PROPERTIES TESTING OF LIGHTWEIGHT COMPOSITES BASED ON HEMP HURDS

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Abstract

Today, the growing trend in the construction industry is to create a sustainable construction by minimizing the production of emissions and replacing the limited material resources for the renewable raw materials. This article deals with the using of alternative materials (plant fibers) that are environmentally friendly. The great importance is attached to the industrial hemp, specifically to the woody part of hemp plant called hemp hurds, as reinforcement for composite materials for the purpose of the construction. In this article, the attention is given to the investigation of physical and mechanical properties (compressive strength, density, thermal conductivity coefficient) of the prepared lightweight composites based on hemp hurds (3 different mean particle length) as a filler and two alternative binders such as MgO-cement and hydrated lime with cement addition after 28, 60, 180 days of hardening.

This paper deals with the problematic of the use of hemp hurds in building materials. Lightweight composites were prepared with hemp hurds slices with different mean particle length. Two alternative binding agents such as MgO-cement and hydrated lime with cement addition were used. The changes in physical (density, thermal conductivity, water absorbability) and mechanical properties (compressive strength) of composites were investigated after 28, 60 and 180 days of hardening. The findings of this study showed that the combination of hemp hurds and alternative binder MgO-cement creates a building material with better properties in comparison to the traditional binder based on hydrated lime with cement and this could be more advantageous for preparing the new valuable "green" composite materials (causing the reduction of carbon emission) and for its using in a construction with a load bearing wooden framework.

1. Introduction

The principles of sustainable construction of the buildings bring new requirements with an emphasis to the rational use of material and energy resources by controlled minimization of the total production of emissions. One of the possible ways of achievement of sustainable development in the construction industry is to use the easily renewable raw material resources instead the limited and finite material resources [1].

A large group of renewable raw materials are materials of plant origin. Plant fibers from hemp, jute, sisal and the others are used for the purposes of the construction in the civil engineering. The great importance is attached to technical hemp like a renewable and fast-growing source of cellulosic fibres. This material has significant environmental and economical advantages because it is a rapidly renewable and non-waste material. The technical hemp (Cannabis Sativa) is currently in the forefront in the manufacture of lightweight composites with hemp hurds as an organic filler. The technical hemp is the source of two types of fibres; bast fibres (used mainly in the paper and textile industries) and woody fibres - hurds. For the construction industry is interesting the woody part of the fibres – hemp hurds [2]. The hemp hurds represents a waste material from hemp processing and is used as filler in lightweight composites. The lime is usually used as a binding material for composites based on hemp hurds. Combination of the lime-based binder and woody hemp fibres brings a new material - hemp concrete that is a perspective building material which has to be used in combination with a load-bearing frame [2-4]. The significant effect on the properties of prepared composites based on hemp hurds is caused by the high moisture sorption and heterogeneity of hemp fibres and/or hurds, their particle size and portion [5 - 7]. Due to the porous structure of hemp hurds and their good strength and thermal properties, this material is predetermined to the production of thermal insulation composites. In the papers [8, 9], the experimental studies of the parameters affecting the physical and mechanical properties of hemp composites based on conventional and alternative binders were performed. The influence of the different mean particle length of hemp hurds origins on the properties of composites with MgO-cement was monitored [10, 11]. Some durability aspects of hardened fibrous composites based on hemp hurds after long termed storage in deionised water were investigated in a paper [12]. The aim of this work is to compare the physical and mechanical properties of hemp hurds composites based on the conventional binder (hydrated lime with Portland cement addition) and alternative binder (MgO-cement).

2. Materials and methods

2.1. Hemp hurds

The technical hemp hurds slices (Cannabis Sativa L.) coming from the Netherlands company Hempflax were used in experiments. This hemp hurds contained more hurds material than bast fibres and its density was 117.5 kg•m^{-3}. The used hemp material (sample 1) was polydispersive with a wide mean particle length distribution (8-0.063 mm). The average moisture content of the hemp hurds determined by weighing of hemp sample before and after drying at 105 ºC for 24 h was found out 10.78 wt.%. A milled and oven-dried sample was used for the determination of chemical composition of hemp hurds. In Table 1, the contents of the main components of the hemp hurds are given. The content of holocellulose was determined by using the modified method according to Wisea. The quantitative determination of cellulose was performed by the Kürschner-Hoffer nitration method. The content of acid-insoluble (Klason) lignin was carried out by two-step hydrolysis of polysaccharides portion in sulphuric acid. Total ash content (mineral substances) was measured by combustion of sample and subsequent annealing. Toluene-ethanol extract containing mainly extractable waxes, fats, resins as well as water extractives was obtained by extraction in a Soxhlet apparatus for 6 – 8 h at 90°C.

