INFLUENCE OF BINDER NATURE ON PROPERTIES OF LIGHTWEIGHT COMPOSITES BASED ON HEMP HURDS

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Abstract: Natural fibres such as hemp, flax and sisal have been identified as attractive candidates for the reinforcement of composites. They are cheap, abundant and renewable, and have good specific properties due to their low densities. However, one of the major drawbacks of natural fibres is their high moisture sorption and their heterogeneity, which leads to a weak interface between the fibres and the matrix in composites materials 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. The object of this work is to study the effect of the particle size of hemp hurds and their chemical modification as filling agents in composites system on selected physicochemical and mechanical properties of the prepared lightweight composites and influence of two kinds of binders (MgO – cement; hydrated lime and Portland cement).

Key words: hemp hurds, chemical modification, lightweight composites, mean particle length

1. INTRODUCTION

Trends in research and development of environmental friendly composite materials are focused on “green approach” what is connected with moving from the limited and non-renewable finite material resources to easily renewable raw material resources. A large group of renewable raw materials are materials of plant origin. The use of natural fibres as well as waste from the processing of plants as reinforcement of composite materials is one of the most important targets in recent materials research (Ashori and Nourbakhsh, 2010) resp. (Ahankari et. al., 2011). In the context of challenging environmental issues and a global energy crisis, bio-based materials are attracting increasing levels of research interest, from both academia and industry, because of their numerous advantages: renewable resource usage, low cost, biodegradability, and so on. Natural fibres such as hemp, flax and sisal have been identified as attractive candidates for the reinforcement of composites. They are cheap, abundant and renewable, and have good specific properties due to their low densities.

A major disadvantage of natural fibre reinforced composites is low microbial resistance and susceptibility to rotting. These properties pose serious problems during shipping, storage and composite processing. The non-uniformity and variation of dimensions and of their mechanical properties (even between individual plants in the same cultivation) poses another serious problem (Maya and Sabu, 2008). This disadvantage and enhanced interfacial adhesion for composites containing natural fibres can be achieved either by fibre and matrix modification with chemical/physical treatments or by use of interfacial additives (Nabi and Jog, 1999; Rowell, 1998). Traditional chemical treatments of the fibres include extraction with alcohol, benzene or NaOH (delignification, bleaching, etc.).

Hemp is one of number of crops known as bast fibre crops. Hemp is a crop that can produce three items-seed, fibre and cellulose bio- mass (hurds). Building industry is focussing on the fibres and hurds that originate in the stem of the plant. There are also many environmental benefits to growing hemp which together with the over 25,000 uses already identified for hemp materials, makes it a vital tool for mankind. Both the hemp fibres used in insulation matting and the hemp hurds used in hempcrete provide a “breathable” material that allows moisture to pass through the structure which prevents condensation problems and must be used with other such breathable materials.

In our previous papers (Kidalova et al., 2012a; Kidalova et. al., 2012b), experimental study of the parameters affecting the physical and mechanical properties of hemp composite based on conventional and alternative binders was performed. Properties of chemically treated hemp hurds as well as behavior of composites based on modified hurds with alternative binder of MgO-cement were investigated too (Terpakova et al., 2012; Cigasova et al., 2013).

In this paper, behaviour of prepared lightweight composites based on alternative binders (lime and

Portland cement; MgO – cement) and untreated and chemical treated of hemp hurds depending on mean particle length of hemp hurds by testing on some important material properties as water absorbability, thermal conductivity coefficient, apparent density and compressive strength was compared.

2. MATERIALS

The technical hemp hurds slices (Cannabis Sativa L.) coming from the Netherlands company Hempflax were used in experiments. Bulk density of used materials was 117 $kg.m^{-3}$. Hemp hurds slices had a wide mean particle length distribution. Three samples of hemp hurds, 1 original sample (polydisperse) and 2 fractions were sieved. Three samples of hemp hurds (Figure 1) were used for experiment: unsorted original (1) and two fractions (2 and 3) prepared by sieving the sample 1. Mean particle length values (calculated from granulometric analysis) of samples are given in Table 1.

