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The Effect of Hemp Fibers on the Mechanical Properties of Cementitious Mortars

By Abdulrezzak Alkan[*], Yunus Gündüz[±] & Yuşa Şahin[○]

Today, various chemical and mineral additives are frequently used in order to improve the brittle structure of cementitious composites. The use of natural products for the sustainability of these materials has recently become widespread and R&D studies have intensified. Hemp, as a natural material, is widely used in the construction industry as well as in many areas. Although there are some studies on the use of hemp products for the insulation sector, studies on the usability of hemp fiber in cementitious composites are still limited. In this study, the use of hemp fibers in cementitious composites was investigated by considering the properties of hemp fibers and the strength of the matrix. The fibers obtained from the stem part of the hemp plant (male and female types) were cut in various lengths (0.5, 2, and 4 cm) and added in different volumes (0.5%, 1%, and 2%) into the mortar consisting of cement and sand. Two different water/cement ratios, 0.5 and 0.7, were used and physical and mechanical properties of the cementitious composites were determined by spread, unit weight, compressive and flexural strength tests. As a result, it was found that the difference between male and female hemp genders did not have a significant effect on the physical and mechanical properties of cementitious mortars. However, long fibers negatively affected the mechanical properties of cementitious mortars. Additionally, the mechanical properties of cementitious mortars were decreased at higher fiber contents.

Keywords: *hemp plant gender, hemp fiber, mortar, spread, mechanical properties*

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Introduction

Hemp is a plant species belonging to the Cannabaceae family. Its fibers, found in the stems, are used in the production of yarn and woven fabrics, while its pulp is used in paper production. Hemp is known as one of the oldest plant-based raw material sources in human history. Native to Central Asia, hemp is structurally tough, shrubby, with hollow stems, palmate leaves, and is dioecious and annual. Its fibers are durable and quite long. Hemp cultivation was first found in temperate regions of East Asia. Later, it began to be cultivated in West Asia, Anatolia, Egypt, Western Europe, and in the 17th century in America.

Hemp has some special properties that are not widely known, some of which can be listed as follows (Hemp Cultivation, 2019):

- One acre of hemp produces oxygen equivalent to 25 acres of forest.
- One acre of hemp can produce paper equivalent to four acres of trees.
- Hemp can be recycled into paper up to eight times.
- Hemp is a true radiation cleaner.
- All plastic products can be made from hemp.
- If a car body is made of hemp, its durability can be 10 times greater than steel.
- It is durable, inexpensive, and flexible for building insulation.
- Hemp requires very little water.
- Hemp is used to reduce the effects of AIDS, cancer chemotherapy, and radiation.

Concrete has been used as a building material for thousands of years. Humans have placed great importance on the physical strength of structures and have continuously improved the durability of the concrete they use. The most practical way to increase the physical strength of concrete is to add fiber materials to the concrete mix. Concrete, which is brittle on its own, gains flexibility with fiber materials and can carry more load without cracking. To ensure the integrity of concrete, materials such as steel fibers, natural fibers (sawdust, wool, linen, cotton, hemp), and artificial fibers (glass wool, plastic-based fibers) are used in concrete mixes (Gedik, 2012).

Studies have shown that the primary function of fibers incorporated into cementitious systems is to prevent cracking by transferring deformative forces from internal or external sources to the brittle concrete. Today, biocomposite materials, which utilize natural fibers in concrete and mortar, are gaining significant importance. Biocomposites are composites where the matrix or fiber portion is natural. Green composites are completely natural composites where the matrix and fiber portions are entirely biodegradable and renewable.

The advantages of biocomposite materials can be listed as follows:

- They are easily obtainable renewable resources worldwide.
- Low cost and energy requirements in their production.
- Low specific gravity, high specific strength, and high hardness.

- Healthier production and less wear on production machinery compared to synthetic composites.
- High electrical resistance.
- Good acoustic insulation properties.

Hemp, a biocomposite material, has recently begun to be used as a natural fiber in the construction sector. Hemp is considered a byproduct and does not harm the environment. With the recent technological advancements, the hemp plant, both its fibers and stem, as well as nanocellulose products obtained from hemp, are used as additives in concrete, and various types of building materials are obtained (Gül, 2008).

