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Potential utilization of recycled waste paper fibres in cement composites

N. Stevulova, V. Hospodarova, J. Junak
Department of Material Engineering, Institute of Environmental Engineering,
Faculty of Civil Engineering, Technical University of Kosice
Vysokoskolska 4, 04200 Kosice, Slovakia
E-mail: viola.hospodarova@tuke.sk

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This paper deals with the utilization of waste paper fibres in cement composites. The characterization of waste cellulosic fibres, their processing methods as well as the density and mechanical properties of cement-based composites with the 2 and 5 wt% fibre content of three fibre kinds compared to a composite based on 99.5 wt.% cellulosic fibre and the control sample without fibres are presented. It is shown that the density and mechanical properties of tested fibre-cement composites are affected by cellulosic fibre content and depend on the nature of fibres, their dimension and dispersion in the matrix. The density of each composite with fibre content was checked in a narrow range (1921–1968 kg/m^3 at 2 % and 5 % replacement of the filler). Composites with recycled waste paper fibres had an increasing character in the values of flexural strength up to 14.9 % in comparison with the wood pulp mortar sample. The compressive strength of composites with 2 % of filler replacement reached up to 18 MPa. However, the 5 % replacement of the filler caused a reduction in the compressive strength values to 7.5 % in comparison with the sample containing wood pulp after 28 days of hardening.

Key words: cement composites, cellulosic fibres, waste paper fibres, physico-mechanical properties

Introduction

The manufacturing process of the conventional building material cement demands the extraction of large quantities of materials, leading to the exhaustion of natural resources and environmental damage. This process is energy-intensive, releasing carbon dioxide and other pollutants such as a particulate matter, sulphur and nitrogen oxides and carbon monoxide into the atmosphere. Environmental and economic concerns (energy required for the production, the increasing lack of natural resources, high transport costs) have generated interest in developing new building materials and construction techniques more sustainable for the environment [1].

In the recent years, the utilization of natural lignocellulosic materials to process new biocomposites has attracted growing interest. Such a success is derived by their low cost and environmentally friendly character. Lignocellulosic fibres or particles are available mainly from wood, but several local annual plants (*Cannabis sativa*, kenos, eucalyptus, rice straw, bagasse and cotton) and agricultural crops (oil palm, pineapple leaf, banana, and sugar palm) as well as industrial residues can also be considered as potential sources of raw materials [2].

Among the potential options, the development of pulp and paper industries and biocomposites using recycled paper is currently at the centre of attention [3]. Waste paper (cellulosic biomass) provides a potential source of raw material for the manufacture of sustainable building materials because paper is produced and used globally, and this leads to the production of enormous quantities of waste paper [4]. Waste paper sources originate from many paper kinds such as newspaper, office and printing papers, boxes and paper packaging. The quality of each paper fibre source is different. The fibre quality is reduced by mixing all waste paper kinds of various qualities. The quality of the cellulosic fibres from recycled paper depends on the waste paper purity.

The utilization of waste paper fibres as an alternative filler/reinforcing material in cement composites could resolve the questions concerning the quality and affordability of building materials and simultaneously ameliorate the associated environmental concerns [5].

The factors that affect the physical and mechanical properties of cement composites reinforced by natural fibres can be divided into three main categories. The first one is the type and nature of reinforcing fibres [6]. Cellulosic fibres have a wide range of physical and mechanical properties related to the natural source, and their characteristics depend on the diameter, length, specific gravity, methods of processing, treatment, etc. [7]. The second factor is represented by the nature of the inorganic matrix and its hydration properties. The third significant factor is connected with the process of mixing, casting and curing these fibre-cement composites. One of the most dominating factors affecting the mechanical properties of these composites is the good adhesion ability of fibres with binder particles and their reciprocal compatibility, leading to a homogeneous distribution of the reinforcing fibres in the matrix of a composite [6].

