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A COMPARATIVE STUDY ON THE STRENGTH AND DURABILITY OF HEMPCRETE AND CONVENTIONAL CONCRETE

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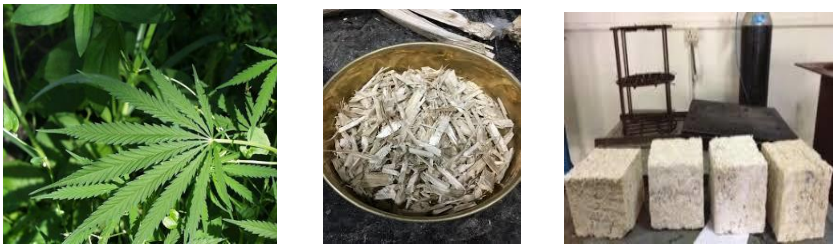
Abstract

This study presents a comprehensive comparative analysis of the strength and durability properties between hempcrete and conventional concrete, aiming to provide detailed insights into their performance characteristics. Hempcrete, an innovative bio-composite material composed of hemp hurds, lime, and water, has emerged as a promising sustainable alternative to conventional concrete due to its renewable nature, low carbon footprint, and potential environmental benefits. This paper discusses various properties and applications of hemp and hempcrete such as mechanical performance and durability, with a focus on its carbon sequestration ability and carbon negativity, and the current research interest as well as its possible contribution towards solution of climate change problems. The research methodology involved the fabrication of hempcrete and conventional concrete specimens according to standardized procedures. Various laboratory tests were conducted to assess and compare their mechanical properties, including compressive strength, moisture absorption behavior and thermal conductivity test was thoroughly investigated. Cube specimens were cured for 24 hours in a carbonation chamber and tested for mechanical property and durability property. The findings contribute to the understanding of hempcrete's potential as a sustainable construction material and facilitate informed decision-making in construction projects aiming for environmental sustainability and resilience.

Index Terms: Hemp, Hempcrete, Sustainability, Carbonation, Lime, Durability, Compressive Strength, Carbon-Negative, Water Absorption.

I. Introduction

In the construction industry, hemp typically refers to a variety of the Cannabis sativa plant. Hemp is used in construction primarily in the form of hempcrete, a bio-composite material made from the inner woody core of the hemp plant which is also known as hemp hurds or hemp shive as shown in Figure 1. Hempcrete is simply a combination of hemp hurd, lime, and water. This composite material does not require any heating process due to which it is considered to be an energy-efficient and low-carbon material. Hempcrete is an environmental sustainable building material with the properties such as thermal insulation, fire resistance, acoustic absorption and mechanical properties etc. Carbon dioxide accounts for the vast majority of greenhouse gases in the atmosphere therefore most industries have to take responsibility for reducing emissions of Carbon dioxide. 40% of global CO2 emissions is caused by buildings and the construction industry.



(a) (b) (c)

Fig. 1: (a) hemp plant, (b) hemp hurds and (c) hempcrete

The further enhancement in the construction industry and the emissions of greenhouse gas will be more effective among others. At this point, bio-based materials have gained attention in packaging, automotive, consumer goods and others along with building industry. Bio-based building materials can be obtained from bacterial, agricultural by products and animal-based products like wood, straw, hemp, flax, wool, and mycelium etc [9]. Correspondingly, hemp-based building materials come to the frontline for reaching sustainable building targets. Hemp plant absorbs carbon dioxide from the atmosphere thus acting as a carbon sink throughout their plant life and grows very fast in 3-4 months. These properties of hempcrete make it a building material with a carbon-negative, sustainable, and nature-friendly alternative [10].

The proportion of hemp in the mix plays an important role in the material properties of the block like density, thermal conductivity, and mechanical properties etc [8]. By measuring its density, physical properties and thermal performance we can make significant conclusions about the future possibilities of this novel building material. The success of hempcrete lies in the fact that it is carbon negative because of its agricultural origin and the use of lime as the mineral binders. Over the time, the advantages of reduced energy consumption in buildings have mirrored the notable savings on cooling and heating expenses throughout the life cycle of the building. Moreover, with the anticipated increase in availability of hemp, we can expect a decrease in the cost of hempcrete which will make it an even more cost effective and appealing choice for builders and homeowners. The main aim of this paper is to offer an in-depth examination of comparison of hempcrete and conventional concrete, highlighting their diverse properties and significance in construction industry. A distinctive focus is placed on vital features of hempcrete such as its density, durability, thermal and mechanical properties and specially its environmental sustainability.