As stated in the introduction, natural and synthetic fibers are frequently used to improve various properties of concrete and cement-based materials. In his study, Ateşli (2019) examined the compressive and flexural strengths of samples obtained by substituting basalt fibers into cement mortars. Basalt fibers were used in the produced cement mortars at rates of 0.3%, 0.4%, and 0.5%. According to the results of the experiments conducted on the produced cement mortars, when the compressive strength values were compared with the control sample, it was determined that the samples with 0.3% basalt fiber additive showed an increase of 12.37% at the end of the 7th day and 12.89% at the end of the 28th day. When the control sample and the samples with 0.4% basalt fiber additive were compared, an increase of 3.6% occurred at the end of the 7th day and 4.18% at the end of the 28th day. When comparing control samples with samples containing 5% basalt fiber, a decrease in compressive strength of 3.6% was observed at the end of the 7th day and a decrease of 5.57% at the end of the 28th day. As a result of this study, it was observed that basalt fibers have a positive effect on the compressive and flexural strengths of cement mortars, and the usability of basalt fiber as a substitute material was demonstrated.

In this study, the fibrous structure obtained from the hemp stem was mixed with cementitious composites in specific ratios to investigate their mechanical properties. Thus, the usability of hemp products in cementitious composites was explored.

Materials and Methods

CEM I 42.5 R type cement was used in this study. The chemical composition of the cement is given in Table 1.

Table 1. *Chemical composition of cement*

Chemical composition	%
CaO	61.75
SiO2	17.01
Al2O3	4.8
SO3	3.75
Fe2O3	3.04
MgO	2.53
K2O	1.23
Na2O	0.249
KK	4.86

In this study, crushed limestone sand with a size of 0-5 obtained from a crushed stone plant was used. The specific gravity of the limestone sand is 2.6 kg/m^3 and its water absorption value is 1.95%.

The hemp fibers surrounding the hemp stalk were peeled from the hemp plant in their entirety. These whole hemp fibers were thinned by carding. The thin hemp fibers were cut into 0.5, 2, and 4 cm sizes and prepared for use in the study.

Figure 1. *Hemp Fibers*

In this study, hemp fibers of 0.5, 2, and 4 cm in length and 0.1-0.3 mm in diameter were added to mixtures at percentages of 0.5%, 1%, and 2% to produce mortars with water-to-cement ratios of 0.5 and 0.7. The following examples are provided for sample nomenclature.

Table 2. *Mixture Compositions of Hemp Fiber Mortars (g)*

Sample code	Hemp fiber	Cement	Water	Sand
5S	-	450	315	1350
F05F5S05	2.25			
F05F5S1	4.5			
F05F5S2	9			

-F05F5S05: F05F is a sample of female fibers with a size of 0.5 cm; 5S is limestone sand with a water-to-cement ratio of 0.5%; and 05 is a mortar sample with 0.5% fiber volume.

Within the scope of this study, spreading tests were conducted in accordance with the TS EN 1015-3 standard, compressive strength tests were conducted in accordance with the TS EN 196-1 standard, and flexural strength tests were performed.

Flexural strength tests were conducted on prismatic specimens with dimensions of 4x4x16 cm produced within the scope of this study. The flexural strength test was performed at a loading rate of 0.05 kN/s and on three specimens for each mixture group. The average of the results from the three specimens was taken as the test result.

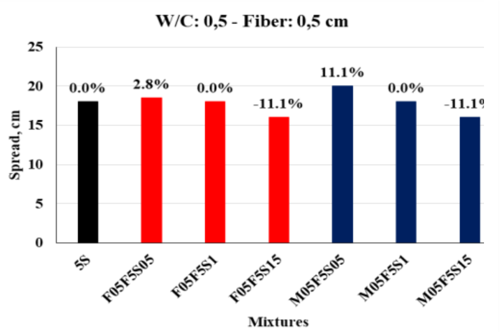
Within the scope of this study, compressive strength tests were performed on the specimens obtained from the flexural strength test. The compressive strength test was performed at a loading rate of 2.4 kN/s and on a total of 6 specimens obtained from the specimens that were divided into 2 parts after the flexural strength test. The test result was determined by taking the average of the results obtained from the 6 specimens.

