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REVIEW ARTICLE

Physical and Mechanical Properties of Hempcrete

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Abstract:

Background:

Environment-friendly materials attract attention whilst the construction sector causes excessive global energy consumption and emission of greenhouse gas. Renewable plant-based biomaterials, which have a low environmental impact, are very beneficial in order to prevent environmental pollution and to preserve natural resources. Hempcrete provides environment-friendly construction materials as well as thermal and hygroscopic properties.

Objective:

This paper presents a review of hempcrete research about understanding the environmental effects and construction methods of hempcrete; moreover, the benefits and innovations it has provided throughout its life cycle, have been investigated.

Methods:

For this purpose, experimental studies of hempcrete were compared to each other in all aspects in order to determine density, thermal conductivity, vapor permeability, hygrometric behavior, durability, acoustic absorption, mechanical properties and life cycle analysis. Moreover, binder characteristics, hemp shiv proportions, water content, curing conditions and results have been focused on to explain the benefits of hempcrete.

Results:

The results obtained show that hempcrete has high porosity and vapor permeability, medium-low density, low thermal conductivity, Young's modulus and compressive strength.

Conclusion:

Based upon the findings of the studies reviewed, hempcrete is an advantageous material in buildings with its extraordinary thermal and hygrometric behaviour. Hemp is also an eco-friendly and economical plant-based raw material for the construction industry.

Keywords: Plant-based material, Industrial hemp, Hempcrete, Hempcrete properties, Hempcrete life cycle assessment.

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1. INTRODUCTION

The building sector is one of the largest primary energy-consuming sectors and contributes substantial atmospheric emissions [1]. The greenhouse gases in the atmosphere are accelerating the earth's climate change at an unprecedented rate in history [2]. Greenhouse gas emissions contribute immensely to global warming [3]. The building and construction sector is responsible for 32% of global energy use and 19% of greenhouse gas emissions [4]. For this reason, the production and use of environmental-friendly building materials are becoming more important day by day. In recent years, the use of renewable energy sources and reducing greenhouse gas emissions has become a global goal [5].

Environmental problems such as global warming and climate change affect the design, construction and use principles of buildings. Energy efficiency and green building principles increase the demand for environment-friendly construction methods [6]. On a global priority scale, efforts to mitigate the impacts of climate change have focused on reducing greenhouse gas emissions within the framework of the Kyoto Protocol and Paris Agreement [7]. Therefore, it has become increasingly important to consider the life cycle analysis and the total environmental impact of the construction

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materials in the design of environment-friendly buildings [8]. Environmental concerns about conservation of natural resources and sustainability have been a significant source of motivation for researchers to work on environment-friendly composite materials which contribute low environmental impact, long-term community benefits as well as profitability [9, 10]. Constructing with sustainable materials reduces the production costs, helps respond to planning policies and preserves our heritage [11].

Environment-friendly construction materials and methods satisfied expectations due to their low environmental impacts and renewable resources. Plant-based biomaterials are frequently used in construction due to their thermal, hygrometric and acoustic properties [12]. Due to its high insulation and thermal properties, plant-based materials can be used as aggregate in non-structural concrete mixtures [13].

Building envelopes influence the hygrothermal behavior, energy efficiency, comfort and indoor air quality in the building. The hygroscopic property depends on the thermal conductivity, heat capacity, absorption curve and vapour permeability of the materials. It has been observed that it is possible to use hygroscopic materials in buildings with low energy [14]. Various efforts have been made to examine innovative energy-saving materials that combine appropriate structural performance and thermal insulation properties [15]. After Künzel's [16] study of hygroscopic building materials, many researchers focused on evaluating hygrothermal properties and modelling in hygroscopic porous materials.

Hemp-based concrete called hempcrete is advantageous for the construction sector compared to traditional materials with low environmental impact and high hygroscopic behavior [17]. Hempcrete provides many significant environmental benefits an amount of CO_2 sequestrated by hemp in its lifespan is much than the production of CO_2 during hempcrete production, transportation and construction phase [18]. A recent review studied by Ingrao et al. [19] concluded that hempcrete is useful with its hygric and thermal properties and also using hempcrete in buildings leads to reduced environmental impacts of the building's life-cycle. As a result, hempcrete offers both environmental and construction opportunities, which can help to deliver sustainable solutions.

