

## MECHANICAL PERFORMANCE OF HEMP FIBRE MODIFIED MORTAR

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### Abstract

In this research the mechanical performance of mortar reinforced with fibres of hemp (*Cannabis Sativa L*) were experimentally evaluated. Bast hemp fibres of 10 mm in length with six different dosages per volume, starting with 0.25 vol% up to 1.5 vol% increasing in steps of 0.25, were mixed in the matrix. The fibres were added to the matrix in two different conditions: wet and dry. The compression strength, flexural strength and flexural toughness of the composite were evaluated. The addition of hemp fibres was found to decrease the mortars compression and flexural strength but significantly improved the flexural toughness of plane mortar. The increase in fibre dosage resulted in increase of the flexural toughness. On the other hand the compression strength of mortar decreased with the addition of fibres. Both the compression strength and flexural toughness slightly decreased in case if wet fibres were mixed in the matrix.

### Keywords:

Hemp (*Cannabis sativa L*), fibre, mortar, cementitious composite, mechanical performance

## 6 INTRODUCTION

Traditional building materials are extremely resource- and energy-intensive to manufacture and their production contributes to high pollution resulting in greenhouse gas emissions, global warming and climate change. The majority of building materials are cement-based. Concrete, as the most relevant one, is at the same time the most widely used building material in the world.

Cementitious materials are quasi-brittle materials with very low crack resistance and energy absorption capacity under tensile load. The addition of fibre reinforcement, usually steel, synthetic or glass is known to be an effective way to enhance these deficiencies [Balagur and Shah 1992]. However, the vast production energy demand and the negative environmental impact of these materials represent the major concern for their further employment.

The growing environmental awareness forces research to find sustainable and environmentally friendly alternatives to steel and synthetic fibre materials. Fibres obtained from various plants like sisal, coir, flax, jute or hemp could be promising and viable alternatives. Natural fibres produced from locally available renewable resources are cheaper, biodegradable and lighter, and their employment ensures the development of economically and ecologically sustainable composite materials that are considerably less dependent on non-renewable energy resources.

Recently considerable research effort has been put in the development of novel sustainable cementitious materials made from natural fibres [Hamzaoui et al. 2014, Sassoni et al. 2014, Awwad et al. 2012]. Several research results demonstrated that the mechanical and fracture mechanical properties of these fibre cementitious composites are comparable to that of conventional ones [Li et al. 2006, Silva et al. 2010,

Merta and Tschegg 2013, Merta 2014, Andiç-Çakir et al. 2014, Zhou et al. 2013].

However, there are still challenges that need to be overcome. The properties of natural fibre composites are affected by various factors such as the fibre's quality depending on the environmental conditions, location of the plantation, growing, harvesting and processing method. Additionally, the durability of natural fibre composite associated with the degradation of fibres in the alkaline environment of the cement matrix, accompanied with moisture absorption, is still a challenging question and needs substantial further research [Toledo Filho et al. 2009, Melo Filho et al. 2013, Merta et al. 2012].

In this research the mechanical performance of mortar reinforced with fibres of hemp (*Cannabis Sativa L*) was experimentally evaluated. Hemp fibre mortars with different fibre dosages in matrix were tested under compression and flexural load. The compression strength, flexural strength and flexural toughness of the composites were discussed under two conditions: if the fibres were mixed in the mortar dry or wet.

## 7 MATERIALS AND METHODS

### 7.1 Hemp fibres

As reinforcement for the mortar matrix industrial hemp (*Cannabis sativa L*) was used (Fig. 1). It is a bast fibre crop and its stem consist of a woody core with a hollow, open, sponge like structure, surrounded by bast fibres. There are two principal types of bast fibres: primary and secondary fibres and these fibres represent around 20-30% of the whole hemp stalk. The most valuable part of the stalk are the primary bast fibres and these are the strongest vegetable fibres known. They make up approximately 70% of the fibres and are long, high in cellulose and low in lignin. The secondary bast fibres are less valuable and they make

up the remaining 30% of the bast fibres. They are medium in length and have higher lignin content.

