**Assessing the Sustainability and Performance of Hempcrete in Concrete Manufacturing**


## ABSTRACT

**Aim:**
Traditional construction materials like cement, concrete, glass, asphalt, and steel require more energy in the manufacturing process, which results in high GHG emissions. Therefore, researchers from all over the world are focusing on solutions to tackle carbon emissions, with hempcrete emerging as a less polluting construction material. Hempcrete is a bio-composite comprising a woody core of hemp stem and hydrated lime. The objective of the study is to find out the physical and mechanical properties of hemp-lime concrete.

**Study Design**

The present research paper is part of the ongoing study on hempcrete at G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India. The present study chose an experimental research design.

**Methodology**

The study presents its results in two parts: performance and sustainability. The first part investigates the performance of hempcrete in terms of its physical and mechanical characteristics. The researcher conducted numerous trials to fix mix designs, focusing on their workability. The second part of the paper examines the sustainability aspect of hemp-lime concrete via a relevant literature review. Cubes of size 10 cm were cast manually for five distinct mix designs. The present research paper is part of the ongoing study on hempcrete at G.B. Pant University of Agriculture & Technology, Pant Nagar, Uttarakhand, India. The present study chose an experimental research design.

**Results**

During the specified time intervals of 28, 56, 84, and 112 days, the cubes exhibited a range in weight density from 506 to 674 kg/m3. In parallel, the compression test results demonstrated varying values, spanning from 0.510 Mpa to 0.810 Mpa across the same time points. Results show that there is a negative correlation between density and compressive strength and a positive correlation between density and water absorption rate.

**Conclusion** The results pertaining to weight density highlight the lightweight nature of hempcrete, to the extent that the cubes have the propensity to float in water. Due to its relatively low compressive strength values, hempcrete is deemed suitable for non-load-bearing applications within building construction.



Keywords: Sustainability, Hempcrete, GHGs, non-structural applications, lightweight


## 1. INTRODUCTION

As per Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6), 2023, IPCC reported that there is a more than 50% chance that global temperature rise will reach or surpass 1.5 degrees C (2.7 degrees F) between 2021 and 2040 across studied scenarios, and under a high-emissions pathway, specifically, the world may hit this threshold even sooner between 2018 and 2037. Reports consistently highlight those emissions from the construction and building sector represent approximately one-third of total global emissions. This alarming statistic underscores the urgent need for humanity to explore sustainable building materials as alternatives to traditional construction materials. Some examples of sustainable building materials are bamboo, recycled plastic, hempcrete, rammed earth, cork and straw bale construction and many others. These days, Lime-Hemp Composites (LHC) or Hempcrete—which were initially created and tested in the early 1990s—are the most advanced bio aggregate-based building material in Eastern Europe[23,24,25,26]. When lime is mixed with shiv (woody chips of hemp stem), it is called hempcrete. Due to its good thermal properties and lightweight characteristics, it is gaining popularity among civil engineers, researches and academician. Hemp (*Cannabis Sativa L.)* is a multipurpose crop that can be cultivated for either fibre, seed or cannabidiols and building material. The 21st century has seen an increase in the demand for hemp and its products. Over the past 20 years, most countries have legalized the growing of industrial hemp, which has sparked a lot of research into the health advantages of hemp and products derived from it. Uttarakhand is the first state of India to legalise the industrial and horticultural growing of hemp. The temperate zone, which spans from 1200 meters to more than 2200 meters, has the ideal climate for hemp cultivation. It requires soil that is well-aerated, has a pH of six, and is wet. Owing to space constraints in Uttarakhand's mountainous regions, hemp is typically grown in cropping patterns with other crops. It is an extremely valuable resource for industrial application, especially in developing nations, due to its greater potential for carbon absorption and cheap cultivation capital requirements [1].

Concrete, in general, is a solid mass made of various aggregates bound together by a binder, or "glue." It has many types of aggregates and binders. Hemp wood act as an aggregate and lime as binder, to form hemp-lime, also known as hempcrete. For various applications, such as plaster, walls, floors, and roofs, different formulations of hempcrete are required [2]. Hemp buildings were used by ancient Indians as early as the sixth century, as evidenced by the Ellora caves. They investigated the sample of clay plaster taken from Buddhist cave number 12. After the hemp was extracted from the lime plaster, it was analysed using a variety of microscopic techniques. The sample was then compared to a fresh specimen of *C. sativa* that had been taken from Jalna in the Aurangabad area of Maharashtra, and the results verified the similarities between the two [3].

France is linked to the use of hempcrete in more recent times. Charles Rasetti, a historical building expert, originally created this method in 1986 for restoring oak-framed structures that were filled with straw, lime, and rubble and were typical of the Champagne area of France. Rasetti discovered that hempcrete worked far better than cement because the infill of these buildings deteriorated even more when cement was used to fix them [4].

Because of its lower mechanical strength, hempcrete is not a load-bearing material. It is used as a filling material for single-layer walls with a structural frame and as insulation material for existing walls, floors and roofs. Construction techniques include forming monolithic walls by compacting the mix in a formwork, spraying, bricklaying from precast blocks and prefabrication of entire wall elements [5]. The quantity of shiv in hemp concrete affects density and thermal conductivity. The density drops from 611 to 369 kg/m3 and the thermal conductivity drops from 140.8 to 94.7 W/ (m K) for hemp percentages in weight between 20% and 40% [6].

