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PROPERTIES OF COMPOSITES INCORPORATING CELLULOSIC FIBERS

Nowadays, with the understanding of the importance of the green building concept, there is a constantly increasing demand for ecological construction materials. The application of raw materials from renewable sources such as wood, plants and waste to building materials preparing has gained a significant interest in this research area. With the consideration of environmental consciousness, natural fibers are biodegradable so as they can alleviate the problem of massive solid waste produced and relief the pressure of landfills, they are used for replacing other non-degradable materials for product development.
In this experimental work, wood pulp and recycled waste paper fibers in addition 0.2%, 0.3% and 0.5% were used. The fiber cement composites were subjected to a characterization of their composition including the assessment of a complex set of basic physical and mechanical properties after 7 and 28 days of hardening. Experimental results show that application of small amount of cellulosic fibers lead to a reduction of density up to 6% when compared with the reference composite. However, cement composites based on wood pulp showed better mechanical properties such as compressive and flexural strength in comparison with cement composites with recycled waste paper fibers.

Keywords: cellulosic fibers, building material, fiber cement composite, density, mechanical properties

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1. Introduction

It is widely known that the rising carbon dioxide emissions level in the atmosphere is causing an increase of the global temperature of the earth that demands an urgent global response. In this sense, the atmospheric concentration of CO_2 has increased from a pre-industrial concentration of about 280 ppm to around 390 ppm at present. Approximately 50% of these emissions are produced by the building sector, during both the construction and the operational phase of buildings. The building sector is responsible for about 40% of the European Union total final energy consumption and 36% of its total CO_2 emissions. Innovations to improve the energy efficiency of buildings are thus of practical importance [1]. The field of environmental engineering has emerged to investigate ways of enhancing the ecological value of concrete structures in an effort to maximize their potential and reduce carbon footprint. The environmental footprint of concrete can be reduced by both ways. One is a partial replacement of traditional binder – Portland cement by alternative pozzolanic by-products [2] and waste materials [3], the second opportunity is to use natural fibers/aggregates as filler replacement. With respect of these ideas, the use of more environmentally friendly materials obtained from renewable sources with sustainable processes could be an interesting solution for the reduction of CO_2 emissions [4].

Renewable ligno/cellulosic raw materials are one of the most promising biodegradable polymers owning good mechanical properties and process ability. Natural fibers exhibit advantages such as low density, low cost, good thermal and acoustic insulation properties, easy processing, excellent strength and high specific modulus [5, 6]. Therefore, this fibrous material is widely used for processing so-called "green" or "eco" concretes [7].

Natural fibers such as sisal, jute, cotton, flax, hemp, kenaf, wood, agricultural waste and waste from papermaking process (waste paper) and so on, have already been considered as potential alternatives to traditional fibers (steel fiber, polymer fibers, glass fiber), given their environmental friendliness and ready availability in fibrous form and by the fact that they can be extracted from plant leaves at low cost [8, 9]. Natural fiber reinforced composites also offer other advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and biodegradability. Composites with natural fiber reinforcements are currently considered amongst the most promising structural materials in sustainable engineering technologies [10].

Many studies describing the use of cellulose-based fibers as a reinforcement for cement-based composites have been published [11–13]. Also recycled cellulosic fibers obtained from waste paper packaging [14], waste packaging boxes and papers [12, 15] were used in cement based composites.

The aim of the present research was to investigate the use of cellulosic fibers coming from two sources (wood pulp and recycled waste paper) in cement composites. Their physical (density) and mechanical properties (compressive and flexural strength) were tested after 7 and 28 days of hardening. Two types of cementitious composites were produced with various cellulosic fiber contents (0.2%, 0.3% and 0.5%) with the same w/c ratio of 0.55. For comparison there was prepared reference sample (without fibers).

2. Materials and methods

2.1. Materials

Ordinary Portland cement type I 42.5 N obtained from Cement Factory Ltd. (Povazska cementaren Ladce, Slovakia) was used in the preparation of all the cement-based samples. Standard silica sand as filler was acquired from company Filtracni pisky Ltd (Chlum, Czech Republic) in accordance with European standard STN EN 196-1 [16]. Two types of cellulosic fibers Greencel used in this experiment were supplied from company Greencel Ltd (Hencovce, Slovakia). The cellulosic fibers (Fig. 1) originating from different sources: bleached wood pulp and unbleached waste paper are different in the nature, morphology and dimensional characteristics. The physical and chemical properties of white wood pulp (GW-500) and grey waste paper fibers (G-500T) are presented in Table 1.

