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Hemp Fibre Reinforced Composites

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Abstract. The conventional homogeneous materials can no longer effectively satisfy the growing demands on product capabilities and performance, due to the advancement in products design and materials engineering. Therefore, the fibre reinforced composites with better properties and desirable applications emerged.
Natural fibres have high strength to low weight ratios and have good sound and thermal insulation properties. Combination of organic filler and inorganic matrix creates high-quality products such as fibre boards and composites. The great importance is attached to industrial hemp as source of the rapidly renewable fibres and as non-waste material. Industrial hemp fibre has great potential in composite materials reinforcement. However, improving interfacial bonding between fibres and matrix is an important factor for its using in composites.
This paper deals with hemp fibre reinforced composites in civil engineering as component part of sustainable construction. Prepared lightweight composites based on original and pre-treated hemp hurds are characterized by selected physical and mechanical properties (density, thermal conductivity, water absorbability, compressive and tensile strength) in dependence on used inorganic binder (traditional Portland cement and alternative MgO-cement).

Keywords: bio-based resource, conventional and non-conventional binder, hemp hurds, lightweight composites, physico – mechanical properties.

Conference topic: Environmental protection.

Introduction

The environmental and economic global treats today have called to produce natural fibre reinforced, bio-resoured and sustainable composite materials as a substitute for synthetic (conventional) fibre reinforced composites (Omrani *et al.* 2016). 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 *et al.* 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, Jalali 2011).

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 *et al.* 2008). Initial water content in the hemp and water exchanges between hemp and binder play a major role in these processes (Fourmentin *et al.* 2016). Optimizing the adhesion of fibres consists in their physical/chemical pre-treatment leading to removing impurities and amorphous components (pectin, lignin, hemicellulose) and separation of bundles of fibres in the fibrils (Thomsen *et al.* 2006).

This paper discusses the properties of hemp fibre reinforced composites based on waste material of hemp stem processing (hemp hurds) in interaction with traditional Portland cement in comparison to alternative binder material (MgO based cement).

The aim of this work is to investigate the effect of hemp hurds pre-treatment processes and binder nature on selected physico-mechanical properties (density, water absorbability, thermal conductivity, compressive and tensile strength) of hemp-based composites.

Different pre-treatment processes (ultrasound 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 parameters based on original and treated hemp hurds as filling material and on inorganic binding agents (conventional binder Portland cement and non-conventional binder MgO-based cement).

Materials and Methods

Technical hemp hurds used for this study is shown in Fig. 1 and this hemp material is coming from the Netherlands Company Hempflax (Oude, Pekela, Netherlands). Used hemp material consisted of a large majority of core fibres (hemp hurds) 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 hemp hurds is constituted by 44.5% cellulose, 32.8% hemicelluloses, 21% lignin, 3.5% components soluble in toluene and ethanol extract and 3% ash.

Fig. 1. Technical hemp hurds.

Traditional Portland cement CEM I 42.5 R (Holcim Slovakia a.s.) and alternative MgO-based cement were used as binding agents in the experiments. MgO cement 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 (Kidalova 2011). 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. 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 *et al.* 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, Jalali 2011).

Pre-treatment processes of dried hemp hurds were carried out by its ultrasound and chemical modification. An ultrasonic bath TESON 10 (Tesla, Slovakia) with deionized water as a cleaning medium was used for ultrasonic cleaning process of organic filler. The ratio s: l (solid to liquid phase) used for the experiments was 1:10. The chemical modification of hemp hurds was carried out by its alkalization. The dried hemp hurds was soaked in 1.6 M NaOH (p.a., CHEMAPOL, Czechoslovakia) solution during 48 h and then neutralized in a 1 vol. % acetic acid until the pH was 7 (Terpakova *et al*. 2012).

Hemp composite samples were prepared according to the recipe (Bydzovsky 2009) consisted of 40 vol. % of hemp hurds (original and treated samples), 29 vol. % of binder (Portland and MgO-based cement) and 31 vol. % of water. The components of mixture were homogenized in dry way and then mixed with water addition as mixing water for concrete (STN EN 1008:2003). Standard steel cube forms with dimensions 100x100x100 mm were used for samples preparation. The prepared samples 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.

Selected physico-mechanical characteristics of hemp reinforced composites were determined. Density was determined in accordance with standard STN EN 12390-7 (2011). Short-term water absorbability (1 h) was specified in accordance with the standard STN EN 12087 (2013). Thermal conductivity coefficient of samples was measured by the commercial device ISOMET 104 (Applied Precision Ltd., Germany). Compressive strength of the all cube specimens was determined by using the instrument ADR ELE 2000 (International Limited, United Kingdom) under controlled conditions after hardening in accordance with the standard STN EN 12390-3 (2010). Tensile strength was determined by using the instrument M350-20 AT (Testometric, United Kingdom) in accordance with the standard STN EN 319 (1995).