**1.1 Significance of the Study**

Brick is a well-known and ancient building material. Generally, manufacturers mix clay and sand in an appropriate ratio and heat the mixture in a kiln at a high temperature using coal or firewood to make bricks. Thus, brick production leads to high embodied energy and a large carbon footprint. Therefore, to tackle the problem of the use of high-embodied energy materials in construction, there is a need to have alternatives such as hempcrete with a negative carbon footprint. Most research on hempcrete is concentrated in Western countries, especially the USA. As a result, the USA has become the first country in the world to develop a building code for hemp-lime construction. Researchers have conducted very little research on the manufacturing of hemp-lime concrete in the Indian context. Hence, the present study, its methodology, findings, and implications will open the door for more studies.

### 1.2 Objective

The objective of the present study is to achieve a concrete mixture that meets the requirements of being lightweight, providing good insulation, and exerting minimal environmental impact. Hence, examining the physical and mechanical properties of hempcrete.

## 2. REVIEW OF LITERATURE

**Sinka (2015)** prepared a hempcrete mix using a laboratory mixer. The first shiv was inserted into the mixer, and then the mixer was turned on. During this process, all kinds of dust were emitted. Subsequently, water was added by spraying it evenly on the overall shivs, so that the surface of all shivs was slightly wet. After this, a premixed binder was added. It was evenly dispersed over the shivs in a 30-second period, and as the shivs were wet, the binder quickly stuck to them.

**Murphy et al. a (2010)** used dry mix technique for mixing process. After about ten seconds of dry mixing the shiv and binder, 100 millilitres of water were poured gently at regular intervals. Following mixing, the samples were put into three-layered prismatic moulds and tamped 25 times each. A steel trowel was used to level off the last layer.

**Picandet *et al.* (2016)** found that compacting process clearly improves the compressive strength of lime hemp concrete (LHC). The relative increase in thermal conductivity of LHC is less significant. However, it reduces the volume of entrapped air, which contributes to reducing the thermal conductivity. Indeed, the data measurements show a slight increase in thermal conductivity, but it is definitely less sensitive than the improvement of mechanical strength. This process constitutes, therefore, an interesting way to develop the use of such materials.

**Manohari *et al.* (2016)** concluded hempcrete can experience deformation after achieving the ultimate load is another significant characteristic that the compression test revealed. This demonstrates that hempcrete behaves in a quasi-ductile manner as opposed to the abruptly brittle failure of concrete. This shows hempcrete has a quasi-ductile behaviour, unlike the sudden brittle failure associated with concrete.

## 3. METHODOLOGY

This paper represents its results into two sections: the first section presents the experimental findings, while the second part reviews relevant literature to examine whether hempcrete is a sustainable material.

All experimental work for this study was conducted at the Department of Civil Engineering of G.B. Pant University of Agriculture & Technology, located in Pantnagar, Uttarakhand, India. This division of the paper allows for a comprehensive exploration of both the practical applications and theoretical implications of hempcrete.

## 3.1. Materials Used for The Study

### 3.1.1. Hemp shiv

Small woody chips of hemp stem are called hemp hurd or shiv shown in figure 1. it was procured from Gohemp Agroventures Pvt Ltd., based in Roorkee, Uttarakhand. The hemp plant used for the shiv was naturally grown locally. Figure 2 illustrates the composition of shiv, indicating that it consists of 2% dust, 7% fibre, and the remaining percentage is shiv by weight.

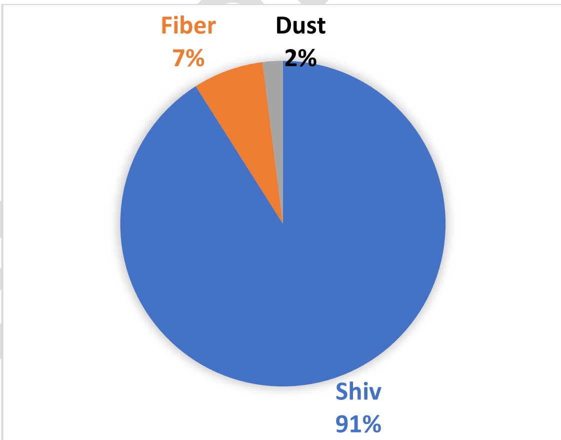




**Figure.1 Shiv sample**

**Figure.2 Composition of Shiv by weight percent**

### 3.1.2. Quick lime: a binding agent

Lime is a traditional building material. Naturally available limestone ($CaCo_3$), when heated up, releases $Co_2$, and the resulting white powder is referred to as quicklime (CaO). The quicklime was sourced from **ONGC Additions Ltd. (OPAL)** based in taluka Vaghra, Bharuch, Gujarat. Before use quicklime was slaked for 24 hours thus convert it into hydrated form. Lime has the ability to collect and release moisture by maintaining humidity levels, this lowers the moisture damage and makes the living area comfortable.

### 3.1.3. Water

Locally available, good-quality potable water was used for the slaking of lime and all other experiments. The amount of water used in the lime process totally depends on the outside temperature. Compared to winters, summers require a greater quantity of water as water evaporates quickly through exothermic reactions.

## 3.2 Properties of Materials Used

### 3.2.1. Hemp shiv

#### *3.2.1.1. Physical properties of shiv*

The physical properties of the shiv are moisture content, ash content and dry matter. these are measured without changing the chemical composition of it. Preliminary test results shows that moisture content of hemp shiv was 4.5 %, ash content was found 1.94 % and rest was dry matter percentage. shown in table 1.

