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Lightweight Composites Based on Technical Hemp Hurds in Construction Industry

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This article discusses about the possibility of using technical 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 its environmentally friendly properties in comparison to the conventional materials (such as insulating materials with polymer matrix or based on mineral wool). Due to the low density and high porosity of the hemp fibres, the combination of hemp and binder creates high-quality products such as hemp concrete, fibre boards and lightweight composites.
In this paper, the physical and mechanical properties of lightweight composites based on pre-treated hemp hurds and alternative binder MgO-cement are studied after their hardening in indoor condition for 28 days. The results of the parameters (density, density changes after thermal stress, water absorbability, thermal conductivity coefficient, compressive and tensile strength) of composites presented with emphasis on their usage as thermal insulation material show some differences which are determined by properties of modified filler (hemp material) as well as by properties of filler/binder interface.

1. Introduction

Because of increasing environmental awareness, the use of sustainable, renewable and environmentally friendly materials is currently gaining interest. Principles of sustainable construction of the buildings bring new requirements to develop sustainable materials (Bourmaud and Morvan, 2013). Over the last few years there has been a renewed interest in the use of vegetable fibres as constituents in composite materials made of polymer or mineral matrix, such as cement, plaster or lime. The incorporation of fibres modulates mechanical and insulating properties of the resulting composite material (Pacheco-Torgal and Jalali, 2011).
Building industry is focused to using of rapidly renewable resource – natural plants as reinforcement for composite materials for construction purposes. Building materials based on natural plant fibres with inorganic binder represent a group of lightweight materials providing a healthy living in buildings (Preikss and Skujans, 2013). In particular new concretes are used that contain vegetal aggregates (e.g. hemp hurds that is by-product resulting from the pulping of hemp stalks).
From a “life-cycle assessment” perspective hemp construction materials are far more interesting: hemp is naturally produced, does not require maintenance and consumes CO_2 to grow, making the hemp concrete a carbon-negative construction material (Boutin and Flamin, 2005). Composites based on hemp hurds are a prospective building material because of its very interesting properties: antiseptic, lightweight, provides excellent acoustic absorption, thermal insulation and hydric regulation, prevents condensation (Collet and Bart, 2008). Initial water content in the hemp and water exchanges between hemp and binder play a major role in these processes (Fourmentin and Faure, 2016).

Therefore, research about building materials based on renewable and alternative material resources fibres is needed. This paper discusses the use of lightweight composites based on waste material of hemp stem processing (hemp hurds) in interaction with alternative binder material (MgO based cement) in construction industry. The objective of this work is to investigate the effect of hemp hurds pre-treatment processes on the selected physico-mechanical properties (density, water absorbability, thermal conductivity, compressive and tensile strength) of hemp composites. Different treatment processes (ultrasonic and NaOH treatment) were used to remove non-cellulosic compounds from natural hemp material and thus improve the composites properties. This paper covers the composite materials of original and treated hemp hurds and an inorganic alternative binder (MgO-cement).

2. Materials and Methods

2.1 Hemp hurds

Technical hemp hurds coming from the Netherlands Company Hempflax (Oude, Pekela, Netherlands) used for this study is shown in Figure 1. This hemp material consisted of a large majority of core fibres (hemp hurds, what is waste of hemp stem processing) over bast fibres, and it also contained fine dust particles originating from the manufacturing grinding process. Original hemp hurds sample had particle length distribution 8–0.063 mm. The mean particle length of used hemp hurds calculated from granulometric data was 0.94 mm. Density of hemp material was 117.5 kg/m^3. The average moisture content of hemp material samples determined by its weighing before and after material drying for 24 h at 105 °C was found 10.78 wt%. The hemp hurds is constituted by 44.5 % cellulose, 32.8 % hemicelluloses, 21 % lignin, 3.5 % components soluble in toluene-ethanol extract and 3 % ash. The chemical composition of hemp hurds was determined separately for each its component and more described in the literature (Cigasova and Stevulova, 2014).

