Hemp Fibres: A Novel Sustainable Curing Agent for Concrete

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Abstract: Hemp fibres are considered a sustainable "green" material for construction. Superior water retention capacity is one of its many notable characteristics and is the point of interest of the current research. Concrete requires significant water for hydration and strength development. The current study explored the possibility of utilising hemp fibres in their raw form to improve the mechanical properties of concrete in the absence of conventional curing. In the experimental program, two different concrete mixes were prepared by adding 1% and 2% of hemp fibres as a mass percentage of binder material, cement. Fibres were sized in 5 mm pieces and added in a pre-saturated condition to the concrete. The samples were cured in two approaches, i.e., sealed curing and unsealed curing. Compression tests were performed to evaluate the strength development at 1, 3, 7 and 28 days. The results from sealed and unsealed cured specimens showed that mixes with 1% hemp fibre dosage increased the concrete compressive strength. However, there was a significant reduction in compressive strength compared to the control mix in the mix with 2% hemp fibre dosage.

Keywords: Hemp fibre, concrete, curing, water absorption, hemp shives.

1. Introduction

The hemp plant has served humanity in different ways for thousands of years. It has a vast diversity of applications [1-3] in various fields. Its porous anatomical structure contributes to its unique properties as low density, low thermal conductivity, and superior acoustic insulation ability [4]. Moreover, as a carbon-sequestering material [2, 5], hemp can potentially serve as a sustainable 'green' construction element.

One of the many uses of hemp in construction is 'lime hemp concrete' [6, 7] and its application in improving concrete flexural properties [8-10]. Hemp, a lignocellulosic natural fibre, has an excellent water-holding capacity, making it a potential candidate for the internal curing of concrete. Recent research [11] on applying hemp shives in the internal curing of concrete showed a promising outcome since the material benefitted from the water-holding capacity of hemp shives.

This research aims to study the performance of hemp fibre addition in the strength development of 50 MPa grade concrete when added in saturated conditions. The fibres were added in 1% and 2% dosages by a mass percentage of the binder material. The fibres are expected to replenish the moisture depletion caused due to evaporation as well as the autogenous volume change during curing. Thus, sealed and unsealed curing environments were adopted to simulate the effect of 'internal drying' and both 'external' and 'internal' drying when exposed to the environment, respectively. For adequate curing, the water stored by hemp fibres should sufficiently meet the demand for both 'external' and 'internal' drying.

2. Materials and methods

2.1 Materials

The hemp fibres used in this experiment are raw, untwisted silver taupe hemp. In this state, they have not been degummed or had their lignin removed. The fibres were cut manually to 5 mm lengths to ensure good dispersibility in the concrete without significantly affecting the mixture's workability (Figure 1).

a) Raw fibre b) 5 mm chopped fibres

Figure 1. Hemp fibre used in the study.

Concrete mixes were prepared following ASTM C192 / C192M-19 [12] by mixing General Purpose Cement, 12 mm coarse aggregate and 2 mm fine aggregate to achieve 50 MPa design strength. A water-cement ratio was selected as 0.45 with a slump value of 80-100mm to ensure complete and unimpeded hydration of the cement.

The fibres were pre-saturated in water for 15 minutes and then hand-squeezed carefully to remove the excess water before mixing with other components. To determine the effect of hemp fibres in internal curing, two different percentages of fibres – 1% and 2% as a mass percentage of the binder material were added to the mix. Note that the fibre mass was considered as the oven-dried mass. The additional water was estimated from the mass difference between the saturated and oven-dried fibres.

Table 1 presents the cement mixes considered in the study.

Table 1. Mixture proportion with hemp fibre and dosage

Concrete mix ID	Mixture composition				
	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Hemp fibre (oven dry weight) kg/m^3
Control Mix (CM)	250	556	806	729	-
MHF01	250	556	806	729	5.56
MHF02	250	556	806	729	11.12

The preparation of the hemp fibres and inclusion in the concrete mix is presented in Figure 2.