**Table 1. Physical Properties of hemp shiv**

| | |
|---|---|
| **Moisture Content** | **4.5 %** |
| **Ash content** | **1.94 %** |
| **Dry matter** | **95.5%** |

#### *3.2.1.2 Sieve analysis of hemp shiv*

In the present study, shiv was used as coarse aggregate. Traditional examples of coarse aggregates are sand, gravel, and crushed stone. Sieve analysis was used to obtain the particle size distribution of solid material by determining the amount of shiv retained on a series of sieves with different size apertures.

The sieve analysis procedure is carried out in accordance with **IS 383-1970**, and the total sample size was1 kg. it was sieved manually. Minimum i.e. approx. 16 percent particle retained on sieve size 10 and maximum about 23 percent retained on 2.36 mm sieve displayed in **table 2.**

**Table 2. Sieve analysis of shiv particles**

| Sieve Sizes (mm) | Retained (gm) | Retained Percentage | Cumulative Percentage Retained | Percentage Passing/ Percent Fine |
|---|---|---|---|---|
| 10 | 155.58 | 15.57 | 15.57 | 84.42623 |
| 8 | 90.10 | 9.01 | 24.59 | 75.40984 |
| 5.6 | 223.60 | 23.36 | 47.95 | 52.04918 |
| 4.75 | 65.55 | 6.55 | 54.50 | 45.4918 |
| 2.36 | 229.50 | 22.95 | 77.45 | 22.54098 |

| | | | | |
|---|---|---|---|---|
| Pan | 225.54 | 22.54 | 100 | 0 |
| **Total** | **1000** | | | |

### 3.2.2 Quick lime

#### *3.2.2.1 Physical properties of quick lime*

Physical properties of lime discussed here are specefic gravity, fineness modulus and compressive strength. Specific gravity refers to the ratio of the density of building material to the density of water. It means how heavy is material with respect to the water. Quick lime used in the study has specific gravity of 2.61 it means it is 2.61 times heavier than water. Fineness modulus value was 3.26 and compressive strength of lime at 28 days was 1.29 MPa presented in table 3.

**Table 3. Physical Properties of Quick Lime**

| Properties | Results | Methods |
|---|---|---|
| Specific Gravity | 2.61 | IS-2386 Part: III, 1963 |
| Fineness Modulus | 3.26 | IS 1514:1990 |
| Compressive Strength | 1.29 MPa | IS: 6932 Part: VII |

### 3.3 Mix Proportions of Ingredients

Several trials were carried out to determine a suitable base concrete mix consisting solely of the fundamental ingredients of hempcrete, namely shiv and quicklime. The quicklime was slaked for 24 hours, and the following day, it was utilized for mix preparation in accordance with BIS regulation. The amount of water needed for the slaking process couldn't be set definitively because it varied based on the external temperature and humidity. In this study, five distinct combinations of hemp and lime ratios illustrated in table 4, were selected for examination or analysis. Following mix proportions was used for the entire study.

**Table 4. Composition for making 10 $cm^3$ cube**

| Specimen Code | H/L | Shiv (in grams) | Slaked Lime (in grams) |
|---|---|---|---|
| **HC0.30** | 3:10 | 231 | 770 |
| **HC0.35** | 7:20 | 238 | 660 |
| **HC0.40** | 2:5 | 238 | 595 |
| **HC0.45** | 91:200 | 237 | 520 |
| **HC0.50** | 1:2 | 238 | 476 |

### 3.4 Production of Concrete

The production of hemp-based concrete entails a four-step process, as illustrated in the flow chart depicted in Figure 3, and is elaborated upon below. In the production of concrete, weigh batching is adopted instead of volume batching. This method is chosen because each cube is cast manually, and using a pan mixer would necessitate larger quantities of concrete. Lime was slaked in a 20-liter iron bucket for the slaking process for 24 hours. The next day, excess water was removed from it, and the slurry was stirred with a wooden rod for 1-2 minutes before being left to settle for 5-10 minutes. Any extra water that rose to the surface was then removed by tilting the bucket to one side. This process was repeated 3-4 times depending on the amount of excess water, resulting in the formation of a thick paste of slaked lime. Water was sprinkled on shiv to moisten it, enabling the lime to adhere easily to its surface and enhance the workability of the mixture. Lime was poured onto the moistened shiv and thoroughly mixed until a homogeneous mixture was obtained. The cast iron cubes were oiled before being filled with mixture. The mixture was filled in four layers. In each layer, a handful of the mix was taken, filled, and then compacted with a 3.5 kg weighted iron rod with a diameter of 5.5 cm for 30 blows. All the cubes were dried in open air in laboratory conditions. The pictorial representation, figure 4, provides a visual guide to the production sequence, outlining each key step involved in the creation of hempcrete construction elements.