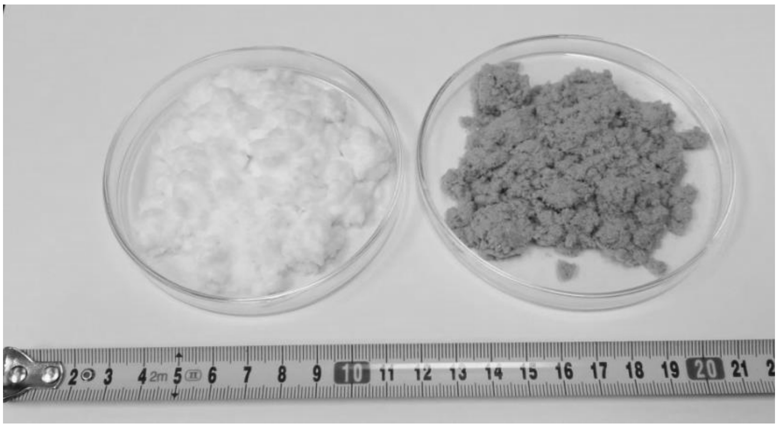

Fig. 1. Greencel cellulosic fibers from wood pulp (white GW500) and recycled waste paper (grey G-500T)

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

Cellulosic fiber	Cellulose content [%]	Bulk density [kg/m^3]	Max. length [µm]	Dry matter [%]	Ash [%]	Thermal conductivity [W/m.K]
GW-500	99.5	60–80	500	93	0.5	0.0674
G-500T	80	50–100	400	93	20	0.0634

2.2. Specimen preparation

Prepared cement mixtures contained 25% cement and 75% sand (cement/sand ratio of 3) at w/c ratio of 0.55. Tap water was used in preparation of mixtures in accordance with European standard STN EN 1008 [17]. The control sample was manufactured without addition of cellulosic fibers. The preparation of fiber-cement composite specimens was realized in two stages. At first, a given amount of cellulosic fibers (0.2; 0.3 and 0.5 wt.%) in the water (approximately 50 wt.% of water) was manually stirred to fiber soaking, followed with the addition of remaining water to suspension and next dispersing. Subsequently, cement and sand were added and continuous mixing by mixer to uniform fiber dispersion in the mixture proceeded. The prepared mixtures were then cast into standard prismatic steel molds (dimensions 40×40×160 mm), consolidating by a jolting apparatus and cured one day under laboratory conditions (+20°C). All samples were demolded after 24 hours and placed into water bath for up to 7/28 days. Each set of composite samples consisted of 3 prismatic bodies. Demolded fiber-cement composite samples were subjected to measurements of density and mechanical properties.

Densities of 7 and 28 days hardened fiber-cement composites were calculated in accordance with European standard STN EN 1015-10 [18]. Compressive strength and flexural strength of prepared cement samples reinforced with cellulosic fibers were measured by using a combined compression/three point bending test machines (FORM+TEST Seidner & Co. GmbH, Riedlingen, Germany) in accordance with the specifications of STN EN 1015-11 [19].

3. Results and discussion

3.1. Density of fiber cement composites

As shown in Fig. 2, changes in densities of 7 and 28 days hardened cement composites reinforced with varying amount (0.2; 0.3 and 0.5 wt.%) of cellulosic fibers obtained from wood pulp and waste paper fibers are observed. Densities of tested composites with cellulosic fibers in the matrix after 7 and 28 days hardening ranged from 2229 to 2105 kg/m^3. The increasing amount of cellulosic fibers in the hardened composites led to their lower densities about 6% when compared to reference composites. This is caused by incorporation of lightweight cellulosic fibers into the cement matrix and due to this fact density of fiber cement composite decreases in accordance with the results in paper [20]. The density values of composites based on cellulosic fibers from bleached wood pulp (GW-500) are slightly higher than values of composites with fibers from recycled paper (G-500T).

