POSSIBLE APPLICATIONS OF NATURAL FIBER AND STRAW OF FLAX AND HEMP IN THE CONSTRUCTION INDUSTRY

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Summary:
High energy consumption, carbon dioxide emission, air pollution and slow depletion of conventional fuels contribute to the production of various building materials. The idea of sustainable development in the construction industry is to reduce these effects to a minimum by seeking alternatives such as ecological and energy efficient building materials and technologies of their production. More importantly, the economic dimension expressed by lower operating costs of energy efficient buildings is a relevant issue.
The purpose of this paper is to present the possibility of using natural resources in the production of building materials.
The article describes the characteristics of lightweight composites composed of natural fibers and straw from flax and hemp, on the lime binder modified with different additives and admixtures. The pilot study, executed in several European countries including our own, was described on the basis of world literature which focuses on mechanical and thermal properties of these materials [1,5]. In addition, other uses of flax and hemp, known in the construction industry for a long time, were presented.
As far as conclusion is concerned, the current progress in the study of these materials was evaluated. The obtained results indicated the direction for further development of research and allowed to assess the potential for wider application in construction industry.

Keywords: natural fibers, ecology, building materials

Introduction

Flax and hemp are fully biodegradable, non-waste materials with health and ecological properties [3]. Flax and hemp fibers have high tensile strength and resistance to abrasion and for this reason, they can be used as an alternative to synthetic materials. Even in ancient times and in the early centuries of our era, they were frequently used in construction. These fibers and linseed oil (the oil in flax) were added in order to improve the mechanical and physical properties of lime mortar used for instance, in the construction of aqueducts and water reservoirs. Linseed oil is used for the manufacture of linoleum flooring [7]. This environmentally responsible material is biodegradable and does not release harmful gases or toxins into the air as it breaks down, in contrast to common PVC flooring. Not to mention the fact that oil from flax preserves providing protection on wooden surfaces in buildings. Dry chopped stalks of flax and hemp after the separation from fibers are used in the manufacture of chipboards. Flax straw is mainly used as a bio-fuel. It is a carbon neutral fuel. When the straw is burnt, carbon, in the form of carbon dioxide, is released into the air, where it can, once again, be used the following year in the production of straw. Flax fibers are more frequently used in the production of geotextiles as a substitute for common synthetic or coconut fibers whose transport costs are relatively high [7]. When the fibers are aggressively processed, they can be turned into quite soft, fine fibers. Whereas coarse and fine fibers can be blended and processed so as to produce insulation batts with insulating properties similar to the fiberglass batts, so commonly used to insulate walls and ceilings. More importantly, flax fibers can be used in place of fiberglass in many plastic composite applications. They are cheaper, lighter in weight and impart more springiness than fiberglass. In addition, such natural fibers require less energy in manufacture and are easier to be decomposed or burnt. The following images represent the fiber and the straw of flax and hemp.

Fig 1. Flax fiber and straw [8]

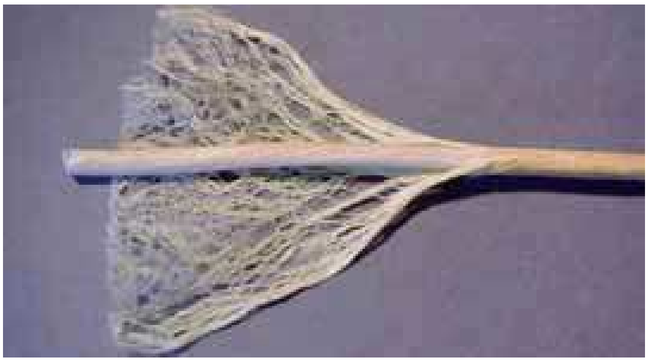

Fig 2. The fiber separated from the woody part of the hemp stalk [6]

The aim of this study is to evaluate the suitability of the use of these materials in the production of lightweight composite materials (wall materials); and to make a contribution to the development of sustainable construction by developing ecological material of reproducible natural resources.

