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Research Article

The effect of hemp fiber usage on the mechanical and physical properties of cement based mortars

Gökhan Kaplan*[1,a], Oğuzhan Yavuz Bayraktar[2,b]

[1]*Atatürk University, Faculty of Engineering, Department of Civil Engineering, Erzurum, Turkey.*
[2]*Kastamonu University, Faculty of Engineering and Architecture, Department of Civil Engineering, Kastamonu, Turkey*

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Abstract

In this study, the impact of hemp fibers used in different lengths and ratios on the physical and mechanical properties of mortars has been examined. In this context, the flow diameters, dry unit weight, porosity, bending and compressive strength and capillarity properties of the mortars have been determined. Hemp fiber was used in the lengths of 0.5, 1 and 2 cm and was added to the mixtures in ratios of 1, 2 and 3%. The increase in fiber length and ratio decreased the flow diameter of the mortars and increased the porosity values. In the case of using 3% fiber, the dry unit weight values of the mortars fell below 2100 kg/m^3. It is understood from the flexural strength results that the curing process is very important for the improvement of the fiber-matrix interface when hemp fiber is used. As a result, as the fiber ratio increased, the flexural strength increased in both 7 and 28 days. But the increase in fiber ratio decreased the 7 and 28 days compressive strength values. According to the capillary test results, it was observed that the optimum fiber ratio was 1%. As the fiber ratio increased, the capillarity coefficients of the mixtures also increased. Compressive strengths of 50 MPa and above were obtained in mixtures having 1% fiber with a capillarity coefficient of less than 0.10 mm/min$^{0.5}$. As a result, it was determined that the most suitable fiber length is 1 cm. It has been determined that 1 or 2% fiber content is more suitable in the production of mortars.

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1. Introduction

Nowadays, concrete ranks at the top among building materials that are mostly used in the world. Concrete is a brittle building material with very low tensile strength, energy absorption capacity and flexural toughness [1]. In order to eliminate this disadvantage of concrete, steel or synthetic fibers are added into it. [1]. Extensive research continues today to evaluate and determine the advantages of fiber-reinforced concrete. Various fiber types such as steel, carbon, glass, polypropylene, polyolefin are used in concrete production. The use of steel or synthetic fiber is expensive and environmentally harmful with respect to production [1]. For this reason, researches have been made in relation to the use of natural fibers in concrete production in recent years. Use of natural fiber goes back to about 5,000 years ago. Asbestos fibers have been used to strengthen clay pots in Scandinavia. In addition, the Egyptians added straw fiber into the clay blocks used in the construction of the walls [2]. Natural fibers are mostly preferred in developing countries. Since natural fibers are not fully accepted as an alternative to synthetic fibers, the use of natural fibers in developed countries is still limited. Another disadvantage of natural fibers is that their long-term durability properties are not known exactly. [3]. Natural fibers absorb more water than synthetic fibers and its distribution in concrete can sometimes create a

*Corresponding author: gkaplan@atauni.edu.tr
[a] orcid.org/0000-0001-6067-7337; [b]orcid.org/0000-0003-0578-6965
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problem. [1]. Unlike steel or synthetic fibers, natural cellulosic fibers contribute to a more sustainable structure. The environmental impact of natural fibers is less CO_2 emissions as they can be grown locally and require a low amount of energy for production. Besides, it is thought that natural fibers have negative carbon feature due to the photosynthesis of plants [1]. Mehta and Monteiro stated that natural fibers increase the tensile strength and bending toughness. [2]. It has also been observed that natural fibers improve the thermal insulation properties of concrete by reducing the thermal conductivity coefficient [4]. There are studies showing that natural fibers reduce the compressive strength because they cause adherence problems due to their superficial properties [5]. Hemp fibers, which are among natural fibers, have recently been used in the production of cement-based composites. Natural fibers must have appropriate physical and mechanical properties to be used in concrete. [6].

