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Innovative Use of Plant Wastes- Hemp Hurds Slices

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Green materials and structures have gained the worldwide attention over the past few years. Interest in the utilization of lignocellulosic biomass in the form of natural fibres (biofibres usually derived from plant) as organic filler into lightweight fibre reinforced composites for sustainable building constructions is steadily increasing.
Excellent physical and mechanical properties of hemp as fast growth predetermine its use in building materials (biocomposites) prepared with inorganic matrix.
With a world production of 214,000 ton, hemp is one of the 10 major primary plants grown as source of bast fibres (i.e. fibres obtained from the exterior part of the stem) and hurds (i.e. inner woody part of the stem, also called shives), used for various industrial purposes, such as: textiles, cordage, panelling, biofuel, paper, plastic composites and building materials.
In particular, the hemp hurds, which in the past was discarded (only fibres and seeds were used), is now of great interest for the unique properties that confers to building materials. Key problem for successful application of hemp hurds is heterogeneity and hydrophility resulting in high moisture sorption sensitivity of biomaterial. Chemical and/or physical treatment of the fibres surface is applied to decrease the hydrophility and modify lignocellulosic material composition.
In this paper presented results of capillary absorption of biocomposites based on hemp hurds slices (untreated and chemically treated) as a filler and two various type of binders (conventional Portland cement and alternative MgO-cement). Capillary absorption demonstrates the ability of building materials containing open pores the absorbing moisture. Effect of various types of binder and influence of modified hemp hurds on properties of composites were observed.

1. Introduction

Moisture transport in porous media plays an important role in a wide variety of processes of environmental and technological concern, such as the degradation of building materials (e.g. mortar and concrete), the spread of hazardous wastes in the ground, oil recovery, and the containment of nuclear wastes. The presence of water in building materials can lead to cracks which result from freeze/thaw cycles or, in combination with very low permeabilities, to the spalling of high performance concrete exposed to fires. In addition, the invasion of water in building materials provides a mechanism and path for the penetration of deleterious materials like chloride and sulphate ions. While the primary transport mechanisms by which chloride and sulphate ions ingress concrete are diffusion and capillary action, diffusion alone can be a very slow process, hence it may be that capillary transport, especially near an unsaturated concrete surface, is the dominant invasion mechanism. Clearly, an understanding of moisture transport in concrete and mortar is important to estimate their service life as a building material and to improve their quality (Nicos et. al., 1997).
Hemp-based composite (also called hemp concrete or hemp lime) is a lightweight concrete produced by mixing hemp hurds (i.e. inner woody part of the stem, also called shives) with a binder. Since its production entails the use of a natural and renewable resource (the hemp plant), low carbon and pollutant emissions during the manufacturing process, low net waste at the construction site, increased energy efficiency in the building and improved quality of indoor air, hemp-based composite is being increasingly used as sustainable building material, as a valid and efficient alternative to traditional construction.

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In particular, hemp-based composites are characterized by a very low bulk density and high porosity when hardened, exhibit a very low thermal conductivity (λ = 0.1–0.2 W/m.K), a high acoustical absorption factor compared to traditional concrete and, finally, a high fire resistance (Newman, 2014), without the need to use fire-retardant additives.

Besides the high water absorption of hemp hurds (they can absorb 300–400 times their weight in water (Nozahic et. al., 2012), they also show a good transpirability. This characteristic encourages the use of hemp hurds especially in rendering mortars, since they might lead to a reduction of moisture in the interior of a building. In summary, the use of hemp-based composites for rendering applications presents several advantages, such as the decrease of the material density when hemp shives are used in the place of a stone aggregate (lightweight rendering mortar); improvement of the water retention properties of the render and consequent reduction of shrinkage; increase of the material flexibility and consequent decrease of the tensions between the render and the materials of the wall; and development of a healthier environment in the interior of the building (Arizzi et. al., 2015).

In the other hand, problem for successful application of hemp hurds is heterogeneity and hydrophility resulting in high moisture sorption sensitivity of biomaterial. Chemical and/or physical treatment of the fibres surface is applied to decrease the hydrophility and modify lignocellulosic material composition. Several studies of chemical modification effect on hemp hurds and hemp hurds composites were published (Pejic et. al., 2008; Cigasova et. al., 2013; Cigasova et al., 2014; Stevulova et al., 2014; Stevulova et al., 2015).