Figure 2. *Flexure and Compressive Strength Apparatus*

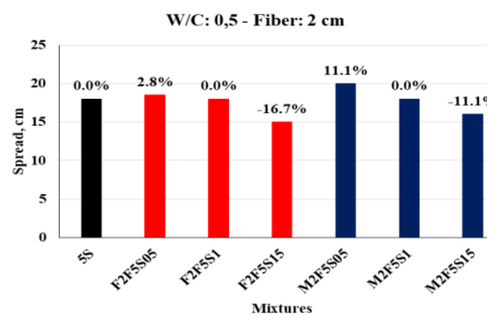
Results

Graphs showing the dispersal experiment results are given in Figures 3 and 4.

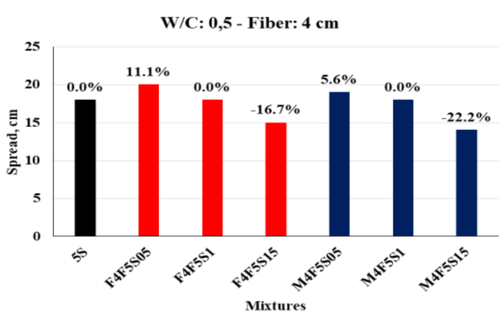
Figure 3. *Spreading Test Results of Fiber-Containing Mortars with a 0.5 Water/ Cement Ratio*



a) 0.5 cm fiber



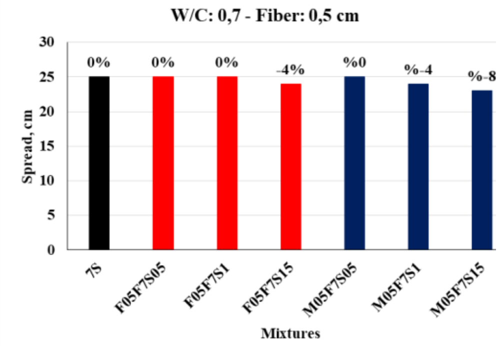
b) 2 cm fiber



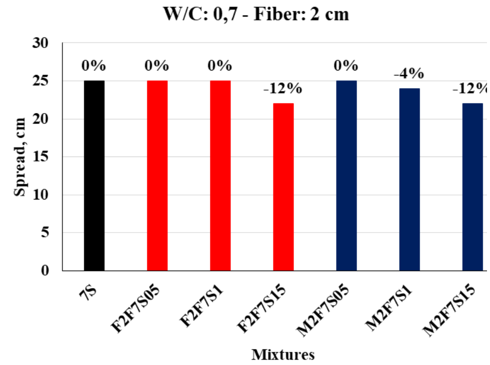
c) 4 cm fiber

In hemp fiber mortars with a water-to-cement ratio of 0.5, a decrease in spreading values was observed as the hemp fiber content increased. Mixtures with 2% hemp fiber content by volume showed a decrease in spreading value compared to the reference mixture: 11.1% for the 0.5 cm fiber mixture, 11.1% to 16.7% for the 2 cm fiber mixture, and 16.7% to 22.2% for the 4 cm fiber mixture. Mortars containing male and female hemp fibers yielded similar spreading value results. In this context, it was observed that the type of hemp fiber had no effect on the spreading value.

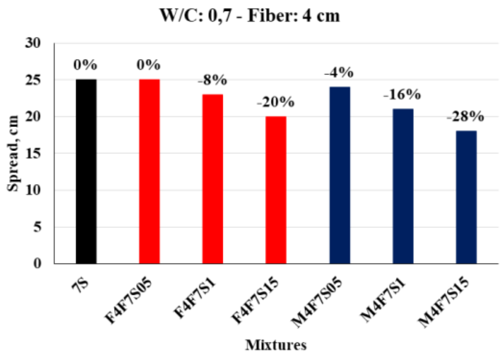
Figure 4. *Spreading Test Results of Fiber-Containing Mortars with a 0.7 Water/ Cement Ratio*



