Effect of selected cellulosic fibers on the properties of cement based composites

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Abstract

In this paper, the experimental work providing the testing of cement mixture containing two types of cellulosic fibers, namely fibers from bleached wood pulp and recycled waste paper fibers, is given. Fibers are described by selected characteristics such as length, density, and pH. They were applied as additive to the cement composite/plaster while they were dosed in different amounts: 0.2 %, 0.3 % and 0.5 % of the weight of both the filler and binder. Mixtures without fibers were prepared as reference samples. Density, water absorption, thermal conductivity, flexural and compressive strength were studied following by analyses of differences between resulting values. The observed differences in the physical, mechanical and thermal properties were found to be influenced by the properties (such as type, amount and other characteristics) of cellulosic fibers. Copyright © 2018 VBRI Press.

Keywords: Fiber cement composite, cellulosic fibers, wood pulp, waste paper, water absorption, thermal conductivity, flexural strength, compressive strength.

Introduction

At present, new building materials are developed using alternative raw materials of renewable character. Also, there is growing trend in development of building materials using recycled materials. Principles of sustainable construction brought in new construction requirements. There is observed a transition from application of non-renewable sources of raw materials to renewable ones. These renewable organic raw materials are based on plant fibers. This trend of application the organic raw materials is noted in every part of development of new building materials in the construction. Renewable organic raw materials save non-renewable sources that, when producing building mixtures, replace part of binder or part of filler[**1**].

Natural ligno/cellulosic fibers are a renewable resource and are widely available almost all over the world from wood, annual plants as well as cellulosic waste. Their implementation represents another large opportunity in the field of production of vegetable fibers cement-based materials. This is because of cellulosic fibers have several interesting advantages, particularly low density, bio-renewable character, wide availability, cost effectiveness, variety of morphologies, and above all they are environmental friendly. These characteristics make the natural fibers to be convenient materials for the application as matrix reinforcement (suitable for polymer composites as well as fibercement applications). Therefore, to promote the use of cementitious building materials reinforced with vegetable fibers could be a way to achieve a more sustainable construction [**2-4**].The addition of natural fibers in cementitious materials is widespread due to the benefits of enhancing properties of the resulting composite material. As fibers costs significantly less than conventional steel or glass fibers, the use of cellulosic fibers would present a more appealing alternative in non-bearing building materials [**5**].

The increase in industries based on agro-forestry products has accelerated the generation of wastes like wheat straw, coir, bagasse, rice straw and bamboo, banana, coconut, sisal and hemp hurds [**2,3,6-8**] as well as timber waste from demolition of old structures (buildings, railways and bridges) [**9**] and waste from papermaking processes or waste paper [**10,11**]. Cellulose, native material from different sources (plants, agricultural waste, and waste paper), is increasing in popularity due to its eco-friendly nature and favorable thermal and acoustic properties [**12**], ability to bridge the cracks in the matrix, transfer the loads into it to inhibit the development of micro-cracks in the composites [**6**]. The toughness and tensile behavior of cement composite can be improved by adding small volume fraction of short vegetable fibers (0.2 - 0.8 %) and the results of mechanical properties of fiber cement composites are presented to be satisfying [**3,13**]. On the other hand, these composite systems, vegetable fibers as reinforcement of cementitious matrices, present a tension softening behavior with low tensile ultimate strength, resulting in products which are more suitable for non-bearing applications [**14**].

The objective of present work is to evaluate the effect of two different cellulosic fibers, coming from wood pulp and recycled waste paper, on the physical, thermal as well as mechanical properties of fiber cement composites.

Experimental

Materials

Cellulosic fibers used in this experimental work have been obtained from the Greencel Ltd (Hencovce, Slovakia) company. Two types of cellulosic fibers like bleached wood pulp (GW-500) and unbleached recycled waste paper (G-3/00T) were used. Properties of cellulosic fibers Greencel are summarized in **Table 1**.

Table 1. Physical, chemical and thermal properties of cellulosic fibers Greencel.

Characteristics	Cellulosic fibers	
	GW-500	G-3/00T
Cellulose content [%]	99.5	80
Bulk density [kg/m^3]	60-80	30-50
Max. length [μm]	500	1200
Dry matter [%]	93	93
Ash [%]	0.5	20
Color	white	grey
Thermal conductivity λ [W/m.K]	0.0674	0.0595
Volume heat capacity x10^{-6} [J/m^{3}K]	0.1454	0.1709
Thermal diffusivity x10^6 [m^2/s]	0.4639	0.3478

Ordinary Portland cement type I 42.5 N obtained from Cement Factory Ltd. (Povazska cementaren Ladce, Slovakia) was used for the preparation of all the cement-based samples. Standard silica sand was acquired from company Filtracni pisky Ltd (Chlum, Czech Republic) in accordance with European standard STN EN 196-1[**15**]. Tap water for the cement mixtures preparation was used.

