Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

Fast Growing Renewable Materials in Building Industry

Filip Khestl

VŠB - Technical University of Ostrava, Faculty of Civil Engineering, L. Podéště 1875/17, 708 33 Ostrava - Poruba, Email: <filip.khestl@vsb.cz>

ABSTRACT

Today, we have a lot of experience with production of construction materials based on conventional raw materials; nevertheless, like for every material and product, there are also higher and specific requirements. Besides, environmental strain becomes to be more and more noticeable, the load of wastes begins to be unacceptable and the world society is (at last) becoming conscious of this fact. So it's only natural that also building industry begins with using of alternative materials in a higher degree. In recent years, the newest environmental awareness in building industry has generated great interest in fast growing renewable materials. One of the most potential fast renewable alternatives is hemp. This paper offers complete overview about fast renewable materials utilization in building industry and also the latest knowledge of about using hemp in cement-bonded particleboards for structural purposes.

INTRODUCTION

Building industry is, similarly to any other industry, subject to present-day trends. But the industry is not driven and developed by latest excesses but, in particular, by development of new and new materials or by "mere" improvement of properties of the existing materials. On the top of that, the industry is dependant on money provided by end customers. And this is again reflected in present-day way of thinking, creating thus a vicious circle. Environment has been mentioned over and over again. Environment policy has been affecting the building industry as well. More and more attention is being paid to re-use of secondary and fast growing renewable materials that are used more frequently in products, or such products are even produced only on the basis of the fast growing renewable stock. This trend has, in particular, positive effects. First of all, it reduces quantity of wastes on landfills and influences positively economy of re-used or recovered secondary raw materials in composites, achieving new features in final products. Some types of waste have become preferred, well-paid and valuable raw materials. This is, in particular, the case of flue ash or slag that can be used in many industries. Such opportunities are, however, again the result of many years of research and development of new materials.

FAST-RENEWABLE RAW MATERIALS

In past years, alterative raw materials have become a rather preferred solution. They are also referred to as fast renewable raw materials. In addition to timber that has been used in the building industry for many hundreds or even thousand years, such materials include crop the features of which are similar, but are still able to grow faster (physical-mechanical or chemical properties are frequently even better). Such materials are typically used, thanks to their heat or sound insulation properties, as insulation boards, fillings, blocks or other building elements or materials. Cement or lime is typically used as a binding agent. A particular attention should be paid to plastic-based composites. Timber ranks among the oldest building materials. It is used in many applications: for both construction and for production of insulation materials. A good solution is also to combine the timber with silicate bond.

It is understood that natural materials originating from renewable sources are organic mass of plant origin that has been processed and upgraded. If such raw material is a by-product of any other production, it can be also regarded as a secondary waste material. Generally, this proves reasonable use of waste materials.

On one hand, it follows from the investigation into use of building masses produced from natural renewable raw materials that the materials have typically somewhat less favourable mechanical and physical properties than the products with inorganic materials. On the other hand, it has been proved that these limitations can be compensated in practice by a rather high level of other end-use properties.

The fibrous character and low heat conductivity contribute to better heat insulation. Natural materials of plant origin can offer, in contrast to standard silica materials, higher heat capacity c [$J.kg^{-1}.K^{-1}$]. Therefore, such materials, if built into the structure, influence heat accumulation capacity of building structures. They also rank among preferred solutions in outdoor light-weight structures. The natural materials of plant origin are generally water vapour permeable and can accumulate some moisture by air sorption. The plant mass and plant materials are able to absorb moisture into an internal porous system, when the air humidity is rather high, and to release it gradually into environment, when the air humidity is rather low. This mechanism influences favourably air humidity micro-climate inside a building. This is, in particular, the case of winter when the air humidity inside the building might go down for a rather long time. This material, however, changes, to a certain extent its dimensions when the air humidity changes. This can affect negatively appearance of the structure. At the same time, it is necessary to pay more attention to assembly of such materials and to follow conditions and recommendations set by producers who manufacture materials based on natural raw stock. Last but not least, the plant fibre materials have good soundproof features both for airborne sound transmission loss and acoustic attenuation. Specific features, however, depend directly on the structure and volume weight of used materials.