Usage of vegetable fibers such as hemp in terms of cost and performance was largely developed in Europe in the early 1990s and adopted by North American automakers in the late 1990s. [7]. Among the most important properties of hemp fiber, low cost and high tensile strength come to the forefront [6-8]. Hemp fibers vary in cylindrical and l/d (length/diameter) and they often have irregular surfaces. Average tensile strength of hemp fibers is 857 MPa, and E-Modulus is approximately 58 GPa [9]. In the study conducted by Sedan et al, E-Modulus decreased while flexural strength increased in optimum hemp fiber content. But, adherence of the fibers with the matrix was increased with the surface improvement realized with alkalis [10]. In the study they conducted, Elfordy et al improved mechanical and thermal properties of concrete blocks with hemp fiber in their study [11]. Ghalieh et al have obtained promising results regarding the use of polymer blends that are produced from hemp fiber for reinforcing reinforced concrete columns [4,12]. Siriluk et al. investigated the use of hemp fiber in the reinforcement phase of reinforced concrete beams. As a conclusion, they stated that it is more appropriate to apply hemp fiber to the beam in U shape (bottom surface+two side surfaces) [13]. Çomak et al showed that optimum ratio for hemp fiber with 12 mm length is 2-3% [14]. Ghosn et al used hemp fibers in concrete production and they observed improvements in bending toughness of concrete [15]. In the literature, there are studies [16-19] examining the contribution of hemp fiber to durability. Kremensas et al examined thermal and insulation properties of hemp fiber [20]. Besides, the microstructure properties of hemp fiber were also examined. [21-22].

In this study, physical and mechanical properties of mortars being produced from hemp fibers having different lengths and proportions have been investigated. In this regard, fresh and hardened mortar experiments have been carried out using 0.5, 1 and 2 cm long hemp fibers with ratios of 1, 2 and 3%.

2. Material and Method

2.1. Materials

CEM I 42.5R type cement being in accordance with TS EN 196-1 standard has been used in the preparation of the mixtures. Chemical and physical properties of cement are shown in Table 1.

Table 1. Chemical and physical properties of CEM I 42,5 R

Oxide (%)	CaO 64,08	SiO_2 19,03	Al_2O_3 4,15	Fe_2O_3 3,56	MgO 1,04	SO_3 3,01	Na_2O 0,45	K_2O 0,71	LOI 3,55
Specific gravity	3,13		Specific surface area (cm^2/g)		3230		Setting time-Initial/Final (Min.)		210/270

Limestone (limestone) having 0-4 mm sieve opening has been used as aggregate. Grain distribution of aggregate is shown in Figure 1. Specific gravity of aggregate has been determined to be 2.66 and the water absorption value has been determined as 2.6%. Chemical and physical properties of hemp fiber are given in Table 2.

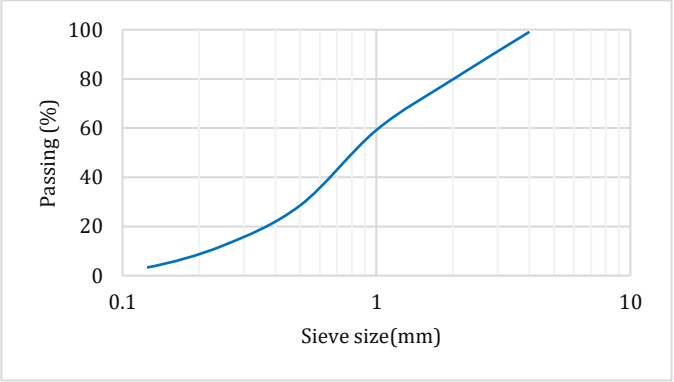


Fig.1 Particle distribution of limestone aggregate

Table 2. Technical properties of hemp fiber

Chemical properties		Physical properties	
Cellulose (%)	70-75	Specific gravity	1.47
Lignin (%)	3.5-6.0	Fiber length (cm)	0.5-2.0
Hemicellulose (%)	18-23	Moisture absorption (%)	~12
Pectin (%)	4-8	Tensile strength (MPa)	690
Wax (%)	1	Elongation at break (%)	3

No water reducing additives have been used in preparation of the mixtures and only potable water (Kastamonu city water) has been used. Hemp fibers were used in the lengths of 0.5, 1 and 2 cm. General view of hemp fibers is shown in Figure 2.

