Industrial Cannabis sativa (Hemp fiber): Hempcrete-A Plant Based and Eco-friendly Building Construction Material

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Abstract:- This **review** paper highlights about the **Industrial hemp (fiber type**) used as a plant based building construction material, **Hempcrete**. Industrial hemp (*Cannabis sativa L.*) is an emerging food and fibre crop. It is a non-drug variety of *Cannabis sativa* with low **Δ9-tetrahydrocannabinol (THC**) content of less than **0.3 per cent**. The use and performance of hempcrete suggested that hempcrete can be considered as an environmentally friendly material. In a **first of its kind in India**, an architect couple, **Namrata Kandwal** and **Gaurav Dixit** have built a house made of using hemp fibre- hempcrete in **Uttarakhand state, India**. **Industrial Hemp (fiber-type**) is both an agricultural and industrial commodity and stem supplies both cellulosic and woody fibers. **Hempcrete** is a construction material made from **hemp fibres, lime and water**. Hemprete showed a **negative carbon footprint** making it a suitable material in the construction industry. This composite, hempcrete breathes, as well as having a good **thermal** and **acoustic-insulation** properties. However, hempcrete does have several key drawbacks that make it less than ideal as a building material. In addition to **poor mechanical performance**, hempcrete also has a **high capacity to absorb and retain water**. Therefore, future in detail study is warranted for the commercialization of hempcrete as a building material.

Key words: Cannabis sativa, hemp, **Hempcrete, Industrial hemp (fiber type**), bio-based composite, Eco-friendly, sustainability, carbon neutral, affordable home construction, **Uttarakhand state, India.**

I. Introduction

Industrial hemp (fiber type) belongs to the family, **Cannabaceae** is considered as one of the oldest plants cultivated to provide the nutritional and medicinal benefits (1-30). Industrial hemp (fiber type) is a versatile commercial crop that has been used for fiber, food, and medicinal purposes (1-50, 60). Further planting **Industrial hemp (fiber type)** has numerous advantages that makes it easy to work (1-40). The **Industrial hemp (fiber type)** plant becomes ready to harvest 100 to 120 days after it has been planted (1-55). **Industrial hemp (fiber type)** does not need much caring, weeding, or cultivation, and hemp can grow on new or old soil (1-63). Hemp plant can withstand extreme temperatures like frost and only requires modest amounts of water (1-63). Moreover, harvesting **Industrial hemp (fiber type)** can be more favourable for the use of land (1-50). Hemp not only allows the soil to be used for other crops after harvesting, compared to growing trees (1-23, 28-62). Hemp also reduces logging and soil erosion drastically, and thus decreases topsoil loss and soil runoffs that may cause pollution in water (1-55). Hence one of the most promising material for building construction is hemp fiber (Cannabis Sativa L.) (1-60). Hemp is both an agricultural and industrial commodity, highlighted by its usefulness as a sustainable resource (1-50). In addition, hemp has the ability to absorb carbon dioxide while it is being grown (1-50). However, as it more specifically relates to the field of **civil engineering**, hemp can be mixed with lime to form a bio-aggregate concrete, known as "**Hempcrete**" (1-62).

Hempcrete is a lightweight concrete, made from hemp pulp (or shiv), and hydraulic or aerated lime (1-50). It is typically used for timber frame infill, roofing tiles, insulation, renders, and floor slabs (1-21). Although hempcrete cannot provide enough structural integrity to be used as a load-bearing material (1-59). In the construction phase, hempcrete is the most commonly used for a timber frame infill, which is built using a removable formwork mold, such as a plastic casing (1-59). The most complicated process of the mixture design is getting the correct ratio between the fluid phases, air, water, the solid phases, hemp shiv and the binder (1-50). For instance, an example of a walling application would include 100 liters of hemp shiv, 22 kg of Tradical ® PF70 lime, and 30-35 kg of water (1-50).

Hempcrete is a highly breathable material, which allows for the regulation of indoor temperature and humidity (1-45). This is mainly caused by the porosity of hempcrete, which allows the transfer of water vapour with the surrounding air (1-50). This phenomenon occurs at times of high humidity, allowing the vapour to condense back into the liquid state and coming to rest on the surface of the pores (1-21). This process can be reversed in times of low humidity, essentially acting as a **natural humidifier** (1-45). Consequently, this has an interesting effect on the thermal conductivity of hempcrete (21). Hempcrete locks

CO_2 within its fibers, has low thermal conductivity, and exceptional acoustic performance and vapour permeability, which regulates the temperature inside structures (1-63).

The tropical and temperate climate helped to cultivate the hemp plant for a longer duration of time (1-50; 60-63). It is essential to battle stereotypes and stigmas and differentiates between the Narcotic medical cannabis **(marijuana type)** and the industrial hemp (fiber type) version so that policy-level changes can be implemented in India (1-59). Hempcrete has been one of the most researched building materials in recent times (1-50, 60-63). The increasing use of conventional building materials in the country is increasing the risk of the catastrophic **level of pollution** in **India** (1-21-30). This needs to be halted at all costs to ensure that future generations are able to live a clean and healthy life in India (1-59). The **Himalayan Hemp Organization, India** are making people aware of the harm of using conventional building materials while at the same time educating them on the massive benefits of building with industrial hemp fiber (1-21;49-59). This paper discusses the main advantages of industrial hemp fiber, and its use in making a type of concrete for construction, as **hempcrete** in the following sections (60-63).

