IOP Conference Series: Materials Science and Engineering



# Hempcrete - modern solutions for green buildings

To cite this article: M L Lupu *et al* 2022 *IOP Conf. Ser.: Mater. Sci. Eng.* **1242** 012021

# Hempcrete - modern solutions for green buildings

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**Abstract.** It is widely established that the building industry has a negative impact on the environment and a significant influence on the phenomena that contribute to climate change. Traditional construction materials, such as cement, contribute considerably to environmental pollution. Given the enormous quantity of energy and materials used by the construction sector, this industry must adopt more sustainable practices. Nowadays, an increasing number of natural building materials are used in the structural component or the insulation of buildings. As a result, natural construction materials may be a superior alternative to accomplish this goal. This article discusses the features and applications of hempcrete in the building industry. Hempcrete is a sustainable material composed of industrial hemp, lime as a binder, and water. Due to hemp's porous structure, it has deformation capacity, sound-absorbing qualities, better hygrothermal properties than conventional concrete, and, depending on the proportions of hemp, lime, and water, fire resistant capabilities due to the presence of lime.

## 1. Introduction

In comparison to other key sectors of human activity, the building industry has a substantial impact on the environment via the use of natural resources and energy. These consumptions result in pollutants being emitted and non-renewable natural resources being depleted. To address these issues, it is vital to limit energy usage and to utilize materials that have a low environmental effect [1].

Combating climate change has been a main priority for a multitude of UN organizations. The New Urban Agenda, which was endorsed in October 2016 at the United Nations Habitat III conference in Quito, Ecuador, was mostly focused on the sustainability and energy consumption of built environments in order to enhance lives and battle climate change [2]. As a result, interest in green buildings will spike in the next years. The World Green Building Council defines a 'green' building as "a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment" [3]. Latest developments in green building design integrate passive as well as active technology designed to increase a building's energy efficiency. While adopting such energy-efficient construction is certainly advantageous, using conventional building materials has a negative impact on the environment. To minimize building energy usage, phase change materials, passive house approaches, and other comparable strategies are being investigated [4, 5]. On a related note, scientists have been researching a relatively new concept known as geoengineering, which entails the intentional, large-scale modification of the environment in order to mitigate certain symptoms of anthropogenic climate change [6]. It was proposed that this environmental manipulation may be accomplished via the use of carbon dioxide reduction (CDR) measures and albedo modifications (AM). Reforestation and afforestation, bioenergy with carbon capture and storage (BECCS), and accelerated weathering are just a few of the $CO_2$ reduction techniques that have proved the potential to capture or remove several gigatons of $CO_2$ from the atmosphere, thereby minimizing the effects of anthropogenic climate change [7, 8]. Thus, commercial cultivation of fast-growing crops/plants such as hemp, sisal, jute, flax, kenaf, and hazelnut must be considered.

Meanwhile, scientists began exploring the possibilities of biomass products as construction materials. Hempcrete, hemp lime, lime-hemp concrete (LHC), or hemp concrete is a kind of cellulose aggregate concrete made from hemp hurds or shivs with a lime-based binder. Hemp concrete is a subset of a broader category of building materials that incorporate bio-based aggregates and a mineral binder. These materials are referred to as cellulose aggregate concrete (CAC) [8], bio-aggregate-based building materials [9], agro-concretes, or vegetal concretes [10]. This article disseminates information on the several features of hempcrete and its uses in building construction that has been investigated and collated via a study of pertinent research published by different writers.

## 2. Mechanical, thermophysical and acoustic properties

Hempcrete is a composite material made up of three components: hemp, binder, and water. Hemp aggregates are the non-fibrous portion of the hemp stem, referred to as "shiv" or "hurd", which exhibits a unique porosity.

The binder is typically lime-based, however some formulations (for example, combining pozzolanic material and hydraulic binder) are utilized to enhance hemp lime's effectiveness. Hempcrete, commonly known as hemp lime, has pores of varying sizes [11]:

- Macropores (up to 1 cm in diameter) caused by the irregular arrangement of hemp shiv in the mix;
- Mesoporores (0.1 to 1 mm) between shiv and binder (trapped air);
- Micropores between hydrates in the binder matrix (less than 0.01m);

This wide range of porosity, which is unique to hemp lime, has a significant effect on the material's thermal, acoustic, and hygrometric properties. Obviously, the microstructure of hemp lime varies with the ratio of hemp to binder; porosity varies with the origin and manufacture of shiv; and density varies with the ratio of hemp to binder and then with the kind of application (walls, roofing, roughcast) and installation method (manually, by projection machine, projection distance). As shown in table 1, a variable density value has an effect on thermal and mechanical performance [12].