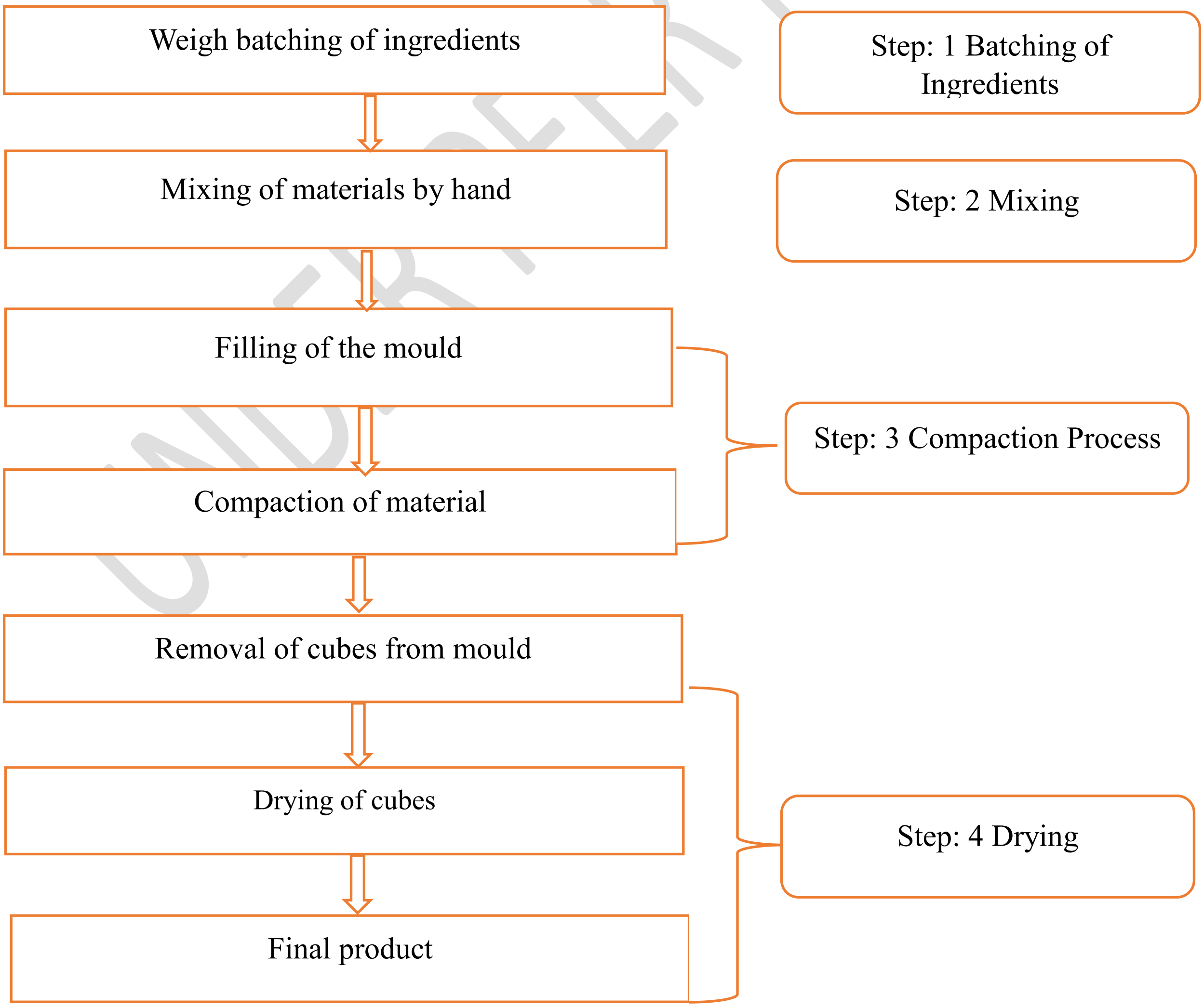



**Figure 3 Flow chart of the manufacturing process of concrete based on hemp shiv**


**Figure 4. Pictorial presentation of production of concrete (a). Slaked lime paste (b) Weight batching of shiv (c) Mixing of lime and shiv (d) Iron rod used for compaction (e) Compaction of concrete into the cube mould (f) Final view of hempcrete cubes**.

## 4. RESULTS

In the initial segment of the results and discussions section, the focus is directed towards the outcomes derived from the experimental phase. Subsequently, the latter portion delves into the exploration of sustainability aspects within the context of existing literature.

### 4.1 Experimental Results & Properties of Concrete

#### 4.1.1. Weight density

The weight of cube is defined as the ratio of the weight of the cube to the volume of cube in Kg/m$^3$. For each cube mix composition, a set of 3 bricks was tested after 28, 56, 84 &112 days. The size of the cube taken for weight density was 100mm × 100mm × 100mm. The weight of the cube noted from a weighing scale with a sensitivity of 0.5 gm. The assessment of weight density plays a crucial role in evaluating both the strength and durability of concrete structures. A denser concrete typically exhibits higher strength by minimizing voids and porosity within its structure. In the context of Hempcrete, as shown in Figure 5, the weight density ranges from 651 to 511 for the H0.30 mix and 632 to 506 for the HC0.50 mix over the 28 to 112-day drying period. Notably, all these density measurements fall below the density of water. In the realm of lightweight concrete, the practical density range is typically considered to be between 500 and 1850 kg/m³. The cube mix composition HC0.30 exhibits maximum density, while the lowest density is observed in HC0.50. As the quantity of shiv increases and lime decreases in successive mixes, the density decreases. A crucial observation is that over time, there is minimal reduction in weight density attributable to lime's slower setting rate.

