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Cellulose Fibres as a Reinforcing Element in Building Materials

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Abstract. Nowadays, construction sector is focusing in developing sustainable, green and eco-friendly building materials. Natural fibre is growingly being used in composite materials. This paper provides utilization of cellulose fibres as reinforcing agent into cement composites/plasters. Provided cellulosic fibres coming from various sources as bleached wood pulp and recycled waste paper fibres. Differences between cellulosic fibres are given by their physical characterization, chemical composition and SEM micrographs. Physical and mechanical properties of fibre-cement composites with fibre contents 0.2; 0.3and 0.5% by weight of filler and binder were investigated. Reference sample without fibres was also produced. The aim of this work is to investigate the effects of cellulose fibres on the final properties (density, water absorbability, coefficient of thermal conductivity and compressive strength) of the fibre-cement plasters after 28 days of hardening. Testing of plasters with varying amount of cellulose fibres (0.2, 0.3 and 0.5 wt. %) has shown that the resulting physical and mechanical properties depend on the amount, the nature and structure of the used fibres. Linear dependences of compressive strength and thermal conductivity on density for plasters with cellulosic fibres adding were observed.

Keywords: fibre-cement composite, cellulose fibres, waste paper fibres, physico-mechanical properties.

Conference topic: Sustainable urban development.

Introduction

Nowadays, there is an increasing demand for a development of environmentally friendly and energy-efficient building materials which used natural sources of fibres into organic or inorganic matrices; thus ligno/cellulosic fibres have been widely used as an alternative material for steel or synthetic fibres as reinforcements within cementitious composites (Yan *et al.* 2016). Fibres can be represented as primary or secondary reinforcement. Fibres work as primary reinforcement in thin-sheet products in which conventional reinforcing bars cannot be used and they are used as primary reinforcement to increase both the strength and toughness of the composite. Fibres are also incorporated in the matrix as the secondary reinforcement to control cracking induced by humidity or temperature variations or to provide post-failure integrity in the event of an accidental overload or spalling (Ozerkan *et al.* 2013). In nature, there is a wide range of natural fibres which can be distinguished by their origin (Célino *et al.* 2013). Fibres coming from flax, sisal, jute, hemp hurds, coir, eucalyptus pulp, pineapple leaf, kenafbast, abaca leaf, bamboo, banana, palm, sugarcane fibres (Cigasova *et al.* 2014), wood and wood waste from wood production and waste from papermaking process (Bentchikou *et al.* 2012), etc. belong to group of cellulosic fibres. Fibres from these natural sources are obtained from different parts of plants such as stem, leaf, seed, bast and wood (Yan *et al.* 2016; Ozerkan *et al.* 2013). Usually, vegetable fibres have been used as reinforcement of cementitious matrices in the form of pulp or short filaments (Ramakrishna, Sundararajan 2005; de Andrade Silva *et al.* 2010). The utilization of vegetable fibres, wood pulp and waste paper fibres as a renewable source have many advantages over most synthetic fibres such as low density, low cost, availability, renewability and biodegradability and cement composites reinforced with these fibres exhibit improved toughness, ductility, flexural capacity, and crack resistance as compared to non-fiber reinforced cement-based materials (Xie *et al.* 2015; Mohr *et al.* 2004; Sangrutsamee *et al.* 2012). Therefore, a combination of interesting mechanical and physical properties of cellulosic fibres and their environmental benefits has been the main driver for their use as alternative materials for conventional reinforcements (Ardanuy *et al.* 2015). Moreover, the addition of cellulosic fibres can reduce free plastic shrinkage (de Andrade Silva *et al.* 2010) and thermal conductivity (Bentchikou *et al.* 2012) of cementitious materials. The utilization of natural fibres in insulation is closely connected to the ecological construction, where choice of materials is based on factors including recyclable, renewable raw materials and low resource production techniques. Moreover, cellulosic fibres as insulation have a higher moisture regain than inorganic materials from environment/interior where are built (Kymäläinen, Sjöberg 2008) and such composite material can offer better comfort inside buildings (Bentchikou *et al.* 2012). Thus, research of composite for building or mortar for plastering, using natural fibres is an attractive option which would solve simultaneously energy and environmental concerns by paying attention to thermal conductivity which is a measure of thermal insulating efficiency of the material based on cellulose fibres (lower value of λ) (Bentchikou *et al.* 2012). Applications of natural fibre cement composites are basically addressed to the non-structural building of thin walled materials, mainly thin-sheet products for partitions, building envelope or ceiling flat sheets, roofing tiles, premanufactured components and mortars for plastering in general (Roma *et al.* 2008).

