DE GRUYTER OPEN

DOI: 10.2478/sspjce-2014-0006

Possibility of Using Wood Pulp in the Preparation of Cement Composites

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Abstract

Sustainable building materials are based on the use of renewable materials instead of non-renewable. Large group of renewable materials composes of plant fibres having high tensile strength are used as fillers into building material with reinforcement function of composite. This study aimed to establish the mechanical and physical properties of cement composites with organic fillers, such as wood pulp. Wood pulp cellulose is very interesting material as reinforcement in cement which contributes to a reduction of pollutants. Varying the producing technology (wood pulp and cement ratio in mixture) it is possible to obtain composites with density from 940 to 1260 kgm^{-3} and with compressive strength from 1.02 to 5.44 MPa after 28 days of hardening. Based on the experimental results, cement composites with using unbleached wood pulp reach higher values than composites based on bleached wood pulp. Volume ratio of unbleached wood pulp in composites influences water absorbability of cement composites.

Key words: wood pulp, cellulose fiber-cement composite, physical and mechanical properties

1 Introduction

Inorganic-bonded wood composites have a long and varied history that started with commercial production in Europe at the beginning of the last century. They are molded products or boards that contain between 10% and 70% by weight wood particles or fibers and conversely 90% to 30% inorganic binder. The properties of inorganic-bonded wood composites are significantly influenced by the amount and nature of the inorganic binder and the woody material as well as the density of the composites. The incorporation of natural cellulosic fibers originating from wood to reinforce cement-based materials has recently received renewed interest because of their renew ability and because of the benefits to

mechanical behavior. The use of cellulosic fibres in cementitious matrices has gained prominence because: they make the composite lighter at high fiber contents, they have comparable cost-performance ratios to similar building materials, and they could be processed from waste paper, thus expanding the opportunities for waste utilization in cementitious materials [1]. Wood pulp fiber is a unique reinforcing material as it is non-hazardous, renewable, and readily available at relatively low cost compared to other commercially available fibers [2]. As a result, pulp fibre–cement composites have found practical applications in recent decades in the commercial market as a replacement for hazardous asbestos fibres. Today, pulp fiber-cement composites can be found in products such as extruded non-pressure pipes and non-structural building materials [3]. Soroushian et al. [4] reported that the flexural strength and flexural toughness values of wood fibre-cement composites were higher than the values for neat cement paste. In the same study, it has also reported that the dynamic modulus of elasticity of neat cement decreased with increasing freezing and thawing cycles while the dynamic module of wood fibre-cement composites remained relatively constant over the same number of freezing and thawing cycles. The effects of moisture on the flexural properties of wood fibre-cement composites were investigated [5]. Flexural strength decreased with increasing moisture contents. In addition, dry wood fibre-cement specimens appeared to have lower flexural toughness values compared to wet wood fibre-cement specimens.
The objective of this work was to study the utilization possibilities of unbleached and bleached wood pulp in cement composites preparing and to compare their selected physical properties as well as compressive strength.

2 Material and methods

2.1 Characteristic of wood pulp

The type of natural renewable material used in this study was wood pulp. Wood pulp is composed of hardwood fibre and we used unbleached (UBWP) and bleached (BWP) sulphate beech wood pulp (supplied from Bukoza Holding, a.s., Hencovce, Slovakia) in the experiment. Chemical analysis of unbleached and bleached wood pulp is in Table 1.

