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Innovative Use of Biomass Based on Technical Hemp in Building Industry

Julia Cigasova, Nadezda Stevulova*, Ivana Schwarzova, Jozef Junak

Technical University of Kosice, Faculty of Civil Engineering, Institute of Environmental Engineering, Vysokoskolska 4, 042 00 Kosice, Slovakia
nadezda.stevulova@tuke.sk

This article discusses about the possibility of using industrial hemp as a source of natural fibres for purpose of construction. The technical hemp (Cannabis Sativa) is the source of two types of fibres; bast fibres (used mainly in the paper and textile industries) and woody fibres - hurds. In recent decades hemp hurds have experienced a renaissance in use in the construction industry. This material is waste resulting from the processing of hemp stem on bast fibres. For the purposes of construction it has potential thanks to their exceptional thermal insulation, antiseptic, acoustic and mechanical properties. One of the aspects of using hemp products in building industry is that these materials are environmentally friendly in comparison to the used conventional materials (such as conventional insulating materials with polymer matrix or based on mineral wool).

In this article, the lightweight composites based on hemp hurds (as a biomass) and nonconventional binders MgO-cement are tested. The physical and mechanical properties of the composites hardened in indoor condition (28, 60, 90, 180 days) are studied. The results of the obtained parameters (density, water content, compressive strength, thermal conductivity coefficient) of hardened composites are presented.

1. Introduction

In the situation of the intensive growth of world population and the lack of raw materials for building materials production, solutions may be found in the return to the almost forgotten natural fibres, like hemp fibres.

Hemp is a multi-purpose crop delivering fibres, hurds and seed. Today, the fibre is used for manufacturing the cigarette paper, the insulation material and biocomposites. The hemp hurds, the woody inner core of the stem, is used for animal bedding and for the construction. Hemp seeds, small nuts have a high nutritional value. Hemp oil has an excellent and unique fatty acid profile. The both of them, seeds and oil are used for human food and animal feed.

Industrial hemp has been grown in Europe for many hundreds of years. Through the Middle Ages and until the end of the sailing ship period hemp was an important crop in many European countries like UK, France, Netherlands, Germany, Spain and Italy. The most important applications for the strong fibre were canvas for sails, sacks, canvas water hoses and fabrics as well as ropes.

Today hemp is crop, cultivated on 10,000 to 15,000 ha in the European Union. Hemp can play a vital role in the move towards organic agriculture. For the organic system to work efficiently weed control is essential for maximising yields. This plant is easy to grow. For its growth needs no chemical fertilizers and herbicides.

Because of its unique properties (thermal insulation, antiseptic, acoustic and mechanical), particularly its environmental benefits and the high yield of natural technical fibres, hemp is a valuable crop for the bio-based economy (Carus et al., 2013). Structural concrete based on cellulosed hemp fibres or hurds is not currently manufactured. The concrete based on a hemp, activated by alkaline hydrated lime, is a more lighter material than the conventional concrete, with excellent insulating thermal and acoustic properties, permeable to water vapour without the occurrence of superficial condensations, fire-extinguishing, resistant to bacteria and insects, and protective of wooden structures. This type of concrete can be

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produced through a variety of methods: concrete with pulp paper, boards of paper pulp with gypsum or fly ashes, or still composites of paper pulp with hemp, mainly used for design pieces. However, none of these materials, can totally fill the functional and economic requirements of current constructions. This is caused by not only the extended curing times, reduced in some cases by the addition of cement, but also for a need for better compaction and more workmanship (Eires and Jalali, 2005).

In our previous paper (Kidalova et al., 2012a), the experimental study of the parameters affecting to the physical and mechanical properties of hemp composite based on conventional and alternative binders, was performed. The properties of chemically treated hemp hurds (Terpakova et al., 2012) as well as behaviour of composites based on modified hurds with alternative binder of MgO-cement (Cigasova et al., 2013a) were investigated too. We also monitored the durability of composites (storage composites in the water environment) based on chemically untreated and chemically treated hemp hurds and alternative binder MgO-cement (Cigasova et al., 2013).

In this article, the physical and mechanical properties of lightweight composites based on hemp hurds (as a biomass) and nonconventional binder MgO-cement are studied after their hardening in indoor condition (28, 60, 90, 180 days). The results of the parameters (density, water content, compressive strength, thermal conductivity coefficient) of composites are presented in dependence on a hardening time.

