Application of Hemp Hurds in the Preparation of Biocomposites

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Abstract. Hemp is a controversial bio-product with promising performance as a sustainable building material. The fact that hemp is an organic, natural product makes it highly relevant in the present reality of global pollution and struggle for coping with planetary warming. The construction sector is among the leading industries when it comes to energy consumption, release of CO₂; it is responsible for great amounts of waste and pollution. The research and implementation of sustainable building materials is a crucial necessity in the modern times. Hemp (Cannabis sativa) is an agricultural crop that can be used as a building material in combination with conventional or alternative binders. Hemp composites have many advantages as a building material, but it is not load-bearing and must be used in combination with a load-bearing wooden frame. Despite this disadvantage, hemp composite materials offer several of appropriate properties, namely: low density, good thermal insulation, antiseptic and breathability. This paper studies the possibility of preparing the lightweight composites based on hemp hurds (treated and/or untreated) as a filler and alternative MgO-cement as a binder. Properties of hemp composites are characterized by mechanical and physical methods.

1. Introduction
Agricultural biomass, also referred to as lignocellulosic material, is produced in billions of tons around the world every year. There are various types of agricultural biomass across the world that can potentially be used as a raw material in different applications, such as oil palm trunks, bagasse, coconut coir, bamboo, kenaf and hemp. Mostly, this biomass is found in the form of residual stalks from crops, leaves, roots, seeds, seed shells, etc. Types of biomass can be divided into main groups depending on the part of the plant which they are extracted from, i.e. bast (stem), leaf, fruit (seed) and straw as it is shown in figure 1. The composition of these organic fibres varies from one plant species to another. In addition, the polymer constituent composition in a single plant varies among species and

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even in different parts of the same plant. It depends on the plant age, development growth, environment and other condition [1]. The properties of biomass vary considerably depending on the fibre diameter, structure, degree of polymerization, crystal structure and source and on the growing conditions. For decades, biomass raw materials have been historically used for ancient tools, food source, construction materials and textiles and as a source of energy. However, recently there has been a dramatic increase in the use of plant fibres for the development of environmentally friendly materials, especially as a reinforcing agent in polymeric composite materials in substitution of synthetic fibres like glass fibres [2]. This situation is largely spurred by environmental awareness, ecological consideration and technological advances.

![Figure 1. Classification of agricultural biomass [2].](image)

Compared to a glass fibre, biomass offers many advantages due to its unique characteristics such as low cost, low energy consumption, zero CO₂ emission, low abrasive properties, low density, biodegradability, non-toxicity and continuous availability [3]. However, biomass fibres also have certain drawbacks, especially when considering their application in composites. They have high moisture absorption and poor compatibility with polymer and/or inorganic matrix, which is responsible for poor mechanical and thermal properties. Modification or treatment (chemically, physically or mechanically) of the fibre is needed to enhance the performance of biomass in different multiple applications [4]. In the past few decades, the development of new materials that involve...
natural resources as the raw material, especially as a composite material, has accelerated. Nowadays, a large number of interesting applications is emerging for these materials due to recent progress in technologies, biomass material development, genetic engineering, and composite science technology that offer significant opportunities for an exploration and development of improved materials from renewable resources usable in various applications such as biocomposites, pulp and paper, construction, automotive, medical, packaging, aerospace, pharmaceutical and biomass energy production [5].

This article deals with utilization of hemp hurds (as waste material from bast fibre production) in preparation of lightweight composites. Hemp hurds were chemically or physically treated to remove impurities from the surface of the fibres as well as amorphous substances. The effect of treatment of fibres and the influence of hardening time on mechanical and physical properties of the prepared biocomposites were monitored.

2. Experiment

2.1. Materials

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

The original material studied in this paper is hemp hurds coming from the Netherlands Company Hempflax. The hemp hurds used had wide particle size distribution (8-0.063 mm). The mean particle size was calculated to be 1.94 mm. Bulk density of hemp material was 117.5 kg.m$^{-3}$. Average moisture content of the used hemp hurds was determined by weighing the sample before and after drying in an oven at 70°C until constant moisture content of 10.78% was reached.

The second sample used in the experiment was hemp hurds chemically modified in an alkaline environment. Dried original hemp hurds were soaked in 1.6 M NaOH solution during 48 h and then neutralized by 1% vol. acetic acid. Hemp hurds were then washed with water until the pH value was 7. The physical modification of dried hemp hurds was made by their thermal treatment in hot water (100°C) for 1 h. Subsequently, hemp hurds slices were dried and their surface was obviously distraught and shredded.

2.1.2. Binder.
Alternative binder MgO-cement was used for the preparation of the specimens. Binder consisted of milled magnesium oxide (MgO), silica sand (SiO$_2$) and sodium hydrogen carbonate (NaHCO$_3$) [6].

