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Effective Utilization of Alternative Materials in Lightweight Composites

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This paper is aimed of possibilities utilization of natural renewable materials (hemp shives, wood cellulose) in lightweight composites preparing. Because in the building industry, one major aim is the reduction of the carbon dioxide production during the manufacture of cement, the effect of using different binding agents in combination with hemp shives in composites was examined. Conventional binders (hydrated lime, cement) in hemp concrete were replacement by alternative materials such as MgO and zeolite. The experimental results of selected mechanical properties indicate that using zeolite as cement replacement does not appear to create a mechanically stronger hemp concrete but magnesium oxide-cement system based on optimal milled caustic magnesite appears be a suitable replacement for cement in lightweight composites, which could lead to new environmentally products such as non-load bearing building materials.

1. Introduction

To build sustainable and affordable building for the future it is advantageous to create links between agriculture and the construction industry. Sustainability can only be possible when construction uses renewable materials or materials recycled from construction wastes. As a result of the increasing demand for environmentally friendly materials and the high cost of synthetic fibres such as carbon, glass or aramid, new bio-based materials containing natural fibres were developed. They are low density materials yielding relatively lightweight composites. Utilization of natural fibers is the subject of several studies, e.g. d´ Almeida et al. (2009), Pehanich et al. (2004), Bruijn (2008), Ouajai, Shanks (2009). Hemp is one of the most interesting renewable materials. Like many natural materials it has been used for centuries as a reinforcing binder in “concrete”, in drainage work and for rope and cloth making. Chopped hemp is frequently used as a loose insulation material, though it requires treatment with borax salts or other material to ensure that the fire risk is minimized. The main experience of hemp is as a composite mixed with lime that can be cast as a solid wall. Chopped hemp shives can be mixed with a range of building limes and cast as a form of “concrete” to

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create walls. The normal practice is to do this around a timber stick frame using plywood shuttering (Woolley, 2004). Europe is leading the way in the discovery of lime-hemp biocomposite as construction material and building method. In France lime-hemp construction is today common and has already been used in hundreds of new buildings. The Britain has recently carried out research, both private and academic, in order to test the claimed benefits of lime-hemp and, after a few pilot projects, the new construction material is now available on the market for those interested (Ronchetti, 2007). Lime-hemp has a typical compressive strength of 0.2 - 1.0 N/mm^2 (HLCPA, 2006). Cement-concrete typical strengths range from 20 N/mm^2 to 65 N/mm^2 (Irish Concrete Society, 2007). The unsuitability of lime-hemp to some kind of applications might as well be a limitation in its take up by the construction industry. According to the builder the specific application must be considered. Lime-hemp is not appropriate for building bridges or structures where cement-concrete is proven to be necessary due to its properties. Due to the global environmental problems as well as to the unsustainability of cement, natural materials should be used in as many applications as possible. Low/medium rise residential and commercial buildings for example could be easily made with lime-hemp (Ronchetti, 2007). The aim of this paper is study of utilization of two types of natural renewable materials (hemp shives and wood cellulose) in composites and testing of their mechanical properties and selected physical properties.

2. Experimental

2.1 Materials

The two types of natural renewable materials used in this study were hemp shives and wood cellulose. Hemp shives as a waste from the production of hemp fibres (supplied from Hungarohemp Rt, Nagylak, Hungary). The density of dried hemp shives was 115 kg.m^{-3} and mean particle diameter was 33.68 mm. Wood cellulose is composed of hardwood fibre and we used unbleached sulphate beech wood pulp (supplied from Bukoza Holding, a.s., Hencovce, Slovakia). As a binder was used hydrated lime in powdered form. Hydrated lime is used for the preparation of masonry mortar, plaster or compositions directly on the site. Calcium hydroxide used for composites preparing had a density of 2240 kg.m^{-3}. For all mixture was used Portland cement (PC) CEM I 42.5 R in this study. Mass yield of fraction under 5 μm was 42.74 %. Mean particle diameter (calculated as the first moment of the density of the volume size distribution function) of this cement was 11.47 μm and its specific surface was 1.18 m^2.g^{-1}. In the mixtures based on hemp shives was added zeolite ZeoSand (Zeocem, a.s., Bystre, Slovakia) as cement replacement. Granulometric composition of natural zeolite is given in Table 1.

Table 1: Granulometric composition of natural zeolite

Fraction [mm]	Mass yield [wt.%]
1-2	33.75
0.5-1	49.5

0.25-0.5	15.5
0.125-0.25	0.75
0.063-0.125	0.25
-0.063	0.25

Zeolite was milled in laboratory vibratory mill VM 4 with in times of 5 – 60 minutes to particle size similar to PC with addition of water glass (aqueous solution of disodium silicate) as a surface active substance with high viscosity (density about 1.4 g.cm^{-3}). Water glass was adding of 1 % by weight of zeolite to protect of zeolite particles against aggregation. The particle size analysis of the milled products was carried out on the laser granulometer Helos with dry dispersion unit Rodos (Sympatec, Germany). The specific surface area of powders was determined by the standard B.E.T. methods using the equipment Gemini (Sy-Lab, Austria). Mass yield of fraction under 5 µm (Q_{-5}) and mean particle diameter (d_m) of milled zeolite products are given in Table 2. Based on fineness of milled products, zeolite milled for 5 min was selected for experimental works.