The characteristic of the composite material

In the recent years in France and in the United Kingdom research has been conducted into the new application of hemp in construction focusing on their specific properties. Hemp is used in the production of composite building materials. The composite known as hemp lime consists of fast-growing and carbon sequestrating plant-based aggregates (hemp core chopped into short pieces of about 25 mm) with a lime-based binder [1]. Such a lightweight material is suited to various construction applications. The composite is formed by mixing together hemp aggregates and lime-based binder. The lime binds chopped hemp core together, giving the material modest structural strength and stiffness. However, this material has good thermal and acoustic performance, provides healthy microclimate and controls the level of indoor humidity. Lime also protects hemp from biological decay. By modifying the mix design and proportions of ingredients, lighter or denser material can be obtained for various applications such as, under-floor or roof insulation and wall material. Moreover, this composite contributes to sustainable building since it can capture and accumulate carbon dioxide and lock it up into buildings [1].

Furthermore, hemp lime may be used in various ways – it can be cast like concrete within shuttering or sprayed (Fig. 4). It can also be cast into blocks (Fig. 3) and panels or cast as a floor screed and used as a plaster. In the case of solid hemp lime, a shuttering can be removed after 24 hours, although the material achieves quickly a self-supporting resilience. Block walls are denser and do not provide very good thermal insulation properties, nevertheless they have high thermal mass. Blocks can be used as infill inside a frame construction mainly made of timber [1].

Hemp lime composite walls need external weather protection provided by a finishing material such as, a lime render providing vapour permeability so that the material can breathe.

Fig 3. Hemp lime blocks [1]

Drying time of hemp lime is normally of about four weeks. A building constructed with the use of such a technology should be well ventilated while the hemp lime dries out. Hemp lime absorbs moisture and ensures breathing of walls. The moisture content in the material serves also as a thermal buffer. Such a hygroscopic performance has beneficial aspects which are the prevention of condensation and control of internal relative humidity. It has been proposed that hemp lime absorbs and releases energy, as moisture is released or absorbed, giving the material a unique apparent thermal mass. Breathable composite with lime provides a protection from biological pathogens and mould growth at the point of construction. The alkalinity of the lime reduces the potential for an attack by pests [4]. Another advantage of using hemp lime is lack of volatile organic emissions from the materials as it occurs in the case of synthetic materials.

Hemp lime solves the problem of thermal bridge because of the homogenous structure of the material. There are no cold points of wooden construction since all the timber frames are buried within the mass of the insulating material [1].