**Table 1.** Mechanical and thermal properties of hempcrete as a function of the ratio of hemp to limestone [12].

| Application | Shiv : binder proportion (by mass) | Target density [kg/m$^3$] | Typical ultimate compressive strength [N/mm$^2$] | Typical thermal conductivity λ [W/mK] |
|---|---|---|---|---|
| Roof | 1:1 | 220 | 0.05 | 0.06 |
| Wall | 1:1.5 | 275 | 0.11 | 0.06 - 0.09 |
| Wall | 1:2 | 330 | 0.22 | 0.09 - 0.115 |
| Wall | 1:2 compressed | 440 | 0.35 | 0.115 |
| Floor | 1:3 | 500 | 0.8 | 0.13 |
| Floor | 1:4 | 600 | 1.15 | 0.14 |
| Pre-cast Structural | 1:4 compressed | 600-1000 | 2 - 6 | 0.14 - 0.27 |

Several compression tests demonstrate this material's exceptional ductility, which enables large deformations and load absorption without delicate fractures or macroscopic cracks. However, compression resistance approaches very low levels, necessitating the use of other structural forms (timber, steel or concrete structures).

Numerous variables have an effect on mechanical characteristics [13]: chemical structure of the binder; composition of the mixture [14, 15] (an increase in lime concentration increases resistance but decreases non-fragile behavior); aging (mechanical performances increase during the first two years); treatment conditions (in shifting humidity levels); shiv nature and dimension (resistance increases with larger but also decreases with longer particles); degree of compactness (greater resistance but lower porosity); thermal properties with increased compacting strength); particle orientation in the mix for anisotropy [15, 16]. In general, it is feasible to consider compression resistance as follows:

$$\sigma_{max} < 1\,MPa \tag{1}$$

Regarding dimension variations, retreat deformations are seen at 20°C, 50% HR, and a rate of about 3 mm/m after 75 days of drying [17]. Due of hempcrete's high porosity, it is very responsive to liquid water. A water absorption test [18] demonstrates hemp's rapid absorption capacity: its degree of saturation is more than 95% after ten minutes of immersion. The exchange of water between hemp and lime is critical throughout the component mixing process, since hemp transfers water to lime during the hydration phase. It is critical to monitor water dosage carefully, since an excessive amount may result in some excellent yields during the drying process.

The hygrothermal and acoustic properties of a material are highly dependent on its composition (formulation and material matrix) and porosity [19]. With regards to thermal characteristics, it's worthwhile to highlight a few key terms: thermal conductivity (λ), specific heat (c), and thermal diffusivity (α). The first one describes a material's capacity to conduct heat. It is dependent on the type and content of the mix, the installation, and the presence of water in the material in hempcrete. In general, it is feasible to examine the following:

$$\lambda = 0.06 \div 0.2\,W/(mK) \tag{2}$$

Specific heat enables the quantification of an element's ability to absorb or release energy due to thermal changes, — in other words its capacity to store heat. It was determined or quantified in a variety of research using various characteristics such as density, the presence of water, and the moisture formulation [20]:

$$c = 940 \div 3000\,J/(kgK) \tag{3}$$

Thermal diffusivity is a property of materials that indicates their capacity to convey temperature fluctuations; it is determined by their density, conductivity, and capacity.

$$\alpha = 0.98 \cdot 10^{-7} \div 3.02 \cdot 10^{-7} m^2/s \tag{4}$$

The excellent acoustic behavior of hempcrete was shown in acoustic experiments. Due to the material's unique porosity, it exhibits a high absorption coefficient ($\alpha_a$). It was determined in relation to various frequency and mix formulations [21].

$$\alpha_a > 0.9\ (100Hz \div 200\ Hz) \tag{5}$$

$$\alpha_a > 0.6\ (400Hz \div 500\ Hz) \tag{6}$$

$$\alpha_a > 0.6\ (1000Hz \div 2000\ Hz) \tag{7}$$

## 3. Comfort aspects

Currently, comfort issues are quite widespread. Even though structural aspects are critical for human safety, how people feel at home or at work has an effect on their productivity. A discomfort sensation might result in health complications, discontent, or energy waste.