The aim of present study is to investigate the utilisation of cellulosic fibres from wood pulp and waste paper as reinforcing element with insulating properties into cement composites/mortars for plastering. The density, coefficient of thermal conductivity and compressive strength of cement composites reinforced with various content of cellulosic fibres (0.2; 0.3 and 0.5 wt. %) were investigated after 28 days of hardening. Water absorbability of the same specimens was evaluated after 1, 7, 14 and 28 days of hardening.

Materials and methods

Materials

The cement used in this experiment was an ordinary Portland cement CEM 42.5 N (Cement factory Ladce, Slovakia). Filler, standard silica sand, was obtained from company Filtracnipisky Ltd (Chlum, Czech Republic) in accordance with European standard STN EN 196-1. The two types of cellulosic fibres (Fig. 1) used in this study were bleached wood pulp (W640) and unbleached recycled fibres (G-3/00T) from different waste papers. Cellulosic fibres were provided by company Greencel Ltd (Hencovce, Slovakia). Table 1 shows characteristics of both types of cellulosic fibres. Tap water was used.

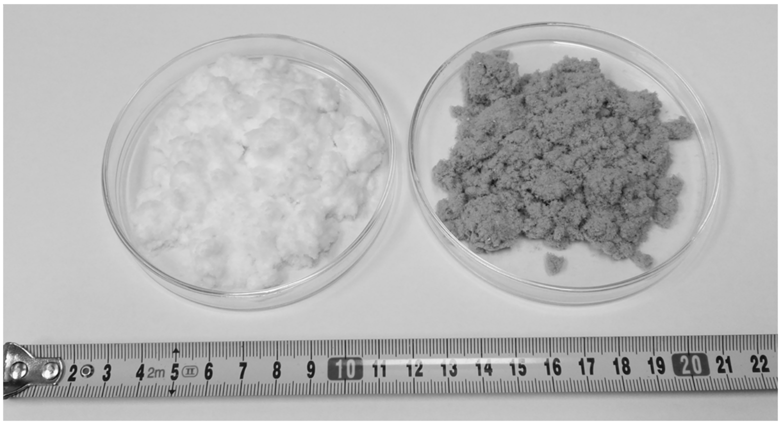

Fig. 1. Cellulosic fibresGreencel from wood pulp W640 (white) and waste paper G-3/00T (grey)

Table 1. Physical and chemical characteristics of cellulosic fibres (Greencel)

Characteristics of cellulosic fibres	Type of cellulosic fibres	
	W640	G-3/00T
Cellulose content [%]	99.5	80
Bulk density [kg/m^3]	35–45	30–50
Max. length [µm]	1000	1200
Dry matter [%]	93	93
Ash [%]	0.5	20
Colour	white	grey

Preparation of cellulosic fibres reinforced cement composites/plasters

The fibre cement composites/plasters were prepared using Portland cement, silica sand and water. Cellulosic fibres from wood pulp and waste paper were used as reinforcing agent in addition 0.2; 0.3 and 0.5 wt.% from weight of filler and binder. The mix proportion of cement specimens were designed with Cement/Sand (C/S) weight ratio of 1:3 and Water/Cement (W/C) ratio of 0.55. Reference cement plaster was manufactured without using of cellulosic fibres to results comparison of fibre cement plasters. Each group of three test specimens consists of 450 ± 2 g of cement, 1350 ± 5 g of sand and 250 ± 1 g of water.

Fibre cement composites with varying amount of cellulosic fibres were made in the first by fibres soaking and manual mixing in approximately 50 wt % of water. After that, remaining part of water, cement and sand were added to the soaked fibres and continued by mechanical stirring in a mixer in accordance with European standard STN EN 196-1 to allow the homogenous distribution of fibre in cement plaster. Fibre cement composite prisms were moulded to steel moulds in the dimension of 40 mm x 40 mm x 160 mm. The fibre cement plasters were placed in the forming mould, compacted and held in for 24 hour. Then de-moulded fibre cement specimens were further cured in water for 27 days (laboratory condition + 20 °C). After curing (28 days) the specimens were used for physical and mechanical testing. For testing coefficient of thermal conductivity was manufactured fibre cement specimens with dimension of 40 mm x 140 mm x 160 mm. Three replicates were taken for each type of fibre cement composites.