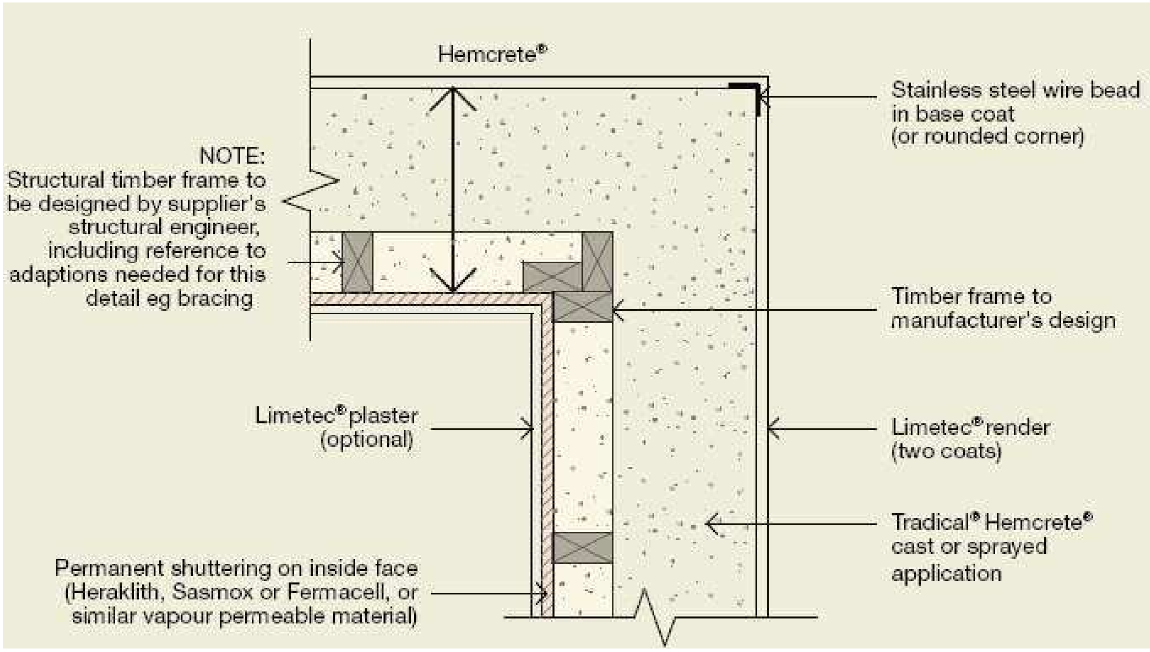

Fig 4. Permanent internal shuttering board and timber frame for spray application of hemp lime [1]

In Slovakia hemp is also used as an ingredient of the lightweight composite, yet on another binder which is described in more details in the next chapter. Whereas in Poland, studies have been undertaken on the possibility of the application of straw and flax fibers in building materials on lime binder.

It is also worth mentioning attempts to use other natural fiber in the construction industry, for instance, in Brazil, research was conducted into concrete wall bricks which were armoured with natural micro-reinforcement of sisal fibers [2].

Composites research and results

The research carried out in France, the UK and Slovakia [1,5]

Material was tested for thermal and mechanical properties. Thermal comfort is improved by the effect of hemp lime walls having a high surface temperature. It is caused by thermal mass and the ability of the composite to absorb moisture, regulate level of humidity and emit heat. The thermal conductivity of the materials was examined with different proportions of ingredients in the mix. Research produced the ‘λ’ values in the range of 0,08 to 0,09 W/mK that were subsequently taken on a wall which was 200 mm thick. Thermal resistance (the ‘R’ value) was calculated to be 2,75 m^2K/W taking plaster and surface resistances into account. On the basis of these figures, the research team agreed that a U-value would amount to 0.36–0.37 W/m^2K. A 300 mm thick wall would have a U-value of about 0,26 to 0,28 W/m^2K. It meets the new Building Regulations thermal standards.

Thermal properties are associated with the density and method of making the material. Due to the high heat capacity and the ability to absorb moisture, hemp lime reaches equilibrium in heat exchange only after 72 hours, whereas the temperature difference on the two sides of the wall amounts to 20 °C (black solid line in the Fig. 5). Whereas cellular concrete of the same thickness needs above 30 hours and the mineral wool 12 hours. Although the heat transfer coefficient of hemp lime wall is slightly smaller than the foregoing materials, the hemp lime wall provides more thermal comfort [1].