Table 1. Mean particle size (dm) values of hemp hurds samples

Sample	Granularity (mm)	dm (mm)
1	8 - 0.063	1,94
2	8 - 2	3,22
3	2 - 0.063	0,94

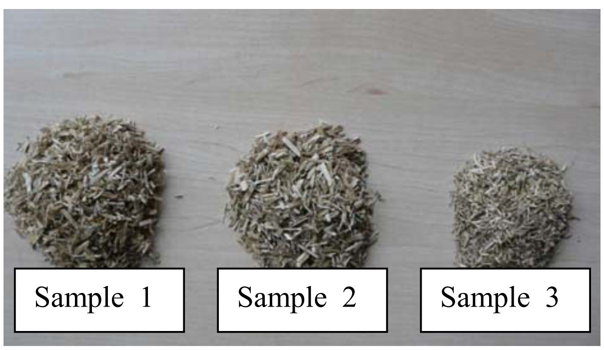


Fig. 1. Samples of hemp hurds

Chemical analysis of hemp hurds showed that content of polysaccharide component (holocellulose) is 74.5 %. Content of other components present in hemp hurds is shown in Table 2.

Table 2. Chemical analysis of initial hemp hurds

Components of hurds	(%)
toluene ethanol extract	3.5
lignin	24.4
cellulose	44.2
hemicellulose	30.3
ash	1.4

Two kinds of binders were used in the experiment. First, combination of hydrated lime and Portland cement CEM I 42.5 R. Second was the MgO-cement, consisted of milled magnesium oxide (MgO), silica sand (SiO_2) and sodium hydrogen carbonate ($NaHCO_3$). The effect of MgO milling has been investigated in order to reduce its particle size and details of milling procedure are described in the paper (Kidalova et al., 2011).

2.1 Chemical modification of hemp hurds

Chemical treatment of dried hemp hurds was carried out in liquid medium of calcium hydroxide (ROTH, Germany; ≥96%, pulv).

In order to saturate fibres with calcium ions, hemp hurds slices were placed in a saturated lime solution ($[Ca^{2+}]=2.10^{-2}M$) for 48h. Following the impregnation, hemp material was washed with water.

Thus chemically treated hemp hurds were used for composites preparing (Figure 2).

Fig. 2. Chemically modified hemp hurds used for composites preparing

3. PREPARATIONS OF COMPOSITES

The fresh mixtures for preparation of composites consisted of 40 vol. % of hemp hurds, 29 vol. % of binder and 31 vol. % of water. For preparation of specimens, the standard steel cube forms with dimensions 100mm x 100mm x 100mm were used. The specimens were cured for 2 days in the indoor climate at approximately +18°C and then removed from the moulds (Figure 3). After that time, the specimens were wrapped in a household film during 28 days. Designation of prepared composites based on various binders and various mean length of hemp hurds (untreated and treated) is shown in Table 3.

a) b)

Fig. 3. Composites prepared a.) with MgO – cement; b.) with hydrated lime and Portland cement

Table 3. Designation of samples

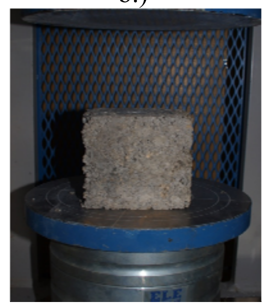
Sample	dm (mm)	Binder	Filler
1	1,94	MgO-cement	Unmodified hemp hurds
2	3,22	MgO-cement	Unmodified hemp hurds
3	0,94	MgO-cement	Unmodified hemp hurds
4	1,94	MgO-cement	Modified hemp hurds
5	3,22	MgO-cement	Modified hemp hurds
6	0,94	MgO-cement	Modified hemp hurds
7	1,94	Hydrated lime and Portland cement	Unmodified hemp hurds
8	3,22	Hydrated lime and Portland cement	Unmodified hemp hurds
9	0,94	Hydrated lime and Portland cement	Unmodified hemp hurds
10	1,94	Hydrated lime and Portland cement	Modified hemp hurds
11	3,22	Hydrated lime and Portland cement	Modified hemp hurds
12	0,94	Hydrated lime and Portland cement	Modified hemp hurds