Table 1: Chemical analysis of wood pulps

Wood pulp	Toluene-ethanol extract (%)	Holocellulose (%)	Lignin (%)	Limiting viscosity number (g/ml)	Average degree of polymerization
UBWP	0.31	96.44	0.775	1343	1650
BWP	0.17	99.81	0.198	642	788

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. Content of

hollocellulose was determined by using the modified method according to Wisea. The content of acid-insoluble (Klason) lignin was carried out by two-step hydrolysis of polysaccharides portion in sulphuric acid. Limiting viscosity number was obtained by viscometric method in the solvent FeTNa. Average degree of polymerization – average length of cellulose chains is given by a share of the number-average molecular weight and the molecular weight of the monomer unit. Molecular weights were determined by using the method of gel permeation chromatography.
Table 2 shows dimensional and shape characteristics of wood pulps, which were measured by equipment L&W Fiber Tester (Lorentzen & Wettre, Sweden). The equipment allows measuring a portion of fine fibers, i.e. fibre shorter than 0.2 mm, a length and width of fiber, shape factor, coarseness of fibers, the number of vessels, local kinks of fibers and identifying the type of pulp (hardwood, softwood, mixed pulp) by the Blend module [6].

Table 2: Dimensional and shape characteristics of wood pulps

Fraction	Length of fiber (mm)		Width of fiber (μm)		Mean shape (%)	
	UBWP	BWP	UBWP	BWP	UBWP	BWC
0.2 – 0.5	0.166	0.175	24.0	23.8	91.55	90.5
0.5 – 1	0.563	0.559	21.4	20.9	91.4	89.4
1 – 2	0.267	0.261	21.8	21.3	89.5	86.4
2 – 3	0.006	0.005	22.8	23.3	72.3	70.8
3 -7.5	0.001	0.001	22.5	30.1	71.3	57.4
	Average dimensions				Average value	
	0.907	0.90	21.85	21.40	90.55	88.30

As a binder was used Portland cement CEM I 42.5 R. 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 area was 1.18 $m^2.g^{-1}$. Composition of the mixture is based on published study [7]. Table 3 shows the composition of experimental mixtures based on wood pulp. Mixtures of 1-3 were prepared using water and 8% solution of water glass was used instead water for preparation of mixtures 4-6. Bleached wood cellulose was used for preparation of mixtures 1-2 and 4-5.

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 proceeded under conditions required by standard. Physical (density, thermal conductivity, water absorption) and mechanical properties (compressive strength) were determined on hardened composites after 28 days of hardening.

Table 3: The composition of experimental mixtures with wood pulp

Mixture	Component content in experimental mixtures (wt.%)			
	Cement	Wood pulp	Water	Water glass
1	60	5	35	-
2	55	10	35	-
3	50	15	35	-
4	60	5	-	35
5	55	10	-	35
6	50	15	-	35

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2.2 Testing of selected properties of bodies

Density was determined in accordance with standard STN EN 12390-7 [8]. The thermal conductivity coefficient of samples, as the main parameter of heat transport was measured using the commercial device ISOMET 104 (Applied Precision, Germany). 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. Figure 1 shows measurement of thermal conductivity coefficient of sample.

Figure 1: Determination of thermal conductivity coefficient of sample

Compressive strength of composites was determined using the equipment ADR 2000 (ELE International Limited, United Kingdom) (Fig.2). Compressive strength of cube concrete specimens at particular ages under controlled conditions was determined as follows:

compressive strength = maximum load/(average cross – sectional area) (MPa) (1)

Figure 2: Experimental sample in equipment for determination of compressive strength

Water absorption was specified in accordance with the standard STN EN 12087/A1 [9].Testing of water absorption (after one hour) is based on determination of weight increase of tested samples during their full immersion in de-ionised water bath, which were stored for required time at a constant laboratory temperature. After one hour the specimens were taken out from water and all surface water was removed with a clean dry cloth. The specimens were reweighed and then from the measured value were calculated their water absorption according to the formula:

$$\text{water absorption} = (m_n - m_s)/m_s \cdot 100 \quad (2)$$

where: m_n - the weight of wet sample
m_s – the weight of dry sample

3 Results and Discussion

In Table 4, density, compressive strength, thermal conductivity coefficient and water absorption values of 28 days hardened composites with unbleached and bleached wood pulp are given.

