Replacement of Polymer Fibers with Hemp Fibers in Concrete

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Abstract. In our experiment, we tried to replace polymer fibers with hemp fibers and verify whether the properties and advantages of polymer fibers in concrete will be retained even with this interchange. Polymer fibers are added to the mixer to produce fresh concrete or mortar, and we did the same in our case. Polymer fibers do not replace conventional structural reinforcement of concrete, but improve some properties, such as suppressing and controlling cracking in concrete, reducing plastic settling and cracking in concrete settling, improving concrete toughness, etc. Cannabis and its cultivation have a long tradition. The growing season lasts about four months and during that time at least 2.5 times more wood mass grows on one hectare than in the same forest area. The plant consists of root, leaves, seeds and stalk, which contains about a quarter of the fiber and the rest is a woody mass, the so-called shives. We used only hemp fiber in concrete. Hemp fiber excels in its strength, durability and natural protection against pests. Sets of beams according to EN 196-6 were produced for the proposed solution. Although the article deals with hempcrete, i.e. concrete, the tests were performed according to the cement testing standard. In total, three blends were produced with different hemp fiber ratios, three strips each. Compressive strength and flexural tensile strength were measured.

1. Introduction
Cannabis and its cultivation have a long tradition. At present, cannabis is seen not only as a traditional plant with many uses, but also as a dangerous drug. We distinguish three basic cannabis strains, namely cannabis hemp, Indian hemp and hemp - Cannabis sativa L. Cannabis Sativa L. is used for construction purposes. During its vegetation, it extracts poisonous substances from the soil and at the same time suppresses the growth of weeds, so that no pesticides or herbicides are needed for cultivation. The growing season lasts about four months and during that time at least 2.5 times more wood mass grows on one hectare than in the same forest area. In construction, hemp is used for hemp insulation, hemp concrete, hemp oils and varnishes, honeycomb plaster and hemp funiculus, ropes and strands.

In this article, we describe the replacement of polymer fibers in concrete with hemp fibers. The plant consists of a root, leaves that are not widely used in the building industry, seeds that are pressed to obtain hemp oil, and a stem that contains about a quarter of the fiber and the rest is a woody substance, called shives. The processing of hemp into hemp fiber and shives is carried out mechanically, without polluting processes. We used only hemp fiber in concrete. Hemp fiber excels in its strength, durability and natural protection against pests.
Polymer fibers are added to the mixer to produce fresh concrete or mortar. They can be made of different types of polymer. Polymer fibers do not replace conventional structural reinforcement of concrete and their use does not reduce the proposed concrete thickness. Polymer fibers in concrete suppress and control cracking in concrete (more thin evenly distributed cracks), reduce plastic settling and cracking during concrete settling, improve concrete toughness - increase resistance to impact and mechanical damage, increase concrete resistance in fire situation - concrete resistance fire, increase segregation resistance of fresh concrete and reduce concrete bleeding, are non-magnetic, corrosion-resistant and alkaline-resistant.

![Cannabis Sativa L. (Technical Hemp) - hemp fibers](image)

**Figure 1.** Cannabis Sativa L. (Technical Hemp) - hemp fibers

In our experiment, we tried to replace the polymer fibers with hemp fibers (Figure 1) and to verify whether the properties and advantages of the fibers in the concrete will be retained in this interchange.

2. Experimental methods

Sets of beams according to EN 196-6 [1] were produced for the proposed solution. Although the article deals with hempcrete, i.e. concrete, the tests were performed according to the cement testing standard. This step was made due to the absence of aggregate and also due to the amount of hemp fiber.

Hemp is an organic material and therefore negatively affects the cement hydration process, which is already described in the article on the use of cement with hemp hurds. Because of this problem, cannabis was mineralized with lime hydrate. The dried hemp fibers were immersed for 14 days in lime hydrate and covered with a film to prevent drying. In the previous article, this process lasted only 7 days. This process was carried out according to the article by K. Mikulica [2] and was modified according to the article by P. Nováková [3]. These values are shown in the following table (Table 1).
Table 1. Composition of a recipe for the preparation of mineralized hemp hurds [2, 3]

| Component          | Quantity per 1 m³ |
|--------------------|-------------------|
| Hemp hurds         | 100 Kg            |
| Hydrated lime      | 110 Kg            |
| Water              | 565 Kg            |
| Hemp fibers        | 100 Kg            |

The treated hemp fibers were further used for cement composites. The composition of the mixture is described in Table 2, which shows a comparison of the articles by K. Mikulica [2], P. Nováková [3] and this article.

Table 2. Composition of hempcrete recipe [2,3]

| Component                               | K. Mikulica [2] | Hemp hurds [3] | Hemp fibers |
|-----------------------------------------|-----------------|----------------|-------------|
| Cement (Portland, 42,5 R)               | 380 kg          | 380 kg         | 380 / 380 / 380 kg |
| Mineralized hemp hurds (fibers)         | 775 kg          | 775 kg         | 0 / 10,13 / 20,26 kg |
| Water                                   | 80 kg           | 167 kg         | 115 / 100 / 100 kg |

According to Table 2, mixtures were calculated for one of the three forms shown in Table 3. Three mixtures were selected. The first mixture was a reference sample that did not contain hemp fibers. The second sample contained 40 g of fibers and the third sample contained 80 g of fibers. Weight is given per three samples.