2. METHODOLOGY

Hemp and hempcrete were used as keywords in the literature search. For this literature review, papers published in the last decade were selected, and a few older studies were included to examine the hempcrete in all aspects. It has been thoroughly researched to investigate the relevance of resources to the subject. Publications such as journals, books, chapters and reports scanned for this review were obtained from Science Direct, Springer Link and Taylor & Francis, etc. databases. To evaluate the literature for relevance, answers to the following questions are needed:

- What is hemp?
- What are the properties of hemp?
- What is hempcrete?
- How is hempcrete produced?
- What are the application areas of hempcrete?
- What are the benefits of hempcrete to the environment?
- What are the physical and mechanical properties of hempcrete?
- What is the cost of hempcrete?

3. HEMP

Hemp is a plant with a wide range of uses, a source of fiber, and seed oil used worldwide. Hemp can reach at least 2 meters of height and is a versatile plant especially grown for industrial purposes [19]. It has been used in paper, textile and rope making for thousands of years and it is also used in the automotive, furniture and construction industries today [20]. Archaeological remains found in China revealed that hemp was the first plant to be cultivated between 4000 and 6000 years ago [21].

Hemp stands out with its wide availability, low irrigation and fertilizing needs. It is also one of the fastest-growing plants in the world; 4 meters of height can be reached in 4 months with minimum fertilization and irrigation [22, 23]. Hemp can be produced efficiently in any geography with its drought-resistant and very low fertilization demand [24]. The hemp plant is resistant even to -6 °C and the best-growing temperature is in the range of 15 °C and 27 °C. While the annual precipitation amount of 200-300 mm is sufficient during the growth phase, hemp production is very efficient in well-drained natural and alkaline soil [25, 26].

Due to its low protein content, it is not consumed by insects and moths; therefore, pesticide use is not required, which is harmful to the environment. Hemp has a woody core surrounded by strong and long fibers, and it is processed to obtain shiv and fiber. Seeds and shiv have commercial value, but the most valuable part of hemp is fiber [27]. Shiv constitutes 40% to 60% of the weight of the hemp stalk and can be used as an animal bed or as an aggregate in biocomposites [28].

The biggest hemp producers in Europe are France, Germany, the UK and the Netherlands, respectively. Production quantities vary depending on the supply but differ from year to year. While hemp was produced in an area of 11300 hectares in 2009 in France, this figure decreased to 5400 hectares in 2011 [29]. China is the biggest hemp producer country in the world. Globally, 52.4% of hemp was produced in Asia, 40.6% in Europe and 7% in America in 2017 on a global scale [30].

3.1. Hemp Production in Turkey

It is known that the first official investment related to hemp cultivated in some provinces, especially in Kastamonu, was the hemp factory established by Sümerbank in Kastamonu Taşköprü in 1946. However, due to the fact that the factory could not be operated with full efficiency in time, it was closed in 1951. The second attempt is the Hemp Industry Establishment established in Kastamonu. However, due to the low profit, jute, which was cheaper than hemp, was imported. Hemp production could be kept alive in 1984 with the factory established in Taşköprü to produce paper for a factory owned by Seka, which was established in Izmit in 1976. The factory, which was privatized in 1998, was sold in 2004 [31].

While hemp had the highest production capacity in the world with 368,373 tons in 1967, total hemp production in 2017 was 59,817 tons. Hemp production between 1961-2017 years in Turkey, the highest production of 14,000 tons was made in 1980, after the gradually decreased production and in 2002, while 950 tonnes in 2004 to 30 tons, is seen can be made only 8 tons of production in 2017 [30]. Today, hemp cultivation can be done in 19 provinces and districts according to the law enacted in 2016 for the purpose of growing industrial hemp [32].