II. Hempcrete: Plant based Building Construction material

Hempcrete is a plant based sustainable building construction material that is made with a low environmental impact that removes waste production, decreases both energy use and the consumption of natural resources (1-59). **Hempcrete** is a building construction material made from **Industrial hemp fibres, lime and water** (21-63). **Hempcrete** is a cost effective and sustainable properties which makes as a promising material in both new projects and those involving renovation (1-59). This composite breathes, as well as having **good thermal** and **acoustic-insulation properties** (1-21). For building purposes, the hemp crop's **inner woody** core, **hurds** is mixed with a lime-based binder forming a bioaggregate concrete, known as "Hempcrete" (1-30). The hemp-lime composite material is mainly used to make walls, although floor slabs, ceiling, and roof insulation can be made (1-50). The relatively denser hempcrete mixture is poured above a base layer into the floor to make floor slabs (1-30). Hempcrete is a bio-composite mixture of hemp shive, lime binder and water (1-40). A lightweight material, which is about one eighth the weight of concrete (1-63). Furthermore, civil engineers confirmed that hempcrete blocks can also be used for roofs as well as the more conventional wall applications since their implementation is easier than other types (1-21; 30-55).

Industrial Hemp is not a new construction material (1-25). Archaeologists have confirmed the use of hemp fiber (also called 'shive') in the construction of a bridge, dated to the 6th century AD, in southern France (1-36). The first modern use of hemp fiber composite construction was in France in 1990 for the renovation of historic timber-framed buildings, casting the hemp lime mixture around the timber frame (1-21; 30-55). These buildings are clear proof of the durability of materials based on lime (1-25). **Cement plaster** **found to be unsuitable as it did not breathe, stopping the escape of moisture and promoting rot; and was not flexible, resulting in surface cracking** (1-30). The **hemp** and **lime** product proved to be a natural alternative to cement based concrete (21). Most importantly, **hemprete** showed a **negative carbon footprint** making it a suitable material in the construction industry (1-63).

III. Hempcrete: House built in India for First time

In a first of its **kind in India,** an architect couple — **Namrata Kandwal and Gaurav Dixit** have built a house made of using hemp fibre in Uttarakhand state, India **(Figure-1, 2, 3, 4)** (49-59). There is an urgent need for sustainable construction materials that can replace the traditional concrete used for building houses by using an eco-friendly alternatives, 'Hempcrete' (45-59). Furthermore, when new buildings in **Uttarakhand state**, India are constructed from industrial hemp, thereby increasing the income of hemp farmers in the **Uttarakhand state, India** (49-59). It will also facilitate proper waste management (49-59). Uttarakhand state, India can also reduce its dependence on other states by creating building materials out of local waste from hemp (43-62). Industrial Hemp (fiber) plant material is light, keeps the **room cool** in summer and warm during winter (49-59). **Industrial hemp (fiber type**) when mixed with lime, it becomes **fire resistant** and is also **antibacterial** and **antifungal** and can last centuries (43-59). Therefore, the youth of Uttarakhand state, India has taken a shine to the commercial usefulness of industrial hemp (45-59). They also market hemp-based products online (49-59). **Hemp regulates moisture and reduces seepage** (49-59). **Industrial hemp (fiber type**) also has the ability to **absorb carbon dioxide** and improves air quality inside the building (43-59).

Namrata, a resident of Kandwal village of Yamkeshwar block in Uttarakhand state, India founded her start-up **Gohemp Agro Ventures**, which researched the **Industrial hemp (fiber type**) (46-59). The company manufactures daily used products from the seeds and fibre of hemp (49-59). The oil from hemp seed is used to make medicine (45-59). Namrata and team has focussed on making construction material out of **Industrial hemp (fiber type**) (43-59). Further **Gohemp Agro Ventures** decided to use **Industrial hemp (fiber type**) as a source of employment for people living in the mountains (49-59). This would not only change the attitude of the people towards industrial hemp [usually associated with medical cannabis **(marijuana type), Charas, Ganja** and drugs] but also prevent migration to cities from mountain villages (47-59).

In another major development, Namrata Kandwal's **Gohemp Agro Ventures**, researched the applications of industrial hemp as an eco-friendly building construction material (49-59). **Gohemp Agro Ventures** have created a durable construction material out of hemp, which has also been used in **Ellora Caves** (49-59). **Ellora caves** in **Maharashtra's Aurangabad district** and **Kandwal village in Uttarakhand's Pauri district** binds the two, because of the **industrial Hemp** (49-59). Further architect Namrata Kandwal of Uttarakhand and her team, who have used a hemp mixture in building construction and made it to the **top five** at the recent **Global Housing Technology Challenge-India**. **Namrata** and team has come up with building insulation material prepared by mixing **hemp wood**, lime and a variety of minerals (49-59). This mixture is very similar to what has been used in the **Ellora caves**, which date back to the **6th and 11th centuries AD**, and the **reason for its longevity** (49-59).

Global Housing Technology Challenge-India was organised by the Union ministry of housing and urban development and launched by prime minister Shri Narendra Modi along with the **Light House Project** on January 1, 2021 (49-59). The prime minister of India launched **Six Light house projects** at different sites in the country, under the **Global Housing Technology Challenge-India** (49-59). These projects will fuse modern technology and innovative processes, bring down construction time and help in affordable housing for the economically underprivileged (49-59). The event was attended by more than 50 companies from across the world involved in innovative construction technologies (49-59). Under the **Light house project**, **one thousand** such houses are to be constructed using plant material such as Hempcrete in Agartala (Tripura), Ranchi (Jharkhand), Lucknow (Uttar Pradesh), Indore (Madhya Pradesh), Rajkot (Gujarat) and Chennai (Tamil Nadu) within a year 2023 (49-59).

Under the **Global Housing Technology Challenge-India**, raw material that will give a thrust to conservation of non-renewable natural resources such as river sand, soil water, and industrial hemp fiber (49-59). This will stop the pollution generated by the traditional construction sector is encouraged (49-59). **Gohemp Agro Ventures** also received the best entrepreneur award at the **Asian Hemp Summit-2020** held in Nepal (49-59). The most sustainable building materials tend to be derived from plants particularly **Industrial hemp (fiber type**) (48-59).