The aim of the cellulosic fibres addition is to increase the mechanical properties (e.g., tensile, flexural and compressive properties) of brittle building materials such as cement, mortar or concrete, particularly for improving the ductility and post-cracking toughness of cement-based composite materials, provided by the fibres after cracking has started [8, 9]. As is shown in [10], treated cellulosic fibres from flax have improved the rheological and mechanical properties of a cement mortar. An increase in the compressive strength values of a cementitious mortar by incorporating rice husk-derived graphene was obtained [11]. Furthermore, investigations of the properties of cement composites with adding agricultural wastes such as coir [12, 13], wheat and eucalyptus [7], rice straw, bark, bagasse [14] and waste paper fibres [3, 5, 15] have shown that the presence of waste fibre has often improved the properties of hardened composites.

The objective of the present study was to investigate the density and mechanical properties of 28 days hardened cement mortars reinforced with three types of waste paper cellulosic fibres – GA (G-500T), GB (G-700T) and GC (G-3/00T), respectively. The resulting properties of fibre cement mortars were compared with those of the reference cement mortar and the mortar reinforced with cellulosic fibres coming from wood pulp.

Materials and methods

In this study, the cement mortar was prepared using an ordinary Portland cement CEM I 42, 5 N (Cement factory Ladce, Slovakia) in accordance with the European standard STN EN 196-1[16] and natural silica sand (fraction 0–1.0 mm). Tap water was used [17]. The Greencel cellulosic fibres were provided by the Greencel, Ltd company (Hencovce, Slovakia). The company supplies three types of cellulose waste paper fibres – GA, GB and GC (G-500T, G-700T and G-3/00T). For comparison, cellulosic fibres from the wood pulp RW (W 640) were used. The colours of cellulosic fibres from recycled waste paper and wood pulp were grey and white, respectively. The chemical and physical features of the Greencel cellulose fibres are shown in Table 1.

The fibre-cement mortars consisted of the CEM I 42.5 N cement, silica sand, cellulose fibres (waste paper fibres, wood pulp), and water. The mix designs of cellulosic mortars are presented in Table 2. The water-cement ratio (w/c) was 0.75. In this experiment, 2.0 wt.% and 5.0 wt.% filler replacement by cellulosic fibres was used (practice requirements). Four experimental sets were designed. The first experimental set contained waste paper fibres G-500T, the second one G-700T, and in the third group the recycled fibres G-3/00T were used. The fourth group of mortar specimen included wood pulp (W 640). The control sample (without fibres) was prepared to compare the results. The bodies of fibre-cement mortars 40×40×160 mm in size were prepared in the standard steel block forms in laboratory conditions.

The mixing of all samples was carried out in two steps. In the first step, the cellulose fibres were mixed with approximately 50 wt.% of water. In the second one, cement, sand and the remaining amount of water were added, and mixing continued until a homogeneous distribution of fibre in the mixture was achieved. After mixing, fresh cement mortars with fibres were cast to the forms and cured for 2 days in the laboratory climate (approximately +20 °C, RH 50 %). After that time, the bodies were removed from the moulds and hept under PVC foil for 26 days. After curing, the mortar blocks were used for testing their density and mechanical properties.

Table 1. Chemical and physical features of the Greencel cellulose fibres

Samples of cellulose fibres	G-500T	G-700T	G-3/00T	W 640
Cellulose content, %	80	80	80	99.5
Bulk density, kg/m^3	50–100	40–70	30–50	35–45
Max. length, µm	400	600	1200	1000
Dry matter, %	93	93	93	93
Ash, %	20	20	20	0.5
pH	7 ± 1	7 ± 1	7.5 ± 1	6 ± 1

Table 2. Mix design of fibre-cement mortars

Type of cellulose fibres		Cement : sand weight ratio	Cellulose fibre content, wt.%
Recycled waste paper	G-500T (GA)	1 : 3	2
		1 : 3	5
	G-700T (GB)	1 : 3	2
		1 : 3	5
	G-3/00T (GC)	1 : 3	2
		1 : 3	5
Wood pulp	W 640 (RW)	1 : 3	2
		1 : 3	5
Reference sample (RF)		1 : 3	0

