Hemp concrete – an innovative wall material made from local raw materials

1. Introduction

The construction and maintenance of buildings generates significant amounts of CO_2. This is mainly due to the high energy and resource capacity of the material production processes, as well as the energy required to heat and cool poorly insulated buildings. To reduce the impact of these factors on the environment, one must transition to innovative construction materials that use renewable natural resources and require less energy to produce. At the same time, these materials must meet the ever-increasing energy efficiency requirements.

One group of low-impact building materials is natural fibre biocomposites. These materials are made from highly porous natural fillers with a low mineral binder content. They are mechanically self-supporting and have low thermal conductivity – typically less than 0.05 W/(m·K). Low environmental impact is achieved by using low-energy, CO_2 absorbing and isolating fillers, and reducing the amount of used mineral binder.

2. Hemp concrete

One of the most common materials in this group is the hemp concrete, or hempcrete, which consists of by-products of industrial hemp production – hemp shives and lime-based binders. During the growth process, hemp absorbs CO_2 through photosynthesis and the carbon is trapped within lime via carbonation, resulting in a carbon-neutral end product, or even one with a negative carbon footprint, accumulating up to 130 kg CO_2 eq/m^3. The material is also a good thermal insulator with λ ranging from 0.05 to 0.12 W/(m·K). It also has excellent moisture buffering and acoustic properties and has a low environmental impact compared to traditional building materials. However, it should be noted that hempcrete is not a structural material, despite it being self-supporting. Its mainly functions as a thermal insulation and vapor barrier material used in conjunction with the main supporting structure of a wall wooden framework.

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Although hemp has been used as a fibre plant for thousands of years and hemp shives have been used locally since the 6th century, they began to gain popularity in construction applications only in the 20th century. Since the 1980s, hempcrete has been used in France

Figure 1. HEMP ECO SYSTEMS LATVIA hemp building, in-situ method.

and is now becoming popular in other countries such as the UK, Belgium, the Netherlands, Canada, Australia and elsewhere. For the time being, the material is rarely distributed in the US, as the ban on industrial hemp has been lifted only in 2018. Thus, a sharp increase in the hempcrete demand is expected in the coming years. According to the estimates by the International Hemp Association, over the last 40 years of hempcrete use in construction, the number of buildings erected and renovated using hempcrete is measured in the thousands.

3. Experience and research in Latvia

Hempcrete has been used in Latvia since 2013, when the first hempcrete building was constructed. At that time there were two companies producing hempcrete products in Latvia – "Hemp Eco System Latvia" Ltd. (Figure 1) and "Esco Būve" Ltd., mostly known for their trademark "Remember Brothers" (Figure 2). Currently only HEMP ECO SYSTEMS LATVIA is engaged in the commercial construction of such buildings, and the remaining buildings are commissioned privately, with a total of ~ 30 hempcrete buildings in Latvia.

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Figure 2. "Remember Brothers", hemp concrete panels.

Previous research at the Riga Technical University (RTU), Department of Building Materials and Construction Products, has been focused on developing and studying composites of various hydraulic binders and hemp shives, as well as their properties and applicability in the Latvian climate [1]–[4]. The binders are based on lime with various pozzolanic additives, mainly waste products (ground lamp and bottle glass, ground ceramic construction debris, metakaolin from foam glass production waste, etc.) [5], [6], thereby improving the compressive strength of the lime binder, reaching up to 15 MPa and simultaneously reducing its impact on the environment.

The application of hempcrete in field conditions has also been studied by means of monitoring buildings constructed from hempcrete. Temperature, heat flux and relative humidity sensors were used to keep track of the conditions inside the buildings, including interior spaces and insulating envelopes of walls, ceiling and floor. This has allowed to verify *in situ* the hempcrete properties established in the laboratory test [7]. By examining the relative humidity dynamics during the initial drying and operation of buildings at different key locations, it was possible to assess the behaviour of the hempcrete and to make sure that there is no risk of mould growth. In addition, laboratory tests have shown that there is no mould formation risk for hempcrete under normal operating conditions. Mould growth risk can only be due to the incorporation of hempcrete with a small amount of binder in high relative humidity environment with low temperature. This is usually the case in autumn when it takes a long time for the material to dry [8], [9].

In addition to the research above, hempcrete material models for various material density values have been established through the efforts at the Institute of Numerical Modelling at the University of Latvia (UL), Department of Physics. Coupled water mass and heat transfer equations including the effects of phase change (vaporization/partial freezing/condensation), solar radiation, etc., were solved for wall insulating envelopes

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comprising hempcrete (and in on instance, hempcrete only). The material model for hempcrete was established using the existing data on hempcrete properties, i.e. dependencies of hempcrete physical properties on temperature and water content, porosity, specific heat capacity. These hygrothermal properties were then varied and optimized so that the defined material model produces simulation output that matches the data due to experiments for the actual assemblies that were monitored using arrays of sensors for extended periods of time. This way, the best-fit material model, which minimizes the deviations between simulation and experiment data, specifically represents the hempcrete material studied by the RTU. The obtained hempcrete models can be used to assess in silico the hygrothermal performance of building envelopes with hempcrete and to forecast the risk of mould growth, excessive water accumulation, water condensation, etc. The applied inverse modelling methodology can also be used for other materials and building envelopes. In this project, it has also been applied to the prototype buildings located at the test site in the Botanical garden, UL. Several material models from certified databases were verified and locally manufactured materials can also be studied via this approach.