India's hemp industry is growing at a steady pace (49-60). Hempcrete is a popular, much-talked-about hemp product (1-60). In fact, many have lauded the Uttrakhand state, Indian couple who built an "all-green" house using hempcrete (49-59). As the climate conditions continue to change around the world, experts are looking for sustainable solutions (1-21). Further, hempcrete offers a number of benefits towards this goal (49-59). **Hemp has eco-friendliness, low carbon footprint, thermal regulation,** and **moisture-absorbing properties. Industrial hemp fiber** is an **ecologically and financially sensible solution, especially in a climatically diverse country like India** (49-59). It can be used to build, renovate, and/or restore all types of buildings—from houses and apartments to public sector buildings (49-59). Hempcrete is versatile and the fact is that it can be made by mixing lime and **hemp hurds** in proportions adapted to the work to be done (49-59).

Hempcrete is eco-friendly and energy-efficient (21-59). The hemp plant is typically grown for either fiber or seed (1-30). In either case, the **hurd** is considered to be a by-product (20-59). Large-scale hemp production can therefore, generate tons of **hurd** for the construction and insulation markets (1-59). Hempcrete's unique ability to store energy and release it at a slow rate to stabilize temperature fluctuations makes it the ideal building material for all Indian weather conditions (2-59). Industrial **Hemp hurds** are able to store considerable amounts of moisture because of their porous structure (40-59). This moisture gets absorbed into the large internal surface area of the **Industrial hemp (fiber type**) plant and moves to the cellular structure (20-59). This storage capacity allows Hempcrete to absorb moisture when it exists and release it when conditions allow (29-59). On the other hand, the presence of lime, which is an inherently antimicrobial and antifungal compound, proves to be useful by creating a surface that resists mold in high temperature and humidity conditions (10-59). This resilience gives hempcrete an edge over other insulation materials, making it a desirable choice in both hot and cold climates as well as anywhere where humidity levels are high (1-21). India's average humidity levels go as high as 70% in the north, 81% in the east, 79% in the south, and 76% in the west (40-59). Therefore, **industrial hemp fiber** is the right plant based building construction material that is hempcrete in India (1-60).

Timber is an obvious example, as is bamboo**.** But there is another fast-growing crop that makes an excellent building material and it is none other than **hempcrete (20-59).** Over the last few years, several hemp innovations have emerged. Hemp has been used to produce a lightweight building material for walling and insulation purposes (10-59). This has the added benefits of superior thermal performance and carbon negativity; plastic for functions ranging from single-use to automotive components; textiles used for technical as well as apparel (30-59). Furthermore hempcrete is found to be several times **more sustainable than cotton** and cheaper to produce (1-59). Hempcrete is a bio-composite made of the inner woody core, hurd of the hemp plant mixed with a lime-based binder (1-50). The hemp core or "Shiv" has a **high silica content** which allows it to bind well with lime (**Figure-1**). This property is unique to hemp among all natural fibers (1-50). The result is a lightweight cementitious insulating material weighing about a seventh or an eighth of the weight of concrete. Fully cured hempcrete blocks float in a bucket of water. It is not used as a structural element, only as insulating infill between the frame members though it does tend to reduce racking (1-21).

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Tarun Jami who founded **GreenJams Infrastructures LLP** with a vision to integrate the "**Built Environment" with the "Natural Environment**" (40-59). They found that adopting carbon-negative materials was the only way to realise their vision, the **birth of their Hempcrete R&D** (49-59). **GreenJams** was also a showcase partner at India's First Hemp Showcase organised by Project H at Hyderabad on the 20th of April, 2019 (49-59). They had showcased hempcrete with a fun DIY "**Make Your Hempcrete**" activity (49-59). Hempcrete, courtesy **Green Jams**, as they got down to **hand-make hemp concrete blocks** (49-59).

Another entrepreneur **Gaurav Dixit,** who is CEO of **GoHemp Agro Ventures Pvt. Ltd** and general secretary of **Uttarakhand Hemp Association** (UHA), India is a non-profit organization found by the people from Uttarakhand state, India to help the state in the implementation of its industrial hemp fiber vision at the grass-root level (49-59). **Uttarakhand Hemp Association (UHA),** India created a sustainable ecosystem of the hemp industry in Uttarakhand state, India which will benefit everyone associated with the hemp revolution especially the people directly connected to industrial hemp cultivation (49-59). **Uttarakhand Hemp Association (UHA), India** can integrate **industrial hemp fiber** in future housing projects as the hemp house gives the privilege to live in a place that is not only safe and non-toxic but also helps in cleaning the air, and the earth (49-59). **Industrial hemp (fiber type**) being a **cellulose material** takes carbon in during its life and lets it back into the atmosphere when it decays (49-59). The hemp plant is put it into a wall, **the carbon is trapped inside** and not released into the atmosphere (https://www.himalayanhemp.in/post/everything-you-need-to-know-about-building-with-hemp) (49-59).

IV. Building Construction Industry: Facing Environmental issues

The building construction industry must currently deal with a number of issues affecting the environment (1-59). Among these are **climate change**, the consumption of natural resources, non-biodegradable waste production, and the overall quality of living (1-30). In addition, the inefficient use of energy in the building construction sector add significantly to these factors (1-50). **Environmental issues**, ranging from global warming responses to life cycle analysis, are becoming more important in the design, construction and use of buildings (10-48). There has been an increase in the demand for nature-friendly methods of construction, leading to design tools and construction systems for improved energy-efficient houses (1-59). The next step is to focus on energy-efficient construction processes, as well as using local raw materials to minimize the building environmental footprint (1-30). The rate of **carbon emission** into the atmosphere has hit a record high in the last decade (5-59). Concerns are on the rise as current atmospheric carbon dioxide levels are increasing alarmingly compared to past decades (2-50). Therefore, building construction industry has been developing methods to reduce as well as to reverse **CO_2** generation (1-59). Demand to reduce or stop building construction practices that harm the environment are driving scientists, architects, and engineers to search, develop, and implement the use of alternative materials, such as bio-aggregates (1-59). With their carbon neutral and carbon negative properties, **bio-composite** materials have been getting more attention in the construction industry (2-50).