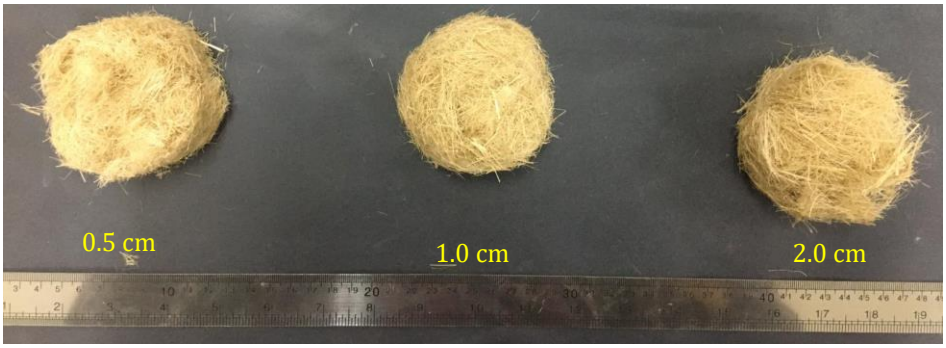


Fig. 2 General view of hemp fibers

2.2. Method

In the preparation of the mixtures, w/c (water/cement) ratio was selected as 0.50, while a/c (aggregate/cement) ratio was selected as 3. Amount of hemp fibers has been selected according to the cement amount. Fibers have been added to the mixture at the ratios of 1, 2 and 3% of the cement weight. Ratios and material quantities of mixtures have been presented in Table 3. Fibers have been added to the mixture in three different lengths and ratios. A total of 10 mixtures have been prepared, including 9 different fiber mixtures and 1 non-fiber mixture (reference). Hemp fibers were latest added to the mixture. After the aggregate, water and cement were mixed homogeneously, the fibers were added to the mixture. The fibrous mixture is mixed at a low speed of 1 minute and at a high speed of 1 minute.

Table 3. Mixing ratios and material quantities

Mixing ratio			Material quantities (g)			
Mix No.	Fiber length (cm)	Fiber raito (%)	Cement	Aggregate	Water	Fiber
1	0.5		450	1350	225	4,5
2	1,0	1	450	1350	225	4,5
3	2,0		450	1350	225	4,5
4	0.5		450	1350	225	9,0
5	1,0	2	450	1350	225	9,0
6	2,0		450	1350	225	9,0
7	0.5		450	1350	225	13,5
8	1,0	3	450	1350	225	13,5
9	2,0		450	1350	225	13,5
10 (Ref.)	-	-	450	1350	225	-

Flow diameters on the mortars have been determined first in accordance with the ASTM C 1437 standard. Mortars have been placed in the molds in two layers by applying vibration. Compressive and flexural strengths of 7 and 28 days have been carried out in accordance with ASTM C 349 and ASTM C 348 standards. For flexural strength test, prism samples of 40x40x160 mm have been used and compressive strength test has been carried out on the samples being divided into two at the end of the test. Capillarity properties of mortars have been determined in samples of 50x50x50 mm and in accordance with ASTM C 1585

standard. At the end of 28 days of curing, samples have been dried at 50 °C for 3 days and capillarity test was started. After water impermeability material has been applied to side surfaces of the samples, amount of water being absorbed by capillary way at 1th, 5th, 10th, 20th, 30th, 60th, 120th, 180th, 240th, 300th, 360th and 1440th minutes has been determined. Water absorption and porosity properties have been determined according to Archimedes' principle. Cube samples having size of 50x50x50 mm were used in relation to water absorption and porosity properties.

3. Results and Discussion

3.1. Fresh mortar properties

As a result of the experiment being performed according to ASTM C 1437 standard, the fresh state properties of some mortars (mixtures sufficient and poor in terms of workability) are shown in Figure 3. Flow diameters of mortars are shown in Figure 4.