A disadvantage of most plant materials is high flammability and some moisture sensitivity. Too much moisture can, if present for a long time, result in biological corrosion and degradation of the material that is exposed to bacteria, fungi or mildew. Therefore, this materials, if built into a building structure, should be always well separated from sources of moisture or, if wet, should dry up as soon as possible. When correct composition is chosen and construction is performed well, moisture in walls should not be a problem. Flammability can be reduced by flame retardant additives. In order to reduce flammability, the surface can be coated with a certain non-flammable layer (plastering or lining). Fire resistant and moisture characteristics can be improved if the material is applied in inorganic bind composites - they stabilize the natural materials and reduce its inclination towards biological degradation.

In addition to timber, other natural materials of plant origin can be used for production of building materials. They include hemp, straw, sisal, jute, flax, reed, rice, rice straw, coco/bamboo/palm fibres, crushed cork, cattail, china grass. Materials of animal origin, such as sheep wool, can be used as well. They can be used as structural components instead of hard wood. However, there are not any problems in recycling or its disposal.

The natural materials above do not rank among latest news, the opposite being true. In most cases, the plants can be used up fully in many industries. But the situation in the building business is rather different and the natural sources are used not so frequently. Typically, they are used as a filling material or for production of heat insulation or soundproof materials. Nevertheless, they are becoming more and more popular in structural materials, such as slabs or blocks. Specific features depend directly on the structure and volume weight of used materials.

These fast-renewable raw materials also include technical hemp that represents an excellent progressive raw material for the manufacture of building materials. One of alternatives that might meet price and technological requirements is substitution of wooden particles by hemp in cement bonded particleboards. Hemp (*Cannabis sativa*) can be used as a full or partial substitute for wood particles.

HEMP (*CANNABIS*) IN BRIEF

Cannabis also known as hemp has become notorious during recent years as an illicit source of narcotic drugs because of its THC content. In fact, the species is versatile and have the wide variety of possible uses. Its seeds, stalks, flowers and oils can be used in wide range of industry, like agriculture, automotive industry, cosmetics, building industry, furniture, paper, textile, food, recycling, etc.

Hemp in building industry

Generally, three basic variants of hemp are distinguished: *Cannabis Indica*, *Cannabis Ruderalis* and *Cannabis Sativa*. The last one is only permitted to grow for technical purposes because it’s low content of THC, lower than 0.3%.

Cannabis Sativa = technical hemp is an excellent alternative to wooden material for building materials; moreover, in some aspects its qualities even surpass the wood characteristics. Clear and evident benefits it is possible to behold in fast renewability; withal in comparison with other similar organic materials attain interesting mechanical qualities, usable in building materials.

Wooden material from hemp stalks offers itself for the manufacture of compressed boards, but also to produce granular mixtures for plasters, floors or in the manufacture of shaped bricks for permanent shuttering.

Hemp utilization in structural cement-bonded particleboards is yet another option. The board is formed with cement matrix and filler material made of hemp scutch. Commercial use of hemp in various building applications can be often seen in the world, especially in France and UK. Produced materials are bonded mainly by pressure or mostly with lime binders with admixtures therefore their function is often a filling one.

HEMP BASED CEMENT BONDED PARTICLEBOARDS

Hemp (*Cannabis sativa*) in cement matrix

For the purpose of the construction boards production can be used stem chopped into scutch which is currently used for its calorific value, in particular, for the production of briquettes.

As a filler of cement bonded particleboards are commonly used wooden particles (Fig 1.). Modification of filler was made step by step by several fractions of hemp (type A to type D) that were obtained from different processing centers. A visual comparison of each hemp fraction and wood particles is shown in the following photographs (Figure 2. to 5.). We completed number of tests to find out hemp diversity. Observed results from previous tests indicate that we can compare test samples from each hemp fraction obtained from different processing centers.

    

Fig. 1. to 5. From the top left corner: wood particles, grounded untreated hemp fibers and grounded and treated hemp of various fraction and from different processing centers.

For hemp utilization as a filler to cement bonded particleboards is very important interaction with bonding component which is cement in this case. The hemp may not impact hydration of cement components which secures compactness of this composite. There is no unified method to prescribe hemp usability as a filler to cement bonded boards. There was made own method in this purpose which was described in [Khestl and Bydžovský 2007]. For result confirmation we performed another test of hemp behavior in the cement matrix.

Heat of hydration

The influence of potential harmful substances in a hemp leach on hydration heat of Portland cement was tested by differential calorimeter DIK 04.

Differential calorimeter DIK 04 is a differential measuring semi – adiabatic device that serve for relatively quick determination of cement (or another material) qualities that could be described by the characteristic shape of hydration curve. It can be strength, false setting, setting times, admixtures influence etc.