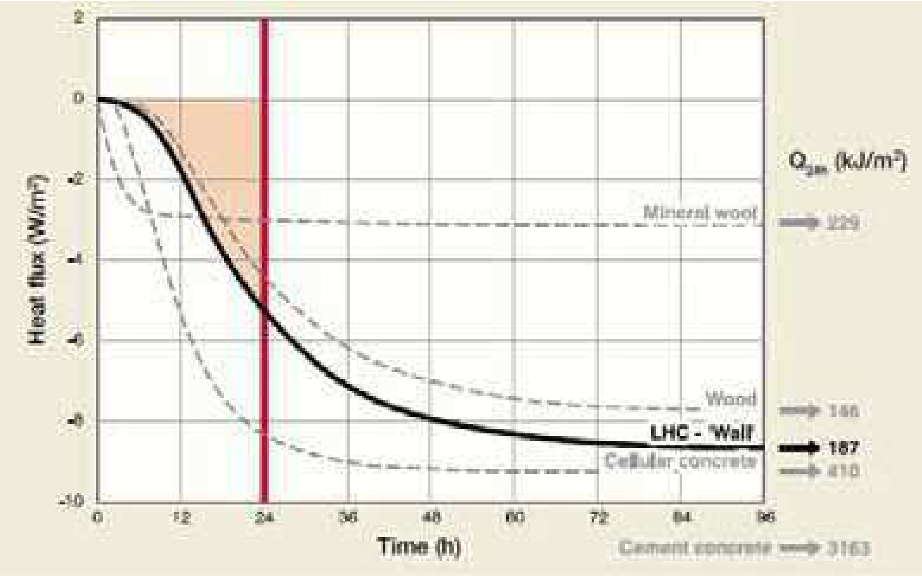

Fig 5. Heat flow through various materials [1]

Hemp lime achieved very good performance in the air tightness test. A building was tested by using a pressure and depressure test. It gave a performance of approximately 3 $m^3/h/m^2$, which is a satisfactory result against the Building Regulations target of 10 $m^3/h/m^2$. The material has good tightness, but there is no likelihood of mould growth, humidity or condensation owing to the vapour permeability of the material. Air tightness is improved with plastered finishes. A compressive strength test is extremely significant to the evaluation of the possibility of hemp lime use. In France, the material was tested on cylindrical specimens; 160 mm (diameter) x 320 mm (height) cylinders were used, whereas in the United Kingdom smaller 100 mm (diameter) x 200 mm (high) cylinders. Such a shape is better than cube for hemp lime because of the deformation characteristics of the material under load. In both cases, there occurs significant ductility in the behaviour of the material under load. Cylinders were tested in uniaxial compression under a steadily increasing load until the failure. Owing to the low stiffness, loading rate should be maintained constant, between 0.5% and 2% per minute to the failure. Specimens were formed by light compacting layers or by uniform static compaction. Hemp lime, like other lime-based materials, becomes significantly stronger with time, as the lime binder carbonates. It was tested after 90 days, which is recommended for lime-based materials. The values received from hemp lime cylinder tests were in the range of 1 to 2 MPa. After two years the 90-day strength doubled [1].

Previous research performed in France indicates that hemp lime under moderate stresses initial loading is inelastic - it does not fully recover when load is removed. However, on the reapplication of load, material behaviour is elastic or near elastic. The initial service loading compresses the open structure [1]. The results obtained from hemp lime cylinder tests in five specimens with various mixes are compared in a graph and table below:

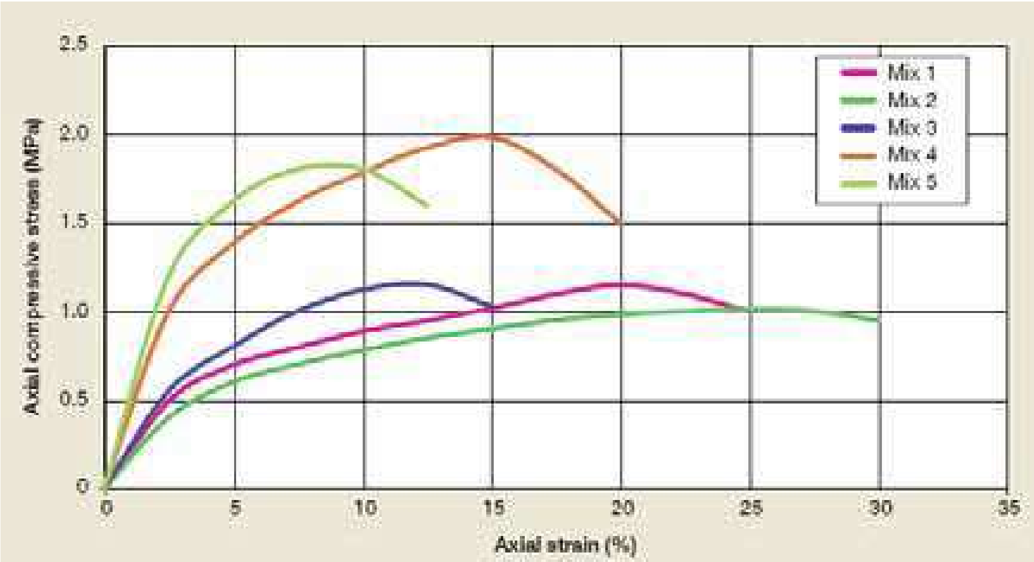

Fig 6. Stress-strain responses of hemp lime cylinders under compression loading [1]