a) 0.5 cm fiber



b) 2 cm fiber

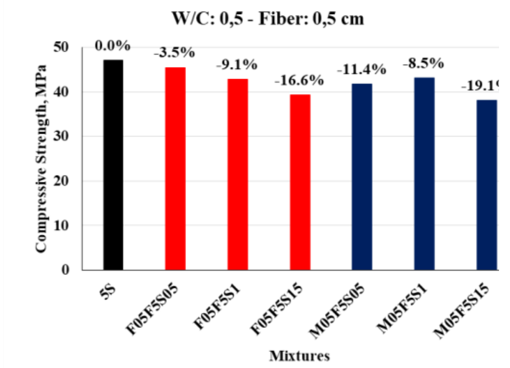


c) 4 cm fiber

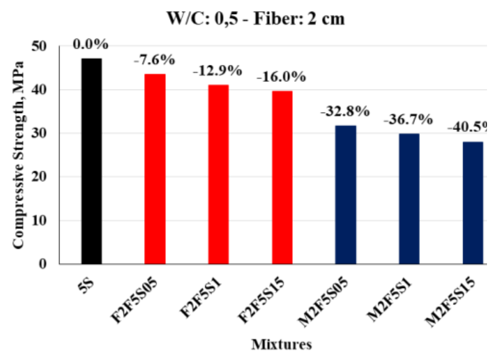
In hemp fiber mortars with a water-to-cement ratio of 0.7, similar to those with a water-to-cement ratio of 0.5, a decrease in spreading values was observed as the hemp fiber content increased. The greatest decrease in spreading value compared to the reference mixture was observed in mixtures with 4 cm fibers, with a decrease of 28%. Except for short fiber length, mortars containing male and female hemp fibers yielded similar spreading value results. In this context, it was observed that hemp fiber type had no effect on spreading value.

Graphs showing the compressive strength results are given in Figures 5 and 6.

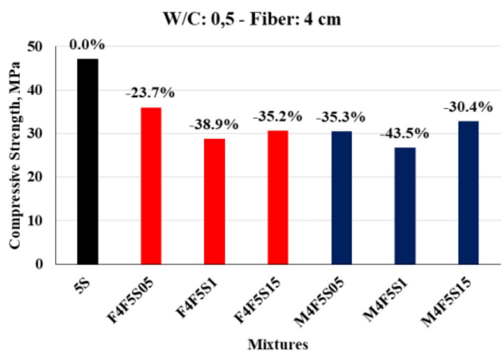
Figure 5. *Compressive Strength Results of Fiber-Containing Mortars with a 0.5 Water/Cement Ratio*



a) 0.5 cm fiber



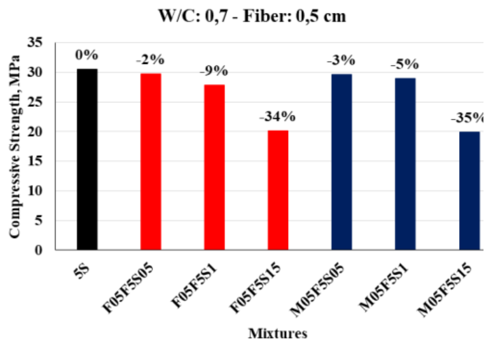
b) 2 cm fiber



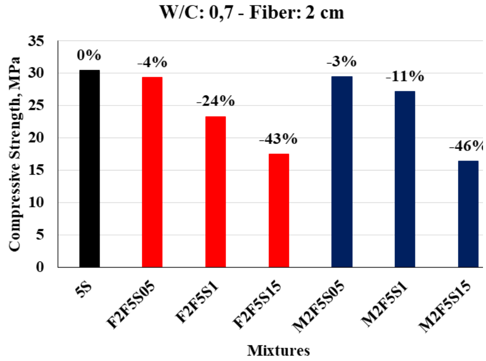
c) 4 cm fiber

In hemp fiber mortars with a water-to-cement ratio of 0.5, a decrease in compressive strength values was observed as the hemp fiber content increased. The compressive strength value of the reference sample was found to be 47.1 MPa. The greatest decrease in compressive strength values was obtained in the mixture using 4 cm long fibers, with a decrease of 43.5%. Except for mixtures using 2 cm long hemp fibers, mortars containing male and female hemp fibers exhibited similar compressive strength behavior. In this context, it was observed that the type of hemp fiber had no effect on the compressive strength value.