The principle of this calorimeter is based on the measurement of heat differences between tested and the comparative sample made of aluminium. From the recorded curve of hydration, compared with reference curves, can be determined mass probability of normative tests results. [ELSYST Ltd. 2003]

Testing samples preparation and testing

Leach was made from wood particles and then from hemp. For comparison there was used common water from water-supply system. To obtain the leach we left to infuse wood or hemp particles in water in ratio 1:10 weight parts. The leaches had been left in laboratory environment for 24 hours. Then we removed from the leach any solids by filtration through the filter paper. So we got net leaches from both, wood and hemp particles. The experiment itself was executed using a comparative method.

The measuring process itself begins with one hour tempering of given weight of Portland cement specimen (5grams) placed in the reaction vessel of the calorimeter and 2ml of water (leach) in separate container. Tempering can be done inside the calorimeter at the laboratory temperature to eliminate heat transmissions as could be. After tempering, the calorimeter is opened and water quickly added to the Portland cement in the reaction vessel and than it is sealed. The temperature is registered by the data logger with the programmed time interval after closing of calorimeter cover.

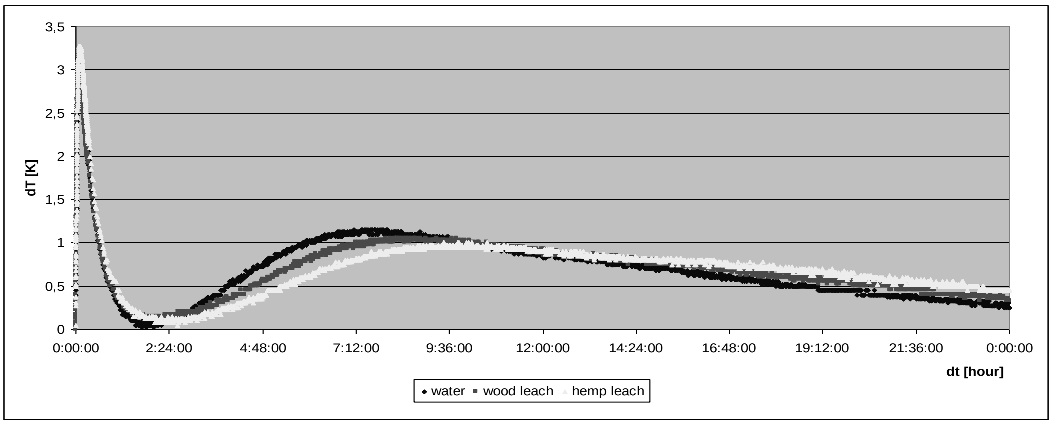

Fig. 6. Hydration heat development of measured specimens and their confrontation

From this type of calorimeter we are able to provide qualitative review of test data. The comparison of the hydration heat developments of the studied Portland cement mixtures containing various water samples is presented in Figure 3.

Two peaks are noticeable both on the time dependence of temperature difference [K] of the studied sample and the reference sample. These peaks are quite characteristic for the hydration process of Portland cement that can be divided into three principal stages:

Stage I: Initial stage (0-15 minutes)
Almost immediately on adding water, some of the clinker sulphates and gypsum dissolve, producing an alkaline, sulfate-rich solution. Soon after mixing, the (C_3A) phase - the most reactive of the clinker minerals - reacts with the water to form an aluminate-rich gel. The gel reacts with sulfate in solution to form small rod-like crystals of ettringite. (C_3A) hydration is a strongly exothermic reaction but it does not last long, typically only a few minutes. [WHD Microanalysis Consultants Ltd.] (The first peak)

Stage II: Dormant stage (15 min-4 hours)
A few hours lasting period of relatively low heat evolution. This is called the induction, or dormant period. The first part of the induction period – up to perhaps half-way through - corresponds to when concrete can be placed. As the induction

period progresses; the paste becomes too stiff to be workable. At the end of the dormant period, the alite and belite in the cement start to hydrate, with the formation of calcium silicate hydrate and calcium hydroxide.

Stage III (4-24 hours)

During this main period of cement hydration concrete strengths increase. The cement grains react from the surface inwards, and the anhydrous particles become smaller. (C_3A) hydration also continues, as fresh crystals become accessible to water. [WHD Microanalysis Consultants Ltd.] The period of maximum heat evolution occurs typically between about 8 and 20 hours after mixing and then gradually tails off. In a mix containing Portland cement as the only cementitious material, most of the strength gain has occurred within about a month. Where the cement has been partly-replaced by other materials, such as fly ash, strength growth may occur more slowly and continue for several months or even a year. Final strengths may exceed those from Portland-cement-only mixes.

