Hempcrete as a Sustainable Building Material

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<u>Abstract</u>

This paper examines the research behind the use of hempcrete, which is a bio-aggregate concrete made from lime and hemp shiv. Hempcrete is a sustainable building material that is made with a low environmental impact that removes waste production, decreases both energy use and the consumption of natural resources. Hempcrete locks CO_2 within its fibers, has low thermal conductivity, and exceptional acoustic performance and vapor permeability, which regulates the temperature inside structures. Some drawbacks to the use of hempcrete include its capacity to retain water, which can cause swelling and bio-decay of the material, as well as poor mechanical performance which currently prevents it from use as a load bearing material. However, some research asserts that the mechanical performance can be increased, depending on what binder is used.

Keywords – hempcrete, bio-aggregate, eco-efficiency, sustainability, bio-concrete

Table of Contents

List of Figures

Introduction

The construction industry must currently deal with a number of issues affecting the environment. Among these are climate change, the consumption of natural resources, non-biodegradable waste production, and the overall quality of living. In addition, the inefficient use of energy in the construction sector add significantly to these factors. As of 2008, residential and commercial structures were responsible for nearly 40% of US energy consumption, in addition to contributing up to 38% of all CO_2 emissions (Tatari and Kucukvar, 2012). Though these statistics seem daunting, the past several decades have produced a shift in both policy and methods to devise a more sustainable approach to construction. Some examples of this include the recycling initiative, which helps decrease the industrial impact on the environment. In addition, alternative materials, such as bio-aggregates, are being researched for the same purpose. Thus far, one of the most promising materials has been hemp (Cannabis Sativa L.). Hemp is both an agricultural and industrial commodity, highlighted by its usefulness as a sustainable resource for an estimated twenty-five thousand different products (Johnson, 2015), in addition to its ability to absorb carbon dioxide while it is being grown. However, as it more specifically relates to the field of civil engineering, hemp can be mixed with lime to form a bio-aggregate concrete, known as “hempcrete”.

Hempcrete is a lightweight concrete, made from hemp pulp (or shiv), and hydraulic or aerated lime. It is typically used for timber frame infill, roofing tiles, insulation, renders, and floor slabs. Although hempcrete cannot provide enough structural integrity to be used as a load-bearing material, it can, however, make up for its mechanical drawbacks through functionality and environmental benefits. For instance, hempcrete exhibits a low thermal conductivity (λ= 0.1–0.2 W/m·K) that regulates the temperature and humidity levels within a dwelling, a high acoustic performance when compared to traditional concretes, and an exceptional resistance to fire without the need for fire-preventative measures (Arizzi et al, 2015).

As this paper will show, hempcrete is characterized as a sustainable and practical building material. While hempcrete does have drawbacks in mechanical performance, it remains an underused, untapped resource that can be used to lower the impact the construction sector has on the environment.

1.0 Eco-Efficiency and Hempcrete

Since the bulk of sustainable infrastructure will be implemented by civil engineers, there needs to be a defined context for eco-efficiency. This can be accomplished on an ethical basis. According to the ASCE Code of Ethics (1.f), “Engineers should be committed to improving the environment by adherence to the principles of sustainable development so as to enhance the quality of life of the general public.” While this seems to be an invariably broad definition, it is useful as a conceptualization of what needs to be accomplished. In addition, it effectively relays the innovative role that civil engineers will play in regard to eco-efficiency.

A more specific criteria for eco-efficiency entails the following characteristics (Omer and Kucukvar, 2012):

- Sustainability of the material: This entails the use of Life Cycle Analysis to determine the durability of the material. In addition, we include how it affects the decrease in consumption of natural resources.
- Reduction of Pollutants: Non-biodegradable and toxic waste production, emission of greenhouse gases, and water contamination is to be objectively avoided.
- Retention of economic value: Regarding the use of sustainable building materials, the goal of engineering remains the same in regard to the efficient and practical implementation of services.

2.0 Hempcrete as an Eco-Material

In light of this, eco-efficiency can have a more hands-on application in the form of an eco-material, or rather, a material that exhibits the qualities of eco-efficiency. This definition sets the context for the use of hempcrete, which is to be defined as an eco-material. A picture of a hempcrete block is shown in Figure 1.

Figure 1: Hempcrete Block (Geiger, 2011).

2.1 An Agricultural Commodity

First off, it is worth noting hemp's sustainability as an agricultural commodity, which aids in decreasing the consumption of natural resources. For instance, the seeding/harvesting time gap of hemp ranges from 70-140 days (Johnson, 2015), and has a maximum yield of 170 bushels per acre (Williams and Mundell, 2015), characterizing hemp as a quickly renewable substance. In addition, while hemp is being grown, it absorbs large amounts of CO_2, which reduces the greenhouse gas emissions associated with the manufacturing process of tradition concrete.