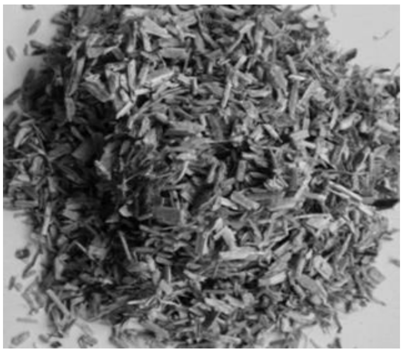


Figure 1: Technical hemp hurds

2.2 MgO cement

MgO-cement used as an alternative binder in the experiments consisted of magnesium oxide obtained by high temperature decomposition of natural magnesite (CCM 85, SMZ Jelsava, Slovakia), silica sand with the dominant component (95-98 %) of SiO_2 (Sastin, Slovakia) and sodium hydrogen carbonate p.a. (Gavax, Slovakia). MgO has been dry milled in laboratory vibratory mill VM 4 for 5 min to reduce its particle size. The mean particle diameter calculated from granulometric data was 6.85 μm. Calcined magnesium oxide is constituted by 84.7 % magnesium oxide (MgO), 7.2 % iron oxide (Fe_2O_3), 5.3 % calcium oxide (CaO), 0.65 % silicon dioxide (SiO_2) and 0.85 % loss on ignition.

2.3 Treatment processes of hemp hurds

The physical modification of hemp hurds sample was carried out by material ultrasonic treatment in ultrasonic cleaner bath (TESON 10, 220 V, 50 Hz, 650 W) with deionized water as a cleaning medium for 1 h duration. The ratio used for the experiments s:l (solid to liquid phase) was 1:10.
The chemical modification of hemp hurds was made by 1.6 M sodium hydroxide solution (NaOH) p.a. (CHEMAPOL, Czechoslovakia). The chemical treatment conditions are described in the literature (Terpakova and Kidalova, 2012).

2.4 Scanning Electron Microscopy

Scanning electron microscopy (SEM) observations of hemp hurds samples were done on a TESCAN MIRA 3 FE (TESCAN, Brno, Czech Republic). Fibre samples were glued on carbon adhesive films and coating with carbon film to avoid charging under the electron beam using a vacuum sputtering coater.

2.5 Preparation and testing of composite samples

Experimental hemp composites were prepared according to the recipe (Bydzovsky, 2009.) consisted of 40 vol. % of hemp hurds (original and treated samples), 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. Standard steel cube forms with dimensions 100x100x100 mm were used for samples preparation. The hemp composites specimens were cured for 48 h in an indoor climate and then were remoulded and covered with a foil. Curing was continued under laboratory conditions during 28 days. The resulting values are the average of three measurements.
Compressive strength of the all cube specimens under controlled conditions after hardening was determined as the maximum load per average cross-sectional area by using the instrument ADR ELE 2000 (International Limited, United Kingdom) in accordance with the standard STN EN 206 (2009). Tensile strength was determined by using the instrument M350-20 AT (Testometric, United Kingdom) in accordance with the standard STN EN 319 (1995). Thermal conductivity coefficient of samples, as the main parameter of heat transport was measured by the commercial device ISOMET 104 (Applied Precision Ltd., Germany). Short-term water absorbability (after one hour) was specified in accordance with the standard STNEN 12087/A1 (2007). Density was determined in accordance with standard STNEN 12390-7 (2011).
Prepared hemp specimens were also monitored in term of bulk density changes after its thermal stress. Initial temperature of measuring was the laboratory temperature (20 ºC). Thermal stress was performed under conditions of 100, 150, 180, 200 ºC in the laboratory oven with air circulation. Bulk density changes after thermal stress were observed on all samples.

