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Implementation of Waste Cellulosic Fibres into Building Materials

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In the last decades, eco-friendly materials have become an important part of the building materials market. Particularly, many studies deal with the use of natural fibres as replacement to synthetic fibres in reinforced composites. Natural fibres are already used in various types of materials, like plastics, concrete and lime-based products. They demonstrate different attributes such as good mechanical, thermal and acoustic properties, low cost, low density and recyclability that allow these types of materials to be used for different applications.
As the most abundant component in wood and most plants, cellulose is an almost inexhaustible polymeric raw material from renewable sources. Using of natural cellulosic fibres as reinforcing components in building materials is constantly growing and can play a leading role in this transition toward renewable materials, which also promotes a healthy and comfortable style of housing.
In this work two types of plasters based on waste cellulosic fibres coming from different biomass resources were prepared and analysed to evaluate the influence on their performance of different fibres used as reinforcement.
In particular each plaster was realised by adding to the mortar the same amount of recycled fibres from waste paper and hemp (Cannabis Sativa) hurds as a woody core of hemp plant coming from hemp stem processing.
This paper deals with characterization of morphology, chemical composition and structure of cellulosic fibres coming from various sources. Subsequently, physico-mechanical characteristics of plasters were also investigated.

1. Introduction

The construction industry is one of the major and most active sectors in Europe. It represents 28% and 7% of employment respectively, of the industry and of all the European economy. Unfortunately this industry is also responsible for the depletion of large amounts of non-renewable resources and for 30% of carbon dioxide gas emissions (Stern, 2006). The use of renewable resources by the construction industry will help to achieve a more sustainable consumption pattern of building materials (Bentur and Mitchell, 2008). In the building industry, one of the current trends is to develop ‘green concrete.’ Natural cellulosic fibres can play a leading role in this transition toward renewable materials, which also promotes a healthy and comfortable style of housing. Indeed, natural cellulosic fibres are abundant, renewable raw materials with a low cost; they are an interesting alternative to synthetic fibres (Li et al., 2006). Vegetable fibres cement based materials are as strong as synthetic fibres, cost-effective and environmentally friendly (Nozahic et al., 2012).
Over the last few years there has been a renewed interest in the use of vegetal fibres as constituents in composite materials made of polymer or mineral matrix, such as cement, plaster or lime. The incorporation of fibres modulates mechanical and insulating properties of the resulting composite material (Pacheco-Torgal and Jalali, 2011). Among natural fibres, hemp is used in concrete composites and mortar. This fibre is generally combined to concrete or mortar as short or long discrete fibrous material uniformly distributed and randomly oriented. The main advantages of hemp are good mechanical, thermal and acoustic properties, low cost, low impact on the environment, breathing and prevention of condensation (Elfordy et al., 2008).

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In the commercial market, there has been a strong trend to produce composite products by using recycled paper and agro-waste fibres. Among the possible alternatives, the development of bio-composites using recycled cellulosic fibres from waste paper is currently at the centre of attention (Hamzeh et al., 2013).
In studies (Torkaman et al., 2014; Ardanuy et al., 2015), the recycling of various types of wood pulp and waste paper fibres for the production of fibre cement composites has shown a significant effect on the mechanical and physical properties.
Therefore, research about building materials based on renewable resources like vegetable fibres is needed. This paper discusses the use of vegetable fibres as reinforcement in cement based materials. It includes fibre characteristics and strength performance of cementitious materials reinforced with vegetable fibres.
In our previous paper (Cigasova et al., 2014), the physical and mechanical properties (density, water content, compressive strength, thermal conductivity coefficient) of lightweight composites based on hemp hurds in dependence on hardening time are studied. The durability of composites (long-term water storage) based on hemp hurds and alternative binder MgO-cement was monitored too (Cigasova et al., 2013).
The aim of this work is to study the influence of two types of waste cellulosic fibres on physico-mechanical parameters of mortar.
This study reports determination morphological features of various cellulosic fibres using by scanning electron microscopy (SEM) and EDX investigation. Hemp hurds and recycled fibres from waste paper are introduced in mortar and their effect on physic-mechanical parameters is studied in dependence on the percentage of used fibrous material.