The elemental analysis of cellulosic fibres from wood pulp and recycled paper was carried out on an energy-dispersive X-ray unit (EDX) of the electron microscope TESCAN MIRA 3 FE (TESCAN, Brno, Czech Republic). Fibre samples were glued on carbon adhesive films and coated with a gold film. The gold film covering cellulosic fibres was used to avoid their charging under the electron beam. The EDX analysis results of cellulosic fibres from wood pulp and recycled waste paper is shown in Fig. 1. Whereas the EDX analysis of pure cellulose 99.5 % (wood pulp fibre) confirmed only the presence of carbon and oxygen (Fig. 1, *a*), characteristic peaks corresponding mainly to aluminium, silicon and calcium elements (Fig. 1, *b*) for recycled waste paper fibres with 80 wt.% of cellulose content are presented. These inorganic impurities are due to the presence of ink, different sources of waste paper and filler in the paper making.

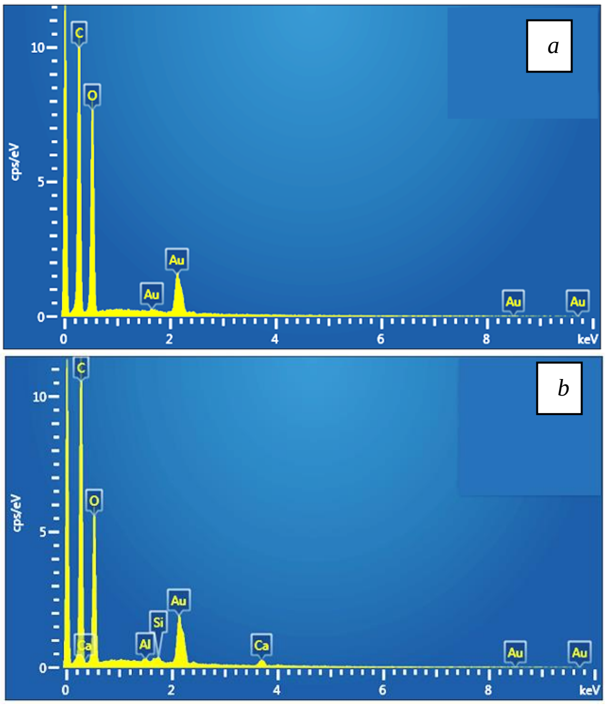

Fig. 1. EDX analysis of a) wood pulp and b) recycled waste paper cellulose fibres

The density of cement mortars for 28 days cured under PVC foil were estimated according to the STN EN 1015-10 [18] standard. The mechanical properties such as compressive and flexural strength of 28 days hardened fibre-cement specimens were determined by using the ADR 2000 instrument (ELE International, England) in accordance with the STN EN 1015-11 [19] standard. The mean values of density, flexural and compressive strength of each specimen were calculated as the average of the three measured values.

Results and discussion

Figure 2 shows changes in the density values of the fibre-cement mortars, which depend on the fibre content. A reduction in the density of each composite with the increase of cellulosic fibre contents was observed. This fact was also confirmed by another study [20]. The density of cellulosic fibre samples was different (30–100 kg/m^3) and influenced the resulting densities of mortars. In general, with an increase in fibre content the density of mortar would reduce. It is important to disperse the cellulosic fibres homogeneously into the cement matrix. The uniform dispersion of cellulosic fibres would inhibit the crack propagation, resulting in improved mechanical properties of the fibre-reinforced mortars [6]. The density of a pure reference sample (RF) was 2073 kg/m^3. Addition of cellulosic fibres to the mortar mixtures caused a decrease of density values in the range of 5.1–7.4 % in comparison with the reference specimen. The density values of composites with 2 wt.% and 5 wt.% fibre contents changed in narrow ranges (1924–1968 kg/m^3 and 1921–1959 kg/m^3, respectively), and they had a similar trend. The lower percentage of cellulosic fibres in a composite shows a higher density value.

