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Some Aspects of Lightweight Composites Durability

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One of the possible ways of achievement of sustainable development in the building industry is moving from the limited and finite material resources to fast renewable raw material resources or materials recycled from construction wastes. Materials of plant origin belong to a large group of renewable raw materials. A great importance is attached to technical hemp like an easily renewable source of cellulosic fibers with potential for reinforcement of composite and/or only the woody core part of the hemp (shive). Renewal of scientific as well as industrial interests in the using both hemp fibres and shives in lightweight composite materials relates to a need of progress of environmental friendly products with high use value in the term of sustainable development.
This article discusses the possibilities of preparing the lightweight fibrous composites based on hemp hurds slices (Hempflax) in combination with MgO-cement binder as well as some aspects of durability for hardened composites after long termed storage in deionised water by testing some important material properties as water absorbability, thermal conductivity coefficient, apparent density and compressive strength.

1. Introduction

In the last decade, green chemistry and renewable natural resources have received considerable interest because of the environmental requirements and their possible application. The use of natural plant fibres as reinforcement in composites for making low cost engineering materials has generated much interest in recent years. New environmental legislation as well as consumer pressure has forced manufacturing industries (particularly automotive, construction and packaging) to search for new materials that can substitute for conventional non-renewable reinforcing materials such as glass fibre (Bledzki and Gassan, 1999). The advantages of natural plant fibres over traditional glass fibres are acceptable as good specific strengths and modulus, economical viability, low density, reduced tool wear, enhanced energy recovery, and reduced dermal and respiratory irritation and good biodegradability (Bolton, 1995). Natural plant fibre reinforced polymeric or inorganic composites also have some disadvantages such as the incompatibility between the hydrophilic natural fibres and hydrophobic thermoplastic and inorganic matrices requiring appropriate use of physical and chemical treatments to enhance the adhesion between fibre and the matrix (Gassan and Cutowski, 2000). Bast fibres like flax, hemp, kenaf, and jute are the most common natural fibres considered as substitutes for synthetic fibres due to their low density, biodegrability, interesting thermal, mechanical, acoustic and aseptic properties. Hemp fibres are widely used in eco-friendly materials as a (partial) substitute for synthetic fibres, such as glass, carbon or metallic fibres. Since their growth, harvest and processing consume overall less fossil energy and chemicals than the synthesis of man-made fibres, their use decreases consequently the carbon dioxide emissions (Joshi et al., 2004) associated with the composite fabrication. Due to of hemp fibres, low cost and eco-friendly raw material, and this natural fibrous material is used as a (partial) replacement of synthetic fibres, such as glass, carbon or metallic fibres. The hemp stem can reach a height of more than four meters when the plant has good growth conditions. Hemp contains cellulosic fibres and a woody material called shives. Fibres consist of mainly crystalline cellulose as well as hemicellulose, lignin and waxy substances (Islam et al., 2010). A cross section of the hemp stem shows different layers (Figure 1). The outside of the stem is covered with bark, also called epidermis. Inside the hemp stems are bast fibres and the woody core. The bast fibres are

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bound by the middle lamella and arranged in bundles those run from top to bottom of the stem (Thomsen et al., 2005). Hemp fibres and shives are used in a wide range of products like textiles, paper and building materials. According to literature data, due to the low density and high porosity of the hemp shives, the combination of hemp and cementations binder creates a building material with good thermal and acoustic insulation properties. In our previous papers (Kidalova et al, 2012; Kidalova et al, 2011a), physical and mechanical properties of lightweight composites based on hemp hurds slices and wood cellulose in combination with various inorganic binders (cement, natural zeolite, lime and MgO-cement) were tested. The obtained results of composites based on hemp shives and MgO-cement showed that this binder has a positive influence on higher compressive strength development of composites. They are low density materials, yielding relatively lightweight composites, suitable for application as insulation materials or non-load bearing building materials (Kidalova et al., 2012).
Indeed, due to highly porous structure of hemp and its strong capillarity effects inside the tubes, hemp is able to absorb large amounts of water (up to five times its own weight). Hemp has an ability to regulate humidity inside buildings by absorbing and/or releasing water depending on air conditions (Elfordy et al., 2008).