4. METHODS

The density, thermal conductivity coefficient, compressive strength and water absorption were measured on hardened composites after 28 days of hardened (Figure 4). 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 (AP Germany). The measurement is based on the analysis of the temperature response of the studied 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 (Ele International Limited, United Kingdom). Water absorption (after one hour) was specified in accordance with the standard STN EN 12087/A1.

a.)

b.)



c.)

Fig. 4. Measurement of a.) thermal conductivity coefficient; b.) water absorption; c.) compressive strength on hardened composites

5. RESULTS AND DISCUSSION

During the laboratory study, impact of mean particle length of hemp hurds slices (treated and untreated) on physical and mechanical properties of composites based on alternative binders: hydrated lime and MgO - cement was studied. Selected properties of hardened composites based on hemp hurds slices with various mean particle length and two binders were compared. In Table 4, density, water absorption values and changes in thermal conductivity coefficient of 28 days hardened composites are given.

Table 4. Values of density, water absorption and thermal conductivity coefficient of composites after 28 days of hardening

Sample	Density (kg/m^3)	Water absorption (%)	Thermal conductivity coefficient (W/m.K)
1	1113	14	0,082
2	1120	8	0,069
3	1230	6	0,074
4	1138	7	0.086
5	1285	7	0.083
6	1192	17	0.086
7	1085	26	0,397
8	1060	10	0,531
9	1113	45	0,263
10	808	46	0.171
11	1156	12	0.266
12	1071	25	0.306

According to the measurements, density values of composites were in a range of 808 - 1285 kg/m^3. Whereas density of prepared composites based on unmodified hemp hurds is increasing with decreasing mean particle length of hemp hurds, density of composites with modified hemp hurds has opposite behaviour. Lightweight composites based on hydrated lime and Portland cement binder have lower values of density (6%) in comparison to composites with MgO - cement. Values of water absorption are in a range of 6 - 46%. From Table 4, it can be observed that here are lower values of water absorption for samples prepared with MgO – cement than for composites based on combination of hydrated lime and cement. Based on published data (Dalmay et al., 2010) the water soluble constituents of the hemp are responsible for affecting the behaviour of lime binder. Pectin as a partially soluble hemp constituent reacts with the calcium ions in hydrated lime resulting in less Ca^{2+} available for the formation of hydration products (Sedan et al., 2007). The high absorption of water by hemp particles results in insufficient water levels required for the hydration process. Measurements show that values of thermal conductivity coefficient of composites with MgO - cement are in a range of (0.069-0.086) W/m.K and samples with hydrated lime reached 1-6.5 times higher values.

In Figure 5, there is illustrated development of compressive strength of composites based on hydrated lime and Portland cement in dependence on various mean particle length of hemp hurds slices and kind of filler (chemically treated and untreated hemp hurds). Observation of Figure 5, the interesting behavior of samples can be seen. Values of compressive strength of composites based on treated hemp hurds slices are higher than values of compressive strength of samples based on untreated hemp hurds slices. The comparison of measured compressive strengths shows the same behaviour of both composites prepared with untreated and treated hemp hurds slices. In the both cases, the values of compressive strength are dependent on mean particle length of hemp hurds slices. Composites prepared with mean length of hurds 1.94 mm have highest values of compressive strength. This result is in accordance with published data (Tröedec et al., 2009; Brencis et al., 2011; Stevulova et al., 2012) where mechanical properties of foam gypsum lime and MgO-cement composite with hemp fibrous reinforcement depend on fibers and hurds slices length and their content in composite. However, compressive strengths don't reach the values of 3-5 MPa which are considered to be sufficient for the load bearing material (de Bruijn et al., 2009). On the other hand, compressive strength is higher for composites prepared by chemically treated hemp hurds. Just such effect has been expected after chemical modification of hemp hurds slices. On the other hand, values of water absorption and thermal conductivity coefficient are considerable higher in comparison for example to composites prepared with MgO - cement as a binder. It can be caused by using lime binder and resulting porous structure of composites.