Components of hurds	(%)
toluene ethanol extract	3.5
lignin	24.4

cellulose	44.2
hemicellulose	30.3
ash	1.4

Table 1. Chemical analysis of original hemp hurds.

Two fractions (samples 2 and 3) from original hemp hurds (sample 1) were sorted. The mean particle length values of samples calculated from granulometric analyses data are given in Table 2.

Sample	Granularity (mm)	d_m (mm)
1	8 - 2	3.22
2	8 - 0.063	1.94
3	2 - 0.063	0.94

Table 2. Values of mean particle length (d_m) of hemp hurds samples.

2.2. Binders

Two kinds of binders were used for preparation of mixtures: binder 1 based on hydrated lime (density 2240 kg*m^{-3}) with addition of Portland cement CEM I 42.5 R and alternative binder 2 – called MgO-cement consisting of milled magnesium oxide (MgO), silica sand (SiO_2) and sodium hydrogen carbonate ($NaHCO_3$).

2.3. Preparation of mixtures and composites

The composition of the fresh mixtures prepared with two binders and fractions of the hemp hurds was: 40 vol. % of hemp hurds, 29 vol. % of binder (24 vol. % of hydrated lime and 5 vol. % of cement) and 31 vol. % of water. Homogenization of the mixtures was carried out in the labor mixer. Standard steel cube forms with dimensions 100 mm x 100 mm x 100 mm were used for preparation of samples. The specimens of lightweight composites were cured for 2 days in an indoor climate and then were removed from the forms. Curing was continued under laboratory conditions during 7, 28, 60, 90 and 180 days. Designation of prepared composites based on different binders and mean particle lengths of hemp hurds is shown in Table 3.

Composite	d_m (mm)	Binder
C1	3.22	Hydrated lime with Portland cement addition
C2	1.94	
C3	0.94	
C4	3.22	MgO-cement
C5	1.94	
C6	0.94	

Table 3. Designation of composites.

2.4. Methods

Density, thermal conductivity coefficient, compressive strength and water absorption were measured on hardened composites. The density was determined in accordance with standard STN EN 12390-7 [13]. The thermal conductivity coefficient of samples, as the main parameter of heat transport was measured by the commercial device ISOMET 104 (AP Germany). The compressive strength of all composites was determined using the instrument ADR ELE 2000 (ELE International Limited, United Kingdom). The water absorption (after 1 h) was specified in accordance with STN EN 12087/A1 [14].

3. Results and discussion

In this study, the influence of mean particle length of hemp hurds slices on physical properties (density, thermal conductivity coefficient, water absorption) and compressive strength of 28 days hardened composites based on two binding agents was compared. As it is shown in Figures 1-3, the values of density, thermal conductivity coefficient and compressive strength of composites depend on the mean particle length of hemp hurds as well as on the kind of used binding material.