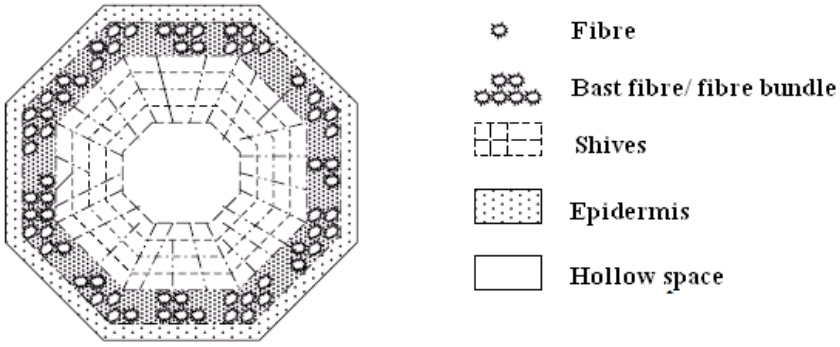

Figure 1: Cross section of a hemp stem showed as a model with the layers of epidermis, cortex with fibre bundles, shives and cavity in the middle (Thomsen et al., 2005).

Several studies in the use of natural fibre reinforced composites with thermoplastic and thermoset matrix have shown of certain mechanical, thermal and dimensional properties to moisture uptake in humid atmosphere and to water absorption at their storage in water (Dhakal et al., 2007; Thwe and Liao, 2002).This sensitivity of properties of fibre reinforced polymer matrix hybrid composites can be reduced by the use of coupling agents and fibre surface treatments (Joseph and Thomas, 1996; Mwaikambo and Ansel, 2002).
The objective of this work was to study of some aspects of hardened fibre composites durability after long termed storage in deionised water and to monitor water uptake influence on mechanical and physical properties of prepared lightweight composites.

2. Experiment

2.1 Materials

The technical hemp hurds slices (Cannabis Sativa L.) coming from the Netherlands company Hempflax were used in experiments. This hemp contains more shives material than fibres and it is polydispersive material containing some small amount of dust (< 0.5 mm) which comes from the shredding process. Mean particle length of hemp slices, calculated from the granulometric analysis (Table 1) was 24.2 mm.

Table 1: Granulometric analysis of hemp hurds slices

Granulometric analysis of hemp hurds		
Fractions [mm]	Mass yield [wt.%]	Mean particle length [mm]
8 - 2	46.4	39.86
< 2	53.6	10.07

Chemical composition of used hemp hurds is shown in Table 2. The density of hemp material was 117.5 kg·m^{-3}. The average moisture content of hemp material determined by weighing of hemp sample before and after drying for 24 h at 105 °C was found 10.78 wt.%. MgO-cement as binder was used in experiments. It 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 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 (Kidalova et al., 2011b; Kidalova, 2011).

Table 2: Selected chemical characteristics of hemp hurds

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

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 bodies. The specimens of lightweight composites were cured for 2 days in an indoor climate and then removed from the forms (Figure 2). Curing was continued under laboratory conditions during 28 days. Finally, all hardened composites were dried in a laboratory oven at temperature of 70 °C to constant weight.

Figure 2: Prepared composites

2.3 Storage of composites in water

Hemp composite after 28 days of hardening (sample 1 – bulk density: 1,110 ± 5 kg•m^{-3}; thermal conductivity coeficient: 0.082 W/m.K; compressive strength: 1.863 MPa) was used for storage experiments in deionised water. Water absorption was carried out by immersing the initial hemp composite in water bath (PE closed container) at laboratory temperature (23 °C) for different time durations. Designation of samples is given in Table 3. After immersion for 28, 60, 90, 180 days (samples 2 - 5), the specimens were taken out from water and water from all surfaces of bodies have been removed by a clean dry cloth. The specimens were reweighed and afterwards were dried in an oven at 70 °C up to constant weight for following measurement of density, compressive strength and thermal conductivity coefficient.