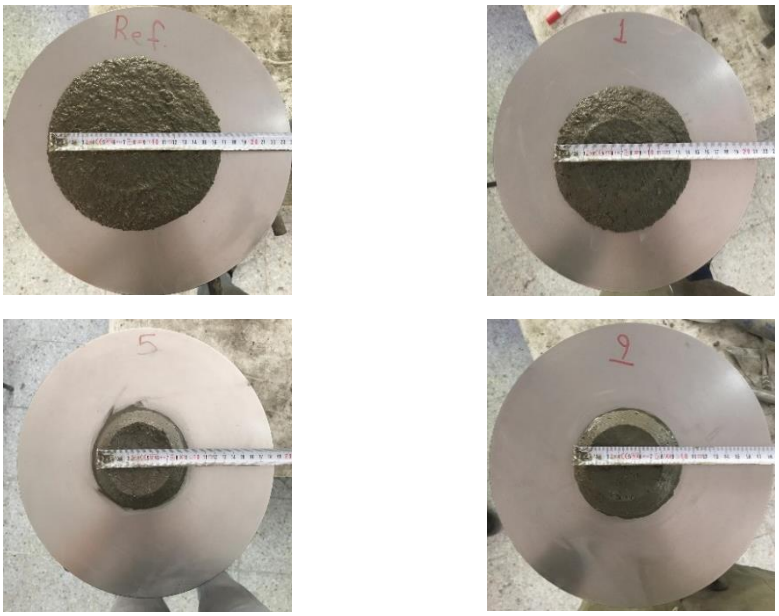


Fig. 3 Fresh properties of some mortars

As it is seen in Figure 4, as the fiber ratio and length increase, flow diameters of mortars get reduced. Flow diameters of mortars vary in the range of 14.4-9.4 cm. While the diffusion diameter of the reference mixture without fibers has been determined as 16.8 cm, the flow diameters of the mixtures with the addition of fiber has decreased below 15 cm. Spread diameter was generally 10 cm or below, especially when the fiber ratio was 2 or 3%. As a result of the increase in fiber length, the maximum processability loss has occurred at the ratio of 1% fiber. If the fiber length increased from 0.5 cm to 2 cm, flow diameter decreased by 29.8%. In the mixtures with 3% fiber, this ratio has been determined as 5%. Flow diameters of mixtures in which fiber with ratio of 2 and 3% has been used, showed similar properties. Usage of 2 cm long or 3% fiber affected the workability of the mortars negatively. Flow diameters of the fiber mixtures decreased by an average of 40% compared to the reference mixture.

As a result of the increase in fiber content and ratio, workability properties of mortars decrease. As a result of the increase in the fiber ratio, internal friction increases, hence decreasing the processability. If the fiber length increases, the fibers are not distributed homogeneously in the mixture and in this case it decreases the processability [23]. Similar results were observed in other studies in the literature [24-26].

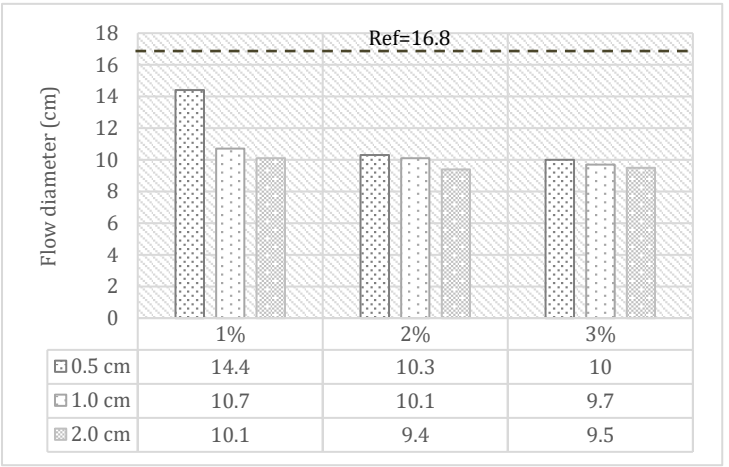


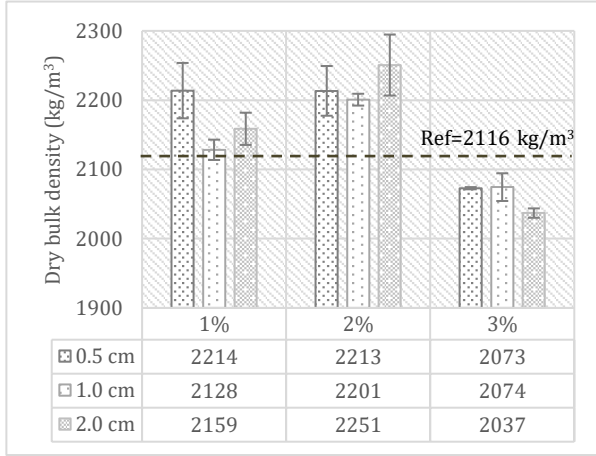
Fig. 4 Flow diameters of mortars with different fiber ratios and lengths