Preparation of specimens

The proportion of cement and sand was kept constant (1:3), as well as the water/cement ratio (w/c) was 0.55 for all samples. The amount of cellulosic fibers was varied and added in portion 0.2%; 0.3% to 0.5% from weight of cement and sand. The reference sample (RF) was prepared without the addition of cellulosic fibers.

Fiber cement samples with varying amount of cellulosic fibers were made in two steps:

a) fibers were soaked and manually mixed in approximately 50 wt. % of mixing water;
b) remaining water, cement and sand were added to the soaked fibers and following by mechanical stirring in a mixer in accordance with STN EN 196-1 [**15**] (to allow the homogenous distribution of fibers in cement matrix).

A steel molds were used to produce the samples with the dimensions of 40 mm x 40 mm x 160 mm. The samples were placed in the forming mold, compacted by a jolting apparatus and held in for 24 hours. Then, demolded specimens were cured in water for 27 days (laboratory condition + 20 °C). After the overall curing (28 days), the testing of physical and mechanical properties was performed. For testing the coefficient of thermal conductivity, the specimens with dimensions of 40 mm x 140 mm x 160 mm were prepared. Three samples were used to measure each property; presented results are then average values.

Methods of testing

The density of fiber cement composites after 28 days of curing was determined in accordance with European standard STN EN 1015-10 [**16**].

The coefficient of thermal conductivity was determined by using the commercial device ISOMET 2114 with surface probe at 28 days after production.

The water absorption behavior of fiber cement composites was determined over the time of 7, 28 and 90 days, based on the standard STN 73 1316 [**17**].

Mechanical properties(compressive strength and flexural strength) of prepared samples were measured by using a combined compression/three-point bending test machine (FORM+TEST Seidner&Co. GmbH, Riedlingen, Germany) in accordance with the specifications of STN EN 1015-11 [**18**]. Mechanical properties were measured after 28 and 90 days of hardening.

Results and discussion

Density and thermal conductivity

Fig. 1 and **Fig. 2** show the results of physical property (density), and thermal characteristic (coefficient of thermal conductivity), of fiber cement composites at 28 days of hardening. Densities of fiber cement specimens ranged from 2208 kg/m^3 to 2091 kg/m^3. The reference sample reached the density value 2244 kg/m^3.The maximal reduction in density (7 %) of fiber cement specimen was observed in the specimen containing G-3/00T 0.5% in comparison to reference sample.

The results (**Fig. 2**) show that the thermal conductivity of the tested composites significantly decreased by 3.4-19.9% and 18.7-34% of the reference cement specimen with increasing contain of wood pulp (GW-500) and recycled waste paper fibers (G-3/00T), respectively.

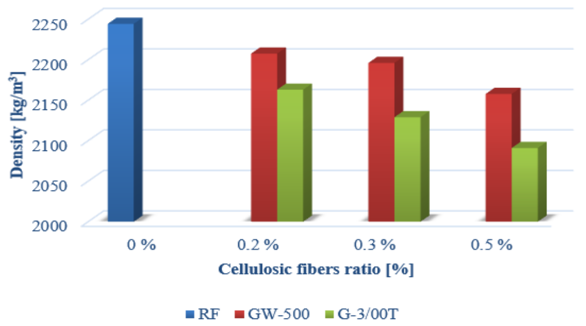

Fig.1. Results of density of cement composites based on cellulosic fibers at 28 days.

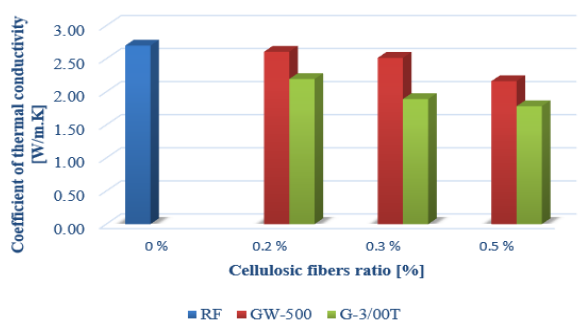

Fig. 2. Results of thermal conductivity of cement composites based on cellulosic fibers at 28 days.

It is apparent that the density and thermal conductivity of the cement composites reinforced with cellulosic wood pulp and recycled waste paper fiber decreased with increasing amount of cellulosic fiber. It seems that the reinforcement cellulosic fibers have a great effect on the density and thermal conductivity of cement composites, as also given in [**19**].

Water absorbability

The water absorption results of the fiber cement composites with using the wood pulp (GW-500) and recycled waste paper fibers (G-3/00T) at the age of 7, 28 and 90 days are presented in **Fig. 3**. It is evident that the water absorption of fibercement composites increased with higher amount of cellulose fibers in the mixture. Water absorption of fiber cement composites reached an increase from 3% to 26% compared to the reference sample (RF) without fibers over the time of 90 days. It can be assumed, that increase in fiber content increases the pores within the cement composite making the composite more porous with further addition. The drawback of the porous composite structure is that there is more available space for water molecules to occupy, as also presented in [**20**].

