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Section: Environmental Protection

Effect of the water storage of biocomposites based on chemically treated hemp hurds on their properties

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Abstract

Due to the limited amount of total world reserves of non-renewable natural resources, the increased attention is devoted to the use of alternative materials. Nowadays, the use of renewable materials such as natural fibres for reinforcement of lightweight composites is attractive. The great importance is attached to industrial hemp as rapidly renewable fibres and non-waste material. Hemp hurds is obtained from the processing of hemp stems (woody core of hemp stems) and used like a filler into composites.
In this paper, the attention is given to the water storage of biocomposites based on unmodified and chemically modified hemp hurds and an alternative binder MgO-cement and to the testing of their mechanical and physical properties (compressive strength, density, thermal conductivity).

Keywords: biocomposites, hemp hurds, chemical treatment, water storage

1. Introduction

Nowadays, the using of alternative building materials and environmental friendly products is an increased trend in the construction industry. The moving from the limited material resources to easily renewable raw material resources is one of the possible ways of achievement of sustainable development in the building industry. A large group of renewable raw materials are materials of plant origin. The great importance is attached to technical hemp like an easily renewable source of fibres and its using as filler in the lightweight composites.

The cannabis plant is a multi-purpose crop delivering fibres, hurds and seeds. The technical hemp is a source of two types of fibres: bast fibres and woody fibres – hurds (Figs 1, 2). The bast fibres are bound by the middle lamella and arranged in bundles those run from top to bottom of the stem. The hemp fibres are situated in the bast of the hemp plant, and have a high tensile strength. The bast fibres contain higher amounts of cellulose compared to hemp hurds. The hemp hurds represents about 60–80% of the stem in hemp and it consists of cellulose (34–48%), hemicellulose (21–37%) and lignin (16–28%) [1].

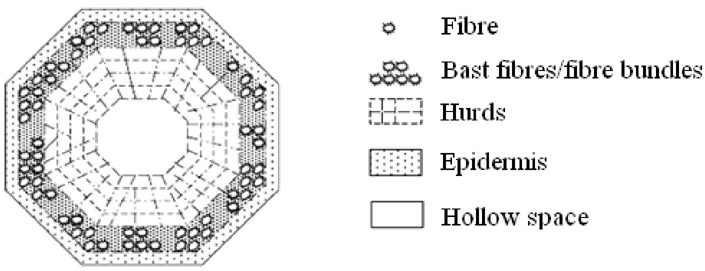

Fig. 1. Cross-section of a hemp stem [1]

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The industrial hemp is suitable to use in a wide range of products such as paper, textiles, insulation, constructions and so on. In the beginning of the nineties, a new building material consisting of hemp particles as a filler and an inorganic binder has been developed. Now in the EU, hemp concrete is a perspective building material that combines a lime-based binder and woody core of the hemp plant [3].

The lightweight composites can be based on only the woody core part of the hemp (hurds) or using both hemp hurds and fibres what can lead to improvement of mechanical properties [4]. In comparison with other conventional materials in construction, the hemp concrete has many advantages such as low density, good thermal insulation, breathability, antiseptic, fire resistance and protection from infestation; however it is not load-bearing and has to be used in combination with a load-bearing frame.

Fig. 2. Cross-section of stem of a cannabis plant [2]

The properties of hemp fibres depend on the fibre chemical composition. High moisture sorption and heterogeneity of hemp fibres cause weak interface between the fibres and the matrix and a poor transfer of the applied stress between the materials. Many research projects have been devoted to the enhancement of the adhesion at the fibres – matrix interface, using for example chemical modifications of the surface of the fibres or physical treatment of hemp fibres [5].

In our previous papers [6–8], the properties of chemically treated hemp hurds as well as behaviour of composites based on modified hurds with alternative binder of MgO-cement were investigated.

The aim of this work is to watch the water uptake influence on mechanical and physical properties of prepared lightweight composites based on unmodified and chemically treated hemp hurds and the comparison of water absorption of these composites.

2. Material and methods

2.1. Material

In the experiments, the technical hemp hurds slices (Cannabis Sativa L.) from the Netherlands company Hempflax, were used. This hemp hurds contains more hurds material than bast fibres and its density was 117.5 kg•m-3. The used hemp material was polydispersive, particle length of hemp slices was 1.94 mm. The average moisture content of hemp hurds determined by weighing of hemp sample before and after drying for 24 h at 105 ºC was found 10.78 wt.%. The chemical composition of used hemp hurds is shown in Table 1.

MgO-cement, as a binder used in experiments, consists of 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 SiO2 (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 [9].