One of the recently rediscovered materials in the industry is **Industrial hemp** fibres because of its high sustainability properties and attributes, serving over 25,000 different products in the global market (1-49). One example is a bioaggregate concrete known as **hempcrete** (1-59). This bio-composite is made up of **hemp hurd**, the inner woody core of the hemp plant, along with a lime-based binder (10-50). As with other plants, during its growth phase, it absorbs **atmospheric CO_2** by photosynthesis, trapping it in the shive and hence in the construction for the lifetime of the building (1-59). **1 ha** of hemp absorbs during its growth **4 times more CO_2** than the same tree forest area (1-62).

V. Hempcrete: A Method of Processing

Hemp-based concretes are among the most promising and environmentally sustainable alternatives to conventional concrete (1-21). After the removal of the outer bast fibre, the remaining woody core of the hemp stalk, referred to **as hurd or shives**, has either been used for animal bedding or simply burned (1-62). The **hemp hurds**, or the center of the stalk, water, and lime (which is powdered limestone) mixed it in a slurry and formed into the **wall of a building** (1-59). Further, over time, the chemical reactions between the **water, lime, and Hemp** will petrify the hemp and turn the lime back into stone (2-59). The use of the hemp hurd in hempcrete can now provide extra value to the hemp grower (1-50). The resurgence of hemp in contemporary concrete mixes first occurred in the early 1990's, in France, with the goal being to lighten conventional concrete using hemp chips (1-21). The process of making hempcrete starts with extracting the interior of a cannabis plant – an interior woody core that is separated from the flower, seed, and the rest of the plant (1-59). This extraction is difficult due to the strong chemical bonds called **pectin** present in the **hemp stem** (Canadian Hemp Trade Alliance 2020) (1-21, 25-59). To overcome these bonds, a process known as **retting** is performed on the stem where water, enzymes, or microbes are applied to separate the bast fiber surrounding the stem from the inner woody core (1-50). When harvested as such, it is given the name hemp "**hurd" or "shiv**" (21, 1-50). The **hemp hurd** is then chopped into lengths of approximately 6–25 mm, often using a decorticator (21-59). The hemp itself has a **high silica** content, which makes it suitable for binding with lime (21-50). The fiber content in hemp increases hemp's density and improves strength (21-50). However, this worsens the thermal performance of hempcrete (21). Accordingly, it is preferable to

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have minimal fiber or no fiber at all present in hempcrete mixtures (1-21). The process begins with the mixture of **hemp hurds** with water followed by the lime-based binder (1-21). The order in which these ingredients are added is very important as the reactions occur rapidly (21). Some hempcrete producers choose to mix the hurds using a mortar mixer (or by hand) with the lime-based binder, followed by misting water until the desired consistency is reached (1-21, 30-48). A chemical reaction known as "**bonded cellulose insulation**" occurs between the water and the lime-based binder, which adheres to the hurd particles together (1-25).

VI. Hempcrete: Advantages of Industrial hemp (fiber type)

1) **Hempcrete** meets condition of eco-friendly material and is made of renewable resources (21). Production is less **energy-intensive**. It has negative greenhouse gas emissions (1-21). It provides resistance and durability construction and healthy living condition. This material is recyclable. It is proposed to undertake a LCA (Life Cycle Assessment) of hempcrete in the future (1-40).
2) Hempcrete does not require agrochemicals like the **common endosulfans, DDT's**, and other **nitrogenous fertilizers** in its cultivation (1-21). The hemp plant absorbs up to **15 tonnes/hectare of carbon dioxide** from the air, thus reducing the **greenhouse gas effect** on the planet (21-59).
3) Hempcrete brick or blocks are **very light** in weight and they are delivered to the building construction sites (1-21). Further much of the drying of hempcrete is already done, leading to a curing process that is sustainable as the **blocks are left out to dry naturally without energy consumption** (21-50).
4) Hempcrete as a green material promotes the **wellbeing and safety of the public** and **minimizes the impact of climate change** whilst maintaining the efficiency and resilience of buildings (1-21; 35-50).
5) **Transporting** hempcrete is more economical compared to concrete, as it is a lightweight and low-density material (1-21). Furthermore, construction with hempcrete (as opposed to normal weight concrete) requires shallower (21-30). Thus more affordable foundations without necessarily requiring joints because of their distinctive properties (1-35).
6) Hempcrete has shown that **hempcrete can absorb more carbon** than it releases during its production phase, hence having negative embodied carbon (21). An average **hempcrete apartment absorbs 7.5 tons of carbon dioxide**, which is equivalent to the energy consumed by an average concrete apartment for heating and cooling in five years (Florentin *et al*. 2017) (21). A comparative life-cycle analysis by Florentin *et al.* (2017) suggests that hempcrete's net carbon balance is 10% less than that of autoclaved aerated concrete (1-50). Overall, hempcrete is **carbon negative** which signifies Earth's total net carbon savings (21-50).
7) Hempcrete walls have a **high degree of sound insulation** by trapping sound waves, thus reducing **noise pollution** (1-21; 30-50). The acoustical performance of hempcrete is highly dependent on parameters like thickness and whether or not hempcrete is rendered (21).
8) Hempcrete costs **less than other synthetic insulation materials**, which can compensate for the larger thickness of hempcrete walls (1-30).
9) The **thermal storage capacity of hempcrete** allows it to store the generated interior heat and release it to the interior later (e.g., at night) when outside is colder (during winter) (1-21). On the other hand, during the summer, **it will absorb the outside heat and does not release it to the interior immediately** (21-40). This will help to avoid overheating, and therefore can reduce energy bills (21).
10) Hempcrete also helps energy saving as its **airtightness** due to being a monolithic and single layer (solid) material (21). This will reduces heat loss through air leakage commonly seen with excessively large amounts through conventional wood-frame walls (1-30).
11) An **ideal insulation material would be renewable and durable**, which can be produced from waste streams or as a byproduct of other processes (1-21). Hempcrete has much of such attributes, besides the potential of creating healthy buildings (49-59). Hempcrete's construction flexibility allows architects and builders to come up with customized designs (1-21).
12) **Hempcrete has high levels of cellulose** (21). Hemp plants and **hurds** are composed of 65%– 70% and 40%–48% of cellulose, respectively (1-30). The high levels of **cellulose prevent carbon** from releasing into the atmosphere (21).