Ferrite hydration also starts quickly as water is added, but then slows down, probably because a layer of iron hydroxide gel forms, coating the ferrite and acting as a barrier, preventing further reaction. [WHD Microanalysis Consultants Ltd.]

With the expected error of measurement, the initial setting times of tested samples were determined from the characteristic development of hydration heat of each tested sample. Final results are compared with results measured by Vicat needle test in the Table 1.

Table 1. Initial setting time of tested samples in minutes

Sample	***Water***	***Wood leach***	**Hemp leach**
Initial setting time (± 15minutes) DIK 04	110	130	135

Table 2. Initial setting time of tested samples in minutes

Samples without admictures	***Water***	***Wood leach***	**Hemp leach**
Initial setting time (±5minutes) Vicat	120	135	155
Final setting time (± 15minutes) Vicat	185	195	200
Samples with admictures	**Water**	**Wood leach**	**Hemp leach**
Initial setting time (±5minutes) Vicat	105	105	110
Final setting time (± 15minutes) Vicat	170	175	175

Hemp based cement bonded particleboards were made from treated hemp particles, cement, water and hydration admixtures. Fine fraction lay on both sides of coarse fraction of slab mixture. This is the reason of fine surface of final products.

  

Fig. 7 to 9. Samples of hemp particleboards (treated hemp, type B+C) – without surface treatment and on the right with surface treatment.

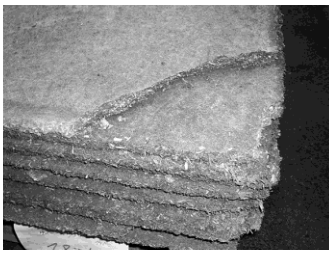 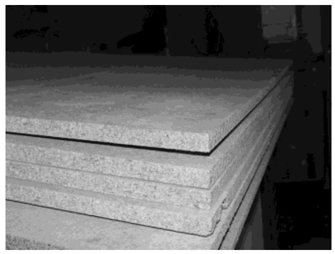

Fig. 10 and 11. Hemp based cement bonded particleboards in fresh condition and final product hemp particleboards

Table 3. Material strength characteristics

Parameter	Particleboards Hemp	Wood	ČSN EN 634-2
Values	Average		Minimal
Bulk density [kg/m^3]	1,285	1,350	1,000
Tensile strength [N/mm^2]	11.9	11.5	9.0
Modulus of elasticity [N/mm^2]	7,330	6,800	4,500

CONCLUSIONS

Experimental results presented in this paper only confirmed results of previously executed experiments [Khestl and Bydžovský 2007]. From these experiments follows that substances contained in hemp did not have noticeably affected bonding interactions between hemp and bonding material – Portland cement.

However, strength characteristics (28 days, standard methodology for cement based materials) of tested samples made from hemp particleboards were about 40% smaller than values shown in Table 3. Through all previous experiment conclusions it is interesting finding. One of the theories is that hempen particles absorb too much mixing water; that slows cement hydration. This behavior will be tested further. Fact is that strength values of two months old samples were much better as shows Table 3.

Currently, it can be said, with certain limitations, that the results of physical-mechanical properties of hemp based cement bonded particleboards are, as compared with the properties of wood-cement particleboards, on a very similar level. It can be expected that hemp based cement bonded particleboards will show better heat insulating and acoustic properties due to hemp material characteristics. Fast renewability, profitability, 100-per-cent utilization and other excellent properties of hemp make it a progressive raw material for the production of building materials in the 21st century that can be a perfect alternative to building materials made of wood.

REFERENCES

ELSYST Ltd. (2003). "Differential Calorimeter DIK 04. Description and Operating Instructions." Prague. p.25.

KHESTL, F. (2010). "Cement bonded particleboards modification with use of secondary raw and fast renewable materials, especially hemp." *Doctoral thesis*. In print

KHESTL, F., and BYDŽOVSKÝ, J. (2007). "Hemp utilization in cement-bonded particle boards." *ISEC-4.* London: Taylor&Francis/Balkema. p. 595 - 598. ISBN 978-0-415-45755-2.

TOŠOVSKÁ, M., and BUCHTOVÁ, I. (2009). "Situation and prospective report about flax and technical hemp." Department of agriculture. ISBN 978-80-7084-695-7, <www.mze.cz>

WHD Microanalysis Consultants Ltd. "Cement hydration." <http://www.understanding-cement.com>