3.2. Dry Bulk Density (BD) and porosity properties of mortars

BD and visible porosity of the mortars are presented in Figure 5. BD values of fibrous mixtures vary in the range of 2037-2251 kg/m^3 (Figure 5a). BD value of the reference mixture without fiber is determined as 2116 kg/m^3. BD of the mixtures using only 3% fiber were lower than the reference mixture. This situation can be explained by the loss of workability. If 1 and 2% fiber is used, BD values are higher than the reference. When 1 and 2% fiber mixtures have been compared, the increase in fiber ratio increased the BD values of mortars. Reason for this effect can be explained by the particular that the mixing ratios are not volume-based and the proportions are fixed. Because as a result of the increase in the amount of fiber, BD values have increased. At 3% fiber content, the difficult placement of the mortars in the mold caused the formation of a hollow structure. When the fiber length is 1 or 2 cm, the BD values of mortars generally decrease. BD value exceeded 2250 kg/m^3 in the case of only 2% and 2 cm long fiber. Mixtures with a flow diameter of 10 cm and less, using 3% fiber, also have BD values below 2100 kg/m^3. Since the increase in fiber length prevents homogeneous distribution, it decreased the processability and as a result, the BD values generally decreased.

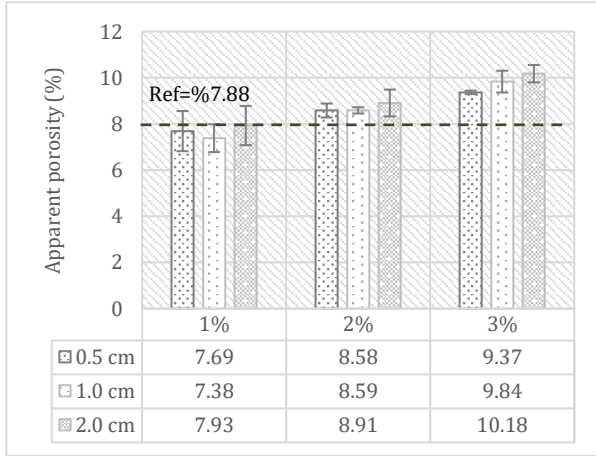
In Figure 5b, it is seen that the porosity values of fiber-based mixtures vary between 7.38-10.18%. As the fiber ratio in the mixtures increases, the apparent porosity values also increase. In addition, the increase in fiber length increased the apparent porosity values. Values closest to 7.88%, which is the porosity value of the reference mixture, were obtained in mixtures in which 1% fiber was used. Even the use of 0.5 and 1 cm long fibers made the porosity values come below the reference mixture. Mixtures produced from 0.5 cm long fibers were more homogeneous than other mixtures, as the spread diameter was 14.4 cm. This situation caused a decrease in porosity values. In addition, it has been stated in some studies that short fibers reduce porosity by acting as micro aggregates. The porosity values of the mixtures using 2 and 3% fiber are above 8%. (2037 kg/m^3) It is seen that the use of fiber with a length of 2 cm and 3% in mixtures provides the lowest BD value

and the porosity value exceeds 10%. In the study conducted by Olivito and Zuccarello, as the length of the steel fiber increases, the unit volume weight values decrease. However, this reduction is negligible. In addition, as the steel fiber ratio increased, the unit weight values of the mixtures increased [27]. In the study conducted by Asasutjarit et al, as the fiber length increased, the density of the composites decreased and the water absorption values increased. [28].



	1%	2%	3%
0.5 cm	2214	2213	2073
1.0 cm	2128	2201	2074
2.0 cm	2159	2251	2037

(a) Dry bulk density



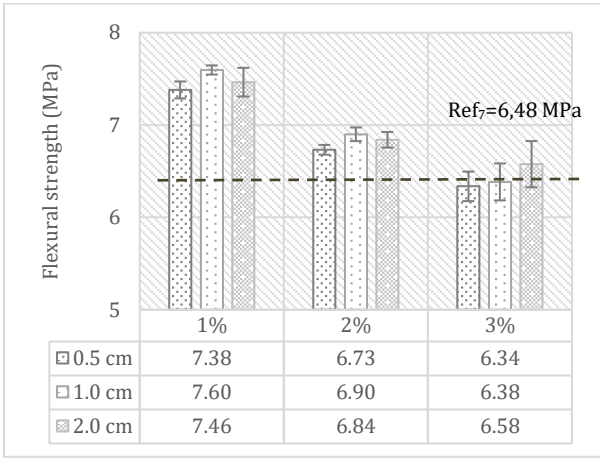
	1%	2%	3%
0.5 cm	7.69	8.58	9.37
1.0 cm	7.38	8.59	9.84
2.0 cm	7.93	8.91	10.18