VII. Hempcrete: Disadvantage

Some drawbacks to the use of hempcrete include its **capacity to retain water**, which can cause swelling and bio-decay of the material, as well as **poor mechanical performance** which currently prevents it from use as a load bearing material (1-37). Despite its many benefits, hempcrete does have several key drawbacks that make it less than ideal as a building material (1-40). For instance, the porous structure of the hempcrete **decreases its mechanical performance**, and increases its **ability to retain water** (1-57). Though these issues are not a big problem as to prevent the use of hempcrete within the construction sector which provide strong limitations regarding what it can be used for (1-29). The most significant setback of hempcrete is its **poor**

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mechanical performance, which prevents hemp from being used as a load-bearing material (1-57). This is primarily due to the fact that hempcrete is **highly porous**, causing a **poor adhesion** to the lime binder that results in an **Elastic-like behaviour** (Arnaud et al, 2013) (1-40). Theoretically, this can be a useful trait in some situations, such as **earthquakes**, in which the material can bend without compromising its structure or cracking (1-40). On the other hand, it does cause hempcrete to deform a significant amount under stress (1-45). **One good news** is that recent experimentation has indicated that this can be avoided (1-40). In addition to poor mechanical performance, hempcrete also has a high capacity to **absorb and retain water** (1-40). This can be of benefit to **the agricultural process**, in that it decreases the irrigation requirements of the hemp crop, it can be a significant detriment to its use as a construction material (1-45). For instance, the hemp shiv is able to absorb up to 300-400 times its weight in water (1-50). A recent study utilized a recycled high-density polyethylene (rHDPE) in order to increase the mechanical strength of hempcrete (1-21). Following an alkali treatment, which consisted in dousing the hemp fiber in a **5% NaOH** solution, the material was then coated with the polyethylene composite, resulting in an **increased surface coarseness and surface area** (1-39). This is allowed for greater adhesion to the binder (1-50).

However, some research asserts that the mechanical performance can be increased, depending on what binder is used (1-40). More recently, research has been conducted on a building material utilizing hemp known as hemp lime concrete or hempcrete (1-21). Since then, much research has been carried out regarding the mechanical properties of hemp reinforced concrete as well as the different binder mixes that may be used (1-40).

A study by de Bruijn et al. (2009) examined the effect of varying the proportions of hydrated lime, hydraulic lime, and Portland cement (21). The composition of the hemp used by weight was 35% fibres, 62% shives (hurds), and 4% dust (1-21). Hempcrete has been shown to quickly reach steady state temperatures within a test wall and has a wider variation in relative humidity when compared to more conventional materials such as aerated autoclaved concrete and vertically perforated brick (1-50). More research will be required to study how the moisture migration occurs (21). The power consumption of the hempcrete building was relatively close to that of the **fibreglass building** (4-21). **The hempcrete building is not as airtight as the fibreglass building** (1-21).

Hempcrete is a useful material for reducing the impact on the construction sector has on the environment, while retaining good economic value (1-50). Although, with the current methods of application, **hempcrete is not an ideal material for construction**, it does present many characteristics that set it apart from traditional concrete in terms of economic and environmental benefits (1-40). The material's density provides airtightness, guaranteeing uniformity within the structure (21). In contrast, it is argued that these hempcrete walls are too thick, subsequently leaving residents with less carpet space (1-30).

Hemp is not readily available everywhere and is **even illegal** in a few countries, so procuring the material for construction can be **difficult or expensive** (1-21). There is a process that one has to go through to earn a permit application for a hempcrete building (1-23). It starts off with the applicant understanding the **local code** while taking into consideration the parts of the building that do and do not meet that specific code (21).

Recycling is also an option to get rid of hempcrete building once it reaches the end of its life (1-39). However, **hempcrete is still a relatively new material** and not **many hempcrete buildings have been built to reach their end of life** (21). So, while R&D efforts are still ongoing for the efficient recycling of hempcrete, landfill disposal is currently the best option with the caveat that the disposed hempcrete will not emit carbon dioxide when decomposed (1-30). Hempcrete showed lower thermal diffusivity when compared to other materials like concrete, earth block, and solid brick (21). The hemp shiv contains air spaces between its particles and microscopic pores within the material itself, which provide **thermal resistance**, i.e., the **more air pockets, the higher the insulation** (1-45).

Life cycle assessment (LCA) can comprehensively analyze the sustainability of a hempcrete building's material composition in terms of embodied energy, the effect of waste products during manufacturing and construction processes, as well as any material restoration over the building's lifetime (1-35). **The life span of hempcrete is not accurately known** (1-21). However, the lifecycle assessments performed on the material estimated the lifespan of hempcrete walls to be around 100 years with hardness and rigidity increasing over time (21-45).