Thus, it is essential to consider not only the mechanical properties of materials but also their thermal, hygrometric, and acoustic properties.

### *3.1. Acoustic characteristics*

Noise protection (from the external environment or adjacent rooms) and noise absorption are critical in both residential and commercial structures. Absorption is mostly determined by porosity. In the case of hempcrete, some measures are made based on material qualities and structural systems [22].

Cerezo's research reveal that hempcrete, due to its high porosity, has absorption coefficient values between 0.3 and 0.9 at frequencies of 100 - 200 Hz [12] . These values are especially interesting when contrasted with those of other more conventional materials, such as cellular concrete (porosity between 0.2 and 0.3), which has a mostly closed porosity.

The formulation and thickness of samples may be exploited to enhance their acoustic qualities.

With a large lime dose, the absorption peaks are shifted to lower frequencies, limiting the global amount of absorption. Additionally, increasing the thickness results in a reduction of the absorption peaks without a significant change in absorption.

Bütschi et al. also conducted studies on phonic insulation in hempcrete bricks with a thickness of 31 cm and a density of roughly 700 kg/m$^3$ [23]. Acoustic intensity levels range from 43 dB when using raw hempcrete to 47 dB when using plaster on two wall facing.

Another research revealed that hempcrete absorbs sound due to its porosity. Gle et al. have also demonstrated that altering the ingredients and manufacturing technique of hempcrete may affect its acoustic absorption [24].

### *3.2. Hygrothermic characteristics*

Thermal comfort is one of the most key design parameters nowadays due to its impact on energy waste: high-performance buildings and user well-being enable energy load reduction and improved health. Several studies on the hygrothermic behavior of hemp lime [25, 26] demonstrate the difficulties of the issue because to the complexity of the physical transfer of water vapour and liquid water, making it critical to accurately define the material and do more research on the subject. Phase altering nonlinear occurrences are related with energy release and absorption. These factors enhance insulation performance by maintaining a steady ambient temperature.

The Bath University study demonstrated significant stability of conditions in an experimental building constructed of hempcrete and timber (called HemPod) in concepts of Relative Humidity and Temperature when comparison to a mineral wool-insulated timber-framed building, indicating that hempcrete can help reduce daily interior Relative Humidity variations [27].

Hempcrete is known to have phase change qualities as a consequence of its latent heating effects, these are a consequence of the material's high heat capacity paired with its permeability and high moisture absorption capacity. The connection between relative humidity and thermal capacity of a hempcrete wall is seen in figure 1. Thus, whereas thermal bridges created by mortar joints boost heat fluxes, they are reduced by moisture absorption during periods of high humidity. Moreover, the quantity to which moisture migration suppresses is unknown [28, 29].