(b) Apparent porosity

Fig. 5 Physical properties of fibrous and non-fibrous mortars

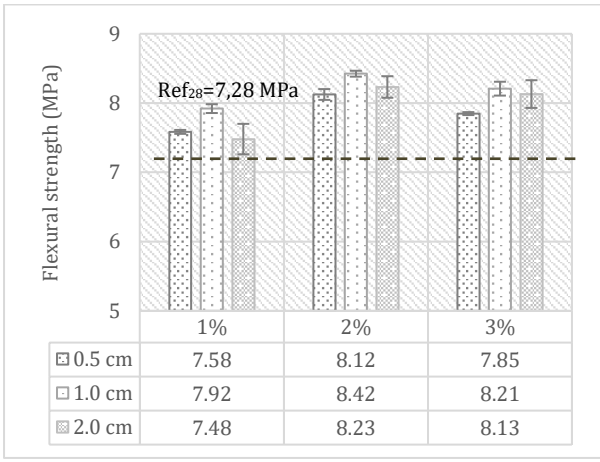
3.3. Mechanical properties of mortars

The 7 and 28 days flexural strength results of the mortars are given in Figure 6. As seen in Figure 6, it is seen that the 7 and 28 days flexural strength of the mortars do not show parallelism.



	1%	2%	3%
0.5 cm	7.38	6.73	6.34
1.0 cm	7.60	6.90	6.38
2.0 cm	7.46	6.84	6.58

(a) 7 days



	1%	2%	3%
0.5 cm	7.58	8.12	7.85
1.0 cm	7.92	8.42	8.21
2.0 cm	7.48	8.23	8.13

(b) 28 days

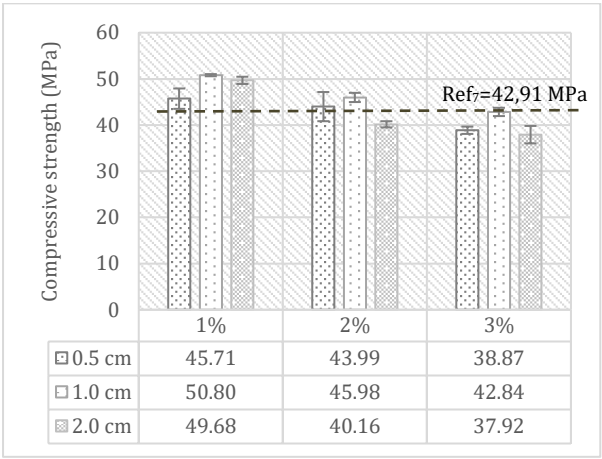
Fig. 6 Flexural strength of mortars

Figure 6a shows that the bending strength of the fiber-free mixture is 6.48 MPa. When using 3% of 0.5 and 1 cm long fibers, the flexural strength was lower than the reference. This situation is thought to be caused by the loss of workability. Fiber length of 2 cm relatively increased flexural strength. In general, the increase in fiber length increases the bending strength. The highest bending strength was obtained when 1% fiber of 1 cm length was used. Flexural strength increased by 14.7% compared to the reference mixture. As a result of the increase in fiber ratio, their bending strength decreases. In particular, the use of 3% fiber has reduced the flexural strength to less than 6.50 MPa.