Although hempcrete homes can save on electricity, **their construction is currently more expensive** compared to the conventional wood frame with fiberglass batt insulation (1-40). Because **hempcrete building construction is relatively new, not enough research and development** (R&D) has been conducted on industrial hemp and hempcrete usage to lower the cost (1-40). However, **as with any other innovative product, with more use and sales of the product, more economical options will evolve** (21). Needless to say, more R&D can help hempcrete to be accepted by the builders (1-48). The **lack of architects, engineers, builders with an interest in hempcrete,** and the current knowledge gaps require more training programs for design professionals and builders (1-49). In the long run, this will help to lower the costs (21). Looking ahead, further research on increasing the mechanical capabilities and decreasing the water absorption will go a long way **toward unlocking the potential of hemp as a sustainable building materia**l (1-49).

As mentioned earlier, there are **no hempcrete constructions** in **India** that are validated by scientific investigations to prove its suitability for adoption by the Indian consumers (49-59). Even the most basic **material characteristics of hempcrete when manufactured in India** are not determined (49-59). Needless to say, the manufacturing processes are not standardised either, resulting in inconsistent hempcrete material behaviour (1-59).

VIII. Conclusion

Industrial hemp (fiber type) is a versatile commercial crop that has been used for fiber, food, and medicinal purposes. The Hempcrete material's ability to absorb **carbon dioxide makes it an ideal eco-material** in lessening the negative environmental impact of the construction sector (1-21). It displays the good economic value as well as excellent **thermal and insulative properties** (1-59). **It holds an excellent lifespan and offers a low maintenance cost.** Growing the durable hemp material requires limited use **of fertilizers** (1-30). Hempcrete has a significant contribution to the building construction industry as it involves planting, building, installing, and more, instilling opportunities in other sectors of business (21). Hempcrete is a variety of **vegetal concretes**, an emerging class of building construction materials being actively developed and used in countries like **England, France, USA, Canada and Belgium**. Their authorities have formulated certification and authorisation procedures for the manufacture and use of materials like hempcrete (21). Hempcrete and its relevance to New Zealand (where hempcrete has already been used) and the Czech Republic (where the first hempcrete house is under construction) has been reviewed (1-50).

In **India**, **hempcrete materials are not in great use** and public organisations have not taken it upon themselves to promote or recognise them (49-59). Public organisations such as **BUILDING MATERIALS AND TECHNOLOGY PROMOTION COUNCIL (BMTPC),** Ministry of Urban Development, Government of India, New Delhi are responsible for the promotion and adoption of innovative building materials and technologies in **India** (49-59). **BMTPC** is mandated to promote resource-efficient, climate resilient, disaster resistant construction practices including emerging building materials and construction technologies for field level applications. BMTPC is also one of the resource institution for the Ministry to provide S&T support in the area of innovative building materials & construction technologies and disaster mitigation & management.

An architect couple has built a sprawling **5-room house in Yamkeshwar block of Pauri Garhwal district, Uttarakhand state, India using 'hempcrete'** – a mixture of parts of "bhang" or hemp plant, lime, wood, mud, water and other minerals – which can be used as a green alternative to concrete (49-59). **This is the first time hempcrete** has **been used as a building construction raw plant material to build a house in India**. This technique is prevalent in countries like USA, Canada, Australia and New Zealand (1-21).

Hempcrete is at a great disadvantage since it is not suitable for being a load-bearing material like concrete. However, its ability to resist fire, mold, fungus, and moisture along with its carbon- negative properties compensates for that. **Seeing a shift in the global selection of concrete as a building material to utilizing hempcrete will be contingent on costs, hemp availability, awareness, and project suitability** (1-40). Therefore, in detail experimental study is warranted for the commercialization of hempcrete as a building material. Finally, the future of the Industrial hemp (fiber type and grain type), strongly depends on market demand for its bio-based products that will help the plant to establish itself as a worthy sustainable crop.

References

1. Grof CPL. Cannabis, from plant to pill. J. Clin. Pharmacol. 2018; 84: 2463–2467.
2. Hall J, Bhattarai SP, Midmore DJ. Review of flowering control in industrial hemp. J. Nat. Fibers. 2012; 9: 23–36.
3. Pavlovic R, Panseri S, Giupponi L, Leoni V, Citti C, Cattaneo C, Cavaletto M, Giorgi A. Phytochemical and Ecological Analysis of Two Varieties of Hemp (Cannabis sativa L.) Grown in a Mountain Environment of Italian Alps. Front. Plant Sci. 2019; 10:1265.
4. Schluttenhofer C, Yuan L. Challenges towards revitalizing hemp: a multifaceted crop. Trends Plant Sci. 2017; 22 (11): 917–929.
5. Struik PC, Amaducci S, Bullard MJ, Stutterheim NC, Venturi G, Cromack HTH. Agronomy of fibre hemp (Cannabis sativa L.) in Europe. Ind. Crops Prod. 2000;11: 107–118.
6. Baldini M, Ferfuia C, Piani B, Sepulcri A, Dorigo G, Zuliani F. et al. The performance and potentiality of monoecious hemp (Cannabis sativa L.) cultivars as a multipurpose crop. Agronomy. 2018; 162, 1–16.
7. Nath MK. Benefits of Cultivating Industrial Hemp (Cannabis sativa ssp. sativa)—A Versatile Plant for a Sustainable Future. Chem. Proc. **2022**; 10: 14. https://doi.org/10.3390/ IOCAG2022-12359.