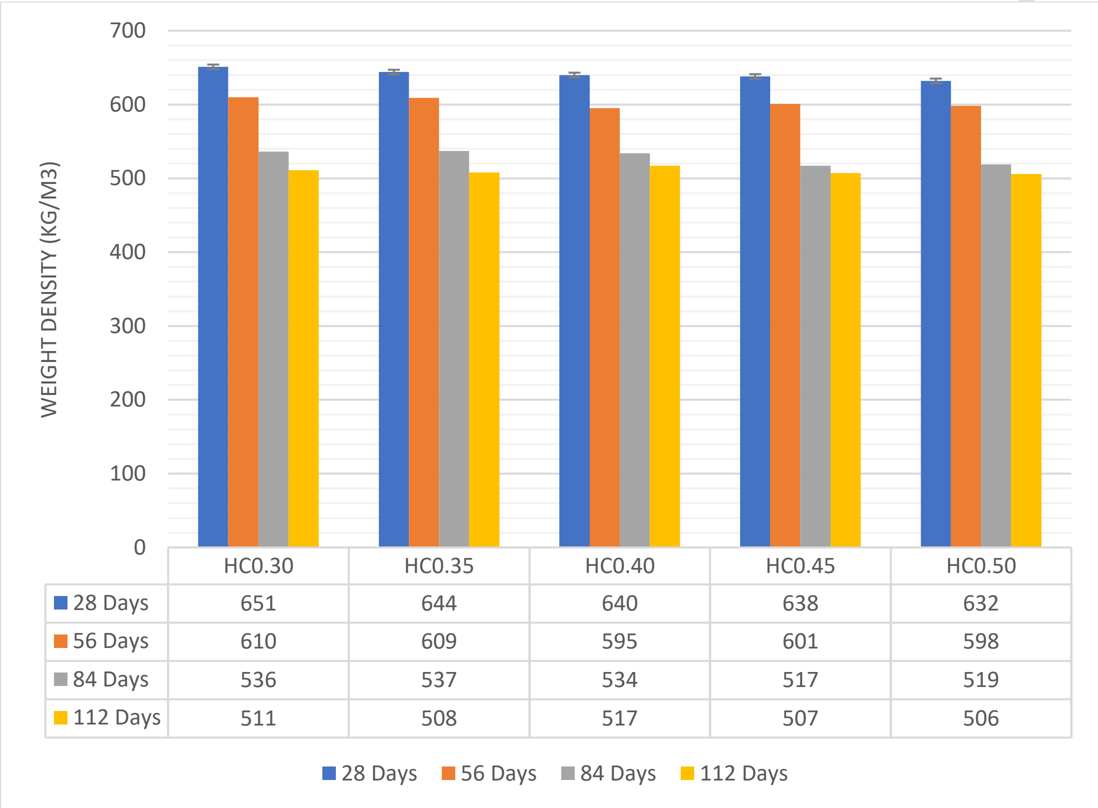



**Figure 5. Demonstrate the weight density of concrete at different days**

#### 4.1.2. Water Absorptions

The water absorption test provides insights into the internal structure of concrete. Typically, materials with higher porosity tend to absorb more water. Hempcrete is a very porous material, hence its results for water absorption were quite high. The test results revealed that the hempcrete mix HC 0.30 resulted in a minimum absorption rate of 86%, whereas the HC 0.50 mix showed a maximum water absorption rate of 117%, as displayed in Figure 6.