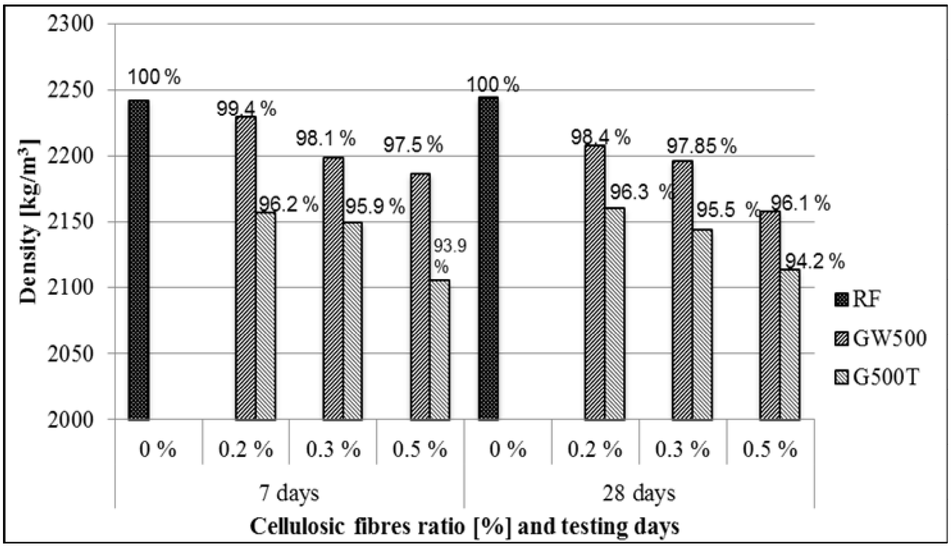

Fig. 2. Density of 7 and 28 days hardened fiber-cement composites with cellulosic fibers adding compared to reference composite RF (data in percentages above the columns indicate the ratio of the densities of fiber composites and reference composite)

3.2. Mechanical properties of fiber cement composites

The mechanical properties of cement composites reinforced with cellulosic fibers were analyzed by testing the compressive and flexural strength with three-point bending. As it can be seen in Figs. 3, 4, the cellulosic fibers addition to the matrix leads to gradual decrease in compressive and flexural strength values of 7 and 28 days cured cement composites with increasing fiber amount. However, strength values of all fibers cement based composites are lower when compared with strength parameters attributed to the reference samples. As concluded in [21, 22], adding cellulosic fibers to concrete resulted in similar behavior of fiber reinforced cement composites. This decrease in compressive and flexural strength of cellulosic fiber reinforced cement composite is probably caused by formed air voids due to the incorporation of fibers in cement matrix resulting in a reduction of bond strength between fibers and of the matrix particles, leading overall reduction in strength [23]. Composites containing cellulosic fibers from wood pulp reached higher strength values by 6–10% in comparison to cement composites reinforced with waste paper fibers. Compressive strength value of 28 days hardened concrete sample with 0.5% wood pulp (GW-500) addition was reduced by 15%, whereas the decrease in strength parameter of composite reinforced with fibers from recycled paper was even lower 26%.

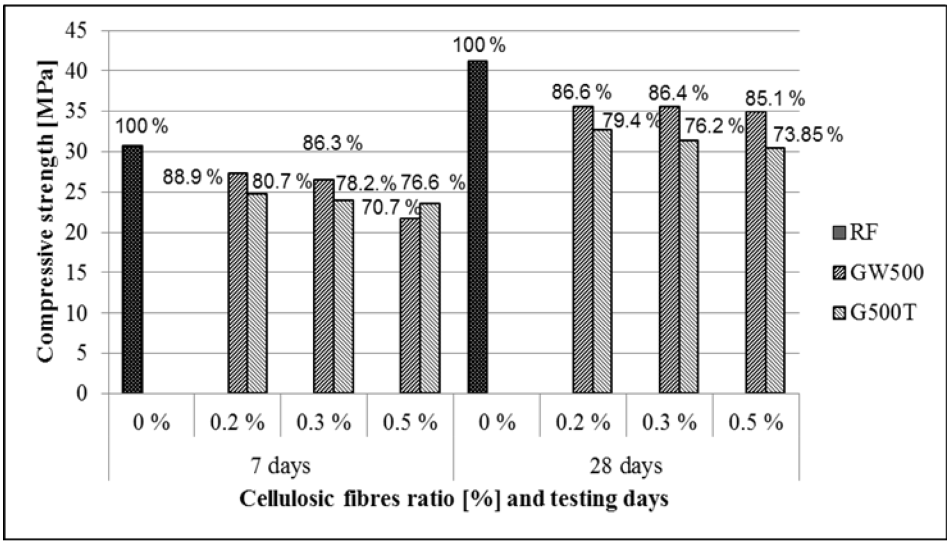

Fig. 3. Effect of Greencel cellulosic fibers adding on compressive strength of 7 and 28 days hardened fiber cement composites in comparison to reference composite RF (data in percentages above the columns indicate the ratio of the compressive strengths of fiber composites and reference composite)