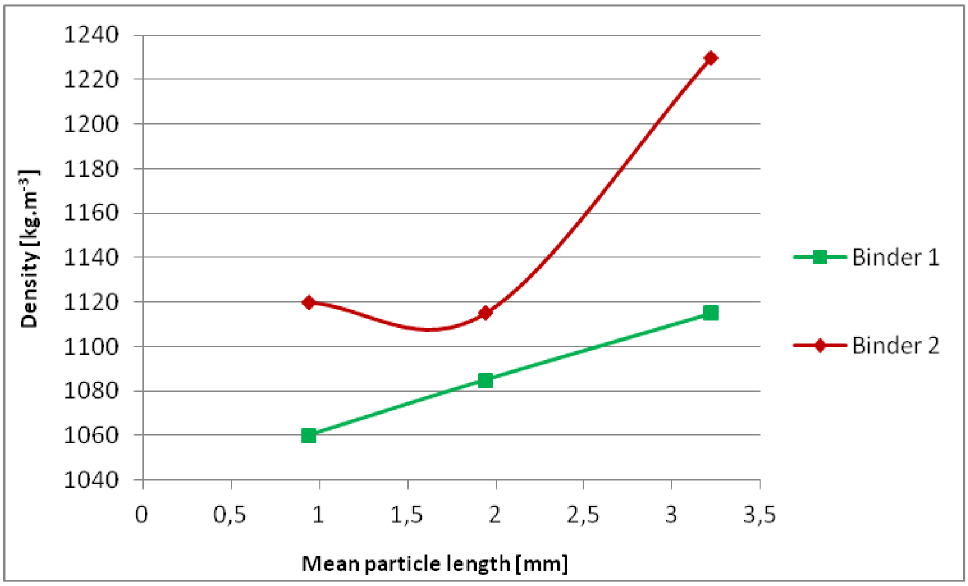

Figure 1. Dependence of density of composites based on binder 1 (hydrated lime with Portland cement addition) and binder 2 (MgO-cement) on mean particle length of hemp hurds.

Whereas the values of density and thermal conductivity coefficient of composites increase with increasing mean particle length of hemp hurds, decrease of values of compressive strength in dependence on the growing mean particle length of the organic filler is observed. The values of density are higher by 2.6-10 % for composites based on MgO-cement (C4 - C6) in comparison to the specimens with hydrated lime and Portland cement addition (C1 – C3). Lightweight composites C1 – C3 have lower values of thermal conductivity coefficient (0.069-0.082 $W*m^{-1}*K^{-1}$) than composites based on binder 1. It seems that the thermal property increases when the density is increasing due to increased surface interface. As it can be clear from the Table 4, the specimens with binder 1 (C4 - C6) have lower values of water absorption than composites C1 – C3 based on binding agent 2. Whereas the composites based on binder 1 have the increasing values of water absorption with mean particle length of hemp hurds, the specimens prepared with binder 2 behave differently. This fact is probably connected with the nature of binder and the porosity of hemp hurds and composite.

Composite	Binder	Water absorption (%)
C1	1	10
C2		26
C3		45
C4	2	8
C5		14
C6		6

Table 4. Water absorbability of 28 days hardened composites.

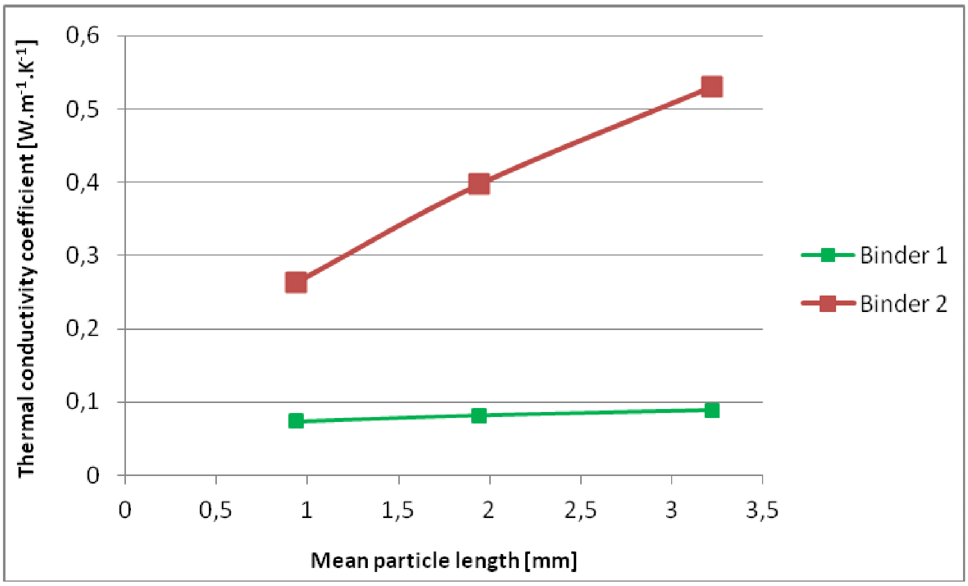

Figure 2. Dependence of thermal conductivity coefficient of composites based on binder 1 (hydrated lime with Portland cement addition) and binder 2 (MgO-cement) on mean particle length of hemp hurds.