2. Materials and Methods

2.1 Hemp hurds

Technical hemp hurds coming from the Netherlands Company Hempflax (Oude, Pekela, Netherlands) was used in the experiments. This hemp material consisted of a large majority of core fibres (hemp hurds, which is waste of hemp stem processing) over bast fibres, and it also contained fine dust particles originating from the manufacturing grinding process (Figure 1a). Original hemp hurds slices had wide particle length distribution (8–0.063 mm). The mean particle length of used hemp hurds was 0.94 mm. Density of hemp material was 117.5 kg/m3. The average moisture content of hemp material determined by weighing of hemp sample before and after its drying for 24 h at 105 °C was found 10.78 wt%. The physical and chemical parameters of hemp material are shown in Table 1.

2.2 Recycled paper fibres

Cellulose fibres from recycled paper (Figure 1b) - Greencel were supplied by Bukoza Invest s.r.o. (Hencovce, Slovakia). Their physical and chemical properties are shown in Table 1.

a)

b)


Figure 1: Hemp hurds slices (a), cellulose fibres from recycled paper (b)

Table 1: Physical and chemical properties of cellulose fibres

Fibres sample	Cellulose content [%]	Bulk density [kg/m3]	Mean particle size [μm]	Ash [%]
Hemp hurds	45	117.5	1,940	3.05
Recycled fibres	80	30 – 50	1,200	20

2.3 Scanning Electron Microscopy

Scanning electron microscopy (SEM) observations were done on a TESCAN MIRA 3 FE (TESCAN, Brno, Czech Republic). Characterization was done on hemp hurds and cellulose fibres from recycled paper. Fibre samples were glued on carbon adhesive films and coating with carbon/gold film using a vacuum sputtering coater. The samples were coated with carbon (hemp hurds) and gold (recycled paper) film to avoid charging under the electron beam.

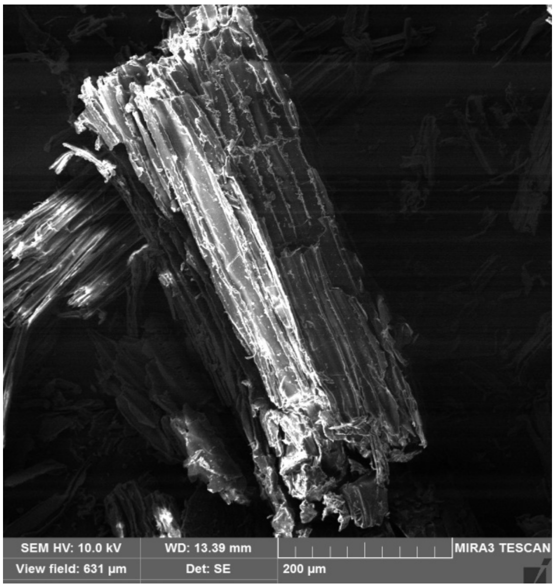
2.4 Preparation and testing of composite samples

Two samples of cellulosic fibres – hemp hurds and waste paper fibres in various portions (2.0 and 5.0 %) were selected for preparation of cement mortar composites. Portland cement CEM I 42.5 R (Holcim Slovakia a.s.) as binder and natural silica sand (fraction 0-0.6 mm) as filler were used into mixtures. Water for the cement mixtures preparation was used in accordance with standard STN EN 1008. Fresh reference mortars were prepared with Cement/Sand (C/S) weight ratio of 1:3 and Water/Cement (W/C) ratio of 0.75. Each batch of three test specimens consists of 450 ± 2 g of cement, 1350 ± 5 g of sand and 337 ± 1 g of water. Fresh mortar plus hemp fibres were prepared with cement/(sand + fibres) weight ratio of 1:3. The fibre content was subtracted from the silica sand content which means that fibres were used as substitutions. The sand content was then adjusted based on mixing rule where the ratio water/cement is kept constant.
Preparation of fibre reinforced cement composites was carried out in two different ways. At first, the components of mixture with hemp hurds were homogenized in dry way and then mixed with water addition At second, the recycled paper fibres were dispersed in water by mechanical stirring (approximately 50 wt. % of water). Subsequently, cement, sand and remaining amount of water were added, and mixing continues to allow uniform fibre dispersion in the mixture. After mixing, the mortars were immediately poured into the standard steel block forms with dimensions 40 x 40 x 160 mm. The specimens were cured for 2 days in the indoor climate at approximately +18°C and then they were removed from the forms. After that time, the specimens were held under PVC foil for 26 days. For each measurement were prepared 3 samples. Compressive strength of the all specimens under controlled conditions after 28 days of hardening was determined as the maximum load per average cross-sectional area by using the instrument ADR ELE 2000 (International Limited, United Kingdom) in accordance with the standard STN EN 206-1/A1. The density of cement mortar composites were determined in accordance with standard STN EN 12390-7 and STN EN 12390-3.