Table 3: Designation of experimental samples

Sample	Storage time in water [d]
1	0
2	28
3	60
4	90
5	180

2.4 Testing methods

Density, thermal conductivity and compressive strength were measured on 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. 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. Compressive strength of all composites was determined using the instrument ADR ELE 2000.

3. Results and discussion

The results of investigations showed that values of water content in composites are in a range of 7.27 - 28.66 wt.%. As it can be seen in Figure 3, water content in specimens increases with an increasing time of their immersion in water. The water content in composites reached saturation after 180 days of water storage. It is known that natural fibre composite absorbs water more rapidly than, e.g. cement mortar and concrete. Sorption behaviour of hemp composites in water at room temperature is the results of several diffusion processes. First water molecules diffuse into the micro gaps inside inorganic matrix. Then molecules are capillary transported of into the gaps and flaws at the interfaces between hemp fibre and/or shives and the matrix during immersion of composites in water. Further water molecules penetrate into hemp structure, mainly into capillaries and spaces between bundles of fibres and fibrils as well as into shives spaces. The cellulose structure can be destroyed by penetration of water molecules into the cellulose network of the fibres. The initial absorption stage results in poor wetting and water impregnation of hemp material. According to papers (Karmakar et al., 1999; Ayensu, 2000), high amount of water causes swelling of the fibres and/or shives. Due to the swelling of the hemp material, microcracking in the matrix of tested composites occurs. These microcracks can be filled with water. However, it is not only water absorption important but also the rate at which the sorption as well as desorption of water molecules takes place (Bruijn et al, 2009). Another phenomenon of water sorption 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 ($NaHCO_3$), leading to increased pH values of solution up to 12.

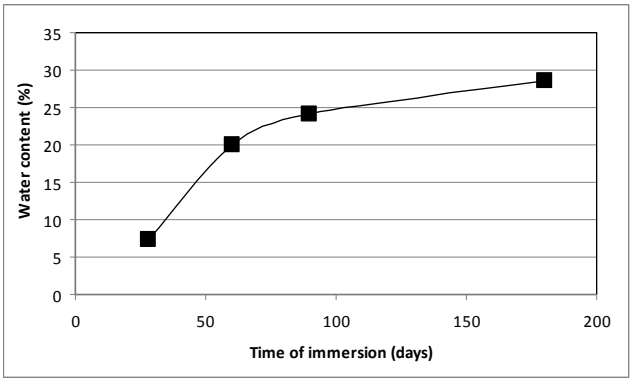

Figure 3: Dependence of water content in composites on time of their immersion in water

Values of thermal conductivity coefficient of composite samples were measured in the range of 0.05883 - 0.06858 W m^{-1} K^{-1}. These measurements show that values of thermal conductivity coefficient decrease in dependence on long termed storage of composite specimens in water. This is probably due to higher porosity and the insulation properties of composite are improved. The density values of samples was found to be in the range of 963 – 1,100 kg m^{-3}. The determined values of thermal conductivity coefficient and density of hemp composites are comparable to other building materials such as aerated autoclaved concrete (for thermal conductivity coefficient: 0.04 - 0.17 W m^{-1} K^{-1}; for bulk density: 800 – 1,200 kg m^{-3}). The results revealed reduction in the density values with increasing the immersion time in water of composite samples. According to Figure 4, the lighter the specimen, the lower the thermal conductivity coefficient.