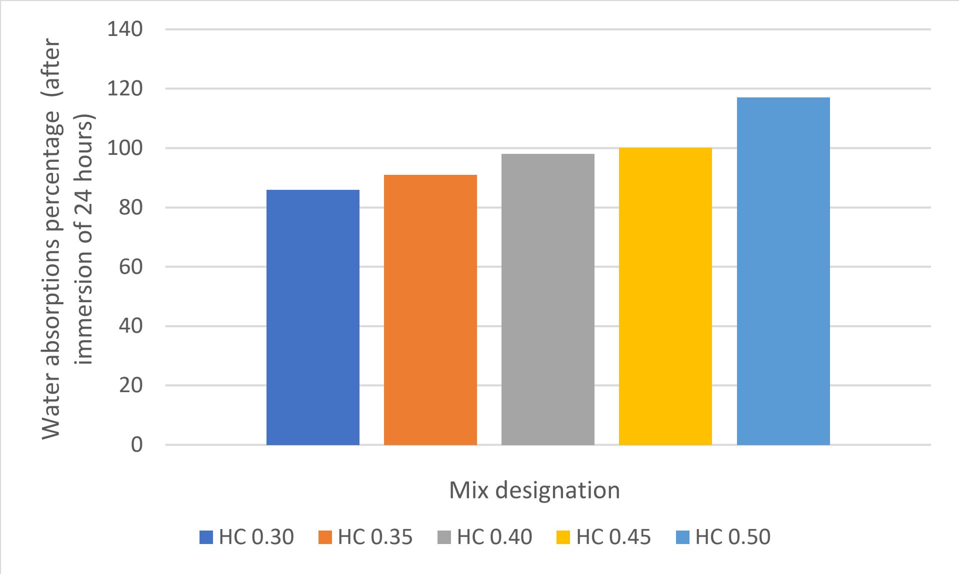


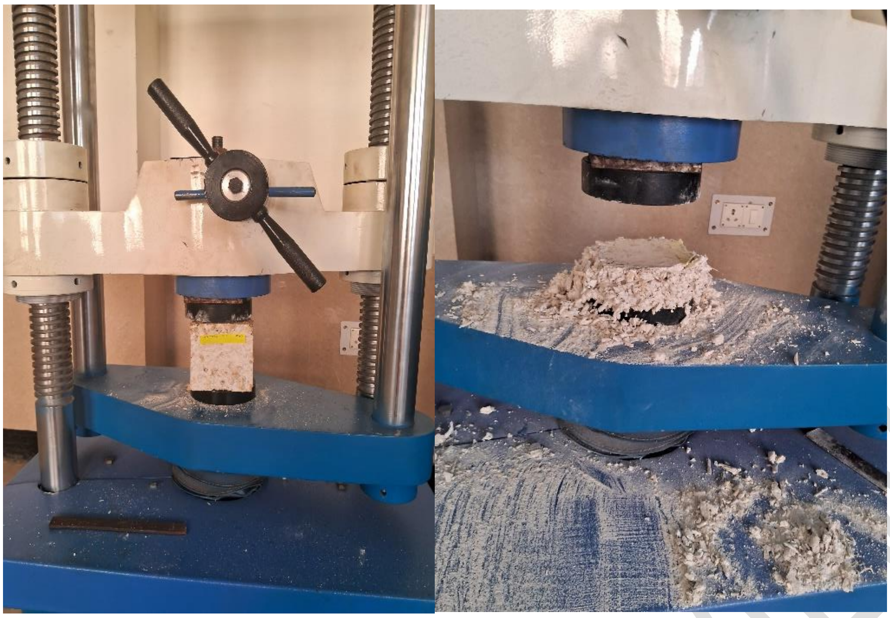

**Figure 6. Water absorptions of hempcrete**

### 4.1.3. Compressive strength

The ability of a material to support weight and withstand deformation in the presence of compressive stress is known as its compressive strength. The samples were dried in natural condition at 28, 56, 84, and 112 days and then tested in compression mode using a Universal Testing Machine SERVO 200 kN at loading rate of 0.10kN/min. The HC0.30 mix with the highest content of lime showed a maximum compressive strength of 0.810 MPa for 112 days. At 28 days' time period, mix HC0.50 exhibited minimum strength of 0.51 MPa shown in table 5. Hempcrete displayed ductile properties by avoiding brittle cracking (shown in figure 7).

**Table 5. Compressive strength of cube at different days**

| Specimen Code | 28D | 56D | 84D | 112 D |
|---|---|---|---|---|
| **HC 0.30** | 0.617 | 0.791 | 0.717 | 0.810 |
| **HC 0.35** | 0.584 | 0.591 | 0.634 | 0.765 |
| **HC 0.40** | 0.594 | 0.677 | 0.680 | 0. 735 |
| **HC 0.45** | 0.526 | 0.555 | 0.593 | 0.663 |
| **HC 0.50** | 0.510 | 0.548 | 0.619 | 0.673 |



(a) (b)

**Figure 7. (a) Cube under compression (b) Cube after compression test**

## 4.2 Analyses of Experimental Results

Hempcrete is a very light-weight material, which means it has a very low density. In general, high-density material has high compressive strength and low volumes of void. So as the density of concrete increases, compressive strength also increases, which means there is a positive correlation. For hempcrete, it is the opposite during the early stages until it reaches complete drying. Figure 8 shows a negative correlation value of -0.586 between density and compressive strength, meaning that as density decreases over a period of time, compressive strength increases. This is due to the slower setting rate of hydrated lime as it solidifies and gains strength slowly.