3. Results and Discussion

3.1 Scanning electron microscopy

The fibre quality was checked using Scanning Electron Microscopy (SEM) to reveal surface roughness, imperfections and overall geometry. Examinations were carried out on the hemp fibres and re-pulped waste paper fibres to find out the morphological changes. The SEM micrographs of surface of cellulose fibres from hemp hurds (a) and recycled paper (b) are shown in Figure 2. Hemp fibre surface topography shows the presence of surface impurities like ash and waxes. The fibre structure is formed by several bundles of filaments aligned the plant´s length. Waste paper fibres have on their surfaces impurities that come from re-pulped waste paper (ink, different resources of waste paper and filler in paper making).

a)


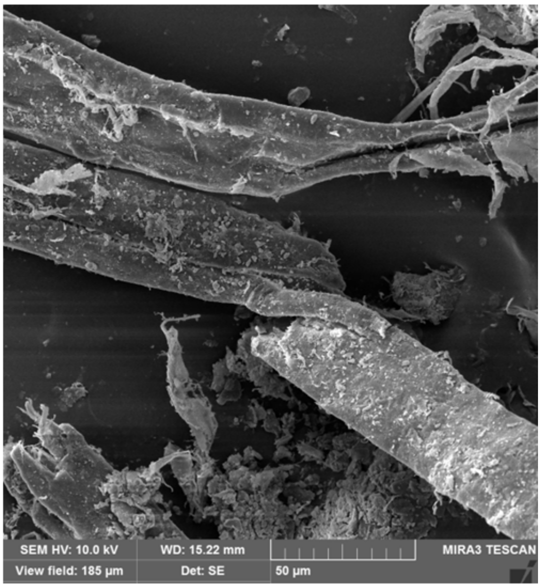
b)


Figure 2: Scanning electron microscopy (SEM) micrographs of cellulose fibres from (a) hemp hurds (450 times of magnification) and (b) waste paper (1500 times of magnification)

3.2 Density of cellulosic composites

One of the physical parameters - density was measured after 28 days of fibre-cement composites hardening. Fibres were added with different percentages (2 wt. % and 5 wt. % replacement of sand) into cement mortar composites. Three mixtures of mortar composites were prepared. The first mixture was prepared without fibres addition, in the second mixture was used hemp hurds and in the third one fibres from recycled paper were used. In Figure 3 is shown dependence of cellulose fibres amount on density of composites. It is evident that higher amount of fibres from hemp hurds and waste paper caused lower density of all specimens in comparison to reference sample RF. Density of composites with fibres is in the range from 1,981 kg/m3 to 1,864 kg/m3 and for reference sample (without fibres addition) is 2073 kg/m3. Decrease of density values are in the range 4.44 – 10.08 % in comparison with reference sample, samples with hemp hurds HH (8.88 – 10.08 %); samples with recycled paper RP(4.44 – 5.07). This is caused by amount of fibres, their nature and physical and chemical characteristics (Kidalova et al., 2011).