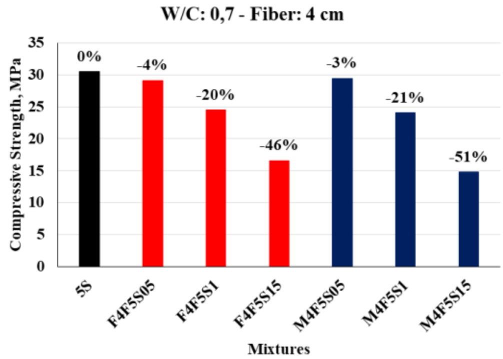
Figure 6. *Compressive strength results of Fiber-Containing Mortars with a 0.7 Water/ Cement Ratio*



a) 0.5 cm fiber



b) 2 cm fiber

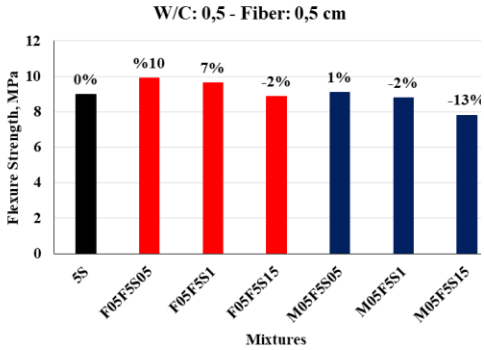


c) 4 cm fiber

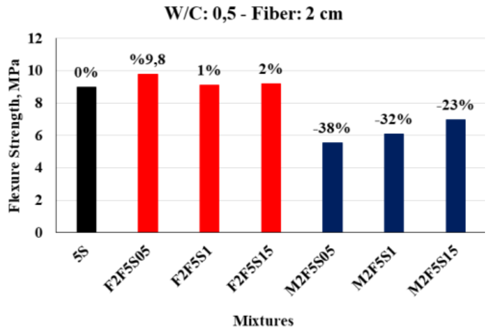
In hemp fiber mortars with a water-to-cement ratio of 0.7, it was observed that the compressive strength values of the mortars decreased as the hemp fiber content increased. The compressive strength value of the reference sample was found to be 30.5 MPa. The greatest decrease in compressive strength values was obtained in the mixture using 4 cm long fibers, with a decrease of 51.3%. Mortars containing male and female hemp fibers yielded similar compressive strength values. In this context, it was observed that the type of hemp fiber did not have an effect on the compressive strength value.

Graphs showing the flexure strength results are given in Figures 7 and 8.

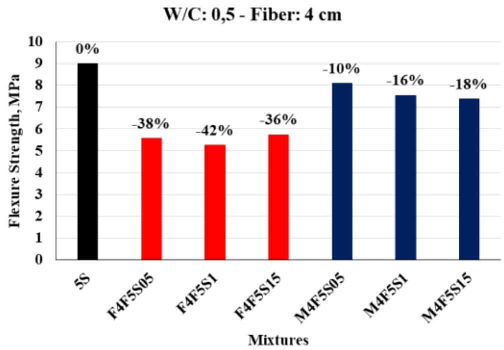
Figure 7. *Flexural Strength Results of Fibrous Mortars with a 0.5 Water/Cement Ratio*