Method of investigation of cellulosic fibres

Scanning electron microscope (SEM) (TESCAN MIRA 3 FE, Brno, Czech Republic) with Schottky emitter for high-resolution was used to capture and observe the changes in morphology of cellulosic fibres (Greencel) which come from wood pulp (W640) and waste recycled paper (G-3/00T).

Fibre samples were glued on carbon adhesive films and coating with a gold film. The samples were coated with the gold film to avoid charging under the electron beam.

Methods of physical and mechanical testing of fibre cement composites/plasters

The density of fibre cement composites after 28 days of curing was determined in accordance with European standard STN EN 1015-10. The next physical property, water absorption of cement composites reinforced with cellulosic fibres was evaluated after 1, 7, 14, 28 days of hardening in compliance with standard STN 73 1316.The coefficient of thermal conductivity was determined by using the commercial device ISOMET 2114 with surface probeat 28 days after production. Fig. 2 shows determination of thermal conductivity coefficient of cement plaster reinforced with cellulosic fibres.

The measurements of mechanical property, compressive strength of fibre cement plasters with different type of cellulosic fibres and amount in mixture were carried out by compression testing machine (FORM+TEST Seidner&Co. GmbH, Riedlingen, Germany) with using a loading rate 2400 ± 200 N/s in compliance with European standard STN EN 1015-11. The fibre cement prisms were tested after 28 days of hardening.

The mean values of density, water absorbability, coefficient of thermal conductivity and compressive strength of each specimen were calculated as the average of the three measured values.

Fig. 2. Measurement of thermal conductivity coefficient of cement plaster reinforced with cellulosic fibres

Discussion

Morphological analysis of cellulosic fibres by Scaning Electron Microscopy

The morphology of both cellulosic fibres was studied by SEManalysis. Fig. 3a, Fig. 3b show SEM micrographs of the surfaces of cellulosic fibres from bleached wood pulp (W640) and unbleached recycled waste paper fibres (G-3/00T) at magnification 1500 times, respectively. As it can be seen in Fig. 3a, Fig. 3b, there are differences on the surfaces obtained from both fibres. They are slightly roughened and it can improve their adhesion ability with matrix (Sawsen *et al.* 2015). The bleached wood pulp fibre surface appears quite smooth and homogenenous. This SEM image presents clear fibrous structure. However, the surface of recycled paper fibre is quite sufficiently covered by impurities and shows less homogenenous fibrous material (Silva *et al.* 2008). The presence of impurities is caused byrepulped waste paper (ink, different resources of waste paper and filler in paper making) (Hospodarova *et al.* 2016).

a) b)

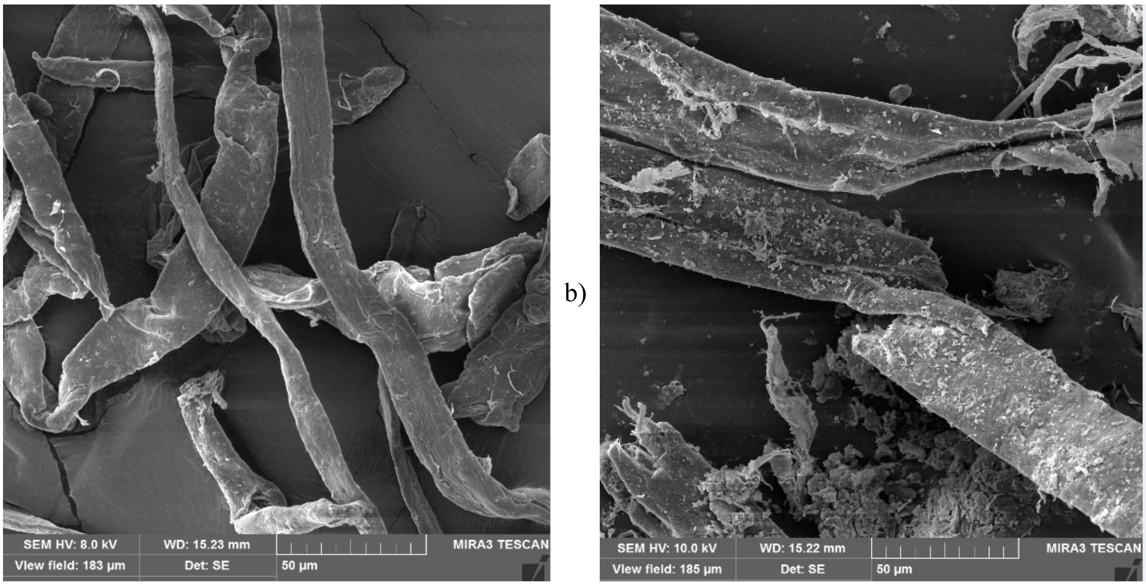

Fig. 3. SEM image of a) wood pulp fibres W640 at magnification 1500 times and b) recycled waste paper fibres G-3/00T at magnification 1500 times