2.2. Preparation of specimens
Experimental mixtures were prepared according to the recipe published in [7]. Mixture recipe is presented in figure 2. The mixtures were homogenized in the classical concrete mixer and the standard steel cube forms with dimensions 100mm x 100mm x 100mm were used for the preparation of the bodies. Two days later the composites were taken out of the forms and cured under laboratory conditions (18°C, 65 % of relative humidity) during 28, 60 and 90 days. The number of tested specimens for each set was 3.
2.3. Testing methods
For all hardened composites, the following properties were measured: density, thermal conductivity coefficient, compressive strength and water absorbability. Density was determined in accordance with standard STN EN 12390-7 [8]. The thermal conductivity coefficient of samples as the main parameter of heat transfer was measured by the commercial device ISOMET 104 (Applied Precision Ltd, Slovakia). 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. The water absorption of hardened composites was determined after their short-term storage in water during 1 hour in accordance with standard STN EN 12087/A1 (727056) [9]. After immersion period, 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.

Compressive strength of all composites was determined using the instrument ADR 2000 (ELE International, England) according to standard STN EN 12390-3 [10].

3. Results and Discussion
In this paper, the impact of chemical and physical modification of the hemp hurds slices and hardening time on the selected physico-mechanical properties (density, compressive strength, thermal conductivity, water absorption) of biocomposites with alternative binder MgO-cement was studied. The results of testing the parameters of hardened composites (after 28, 60, 90 days) are presented. As it can be seen in figure 3, the values of compressive strength of hemp composites depend on the time of hardening as well as on the surface modification of hemp hurds slices. Hemp composites based on untreated original hemp hurds have higher values of compressive strength (1.84 – 4.9 MPa) in comparison with the composites based on physically treated hurds (1.12 – 2.74 MPa). The same behaviour of composites has been observed in the case of hardened specimens with chemically treated hemp hurds, strength values were lower than values of physically treated filler (1.08 – 1.80 MPa). One of the reasons leading to reduced values of strength parameter of the hardened composites based on modified filler is the high alkalinity of MgO-cement and poor adhesion of biomass aggregate with binder particles as a result of release of extractable substances inhibiting the process of hydration, too [11, 12]. The setting impairment caused by extracts and/or degradation by products could be explained by various phenomena like adsorption on hydrated or unhydrated MgO-cement particles, ionic complexation or the formation of a thin layered barrier around binder grains by precipitation [13].

![Figure 2. Scheme of mixture recipe.](image-url)
Figure 3. Dependence of compressive strength of the biocomposites on the time of hardening.

The density values of biocomposites ranged from 910 to 1200 kg·m$^{-3}$, which puts them in the category of lightweight composites. The linear dependency of the compressive strength on bulk density of hemp hurds composites was confirmed [14].

The hemp composite samples based on modified hemp hurds have lower values of thermal conductivity coefficient. The values in the range 0.071-0.085 W·m$^{-1}$·K$^{-1}$ were recorded for physically treated samples. Composites with chemically modified hemp hurds reached the values of thermal conductivity coefficient in the range of 0.058 – 0.072 W·m$^{-1}$·K$^{-1}$ which were lower than those of reference composites based on original hemp slices (0.08-0.098 W·m$^{-1}$·K$^{-1}$). All measured conductivity values of the prepared biocomposite samples are in the range acceptable for thermal insulation materials.

The water contents in the prepared composite samples after their short-term immersion in water, shown in figure 4, decreased along with the increasing time of hardening. Water absorbability values of composites are influenced by treatment methods of hemp hurds. The highest values of water content (13.9 – 26 wt. %) are demonstrated by biocomposites based on unmodified hemp hurds for each hardening time. The results confirmed that the absorbability decreases over time; that may indicate the fact that hydration products of the binder gradually fill the vacant interior spaces in the composite. The reduction of water absorption during aging could be explained by additional hydration during cement matrix hardening and creation of a denser structure inside the paste.
As it can be clearly seen from figure 4, the specimens with modified hemp hurds have observably lower water absorption values than the composites based on unmodified fibres. It means that the chemical and/or physical modification of hemp hurds reduced water absorption of the lightweight composites. According to literature data [15], physical treatment changes structural and surface properties of the fibres but it does not extensively change their chemical composition. On the other hand, chemical modification led to significant changes in defibrillation of bundles, chemical and phase composition and cellulose crystallinity [16].

4. Conclusions
This paper has analysed the application of hemp hurds as organic filler in unmodified and modified (physically or chemically) form in building materials. Thermal treatment (cooking in hot water) and alkali activation (leaching in NaOH solution) were used as the methods for removal of organic and inorganic loosely bound contaminants from the surfaces of hemp hurds. The influence of the used method on hemp hurds slices on the mechanical (compressive strength) and physical properties (density, thermal conductivity, water absorbability) of the hardened composites was observed. The following conclusions can be made:

The compressive strength of biocomposites prepared with hemp hurds increased with increasing time of hardening. However, physical and chemical treatment of hemp hurds has a negative impact on compressive strength of composites in comparison to composites based on untreated organic filler.

The values of thermal conductivity of composites prepared with unmodified and modified hemp hurds had the lowest values of thermal conductivity coefficient.

Hot water treatment and alkali activation of hemp hurds affect the water absorption properties of the hardened composites. Lower water contents in composites were observed in the case of specimens containing hemp hurds with the treated surface.

Further investigations are needed to understand and explain the influence of natural fibres as filler in composites structure by using physical method.
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