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AN EXPERIMENTAL STUDY OF PARAMETERS AFFECTING PHYSICAL AND MECHANICAL PROPERTIES OF HEMP COMPOSITES

A new approach in the field of sustainable building materials is based on the use of renewable raw materials instead of non-renewable ones. A great potential for the use of fast renewable raw material has a group of plants that are the source of fibers and non-fibrous components. The use of plant fibers and/or particles as fillers into building material with reinforcement function of composite is motivated by the need to develop environmentally friendly products in accordance with principles of sustainable development in the building industry. Our research interest is concentrated on the possibilities of using technical hemp especially hemp waste – hurds/shives like non-fibrous fraction originating from the production of hemp fibers into lightweight composite.

This paper gives an overview of the results of an experimental study of the parameters affecting the physical and mechanical properties of hemp composite based on MgO-cement as a binder. The influence of parameters such as hemp proportion (20-60 vol. %) and mean particle length of anisometric hemp hurds slices (2,33 – 7,42 mm; 40 vol. % hemp hurds) on some physical (density, thermal conductivity, water absorption) and mechanical properties (compressive strength) of composite after different curing time is studied. Composites prepared by varying the proportion of hemp hurds in the mixture reached increase in values of compressive strengths in dependence on organic filler content and hardening time. Strength characteristics of hardened composites depend not only on the proportion of hemp hurds in the mixture, but also on the mean lenght of hemp particles. Effect of mean length of hemp hurds slices on the above mentioned characteristics of composites was confirmed. Physical properties of hardened composites are improved when mean hemp particle length decreases what is related to the creation of more dense structure for composite with particle dimensions smaller.

Key words: lightweight composites, hemp hurds, mechanical properties, physical properties.

Новий підхід в області виробництва будівельних матеріалів базується на використанні поновлюваних джерел сировини замість непоновлюваних. Великий потенціал як швидко поновлювана сировина мають певні групи рослин, що можуть служити джерелом волокнистих та неволокнистих матеріалів. Використання органічних волокон та/або просто частин рослин як наповнювачів в композитних будівельних матеріалах мотивовано необхідністю розробки екологічно чистих продуктів згідно з принципами розвитку будівельної промисловості. Наші зусилля були зосереджені на дослідженні можливості використання технічних конопель, а саме відходів їх переробки у волокно, – костриці – для виготовлення легких композитних матеріалів.

Здійснено огляд результатів експериментального дослідження параметрів, що впливають на фізичні та механічні властивості композитів на базі конопель з MgO-цементом як зв'язуючої речовини. Досліджувався вплив таких параметрів, як вміст костриці (20 – 60 об. %) та середня довжина анізометричних фрагментів костриці (2,33 – 7,42 мм; при вмісті 40 об. %) на деякі фізичні (густина, теплопровідність, водопоглинання та стійкість) та механічні (міцність на стиск) властивості композитів залежно від тривалості затвердівання. Композити з різним вмістом костриці досягають значень міцності на стиск залежно від вмісту органічного наповнювача. Міцність загартованого композиту залежить не тільки від об'єму костриці в суміші, але й від

середньої довжини фрагментів. Був підтверджений вплив середньої довжини частинок кострицi на вищезгадані параметри. Фізичні властивості загартованих композитів змінюються із зменшенням середньої довжини фрагмента, що пов'язано з утворенням більш щільної структури композиту при менших лінійних розмірах частинок.

Ключові слова: легкі композити, костриця, механічні властивості, фізичні властивості.

Introduction

Progressive building materials are developed on base of environmentally friendly materials by using best available techniques and clean production technologies and procedures. Research and development of new composite materials led to partial or complete replacement of cement by non-traditional active ingredients of natural character and/or use of secondary raw materials. Renewal of scientific as well as industrial interests in the use of natural cellulosic fibres and especially hemp fibres as reinforcing constituents in composite materials as well as consumer pressure relates to a need of a (partial) substitution for conventional non-renewable reinforcing synthetic fibres, such as glass, carbon or metallic fibres. Because the growth, harvesting and processing of hemp consume overall less fossil energy and chemicals than the synthesis of man-made fibres, their use decreases consequently the carbon dioxide emissions associated with the composite fabrication [1]. Mineral matrix properties as well as composition of mixture belong to important parameters determining the mechanical and physical properties of hemp composites too. At present, the usage of hemp fibres in mineral matrix (such as lime) is known in Europe (France, Great Britain and Germany). Lime-hemp construction has been used in hundreds of new low/medium rise buildings. The application of hemp in composites with other alternative binders or admixtures has not yet been systematically studied. The aim of our research is to develop the production technology for a new energy resources saving composite building material based on MgO-cement as an alternative binder with hemp hurds reinforcement, as well as testing mechanical and physical properties. Hemp as an annual plant provides two materials used in civil engineering: hemp hurds (granular form of hemp descended from the inner woody core) and hemp fiber (fibrous form of hemp from the bark-like bast fibres). Hemp hurds is basically regarded as a waste – wooden part of the hemp stem in the processing of hemp plant to the fiber. Our previous research was oriented on utilization of different binding agents (hydrated lime, cement and zeolite) in combination with hemp shives in hemp concrete [2]