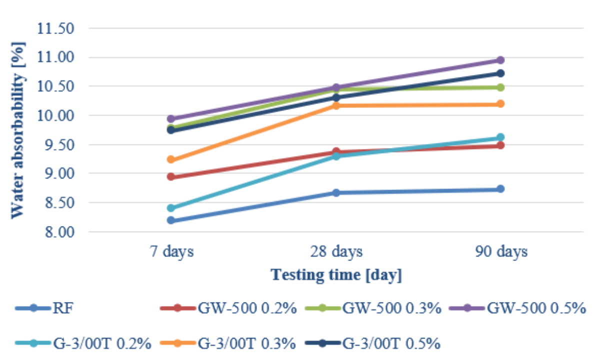

Fig. 3. Water absorbability of fiber cement composites after 7, 28 and 90 days of hardening.

Mechanical properties

Results of mechanical properties, including compressive and flexural strength, of the prepared fiber cement composites after 28 and 90 days of curing are shown in **Fig. 4** and **Fig. 5**. Increase in compressive strength over the time is clear, as it is typical for cement-based materials; the difference between 28 and 90 day values falls in range 1.7-18.1% for both sets of fiber cement composites. In the case of reference sample, this increase was 17.6%.From the results (**Fig. 4**), there is observed reduction in compressive strength for specimens with wood pulp and waste paper after 28 and 90 days compared to reference sample 13.4-15.0% and 21.1-32.8%; 21.2-26.5% and 20.8-35.5%, respectively. Reduction of compressive strength is caused by increasing amount of implemented cellulosic fibers in the mixture.

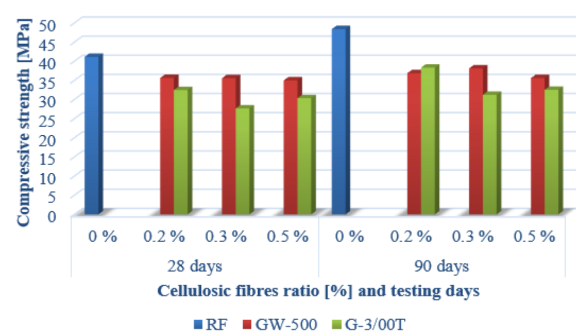

Fig. 4. Compressive strength of fiber cement composites after 28 and 90 days of hardening.

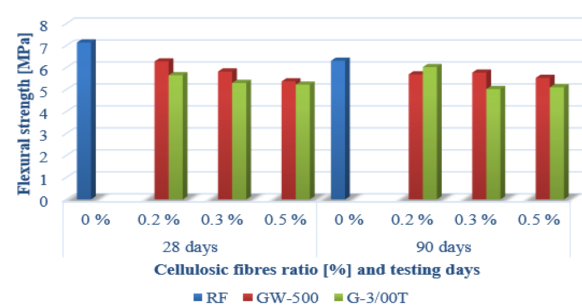

Fig. 5. Flexural strength of fiber cement composites after 28 and 90 days of hardening.

After the three-point bending test, the values of flexural strength have showed decrease in this parameter what was observed with increasing amount of cellulosic fibers in the samples comparing the reference sample after 28 and 90 testing days (**Fig. 5**). The flexural strength of wood pulp cement composites was slightly higher than that of recycled waste paper cement specimens. This trend was observed for both testing days (after 28 and 90 days).

The mechanical properties of fiber cement composites depend especially on the fiber content as well as on the quality of the load transfer between the matrix and the reinforcement. This fact is closely related to the strength of the interface and consequently to the quality of bonding between the matrix and the fibers [**21**].

Conclusion

This study evaluated the physical, thermal and mechanical properties of hardened cement composites with addition (0.2%; 0.3% and 0.5%) of cellulosic (wood pulp and recycled waste paper) fibers. Parameters of hardened fiber cement mixtures were analyzed comparing the reference sample, taking into account the type of fiber and their amount. Although increasing content of cellulose fibers in composites led to the increase of water absorption and to decrease of flexural and compressive strength, the expected target was achieved: positive effect on density and thermal conductivity. As for the type of fiber material, specimens containing wood pulp show better mechanical properties than samples with waste paper fibers. On the other hand, better (lower) thermal conductivity gives waste paper fibers. The obtained results are very useful for ongoing research. More investigations of these cellulosic cement based materials are needed for better understanding of properties, to optimize the way of their applicability for structural purposes.

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Author's contributions

Conceived the plan: NS, VH, VV; Performed the experiments: VH, TD; Data analysis: VH, NS; Wrote the paper: AS, VH, NS. Authors have no competing financial interests.

Supporting information

Supporting informations are available from VBRI Press.

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