II. Literature Review

Hemp is developed within the tropical locales of the world as one of the prevalent crops in those locales. The organic title of this plant is Cannabis Sativa. The filaments produced from the hemp stack are utilized as a building item alongside lime and cement [3]. Hemp may be a quickly developing annually abdicates (1.5 - 4 m height) which is for the most part created for its tall inflexibility common fiber which creates within the shoot adjacent the timbered center of the plant [4]. Hemp is cultivated for different purposes, the foremost common for the stem's bast fiber. The stem comprises two parts: a fiber sheath wrapped around a woody center known as shive, Hurd, or shive, and the stem itself [5].

As a composite fabric made from hemp shive and a lime-based folio, hempcrete is profoundly impacted by its constituent components. Cellulose present in hemp shive offers pliable quality and contributes to hempcrete's cover properties due to its porosity, Hemi cellulose ties the strands and helps in dampness control and lignin confers compressive quality and ensures against rot, whereas extractives impact color, odor, and solidness. Moreover, the strength of hempcrete is straightforwardly connected to the concentration of cellulose and lignin within the hemp shive; a more noteworthy amount of these filaments comes about in upgraded quality and life span [6].

With cellulose and hemi cellulose inalienable porosity, their wealth in hemp shive connects with prevalent warm separator, successfully blocking the exchange of warm and cold. These filaments moreover play a part in sound hosing, with expanded levels moving forward hempcrete's sound assimilation capacities. Hemi cellulose ability to oversee dampness through assimilation and discharge aids in keeping up ideal indoor stickiness. Besides, the fire-resistant quality of hempcrete is opened up by the nearness of lignin, a normal fire retardant [2, 7].

This timbered center of the plant is sliced up into small sizes (5-25 mm) (hurd/shive) and mixed in with lime, water and a small sum of concrete (to speed up setting time) to shape of composite mix called hempcrete [1]. The primary goal of this paper is to introduce hempcrete as an emerging construction composite material, with the main objective of exploring its mechanical properties it offers. In particular, we delve into the practical application of hempcrete as a new construction material, outlining its advantages, shortcomings, and potential uses. By providing a comprehensive overview of hempcrete's properties and potential applications, this paper illustrates its viability as a sustainable and environmentally friendly building material.

The literature also underscores the environmental sustainability of hempcrete. Carbon-negative properties, resulting from the carbonation process during production, highlight its potential contribution to reducing carbon emissions in the construction industry. Overall, the literature reflects a growing recognition of hempcrete as a promising eco-friendly alternative in construction. Researchers advocate for further exploration of its properties and applications, emphasizing its potential to meet the demand for sustainable building materials in the face of environmental challenges.

III. Methodology

3.1 Composition of Conventional Concrete

In this research work, the conventional concrete involves a systematic process aimed at achieving the desired strength, durability, and workability for a variety of construction applications. The composition of conventional concrete mentioned in table 1 includes the three primary ingredients which are cement, aggregates and water. To prepare conventional concrete, the process begins with the selection of cement and aggregates, chosen for their strength and workability. Clean water is then added to initiate the hydration process. The optimal mix proportions are determined to ensure the desired properties of the concrete. The concrete mixture is then molded into blocks of various grades, typically sized at 150 mm x 150 mm x 150 mm as shown in Figure 2. These blocks are cured for 28 days to allow them to develop the necessary strength.

(a) (b) (c)

Fig. 2: (a) Mixing, (b) Molding & (c) Curing Of Concrete

Table 1: Mixing Proportions of Conventional Concrete

Materials	Proportions		
	M15	M20	M25
Cement	1	1	1
Coarse Aggregate	2	1.5	1
Fine Aggregate	4	3	2

3.2 Composition of Hempcrete

Hempcrete, also known as hemp-lime or hemp concrete, is a sustainable building material renowned for its eco-friendly properties and thermal insulation capabilities. The composition of hempcrete mentioned in table 2 includes the three primary ingredients which are hemp hurds, lime and water. Preparing hempcrete involves a series of detailed steps to ensure the final product meets the required specifications for strength, durability, and workability. The process begins with collecting the stalks of the hemp hurd of a specific size. A lime-based binder is then selected for the hempcrete mix. Clean, potable water is used for mixing the components. The mixture is then molded into hempcrete blocks of various mixes, typically sized at 150 mm x 150 mm x 150 mm as shown in Figure 3. These blocks are cured for 28 days to develop the necessary strength.