a) 0.5 cm fiber



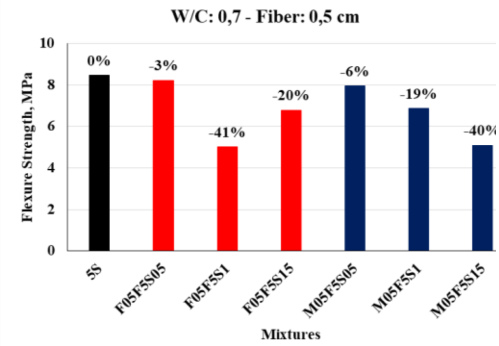
b) 2 cm fiber



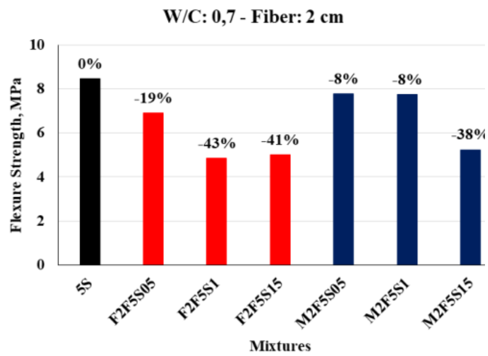
c) 4 cm fiber

In hemp fiber mortars with a water-to-cement ratio of 0.5, it was observed that the flexural strength values of the mortars decreased as the hemp fiber content increased. The flexural strength value of the reference sample was found to be 9 MPa. In general, flexural strengths decreased with the use of hemp fibers. The greatest decrease was observed in the mixture containing 4 cm long fibers, with a decrease of 41.5%. In mixtures using only short fibers, mortars containing male and female hemp fibers yielded similar flexural strength values. In this context, it can be said that the type of hemp fiber does not have a significant effect on the flexural strength value.

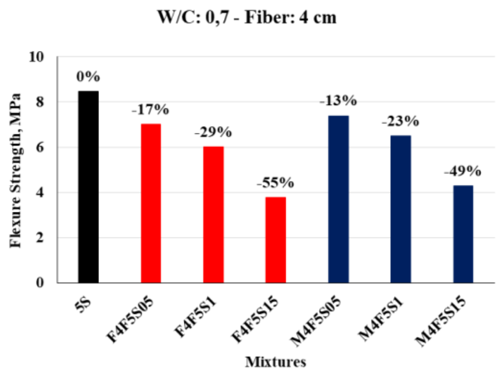
Figure 8. *Flexural Strength Results of Fibrous Mortars with a 0.7 Water/Cement Ratio*



a) 0.5 cm fiber



b) 2 cm fiber



c) 4 cm fiber

In hemp fiber mortars with a water-to-cement ratio of 0.7, it was observed that the flexural strength values of the mortars decreased as the hemp fiber content increased. The flexural strength value of the reference sample was found to be 8.46 MPa. The greatest decrease in flexural strength was observed in the mixture containing 4 cm long fibers, with a decrease of 55.3%. Mortars containing male and female hemp fibers yielded similar flexural strength values. In this context, it was observed that the type of hemp fiber had no effect on the compressive strength value.

Conclusions

In cementitious composites, it has been observed that the spreading value decreases as the volume of hemp fibers increases. Similarly, the spreading value is negatively affected as the length of the hemp fibers increases. The greatest decrease in spreading values was obtained in the mixture with a high water-to-cement ratio, specifically in the mixture containing 2% 4 cm long fibers, reaching a decrease of 28%. It is thought that the high water absorption capacity of hemp fiber products negatively impacts the processability of the mixtures.

It has been observed that as the volume of hemp fiber products increases in cemented composites, the unit weight decreases. Similarly, as the length of the hemp fiber increases, the unit weight is negatively affected. The highest decrease in unit weight was obtained in mixtures with a high water-to-cement ratio, specifically in a mixture containing 2% of 4 cm long fibers, reaching a decrease of 13.3%. This decrease in unit weight in cemented composites is due to the low specific gravity of hemp fiber.

It has been observed that as the volume of hemp fiber products increases in cementitious composites, the compressive strength decreases. Similarly, as the length of the hemp fiber increases, the compressive strength is negatively affected. The highest decrease in compressive strength was obtained in mixtures with a high water-to-cement ratio, specifically in a mixture containing 2% of 4 cm long fibers, reaching a decrease of 51.3%.

It has been observed that as the volume of hemp fiber products increases in cementitious composites, the flexural strength value decreases. Similarly, as the length of the hemp fiber increases, the flexural strength value is negatively affected. The highest decrease in flexural strength values was obtained in the mixture where 2% of the fiber was 4 cm long, representing 55.3%. Composites containing hemp fibers with a length of 0.5 cm yielded results closer to the reference sample.

In conclusion, hemp fiber has been shown to be usable in cementitious composites. However, performance comparisons of hemp fiber with commonly used natural fibers in the market are necessary. Furthermore, the usability of hemp fiber in cementitious composites should be investigated through long-term performance tests.

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