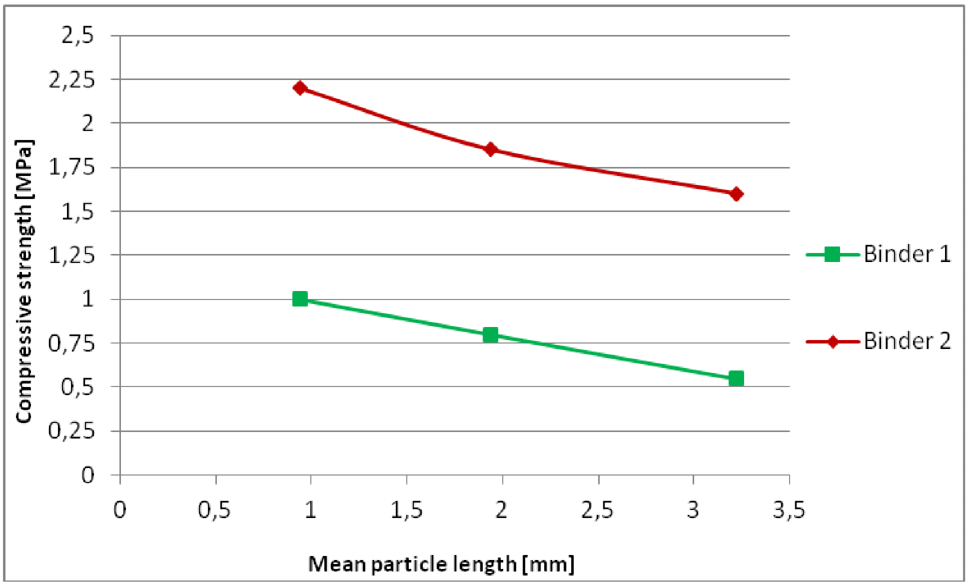

Figure 3. Compressive strength of composites based on binder 1 (hydrated lime with Portland cement addition) and binder 2 (MgO-cement) vs. mean particle length of hemp hurds.

As it can be seen in Figure 3, the values of compressive strength were reached to 1.6 – 2.2 MPa and 0.5 – 1 MPa for composites C4 – C6 and C1 – C3, respectively. The hydraulicity degree of used binder materials influences the mechanical properties of lightweight composites. The linear relationship between the compressive strength of prepared lightweight composites and their density was found [15]. The compressive strength of these composites increases with decreasing mean particle length of hemp hurds slices. This result is in accordance with published data [6], where mechanical properties of gypsum lime composites with hemp hurds filler are depended on the length of hemp fibers and on their concentration in composites. This fact confirms that the alignment of the fibres and/or hurds slices in the matrix of the composites plays an important role in the creation of such materials. Higher values of compressive strength are connected with better alignment of hurds slices in volume of inorganic matrix of the composites and with the formation of denser composite structure. The measured lower values of compressive strength for composites containing the hydrated lime with Portland cement addition are in a good agreement with the compressive strength values of composites with lime reported in the literature [2, 4, 16]. However, the compressive strengths don’t reach the values of 3-5 MPa which are considered to be sufficient for the load bearing material [2]. Based on the results presented above, better physical and mechanical properties have composites with alternative binder (MgO-cement) after 28 days of hardening. Therefore, our further research was to study the development of compressive strength in biocomposites with this binder. Figure 4 illustrates that the values of compressive strength of composites increase with prolonging the hardening time depending on mean particle length of hemp hurds.

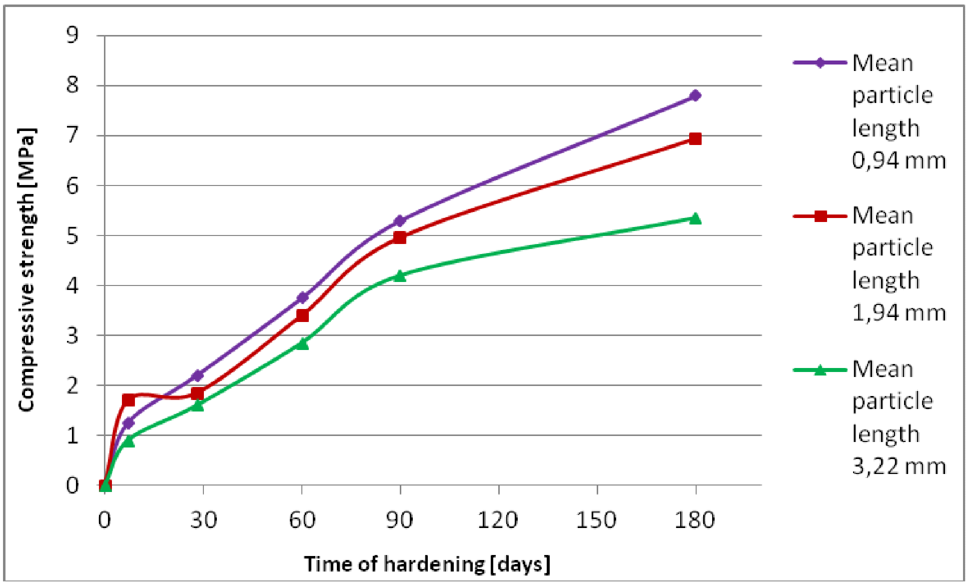

Figure 4. Development of compressive strength in with binder 2 (MgO-cement) and different mean particle length of hemp hurds.