Hemp fibres are within the range of microfibrils with a diameter of 16–50  $\mu\text{m}$  and have an extremely high tensile strength between 300–1100  $\text{N}/\text{mm}^2$ . In this research primary bast fibres cultivated and processed in Hungary were used. The fibre bundles were cut (Fig.1) to an average length of 10mm and added to the mortar matrix in six different volume percentages ( $\text{vol}\%=0.25, 0.5, 0.75, 1.0, 1.25$  and  $1.5$ ) according to Table 1. The density of the fibres was about  $1.5 \text{ g}/\text{cm}^3$ .

Hemp fibres are highly hydrophilic, absorbing water up to 2.5 times of their weight. If they are mixed in a cementitious matrix in dry condition they will absorb a part of the water that is needed for cement hydration. In order to study the influence of this effect on the mechanical properties of the composite, the fibres were mixed in the mortar matrix in two different conditions: dry and wet.



Fig. 1: Dry hemp fibres and fibres soaked with water.

## 7.2 Mortar specimens

The mortar mix design of cement/sand/water was 1:1:0.4 by weight, with a water-cement-ratio of 0.4. The hemp fibres were added to the cement-sand mixture in dry and wet conditions. In the wet mix procedure the fibres were first soaked with water (saturated surface dry condition) and then added to the cement-sand mixture together with the water. In the dry mix procedure the fibres were added to the cement-sand mixture in dry condition together with the water as well as with some extra water that was needed for fibre absorption.

## 7.3 Three point bending test (3PBT) and compressive test

The three point bending- and compressive tests were conducted on the mechanical testing machine Schenck RSA with a load capacity of 100 kN and a rigidity of  $8 \times 10^{-3} \text{ mm}/\text{kN}$  according to the standard [ÖNORM EN 1015-11]. The tests were carried out at room temperature of  $21^\circ\text{C}$  and relative humidity of 50%. In bending tests the load was applied at the middle of the specimens with the span length of 100mm. The compression tests were carried out on one half of the broken specimens by applying the compressive force on  $40 \times 40 \text{ mm}^2$  area. All tests were accomplished on 6 identical specimens.

From the load-displacement curves of the 3PBT the toughness of the specimens were calculated as the area under the curve up to a mid-span deflection of 5.5mm.

Tab. 1: Mix design of the specimens.

Specimen	Fibre condition	Fibre volume percentage [vol%]	Fibre dosage [ $\text{kg}/\text{m}^3$ ]
00	--	--	--
MD1		0.25	3.75
MD2		0.50	7.50
MD3	dry	0.75	11.25
MD4		1.00	15.00
MD5		1.25	18.75
MD6		1.50	22.50
MW1		0.25	3.75
MW2		0.50	7.50
MW3	wet	0.75	11.25
MW4		1.00	15.00
MW5		1.25	18.75
MW6		1.50	22.50





Fig. 2: Three-point bending test and compression test.

## 8 RESULTS AND DISCUSSION

### 8.1 Compression strength

In Fig. 3 the compression strength of the specimens are shown. Generally with the addition of fibres, the compression strength of the composite decreases. At lower fibre contents (between 0.25 vol% and 0.5 vol%) the compression strength is on average up to 20% lower than that of the reference mortar (Fig. 4). At higher fibre contents a much more distinctive compression strength loss is observed, up to 40%. Specimens with a lower fibre content (up to 0.75 vol%) exhibit somewhat lower compression strength in case the fibres are mixed in wet condition into the mortar. At higher fibre contents (over 0.75 vol%) this trend changes and wet fibre specimens have slightly higher compression strength than the dry ones. This is consistent with the findings reported in [Hamzaoui et al. 2014] where mortars containing carbon nanotubes with hemp fibres ranging from 1.1 wt% to 3.1 wt% (per weight) were tested and it was found that wet fibre specimens have higher compression strength than dry ones.