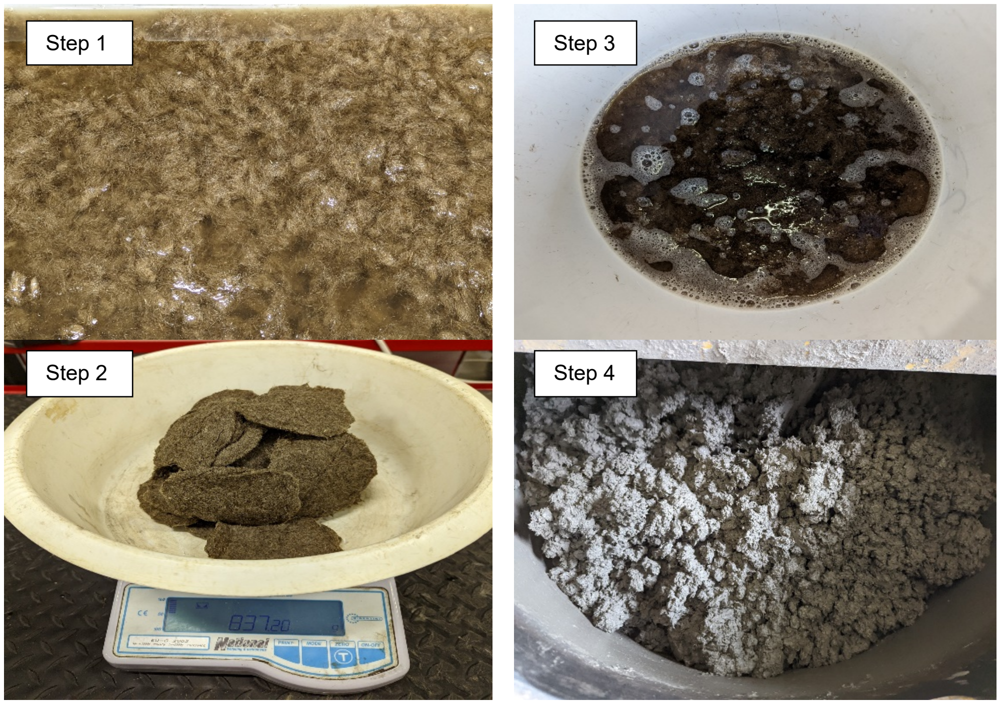

Figure 2. Batch mixing of hemp fibre - concrete composite

100 × 200 mm cylindrical samples were prepared from the mixes with three repeats for test specimen representing different curing ages (i.e. one day, three days, seven days and 28 days) totalling 72 cylinders. A mix without fibres was also prepared as a 'control mix' – CM. In addition, the mix containing the fibres was named MHF01 and MHF02, corresponding to 1% and 2% hemp fibre addition. All the samples were demolded after 24 hours of casting. Half of the control mix specimen was cured in an unsealed condition (e.g. in the lab environment) and is referred to as 'CM-Unsealed'. Half of the CM samples were submerged in water tanks as standard curing of the 'CM-Water cured' samples. For samples with fibres, no water curing was used; instead, left to cure in the lab environment. Half of the samples were wrapped with water-sealant plastic to minimize moisture loss, while the other half were cured in unsealed conditions.

All the samples were kept in a controlled curing environment of 23°C and 50%RH until testing.

2.2 Laboratory testing

Four combinations of sealed and unsealed samples and the control mix were tested for uniaxial compressive strength (UCS) at one day, three days, seven days and 28 days. Here, UCS at 1-7 days were considered to represent the effect of curing at an early age, while at 28 days, it represented the strength at the mature concrete state. The testing was conducted following ASTM C39/C39M [13].

3. Result and discussion

3.1 Effect on concrete compressive strength

Table 2 presents the UCS of the concrete mixes at 28 days and their density when subjected to sealed and unsealed conditions. The difference in UCS of the mixes to that of a water-cured control mix is also presented. The negative value represents the reduction in strength of the mix compared to that of the control mix. Figure 3 shows a graphical representation of the time-dependent compressive strength development of the concrete mixes.

Table 2. UCS and density of the mixes subjected to different curing conditions.

	Mix ID	Curing Condition	Density (28 days) (kg/m³)	Compressive strength 28days (Mpa)	Comparison to CM (water cured) at 28 days
Control mix	CM-Water cured	Water cured	3.93	48.12	0%
	CM-Unsealed	Air cured	3.82	41.78	-13%
Mix with 1% of fibre	MHF01-Unsealed	Air cured-Unsealed	3.56	40.03	-17%
	MHF01-Sealed	Air cured-Sealed	3.60	46.06	-4%
Mix with 2% of fibre	MHF02-Unsealed	Air cured-Unsealed	3.54	38.01	-21%
	MHF02-Sealed	Air cured-Sealed	3.62	36.57	-24%