Results and Discussion

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 *et al.* 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 *et al.* 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 changes of hemp hurds after pre-treatments

Hemp hurds component [%]	Original sample	Ultrasonic treated	NaOH treated
Holocellulose	77.3	79.3	66.0
Cellulose	44.5	46.7	53.9
Hemicelluloses	32.8	32.6	12.1
Lignin	22.0	23.3	27.4
Compounds soluble in toluene and ethanol	3.5	2.6	2.8
Ash	2.6	1.3	1.3

The abbreviations of hemp samples prepared for physico-mechanical characteristics determination of hemp reinforced composites based on original and pre-treated hemp hurds with traditional Portland cement and alternative MgO-based cement are given in Table 2.

Table 2. Abbreviation of hemp composites samples

Hemp hurds sample	Portland cement	MgO-based cement
Original sample	OHHPC	OHHMC
Ultrasonic treated sample	UTHHPC	UTHHMC
NaOH treated sample	NTHHPC	NTHHMC

Density values of prepared composite samples after 28 days of hardening were ranged from 1070 to 1300 kg/m^3 which place this material into category of lightweight composites. 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. Table 3 has shown that lower value of this parameter was recorded for the composite samples based on NaOH treated hemp hurds with both used binding agents. Thermal conductivity coefficient values of all specimens prepared with alternative binder MgO-cement were generally lower than thermal conductivity coefficient values of hemp composites prepared with traditional Portland cement (Table 3) or with lime binder (Cigasova *et al.* 2013). The all measured values of specimens were in range acceptable for thermal insulating materials. As it can be seen in Table 3, the samples with pre-treated hemp hurds have lower values of short-term water absorbability than composites based on original hemp material. The strength characteristics of pre-treated and untreated hemp composite specimens on dependence of used binder are given in Table 3. The significant difference in determined strength values of composites with physically and chemically treated hemp hurds has been observed. Cause of this phenomenon can be in a nature of used filler and of used binder which led to poor interaction of its particles and hemp fibres. In case of chemically modified hemp hurds in combination with alternative MgO-based binder, there was significant differences of measurement due to the alternative binder nature that made the surface of composite hard adhesive. Natural fibres require higher water content in the production, which leads to lower density and reduced compressive strength. The mechanical properties of the hemp fibre reinforced composites depend mainly on the content of fibres, their orientation and on the quality of load transfer between the reinforcement and matrix (Machovic *et al.* 2008).

The water absorbability values of fibre reinforced composites based on conventional and non-conventional binder in dependence on samples density are shown in Fig. 2. Water absorbability in hardened composites is dependent on internal porous system (Collet *et al.* 2008). As it can be seen, decreasing water absorbability of composites based on pre-treated hemp hurds is monitored in dependence on used inorganic binder. Values of water absorbabilty are 15.2 and 22% for composites based on original hemp hurds with conventional and non-conventional binder respectively. Pre-treatment by ultrasound reduced water absorbability by 12 and 40% and chemical modification reduced this parameter by 24 and over 50% for composites prepared with conventional and non-conventional binder respectively.

Table 3. Physico-mechanical characteristics of 28 days hardened composites.

Physico-mechanical characteristics	Water absorbability [%]	Thermal conductivity coefficient [W/m.K]	Compressive strength [MPa]	Tensile strength [MPa]
OHHPC	22	0.1	1.75	0.49
UTHHPC	13	0.13	1.52	0.22
NTHHPC	10.3	0.08	0.98	0.08
OHHMC	15.2	0.13	1.93	0.8
UTHHMC	13.4	0.17	2.51	0.53
NTHHMC	11.6	0.11	1.12	0.92

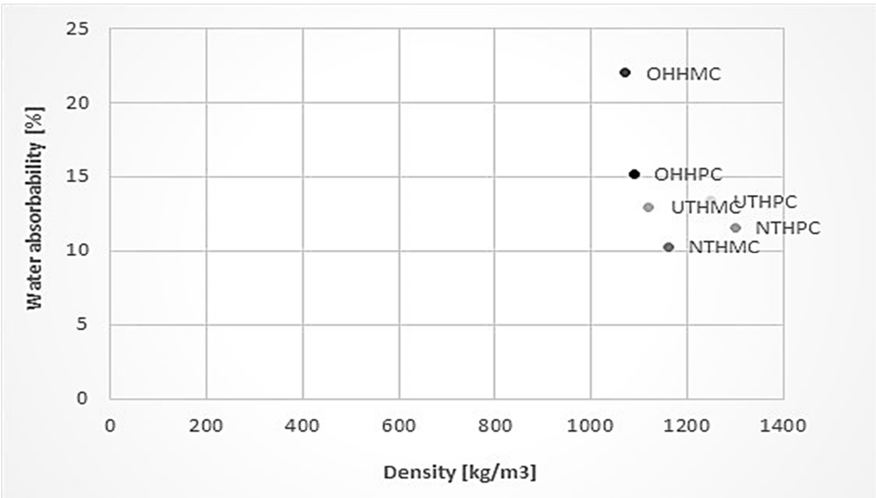

Fig. 2. Water absorbability of 28 days hardened samples in dependence on density.