In this paper presented results of sorption property (capillarity) of biocomposites based on hemp hurds slices (untreated and chemically treated) as a filler and two various type of binders (conventional Portland cement and alternative MgO-cement). Capillary demonstrates the ability of building materials containing open pores the absorbing moisture. Effect of various types of binder and influence of modified hemp hurds on properties of composites were observed.

2. Materials and Methods

2.1 Hemp hurds

Hemp is an annual plant which provides two materials used in civil engineering: hemp hurds (granular form of hemp descended from the inner woody core) and hemp fibres (fibrous form of hemp descended from the bark-like bast fibres).

The original material studied in this article is hemp hurds coming from the Netherlands Company Hempflax (Figure 1).

Figure 1: Used hemp hurds.

Used hemp hurds had wide particle size distribution of particles (Figure 2); the mean particle size was calculated to 1.94 mm. Density of hemp material was 117.5 kg•m^{-3}. Average moisture content used hemp hurds was determined by weighing the sample before and after drying in an oven at 70°C until a constant weight (10.78%). Hemp hurds mainly consisted of 44.5% cellulose, 32.78% hemicellulose and 21.03% lignin.

The second sample used in experiment was hemp hurds chemically modified in alkaline environment. Alkali treatment of fibers is expected to result in increased surface roughness, in better mechanical bonding between the fibers and inorganic matrix also. The treatment removes significant amount of wax, pectin, hemicellulose and lignin, exposing more cellulose that result in increased reaction sites for bonding with matrix (Stevulova et. al., 2014).

Dried hemp hurds were soaked in 1.6 M NaOH solution during 48 h and then neutralized with 1% vol. acetic acid. Hemp hurds were then washed with water until the pH value was 7.

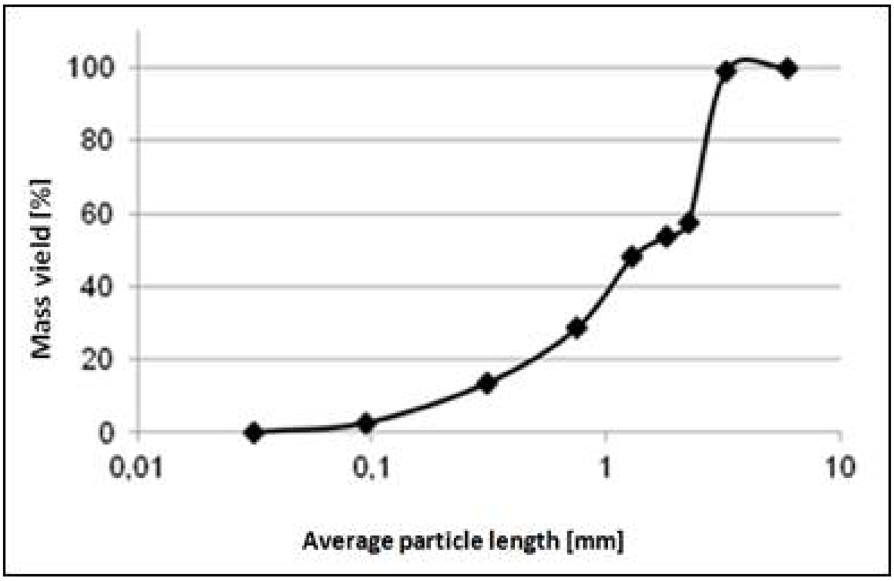

Figure 2: Size distribution of hemp particles.

2.2 Binders

Two kinds of binders were used in the experiment. Conventional Portland cement CEM I 42.5 N was as comparative binder. Characteristic properties of cement are in Table 1. Second binder was the MgO-cement, consisted of milled magnesium oxide (MgO), silica sand (SiO_2) and sodium hydrogen carbonate ($NaHCO_3$) (Kidalova et. al., 2011).