Table 4: Results of experimental mixtures

Mixture	Density ($kg\ m^{-3}$)		Compressive strength (MPa)		Thermal conductivity coefficient ($W\ m^{-1}\ K^{-1}$)		Water absorption (%)	
	UBWP	BWP	UBWP	BWP	UBWP	BWP	UBWP	BWP
1	1260	1320	5.44	1.02	0.24	0.16	25.1	25.4
2	940	1260	1.42	1.41	0.13	0.10	42.5	30.6
3	1010	-	1.30	-	0.15	-	45.5	-
4	1130	1290	2.98	1.34	0.12	0.13	25.9	25.8
5	1010	1250	2.44	1.20	0.12	0.14	41.4	31.5
6	1080	-	2.00	-	0.13	-	47.9	-

3.1 Composites based on unbleached wood pulp (UBWP)

According to the measurements, values of density of composites based on unbleached wood pulp were in a range 940-1260 kg m^{-3} and compressive strength takes the values from 1.3 MPa to 5.44 MPa in dependence on the amount of wood pulp. The highest values of this parameter had the samples 1 (5.44 MPa) and 4 (2.98 MPa) containing only 5 wt. % wood pulp. On the other hand, composites containing 10 and 15 wt. % of unbleached wood pulp had the lower values of thermal conductivity coefficient and the higher values of water absorbability. Water uptake increased with increasing the volume ratio of wood pulp in composites prepared with water as well as solution of water glass (UBWP samples 1-6). This fact is found in accordance with the work [10] in which was reported dependence of absorbed water amount on the volume ratio of hemp fibre in composites based on unsaturated polyester matrix. Water absorbability is related to porous structure of composites that is determined by the micro gaps inside concrete matrix, the gaps and flaws at the interfaces between wood pulp and matrix, the hollow spaces in wood structure, the capillaries and spaces between bundles of fibrils and micro fibrils.

3.2 Composites based on bleached wood pulp (BWP)

Values of density of composites prepared with bleached wood pulp were in range 1250-1320 kgm^{-3}. A set of samples of these composites reached very similar values of compressive strength (1.02-1.41 MPa) but they are lower in comparison to values of composites with unbleached wood pulp. Measurements showed that values of thermal conductivity coefficient of experimental composites ranged from 0.097 to 0.16 $Wm^{-1}K^{-1}$. Whereas thermal conductivity coefficients of wood specimens prepared with water glass solution (samples 4 and 5) are almost the same, differences in the value of this parameter were recorded for wood composites samples 1 and 2. Lower values of water absorbability reached BWP composites compared with 10 wt. % of bleached wood pulp compared to UBWP composites where

absorbed water amount increased with increasing percentage of filler in composites. Good knowledge of the interaction between the fibre and the matrix and how the wood fiber-based material interacts with water; it will be the objective of our future research.

4 Conclusion

Our experiment was focused on using of unbleached and bleached wood pulp for preparing composites. The compressive strengths of composite after 28 days are relatively low. In terms of their use and comparison with analog materials (masonry bricks) it can be concluded that it is not appropriate to apply them as load bearing, but it is more efficient to use them as filler material. The value of thermal conductivity is also important to determine composite suitability for their building use. From the resulting values of thermal conductivity, it follows that composites have relatively good heat properties. Wood fiber content is the major factor affecting water absorption of composites. It enhances matrix porosity by creating more paths for penetration of water molecules into the matrix. Poor adhesion between fiber and matrix forms voids spaces around the fibers particles. Water immersed composites with higher volume ratio of wood pulp show decrease in compressive strength compared to dry specimens. Water absorption of wood fibres was reduced by bleaching what led to surface modification. Higher values of composites water absorbability are unfavorable for circuit elements (impact on frost-resistance). More research is required to understand the water interaction with wood fiber-based material as well as the effect of bleaching.

Acknowledgements

This research has been carried out within the project NFP 26220120018 supported by the European Union Structural funds.

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