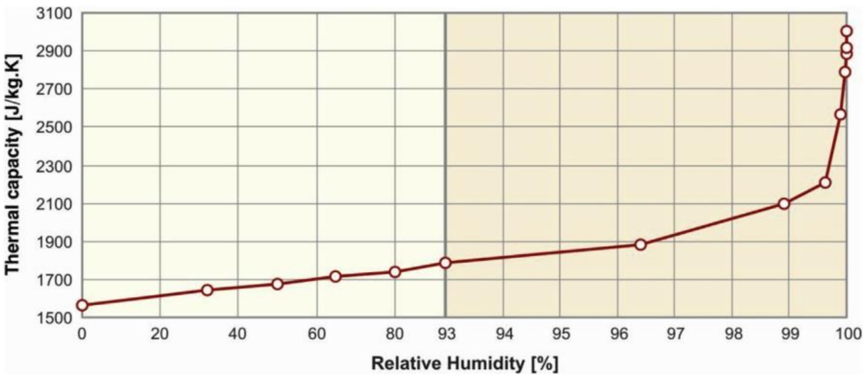


**Figure 1.** The relation between Relative humidity of hempcrete and its thermal capacity [30].

### *3.3. Reaction to fire*

Fire response is essential to evaluate since it related to building safety, which has an effect on construction permits and insurance. This is, though, a relatively unexplored feature of hempcrete, with a small number of investigations. However, the research have unanimously acknowledged hempcrete's superior fire resistance [31]. Fernea et al. [32] discovered that hemp concrete passed the fire test standards in their examination of the material's response to fire. The investigated samples were constructed as an acoustic absorption medium using lime and water. Three samples were investigated with a constant volume of lime and a variable hemp/lime ratio. The ratios were 1:1, 2:1, and 3:1, respectively. The sample with a 2:1 ratio was used as a control/reference. The water-lime ratio was maintained at 1:2 throughout. No information was provided regarding the curing period. The samples were subjected to a fire reaction test in accordance with SR EN520/A1:2010 [31].

As part of their multi-criteria research, Sassoni et al. investigated the fire resistance of a hemp composite. The samples were classified as low density (LD; 330 kg/m$^3$) or medium density (MD; 640 kg/m$^3$). The fire resistance test was done in accordance with EN 13823, and the LD samples passed with a class 'C' rating, while the MD samples passed with a class 'B' rating [15].

## 4. Environmental studies

Environmental issues arise all across the agriculture and construction processes. Concerning the agricultural process, hemp cultivation may have a negative influence on the environment owing to the use of nitrogenous fertilizer and transportation (see table 2). Performance of hemp hurd may be enhanced by minimizing nitrogen fertilizer use and cultivating hemp types that make the greatest use of available nitrogen. Reduced travel distance for the hemp straw would also enhance its environmental performance; in the case of France, transportation issues are overcome by widespread hemp production across the country. Concerning the construction process, the research emphasizes the beneficial influence on the greenhouse effect of a hempcrete wall's potential to operate as an overall carbon sink for at least 100 years [33]. The manufacturing of lime-based binder is the single largest contributor to greenhouse gas emissions, non-renewable energy usage, photochemical ozone generation, and resource depletion. Transportation is the primary contributor to ozone layer degradation and the second largest contributor in terms of effects on non-renewable energy use and the greenhouse effect. Reduced greenhouse gas emissions from the production of lime are contingent on its manufacturing sector. Reduced transportation time between the facility manufacturing the lime binder and distributors would also boost the construction stage's total potential effect. Additionally, the environmental performance of end-of-life products may be enhanced with the inclusion of recycling choices or recovery methods [34]. Hempcrete has a remarkably low ecological impact compared to other building materials since it can retain roughly 35 kg of $CO_2$ per square meter of wall (25 cm thickness) during a 100-year period.

**Table 2.** Environmental impacts of hemp culture - Life Cycle Assessment [34].

| Impacts | Production of raw materials | | Construction | Use | End of life | Transport | Total |
|---|---|---|---|---|---|---|---|
| | Hemp hurd | Other materials | | | | | |
| Resource depletion (kg Sb eq) | $2.8\cdot10^{-2}$ | $7.7\cdot10^{-2}$ | $1.2\cdot10^{-3}$ | 0 | 0 | $2.6\cdot10^{-2}$ | $1.3\cdot10^{-1}$ |
| Atmospheric acidification (kg $SO_2$ eq) | $5.1\cdot10^{-2}$ | $4.8\cdot10^{-2}$ | $1.3\cdot10^{-3}$ | 0 | 0 | $5.1\cdot10^{-3}$ | $1.1\cdot10^{-1}$ |
| Greenhouse effect 100 years (kg $CO_2$ eq) | -45.9 | 23.1 | 0.2 | -13.6 | 0 | $6.7\cdot10^{-1}$ | -35.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Destruction of $O_3$ layer (kg CF-11 eq) | $7.1 \cdot 10^{-7}$ | $3.3 \cdot 10^{-6}$ | $3.4 \cdot 10^{-7}$ | 0 | 0 | $5.7 \cdot 10^{-6}$ | $9.9 \cdot 10^{-6}$ |
| Formation of photochemical $O_3$ (kg $C_2H_4$ eq) | $7.1 \cdot 10^{-4}$ | $4.2 \cdot 10^{-3}$ | $5.0 \cdot 10^{-5}$ | 0 | 0 | $3.8 \cdot 10^{-4}$ | $5.4 \cdot 10^{-3}$ |
| Nonrenewable energy (MJ) | 52.3 | 265.8 | 19.9 | 0 | 0 | 56.3 | 394.2 |
| Air pollution ($m^3$) | 674 | 207.2 | 19.9 | 0 | 0 | 128.2 | 1024 |
| Water pollution ($m^3$) | 4.3 | 2.2 | $6.1 \cdot 10^{-2}$ | 0 | 0 | $1.1 \cdot 10^{-1}$ | 6.7 |
| Generation of waste (kg) | 6 | n.a. | 0.9 | 0 | 98 | n.a. | 104.9 |