8. de Bruijn PB, Jeppsson KH, Sandin K, Nilsson C. 2009. Mechanical properties of lime-hemp concrete containing shives and fibres. Biosystems Engineering. 2009; 103: 474-479.
9. Evrard A, De Herde A, Minet J. Dynamical interactions between heat and mass flows in lime-hemp concrete. In Proceedings of the 3rd International Building Physics Conference – Research in Building Physics and Building Engineering, 69-76. Montreal, PQ. Aug 27-31. 2006.
10. Hirst EAJ, Walker P, Paine KA, Yates T. Characterization of low density hemplime composite building materials under compression loading. In *Second International Conference on Sustainable Materials and Technologies*, 1395-1406. Ancona, Italy. June 28-30, 2010.
11. Jeremy Pinkos. The Effectiveness of Hempcrete as an Infill Insulation in the Prairies Compared to a Standard Building Based on Power Consumption. By Jeremy Pinkos. A thesis submitted to the Faculty of Graduate Studies in partial fulfilment of the requirements for the degree of Master of Science. Department of Biosystems Engineering, Faculty of Engineering University of Manitoba Winnipeg, Manitoba, July 2014.
12. **Updike J, Felker** T. Hempcrete as a Sustainable Building Material. South Dakota School of Mines and Technology ASCE Student Member 7296671 501 E. Saint Joseph St. Rapid City, SD 57701 605-890-3981.
13. Bedlivá H, Isaacs N. Hempcrete – An environmentally friendly material?. Advanced Materials Research. 2014; 1041: 83-86.
14. **Arnaud** L, Amziane S, Nozahic, V, Gourlay E. Bio-Aggregate-Based Building Materials: Applications to Hemp Concretes. Mechanical Behavior. 2013; 153-178. ISTE Ltd, United Kingdom. Wiley. New Jersey.
15. **Arnaud** L, Samri D, Gourlay E. Bio-Aggregate-Based Building Materials: Applications to Hemp Concretes. Hygrothermal Behavior of Hempcrete. 2013; 179-243. ISTE Ltd, United Kingdom. Wiley. New Jersey.
16. Arizzi A, Brummer M, Martin-Sanchez I, Cultrone G, Viles H. The Influence of the Type of Lime on the Hygric Behaviour and Bio-Receptivity of Hemp Lime Composites Used for Rendering Applications in Sustainable New Construction and Repair Works. PLoS One. 2015;10(5): 1-19.
17. Gle P, Gourdon E, Arnaud L. Bio-Aggregate-Based Building Materials: Applications to Hemp Concretes. Acoustical Properties of Hemp Concretes. 2013; 242-265. ISTE Ltd, United Kingdom. Wiley. New Jersey.
18. Lanos C, Collet F, Lenain G, Hustache Y. Bio-Aggregate-Based Building Materials: Applications to Hemp Concretes. Formulation and Implementation. 2013; 118-152. ISTE Ltd, United Kingdom. Wiley. New Jersey.
19. Lu N, Korman TM. Engineering Sustainable Construction Material: Hemp-Fiber-Reinforced Composite with Recycled High-Density Polyethylene Matrix. Journal of Architectural Engineering. 2013; 19(3): 204-208.
20. Johnson R. “Hemp as an Agricultural Commodity.” Congressional Research Service. 2015; < http://fas.org/sgp/crs/misc/RL32725.pdf> (Feb. 13th, 2016).
21. **Zuabi W, Memari AM**. Review of Hempcrete as a Sustainable Building Material. International Journal of Architecture, Engineering and Construction. 2021; 10(1):1-17. 22021001. http://dx.doi.org/10.7492/IJAEC.2021.004.
22. **Sparrow** A. Building with hempcrete (hemplime): Essential tips for the beginner (part 2). The Last Straw. 2014; 65.
23. **Stanwix** W, Sparrow A. The Hempcrete Book: Designing and Building with Hemp-Lime. 2014; Green Books, West Berkshire, UK.
24. Schluttenhofer C, Yuan L. Challenges towards revitalizing hemp: A multifaceted crop. Trends in Plant Science. 2017; 22(11). https://doi.org/10.1016/j. tplants.2017.08.004.
25. Protchenko T. Prototype of hempcrete noise barrier wall. Bachelor thesis, Hame, University of Applied Sciences, 2019; Hameenlinna, Finland.
26. Pure Earth. Different mixes used for the hempcrete wall. Available at <https://uku.eu> (accessed on 2020/9/5). 2020.
27. Rhydwen R. Building with hemp and lime. Available at <https://www.votehemp.com/wp-content/ uploads/2018/09> (accessed on 2020/8/10) 1999.
28. Tran Le AD, Maalouf C, Mai TH, Wurtz E, Collet F. (2010). Transient hygrothermal behavior of a hemp concrete building envelope. Energy and Buildings. 2010; 42(10): 1797–1806.
29. Pretot S, Collet F, Garnier C. Life cycle assessment of a hemp concrete wall: Impact of thickness and coating. Building and Environment. 2014; 72: 223– 23.
30. Strandberg P. Hemp Concretes: Mechanical Properties using both Shives and Fibers. Bachelors thesis, 2008, Lund University, Lund, Sweden.
31. O’Dowd J, Quinn D. Investigating Properties of Hemp and Lime Construction. Bachelor thesis, University College Dublin, Dublin, 2005, Ireland.
32. Stevulova N, Cigasova, J, Schwarzova I, Sicakova A, Junak J. Sustainable bio-aggregatebased composited containing hemp hurds and alternative binder. Buildings. 2018; 8(25): 1–14.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue III March 2023