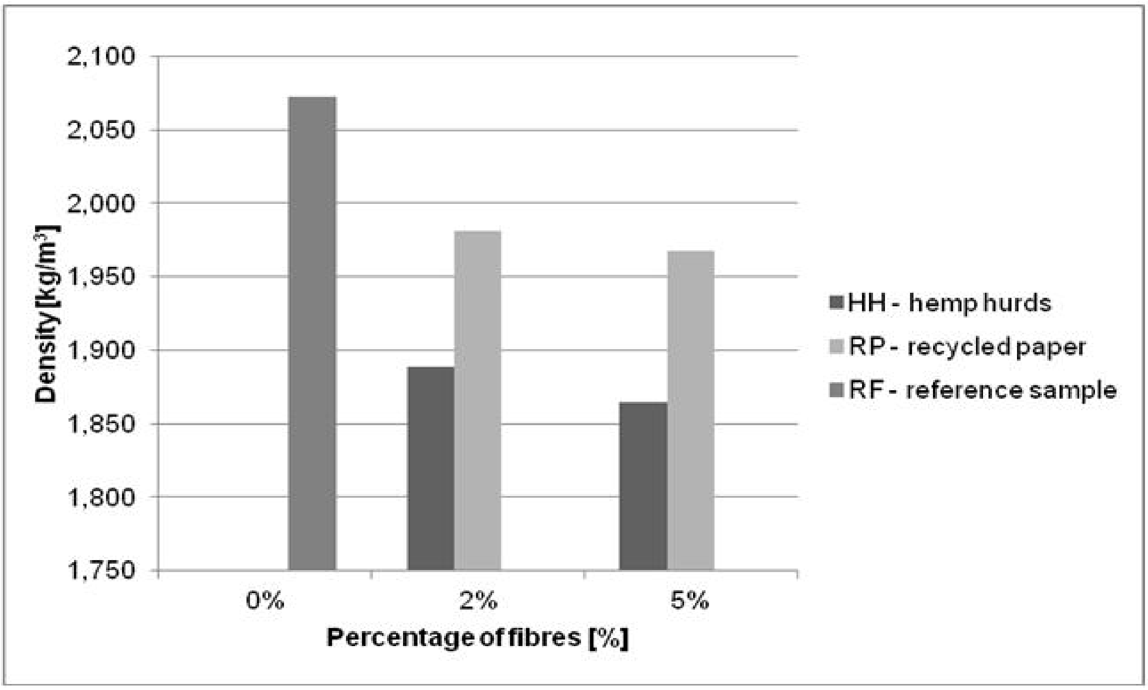


Figure 3: Influence of cellulosic fibres content on density

3.3 Compressive strength of cellulosic composites

The compressive strength values of cement pastes blended with various amount of fibres from hemp hurds and waste paper are shown in Figure 4. These values reached 15.68 – 18.00 MPa and for reference sample this value is 26.6 MPa. The compressive strength values of composites with hemp hurds and also with waste paper fibres increases in dependence on amount of fibres addition. However, samples with fibres from waste paper reached higher values (10.5 % and 7.0 %) of compressive strength in comparison with hemp hurds samples in 2 % and 5 % percentage of fibres, respectively. The results show that compressive strength increases with an increasing fibres content in followed range up to 5.0 wt.%. This confirmed known fact that fibre content is the major factor affecting properties of fibre composites. Differences in values of compressive strength are caused by the different nature and structure of used fibres.

The relationship between the compressive strength and the density of fibre-cement mortar specimens is shown in Figure 5.