Table 3. Composition of recipes

| Component                               | Cement Composite | Cement Composite with PP fibers | Cement Composite with 40 g Hemp fibers | Cement Composite with 80 g Hemp fibers |
|-----------------------------------------|------------------|-------------------------------|--------------------------------------|---------------------------------------|
| Cement (Portland, 42,5 R)               | 1500 g           | 1500 g                        | 1500 g                               | 1500 g                                |
| Mineralized hemp fibers                 | 0 g              | 0 g                           | 40 g                                 | 80 g                                  |
| Polypropylene fibers                    | 0 g              | 1 g                           | 0 g                                  | 0 g                                   |
| Water                                   | 450 g            | 450 g                         | 400 g                                | 400 g                                 |

In this article was used Portland cement 42.5 R provided by Cemex, Ltd., Czech Republic. This cement disposers the specific surface area of 344 m²·kg⁻¹ on average and met the specifications according to the EN 197-1 [4]. Oxide composition and some material characteristics of used cement, provided by its producer, are introduced in table 4.

Table 4. Oxide composition and material characteristics of used Portland cement

| Oxide composition (mass %) | |
|----------------------------|---|
| SiO₂                       | 18.21|
| Al₂O₃                      | 5.18|
| Fe₂O₃                      | 2.98|
| CaO                        | 62.89|
| MgO                        | 2.40|
| K₂O                        | 0.70|
| Na₂O                       | 0.40|
| SO₃                        | 3.27|
| Cl⁻                        | 0.08|

| Powder density (kg·m⁻³)     | 960 |
| Specific surface (m²·kg)    | 344 |
| Loss on ignition (wt.%)     | 4.89 |
3. Results and discussions
The measurement was carried out 28 days after the production of the brackets. Samples of hemp concrete and cement composite were measured at the same time to maintain the same conditions. The results of the measurements are shown in Table 5. This table shows the averaged values from all measurements.

|                        | Cement Composite | Cement Composite with PP fibers | Cement Composite with 40 g Hemp fibers | Cement Composite with 80 g Hemp fibers |
|------------------------|------------------|-------------------------------|---------------------------------------|----------------------------------------|
| Bulk density (kg·m$^{-3}$) | 1992             | 1950                          | 1827                                  | 1690                                   |
| Compressive strength (MPa) | 64.08            | 64.49                         | 63.85                                 | 59.32                                  |
| Flexural strength (MPa)   | 11.68            | 12.96                         | 9.57                                  | 10.24                                  |

It can be seen from Table 5 that the addition of polypropylene fibers will increase the flexural strength by 11% and increase the compressive strength is negligible, a result that can be expected. When replacing polypropylene fibers with 40g hemp fibers for 3 test specimens, the compressive strength decreases only by 0.4%, which is also a negligible deterioration. However, the bending tensile strength decreased by 18%, which is very negative. When replacing polypropylene fibers with 80g hemp fibers for 3 test specimens, the compressive strength is already reduced by 7.5% and the bending tensile strength is already better than using 40g but is still worse than the reference sample by 12%. These data show that as the amount of hemp fiber increases, the bending tensile strength increases while reducing the compressive strength. Compared to the reference sample, it is always deterioration in properties.

In our previous research, which was carried out on hemp concrete, strengths were quite different, as seen in Table 6. In previous research, Portland cement 32.5 R was used and Portland cement 42.5 R was used in this article, which is seen in cement composites, it is difficult to compare these data, but there is clearly deterioration in strength in the previous measurement compared to this research. This difference is due both to the use of hemp fibers as opposed to hemp shives, but also mainly to the process of hemp mineralization, in this article, this process was twice as long, i.e. 14 days.

|                        | Previous article [3] | Previous article [3] | This article | This article | This article |
|------------------------|----------------------|----------------------|--------------|--------------|--------------|
|                        | Cement Composite    | Cement Composite with Hemp hurds | Cement Composite | Cement Composite with 40 g Hemp fibers | Cement Composite with 80 g Hemp fibers |
| Compressive strength (MPa) | 33,05                | 1,13                 | 64,08        | 63,85        | 59,32        |
| Flexural strength (MPa)   | 8,98                 | 0,36                 | 11,68        | 9,57         | 10,24        |

4. Conclusions
The first part of this work summarizes the research concerning the addition of hemp shives and hemp fibers to concrete. Hemp concrete is a term we are increasingly encountering, but still only in filler constructions. Cannabis itself, as an organic substance, unpleasantly disrupts the hydration processes of cement, and thus, it is not possible to achieve the same strengths as with conventional concrete.
The article did not confirm the hypothesis whether it is possible to increase the tensile strength of a concrete composite by using hemp fibers, on the contrary, it refuted this hypothesis. Nevertheless, hemp concrete remains an interesting material for filling constructions.

A possible improvement in bending tensile properties would be the use of coiled hemp fibers, or various mats and the like. An interesting way of using hemp mats is described in the study Effect of natural fiber reinforced polymers on confined compressive strength of concrete [5]. In this work, only hand-ripped fibers were used to obtain hemp shives for another cell.

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