After 28 days of hardening, the highest values of compressive strength reach composites with the lowest mean particle length. For 180 days hardened composite samples, the values of this mechanical parameter varies from 5.35 to 7.80 MPa in dependence on the mean particle length. Because the mean particle length of hemp hurds had no significant effect on the values of thermal conductivity coefficient (0.069-0.082 $W*m^{-1}*K^{-1}$) of 28 days hardened composites, thermal conductivity measurements were carried out only in the case of composites with polydisperse hemp hurds. As it is shown in Figure 5, the values of thermal conductivity coefficient of composites C5 are decreasing with the prolonged time of hardening. After 180 days of hardening, the thermal conductivity coefficient of composites has a value of 0,065 $W*m^{-1}*K^{-1}$, which is similar to published data for composites prepared by using hemp hurds and starch binder [17].

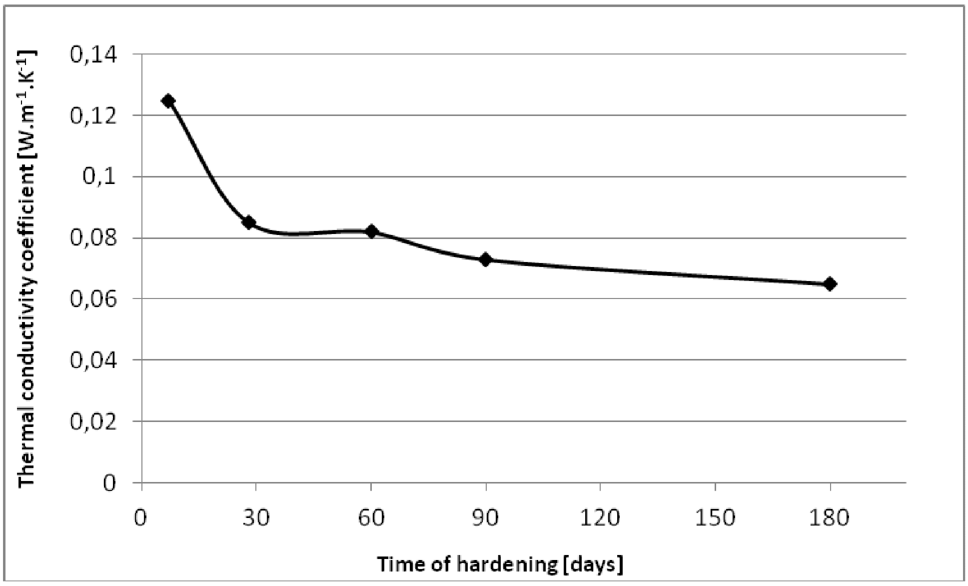

Figure 5. Development of compressive strength in with binder 2 (MgO-cement) and different mean particle length of hemp hurds.

The processes occurring in composite materials based on a natural cellulosic fibres and on an alternative binder are complicated. Their observation will be executed in our further research.

4. Conclusions

This article deals with the problematic of the using of hemp hurds as an organic filler in building materials. Testing the physical and mechanical properties of the composites prepared with hemp hurds slices 3 different mean particle lengths and with two binding agents (the conventional - hydrated lime with cement addition and the alternative one - MgO-cement) showed that the composites depend on the mean particle length of hemp hurds as well as on the kind of used binding material. Conclusions can be summarized as follows:

1. The 28 days hardened composites based on MgO-cement had higher values of density, compressive strength and lower values of thermal conductivity coefficient and water absorption in comparison to the lime composites for all mean particle lengths of hemp hurds. The combination of hemp hurds and alternative binder MgO-cement creates a building material with better properties compared to traditional binder.
2. The values of compressive strength of MgO – cement composites increase with decreasing mean particle length of used hemp hurds slices and with prolonging the hardening time.
3. The values of thermal conductivity coefficient of MgO – cement composites based on polydispersive hemp hurds are decreasing with prolonged time of hardening.

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