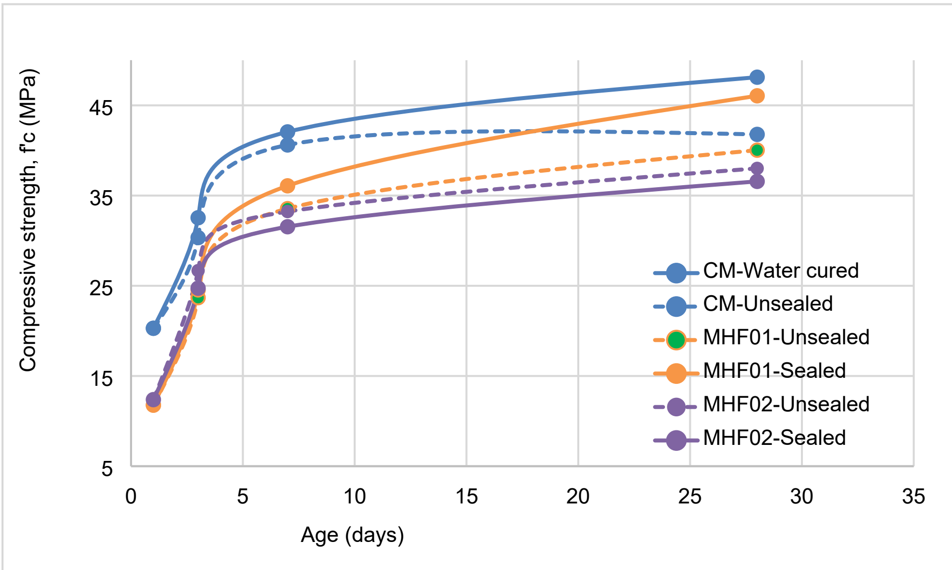

Figure 3. Development of compressive strength of concrete with curing age

In the absence of curing water, the strength development of concrete gradually slows with age. As a result, a 13% reduction of 28-day compressive strength was observed compared to that of a water-cured sample.

The addition of fibres can be seen based on the fibre dosage and curing condition. In general, increasing the fibre content reduced the compressive strength E.g. mixes with 1% fibre addition provided higher UCS strengths than 2% fibre mixes. At 2% dosage, the unsealed curing condition yielded more strength than the sealed curing conditions. However, at 1% dosage, the unsealed samples provided less strength than the sealed samples. In this case, more internal curing water was available with more fibre addition. As such, in the case of 2% sealed mixes, the water present was more than required for curing. This trapped water inside, causing a reduction in strength. However, the unsealed samples let the additional water evaporate when exposed to air drying. In the 1% fibre mix, sealed conditions increased the compressive strength compared to the unsealed models. In sealed situations, the inner water helps to develop strength with time and eventually exceeds that of the CM-Unsealed mix. Thus, fibre containing the internal curing water, when present at a higher level than required, reduces the strength of concrete under sealed conditions.

1% fibre addition under sealed conditions was observed to exceed the compressive strength of the control mix exposed to the air. This effect increased with curing age as the internal relative humidity dropped. Figure 4 provides photographs of the 1% sealed samples after 3,7, and 28 days of curing.

a) b) c)

Figure 4. Cross section of MRF01-unsealed samples at different curing ages a) 3-day, b) 7-days and c) 28-days

The following comparison has been made on the test results observed from this study to that of a previous study [11] performed on hemp shives in similar percentages to improve the concrete property.

1) The addition of shives to the mix produces a lower-density concrete than that of the fibre-concrete mix.
2) The UCS of the Hemp shive-concrete mix was higher than the compressive strength of Hemp-fibre concrete mix at similar percentages.
3) When subjected to unsealed states, the UCS of 1% and 2% of hemp shives were higher than that of the sealed condition. This observation was different to that of the hemp fibre-concrete mix.

Hemp shive and fibres increase the compressive strength of concrete by desorbing their absorbed moisture content when added at a lower volume. Like hemp shives, this increase in strength was more evident with the increase in curing age in hemp fibre concrete mix. From the differences observed in the density of the mixes, it can be seen that hemp fibres, due to their lower volume and greater surface area, replace less concrete volume than the shives. Consequently, water is more evenly distributed in the case of fibres than shives. As such, sealed samples of mix with 2% fibres had less compressive strength than unsealed ones due to the excessive water trapped inside, while 2% of hemp shive sealed mixes showed more compressive strength than the unsealed condition. Hemp fibre with 1% sealed samples yielded a UCS value 4% less than that of the control mix, while hemp shive 1% unsealed mix showed a UCS less than 5.5% than the control mix.

3. Conclusions

The research demonstrates the curing effect of cementitious materials with various volumes of hemp fibres by evaluating the time-dependent compressive strength development. The findings from the study are summarised as follows:

1) Saturated hemp fibres can aid in developing the compressive strength of concrete.
2) An increase in the fibre-concrete ratio decreases the compressive strength of the mix due to the availability of excessive water content per unit volume.
3) The best result was observed when hemp fibres were added to 1% dosage of the cement content. It can develop UCS as high as 4% less than a control mix subjected to proper curing. Credit goes to the uniform distribution of curing water in optimum quantity throughout the concrete volume. Also, the elimination of the effect of evaporation contributed to the improvement of strength.

These preliminary results form a valuable benchmark to further evaluate the contribution of hemp fibre in concrete curing in detail.

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5. References

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