Possibilities of Using Cellulose Fibres in Building Materials

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Abstract. Nowadays, utilization of wastes from agriculture, paper production and building construction is becoming increasingly important due to environmental concerns. Material recycling is a growing trend in the development of building materials; some waste materials can be used in construction as secondary raw materials. The demand for natural non-renewable raw materials is increasing rapidly, therefore, wastes as resources for secondary raw materials can be a good substitute in the production processes. In this way, the shortage of natural raw materials can be supplemented. Construction industry uses secondary raw materials very effectively thereby substituting virgin materials. One of the interesting secondary raw materials is waste coming from natural plant fibres. In this paper, characterization of cellulose fibres from wood pulp, waste paper and their use in cement composites are considered. Technically important parameters of hardened composites are determined and tested (density, water absorbability and compressive strength).

1. Introduction
In the recent years, much more attention has been paid to sustainable, green and environmentally friendly materials for various applications. In this regard, the application of renewable and biodegradable biomass fibres reinforced composite materials has been developed to get subsequent generation of sustainable and green materials in this field [1].

Producing more sustainable and environmentally friendly materials has gained the attention of researchers at the international level. It includes a search for alternatives to petroleum-based materials. The development of biomaterials holds great promise to mitigate many of the sustainability problems, offering the potential of renewability, biodegradation, and a path away from harmful additives. The research reported here involves the development of efficient techniques for the production of natural fillers as reinforcing agents for composite applications. Chemical composition, morphological structure, physical and thermal properties of the fibres can be evaluated to estimate their ability to be used as fillers in biocomposite applications [2].

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The cellulosic fibres are produced in large quantities, different morphologies and sizes, derived from renewable resources, such as agro-industrial and waste material, and available at reduced cost as compared to synthetic fibres (i.e., polypropylene and polyvinyl alcohol fibres). The increase in the agro-industrial activities generates a large quantity of waste in this sector. The use of lightweight cellulosic pulp from agro-industrial by-products as reinforcement in low cost building materials is an interesting strategy for managing these by-products, from the point of view of their mechanical properties, environmental and social-economic impacts [3].

The use of wood fibres and recycled paper fibres in cement composites has many advantages. Wood fibre reinforced composites are easy to cast to mold into a desired shape, they are resistant to fire, as well as resistant to harmful effects of sunlight, rain, and insects. These composites also have low thermal conductivity, a great degree of processing flexibility, in addition, they might help eliminate environmental pollution by recycling wood fibre. Some of the advantages of wood fibres in cement fibre composites are availability, high tensile strength, relatively high modulus of elasticity, and the well-developed technology to easily extract the fibres from wood for use in the composites. The main disadvantage is their vulnerability to chemical decomposition of certain wood chemical constituents in the alkaline cement environment [4].

The primary advantages of using lignocellulosic fibres as additives in cement are low density, low cost, nonabrasive nature, high filling levels possible, low energy consumption, and wide variety of fibres available throughout the world. With an increasing worldwide shortage of wood resources, there has been a strong trend to produce composite products using recycled paper, non-wood plant materials and agricultural residues. Among the possible alternatives, the development of pulp and paper industries and bio-composites using recycled paper is currently at the centre of attention [5].

The objective of this study was to determine physical and mechanical properties of fibre-cement composites and compare those properties with the properties of composites made without fibres. The density, water absorbability and compressive strength properties of hardened cement-based composites were analyzed.

2. Materials and methods

2.1. Materials

In this experiment, a renewable raw material based on cellulosic fibres was used. Cellulose fibres - Greencel (figure 1) were obtained from bleached wood pulp (white sample GW-500) and unbleached recycled waste paper (grey sample G-700T). The Greencel fibres came from company Bukoza Invest Ltd (Hencovce, Slovakia). Two types of samples were tested. Physical and chemical properties of cellulose fibres are shown in table 1.
Figure 1. White wood pulp and grey waste paper cellulose fibres.