Table 1. Chemical composition of hemp hurds

Chemical composition of hemp hurds [%]				
Toluene-ethanol extract	Cellulose	Hemicellulose	Lignin	Ash
3.6	44.5	32.8	21.0	3.0

2.2. Chemical modification of hemp hurds

The chemical modification of hemp hurds was made by three different solutions (Table 2): sodium hydroxide (NaOH), calcium hydroxide ($Ca(OH)_2$), ethylenediamintetracetic acid (EDTA).

Table 2. Chemicals used for modification of hemp hurds

Name	Formula	Producer	Purity
sodium hydroxide	$NaOH$	CHEMAPOL, Czechoslovakia	p.a.
calcium hydroxide	$Ca(OH)_2$	ROTH, Germany	≥96%, pulv.
ethylene-diamine-tetracetic acid	$C_{10}H_{16}O_8N_2$	GAVAX s. r. o., Slovakia	p.a.
acetic acid	CH_3COOH		8%

Chemical treatments of dried hemp hurds were performed under the conditions described in the paper [7]. All of the hurds samples, treated and untreated, were finally dried in an oven during 48 h at 50 °C.

2.3. Preparation of composite specimens

Experimental mixtures prepared according to the recipe published in work [10] consisted of 40 vol. % of hemp hurds (unmodified as a referential material and chemically treated), 29 vol. % of MgO-cement (consisting of 9,6% milled caustic natural magnesite, 9,6% silica sand, 9,6% sodium hydrogen carbonate p.a.) and 31 vol. % of water. For a preparation of specimens, the standard steel cube forms with dimensions 100 mm × 100 mm × 100 mm were used. The specimens were cured for 2 days in the indoor climate at approximately +18 °C and then they were removed from the moulds. After that time, the specimens were wrapped in a plastic film during 28 days.

2.4. Water storage

After 28 days of hardening, the hemp composites were used for long termed storage experiments in deionised water. Water absorption of biocomposites was carried out by full immersing in de-ionised water bath (PE closed container) at laboratory temperature (20 ºC) for 7, 28 and 60 days. After immersion time, the specimens were taken out from the water and were reweighed. Water content of the composite samples was determined from the weight differences between wet and dry test samples.

2.5. Testing methods

Density, water content, thermal conductivity and compressive strength were measured on the specimens dried in an oven at 100 °C up to a constant weight after their water storage. The density was determined in accordance with standard STN EN 12390-7 [11]. The water content was determined in accordance with standard STN EN 12087/A1 (727056). The thermal conductivity coefficient of samples as the main parameter of heat transport was measured by the commercial device ISOMET 104 (Applied Precision Ltd, Slovakia). Compressive strength of all composites was determined using the instrument ADR 2000 (ELE International, England).

3. Results and discussion

3.1. Characterization of chemically modified hemp hurds

The chemical composition of used hemp hurds before and after chemical modification (in three chemical solutions: NaOH, Ca(OH)2, EDTA) is shown in Table 3. In the case of modification of hemp hurds with NaOH, the increased content of cellulose and lignin was observed. On the other hand, using EDTA and Ca(OH)2 led to insignificant changes in content of hemicellulose, cellulose and lignin. Amount of lipophilic extractives and ash in all treated samples in comparison with referential sample was reduced.

Table 3. Selected chemical characteristics of hemp hurds before and after modification

Hemp hurds component [%]	Sample			
	referential	modified with NaOH	modified with $Ca(OH)_2$	modified with EDTA
toluene-ethanol extract	3.6	2.8	2.5	2.9
lignin	21.0	27.3	24.0	24.2
celullose	44.5	53.9	45.8	45.7
hemicellulose	32.8	12.1	28.9	31.1
ash	3.0	1.2	1.4	1.0

3.2. Water absorption of composites

The results of water absorption investigations showed that values of water content in composites are in a range of 5.69–39.7 wt. %. As it can be seen in Figure 3, water content in specimens based on unmodified and modified hemp hurds is increasing with a prolonged immersion time of composites in water. Due to the high content of cellulose in hemp fibres, the hemp composites absorb water more rapidly than, e.g. cement mortar or concrete. The water absorption behaviour of hemp composites at room temperature is the result of several diffusion processes.

Water content in specimens prepared with chemically modified hemp slices is considerably lower in comparison to values of referential composite with unmodified hemp hurds. The most obvious change is observed in the samples modified with NaOH. According to paper [12], high amount of water causes swelling of the fibres and/or hurds slices. Due to the swelling of the hemp material, micro cracking in the matrix of tested composites occurs [13]. These micro cracks can be filled with water. Another phenomenon of water sorption in composite is connected with the additional hydration of MgO-particles during water storage of composite. On the other hand there is dissolution of alkaline component in the matrix (NaHCO3), leading to increased pH values of solution [7].