2. Materials and Methods

2.1 Materials

Hemp is an annual plant which provides two types of material used in civil engineering: hemp hurds (granular form of hemp descended from the inner woody core) and hemp fibres (fibrous form the bark-like bast fibres).

The material studied in this article is hemp hurds coming from the Netherlands Company Hempflax (Figure 1). The used hemp hurds had wide particle size distribution of particles (8-0.063 mm). Cumulative distribution curve of hemp hurds slices sample is in Figure 2. The mean particle length of hurds was calculated to 1.94 mm. Bulk density of hemp material was 117.5 kg • m^{-3}. The average moisture content of the hemp material determined by weighing of hemp sample before and after drying at 105ºC for 24h was found out 10.78 wt.%. The chemical composition of material is shown in Table 1. A milled and oven-dried sample was used for the determination of chemical composition of hemp hurds. The content of holocellulose was determined by using the modified method according to Wisea. The quantitative determination of cellulose was performed by the Kürschner-Hoffer nitration method. The content of acid-insoluble (Klason) lignin was carried out by two-step hydrolysis of polysaccharides portion in sulphuric acid. Total ash content (mineral substances) was measured by combustion of sample and subsequent annealing. Toluene-ethanol extract containing mainly extractable waxes, fats, resins as well as water extractives was obtained by extraction in a Soxhlet apparatus for 6 – 8 h at 90°C.

Figure 1: Hemp hurds slices

Table 1: Chemical composition of hemp hurds slices

Chemical composition of hemp hurds [%]					
Toluene-ethanol extract	Holocellulose	Cellulose	Hemicellulose	Lignin	Ash
3.5	74.5	44.2	30.3	24.4	1.4

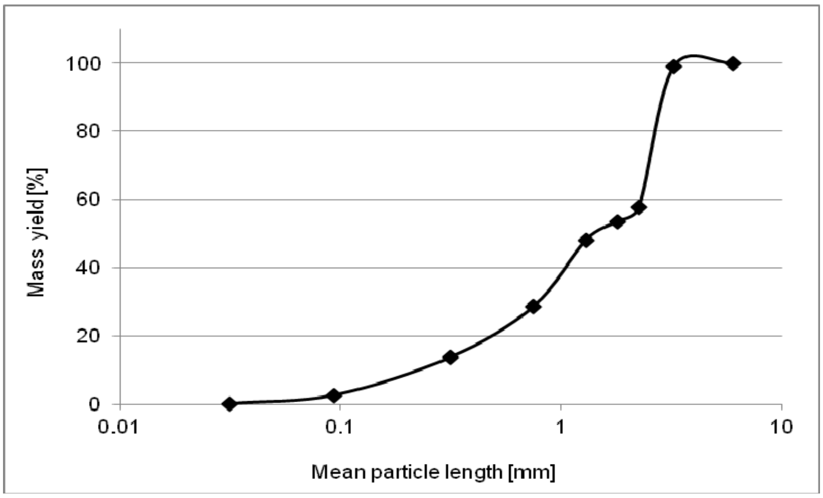

Figure 2: Cumulative distribution curve of hemp material used in this study

MgO-cement as a binder was used in experiments. It consists of a caustic magnesite obtained by low temperature decomposition of natural magnesite (CCM 85, SMZ a.s. Jelšava, Slovakia), silica sand (Šaštín, Slovakia) with the dominant component of SiO_2 (95-98%) and sodium hydrogen carbonate (p.a). MgO has been milled in order to reduce its particle size. Dry milling was carried out in laboratory vibratory mill VM 4 for 5 min.

2.2 Preparation of composites

Experimental mixtures consisted of 40 vol. % of hemp hurds, 29 vol % of MgO-cement and 31 vol % of water. The components of mixture were homogenized in dry way and then mixed with water addition in concrete mixer at a speed of 120 rpm for 5 min. Standard steel cube forms with dimensions 100 mm x 100 mm x 100 mm were used for preparation of samples. The specimens of lightweight composites were cured for 2 days in an indoor climate and then were removed from the forms. Curing was continued under laboratory conditions during 28, 60, 90 and 180 days. Designation of composites samples is given in Table 2.

Table 2: Designation of experimental composites samples

Sample	Cured time [days]
I	28
II	60
III	90
IV	180

Finally, all hardened composites were dried in a laboratory oven at temperature of 100 ±5 °C to the constant weight.