Table 1. Comparative compression performance of hemp lime materials [1]

Mix	Mix proportions (by volume)	Dry density (kg/m^3)	Ultimate stress (MPa)	Axial strain at maximum load (% strain)
1	Lime: Hemcore*: water 1:3:0,9	620	1,15	22,5
2	Lime: Isochanvre**: water 1:3:0,9	500	1,01	25,0
3	Lime: Hemcore*: sharp sand: water 1:3:0,5:0,9	700	1,15	12,5
4	Tradical PH 70***: Hemcore*: water 1:3:0,7	610	1,98	15,0
5	Tradical PH 70***: Hemcore*: sharp sand: water 1:3:0,5:0,7	830	1,88	10,0
	* Hemcore – registered name for chopped hemp straw ** Isochanvre – registered name for mineralised hemp *** Tradical PH 70 – registered name for lime binder [9]			

There are no published data on bending and shear resistance and shrinkage, creep or settlement of hemp lime materials. Fire safety is an impostant requirement because of hemp and timber frame use in this technology. Fire tests have been carried out in France on 250 mm thick walls of hemp lime blocks, laid in a lime mortar. There were no emissions of toxic material and no re-ignition. The wall remained intact for 1 hour 40 minutes. The wall blocks were not damaged, but the mortar joints failed. This research indicates that the wall made of solid hemp lime mass has better fire performance than the wall made of hemp lime blocks. In addition, the composite meets building regulations of sound insulation. A research team tested a sound transmission between the two pairs of houses. The hemp house tests measured a sound reduction of 57 dB. The ability to absorb sound occurs due to the high porosity of this material [1].

Tests on building materials containing hemp were also performed in Slovakia [5]. The aim of the research was to check the influence of thermal loading on material with regard to mechanical, structural and thermal properties. Tested composite contained 'hemp shiv' in the mix (which is the waste from the production of hemp fibres), binder (containing caustic magnesite, silica sand, sodium hydrogen carbonate) and water. Material was prepared in steel cube forms with dimensions 100x100x100 mm. Samples were tested after 28 days of curing under laboratory conditions. Initially the composites were put inside furnace for thermal loading in temperatures of 20, 50, 100, 200°C in the period of time 48 or 72 hours. Mechanical properties of material were tested before and after different thermal loading [5]. Changes in compressive strength are shown in the graph below.