4. Magnesium-based binders for hemp concrete

Turning back to the hempcrete properties, an important issue must be noted: the lime-based binders traditionally used in hempcrete have a relatively low compressive strength and the proportion of used hemp aggregates is relatively high, so the effective compressive strength at a normal density of 350-450 kg/m^3 is also low. In addition, there is a delay in setting and hardening of the lime-based binder in hempcrete, which can be explained by the organic compounds in the hemp clumps, which act as hardening retarders and reduce the mechanical properties of the hardened mortar. As a result of these properties, hempcrete is mainly used in construction only as a self-supporting thermal insulation material with application, mainly on site.

One potential replacement for the lime-based binders in hempcrete that can improve its mechanical properties is a magnesium-based binder – magnesium oxychloride cement. This binder is commonly used in combination with various fillers of biological origin, such as wood chips, rapeseed straw and other agricultural by-products, and is used to make boards and other building materials via extrusion. The advantage of magnesium binders, as opposed to lime-based counterparts, is their significantly better compatibility with organic fillers and increased mechanical strength.

RTU has developed and studied natural fibre building materials based on magnesium. Magnesium oxychloride cement and hemp shives were used as fillers to produce composites of different densities and mechanical properties for different applications – load-bearing high-density and low-density thermal insulation composites, with density from 200 to 520 kg/m^3, compressive strength from 0.15 to 1.5 MPa and thermal conductivity from 0.062 to 0.13 W/(m·K) [9], [10].

Over the course of the study, the composite was tested for fire resistance and microbiological stability, and environmental impact was also assessed. Magnesium-hemp composite with 400 kg/m^3 density is able to provide B s1, d0 class fire resistance and exhibits lower heat output than lime-hemp materials due to the chemically bound water in magnesium oxychloride cement, which is released during combustion and reduces the fire reaction of the

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material. Although the composite has a lower pH than lime-hemp composite (9.4 versus 11.9) and thus has lower microbiological resistance, it is enough to avoid the risk of mould growth under normal operating conditions[9].

An experimental wall panel (Figure 3) and its prototype (Figure 4) consisting of 3 layers with different densities and varying amounts of binder have also been developed. The outer layer serves as a barrier and its density is ~ 450 kg/m^3 with compressive strength of ~ 1 MPa, suitable for loads expected during transportation and assembly. The middle layer provides thermal insulation and has a density of ~ 200 kg/m^3 and a thermal conductivity of 0.062 W/(m·K). The internal layer density is ~ 330 kg/m^3 and it can be used as space for cables and other components. The hemp-magnesium composite layers in the panel serve only as self-supporting thermal insulation and enclosing materials. The total thickness of the panel is 370 mm and its U value is 0.18 W/(m^2·K) [11].

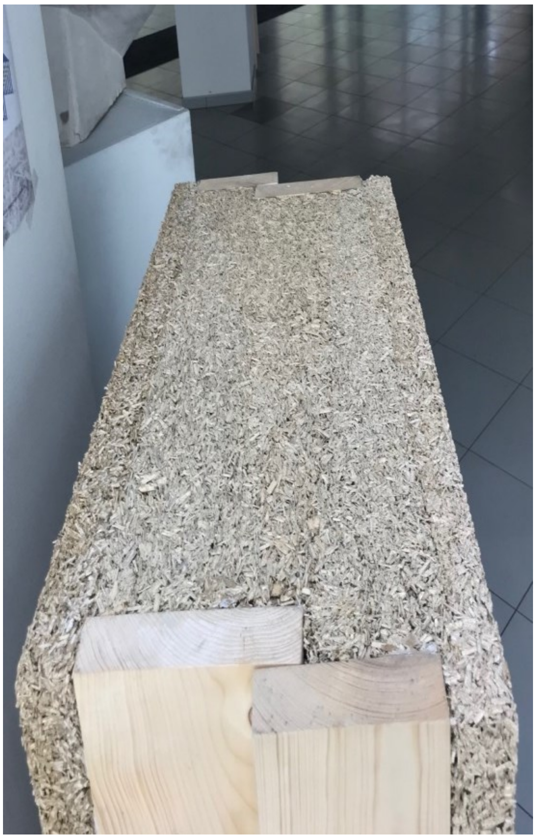

Figure 3. Experimental magnesium-hemp panel prototype.

5. Conclusion

The results of the study allow to conclude that magnesium-hemp panels can generally meet the increasingly strict requirements for building materials: high levels of thermal insulation, sufficient compressive strength, adequate fire and microbiological resistance, and reduced environmental impact. The low thermal conductivity of the material corresponds to an optimal wall thickness of 35-40 cm, yielding U values < 0.18 W/m^2·K. At the same time, this type of material is almost CO_2- neutral – only 12.7 kg/CO_2 equivalent per 1 m^2 of panel. This

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is about 5-6 times less than for traditional building materials, such as aerated concrete insulated with stone wool or similarly insulated expanded clay concrete walls an identical U value. For this reason, magnesium-hemp panels can be recommended for wide use in the construction industry, especially for living houses with 1 to 2 floors.

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