Influence of Cellulosic Fibres on the Physical Properties of Fibre Cement Composites

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Abstract. Nowadays, there are new approaches directing to processing of non-conventional fibre-cement composites for application in the housing construction. Vegetable cellulosic fibres coming from natural resources used as reinforcement in cost-effective and environmental friendly building products are in the spotlight. The applying of natural fibres in cement based composites is narrowly linked to the ecological building sector, where a choice of materials is based on components including recyclable, renewable raw materials and low-resource manufacture techniques. In this paper, two types of cellulosic fibres coming from wood pulp and recycled waste paper with 0.2%; 0.3% and 0.5% of fibre addition into cement mixtures were used. Differences in the physical characteristics (flowability, density, coefficient of thermal conductivity and water absorbability) of 28 days hardened fibre-cement composites are investigated. Addition of cellulosic fibres to cement mixture caused worsening the workability of fresh mixture as well as absorbability of hardened composites due to hydrophilic nature of biomaterial, whereas density and thermal conductivity of manufactured cement based fibre plaster are enhanced. The physical properties of cement plasters based on cellulosic fibres depend on structural, physical characteristics of cellulosic fibres, their nature and processing.

1. Introduction

Building materials are commonly used even though they are highly polluting due to their CO₂ manufacturing emission and their disposal environmental issues. Therefore, in the search of sustainable building construction, attention turns to natural materials which offer several advantages, such as availability, recyclability, low cost, environmentally friendly, no toxicity, no abrasion, biodegradability, interesting physical and mechanical properties such as low density, well-balanced stiffness, toughness and strength and good thermo-mechanical performance [1,2].

Natural/lignocellulosic materials are acquired from wood, natural plants, agricultural waste, and paper-making industry and from various human activities [3]. The cellulosic fibres are manufactured in large quantities, different morphologies and sizes obtained from natural renewable sources [4].

The utilisation of natural fibres as alternatives for conventional reinforcements is in the aforementioned combination of attractive physical, mechanical properties and environmental benefits which are provided by natural fibres [2]. Natural fibres as a reinforcing agent in cement matrix are nowadays being considered as an effective alternative to steel and other inorganic synthetic fibres [5].
There are three major groups of factors which influence on physical and mechanical properties of cement composites reinforced with natural fibres. The first group is kind and characteristics of used cellulotic fibres. The second and the third group of factors are important as well and belong to nature of cement base matrix, mix design and the process of manufacturing of fibre cement composites (way of mixing, casting, curing of the composites) [6].

Fibres of agricultural raw materials constitute an important class of biomaterial with their usage in sustainable constructions. Many wood product standards make mention of alternative sources of lignocellulosic fibres, which constitute the primary sources of useful lignocellulosic fibres in biomass. Fibres of agricultural materials and their particles are in many ways similar to wood fibres and particles. Their specific characteristics depend on species and degree of processing [7].

There are many studies aimed at cellulotic fibres utilizing and describing the properties of composites based on this biomaterial. In the study [5], the authors investigated the effect of jute fibre as a reinforcing agent to cement mortar and influence of jute fibre on physical and mechanical properties. In another work [8], hemp hurds as cellulotic material was used after chemical and physical treatment in preparation of lightweight composites and its impact on physico-mechanical properties was monitored. In many papers, the behaviour of cement composites with agricultural by-products or waste based on ligno/cellulosic nature fibres/aggregates from sisal [9], hemp hurds [10], flax [11] and wood pulp and waste paper [12, 13] is described.

The aim of present study is to investigate the influence of two different types of cellulotic fibres (wood pulp and waste paper fibres) in various portions (0.2%; 0.3% and 0.5%) on the physical properties of fresh and hardened cement composites/plasters reinforced with fibres. Flowability, density, thermal conductivity and water absorbability were studied and compared to properties of cement plaster which contain no fibres.

2. Materials and methods

2.1. Materials

For this study, as the binding agent was used ordinary Portland cement type CEM I 42.5 N and obtained from Cement Factory Ltd. (Povazska cementaren Ladce, Slovakia). This cement is composed of a silica-calcium mixture comprising Al₂O₃, Fe₂O₃, and MgO with the addition of finely milled natural gypsum.

Cement mixtures with 0.2%, 0.3% and 0.5% addition of cellulotic fibres were manufactured using standard silica sand supplied by company Filtraci pisky Ltd (Chlum, Czech Republic) in accordance with European standard STN EN 196-1 [14].