3. Results and Discussion

3.1 Chemical composition of hemp hurds samples

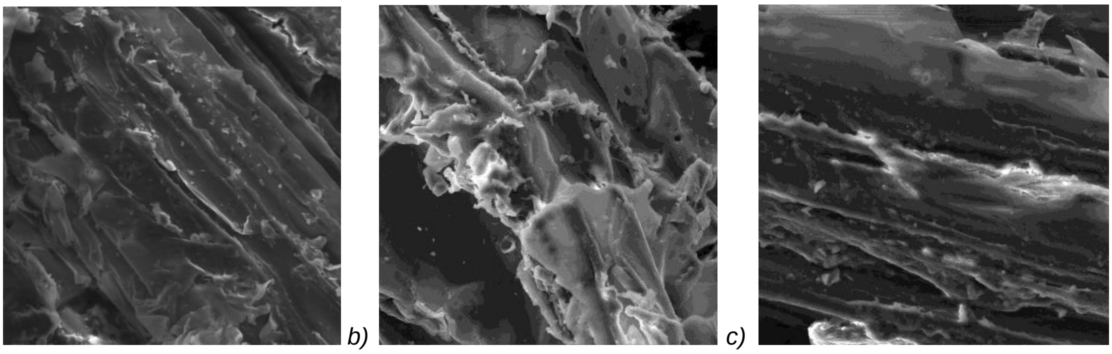
The effect of treatment processes on chemical composition of hemp hurds was monitored and the composition changes of main components are given in Table 1. Comparing the main hemp hurds components, ultrasonic treatment procedure does not markedly change the chemical composition what is in accordance with literature (Renouard and Hano, 2014). On the other hand, it is obvious that in the case of NaOH treated samples the hemicelluloses percentage is significantly lower which is associated with its degradation process caused by using this agent (solution of NaOH), what is well-known to remove amorphous materials (hemicelluloses, pectins) from the hemp hurds surface (Le Troëdec and Rachini, 2011). The reduction of lipophilic extractives and ash content in both treated samples were measured in comparison with original hemp hurds sample.

Table 1: Chemical composition of original and treated hemp hurds samples

Hemp hurds component [%]	Original sample	Ultrasonic treated	NaOH treated
Cellulose	44.5	46.7	53.9
Hemiceluloses	32.8	32.6	12.1
Lignin	22.0	23.23	27.4
Compounds soluble in toluene and ethanol	3.5	2.6	2.8
Ash	2.6	1.3	1.3

3.2 Scanning electron microscopy

The hemp fibre quality was checked using Scanning Electron Microscopy (SEM) to reveal surface roughness, imperfections and to detect the morphological changes after treatments. The SEM micrographs of hemp hurds samples surface are shown in Figure 2. The original sample shows the impurities presence (ash, waxes...) and its structure is formed by several bundles of longitudinally arranged fibrils. The impacts of physical and chemical treatments are shown as a partially cleaned hemp samples surface and fibrillate structure.



a) b) c)

Figure 2: SEM micrographs of: (a) original; (b) ultrasonic treated; (c) NaOH treated hemp hurds samples (4000 times of magnification)

3.3 Hemp composites characteristics

For physico-mechanical characteristics determination of lightweight composites based on hemp hurds, three types of composites specimens were prepared, samples based on original untreated hemp hurds as a referential material and samples based on physically (ultrasonic treated) and chemically (NaOH treated) hemp hurds. The resulting values shown in Table 2 are the average of three measurements.

Table 2: Physico-mechanical properties of 28 days' composites based on treated and untreated hemp hurds

Physico–mechanical properties of hemp composites	Original sample	Ultrasonic treated	NaOH treated
Compressive strength [MPa]	1.75	1.52	0.98
Tensile strength [MPa]	0.463	0.219	0.058
Thermal conductivity coefficient [W/m.K]	0.103	0.130	0.071
Water absorbability [%]	22	13	10
Density [kg/m^3]	1070	1120	1160

Density values of prepared composite samples after 28 days of hardening were ranged from 1070 to 1160 kg/m^3 which place this material into category of lightweight composites. The measured density values are comparable with building materials, such as aerated autoclaved concrete (800 - 1200 kg/m^3) (standard STN EN 206). Since lightweight composites are used as thermal insulation in buildings, their thermal isolation properties, as very important for such application, were assessed by measuring their coefficient of thermal conductivity. The lower value of this parameter was recorded for the composite samples based on NaOH treated hemp hurds in comparison to composite with ultrasonic treated filler. The thermal conductivity coefficient values of specimens prepared with alternative binder MgO-cement were generally lower than thermal conductivity values of hemp composites with lime binder (Cigasova and Stevulova, 2013) or with traditional Portland cement (Schwarzova and Cigasova, 2014). The all measured values of specimens were in range acceptable for thermal insulating materials. As can be seen from Table 2, the specimens with treated hemp hurds have observably lower values of short-term water absorbability than composites based on original hemp material. Treatment processes of hemp hurds reduced water absorbability of hemp composites specimens by 40 % in case ultrasonic treated specimens and by 53 % after chemical treatment. The strength parameters of treated hemp composite specimens were lower than specimen based on original hemp material. The significant difference in determined strength values of composites with chemically treated hemp hurds has been observed. Cause of this phenomenon can be in a nature of used binder which led to poor interaction of its particles and hemp fibres (Stevulova and Schwarzova, 2014.).