Figure 6b shows the 28-day flexural strength of the mortars. As a result of the increase in curing time, the flexural strength of the mortars has improved significantly. While the increase in fiber ratio in the 7-day bending strength caused a loss of strength, the opposite was observed in the 28-day blends. Especially, the strength of the mixture with a 7-day bending strength of 6.58 MPa, 2 cm long and containing 3% fiber, increased by 23.6% on the 28th day. On the 28th day, flexural strength of all mixtures is higher than the reference

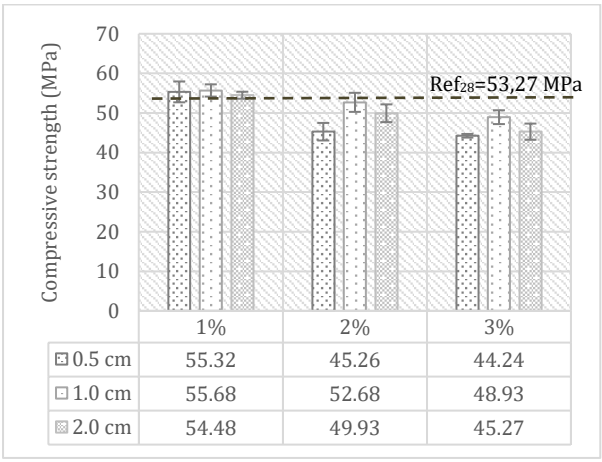
mixture. Up to 2% fiber ratio, as the fiber length and ratio increases, the bending strength increases. Reductions in flexural strength were observed at 3% fiber content. It is understood that the ratio of 1 cm of the optimum fiber length is 2%. As a result of the increase in curing time, the fiber-matrix interface improved and resulted in an increase in flexural strength. It may be necessary to keep the curing period long for natural fibers such as hemp. It would be more appropriate to examine these findings with SEM analysis. Page et al. As the hemp fiber ratio increased, the bending strength increased. The increase in fiber length decreased the bending strength [29]. In addition, it was emphasized that the consistency of the mixture is effective in fiber orientation and that in this case it affects the bending strength. [30].

As seen in Figure 7a, the highest compressive strengths were obtained at 1% fiber content. As a result of the increase in fiber ratio, their 7-day compressive strength decreased. Using 1% of the 0.5 cm long fiber increased the compressive strength by 4.2% compared to the reference mixture. Fiber length of 1 cm generally increases compressive strength. It has been observed that blends produced from 0.5 and 2 cm long fibers have similar properties. If the fiber content was 3%, the compressive strength remained below the reference mixture. Figure 7b shows that the compressive strength increases as a result of the increase in curing time. All blends produced with 1% fiber provided higher compressive strength than the reference blend. However, as the fiber ratio increases, the compressive strength of the mortars decreases. Compressive strength of mixtures especially produced with 3% fiber is below 50 MPa. However, the fiber length being 1 cm generally increases the compressive strength. Page et al. Similar results were observed in the study conducted by [29]. Since the porosity values of the mixtures using fiber at 2 and 3% ratios are high, their compressive strength has decreased. However, an increase in bending strength was achieved at 2% fiber content. Although the porosity is high in these mixtures, the fibers act as reinforcement, preventing the crack propagation and increasing the bending strength.



	1%	2%	3%
0.5 cm	45.71	43.99	38.87
1.0 cm	50.80	45.98	42.84
2.0 cm	49.68	40.16	37.92

(a) 7 days



	1%	2%	3%
0.5 cm	55.32	45.26	44.24
1.0 cm	55.68	52.68	48.93
2.0 cm	54.48	49.93	45.27