Table 1: Characteristic properties of used cement

Density (kg/m^3)	Specific surface area (m^2/g)	Mean particle size (µm)	Compressive strength after 28 days of hardened (MPa)
3050	0.610	29.90	52.1 ± 1.3

2.3 Preparation of specimens

The fresh mixtures for preparation of composites consisted of 40 vol. % of hemp hurds (modified or unmodified), 29 vol. % of binder and 31 vol. % of water. For preparation of specimens, the standard steel cube forms with dimensions 100 x 100 x 100 mm were used. The specimens were cured for 2 days in the indoor climate at approximately +18°C and then removed from the moulds. After that time, the specimens were wrapped in a household film during 28 days.

Designation of prepared composites based on various binders and modified or unmodified hemp hurds is shown in Table 2.

Table 2: Designation of specimens

Sample	Filler	Binder
1	Untreated	Portland cement
2	Treated	Portland cement
3	Untreated	MgO-cement
4	Treated	MgO-cement

2.4 Test of capillarity

The all hemp concrete specimens were after hardening time (28 days) dried in the oven at about 105 ºC ± 5 ºC until constant mass.

As shown in Figure 3, test specimens were exposed to the water on one face by placing it on a pan. The water on the pan was maintained at about 5 mm above the base of the specimens during this experiment. At certain times (5, 10, 20, 30, 60, 90 min.), the mass of the specimens was measured using a balance, then the amount of water absorbed was calculated and normalized with respect to the cross-section area of the specimens. Capillarity was calculated by use of the formula (1):

$$v_r = \frac{m_s - m_d}{m_d} \times 100 \quad (1)$$

Where:
m_s– weight of saturated sample (g)
m_d – weight of dry sample (g)

For comparison, as additional method, capillarity as a result of height to which water soak (in cm) was tested during the previous test. The results were determined as the arithmetic mean of measurements on 4 sides of the samples.

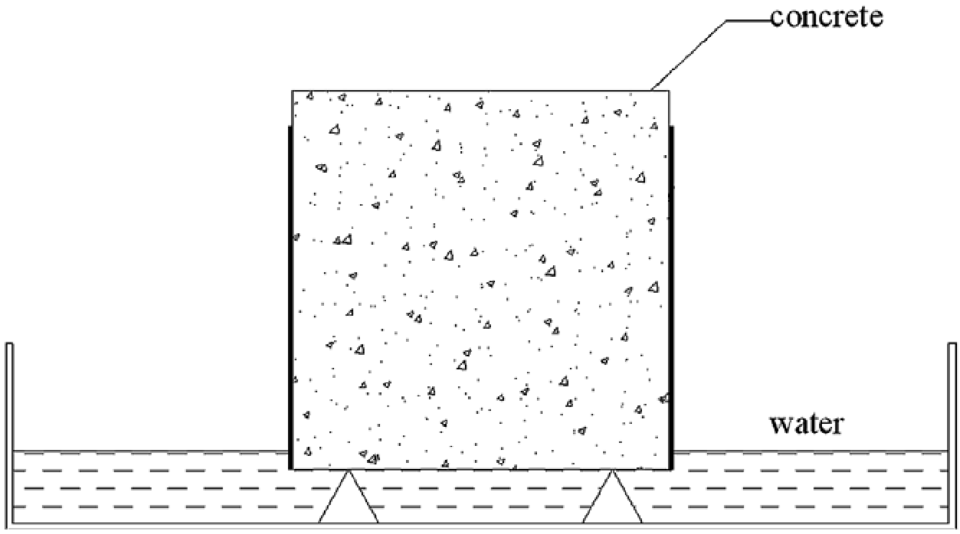

Figure 3: The measurement of capillarity (Gonen and Yazicioglu, 2007).

3. Results and Discussion

Sorption properties were tested in view of the intended function of tested materials: non -load bearing construction material or thermal – insulation material. Results of capillarity expressed by height of saturation are given in Figure 4.

As can be seen in Figure 4, the lines of values of capillarity are divided into two sections. First section contains the value of capillarity for samples 4. Samples were prepared with treated hemp hurds and with MgO – cement. The maximal values of capillarity were observed for these samples. On the other hand, the minimal values of capillarity had samples number 1 (based on Portland cement + untreated hemp hurds). Based on observed results is evident influence used binder on capillarity of prepared samples. Effect of used binder on mechanical and thermal – insulation properties was found, too (Cigasova et. al., 2013; Cigasova et. al., 2014a; Cigasova, 2014b; Stevulova et. al., 2015).