## 5. Manufacturing

Hemp hurd, which are generally free of fibrous layers, are treated in a hammer mill to reduce them to fragments no bigger than 40 ± 5 mm in their widest diameter [35, 36].

**Figure 2.** Molded hempcrete [35].

Sinka et al. utilized hemp hurds with an average length of roughly 15 mm and the longest hurd particle measuring 55 mm in their investigations [36]. Alternatively, some commercial methods use the decorticator, which simultaneously separates the fiber from the whole hemp straw and reduces it to minute particles. The binder is mostly composed of hydrated lime with a little amount of pozzolanic material or a commercial hydraulic lime-based binder. Hempcrete walls may be constructed on-site in two ways: by pouring the mixture into a temporary formwork and manually tamping it (see figure 2), or by spraying the material onto the target location using the projection method (see figure 3). Both processes result in low compaction, and there is no control over the material's maturation conditions.

**Figure 3.** Sprayed hempcrete [37].

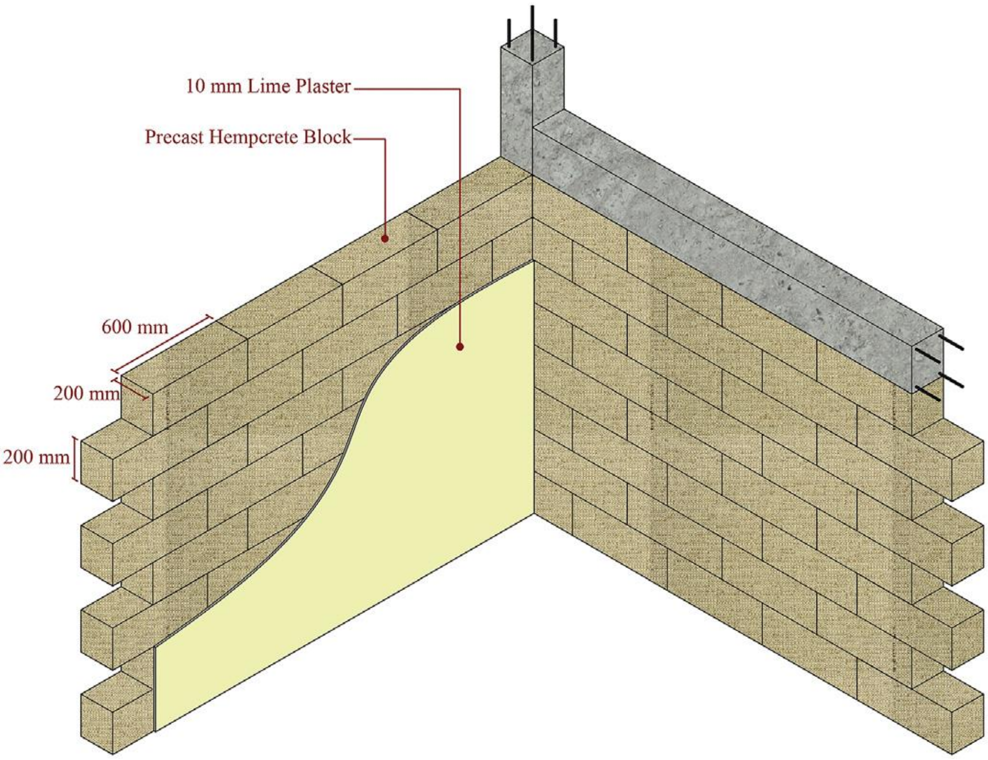


**Figure 4.** Wall assembly made of large hempcrete blocks [30].

Recent developments in the industry show a higher interest in pre-cast blocks rather than cast hemp concrete walls [38, 39]. Some innovations also help with stacking the blocks without mortar joints through physical interlocking [40]. Figure 4 illustrates how pre-cast blocks are used to build infill walls using conventional masonry in a reinforced cement concrete frame [30]. Some of the advantages of pre-cast blocks are:

- controlling the compression applied to the mixtures ensures uniformity in mechanical strength and performance;
- they may be cured individually and then transported to the site, removing seasonal limits from the building process.