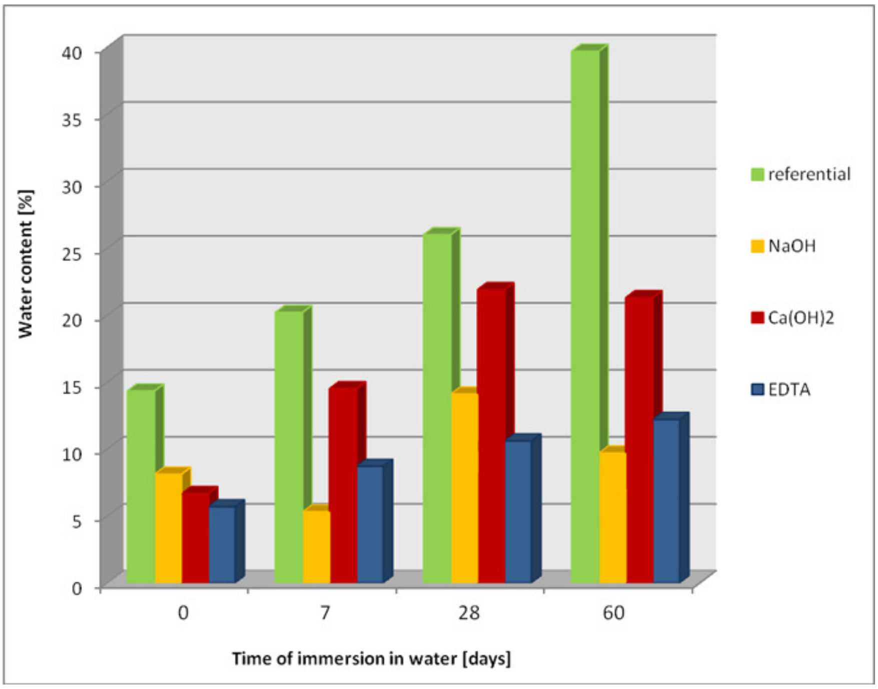

Fig. 3. Dependence of water content in composites on time of their immersion in water

3.3. Testing the properties of composites

Values of thermal conductivity coefficient of composite samples measured in the range of 0.072–0.185 W•m-1•K-1 are comparable to other building materials. The Figure 4 illustrates dependence of thermal conductivity coefficient on time of immersion in water. The all composites based on modified hemp hurds have lower values of this parameter in comparison with composites based on unmodified hemp hurds. The lowest values of thermal conductivity coefficient has composite based on hemp hurds chemically modified by NaOH.

The density values of composite samples were determined in the range of 780–1050 kg•m-3.

From the results of the compressive strength of the composites before and after water storage (Figure 5), it is clear that specimens based on chemically treated hemp hurds have lower values of compressive strength (0.91–2.3 MPa) in comparison to referential composites (1.9–3.74 MPa). This decrease in values of strength parameter of water immersed hemp composites corresponds with the results observed for hemp fibre reinforced unsaturated polyester composites [14].

In all cases of samples with modified and also with unmodified hemp hurds, the values of compressive strength increase with increasing time of immersion up to 28 days of immersion in dependence on nature of used filler. This increase of values of compressive strength can be caused by hydration process of binder. The strength decrease observed in the case of samples immersed in water more than 28 days can be caused by the formation of hydrogen bonds between the water molecules and cellulose in hemp hurds. The second reason of this phenomenon can be due to the weakening in the filler-matrix interface caused by water absorption. However, the relative extent of decrease in compressive strength values of immersed composites for increasing time in comparison to dry specimens was expected.