Conclusions

This paper studied the properties of hemp fibre reinforced composites based on untreated (original sample) and treated (physically and chemically) hemp hurds as a filling material and conventional (Portland cement) and non-conventional (MgO-based cement).

The effect of pre-treatment processes on the hemp hurds chemical composition and binder influence on the selected physical (density, thermal conductivity and short-term water absorbability) and mechanical (compressive and tensile strength) properties of hemp reinforced composites were investigated.

The results presented in this article clearly show that the process of hemp hurds pre-treatments affects the change in the structure and chemical composition (non-cellulosic components such as hemicelluloses and waxes removal in after both treated procedures) of fibres thus influences the physico-mechanical characteristics of 28 days hardened composites.

The physico-mechanical characteristics of hemp composites were also determined. Reduction of water absorbability was monitored after both treatment processes and with both used binders. Thermal conductivity coefficient measured for the all specimens were in range acceptable for thermal insulating materials.

Studied composite materials demonstrated good physico-mechanical characteristics for its using in construction industry such as non-load bearing material and also that alternative binder MgO-based cement seems to be the suitable binding agent for fibre reinforced composites with less CO_2 emissions production.

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Disclosure statement

The authors declare that they have not any interests.

References

Bourmaud, A.; Morvan, C.; Bouali, A.; Placet, V.; Perré, P.; Baley, C. 2013. Relationships between micro-fibrillar angle, mechanical properties and biochemicalcomposition of flax fibers, *Industrial Crops and Products* 44: 343–351.

Bydzovsky, J. 2009. Utilization of fast renewable raw materials in building products, in *Proceedings of the 12th International Scientific Conference*, Brno, Czech Republic.

Cigasova, J.; Stevulova, N.; Junak, J. 2013. Influence of binder nature on properties of lightweight composites based on hemp hurds, *International Journal of Modern Manufacturing Technologies* 5: 27–31.

Collet, F.; Bart, M.; Serres, L.; Miriel, J. 2008. Porous structure and water vapour sorption of hemp-based materials, *Construction and Building Materials* 22: 1271–1280.

Fourmentin, M.; Faure, P.; Pelupessy, P.; Sarou-Kanian, V.; Peter, U.; Lesueur, D.; Rodts, S.; Daviller, D.; Coussot, P. 2016. NMR and MRI observation of water absorption/uptake in hemp shives used for hemp concrete, *Construction and Building Materials* 124: 405–413.

Kidalova, L. 2011. Determination of selected characteristics in hemp concrete, in *Young Scientist: 3rd PhD Student Conference of Civil Engineering and Architecture*, April, Kosice, Slovakia.

Le Troëdec, M.; Rachini, A.; Peyratout, C.; Rossignol, S.; Maxb, E.; Kaftan, O.; Fery, A.; Smith, A. 2011. Influence of chemical treatments on adhesion properties of hemp fibres, *Journal of Colloid and Interface Science* 356: 303–310.

Machovic, V.; Andertova, J.; Kopecky, L.; Cerny, M.; Borecka, L.; Pribyl, O.; Kolar, F.; Svitilova, J. 2008. Effect of aging PET fibre on the mechanical properties of PET fibre reinforced cement composite, *Ceramics – Silikaty* 52: 172–182.

Omrani, E.; Menezes, P. L.; Rohatgi, P. K. 2016. State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world, *Engineering Science and Technology, an International Journal* 19: 717–736.

Pacheco-Torgal, F.; Jalali, S. 2011. Cementitious building materials reinforced with vegetable fibres: a review, *Construction and Building Materials* 25: 575–581.

Renouard, S.; Hano, Ch.; Doussot, J.; Blondeau, J. P.; Lainé, E. 2014. Characterization of ultrasonic impact on coir, flax and hemp fibers, *Materials Letters* 129: 137–141.

Terpakova, E.; Kidalova, L.; Estokova, A.; Cigasova, J.; Stevulova, N. 2012. Chemical modification of hemp shives and their characterization, *Procedia Engineering* 42: 1017–1028.

Thomsen, B. A.; Thygesen, A.; Bohn, V.; Nielsen, K.V.; Pallesen, B.; Jorgensen, M. S. 2006. Effect of chemical-physical pretreatment processes on hemp fibres for reinforcement of composites and for textiles, *Industrial Crops and Products* 24: 113–118.

STN EN 1008. 2003. Mixing water concrete, Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete.

STN EN 12087. 2013-09. *Thermal insulating products for building applications. Determination of long term water absorption by immersion.*

STN EN 12390-7. 2011. Testing hardened concrete, Part 7: Density of hardened concrete.

STN EN 12390-3. 2010. Testing hardened concrete, Part 3: Compressive strength of test specimens.

STN EN 319. 1995. Particleboards and fibreboards. Determination of tensile strength perpendicular to the plane of the board.