(b) 28 days

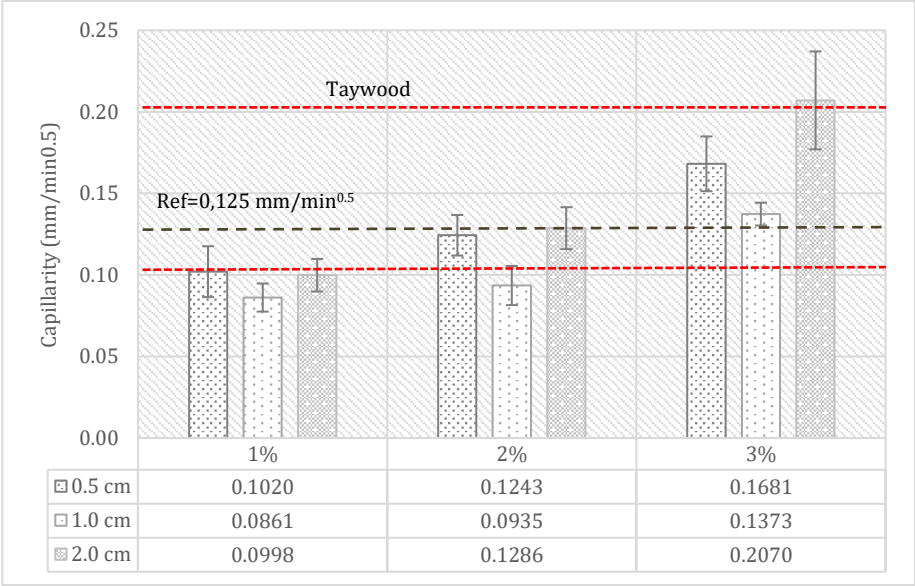
Fig. 7 Compressive strength of mortars

3.4. Sorptivity properties of mortars

Sorptivity properties of mortars based on time are shown in Figure 8. With the increase in the fiber ratio, capillary coefficient of mortars also increased. Besides, the use of 1 cm long fiber reduces the capillarity coefficient, while the situation where fiber length is 2 cm negatively affects this. Capillarity coefficient of the reference mixture was measured to be 0.125 mm/min$^{0.5}$, and mixtures with 1% fiber ratio remained below this value. It was observed that the mixtures with 2% fiber content showed values close to the reference mixture. It is seen that capillarity and compressive strength show similar properties. It was observed that mortars with low capillarity coefficient showed higher compressive strength.

Taywood has made a quality classification for capillary properties of cement-based composites [31]. Classification is graded as good if the capillarity coefficient is less than 0.10 mm/min$^{0.5}$, it is graded as medium if it is between 0.1-0.2 mm/min$^{0.5}$, and it is graded as bad if it is greater than 0.2 mm/min$^{0.5}$. Using 1% of fibers of 1 and 2 cm long fibers

reduced the capillarity coefficient below 0.10 mm/min$^{0.5}$. The capillarity coefficient exceeded 0.20 mm/min $^{0.5}$ in the case of using 3% of 2 cm long fiber. It is observed that the mortars generally have a medium level of capillarity. In the study conducted by Nibudey et al, capillarity coefficient of the mixtures increased as the fiber ratio increased [32]. Similar results were found in the study conducted by Ramezanianpour et al. [33]. Rostami et al reported that fibers can also reduce the porosity of mixtures by closing gaps in some cases. [34].



	1%	2%	3%
0.5 cm	0.1020	0.1243	0.1681
1.0 cm	0.0861	0.0935	0.1373
2.0 cm	0.0998	0.1286	0.2070

Fig. 8 Sorptivity properties of mortars

4. Conclusions

Increasing of fiber length and ratio has decreased the flow diameter of mortars. Especially if 3% fiber is used, flow diameters have decreased below 10 cm. Increasing of fiber length and ratio prevents homogeneous distribution of fibers.

Using 2% fiber increased the BD values of the mixtures. But with the fiber ratio being 3%, the BD values decreased depending on the processability. There is a difference of approximately 10% in the BD values between the mixtures. As the fiber length and ratio increase, porosity values of mixtures increase. Especially if 2 and 3% fiber was used, higher porosity value was obtained compared to the reference mixture.

As the fiber ratio increased in the 7-day mixtures, the flexural strength decreased. However, the increase in fiber length increased the flexural strength relatively. In 28-day mixtures, as the fiber ratio increased, the flexural strength increased. This is an indication of the improvement of the fiber-matrix interface with improved hydration. It has also been observed that 1 cm long fibers are more suitable in terms of flexural strength.

As the fiber ratio increases in 7- and 28-day mixtures, the compressive strength decreases. If the fiber length was 1 cm, the compressive strength increased, while the strength loss occurred at 2 cm fiber length. It has been observed that with 1% hemp fiber, compressive strengths of 50 MPa and above can be obtained.

Capillarity coefficients of mixtures produced with 3% fiber ratio were relatively higher. But the capillarity coefficients of the mixtures using 1% fiber are below 0.10 mm/min$^{0.5}$. Fiber length' being 2 cm significantly increased capillary coefficients. It was observed that the optimum fiber length in terms of capillarity is 1 cm.

As a conclusion, it was determined that the best performance in terms of fiber length should be 1 cm. Considering the flexural strength, it has been determined that the optimum fiber ratio should be 2%.

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