Table 1. Properties of cellulose fibres Greencel.

| Cellulose fibres | Cellulose content [%] | Bulk density [kg/m³] | Max. length [µm] | Dry matter [%] | Ash [%] | pH   | Colour |
|------------------|-----------------------|----------------------|------------------|----------------|---------|------|--------|
| GW-500           | 99.5                  | 60-80                | 500              | 93             | 0.5     | 6±1  | white  |
| G-700T           | 80                    | 40-70                | 600              | 93             | 20      | 7±1  | grey   |

Portland cement CEM I 42.5 R (Holcim Slovakia Ltd) was employed the binding agent. Natural silica sand of the fraction 0–0.6 mm was used as filler into the mixtures. Water for the preparation of cement mixtures was used in accordance with standard STN EN 1008 [6].

2.2. Preparation of composites

The cement composites consisting of cement, sand, water and cellulose fibres were prepared according to the recipe given in Table 2. The cellulose fibres substituted 0.2%, 1.0% and 5.0% weight of filler (sand). Fibres from wood pulp (GW-500) were used in the first set of experiments. A partial sand replacement by fibres from waste paper (G-700T) was performed in the second experimental set. Reference sample (RF) was prepared without addition of cellulosic fibres. Water-cement ratio (w/c) was 0.75 for each sample.

Table 2. Mixture proportion of fibre-cement composites.

| Mixture samples  | CEM I 42.5 R (wt.%) | Sand (wt.%) | Water (wt.%) | Cellulosic fibres (wt. %) |
|------------------|---------------------|-------------|--------------|-------------------------|
|                  |                     |             |              | GW-500                  |
| Alternative 1    | WP1                 | 21.05       | 62.96        | 15.79                   | 0.2                     |
|                  | WP2                 | 21.05       | 62.16        | 15.79                   | 1.0                     |
|                  | WP3                 | 21.05       | 58.16        | 15.79                   | 5.0                     |
| Alternative 2    | RP1                 | 21.05       | 62.96        | 15.79                   | -                       |
|                  | RP2                 | 21.05       | 62.16        | 15.79                   | -                       |
|                  | RP3                 | 21.05       | 58.16        | 15.79                   | -                       |
| Reference mixture| RF                  | 21.05       | 63.16        | 15.79                   | -                       |
Preparation of fibre reinforced cement composites was carried out in two steps. At first, cellulose pulp was dispersed in water by mechanical stirring (approximately 50 wt.% of water). Subsequently, cement, sand and remaining amount of water were added, and mixing continued to allow uniform fibre dispersion in the mixture. After mixing, the cement pastes were immediately cast into the standard steel block forms with dimensions 40 mm x 40 mm x 160 mm, which were used for preparation of specimens. The bodies were cured for 2 days in the indoor climate at approximately +18°C and then they were removed from the moulds. After that time, the specimens were held under PVC foil for 26 days. On completion of the cure, specimens were tested at 28 days after production. The cement composites were weighed and their density, water absorbability and compressive strength were tested. Three specimens were prepared for each physical and mechanical test.

2.3. Testing methods

The density of 28 days hardened composites was determined in accordance with standard STN EN 12390-7 [7]. Water absorption test was carried out by immersing the composites in water bath (PE container) at laboratory temperature (20°C). The specimens were reweighed and afterwards were dried in the oven at 80°C up to constant weight for the following measurement of water absorption. Water absorbability was determined in agreement with standard STN 73 1316 [8]. Compressive strength was the mechanical property determined after 28 days curing and it was performed using the instrument ADR 2000 (ELE International, England) according to standard STN EN 12390-3 [9].

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

3. Results and discussion

3.1. Density of cellulosic composites

As shown in Table 3, density values of composites based on two types of cellulosic fibres (wood pulp composites WP and recycled waste paper composites RP) were lower in comparison to reference sample (RF). Density of composite samples in the first and second experimental sets was not influenced by fibre amount in specimens. Differences in density of composites with various portions of cellulose fibres were too small (0.2; 0.4 and 0.6 %) when compared with each other.