Density and compressive strength

Results of density and compressive strength of tested fibre cement plasters with 0.2; 0.3 and 0.5 wt. % cellulosic fibres content are presented in Table 2. As it can be seen, the fibre addition to plasters mixture caused decrease in density and compressive strength values in comparison with the reference sample. Due to lower fibre addition the density decrease is not very significant; it ranges from 1.9 % to 8.4 %. However, the specimens with 0.5 % fibre addition reached the lowest values of density. Reduction of density is also caused by fibre incorporating air into the matrix during the plaster mixing. This occurrence becomes more significant in the case of using high percentages of fibres (Pereira-de-Oliveira *et al.* 2012).

Table 2. Results of density and compressive strength of hardened fibre cement composites

Fibre cement samples	Density [kg/m^3]	Compressive strength[MPa]
RF	2244 ±7	41.2 ± 1.1
W640 0.2%	2201 ± 4	35.6 ± 0.4
W640 0.3%	2170 ±9	34.3 ± 1.6
W640 0.5%	2056 ± 9	17.2 ± 0.4
G-3/00T 0.2%	2163 ±4	32.5 ± 0.8
G-3/00T 0.3%	2129 ±10	27.7 ± 0.6
G-3/00T 0.5%	2091 ± 8	30.3 ± 0.8

The compressive strength of the reinforced fibre cement composites decreased with increasing fibre content. The corresponding reduction in the compressive strength values of composites with wood pulp W640is in the range 13.6% – 58.2% of the control sample while decrease in strength parameter of composite based on waste paper fibres G-3/00T has been between values of 21.1–32.8% compared to control sample. Decreasing compressive strength caused by addition of cellulosic fibres represents poor interfacial bonding between fibre and matrix. According to paper (Venkateshwaran *et al.* 2011), mechanical properties are influenced by type of fibre, fibre length and weight percentage.

As it can be seen in Fig. 4, a close correlation was found between experimentally determined parameters of the compressive strength and density of cement composites reinforced with wood pulp and waste paper fibres after 28 days of hardening. The value of calculated correlation coefficient 0.7825 is higher than the critical value of the correlation coefficient (0.7545) for a set of measured values at elected significance level p = 0.05.

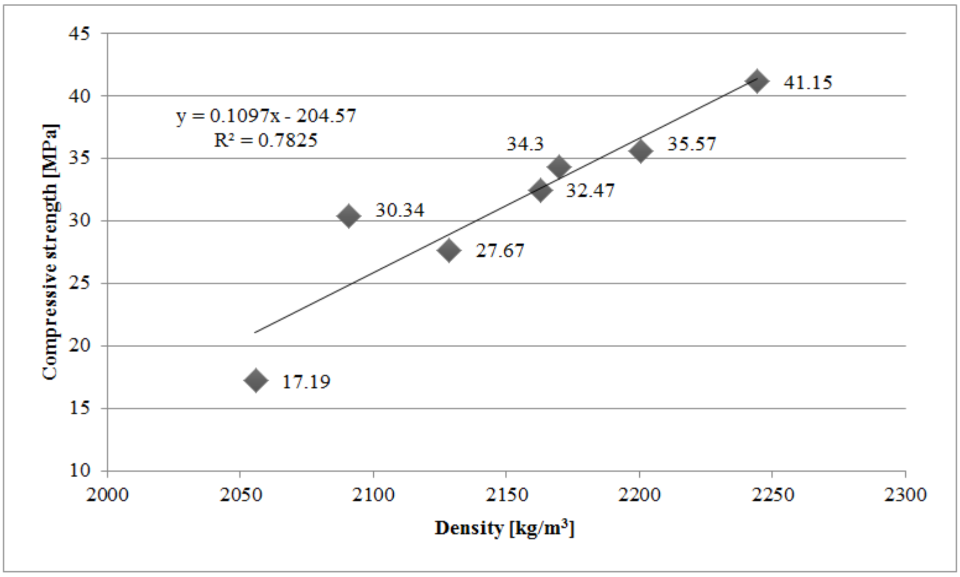

Fig. 4. Relationship between compressive strength and density of fibre cement composites after 28 days of curing

