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# EFFECT OF HEMP FIBER PRE-TREATMENT ON REPAIR CEMENT MORTAR MECHANICAL PROPERTIES

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**Abstract**

*In recent years, the construction industry has seen a significant rise in the usage of natural fibers such as hemp fiber (Cannabis sativa L.) for composite materials reinforcement. The objective of the research presented in this paper was to examine the impact of the hemp fiber pre-treatment (saturated with $Ca(OH)_2$ solution or 1.6 M NaOH solution) and condition (untreated or saturated with deionized water) on the mechanical properties of the fiber-reinforced repair cement mortar. The total of five mortar mixtures, reference one and four mixtures containing 1% hemp fibers (cut to length of the 10 mm) by mass of the cement were prepared, and their 7-day and 28-day compressive and flexural strengths were determined. The effectiveness of the applied hemp fiber pre-treatment or condition was evaluated primarily from the aspect of the mechanical properties of the examined mortars. Furthermore, based on the 28-day compressive strength results, the examined mortars were classified into one of the four classes of repair cement mortars in accordance with the standard SRPS EN 1504-3.*

***Key words**: natural fiber, chemical pre-treatment, repair cement mortar, compressive strength, flexural strength.*

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# 1. Introduction

In recent years, the usage of natural fibers as reinforcement in cement-based composites has increased significantly. Natural fibers are preferred compared to artificial fibers, as they are renewable, low-cost, easy to access and less harmful to the environment (Çomak et al., 2018, pp. 794–799), (Rocha et al., 2022, 2043). Natural fibers can be obtained from natural resources such as plant bast (from i.e. hemp, jute, ramie, flax, kenaf, mesta and roselle) (Samanth & Bhat, 2023, 100034). Industrial hemp (i.e. *Cannabis sativa L.)* consists of around 23% of the fibers and 75% of the shive and reaches a height of 2 to 6 meters during the growth period lasting 100 to 120 days (Nováková, 2018, 03011). Furthermore, it can grow on new or old soil, withstand extreme temperatures while requiring only modest amounts of water (Malabadi et al., 2023, pp. 67-78). Çomak et al. (2018, pp. 794–799) examined density, water absorption, compressive strength, flexural strength, compressive strength after flexural tensile and splitting tensile strength of the cement mortars reinforced with previously untreated hemp fibers. The fibers were added in the different ratios (0%, 1%, 2% and 3%) and different lengths (6 mm, 12 mm and 18 mm). The obtained results showed that cement mortars reinforced with 2–3% amount and 12 mm length of natural hemp fiber give the optimum results. According to Merta (2016, pp. 291–303), the optimal balance between the increased energy dissipation capacity and the resulting loss in compression strength of the cement-based composite was obtained with hemp fibers of 10 mm in length. The different fiber surface pre-treatments, such as chemical one, can also determine the bond between the fiber and the cement-based matrix and affect the final characteristics of the cement-based composites. Zhou et al. (2017, pp. 1-10) examined enhancing the mechanical properties of hemp fiber-reinforced concrete through the $Ca(OH)_2$ solution pre-treatment of 15-mm length fibers, at a volume fraction of 1%. Besides saturated lime water treatment, a variety of recent studies (Shah et al., 2021, pp.1-19) showed that sodium hydroxide (NaOH) treatment also plays a significant role in the adhesion of fiber concrete composites.

The research presented in this paper deals with the effect of the different hemp fiber conditions (e.g. untreated, or saturated with deionized water), and chemical pre-treatments (e.g. saturated $Ca(OH)_2$ solution, or 1.6M NaOH solution) on the 7-day and 28-day flexural and compressive strengths of the fiber-reinforced repair cement mortars that contain 1% hemp fibers (cut to the length of the 10 mm) and added by mass of the cement.

# 2. Materials, mixtures and methods

## 2.1 Component materials

In order to examine the effect of the different fiber pre-treatments (e.g. untreated, or saturated with: (i) deionized water, (ii) saturated $Ca(OH)_2$ solution, and (iii) 1.6M NaOH solution) on the hemp fiber-reinforced repair cement mortar 7-

day and 28-day flexural and compressive strengths, the following component materials were used for the preparation of repair mortars:

- Ordinary Portland cement (PC) CEM I 42.5R (Lafarge-BFC Serbia) with specific gravity of 3.1 g/cm$^3$ and Blaine fineness of 4000 cm$^2$/g,
- Hemp fibers (*Cannabis sativa L.)* cut to the length of 10 mm,
- CEN standard sand, in accordance with SRPS EN 196-1 (2008),
- Deionized water.