3.2. The Main Uses of Hemp

Hemp is used in about 25000 products in different sectors such as agriculture, textile, recycling, automotive, furniture, food, beverage, paper, building materials and personal care. The fibers are used especially in yarn and fabric production, carpet, rug and home decoration and composite materials used in the automotive industry, while shivs are used in animal bedding, paper production and oil absorbent materials. Seeds and seed oil are used in the food and beverage industry and soap production [33].

The woody core of hemp is cut into shivs of 5 to 25 mm in size and mixed with a binder such as lime or cement and water, a biocomposite with high thermal insulation properties called hempcrete is obtained [34]. Hempcrete can be produced in different compositions and different methods for walls, floors and roofs. For wall applications, a prefabricated or spray method can be applied, but it is necessary to use it in a frame since it does not have a sufficient compressive strength [35].

4. HEMPCRETE

Hempcrete is a mixture created with plant-based aggregate called shiv and binder in very variable proportions. The porous structure of hemp shiv provides deforming capacity, sound absorption and hygrothermal transferability [36]. Early assumptions were to using cement as a binder, but recent researches are about using other binders such as lime and pozzolana to improve the performance of hempcrete. Hempcrete produced with cement or lime provides much better hygrothermal behavior than conventional concrete depending on component proportions and wall, floor, or roof application [28].

The proper mix design of hempcrete differs according to application in the building. A small amount of binder is used for interlocking shivs in roof insulation; however higher amount of binder is required for the wall since higher mechanical properties are expected in the wall. The highest proportion of binder is used to obtain the highest mechanical properties in floor application [37].

Similar to conventional concrete, it can be produced in 3 different methods [38]: producing as prefabricated blocks, moulding in place and spraying. Each method has its advantages and disadvantages. In the on-site moulding method, long drying time is required. The spraying method is a quick method, provides short drying time and lower density. On the other hand, the prefabricated production is the fastest method [39].

Remarkable physical properties are explained by the unique variable-sized pores of hempcrete, micropores in the shives, mesopores formed by the air inside the mixture matrix and macropores between the shives in the matrix [40]. The presence of macro and mesopores is associated with the low compaction ability and the difficulty of compressing shiv with a density of 50 to 100 kgm^{-3} [41]. The porosity ratio of hempcrete is considered to be approximately 80% [42]. The chemical properties of hemp are presented in Table **1** [43].

Table 1. Chemical properties of hemp [43].

Substance	%
Cellulosic residue	56.1
Pectins	20.1
Hemicelluloses	10.9
Lignins	6
Others (waxes, fats, ashes)	7.9

Despite its insulation and hygroscopic advantages, hempcrete has high water absorption as a disadvantage. The use of excessive water in the mixture extends the hardening and drying time, which is not suitable in modern constructions. Moreover, its highly porous structure and strong capillarity effect absorb water up to 5 times its weight. Excessive use of water increases the drying time up to several months, but it is not an acceptable time on an industrial scale [44]. Considering that there is water exchange between the shiv and the paste, therefore, it is not possible to optimize the mixing water [40].

In the experimental studies conducted, the density of hempcrete was obtained between 300 and 600 kgm^{-3} depending on the mixing proportions. Hempcrete, which has the lowest porosity rate of 65% [45], has a thermal conductivity of 0.07 to 0.2 $Wm^{-1}K^{-1}$ at 23 ° C, 50% relative humidity (RH) [46]. The acoustic absorption coefficient was obtained from 0.5 to 0.9 [47].

4.1. Physical and Mechanical Properties

The physical properties of hempcrete are relatively low thermal conductivity, medium-low density, very high specific heat, strong thermal insulation and thermal mass, which provide building comfort and prevent sudden heat changes [48, 49]. The lack of a heat bridge and airtightness prevents heat losses. The hygroscopic feature that provides vapor permeability to the material ensures that the humidity in the building is in the comfort of microclimate [50]. Various parameters affect the mechanical properties such as binder type, curing conditions, production method and moulding [51]. Binder type, shiv/binder ratio (S/B), water/binder ratio (W/B) curing conditions, physical and mechanical results of experimental studies of hempcrete are presented in Table **2**. These experimental studies have been selected because they conducted with different binders, different shiv ratios and different cure conditions to be able to see the various properties of hempcrete.