3.4 Bulk density changes after thermal stress

Figure 3 illustrates changes in bulk density of lightweight composites based on hemp hurds after its thermal stress. The resulting values are the average of three measurements. A gradual decrease of bulk density was observed in the all hemp specimens. The largest decrease of bulk density was observed for the all samples heated up to 100 ºC. In this case, reduction in bulk density of composites with ultrasonic treated hemp material in comparison to original hemp specimens is about 20 % and for composites with NaOH treated hemp hurds in comparison to original specimen it is about 28 %. Gradual temperature increase up to 200 ºC leads to reduction of composites bulk density about 30-40 %. This process relates to mass loss of composites due to the releasing of the adsorbed moisture and/or physically bound water as well as degradation of organic compounds present in hemp fibres as pectin, hemicelluloses and cellulose (Stevulova and Estokova, 2016).

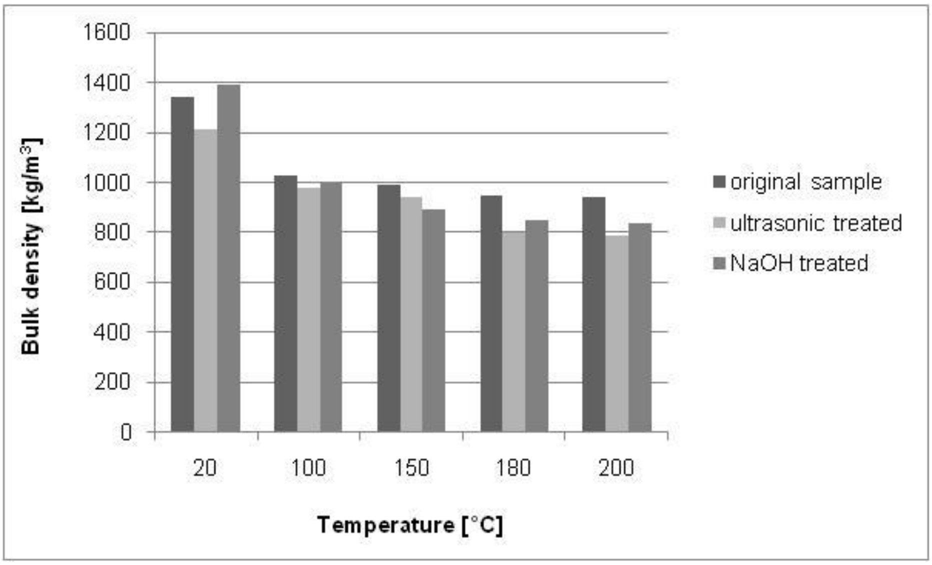


Figure 3: Bulk density changes of 28 days hardened composites in dependence on temperature

4. Conclusions

This paper studied the properties of lightweight composites based on untreated and treated (physically and chemically) hemp hurds as a filling material and alternative binder MgO – cement. Influence of treatment processes on the chemical composition and morphology of hemp hurds, physical (density, thermal conductivity and short-term water absorption) and mechanical properties (compressive and tensile strength) of hemp composites and bulk density changes after thermal stress was investigated.

The treatments of hemp material were used for removal of organic and inorganic loosely bound contaminants from hemp hurds surface. The non-cellulosic components such as hemicelluloses and waxes were partially removed after both treatment processes and morphological changes were observed by Scanning Electron Microscopy (SEM).

Selected physico-mechanical characteristics of hemp composites were also determined. Reduction of water absorbability was monitored after both treatment processes. Thermal conductivity coefficient measured for the all specimens were in range acceptable for thermal insulating materials. Decrease in bulk density values of all hemp composite specimens after thermal stress was observed whereby sample prepared by using chemically treated (with 1.6M NaOH solution) hemp hurds had the greatest decrease in bulk density and had stable behaviour after reaching 150 °C.

Studied composite materials demonstrated good characteristics for its using in construction industry such as non-load bearing material even it is more necessary to study the alternative binder MgO-cement.

Acknowledgments

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