2.3 Testing methods

Density, thermal conductivity, compressive strength and water content were measured on cured specimens under laboratory conditions and dried specimens after their water storage. The density was determined in accordance with standard STN EN 12390-7. The thermal conductivity coefficient of samples as the main parameter of heat transport was measured by the commercial device ISOMET 104 (Applied Precision Ltd., Germany). The measurement is based on the analysis of the temperature response of the analyzed material to heat flow impulses. The heat flow is induced by electrical heating using a resistor heater having direct thermal contact with the surface of the sample. The compressive strength of all composites was determined using the instrument ADR 2000 (ELE International Ltd., England). The water content was determined in accordance with standard STN EN 12087/A1 (727056). Water absorption testing (after 1h) is based on determination of weight increase of test samples during their full immersion in de-ionised water bath under constant laboratory temperature in comparison to the weight of dry samples.

3. Results and discussion

Prepared samples were used for measurement of some physical and mechanical properties. The density of specimens after curing ranged from 910 to 1200 kg • m^{-3}. The measured values of density are comparable with other building materials, such as aerated autoclaved concrete (800 – 1200 kg • m^{-3}). Compressive strength for the hardened samples were in the range of 1.86 – 6.94 MPa. The highest value of compressive strength reached composite after 180 d of hardening. Dependence of compressive strength on the time of hardening is shown in Figure 3. From the curve, it is clear that the process of curing is linear at the beginning, then slows down and even after 180 d the hydration process it is not finished. Probably, the reason is in the slow hydration of MgO particles.

Measurements indicate that the values of thermal conductivity coefficient are in the range of 0.085 to 0.065 W • m^{-1} • K^{-1}. In Figure 4, dependence of thermal conductivity coefficient on hardening time is illustrated. With the increasing time of hardening of composites, the values of thermal conductivity coefficients are decreasing.

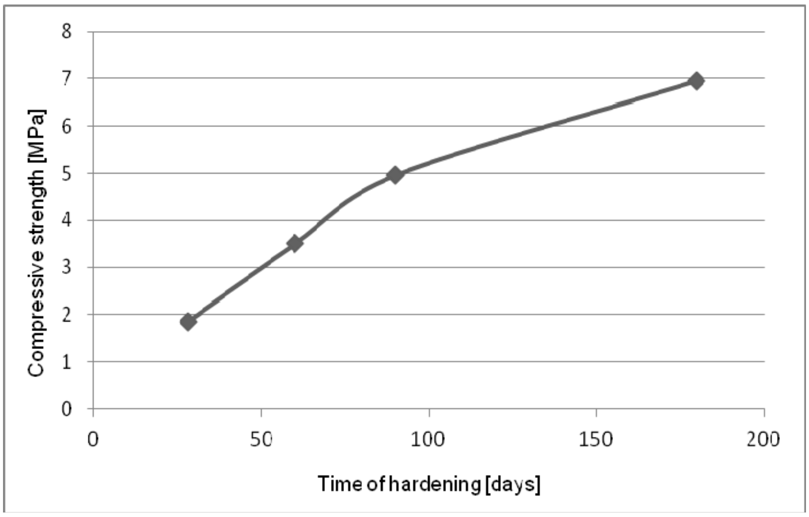

Figure 3: Dependence of compressive strength of composites on time of hardening

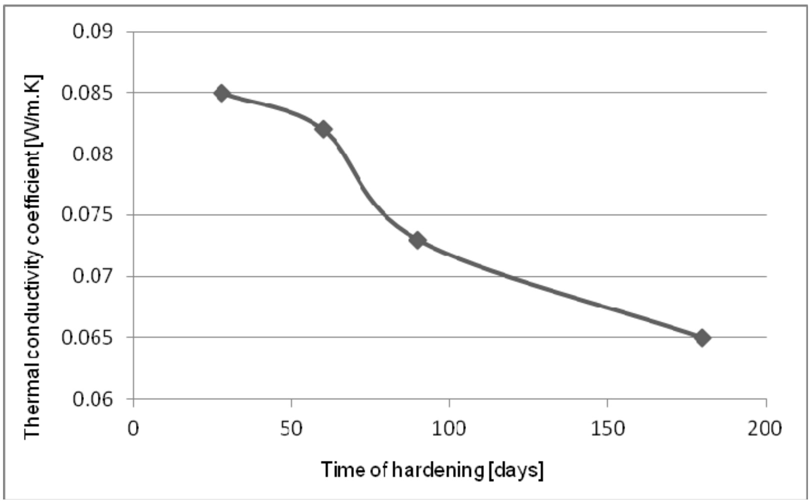

Figure 4: Dependence of thermal conductivity coefficient of composites on time of hardening