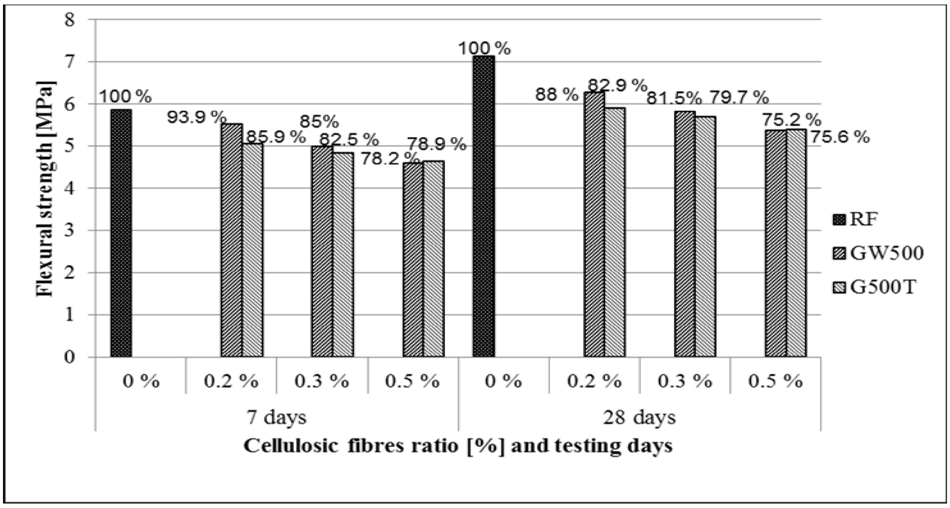

Fig. 4. Effect of Greencel cellulosic fibers adding on flexural strength of 7 and 28 days hardened fiber cement composites in comparison to reference sample (RF) (data in percentages above the columns indicate the ratio of the flexural strengths of fiber composites and reference composite)

As shown in Fig. 5, linear relationship between compressive strength and density of fiber cement composites after 28 days of hardening is observed.

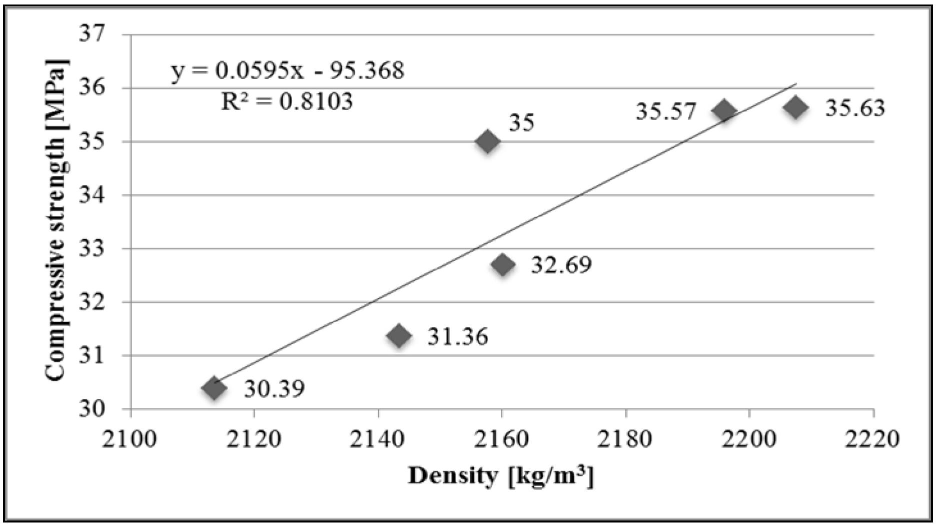

Fig. 5. Dependence of the compressive strength on density of fiber cement specimens after 28 days of curing

4. Conclusion

Changes in the density and compressive and flexural strength of 7 and 28 days hardened cement composites based on cellulosic fibers coming from wood pulp and recycled waste paper in dependence on their increasing portion (0.2%; 0.3% and 0.5%) were demonstrated. The results of comparing study of these parameters of the hardened fibers cement composites with reference sample indicated decrease in their values with increasing percentage of cellulosic fibers. However, cement composites with wood pulp showed better mechanical properties in comparison to composites with waste paper fibers. These changes can be connected with higher porosity, type of cellulosic fibers and their physico-chemical properties. Dependence of compressive strength on density of fiber cement composites is indicated.

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