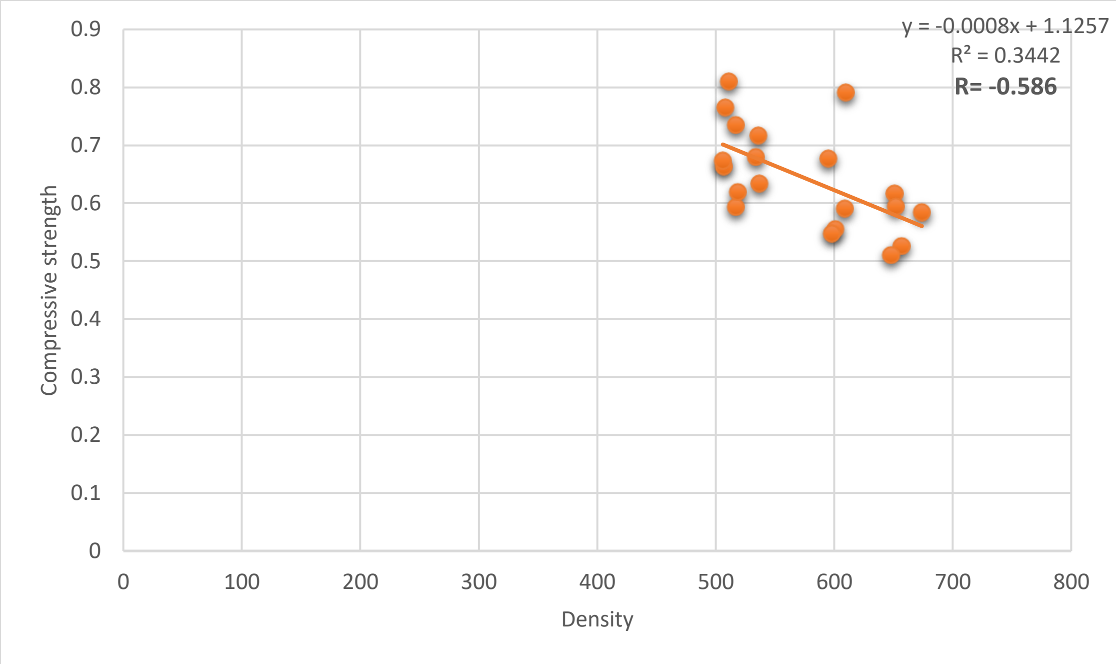



**Figure 8. Correlation between Density and compressive strength**

The aforementioned ratios of hemp, shiv, and lime were fixed at 0.30, 0.35, 0.40, 0.45, and 0.50. As the amount of shiv increases and the lime content decreases in the mix, there is a corresponding rise in the voids present in the mix from 0.30 to 0.50. Therefore, the presence of voids determined the water absorption rate in the mix and showed a positive correlation between the ratios of hempcrete and the water absorption rate displayed in figure 9.

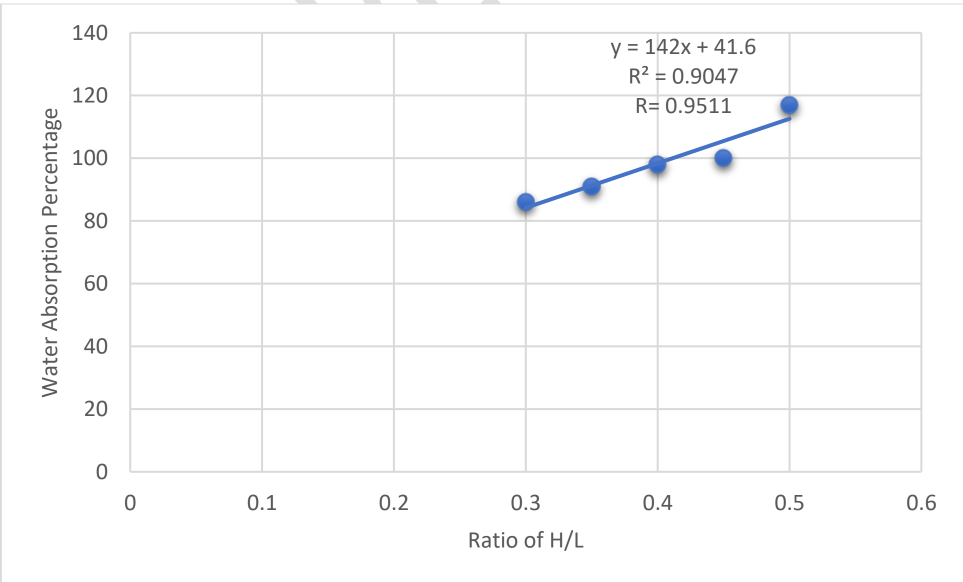



**Figure 9. Correlation between Hemp-lime ratios and water absorption percentage**

## 4.3 Review of Literature on Sustainability of Hempcrete

Assessing the sustainability of hempcrete involves initially examining the individual benefits of hemp and lime. Subsequently, it entails exploring the unique advantages of combining hemp and lime in hemp concrete.

### 4.3.1. Hemp

Hemp (Cannabis Sativa L.) is a multipurpose crop that can be cultivated for either fibre, seed or cannabidiols and building material. The 21st century has seen an increase in the demand for hemp and its products. Over the past 20 years, most countries have legalized the growing of industrial hemp, which has sparked a lot of research into the health advantages of hemp and products derived from it. In India, the states of Uttarakhand and Uttar Pradesh currently allow the cultivation of hemp; Madhya Pradesh, Manipur, and Himachal Pradesh will follow suit. Hemp is a multidimensional crop or plant, as all the parts can be used commercially. Its fibres are strong and pliable. And hemp seeds are valued for their high content of micro- and macronutrients such as potassium, iron, and zinc [7]. Hemp cultivation can be achieved with minimal or no reliance on chemical pesticides or fertilizers, offering the potential to substantially decrease the environmental carbon footprint. The rise in public health awareness during the COVID-19 pandemic has fuelled the growth of the hemp industry. Hemp is versatile, with its stalks, seeds, and leaves being utilized to create a wide range of products such as building materials, fabrics, paper, food, furniture, cosmetics, and medical supplies. Moreover, bioplastics, biofuels, and biopesticides are among the most extensively researched and discussed applications of the hemp plant [8]. bio-based building materials derived from hemp offer several advantages over traditional building materials. These advantages include being lightweight, fireproof, self-insulating, pest-resistant, and cost-effective in production [9].

### 4.3.2. Lime

Lime is a naturally occurring material found in the form of limestone ($CaCO_3$). When heated in a lime kiln at approximately 900°C, it transforms into quicklime (calcium oxide, Cao), which can be used directly from the kiln or slaked to produce hydrated lime [$Ca(OH)_2$] or lime putty, depending on the amount of water added. Lime mortar offers several eco-friendly advantages over conventional options like cement. In the realm of environmentally friendly construction materials, lime emits fewer greenhouse gases during production due to lower energy requirements compared to cement. Additionally, through a process known as carbonation, lime absorbs $CO_2$ throughout its lifespan, a phenomenon referred to as carbon sequestering. This process helps offset the initial carbon emissions from the production stage.