Table 2: Mass yield of fractions under 5 µm and mean particle diameter of milled products of zeolite

Milling time [min]	Q_{-5} [wt.%]	d_m [µm]
5	75.11	3.22
15	53.64	5.60
30	48.58	5.61

2.2 Preparing of composites

2.2.1 Composites based on hemp shives

Mixtures 1 – 3 and mixtures 4 – 5 were prepared according to recipe published in (Bydzovsky, 2009) and (Allin, 2005), respectively. The compositions of mixtures are characterized in Table 3. Cement amount in mixture 2 and 3; 5 and 6 was partial or total replaced by milled zeolite product.

Table 3: The composition of experimental mixtures with hemp shives

Mixture	Component content in experimental mixtures [vol.%]				
	Hemp shives	Hydrated lime	Cement	Zeolite	Water
1	40	24	5	-	31
2	40	24	2.5	2.5	31
3	40	24	-	5	31
4	60	12	3	-	25
5	60	12	1.5	1.5	25
6	60	12	-	3	25

2.2.2 Composites based on wood cellulose

Composition of the mixture is based on study (Pehanich et al., 2004). Mixtures 1 and 2 were prepared using water and 8% water glass solution instead water for preparation of mixtures 3 and 4. Table 4 shows the composition of experimental mixtures with wood cellulose.

Table 4: The composition of experimental mixtures with wood cellulose

Mixture	Component content in experimental mixtures [wt.%]			
	Cement	Wood cellulose	Water	Water glass
1	60	5	35	-
2	55	10	35	-
3	60	5	-	35
4	55	10	-	35

The mixtures were homogenized in the labour mixer type ZZ 150 SH with horizontal rotary drum. The standard steel cube forms with dimensions 100mmx100mmx100mm were used to preparation of bodies. Each form was rammed on the vibration plate VSB 40 for the 3 min. The moulds were cured under laboratory conditions according to standard rules. At the end of the 24 h, the samples were demolded and their hardenings were proceeded under conditions required by standard (STN EN 206-1, 2004).

2.3 Testing of selected properties of bodies

Compressive strength (equipment ELE ADR 2000), density and in the case of wood cellulose also thermal conductivity and absorbability after 28 days of hardening were determined. Three replications were used for each property. Compressive strength of cube concrete specimens at particular ages under controlled conditions was determined as follows:

$$\text{Compressive Strength} = \frac{Maximum\ Load}{Average\ Cross\text{ - }Sectional\ Area}$$

The thermal conductivity coefficient as the main parameter of heat transport was determined using the commercial device ISOMET 104 for measuring the thermal conductivity, thermal diffusivity, and volumetric heat capacity. The measurement is based on the analysis of the temperature response of the analyzed 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. Testing of absorbability is based on determination of weight increase of test samples during their full immersion in water, which were stored for required time at a constant temperature.

3. Results and discussions

3.1 Composites based on hemp shives

Table 5 shows the results of density and compressive strength. The sample 1 and 4 containing only cement reached the highest compressive strength. The obtained data show that the strength significantly decreases with percentage reduction of cement. Same dependence is observed in the case of density.

Table 5: Density and compressive strength values of composites based on hemp shives

Mixture	Density [kg.m^{-3}]	Compressive Strength [MPa]
1	790	0.3
2	760	0.27
3	720	0.23
4	630	0.83
5	580	0.64
6	540	0.54

3.2 Composites based on wood cellulose

Table 6 shows the results of density, compressive strength, thermal conductivity coefficient and absorbability of hardening composites based on wood cellulose (Lukcova, 2010). The highest values of compressive strength as well as absorbability had the samples 1 and 3 containing only 5 wt.% wood cellulose, on other side the lower values of thermal conductivity reached the composites 2 and 4 containing 10 wt.% of wood cellulose.

Table 6: Density, compressive strength, thermal conductivity coefficient and absorbability values of composites based on wood cellulose

Mixture	Density [kg.m^{-3}]	Compressive strength [MPa]	Thermal conductivity coefficient [W.m^{-1}.K^{-1}]	Absorbability [%]
1	1260	5.44	0.24	25.1
2	940	1.42	0.13	42.5
3	1150	2.98	0.15	25.9
4	1030	1.44	0.12	41.4

4. Conclusion

Our experiments were focused on a partial cement replacement by natural zeolite in lightweight composites. The highest strength was determined in mixtures without cement replacement and the lowest strength with 100 % cement replacement by milled zeolite. These results showed that cement replacement by natural zeolite is not obtaining new stronger material. This materials have also relatively low density compared with normal concrete, thus it is suitable material for insulation materials or non-load bearing building materials. As regards suitability of using wood cellulose, composites based on wood cellulose compared with analog materials as masonry brick is effective utilization as filler material with suitable thermal insulation properties.

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