Water absorbability

Water absorbability of cement composites reinforced with cellulosic fibres is represented in Fig. 5. Development of water absorbability of fibre cement plasters was studied in time 1, 7, 14 and 28 days. Water absorbability is increasing in duration progress. As it can be seen from the results, the water absorbability of both mixes has similar increasing character. Maximal water absorbability reached samples W640 0.5 % and G-3/00T 0.5 % and their increase is about 19% in comparison with reference sample (RF 8.66%), respectively. In fact, specimens with lowerdensity have more void spaces than the density of composite without fibre content; so that more water can be absorbed (Konin 2012). Next point, increasing of water absorbability also may be caused by rising of fibre amount in cement matrix because cellulosic fibres have hydrophilic character.

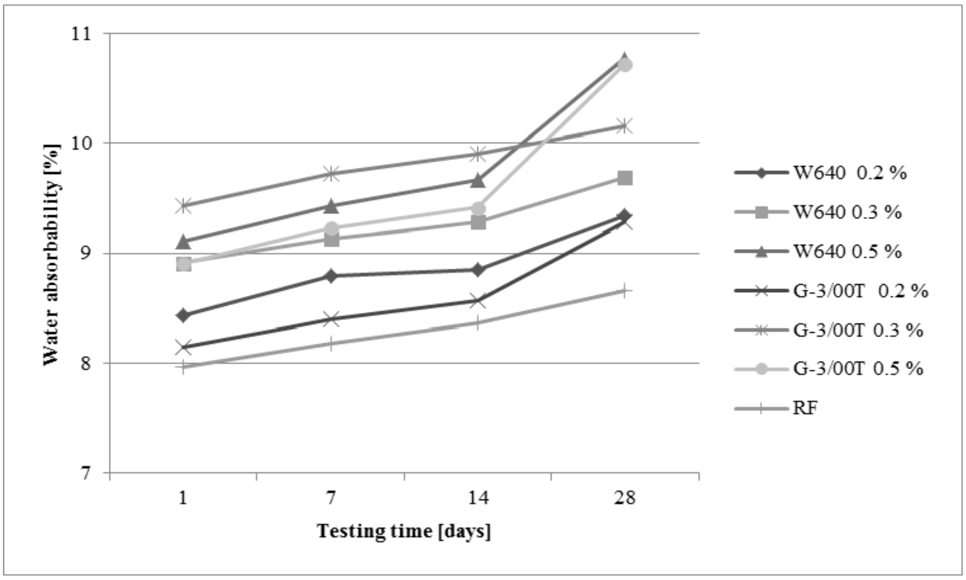

Fig. 5. Development of water absorbability of fibre cement composites in time

Thermal conductivity

The coefficient of thermal conductivity characterises the ability of materials to conduct heat energy (Bentchikou *et al.* 2012). Values of the thermal conductivity of composites depicted in Fig. 6 showed that with increasing content of cellulosic fibres in the matrix of tested fibre cement composites decreases their thermal conductivity. This decrease is in range 16–34% in comparison with the reference sample (RF; without cellulosic fibres in the matrix). The composite with 0.5% wt. cellulosic fibres from waste paper fibres (G-3/00T 0.5%) has good insulating property because the resulting thermal conductivity is lower than the thermal conductivity of reference sample (λ = 2.6988 W/mK). The similar behaviour was observed on the composites based on recycled waste paper and packaging (Bentchikou *et al.* 2012) and waste originating from young coconut and durian (Khedari *et al.* 2001). Dependence of the thermal conductivity coefficient on density of studied plasters is shown in Fig. 7. The correlation coefficient value of this dependence confirms the linear relationship between studied parameters of hardened specimens.The lighter samples in densities have lower coefficients of thermal conductivity. Similar results are also described in the work (Bentchikou *et al.* 2012).