In the earliest construction work, lime was used as mortar to join building blocks, such as bricks, stones, and concrete masonry units. Among all the binders available in the past, the oldest one was lime mortar [10]. Lime-based mortars are well known for their excellent performance in conserving buildings. Currently, they are popularly used in restoring old buildings and rehabilitating historic masonry [11].

Rich lime (calcium oxide) is more appropriate for use in hemp than cement. The Ph of lime protects the hemp shives from mould and bacteria (antiseptic) for a long time [12]. One of the limitations of lime is its slow setting rate, leading to gradual solidification and strength development. Consequently, with urbanization, industrialization, and advancements in the construction industry, cement gained popularity in the 12t[h] century due to its rapid setting rate and superior mechanical strength. This led to a reduced demand for lime [13].

#### 4.3.3. Hempcrete

Hempcrete offers numerous sustainable advantages as a building material, but it is non-load-bearing and should be used in conjunction with a load-bearing wooden frame. The sustainability aspects of hempcrete can be further explored in terms of thermal conductivity, hygrothermal properties, and environmental credibility. Thermal conductivity (k value) describes a material's capacity to conduct heat. Heat transfer by conduction happens when energy passes within a material without any motion of the material. Lower k values indicate lower conductivity and higher insulating properties for the material. Hempcrete typically exhibits a thermal conductivity ranging from 0.06 to 0.18 W/m.K for densities of 200 to 800 kg/m3 [14], whereas traditional concrete has thermal conductivity values between 1.33 W/mK and 1.95 W/m.K at 20°C, which is significantly higher [15].

Hempcrete present excellent hygrothermal behaviour or properties. The term "hygrothermal properties" of a material pertain to the alterations in its physical characteristics resulting from the combined absorption, retention, and release of heat and moisture in either liquid or vapor form. Hempcrete demonstrates a high specific heat capacity value of approximately 1500 J/kg.K in a dry state, which can increase to over 2900 J/kg.K at 95% relative humidity [16]. The elevated specific heat capacity values of hempcrete indicate that more energy is needed to alter its temperature. This property enables hempcrete to offer thermal comfort indoors even when external temperatures rise.

One square meter of lime hemp concrete wall stores between 14 and 35 kg of $Co_2$ over its lifespan of 100 years. This is due to $Co_2$ storage in the hemp and construction wood, but also in the lime, which catches up $Co_2$ as it sets [17]. Another significant finding concerning hempcrete blocks reveals that the net carbon emission of hempcrete blocks was recorded at -48.36 kg $CO_2$eq/m^3 illustrated in figure 8. [18].

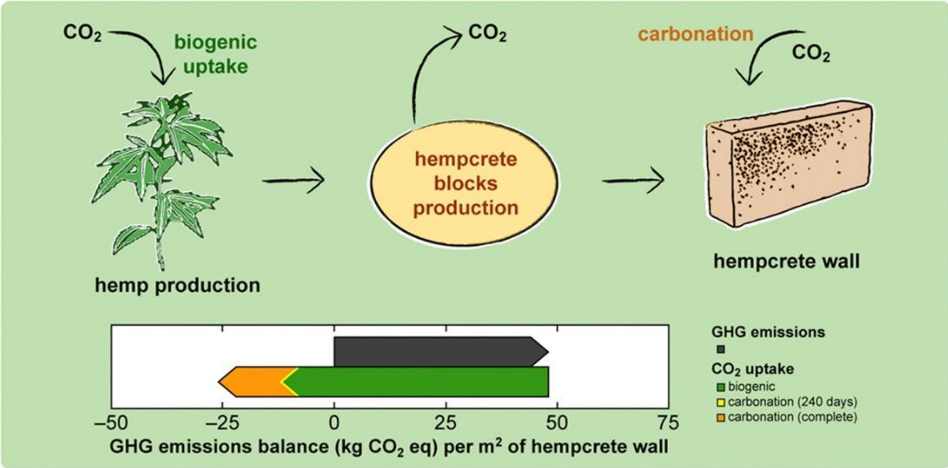



**Figure 10: Illustration of the carbon emissions and sequestration of hempcrete, showcasing a net emissions balance that demonstrates carbon negativity**

## 5. CONCLUSION

The present paper discusses the physical and mechanical properties of hempcrete through a series of experiments. It highlights that hempcrete is a lightweight, porous material with a higher water absorption ratio. Additionally, the study indicates that the compressive strength of hempcrete does not exhibit significant improvement over time, suggesting that it may not be suitable for direct use as a load-bearing material in building construction.

The sustainability aspect of hempcrete is further illuminated through a literature review, offering valuable insights into its environmental benefits. The examination reveals that hempcrete boasts a low thermal conductivity and a high specific heat capacity, enhancing its thermal insulation properties and ensuring comfortable indoor environments. Moreover, the lifecycle assessment of hempcrete classifies it as a good for sustainable development. These findings underscore the eco-friendly attributes of hempcrete and its potential to contribute positively to sustainable construction practices.

## 6. Disclaimer (Artificial intelligence)

The author hereby declares that ChatGPT Pus V4.0, a generative AI technology, has been used during the editing of manuscripts. It was used to improve readability and grammar checks only, and it does not replace key authoring tasks such as writing abstracts, introduction, methodology, producing experimental results, etc.

After writing the paragraph, the author used the following prompts:

1. Write the above paragraph appropriately.
2. Correct the above paragraph grammatically.

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