Poletanović et al. (2021, 125072) reported the characterization results of the same hemp fibers that were applied in this research: (i) tensile strength up to 900 MPa, (ii) density of 1500 kg/m$^3$, and (iii) water absorption 100% after 120 min.

## 2.2 Pre-treatment of the hemp fibers and mortar mixtures

The experimental study was performed on five different repair mortar mixtures made with water-to-cement ratio of 0.5: the reference cement mortar (RM1), and four cement mortar mixtures (RM2-5) containing 1% hemp fibers (length: 10 mm) added by mass of the cement:

- RM2 – repair cement mortar containing 1% untreated hemp fibers,
- RM3 – repair cement mortar containing 1% untreated hemp fibers saturated with deionized water,
- RM4 – repair cement mortar containing 1% dried hemp fibers treated with saturated limewater solution, and
- RM5 – repair cement mortar containing 1% dried hemp fibers treated with 1.6 M NaOH solution.

The labels and quantities of component materials for each mortar mixture are listed in Table 1.

*Table 1: Repair mortar mixtures*

| **Component material** | **RM1** | **RM2** | **RM3** | **RM4** | **RM5** |
|---|---|---|---|---|---|
| CEM I 42.5 R (g) | 450 | 450 | 450 | 450 | 450 |
| Hemp fibers (g) | - | 4.5 | 4.5 | 4.5 | 4.5 |
| Standard sand (g) | 1350 | 1350 | 1350 | 1350 | 1350 |
| Deionized water (g) | 225 | 225 | 225 | 225 | 225 |

The hemp fiber surface pre-treatments (with saturated limewater solution as well as with 1.6 M NaOH solution) were provided according to the procedure described in (Troedec et al., 2008, pp. 514-522), i.e. fibers were pre-drying at 40°C for 24 h, and then were placed for 48 h in a saturated lime solution (pH 12.7) or 1.6 M NaOH solution (pH 14.2). After that, fibers saturated with calcium ions were washed with deionized water, while fibers soaked in 1.6 M NaOH solution were, at first, neutralized with 1% vol. acetic acid and then also washed with deionized water. Furthermore, chemically treated fibers were dried at 40°C for 24 h. Untreated hemp fibers as well as chemically treated are presented in Figure 1, and there are noticeable differences in the color shade.

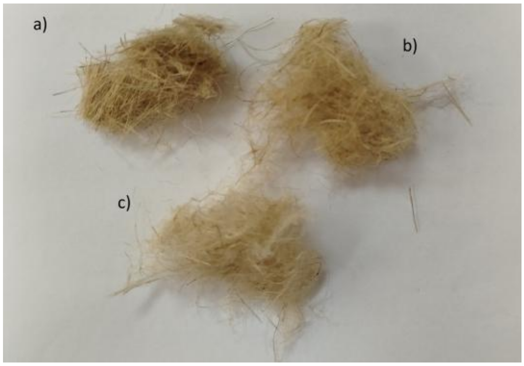


*Figure 1: Hemp fibers: a) untreated, b) treated with saturated limewater solution, and c) treated with 1.6 M NaOH solution*

### 2.3 Methods

The 7-day and 28-day flexural strengths of the mortars were determined according to the standard SRPS EN 196-1 (2008) using prism-shaped specimens with dimension of 40 mm × 40 mm × 160 mm, after recommended curing resume (covered in film for 24 h, demoulded after 24 h and cured under water at (21 ± 2)°C until testing). The mean strength values were obtained by testing the three prisms per mortar mixture. The load at failure was determined using the Michaelis scales.

The 7-day and 28-day compressive strengths of the mortars were determined according to the standard SRPS EN 12190 (1999) on the halves of the prisms remained from flexural strength testing. The mean strength values were obtained by testing the six prism halves per mortar mixture. The load at failure was determined using a hydraulic press with a capacity of 150 kN.

## 3. Results and discussion

### 3.1 Flexural strength

The 7-day and 28-day flexural strength results of the tested mortars, prepared with a water-to-binder ratio of 0.5, are shown in Figure 2. The ranges of flexural strengths after 7 and 28 days of curing were 7.86-9.09 MPa and 9.13-9.60 MPa, respectively.