Table 3. Physical and mechanical parameters of fibre-cement composites.

| Sample | Density [kg/m³] | Compressive strength [MPa] |
|--------|----------------|---------------------------|
| WP1    | 1940±3         | 13.84±0.89                |
| WP2    | 1945±3         | 17.79±0.62                |
| WP3    | 1945±5         | 18.72±0.81                |
| RP1    | 1947±4         | 18.51±0.83                |
| RP2    | 1935±5         | 16.28±0.65                |
| RP3    | 1955±5         | 21.85±0.72                |
| RF     | 2096±7         | 26.44±0.59                |
3.2. Water absorbability of cellulosic composites

The influence of wood pulp and recycled paper fibres on water absorbability of cement based composites is shown in figure 2. It is evident that the water absorbability of fibre-cement composites increased with higher amount of cellulose fibres in the mixture. Dependence of water absorbability on the quantity of fibres up to 5.0 % in composites has a linear character. Values of water absorbability of composite specimens both alternatives were measured in the range of 12.10–12.70 ± 0.15 %. All the wood pulp based composite specimens seem to have slightly higher water absorbability than the specimens with waste paper fibres. The sample with recycled waste paper fibres RP1 with fibre content 0.2 % achieved the lowest water absorbability. In comparison with the reference sample, it was higher by 2.11 %. Composite WP3 had the highest water absorbability (12.70 %). This value was higher by 7.17 % compared to the RF sample.

![Figure 2. Influence of cellulosic fibres content on water absorbability.](image)

3.3. Compressive strength of cellulosic composites

The variation of the compressive strength values of composites with different amount of cellulosic fibres is evident (Table 3). These values reached 52-83 % of strength parameter value for the reference composite. The results show that compressive strength increases with an increasing fibre content in the given range up to 5.0 wt.%. This confirmed a known fact that wood fibre content is the major factor affecting the properties of composites.

Composites of the second set show higher values of strength parameter (16.28-21.85 MPa) when compared to compressive strength values of the first set (13.84-18.72 MPa). This fact can be explained by different nature of surface fibres. Similar results were obtained in paper [10], where the impact of unbleached and bleached wood pulp on cement composite properties was studied. In the case of cellulosic fibres from wood pulp, no active centres are present on the surface of fibres due to bleaching process and therefore interaction between surface fibres and cement particles is weaker.

Figure 3 illustrates linear relationship between the compressive strength and density of composites based on two types of cellulosic fibres.
4. Conclusion

In this paper, physical and mechanical properties of fibre-cement composites were investigated. Wood pulp and waste paper fibres were used in various proportions (0.2; 1.0; 5.0 %). Cellulosic fibres are a more effective lightweight raw material. Addition of cellulosic fibres led to the reduction of density of cement composites, slightly increased water absorbability and compressive strength depending on the amount of cellulose fibres as well as the type of cellulose fibres in cement composites. Wood and waste paper cellulose fibres have approximately the same effect on the properties of fibre cement composites, but there are slight differences in the density of composites 0.2; 0.4 and 0.6 % in comparison to each other. Waste paper fibres provide lower water absorbability than wood fibres but the differences between values of water absorbability are very small (3.04; 0.23; 0.15%). The values of compressive strength of composites with waste paper fibres show better results in comparison with wood pulp composites as well (25.23; 8.48; 14.32 %). Properties of fibre cement composites depend on the nature of cellulose fibres and the processing methods. In accordance with the previous research, the results show that physical and mechanical properties of composites are determined by the properties of cellulosic fibres. Further research on cellulose fibres cement composites is needed to better understand the properties and behaviour of fibre-cement composites and to enable their wide implementation in sustainable building materials such as non-load bearing building products.

5. References

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