2.2 Application of Hempcrete

In the construction phase, hempcrete is most commonly used for a timber frame infill, which is built using a removable formwork mold, such as a plastic casing. The hempcrete is poured between the two formwork plates into a dismountable mold. Each layer is carefully leveled when placed in the mold, around 20 cm in thickness for each addition. This infill consists of a density at 400 kg/m^3, and a thermal conductivity (λ) of 0.1 W/m.K, at 0% RH. Alternatively, hemp can be applied as roofing insulation with a density of 200-250 kg/m^3 (λ=.06 W/(m.K), at 0% RH), as well as a floor application, where the density becomes 500 kg/m^3 (λ=0.12 W/(m.K) at 0% RH). The walling and roofing applications must meet a minimum compressive strength greater than .2 MPa, and .05 MPa, respectively, with an elastic modulus greater than 15 MPa for walls, 3 MPa for the roofing application, and 20 MPa for flooring (Lanos, et al, 2013).

The most complicated process of the mix design is getting the correct ratio between the fluid phases, air and water, and the solid phases, hemp shiv and the binder. For instance, an example of a walling application would include 100 liters of hemp shiv, 22 kg of Tradical ® PF70 lime, and 30-35 kg of water (Lanos et al, 2013). However, this is an area for future research, as the type of binder that is used can have different effects on the overall performance of the material.

2.3 Vapor Permeability

Hempcrete is a highly breathable material, which allows for the regulation of indoor temperature and humidity. This is mainly caused by the porosity of hempcrete, which allows the transfer of water vapor with the surrounding air. This phenomenon occurs at times of high humidity, allowing the vapor to condense back into the liquid state and coming to rest on the surface of the pores. This process can be reversed in times of low humidity, essentially acting as a natural humidifier. Consequently, this has an interesting effect on the thermal conductivity of hempcrete. As the physical states of water (which has a heat conductivity of λ=0.6 W/m.K) alternate from liquid to vapor, it will actually modify the specific heat and thermal conductivity of hempcrete (normally λ= 0.1 W/m.K). This works to regulate the indoor temperature, reducing the need for heating and cooling systems, in addition to lending the material greater insulation capacity, while maintaining the quality of the air. (Arnaud, et al, 2013).

2.4 Acoustic Absorption

Acoustic absorption contributes to the economic value of the material. Having a high noise reduction coefficient (NRC) signifies the reduction of general dwelling noises, allowing for greater comfort. According to the current standards, perfect absorption is given a coefficient of 1 NRC, while perfect reflection is signified by 0 NRC. Having a mean NRC of .69 (Abbott, 2014), acoustic absorption is something that hempcrete is well suited for. Figure 2 compares the NRC of hempcrete to several common materials used in houses.

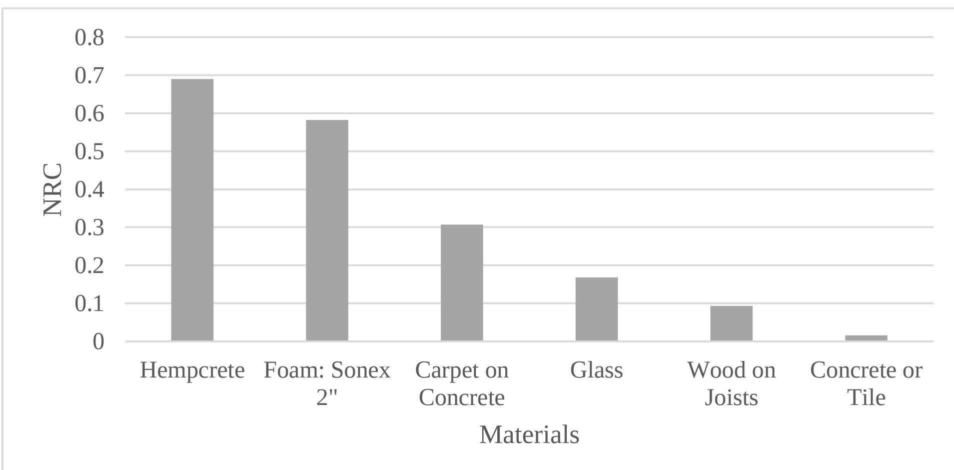

Figure 2: Noise Reduction Coefficients of Common Building Materials (BEMBook, 2013).

3.0 Drawbacks to the Use of Hempcrete

Despite its many benefits, hempcrete does have several key drawbacks that make it less than ideal as a building material. For instance, the porous structure of the hempcrete decreases its mechanical performance, and increases its ability to retain water (Arizzi et al, 2015). Though these issues are not so befouling as to prevent the use of hempcrete within the construction sector altogether, they do, however, provide strong limitations regarding what it can be used for.

3.1 Mechanical Drawbacks

The most significant setback of hempcrete is its poor mechanical performance, which prevents hemp from being used as a load-bearing material. This is due primarily to the fact that hempcrete is highly porous, causing a poor adhesion to the lime binder that results in an elastic-like behavior (Arnaud et al, 2013). Theoretically, this can be a useful trait in some situations, such as earthquakes, in which the material can bend without compromising its structure or cracking. On the other hand, it does cause hempcrete to deform a significant amount under stress. However, recent experimentation has indicated that this can be avoided.