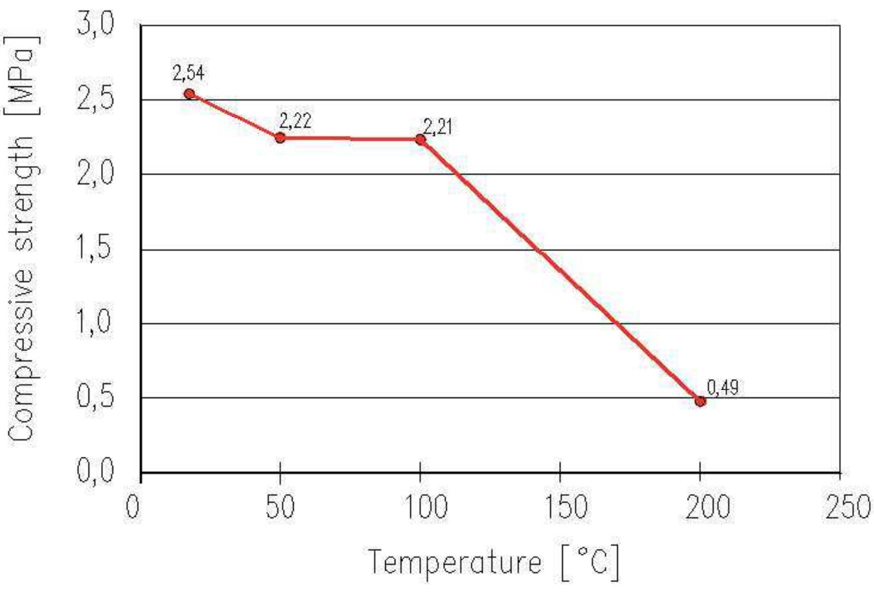

Fig 7. Compressive strength of composites before and after thermal loading [5]

The thermal conductivity coefficient measurement gave satisfactory results. For the material with a density of about 850 kg/m^3, the 'λ' value was about 0,07 W/mK and for density of about 1000 kg/m^3, it was about 0,1 W/mK [5]. A piece of original hemp shiv and sample of hemp shiv from composite loaded up to 200°C were examined under a microscope, which showed the deterioration of fibers surface due to oxidation process of organic constituents after the higher thermal load. The research team also verified thermal stability at higher temperatures up to 800°C. The top of thermal decomposition of cellulose and lignin was observed at 280°C, whereas the loss of weight was of 56,49 wt.% [5].

Own research

In Poland, hemp cultivation gradually discontinued due to the general association of hemp with drugs. For this reason, greater chance of success has flax. A trial research on the possibility of using flax in construction is carried out whose aim is to obtain a lightweight composite which can be used as infill inside a timber-frame construction and which meets thermal building regulations for walls ('U' value below 0,3 W/m^2K). The subject of the study concerned composites containing chopped straw and fibres of the flax with the length of about 25 mm, lime binder with additions (for example, silica sand fraction of 0-1 mm, microsilica or lime powder) and water. Flax is very absorbable and it swells when it is soaked in water. To reduce the absorption, the flax straw was covered with linseed oil. Samples were obtained with a density of about 900-1000 g/dm^3. The volume of the flax straw and fiber in the mixture was 80% by volume of binder, whereas water volume was about 40-50%. Therefore, a material of relatively high density was obtained. The aim of further research will be a gradual reduction of the density of the composite.

The material was tested on cube specimens with dimension 100x100x100mm after 90 days of curing under laboratory conditions [Fig.8, Fig.9]. Samples were formed by light hand tamping of subsequent layers. Compressive strength was in the range of 0,4 to 1 MPa. It is difficult to estimate the maximum strength and the moment of damage of material due to the plastic behaviour of the composite under increasing strain. The sample is considered to be destroyed at the time of the collapse of the force-displacement graph. Displacement of the testing machine was 5 mm/min. At the time of destruction, the displacement was about 15mm.

Fot 8. Compressive strength test

Fot 9. Destroyed sample after the compressive strength test

The thermal conductivity of the samples stored in the laboratory conditions was also investigated. As a result, it amounted to about 0,20 W/mK. Further research will be aimed at reducing the value of λ, so that the use of additional insulation in the walls made of this composite is unnecessary.

Conclusions

The purpose of the article was to review the possibility of using natural resources, rapidly renewing, to the production of new green composites applicable in the construction industry both as a structural and filling element. This is an innovative use of flax and hemp. In Poland, in recent years the cultivation of hemp has become less popular because of its unprofitability. Many farms store the collections of flax from many years ago. New application of fiber and straw can change this situation, contributing to further development of sustainable construction. On the basis of the results, it can be concluded that the materials have good thermal properties, meeting building regulations in this regard. The mechanical properties are sufficient to erect self-supporting walls and to fill their skeleton structure.

Further research is required to evaluate the influence of the mix design, proportion of ingredients, curing conditions, material moisture content and loading duration on physical and mechanical properties of hemp lime. Moreover, the research should focus on seeking optimal recipes which provide greater compressive strength and rapid maturation of the mix, simultaneously maintaining the ecological character. Higher strength parameters give the possibility of extending the applications of these composites in construction, increasing the confidence among investors.

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