As regards compressive strength of composites after water storage, these values ranged from 1.012 to 1.870 MPa. An impact of water storage time on these values was observed. Compressive strength of initial composite has decreased by 54.1 % after 28 d immersion in water. As it can be seen in Figure 5, strength is increasing with the increasing time of storage in water and long termed immersion of composite samples leads to stabilized compression strength value which reaches the same value like initial composite before its water storage. This result is in accordance with observations on fibre reinforced polymer composites (Karmakar et al., 1999; Ayensu, 2000), where after immersion in water the strength characteristics were

increased. Probable reason of this finding is the additional hydration of MgO-particles during water storage of composite what leads to subsequent strengthening of matrix. However, compressive strength of immersed composite samples increases with decreasing value of density as clearly shown in Figure 6. This behavior of water immersed composites is different from that during hardening process, where the denser is the specimen, the higher the compressive strength is.

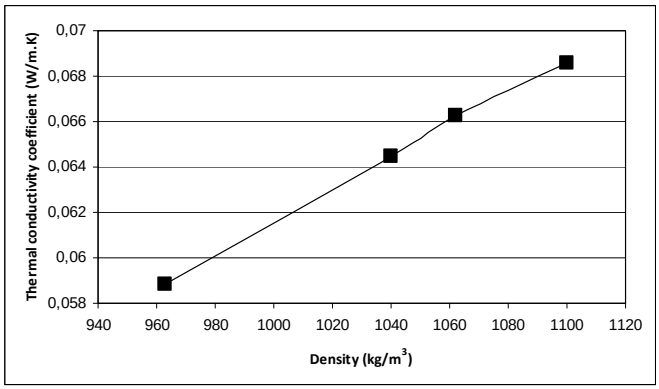

Figure 4: Dependence of thermal conductivity coefficient of water immersed composite on density

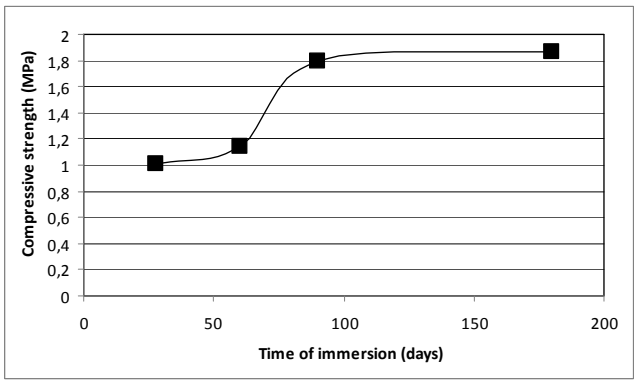

Figure 5: Compressive strength of water storaged composite vs. time of immersion in water

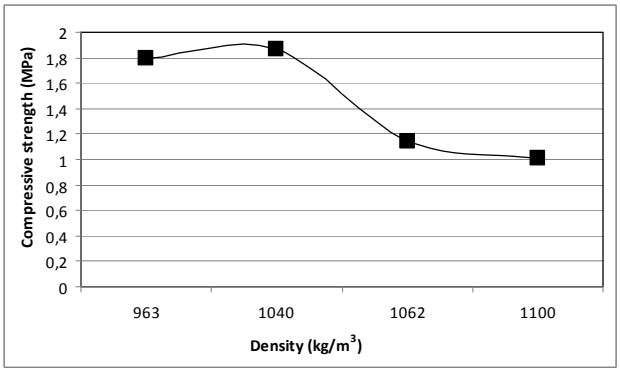

Figure 6: Dependence of compressive strength of composite on density after immersion in water

4. Conclusions

In this paper, durability of lightweight composites based on hemp hurds by their storage in deionised water have been investigated and influence of water uptake prepared composites on their mechanical

(compressive strength) and physical properties (density and thermal conductivity) was monitored. From the results described above, the following conclusions can be formulated:

- water content of fibre reinforced composite increases with prolonged immersion time in water and reaches saturation after 180 days of water storage
- storage time in water influences some physical (density, thermal conductivity coefficient) and mechanical properties (compressive strength)
- whereas compressive strength values increase with increasing storage time in water, values of bulk density and thermal conductivity coefficient decrease
- more investigations is needed in order to explore the influence of water storage on composite structure by using physico-chemical methods

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