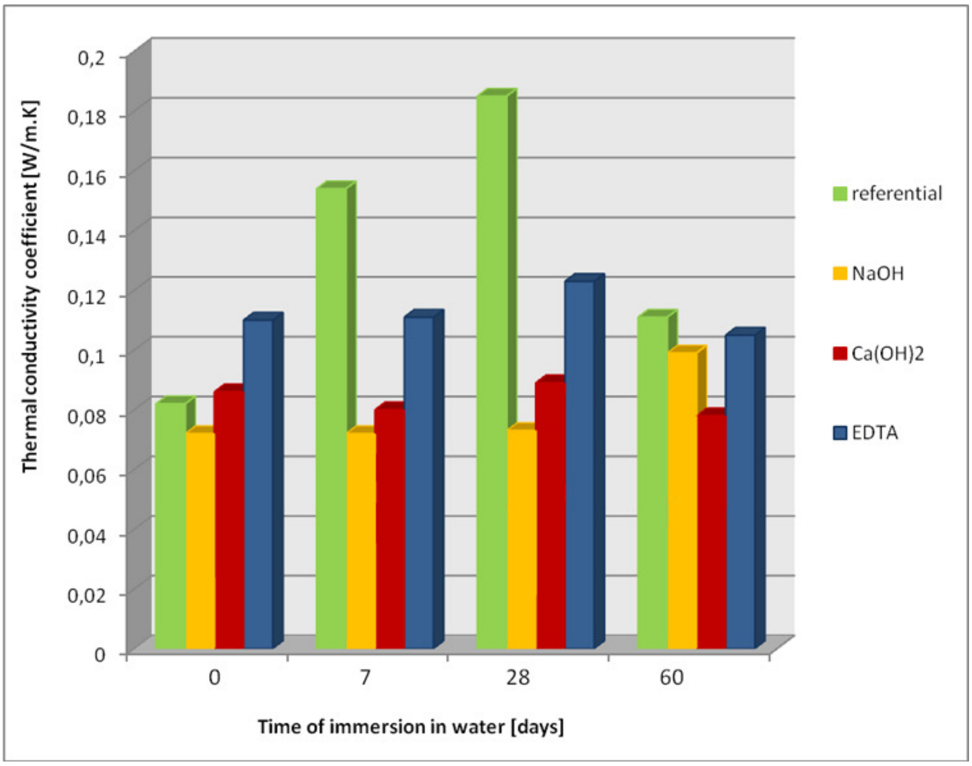

Fig. 4. Dependence of thermal conductivity coefficient on time of immersion in water

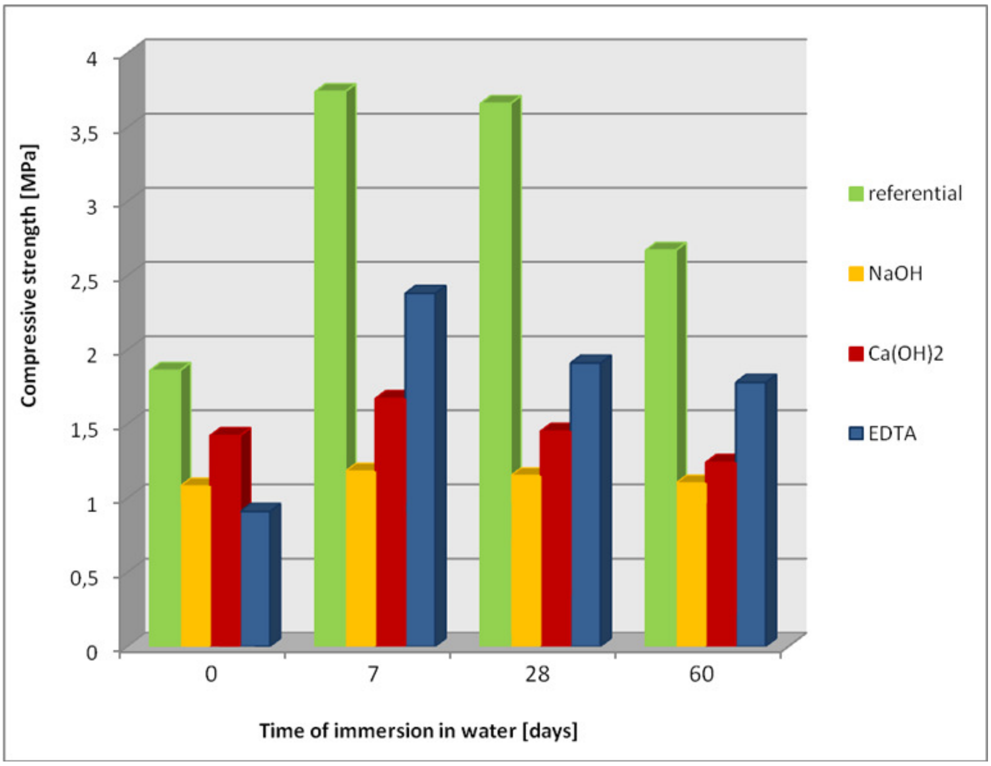

Fig. 5. Dependence of compressive strength of composites on time of immersion in water

4. Conclusions

This paper studied the changes in properties of hardened composites based on unmodified and chemically modified (in NaOH, $Ca(OH)_2$, EDTA solutions) hemp hurds as a filling material and an alternative binder MgO-cement after long term storage in deionised water.

The results show that the chemical modification of hemp hurds has an impact on properties and chemical composition of the hurds. Some important physical and mechanical properties as water absorbability, compressive strength, thermal conductivity coefficient of water immersed composites were tested. The determined values of thermal conductivity coefficient are comparable to other building materials. In case of composites based on chemically treated hemp hurds, the lower values of compressive strength and thermal conductivity coefficient were observed in comparison with referential composite.

Processes occurring in composite based on natural cellulosic material and nonconventional binder during long term storage are complicated. The explanation of observed facts and better understanding of these processes requires to carry out further experiments

Acknowledgements

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