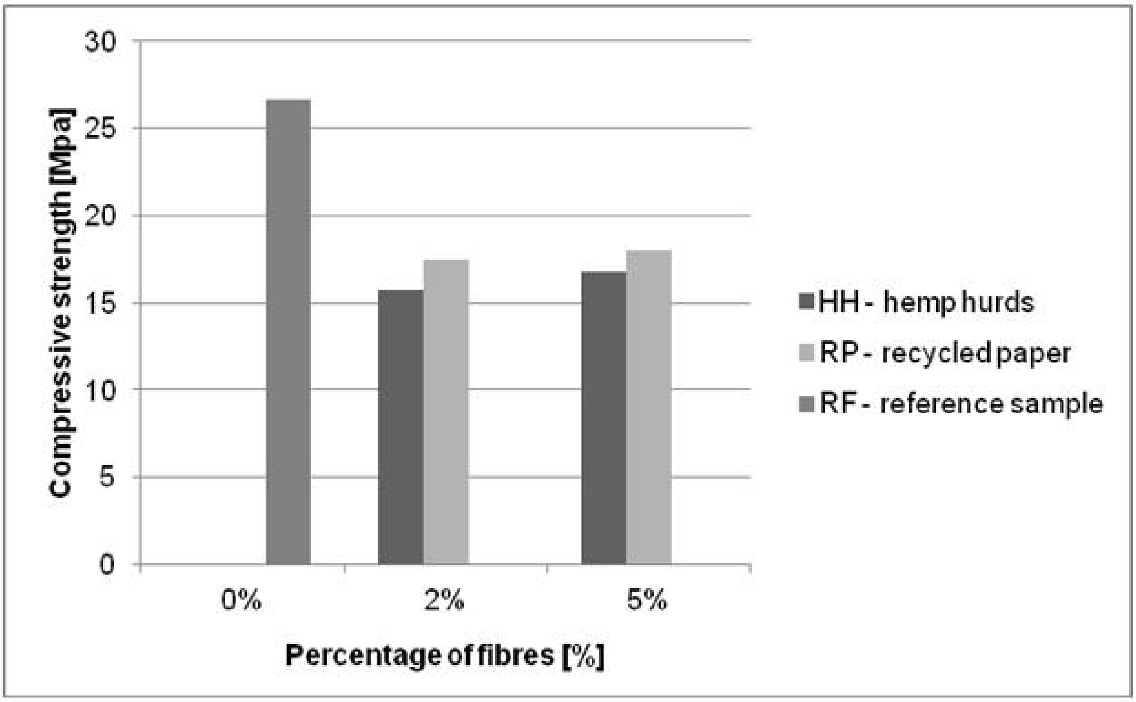


Figure 4: Influence of cellulosic fibres content on compressive strength after 28 days

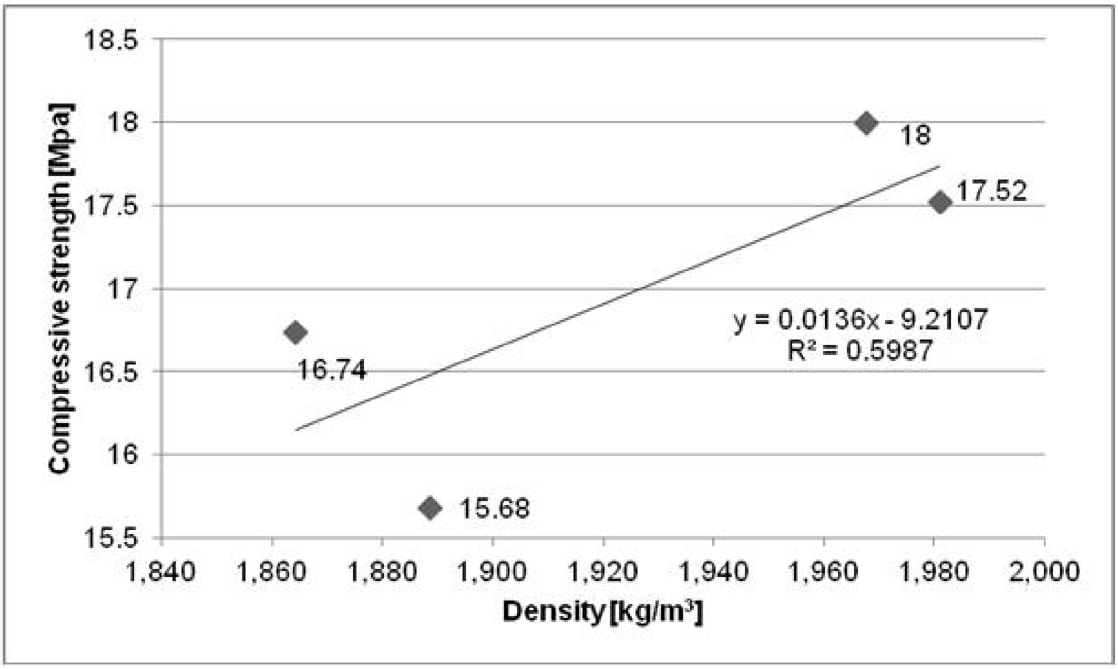


Figure 5: Dependence of compressive strength on density of 28 days hardened composites

4. Conclusions

The effect of waste cellulosic fibres addition on the physico – mechanical properties of cement based mortars was investigated in this paper. Furthermore, the effect of different fibre origin (hemp hurds and recycling waste paper) and various portions (2.0 % and 5.0 %) of cellulosic fibre addition to the composite mixture and the morphologic structure of added waste fibres were analyzed.

Cellulosic samples coming from various sources showed differences in their morphology (surfaces impurities) and structure. Physical and mechanical properties (density and compressive strength) of 28 days hardened composites were tested. The measurements demonstrated that physical and mechanical properties depend on the fibre nature, surface morphology and structure, shape and amount of used fibrous material into cement based mortar mixtures. The density decrease of fibre-cement samples is mainly attributed to the fact that both fibres, hemp hurds and waste paper, are light in weight due to their porous structure and nature. The relationship between the compressive strength and the density of fibre-cement mortar specimens was shown.

Acknowledgments

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