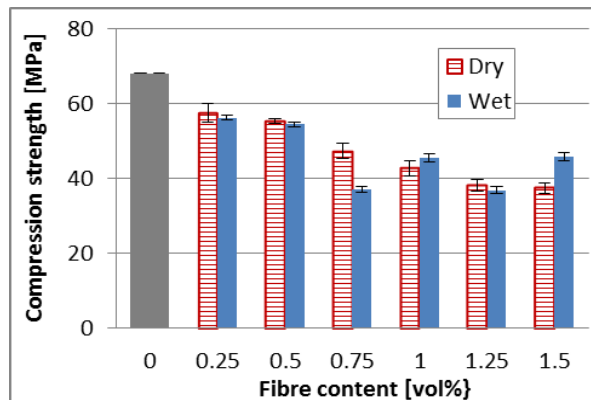


Fig. 3: Compression strength of the specimens.

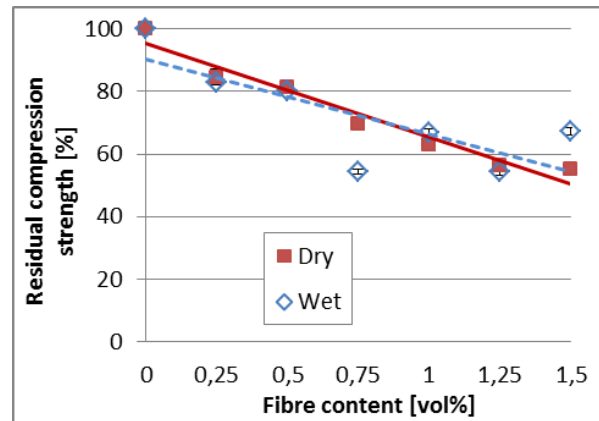


Fig. 4: Residual compression strength of the specimens compared to plain mortar.

### 8.2 Load-deflection curves of the 3PBT

A typical load-midspan deflection curve of the 3PBT is shown in Fig. 5 for dry fibre specimens. The first part of the diagram, up to the peak, is the elastic and plastic region of the composite. After the peak load the sharp drop in load indicates the failure of the cementitious matrix through the propagation of a crack. This peak is governed by the properties of the cementitious matrix. In case of plain mortar, after the peak, a complete loss of the load carrying capacity occurs at very low midspan deflections of approximately 0.2mm.

In case of hemp fibre mortars after the failure of the cementitious matrix the load carrying capacity is not completely lost but at some load level the fibres bridging the crack are starting to be activated in carrying tensile stresses (Fig. 6). This second peak is governed by the properties and amount of the fibres in the matrix. The higher the fibres content in the matrix the lower the load drop after the first peak and the sooner the fibres start to be activated in carrying load. With increasing fibre content in the matrix the height of the second peak along with the corresponding midspan deflection gradually increase. After the second peak the load drop is not as sudden as by plain mortar, but much more gradual, indicating an increased load capacity at higher midspan deflections.

At high fibre contents, almost no drop in vertical load after the first peak is observed, but rather a matrix-fibre composite action is present. The load from the matrix is efficiently transferred to the fibres immediately after the first peak. At high fibre contents (1.5 vol%) the second peak is even higher than the first one and exceeds the peak of the plain mortar specimens.

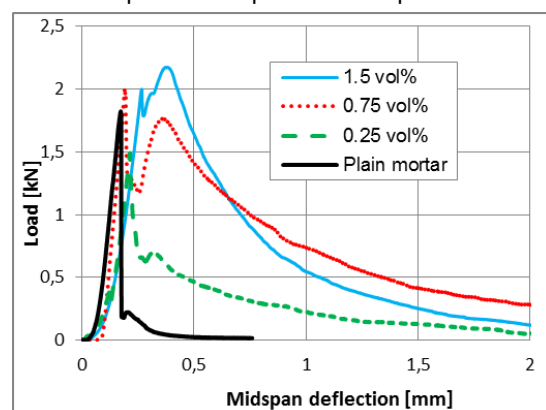


Fig. 5: Load-midspan deflection diagram of dry fibre specimens



Fig. 6: Fibres bridging across the crack.

### 8.3 Flexural strength

The overall peak value of the load-deflection curve is defined as the flexural strength of the specimen. In case of plain mortar and specimens with low fibre contents the first peak represents the flexural strength, whereas with higher fibre contents it is the second peak. Thus with an increase of the fibre content the flexural strength is gradually defined by the second peak controlled by fibres.