Numerous studies have shown that hempcrete outperform equivalent conventional materials not just in terms of embodied energy, but also in terms of net $CO_2$ emissions during the average building's whole life cycle. This is mostly due to hemp's active carbon sequestration throughout the growth period, as well as its rusticity, which requires little agronomic input. Additionally, the minimal number of operations necessary to manufacture the wall (electricity is required to combine hemp and lime) affected the outcomes favorably. Gradual carbon sequestration by lime carbonation after construction, as seen in previous studies, might further enhance the carbon balance, and this could be the subject of future study [41, 42].

## 6. Conclusion

This research enables some thoughts on the real-world uses of hempcrete in relation to envelope technology. Although the material cost is two to three times that of standard insulating materials (such as mineral wool), it is suitable when considering sustainability and hygrothermic performance. Aspects of hemp concrete that are critical include practice and technique.

The hemp variety is determined by climate and producer . With comprehensive control across the whole manufacturing process, it would be successful in developing a hemp variety with very well dimensions and quality features. Given the friable nature of hemp, this may not be easy.

Concerning implementation, projection equipments are not standardized, and it is critical to instruct employees prior to applying the material on the construction site, since material qualities might vary depending on the projection method, distance, and compactness. The mixing formulation demands extra attention throughout the installation phase and for achieving the project's desired thickness. However, the ease of installation enables rapid construction and opens up several application domains. Without a defined standard, the quality of building components is determined by the installation's best practices. In terms of mechanical properties, hemp lime cannot be considered a structural component due to its insufficient compressive strength (1 MPa).

To achieve good thermal performance and a low U value hempcrete walls must be thicker (30 cm). However, it is essential to keep in mind that this is the ultimate thickness, in contrast to other insulating materials that are linked to substructures, and that the benefits of interior thermal comfort are achieved not only via thermal resistance, but also through hygrometric behavior. Since a result of these benefits, hempcrete may be an intriguing alternative to typical insulating materials, as it enables the structure to breathe.

Another advantage is the broad range of applications in both new and existing buildings, but there are a few limitations in terms of building typologies. The height of the building is limited if it is entirely composed of hempcrete and timber structure (a steel or concrete structure has more environmental consequences); the significant thickness of the walls consumes useful surface; in terms of visual characteristics, hempcrete surface, even with smooth work, retains a "rustic" appearance. A viable option is to use an indoor hempcrete plaster in residential structures to enhance their interior acoustic performance.

In terms of energy consumption, a repair of an envelope component with a hempcrete coating results in a decrease of consumptions in particular types of residential buildings due to the hygrothermal properties of hempcrete.

Environmental examination of a 1 $m^2$ hempcrete wall with a timber framework (26 cm in thickness) reveals that the effect of the hemp material is much less than that of other construction methods. In this instance, hempcrete is a wise option.

The following benefits summarize the usage of hempcrete in buildings: it is a light weight material with low conductivity; the porous structure allows for the stabilization of indoor air temperature and humidity regardless of external variations; it has great acoustic properties; it has a lower carbon footprint when compared to traditional construction materials; hemp hurd is more resistant to biological deterioration than other building materials.

Even though hempcrete has superior technical characteristics and superior performance in terms of interior comfort, several practical difficulties remain unresolved. Currently, construction aplications are constrained, and they must be enhanced by more research and technological advancements.

**Acknowledgements**
This paper was elaborated with the support of the “Eco-innovative Products and Technologies for Energy Efficiency in Constructions – EFECON” research grant, project ID P_40_295/105524, Program co-financed by the European Regional Development Fund through Operational Program Competitiveness 2014-2020.

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