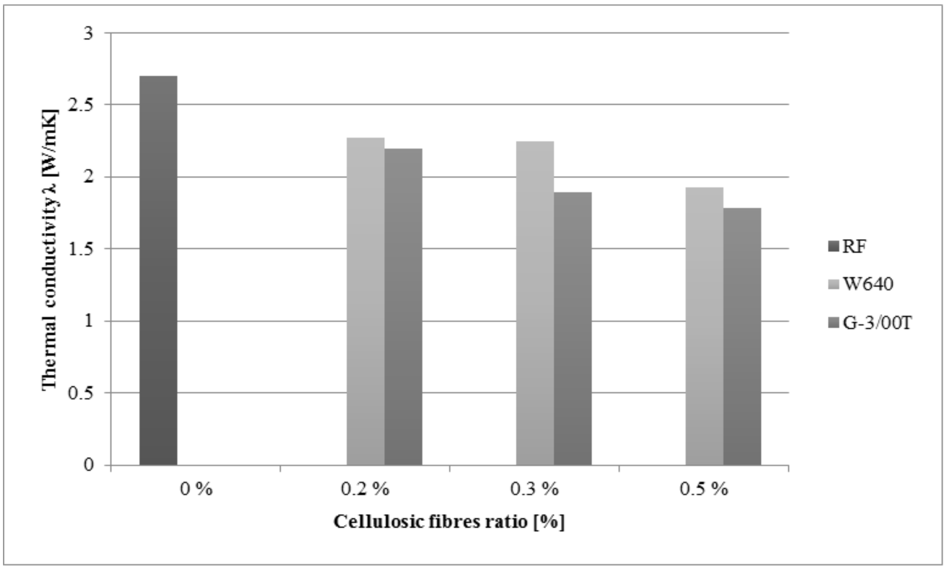

Fig. 6. Dependence of thermal conductivity on cellulosic fibre content

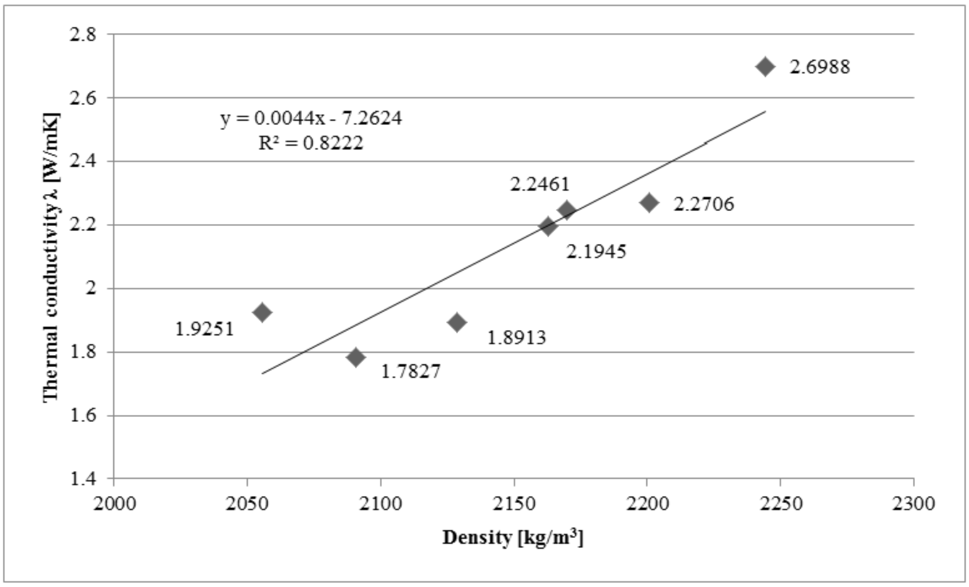

Fig. 7. The relationship between the thermal conductivity coefficient and density after 28 days of curing

Conclusions

In this experimental study, cellulosic wood pulp and recycled waste paper fibres were used to manufacturing fibre cement composites/plasters. Influence of cellulosic fibres amount on resulting physical and mechanical properties of studied plasters based on cellulosic fibres was investigated. Increasing addition of both types of cellulosic fibre to cement composites leads to reduction in density, compressive strength and thermal conductivity; however, water absorbability of the same plasters increased. The variation in the physical and mechanical properties of fibre cement plasters depends on structural, physical characteristcs of cellulosic fibres, nature and their processing. Linear dependences of compressive strength and thermal conductivity on density for plasters with cellulosic fibres adding were observed.

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Disclosure statement

Authors declare that they have not any competing financial, professional, or personal interests from other parties.

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