The aim of this work is give an overview of the results of an experimental study of the parameters affecting the physical and mechanical properties of hemp composite based on MgO-cement as a binder. The influence of parameters such as hemp proportion (20-60 vol. %) and mean particle length of anisometric hemp hurds slices (2.33 – 7.42 mm; 40 vol. % hemp hurds) on some physical (density, thermal conductivity, water absorption) and mechanical properties (compressive strength) of composite after different curing time is studied.

Material and Methods

Components of mixture

Hemp

Dried hemp hurd slices (density – 115 $kg.m^{-3}$; average length – 4.29 mm) used in experiments (supplied by Hungarohemp Rt, Nagylak, Hungary) was polydisperse waste material originating from hemp fibres production. Chemical analysis of hemp hurds showed that content of polysaccharide component (holocellulose) is 71.5 %. Chemical characteristic of components of holocellulose (cellulose and hemicellulose) and other components is in Table 1.

Table 1

Chemical analysis of hemp hurds

Characteristic	[wt.%]
Cellulose	44.3
Hemicellulose	27.2
Lignin	22.0
Toluene-ethanol extract	6.2

Impact of various contents of filler in mixture on mechanical properties (compressive strengths) of hardened hemp concrete based on MgO-cement was studied. Hemp hurds as filler ranging from 20 to 60 vol.% by volume of the total mixture was used.

Two fractions of hemp hurds (< 4 mm; 8-4 mm) with average size slices of hemp hurds (2.33 mm and 7.42 mm) were separated from initial polydisperse hemp hurds in order to study influence of hemp hurds particle size (length) on technical important properties of composite.

Binder

The used binder MgO-cement consists of magnesium oxide obtained by low temperature decomposition of natural magnesite (CCM 85, SMZ a.s. Jelsava, Slovakia), silica sand (Sastin, Slovakia) with dominant component of SiO_2 (95-98%) and the last component of the binder is sodium hydrogen carbonate ($NaHCO_3$) p.a. According to papers [3] and [4], the short term milled MgO was used in our experiments.

Mixture and composite preparing

The compositions of the experimental mixtures with different amount of polydisperse hemp hurds are presented in Table 2. Mixture I.1 was prepared according to recipe published in [5] and [6], respectively. The mixtures I.2 and I.3 are modifications of previously mentioned mixture.

The recipe with 40 % of hemp portion was used for preparation of mixtures based on coarser and finer hemp fraction. Designation of these mixtures is given in Table 3.

Table 2

The composition of experimental mixtures

Mixture	Composition of mixture [vol.%]		
	Hemp hurds	MgO-cement	Water
I.1	20	45	35
I.2	40	29	31
I.3	60	19	21

Table 3

Designation of the experimental mixtures

Mixture	Mean length of hemp shive slices (mm)
1	7.42
2	4.29
3	2.32

Homogenization of the mixtures based on polydisperse hemp and its fraction carried out in labor mixer. Standard steel cube forms of dimensions 100 mm x 100 mm x 100 mm were used for forming the mixture test bodies. Next day the composites were taken out of the forms and cured under laboratory conditions according to standard procedures during 28 and 90 days (STN EN 206-1, 2004). Compressive strength (using an ELE ADR 2000) was determined after 28 and 90 days of hardening.

Methods

The density, thermal conductivity coefficient, compressive strength and water absorption were measured on hardened composites after 28 days of hardening. Density was determined in accordance with standard STN EN 12390-7 [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 [8].

Results and Discussion

Hemp hurds proportion

Developing the compressive strength of hardened composites based on various contents of hemp hurds after 28 and 90 days (average values of strength [MPa]) is shown in Figure 1. The hardened composites containing 20 vol. % hemp hurds (the mixtures I.1) reached the highest compressive strengths. The obtained data show that the compressive strength values decrease with increasing percentage of hemp hurds (filler) in composites. This is probably due to creation of the denser structure of composites based on smaller proportion of hemp hurds. Hardened specimens examined in this study showed higher values of mechanical parameters than composites based on lime binder prepared under the same conditions [2].