Test of capillarity cannot accurately predict the service life of hemp concrete. As we have shown, sorption rates can strongly depend on the degree of saturation and any estimate of service life must make reasonable assumptions about the exposure of the concrete specimen to a variety of weather conditions and wetting-drying cycles. A more general approach may be to consider the capillary diffusivity (Gonen and Yazicioglu, 2007), which relates the rate of sorption to the degree of saturation.

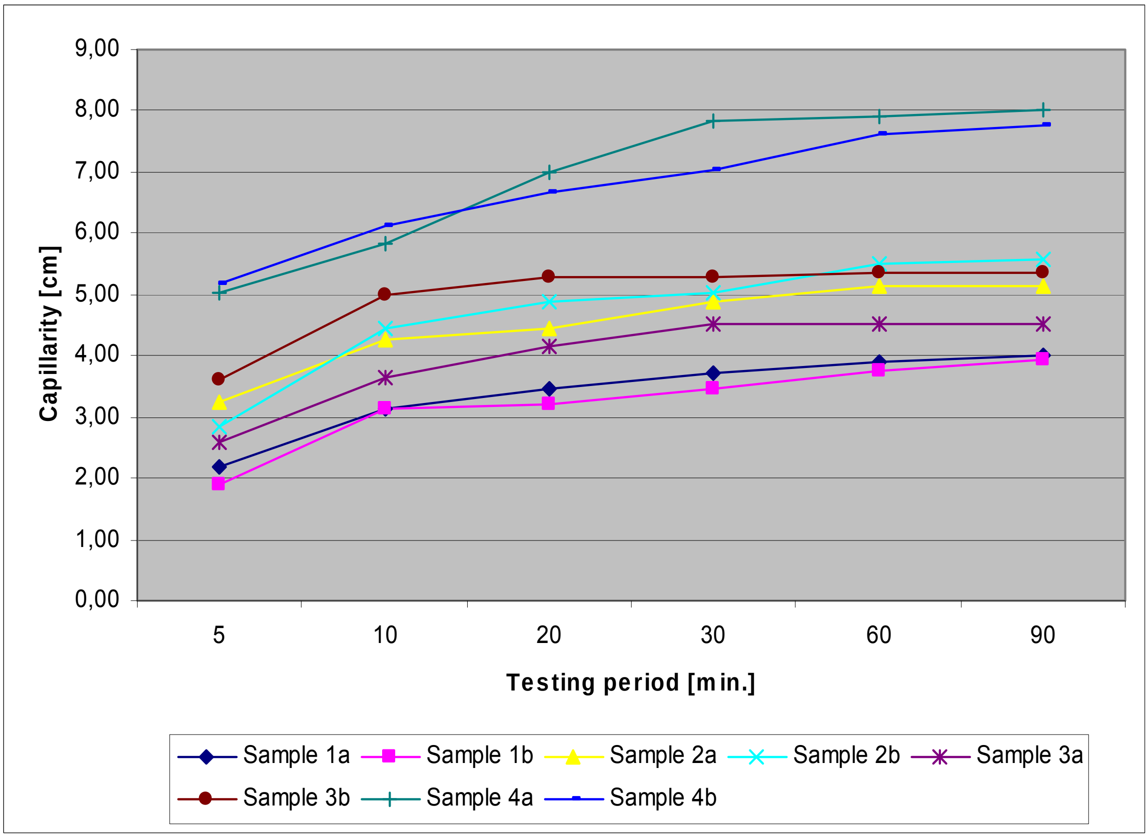

Figure 4: Results of capillarity expressed by height of saturation (cm).

4. Conclusions

In this paper presented results of sorption property (capillarity) of biocomposites based on hemp hurds slices (untreated and chemically treated) as a filler and two various type of binders (conventional Portland cement and alternative MgO-cement). Capillarity demonstrates the ability of building materials containing open pores the absorbing moisture. Effect of various types of binder and influence of modified hemp hurds on properties of composites were observed.

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