Table 2. Binder type, S/B, W/B, curing conditions, physical and mechanical results.

Binder Type	S/B	W/B	Curing Conditions	Mould/ Spray	Physical and Mechanical Results	Ref
NHL 2 NHL 3.5 NHL 3.5 Z	0.2 0.4 0.5	1.16 1.5 1.6	28d 20 C° 30% RH 50% RH 75% RH 98% RH	16x16x32 cm^3 mould	The Young's modulus of the samples produced with NHL 3.5 binder cured in 50% RH was obtained with the maximum 9 MPa and the maximum compressive strength 0.18 MPa. As RH value increased, compressive strength decreased significantly. In samples produced with NHL 3.5Z binder cured 50% RH, compressive strength up to 0.31 MPa was provided and Young's modulus was measured at 36 MPa. Compressive strength in samples produced with NHL 2 ranges from 0.10 MPa to 0.22 MPa and Young's modulus ranges from 5MPa to 24 MPa.	[52]
Magnesium Phosphate Cement	0.08 0.12 0.16 0.2	1	1d, 7d, 28d 20 ± 2 C 50–55% RH	4x 4x16 cm^3 mould 15x15x5 cm^3 mould	Compressive strength obtained 0.714 MPa and thermal conductivity obtained 0.103 $Wm^{-1}K^{-1}$ were measured at the 20% hempcrete sample. It is reported that Young's modulus decreases as the hemp ratio increases. It has been determined that long curing time has a positive effect on Young's modulus. The values of maximum strain slightly increased as the hemp content increased.	[28]
72% unslaked lime 28% hydraulic lime	0.65	0.36	2 years 23° C 50% RH	30x30x16 cm^3 mould	The dry density of hempcrete is 396 kgm^{-3}, the saturated moisture content is 1.805 kgm^{-3}, total porosity is 81% and the specific surface area estimated from the GAB model at 23° C is 59 m^2g^{-1}. It has been found that the hygric capacity decreases along a scanning curve and the hysteresis has a significant effect on the storage or release of moisture in hempcrete.	[35]
70% natural lime, 30% hydraulic lime and pozzolana, natural prompt cement and citric acid	0.4 0.5 0.67	0.52 0.63	90days 20° C 50% RH	16x16x32 cm^3 mould	In samples produced with both types of binders, the thermal conductivity decreased by 8% to 30% as the hemp ratio increased. Thermal conductivity in samples produced with a lime-based binder was obtained by 20% more than samples produced with a natural prompt cement-based binder. The thermal conductivity decreases of about 9%–16% after drying.	[53]
75% hydrated lime, 15% hydraulic lime, 10% pozzolanic binder	0.4 0.5 0.65 1	0.05 gg^{-1} 0.1 gg^{-1} 0.15 gg^{-1} 0.2 gg^{-1}	23° C, 50% RH	Spray	When the effect of water content and density values on thermal conductivity is compared, it is obtained that density has more effect on thermal conductivity than water content. In the same mixture design, the thermal conductivity of the high-density sample is 2 times higher than the thermal conductivity of the low-density sample. The thermal conductivity increases low density (250 kgm^{-3}) to high density (600 kgm^{-3}) by 109% at the dry state and by 117% at 0.10 gg^{-1} in water content.	[54]
Starch	8 10	5.55	40d 50d 20°C	15x15x1510x10x40cm^3 mould	Density at ambient atmosphere is 182.8 kgm^{-3} for S/B=8 and 182.0 kgm^{-3} for S/B=10. The tensile strength is 0.08 MPa for S/B=8 and 0.10 MPa for S/B=10. The compressive strength is 0.57 MPa for S/B=8 and 0.60 MPa for S/B=10. The Young's modulus is 2.47 MPa for S/B=8 and 2.33 MPa for S/B=10. The thermal conductivity at the dry state varies in the range of 0.06-0.07 $Wm^{-1}K^{-1}$. When the S/B ratio increases, the mechanical characteristics slightly decreases due to the increase of the porosity and the decrease of the load transfer.	[24]
50% NHL 3.5 50% hydrated calcic lime	0.5	1.5	10 months 20°C and 50% RH Outdoor	11x22 cm^3 mould	The compressive strength of the samples cured in 10 months at 20 ° C and 50% RH was obtained 0.73 MPa. For 1 month curing at outdoor, the compressive strength was obtained 0.43 MPa and 10 months curing at outdoor the compressive strength was obtained 1.01 MPa. Outdoor curing improved the carbonation process, which enabled samples to reach a compressive strength of 1.01 ± 0.08 MPa after 10 months. This was attributed to favorable %RH conditions for CO_2 diffusion and dissolution.	[55]
75% Aerial lime base 15% hydraulic lime 10% pozzolana	0.48 0.44	1.37 0.77	22°C - 26°C 40 - 50% RH 22°C 30–60% RH	Spray	Densities of samples, whose drying times were measured at 20 and 70 days, were measured as 430 kgm^{-3} and 340 kgm^{-3}. Spraying process leads to lower initial moisture content and lower density, and thus a faster drying time in comparison to the moulding or tamping process. It is observed that the manufacturing process influences the initial water content and the final density whereas the hygrothermal behaviour depends on the material formulation.	[37]