A recent study utilized a recycled high-density polyethylene (rHDPE) in order to increase the mechanical strength of hempcrete. Following an alkali treatment, which consisted in dousing the hemp fiber in a 5% NaOH solution, the material was then coated with the polyethylene composite, resulting in increased surface coarseness and surface area. This allowed for greater adhesion to the binder. The result of the study indicated that a composite of 40% hemp fiber and 60% rHDPE volume yielded an ultimate tensile strength of 60.2 MPa (Lu and Korman, 2013). Figure 3 shows the flexural stress of this composite.

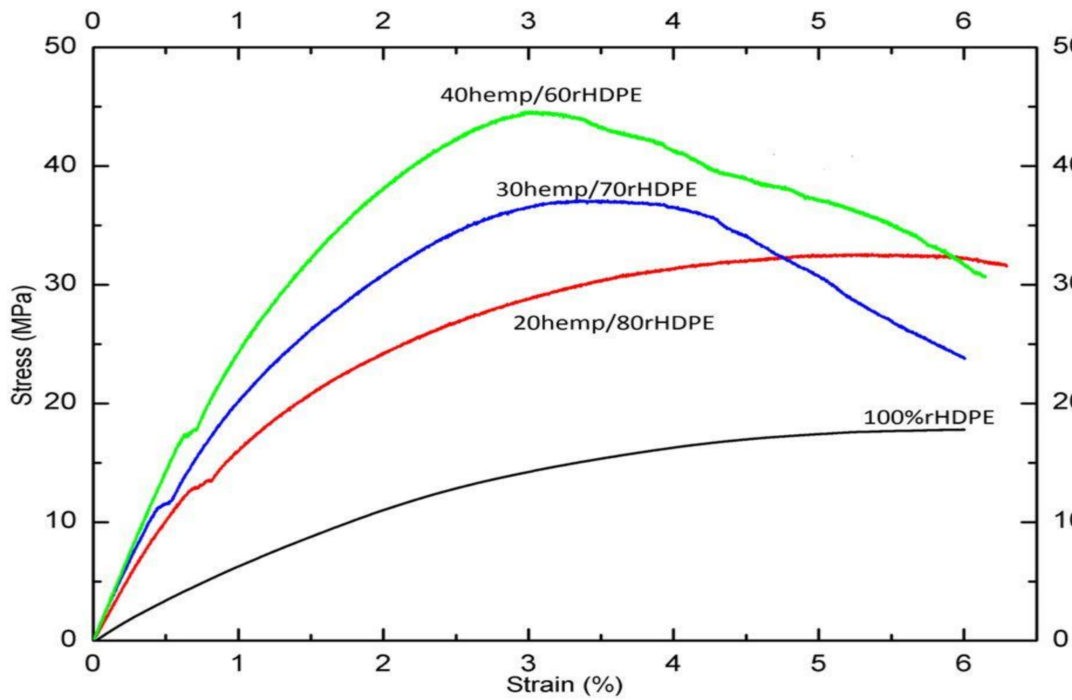

Figure 3: Felxural stress of hemp/rHDPE composite at various fiber fraction along with pure rHDPE (Lu and Korman, 2013).

3.2 Water Retention

In addition to poor mechanical performance, hempcrete also has a high capacity to absorb and retain water. Although this can be of benefit to the agricultural process, in that it decreases the irrigation requirements of the hemp crop, it can be a significant detriment to its use as a construction material. For instance, the hemp shiv is able to absorb up to 300-400 times its weight in water (Arizzi et al, 2015). While the study did indicate that this characteristic can be of some benefit in regard to the vapor permeability of the material, the problem comes when hempcrete undergoes water absorption for an elongated amount of time without proper ventilation. When this occurs, the possibility of bio-decay arises, in addition to freezing and thawing issues, and the formation of salt crystals, which all decrease durability.

This study asserts that the type of lime binder used can affect the drying rate and transpirability of hempcrete. Using a natural hydraulic lime (NHL 3.5) as a binder allowed for better vapor exchange with the surrounding air, and decreased the amount of water it absorbed by immersion. This binder also decreases the tendency for bio-decay in comparison to aerated limes. (Arizzi et al, 2015)

4.0 Conclusion

This paper aims to set the context for the application of hempcrete as an eco-material. Hempcrete is a useful material for reducing the impact the construction sector has on the environment, while retaining good economic value. Although, with the current methods of application, hempcrete is not an ideal material for construction, it does present many characteristics that set it apart from traditional concrete in terms of economic and environmental benefits. Looking ahead, further research on increasing the mechanical capabilities and decreasing the water absorption will go a long way toward unlocking the potential of hemp as a sustainable building material.

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