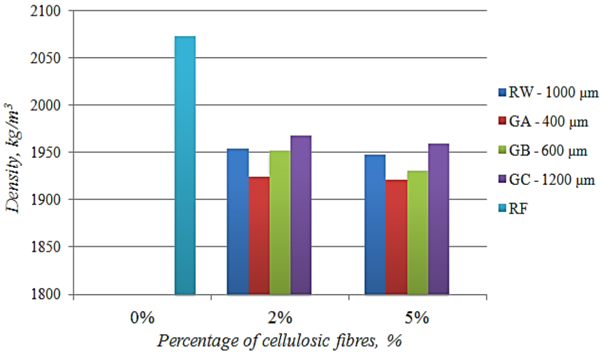

Fig. 2. Density of fibre-cement mortars with 2 % and 5 % of cellulosic fibre contents

As is shown in Fig. 2, the density of cement composites with 2 % and 5 % of the cellulosic fibre content increases with increasing the fibre length.

The mechanical test results including the flexural and compressive strength of fibre-cement mortars are presented in Fig. 3 and Fig. 4. The flexural strength of all specimens was measured by using the three-point bending test. In general, the total flexural strength of the cement mortar reinforced by cellulosic fibres depends on the nature of fibres and their dimension and dispersion in the inorganic (cement) matrix [21]. The flexural strength of reference mortar reached 3.73 MPa. In Fig. 3 we see a reduction in the flexural strength values of each fibre-cement mortar in the range of 7.0–24.4 % in comparison with the control sample RF. As is shown in Fig. 3, the flexural strength of composites with recycled fibres has a slightly increasing character in the range 5.7–14.9 % in comparison with specimen containing wood pulp (RW) at 2 % of filler replacement. However, in the second set of composites containing waste paper (5 % of filler replacement), flexural strength slightly increased (2.9–11.6 %) in comparison with the RW sample containing wood fibres. The maximum flexural strength was shown by the GB mixture with 5 % of fibre content, and it improved the flexural strength by about 11.6 % as compared to with the mortar specimen RW.

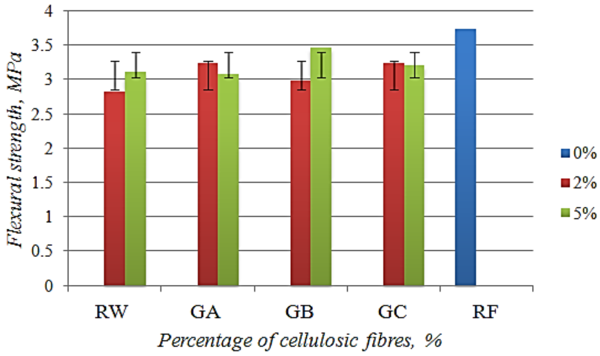

Fig. 3. Effect of cellulosic fibre content on the flexural strength of cement mortar specimens

The compressive strength of the reference mortar achieved 26.6 MPa. The results show that the compressive strength of fibre-cement composites is reduced by 32.3–42.9 % in the control cement mortar. As is seen in Fig. 4, the compressive strength was slightly increased (8.6 %) at the low fibre content (2 %) in comparison with the sample RW 2 %. A high compaction between the fibres and the cement matrix was achieved, leading to a good homogeneity in the mixture with a 2 % fibre inclusion in accordance with the study [22]. However, we observed a decrease of the compressive strength value (8.4 %) for the sample GB 2 % as compared with the mortar mix RW 2 %. A decrease in the compressive strength values (0.35–7.5 %) was recorded for all composites with the 5 % fibre content in comparison with the wood pulp cement mortar RW 5 %. The development of compressive and flexural strength was similar for both mortar sets (Fig. 3 and Fig. 4). The addition of fibres to the cement mortar increases the porosity, and thus the compressive strength decreases [10]. This is mainly due to the fact that the increasing fibre content induces more voids, which makes the composite lightweight and weakens the material [23]. The mechanical characteristics are affected by fibre length, adhesion between fibres and the matrix, uniformly dispersed fibres in the matrix and the adequate fibre orientation [24].