Figure 6 illustrates development of compressive strength of composites based on MgO – cement in dependence on various mean particle length of hemp hurds slices and kind of filler (chemically treated and untreated hemp hurds). Compressive strength of composites based on untreated hemp hurds slices are increasing with decreasing mean particle length of used hemp hurds slices. This result is in accordance with published data (Cigasova et al., 2013). On the other hand, compressive strength is increasing with increasing mean particle length of hemp hurds slices for composites prepared by chemically treated hemp hurds. Only in the case of composites prepared with longest hemp hurds slices (3.22 mm) we observed improvement in mechanical properties (compressive strength) by chemically treated of used hemp hurds slices. These facts confirm that ordering the fibres and/or hurds slices in the matrix of the composites plays an important role in the creation of such materials. The mechanical properties of prepared lightweight composites depend on mean particle length of organic filler. Higher values of compressive strength in the case of composites prepared with MgO – cement in comparison with composites based on lime binder are likely with better ordering of hurds slices in volume of inorganic matrix of the composites and with formation of denser composite structure.

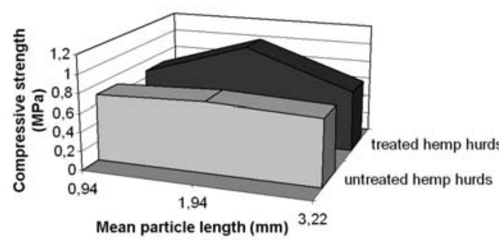


Fig. 5. Development of compressive strength of composites based on hydrated lime and Portland cement in dependence on mean particle length of hemp hurds slices and kind of filler

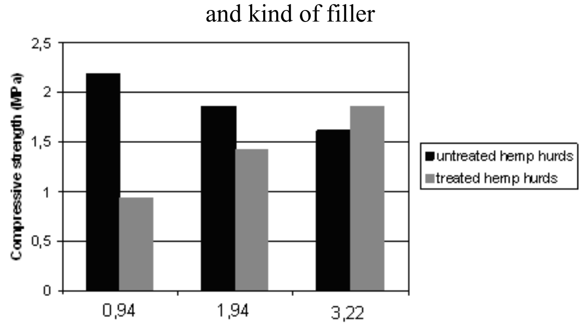


Fig. 6. Development of compressive strength of composites based on MgO - cement in dependence on mean particle length of hemp hurds slices and kind of filler

6. CONCLUSION

This article dealt with the problematic of the use of hemp hurds as organic filler in building material. Composites were prepared using two kinds of binding materials and hemp hurds slices with various particle length acted as filler. Influence of chemical modification of hemp hurds slices and effect of their particle length were monitored. Properties of lightweight composites clearly depend on mean particle length of hemp hurds. Considerable influence on the properties composites has a chemical modification of hemp hurds slices. The hydraulicity degree of used binder's materials influences the mechanical properties. Composites containing MgO - cement have hundredfold higher values of compressive strength in comparison to composites based on combination hydrated lime and cement. Low values of compressive strength obtained for composites with binder based on hydrated lime are likely connected with the hemp properties influencing the formation of hydration products. Reaction Ca^{2+} ions with soluble hemp compounds and the high absorption of water by hemp particles are probably responsible for insufficient conditions for the hydration process.

Properties of hemp biocomposites predetermine this material as a sustainable and carbon – negative which can be applied as a non – load bearing material.

Processes occurring in composite materials based on natural cellulosic material and alternative binder are complicated. Their observation will be executed in our further research.

7. ACKNOWLEDGEMENTS

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