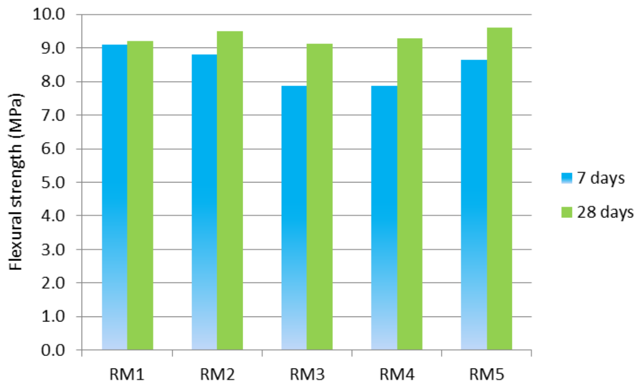


*Figure 2: 7-day and 28-day flexural strengths of examined mortars*

At the age of 7 days, the reference cement mortar (RM1) had the highest flexural strength, while mortar RM2 and RM5 had slightly lower, by 3.2% and 4.9%, respectively. Mortar RM4 and RM3 had lower flexural strengths by 13.5% and 13.6% in comparison to the reference mortar, respectively. At the age of 28 days, the RM5 mortar had the highest flexural strength that was slightly higher in relation to reference cement mortar (by 4.4%), followed by mortars RM2 and RM4, by 3.2% and 0.9%, respectively. Mortar RM3 had a slightly lower flexural strengths by 0.7% compared to the reference mortar.

Based on the obtained results at the age of 28 days, it can be concluded that all tested mortars had flexural strength in the range of the reference one (i.e. the differences were less than 10%).

Due to the presence of hemp fibers, the specimens did not completely physically break into two parts after testing the flexural strength, as illustrated in Figure 3a. Later, they were manually broken in half, Figure 3b.


*Figure 3: RM5 mortar specimens: a) after 7-day flexural strengths examination, and b) before compressive strength examination*

### 3.2 Compressive strength

The 7-day and 28-day compressive strength results of the tested mortars, prepared with a water-to-binder ratio of 0.5, are shown in Figure 4.

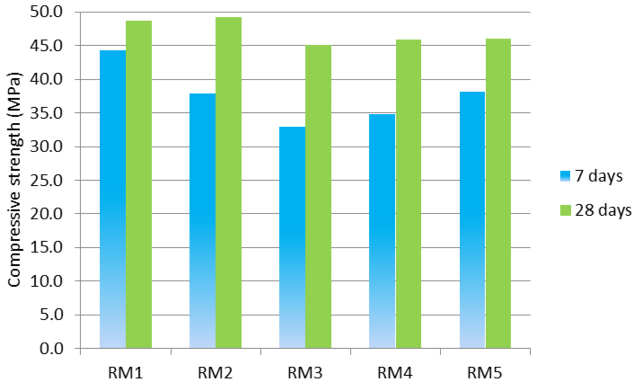


*Figure 4: 7-day and 28-day compressive strengths of examined mortars*

The ranges of compressive strengths after 7 and 28 days of curing were 32.92-44.22 MPa and 45.05-49.22 MPa, respectively. As in the case of the flexural strength, reference cement mortar had the highest compressive strength value at the age of 7 days, while mortar RM5, RM2, RM4 and RM3 had lower by 13.8%, 14.5%, 21.3% and 25.6%, respectively. At the age of 28 days, mortar RM2 had the highest strength, by 1.1% higher than the reference one, while mortars RM5, RM4 and RM3 had slightly lower strength, by 5.5%, 5.7% and 7.5%, respectively.

Based on the obtained results at the age of 28 days, the highest compressive strength had the mortar with 1% untreated hemp fibers, while all tested mortars fulfilled the requirement for class R4 of structural repair mortars according to the standard SRPS EN 1504-3 (2005) in terms of compressive strength (BS EN 12190:1999), i.e. their mean compressive strength values were higher than 45 MPa.

## 4. Conclusions

Based on the obtained experimental results, in terms of the effect of the different fiber conditions (e.g. untreated, or saturated with deionized water), and chemical pre-treatments (e.g. saturated $Ca(OH)_2$ solution, or 1.6M NaOH solution) on the 7-day and 28-day flexural and compressive strengths of the hemp fiber-reinforced repair cement mortars, the following can be concluded:

- All tested mortars fulfilled the requirement for class R4 of structural repair mortar according to the standard SRPS EN 1504-3 (2005) in terms of compressive strength;
- The highest 28-day compressive strength had the repair cement mortar with 1% untreated hemp fibers, while all tested mortars had compressive

strengths in the range of reference one, i.e. the differences were less than 10%;

- At the age of 28 days, the repair cement mortar containing 1% dried hemp fibers treated with 1.6 M NaOH solution had the highest flexural strength (higher by 4.4% in comparison to reference cement mortar), followed by the repair cement mortar containing 1% untreated hemp fibers (higher by 3.2%), while all tested mortars had flexural strength in the range of the reference one, i.e. the differences were less than 10%.

Considering the obtained results as well as environmental aspects of hemp fiber conditions/pre-treatments, it can be concluded that the optimal results were obtained in the case of untreated hemp fibers added in an amount of 1% by cement mass to the repair cement mortar.

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