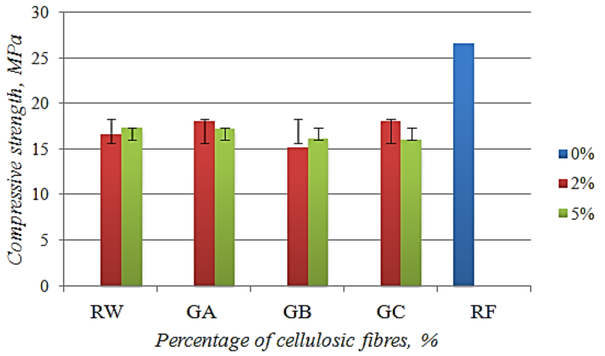

Fig. 4. Effect of cellulosic fibres content on the compressive strength of cement mortar specimens

Conclusions

In this study, the potential utilization of recycled waste paper fibres in cement composites has been investigated. The fibres obtained from recycled waste paper were used as a reinforcing agent in cement mortars. The effect of cellulosic fibres of different nature (waste recycled paper and bleached wood pulp) and their portion (2 % and 5 %) on the density and mechanical properties of mortars hardened for 28 days was investigated. The EDX measurement confirmed the presence of elements such as aluminium, silicon and calcium on the fibre surface of waste paper cellulosic fibres in comparison with wood pulp fibres. The presence of these impurities in recycled fibres is related with the processing and treatment of fibres. The density and mechanical properties of tested fibre-cement composites are influenced by the cellulosic fibre content and depend on the nature of fibres, their dimension, and dispersion in the matrix. The use of cellulose fibres causes a reduction in the density of fibre-cement composites. Their densities become lighter, and this decrease is in the range of 5.1–7.4 % in comparison with the reference specimen. The mechanical properties such as the flexural and compressive strength of cellulosic fibres reinforced cement based composites are determined by the fibre content. The flexural and the compressive strengths of the fibre mortar composite decreased by 7.0–24.4 % and 32.3–42.9 % in comparison with the control sample, respectively.

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N. Stevulova, V. Hospodarova, J. Junak

POPIERIAUS PLUOŠTO ATLIEKŲ UTILIZAVIMO GALIMYBĖ CEMENTO KOMPOZITUOSE

Santrauka

Šiame darbe ištirta popieriaus pluošto atliekų utilizavimas cemento kompozituose. Nustatyta trijų skirtingo atmainų perdirbto popieriaus pluošto priedų įtaka cemento kompozitų tankiui ir mechaninėms savybėms, kai priedo kiekis bandiniuose yra 2 % ir 5 %. Gauti rezultatai palyginti tiek su cemento kompozitu, kuriame popieriaus pluošto priedas paruoštas iš medienos ir celiuliozės kiekis jame yra 99,5 %, tiek ir su grynu cemento bandiniu. Nustatyta, kad cemento kompozitų tankiai ir mechaninės savybės priklauso nuo pluošto sudėties, dalelių dydžio ir jų pasiskirstymo bandinyje. Ištirta, kad bandinių tankis kinta siaurame intervale 1921–1968 kg/m^3, kai priedo kiekis bandiniuose yra 2 % ir 5 %. Nustatyta, kad bandinių stipris lenkiant su perdirbto popieriaus pluošto priedu yra 14,9 % didesnis nei bandinių su medienos popieriaus pluošto priedu. Ištirta, kad po 28 parų hidratacijos stipris gniuždant bandiniuose su 2 % perdirbto popieriaus pluošto priedu yra 18 MPa. Padidinus priedo kiekį iki 5 %, gniuždomasis stipris sumažėja 7,5 %, palyginti su medienos popieriaus pluošto ir cemento kompozitu.