Table 1. Properties of wood pulp and waste paper fibres Greencel.

| Characteristics of cellulotic fibres | Type of cellulotic fibres |
|-------------------------------------|--------------------------|
|                                     | GW-500 | W 640 | G-700T | G-3/00T |
| Cellulose content [%]               | 99.5   | 99.5  | 80     | 80      |
| Bulk density [kg/m³]                | 60-80  | 35-45 | 40-70  | 30-50   |
| Max. length [µm]                   | 500    | 1000  | 600    | 1200    |
| Dry matter [%]                     | 93     | 93    | 93     | 93      |
| Ash [%]                            | 0.5    | 0.5   | 20     | 20      |
| Colour                             | white  | white | grey   | grey    |
| Thermal conductivity [W/m.K]       | 0.0674 | 0.0644| 0.0599 | 0.0595  |
| Volume heat capacity×10⁴ [J/m³.K]  | 0.1454 | 0.1472| 0.1785 | 0.1709  |
| Thermal diffusivity×10⁶ [m²/s]     | 0.4639 | 0.4377| 0.3354 | 0.3478  |
The cellulosic fibres of different sources such as bleached wood pulp (GW-500 and W 640) and unbleached waste paper (G-700T and G-3/00T) were used. The natural cellulosic fibres were provided by company Greencel Ltd (Hencovce, Slovakia). Provided four types of above-mentioned cellulosic fibres were used to manufacture fibre cement plasters. The heat characteristics of cellulosic fibres such as thermal conductivity, volume heat capacity and thermal diffusivity were measured by commercial device ISOMET 2114 with noodle probe. Properties of cellulosic fibres Greencel are summarised in table 1.

Water for the cement mixtures preparation was used in accordance with standard STN EN 1008 [15].

2.2. Preparation of cellulosic fibres reinforced cement plasters

The cement plaster was prepared following the composition which is shown in table 2. Thirteen different formulations were used for the preparation of the plaster samples. In the mix design the weight fraction of cement: sand: water was kept 1:3:0.55. However cellulosic fibres were added in portion 0.2%, 0.3% and 0.5% from weight of cement and sand. Preparation of specimens started with soaking of cellulosic fibres and manual mixing in approximately 50 wt % of water. Remaining water, the required amount of sand and the cement was mixed by mechanical stirring in a mixer in accordance with European standard STN EN 196-1 [14] (to allow the homogenous distribution of fibre in cement plaster). The fresh fibre cement plaster was mould to standard steel prism in the dimension of 40x40x160 mm and for testing coefficient of thermal conductivity was used steel mould with dimension of 40x140x160 mm and consolidating by a jolting apparatus. After 24 h, specimens were demoulded and cured for 28 days in water bath under laboratory conditions + 20 °C. Three replicates were taken for each type of fibre cement composites.

Table 2. Compositions of fibre cement plasters and their marks.

| Type of cellulosic fibre | Mark of composite | Weight ratio of cement : sand | Cellulose fibre content, wt.% |
|-------------------------|-------------------|------------------------------|-------------------------------|
| GW-500                  | WPA 0.2           | 1:3                          | 0.2                           |
|                         | WPA 0.3           | 1:3                          | 0.3                           |
|                         | WPA 0.5           | 1:3                          | 0.5                           |
| W 640                   | WPB 0.2           | 1:3                          | 0.2                           |
|                         | WPB 0.3           | 1:3                          | 0.3                           |
|                         | WPB 0.5           | 1:3                          | 0.5                           |
| G-700T                  | RPA 0.2           | 1:3                          | 0.2                           |
|                         | RPA 0.3           | 1:3                          | 0.3                           |
|                         | RPA 0.5           | 1:3                          | 0.5                           |
| G-3/00T                 | RPB 0.2           | 1:3                          | 0.2                           |
|                         | RPB 0.3           | 1:3                          | 0.3                           |
|                         | RPB 0.5           | 1:3                          | 0.5                           |
| Reference sample        | RF                | 1:3                          | 0                          |

2.3. Methods of testing

Flow behaviour of the freshly prepared fibre cement plaster (which indicates its workability) was estimated by a flow table test in accordance with European standard STN EN 1015-3 [16]. Densities of 28 days hardened plasters were calculated.
The coefficient of thermal conductivity of hardened plaster was measured on surface sample by using the commercial device ISOMET 2114 [17].

The water absorbability of fibre cement composites was also tested according the standard STN 73 1316 [18].

3. Results and discussion

3.1. Flow behaviour

The flow diameter values of the various cellulosic fibre plasters prepared in the presence of cement as a binder are given in figure 1. As shown figure 1, the flow table value of cellulosic fibre cement plasters decreases with increasing quantity of fibres up to 0.5%. Water content was kept constant. In comparison to reference sample (239 mm), the samples with wood pulp show the larger decrease as follows WPA 0.5% (51.46%), WPB 0.5% (55.23%) than samples with waste paper RPA 0.5% (42.26%) and RPB 0.5% (48.12%), respectively.

The reason of such behaviour of fresh mixtures consists in hydrophilic character of natural fibres; they absorb large quantities of mixing water and consequently the consistency of the cementitious mixture is greatly reduced [11]. It is in accordance with published data [6].