Figure 5 shows the course of water absorption values vs. density of composites. According to the Figure 5, the lightest specimen has the highest water content. It is known, that hemp fibres and hurds have poor moisture resistance due to the presence of hydroxyl and other polar groups in their structure what leads to their hydrophilic nature. Hydrophilicity of natural fibres indicates the high moisture absorption. Water absorption for biocomposites is typically 1 - 5 % after 7 days and 18 - 22 % after several months in dependence on the chemical composition of the wood fibre. Hemp contains cellulosic fibres and a woody material called shives (hurds). The most important structural component in hemp is a cellulose, natural polymer with each repeating unit containing three hydroxyl groups. It is present in the hemp structure in the form of crystalline micro fibrils. Hemicellulose as another important component is a lower molecular weight polysaccharide cementing matrix between cellulose fibrils, forming the main structural component of the fibers cell. According to (Azwa et al, 2013), hemicellulose is responsible for a moisture absorption. Lignin is a hydrophobic complex of hydrocarbon polymer, it assists to the transportation of water molecules. Moisture content in fibers influences the degree of crystallinity, tensile strength, swelling behaviour and porosity of fibers. The degree of water sorption and swelling are determined to the ability to interact of water molecules with fibres. In the case of composites, the all water absorbing and holding surfaces, cracks, and cavities are responsible for water uptake. The obtained changes in water content are related to the structural heterogeneity of composites based on porous hemp hurds. In order to understanding the water behaviour of composites based on biomass, more investigations is needed.

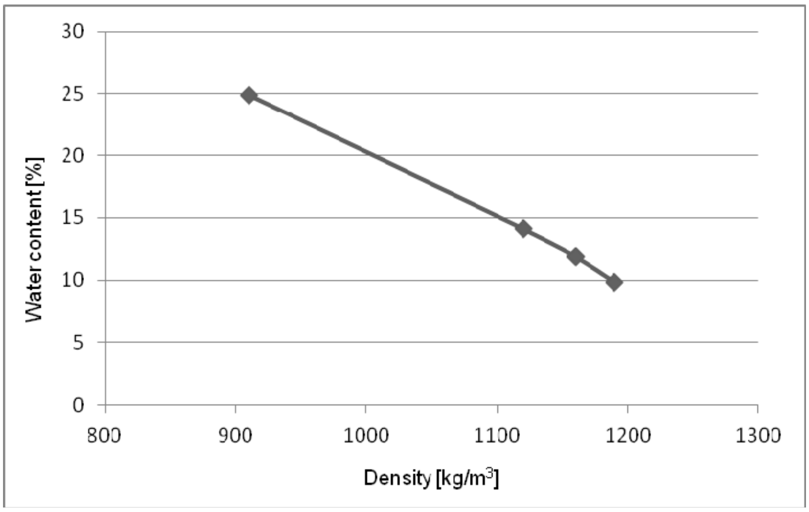

Figure 5: Dependence of water content of composites on density

4. Conclusions

This paper studied the properties of composites based on biomass (hemp hurds) as a filling material and nonconventional binder MgO – cement. The specimens were hardened in different time periods. Influence of hardening time on the mechanical (compressive strength) and physical properties (density, thermal conductivity and water absorption) was monitored.

The following conclusions can be formulated from the results described above:

- Time of hardening has significant effect on the properties of biocomposites,
- Biocomposites with the longest hardening time have the highest value of compressive strength (6.944 MPa) and the lowest values of thermal conductivity coefficient (0.065 W • m^{-1} • K^{-1}) and water content (9.10 %),
- The values of thermal conductivity coefficients are decreasing with increasing time of hardening of biocomposites,
- The water content in hardened composites is determined by their density in dependence on porous structure, higher water content have the composites with lower density,
- More investigations is needed in order to understanding and explanation the influence of biomass fibres as a filling agent on composites structure by using physico - chemical methods.

Acknowledgements

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