Fig. 7 shows the flexural strength of the specimens. All fibre reinforced mortars generally have lower flexural strength than plain mortar specimens. This is the consequence of the lower compression strength of fibre reinforced specimens. However, specimens with dry fibres exhibit slightly higher flexural strength than wet fibre specimens, except for fibre content of 0.25 vol%. Overall a slight increase in the flexural strength with increasing fibre content was observed. If the fibre content is increased up to 1.0 vol% and 1.25 vol% the specimens reach the same flexural strength as plain mortar. At 1.5 vol% fibre content the flexural strength even exceed that of the plain mortar.

### 8.4 Flexural toughness

The toughness of the material is a fundamental property that represents the measure of the material's energy absorption capacity used to characterize the material's capacity to resist fracture when subjected to strain. The flexural toughness is defined as the area under the load-deflection curve until the total separation of the fracture surfaces. The specimens in this research have a range of different deflection values. For a consistent comparison of the results a uniform deflection limit value of 5.5mm was chosen.

In Fig. 8 the flexural toughness of the specimens are shown.

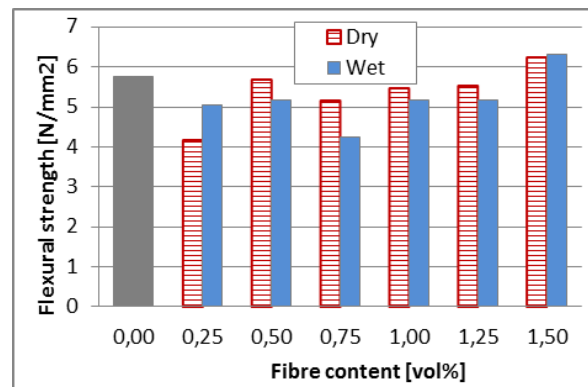


Fig. 7: Flexural strength of the specimens.

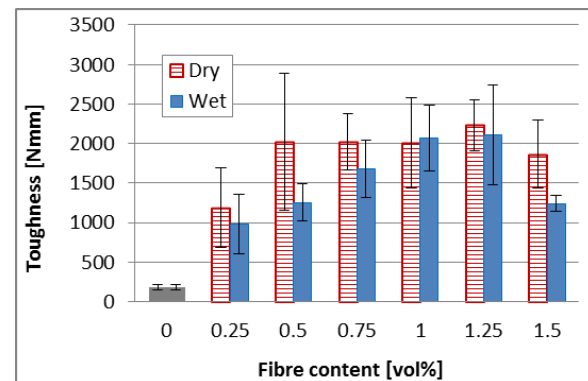


Fig. 8: Flexural toughness of the specimens.

The addition of hemp fibres substantially increases the flexure toughness of plain mortar. Even at a low fibre content (0.25 vol%) the flexural toughness is five times higher than that of plain mortar. At higher fibre content (1.0 vol%) the enhancement is up to twelve times. Generally in case of wet fibres the toughening effect is somewhat lower than in case of dry fibres. The flexural toughness linearly increases with increase of the fibre content in the matrix up to a fibre content of 1.25 vol%. By further increase of the fibre content, i.e. 1.5 vol%, however, the flexural toughness decreases. This is believed to be the consequence of the non-uniform fibre dispersion within the matrix present at high fibre contents resulting in clumping of the fibres.

## 9 SUMMARY

In this research the mechanical performance of mortar reinforced with fibres of hemp (*Cannabis Sativa L*) was experimentally evaluated. For the materials and test methods used the following conclusions could be drawn:

- With addition of fibres, the compression strength of the composite decreases. At lower fibre contents the compression strength is in average up to 20% lower than that of the reference mortar whereas at higher fibre contents up to 40% compression strength loss were observed.
- The addition of hemp fibres was found to decrease the mortars flexural strength. Specimens with dry fibres exhibit slightly higher flexural strengths than wet fibre specimens.
- The addition of hemp fibres was found to significantly improve the flexural toughness of plain mortar. The increase in fibre content in the matrix resulted in an increase of the flexural toughness.

The flexural toughness slightly decreased if the fibres were mixed in the matrix in wet condition.

## 10 ACKNOWLEDGMENTS

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