33. Ministry of Hemp. Building hemp homes in Alaska could save millions in heating cost. 2020; Available at <https://ministryofhemp.com> (accessed on 2020/07/21).
34. Kennedy B. You can build your own tiny hemp home, he'll show you. Available at <https://www. thecannabist.co> (accessed on 2020/08/25). 2018.
35. Kinnane O, Reilly A, Grimes J, Pavia S, Walker, R. Acoustic absorption of hemp-lime construction. Construction and Building Materials. 2016;122: 674–682.
36. Dashore A. Hempcrete blocks for construction. Available at <https://theconstructor.org> (accessed on 2020/08/03). 2020.
37. De Bruijn P, Pohansson P. Moisture fixation and thermal properties of lime-hemp concrete. Construction and Building Materials. 2013; 47: 1235–1242.
38. Collet F, Pretot S. Thermal conductivity of hemp concrete: Variation with formulation, density, and water content. Construction and Building Materials. 2014; 65: 612–619.
39. **Cerezo V**. Mechanical, thermal and acoustic properties of a plant particle-based material: an experiment approach and theoretical modeling. **PhD thesis**, University of Lyon, Lyon, France. 2005.
40. Florentin Y, Pearlmutter D, Givoni B, Gal E. A life-cycle energy and carbon analysis of hemp-lime bio-composite building materials. Energy and Buildings. 2017; 156: 303–304.
41. Evrard A, De Herde A. Hygrothermal performance of lime-hemp wall assemblies. Journal of Building Physics. 2010; 34(1): 5–25.
42. Elfordy S, Lucas F, Tancret F, Scudeller Y, Goudet L. Mechanical and thermal properties of lime and hemp concrete ("hempcrete") manufactured by a projection process. Construction and Building Materials. 2008; 22: 2116–2123.
43. **Asdrubali** F, Schiavoni S, Horoshenkov K. A review of sustainable materials for acoustic applications. Building Acoustics. 2012; 19(4): 283–312.
44. Florentin Y, Pearlmutter D, Givoni B, Gal E. A life-cycle energy and carbon analysis of hemp-lime bio-composite building materials. Energy and Buildings, 2017;156: 303–304.
45. Fourmentin M, Faure P, Pelupessy P, Sarou-Kanian V, Peter U, Lesueur D, Rodts S, Daviller D, Coussot P. NMR and MRI observation of water absorption/uptake in hemp shives used for hemp concrete. Construction and Building Materials. 2016; 124: 405–413.
46. **Canna** Systems Canada Incorporation. Hempcrete block system. Available at <https://www.cannasystems. ca> (accessed on 2020/08/29). 2015.
47. **Canadian Hemp Trade Alliance**. Fiber production: Retting of Hemp fiber. Available at <www.hemptrade. ca> (accessed on 2020/08/29). 2020.
48. **Wilson** C. The future for hemp, An environmental perspective-what can hemp offer? Available at <http://eiha.org/media/2019/08/Catherine_Wilson- CannaWellness-EIHA_2019.pdf> (accessed on 2020/ 9/25). 2020.
49. **Sheel** A. Why Is Hempcrete Perfect for India's Climatic Diversity? June 15, 2022 (Why Is Hempcrete Perfect for India's Climatic Diversity? - Sativa Media).
50. Azad S. **In a first in India, house built using hemp fibre in Uttarakhand** /TNN / Updated: Nov 28, 2021, 18:09 IST. In a first in India, house built using hemp fibre in Uttarakhand | Dehradun News - Times of India (indiatimes.com).
51. **Made with Bhang**: **India's first house built using hemp** in **Uttarakhand**. Nov 28, 2021, 06:07PM ISTSource: TOI.in
52. **Chaudhary S**. **Stay At India's First House Built With Hemp Fibre** In Uttarakhand. Published on : 27 Jun, 2022, 9:16 am. (Himalayan Hemp Eco Stay—India's First House Made From Hemp Fibre In Uttarakhand (homegrown.co.in).
53. Mathew M. **India's First Hemp-Based Cloud Kitchen Is Now Open In Mumbai**. ublished on : 20 Jun, 2022, 2:31 am. Hemp In India: BOHECO & The Hemp Factory Open India's First Hemp-Based Cloud Kitchen (homegrown.co.in).
54. Mathew M. **Homegrown Hemp & Cannabis Brands Paving The Way In India**. Published on : 20 Apr, 2022, 12:00 am (homegrown.co.in).
55. Mathew M. Head To **Asia's First Cannabis & Ayurvedic Wellness Retreat In Kerala** Published on : 18 Apr, 2022, 5:11 am (homegrown.co.in).
56. Mathew M. 7 Homegrown Companies Paving The Way For Hemp Acceptance. Published on : 8 Jun, 2021, 6:29 am (homegrown.co.in).
57. Homegrown Staff. 4 Indian Fashion Labels Using Hemp To Make Eco-Friendly Clothes. Published on : 8 Jun, 2021, 6:26 am(homegrown.co.in).
58. **Himalayan Hemp** Jan 20, 2020. **Can Hemp integrate with the sustainable housing projects in India?.** Can Hemp integrate with the sustainable housing projects in India? (himalayanhemp.in).
59. **Divendra Singh** | Updated: January 9th, 2021 A start-up in Uttarakhand uses hemp fibre in construction; makes it to top five at Global Housing Technology Challenge- India (himalayanhemp.in).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue III March 2023

60. **Malabadi RB**, Kolkar KP, Chalannavar RK. **Cannabis sativa**: Ethnobotany and Phytochemistry. **International Journal of Innovation Scientific Research and Review**. **2023**; 5(2): 3990-3998.
61. **Malabadi RB**, Kolkar KP, Acharya M, Chalannavar RK. **Cannabis sativa**: CANNABIS SATIVA:MEDICINAL PLANT WITH 1000 MOLECULES of Pharmaceutical Interest. International Journal of Innovation Scientific Research and Review. 2023; 5 (2):3999-4005.
62. Kore SD, Sudarsan JS. Hemp Concrete: A Sustainable Green Material for Conventional Concrete. Journal of Building Material Science. 2021; 3(2): 1-7.
63. **Malabadi RB**, Kolkar KP, Chalannavar RK. CANNABIS SATIVA: Industrial hemp (fiber type) - An Ayurvedic Traditional Herbal Medicine. International Journal of Innovation Scientific Research and Review. 2023; 5 (2):

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume VIII Issue III March 2023

Figure-1: Industrial hemp fiber brick used in building construction material

Figure-2: Industrial hemp fiber used in construction of house in Uttarakhand

Figure-3: Himalayan hemp fiber used in construction of house

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Figure-4: Himalayan Industrial hemp fiber in field