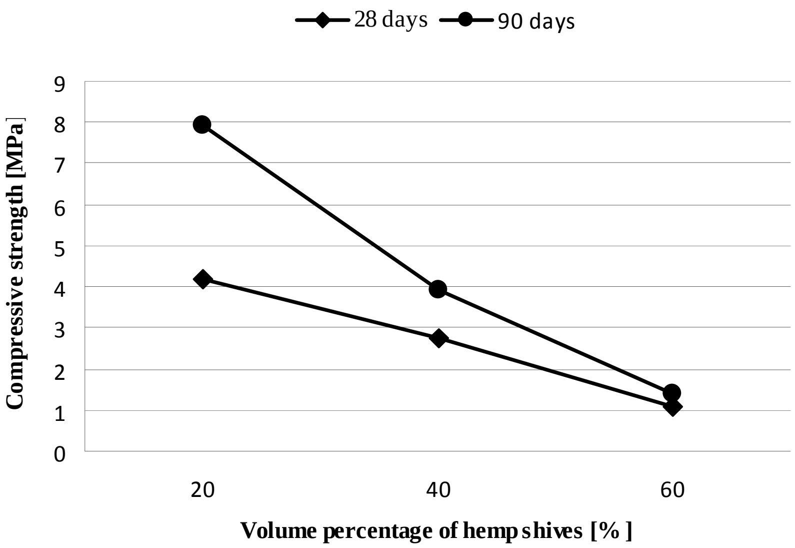

Fig. 1. Compressive strength of composites (mixtures I.1-I.3) after 28 and 90 daysof hardening

Mean particle length of hemp hurds

Table 4 summarizes the results of density, compressive strength, thermal conductivity coefficient and water absorbability of composites containing initial hemp hurds and its fractions after 28 days of hardening. The density of hardened composites increases with decreasing the mean size slices of hemp hurds. In the case of mixture 3 (with the shortest mean length of hemp hurd slices), it represents 10.5 % growth over the composite with the longest slices.

Compressive strength of composite 3 with the shortest hemp hurds slices reaches almost twice the value specified for composite 1 with the longest hemp hurds slices. This result is in accordance with work [9], where mechanical properties of foam gypsum composite with hemp fibrous reinforcement had been determined depending on fibers length and their concentration in composite.

Thermal conductivity coefficient values of all composites are very similar (0.110-0.115 W m-1K-1) and comparable to other building materials [3]. Thus, the influence of mean length of hemp hurds slices on this parameter of hardened composites was not found.

Table 4

Density and compressive strength values of composites based on hemp shive slices of various mean length

Mixture	Density (kg.m-3)	Compressive strength [MPa]	Thermal conductivity coefficient [W $m^{-1}K^{-1}$]	Absorbability [%]
1	1040	2.73	0.111	21.38
2	1070	4.20	0.115	25.81
3	1150	5.20	0.110	11.88

Absorbability is determined by porous structure of composites. In the case of composite 3 (with the shortest hemp hurds slices), the lowest value of water absorbability has yielded as result of the densest arrangement of hemp hurds slices in MgO-cement matrix in composite. Difference in absorbability between samples 1and 2 is caused by porosity of composites. Sample 2 does not content short hemp slices (fraction 8-4 mm) and structure of composite is more porous than that in the composite 1 (with a wide distribution of slices size) what led to higher value of absorbability.

Conclusion

This work deals with hemp hurds composites containing MgO-cement as an alternative binder. Here is comparison of hemp hurds volume percentage influence on the resulting compressive strength of lightweight composites. The highest values of compressive strength of 28 and 90 days hardened composites had specimen with 20 vol. % content of hemp hurds. By presenting our results it is very important to respect the volume ratio of hemp hurds in composite. Application of MgO-cement as binder in composites based on hemp hurds appears to be a suitable alternative instead of traditional binder (hydrated lime).

The results of our experiments confirmed the influence of mean length of hemp hurds slices on physical and mechanical properties of composites based on MgO-cement. Increase in values of density and compressive strength of composites after 28 days of hardening with decreasing length of hemp hurds slices was found. The change in the density determines the compressive strength. The lowest water absorbability was obtained for composite 3 with the shortest hemp hurds slices. The impact of mean length of hemp hurds slices on thermal conductivity parameter was not confirmed.

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