(a) (b) (c)

Fig. 3: (a) Mixing, (b) Molding & (c) Drying of Hempcrete

Table 2: Mixing Proportions of Hempcrete

Materials	Proportions					
	A	**B**	**C**	**D**	**E**	**F**
Hemp	1.5	1.5	1.5	1.25	1.25	1.25
Lime	1	0.75	0.5	1.25	1	0.75
Cement	-	0.25	0.5	-	0.25	0.5

3.3 Various Tests on Conventional Concrete & Hempcrete

3.3.1 Bulk Density Test

Bulk density is described as a property related to the internal structure of the material. To determine the density of conventional concrete and hempcrete first prepare the cubes of size 150 mm then measure the dimensions of each sample to determine the volume. The mass of each sample is then measured using a calibrated balance as shown in Figure 4. Multiple samples are tested to ensure the accuracy and reliability of the results, with the average density and standard deviation reported. This methodology provides an accurate assessment of conventional concrete and hempcrete's density, which is crucial for understanding its structural and thermal performance in construction applications.

(a) (b)

Fig. 4: Measurement of Weight of (a) Hempcrete & (b) Conventional Concrete Cubes

3.3.2 Thermal Conductivity Test

To assess the thermal conductivity of conventional concrete and hempcrete, the process starts with preparing the cubes of size 150 mm. Using a thermal conductivity apparatus, conforming to standards like ASTM C518 or ISO 8301, the equipment is calibrated according to the manufacturer's instructions and relevant standards. The sample is placed between the hot and cold plates of the testing apparatus, ensuring proper contact and alignment to avoid heat losses. A temperature difference, usually around 10-20°C, is set between the plates, and the system is allowed to reach a steady state where the heat flow is constant. The heat flux and temperature difference across the sample are recorded as shown in Figure 5, with measurements repeated at different points on the sample to ensure consistency. Multiple tests on different samples are conducted to ensure reliability and repeatability of the results.

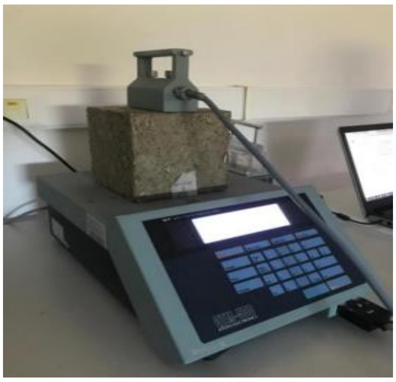


Fig. 5: Thermal Conductivity Testing

3.3.3 Carbonation Test

The carbonation test for conventional concrete and hempcrete begins with the preparation of hempcrete cubes of size 150 mm. Post-curing, the conventional concrete and hempcrete specimens are exposed to a CO_2-rich environment, typically in a carbonation chamber with controlled CO_2 concentrations (about 3-5%), relative humidity (50-70%), and temperature (20-25°C) for an extended period, which can range from several weeks to months, to simulate natural carbonation.

3.3.4 Compressive Strength Test

To assess the compressive strength of conventional concrete and hempcrete as shown in Figure 6, start by preparing cubes of size 150 mm. For the testing procedure, a universal testing machine applies a compressive load to the cured specimens until failure, and the maximum load is recorded. The compressive strength is calculated by dividing this load by the cross-sectional area of the specimen. Multiple specimens are tested to ensure statistical reliability, with results averaged and standard deviations calculated.

(a)

(b)

Fig. 6: Compressive Strength Test on (a) Hempcrete & (b) Conventional Concrete

IV. Results

The key findings of the study show the overall use of hempcrete offers several advantages over conventional concrete, including density, thermal insulation properties, carbon capturing capacity, and environmental sustainability.

4.1 Thermal Conductivity Test

It was found that as the hemp content in the hempcrete increases, the thermal conductivity decreases, while in case of conventional concrete the thermal conductivity increases with the increase in grade of concrete. Also, the study shows that the thermal conductivity of hempcrete is much lower than the conventional concrete. The following test results are shown in Table 3 & 4.

Table 3: Thermal Conductivity Test on Hempcrete

Composition	Hemp: Lime: Cement Ratio	Thermal Conductivity (W/(mk))
A	1.5: 1: 0	0.089
B	1.5: 0.75: 0.25	0.093
C	1.5: 0.5: 0.5	0.098
D	1.25: 1.25: 0	0.092
E	1.25: 1: 0.25	0.096
F	1.25: 0.75: 0.5	0.108

Table 4: Thermal Conductivity Test on Conventional Concrete

Composition	Cement: Coarse Aggregate: fine Aggregate Ratio	Thermal Conductivity (W/(mk))
M15	1: 2: 4	1.15
M20	1: 1.5: 3	1.38
M25	1: 1: 2	1.52

4.2 Carbonation Test

The carbonation test results highlight conventional concrete carbonates more slowly because of its dense matrix and lower permeability, with factors like water-cement ratio and curing conditions influencing the rate. On the other hand, hempcrete carbonates more rapidly due to its open pore structure, facilitating CO_2 diffusion and quicker reaction with the lime binder to form calcium carbonate. This faster rate of carbonation in hempcrete contributes to its mechanical property enhancement over time.

