) before the application of a wall finish, but they also recognise that, owing the hygroscopic nature of hemp, hemp concrete cannot be absolutely dry. Colinart et al. [7] also reported that, whatever the formulation (lime, hemp and water dosage) and the drying modes (forced or free convection), the mass of prefabricated blocks is stabilised after approximately 3–4 months since their preparation, at an average RH of 45%. According to their results, ambient conditions are sufficient to cure every type of hemp concrete block and drying can be accelerated by subjecting all the faces to natural convection rather than only one.

1.2. Hemp-based rammed earth walls

Today the inclusion of straw, flax and hemp fibres is increasingly considered as a good method of improving the hygrothermal performances of rammed earth walls [9].

On the basis of the investigations on the drying process of prefabricated hemp concrete blocks commented above, we understand that predicting the drying kinetics of hemp-based rammed earth walls can be an even harder task, especially because environmental conditions are often far from the ideal values and it can be difficult to maintain them constant during construction. Moreover, rammed earth walls are built by compaction method, so drying is slower than in pressed blocks. And also, drying is unlikely to occur evenly in the building, considering that walls have different orientation (i.e. different exposition to sun radiation and wind pressure). As a consequence, it is not unlikely that a protective coating (plaster or render) is applied before the rammed earth wall has completely dried out. In this case, the coating would reduce and delay vapour diffusion [10] and water would be retained longer in the hemp concrete to the detriment of both the wall and the coating performance, especially in relation with its moisture buffering ability [11] and the risk of microbial growth [12], the latter enhanced under moist conditions on materials with organic components (such as hemp concrete) [13]. An example of the pathologies (e.g. yellowish stains and deposition) that are likely to arise in renders and plasters applied on rammed walls made with hemp is shown in Fig. 1.

It is worth highlighting that, although rammed earth walls are often left without any wall finishes, coating is sometimes required to prevent degradation of the surface (in the form of dusting and cracking) due to exposure to wind and rainfall, as well as to improve thermal insulation of the wall [9]. Therefore, the causes of the deterioration forms shown in Fig. 1 need to be understood and prevented to ensure the function of the render or plaster as a protective coating.

In this work we claim to simulate this negative scenario, fabricating hemp-earth blocks with the same method applied for rammed earth walls (by compaction) and letting them dry for a short time before the render application (2 and 10 weeks), through only one surface (the rendered one) and at high relative humidity (RH = 90%) without ventilation. Simulating incomplete drying before rendering at 2 weeks allowed us to investigate the pathologies arisen, by means of chromatic, microbiological, textural and morphological investigations. According to Delgado et al. [13], indeed, this period is the shortest possible time needed for mould growth to start. The same studies were carried out on blocks rendered after 10 weeks of drying, so as to compare the behaviour of wet and dry rendered hemp-earth blocks.

Furthermore, a mineralogical study of the renders was carried out to investigate the outcome of their hardening processes under these conditions. Four types of rammed earth walls made with hemp were reproduced here: load-bearing (with sand) and non-load-bearing ones (without sand) prepared with two different binders (natural hydraulic lime and a mix of natural hydraulic lime with clay). Two types of renders were prepared with lime putty and natural hydraulic lime as binders. Cement render has not been taken into consideration as its use is not recommended for rammed earth walls [9].

The final aim of this study is to estimate an appropriate time for rendering earth walls made with hemp. Furthermore, we aim to understand the influence of the addition of clay to the hemp concrete and of the type of binder used for rendering on the drying behavior of the hemp-earth blocks, with the purpose to improve their durability.

2. Materials and methods

2.1. Raw materials

The components used for the fabrication of the whole blocks (hemp concrete + render) were: natural hydraulic lime (grey

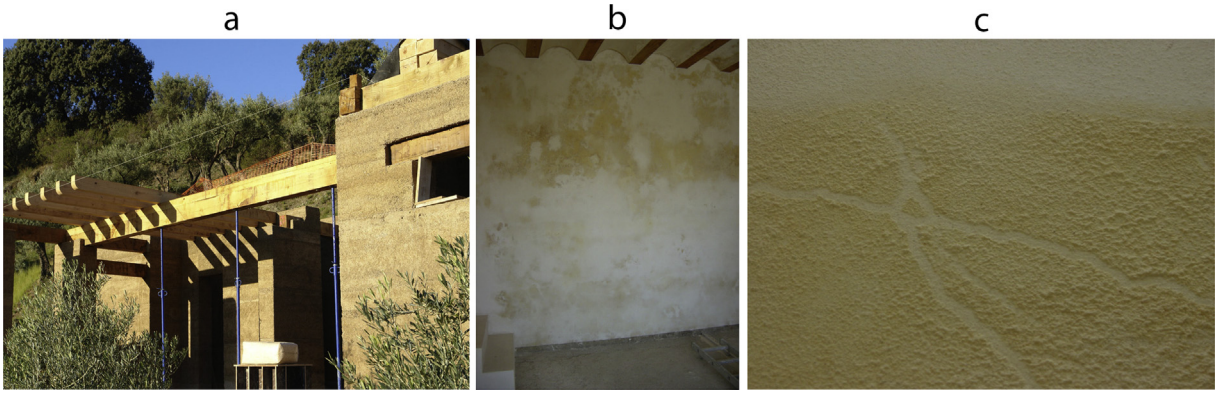

Fig. 1. (a) A house built with rammed hemp concrete walls; (b) pathologies arisen on the plaster of a hemp concrete wall on the inner Northern side of a hemp concrete building (c) detail of the powdered aspect of the yellowish deposition on the same plaster. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)