(Table 2) cont.....

Binder Type	S/B	W/B	Curing Conditions	Mould/ Spray	Physical and Mechanical Results	Ref
70% hydrated lime 20% cement 10% pozzolana	0.5 0.66 1	1.57 1.39 1.37	26d 21°C 50% RH	30.5x 30.5x7.6 cm^3 15.2x 15.2x 15.2 cm^3 mould	The thermal conductivity of the samples with a density of 233 kgm^{-3} to 388 kgm^{-3} varies between 0.074 $Wm^{-1}K^{-1}$, to 0.103 $Wm^{-1}K^{-1}$. The drying process of the samples took 26 days, where minimum density was stabilized. The density of the samples were 233 kgm^{-3}, 316.8 kgm^{-3} and 387.8 kgm^{-3} respectively, while their thermal conductivity were 0.074 $Wm^{-1}K^{-1}$, 0.088 $Wm^{-1}K^{-1}$and 0.103 $Wm^{-1}K^{-1}$, respectively. The increase in the density of the samples caused an increase in thermal conductivity.	[56]
70% hydrated lime, 15% hydraulic lime, 15% pozzolan	0.47	1.47	Undisclosed	Spray	Densities of samples with compressive strength of 0.180 MPa to 0.8 MPa were obtained from 291 kgm^{-3} to 551 kgm^{-3}. Density and thermal conductivity of the samples 0.179 $Wm^{-1}K^{-1}$ for 417 kgm^{-3}, 0.421 $Wm^{-1}K^{-1}$ for 475 kgm^{-3}, 0.542 $Wm^{-1}K^{-1}$ for 496 kgm^{-3} and 0.485 $Wm^{-1}K^{-1}$ for 551 kgm^{-3} was measured. Increasing mortar density provides both thermal conductivity and mechanical properties.	[41]
75% hydrated lime, 15% hydraulic lime, 10% pozzolana	0.33	0.81	23 – 40 °C 50% RH	Mould Spray	The density of the moulded sample was measured as 510 kgm^{-3} and its thermal conductivity was 0.14 $Wm^{-1}K^{-1}$. The density of the sprayed sample was measured as 405 kgm^{-3} and its thermal conductivity was 0.08 $Wm^{-1}K^{-1}$. Moreover, sorption desorption curves should be determined from moderate cycles of RH for proper quantification of hemp concrete hygrothermal behaviour.	[57]
Natural prompt cement	0.5	1.5	7days in sealed mould 83days in 20°C 50% RH 10 days in 40 °C drying oven 80 days 30 °C 40%–90% –98% RH	Mould	Density, porosity and thermal conductivity of hemp fiber used hempcrete sample are; 335 kgm^{-3}, 72.5%, 0.105 $Wm^{-1}K^{-1}$, respectively. Density, porosity and thermal conductivity of non-fibred hempcrete samples are; 342 kgm^{-3}, 75.5%, 0.102 $Wm^{-1}K^{-1}$, respectively. Aging affects the porosity of the hempcrete. However, the aging effect is not sufficient to lead to modifications of acoustical and thermal performances. At the same time, mold growth occurs when the relative humidity is high (98% RH) and when the pH of the binder has decreased due to its carbonation reaction.	[58]