4.2.1 Weight of Hempcrete and Conventional Concrete after Carbonation

The study shows that after carbonation, the weight of hempcrete has increased significantly 3-4% by weight while in case of conventional concrete it increases only 0.5-0.6% by weight. The following test results are shown in table 5 & 6.

Table 5: Difference in Weight of Hempcrete after Carbonation

Composition	Weight Before Carbonation (kg)	Weight After Carbonation (kg)	Difference in Weight (kg)
A	1.967	2.113	0.146
B	1.473	1.503	0.03
C	1.060	1.065	0.005
D	1.762	1.794	0.032
E	1.579	1.591	0.012
F	1.287	1.298	0.011

Table 6: Difference in Weight of Conventional Concrete after Carbonation

Composition	Weight Before Carbonation (kg)	Weight After Carbonation (kg)	Difference in Weight (kg)
M15	7.821	7.852	0.031
M20	7.633	7.691	0.058
M25	7.450	7.495	0.045

4.2.2 Density of Hempcrete and Conventional Concrete after Carbonation

Hempcrete and conventional concrete differ in density. Hempcrete's offers lower density contributes to its lightweight, insulating properties, and environmental sustainability, making it well-suited for certain applications in sustainable construction where weight reduction and thermal performance are priorities. The study shows that after carbonation, the density of hempcrete has increased significantly 2-3% while in case of conventional concrete it increases only 0.6-0.7%. The following test results are shown in the Table 7 & 8.

Table 7: Density of Hempcrete after Carbonation

Composition	Density (kg/m^3)	
	Non- Carbonated	Carbonated
A	583.4	626.12
B	436.4	445.33
C	314.07	315.5
D	522.07	531.5
E	466.85	471.4
F	381.33	384.59

Table 8: Density of Conventional Concrete after Carbonation

Composition	Density (kg/m^3)	
	Non- Carbonated	Carbonated
M15	2317	2326
M20	2261	2279
M25	2207	2221

4.3 Compressive Strength Test

Hempcrete initially exhibits low compressive strength. However, carbonation significantly strengthens it over time as lime binder reacts with CO_2, increasing compressive strength up to 2-3 times the initial value while in case of conventional concrete there is negligible change in compressive strength after carbonation. The following test results are shown in the Table 9 & 10.

Table 9: Compressive Strength of Hempcrete after Carbonation

Composition	Compressive Strength (Map)	
	Non-Carbonated	Carbonated
A	7.11	18.16
B	2.91	8.71
C	2.32	7.04
D	5.85	14.34
E	4.54	11.45
F	2.76	7.96

Table 10: Compressive Strength of Concrete after Carbonation

Composition	Compressive Strength (MPa)	
	Non-Carbonated	Carbonated
M15	15.04	15.89
M20	20.11	21.67
M25	24.86	25.98

4.4 Water Absorption Test

Results have shown that hempcrete can absorb water between 20-30% of its weight in water, depending on the specific mix and density while in case of conventional concrete the absorption is significantly low as between 2-3% of its weight in water. The following test results are shown in the Table 11 & 12.

Table 11: Water Absorption of Hempcrete

Composition	Hemp: Lime: Cement Ratio	Water Absorption (in % by weight)
A	1.5 : 1 : 0	31%
B	1.5 : 0.75 : 0.25	23%
C	1.5 : 0.5 : 0.5	22%
D	1.25 : 1.25 : 0	27%
E	1.25 : 1: 0.25	23%
F	1.25 : 0.75 : 0.5	22%

Table 12: Water Absorption of Conventional Concrete

Composition	Cement : Coarse Aggregate : Fine Aggregate Ratio	Water Absorption (in % by weight)
M15	1 : 2 : 4	2.6
M20	1 : 1.5 : 3	2.3
M25	1 : 1 : 2	2.1

V. Conclusion

The key highlight of this study is that the hempcrete is environmentally sustainable material, as it is carbon-negative due to the carbon sequestration properties of hemp during its growth phase. This makes hempcrete an attractive option for reducing the carbon footprint of construction projects, especially in non-structural and insulation-related applications. It is observed that after carbonation the compressive strength of hempcrete is increased by 2-3 times of its initial strength. Further, it can be improved by proper proportions of the mix and specific environmental condition which can improve its strength and durability.

However, the study also reveals the need for further research and development to address limitations in hempcrete's mechanical properties, long-term durability, and standardization of testing methods. Overall, the findings suggest that hempcrete holds great promise as a sustainable alternative to conventional concrete in construction. Ongoing research and innovation in the field are addressing challenges associated with specialized construction techniques, making hempcrete an increasingly viable option for sustainable building practices.

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