![Figure 1](image_url)

**Figure 1.** Flow table diameter values of reference sample and fibre cement composites/plasters.

Figures 2 and 3 show testing of workability of fresh cement plasters which contained wood pulps and waste paper fibres in portion 0.2%, 0.3% and 0.5% in the matrix and their comparison with figures 2 and 3 reference fresh cement plaster.

![Figure 2](image_url)

**Figure 2.** The spread-flow diameters of mixtures reinforced with fibre W640; a) RF - reference sample 0% fibres; b) WPB 0.2%; c) WPB 0.3% and d) WPB 0.5%.
Figure 3. The spread-flow diameters of mixtures reinforced with fibre G-700T; a) RF - reference sample 0% fibres; b) RPA 0.2%; c) RPA 0.3% and d) RPA 0.5%.

3.2. Density and thermal conductivity

Thermal conductivity is one of the most important properties of building materials [1]. Figure 4 shows the relationship between different amounts of natural cellulosic fibres used in matrix and thermal conductivity and density of cement plaster reinforced with wood pulp and waste paper fibres at the age of 28 days of hardening. As it can be seen in figure 4, densities of each sample are lower (1.64% - 8.4%) in comparison to control sample RF (2244 kg/m³). The results show that better thermal conductivity (values lower by 28.7% and 33.9% in comparison with RF) were observed for samples WPB 0.5 (1.93 W/m.K) and RPB 0.5 (1.78 W/m.K) which were prepared using the highest amount of cellulosic fibres (0.5%), respectively. Also, these results were compared with thermal conductivity coefficient of reference sample (2.70 W/m.K). In general, lower values of densities and thermal conductivity coefficients acquired cement plasters reinforced with waste paper fibres. In accordance with [19] it is apparent that the cellulosic fibres as reinforcing agent influence the physical and thermal properties such as density and thermal conductivity of cement plasters.

For a given fibre content, the short fibre length brings a lot of voids into the sample and thus, it leads to lower thermal conductivity coefficient of specimen. Also, the thermal conductivity is a close function of fibre content. Hence, the thermal conductivity decreased when the quantity of fibre content was increasing [20].

Figure 4. Values of densities and thermal conductivity coefficients of reference sample and fibre reinforced cement plasters.
Figure 5 illustrates a linear relationship between density and thermal conductivity coefficient values of cement plasters reinforced with natural fibres.

\[ y = 0.0046x - 7.8049 \]
\[ R^2 = 0.8044 \]

**Figure 5.** Dependence on thermal conductivity coefficient on density of fibre cement composites/plasters.

### 3.3. Water absorbability

Figure 6 presents water absorption behaviour of 28 days hardened cement composites filled with wood pulp and waste paper fibres adding in various portions. Values of water absorbability of fibre cement composites with bleached fibres and unbleached waste papers fibres were higher in comparison to cement plaster without fibres (8.66%). The water absorption increases with increasing fibre ratio. Lower water resistance of fibres as well as composites reinforced by natural fibres was observed in other studies well [21, 22]. This phenomenon is related to the hydrophilic nature of cellulosic fibres absorbing some volume of water due to their micro-porous structure [23]. The hydrophilic nature of fibres is a major problem for their use as reinforcement in composite/plaster.

**Figure 6.** Influence of type and amount of cellulosic fibre on water absorbability of fibre cement composites/plasters.
4. Conclusion
In the present study, physical properties of fresh and 28 days of hardened cement composites/plasters reinforced with wood pulp and waste paper fibres were investigated. The influence of two different types of cellulosic fibres in portion 0.2%, 0.3% and 0.5% as addition on resulting properties (density, coefficient of thermal conductivity and water absorbability) of fibre cement composites was observed.

Based on the presented results, the following conclusions can be drawn:

- Addition of different cellulosic fibre to cement mixture led to changes in workability of fresh mixture caused by its hydrophilic nature. Fibres absorb water and flowability of fresh mix is reduced.
- Density and thermal conductivity of manufactured cement based fibre plaster are enhanced in dependence on increasing of fibre addition. With increasing fibre amount these properties were improved, it was slightly lighter in density (up to 8.4%) and better thermal conductivity (33.94%). Also there was showed correlation of thermal conductivity with density ($R^2 = 0.8044$; linear relationship).
- Due to hydrophilic nature of fibres water absorbability of fibre cement composites is influenced, as well. There was observed increase in water absorption of fibre cement composites only with 0.5% addition up to 26% (compared with reference sample).
- Cellulosic fibres have influence on the physical properties of cement plasters containing natural fibres. However, differences in the physical properties of cement plasters based on cellulosic fibres depend on structural, physical characteristics of cellulosic fibres, nature and their processing.
- More investigations of these cellulosic cement based materials are needed for their better utilization and applicability into building materials.

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