NHL: Natural Hydraulic Lime, S/B: Shiv/Binder, W/B: Water/Binder, RH: Relative Humidity, d:days

4.1.1. Hygric Property and Heat Conductivity

The energy efficiency of buildings depends on the hygrothermal behavior of the materials used in the building envelope. Despite its low mechanical properties, hempcrete is an environmentally-friendly material that provides very good thermal and acoustic properties with high porosity and low density [53]. Good thermal and hygric properties are attributed to the very high porosity of the shiv aerogel structure [24]. The high open porosity of hempcrete enables the transfer of thermal mass since pores are interconnected [59].

Evrard and Herde [60] reported that the small amount of moisture in hempcrete positively affects the thermal performance of the material and slows down the rapid heat flow when the sudden temperature changes, taking into account a phase change between liquid and vapor. Dhakal et al. [56] determined that hempcrete is able to heat up in a short time because of its high thermal inertia and maintains the temperature for a long time when the ambient temperature decreases. Collet *et al*. [14] stated the hempcrete water vapor permeability of approximately 2.5 × 10−11 kgm-1s-1Pa-1 and moisture buffer value of 2.15 gm-2%RH. Minguela [61] observed that the thermal conductivity of earth blocks had been largely reduced after the addition of fine hemp shiv. Piot et al. [8] reported that using a water-absorbing exterior coating or plaster increases the thermal conductivity of the hempcrete wall. Another risk of using a water-absorbent coating is the growth of mold just below the coating.

In the case of pore size and total porosity decrease, the thermal conductivity increases as the density of hempcrete increases. With the increase of density, the heat transfer interface becomes more connected. The moisture trapped in the pores gives the hempcrete thermal mass [62]. Gourlay et al. [63], in the study in which the amount of water examines the effect of thermal and acoustic properties, found that, as the water content increases, the thermal conductivity increases and the acoustic properties remain constant.

4.1.2. Density, Durability and Acoustic Absorption

The density of hempcrete is dependent on the quality and quantity of materials used, shiv size and porosity, and compaction energy [51]. In the wall applications, the density of hempcrete can be found between 400 and 500 kgm^{-3} by on-site pouring method, while the density of hempcrete can be obtained as 200 to 250 kgm^{-3} by spray method. It is possible to obtain a density of 600 to 1000 kgm^{-3} when a higher proportion of binder is used, while the amount of shiv remains the same [64]. Ohmura et al. [65] reported that hempcrete has better strength and high density with good compaction.

Hempcrete produced using lime binder undergoes carbonization for several years due to its lime content and transforms into limestone and gives strength to the structure and micro bonds in the structure matrix. This strength gain over the years shows the increasing durability over time [66].

Open porosity provides high permeability and acoustic absorption [67]. Kinnane et al. [68] concluded that hempcrete has better sound absorption properties than conventional concrete, and physical parameters such as porosity ratio and density do not affect acoustic absorption. In addition, hempcrete using a lime binder has been found to have better acoustic absorption than hempcrete produced using Portland cement.

4.1.3. Mechanical Properties

Amziane and Arnaud [12] reported that hempcrete produced with low dose binder shows very weak mechanical properties and deformation is very high. The mechanical performance of hempcrete, produced with a high dose of binder, increases and tends towards the performance of the binder.

Bourdot et al. [24] investigated the effect of hemp shiv size on mechanical and thermal conductivity; it was obtained that increasing the rate of 0-5 mm shivs from 15% to 30% increased hygroscopic properties while increasing the shiv proportion, decreased mechanical properties. Arnaud and Gourlay [52] found that the curing conditions, the water used, the type of binder, the length and width of the shiv affect the compressive strength of hempcrete.

4.1.4. Cost and Benefit Performance

The cost of hemp varies depending on the country to be used. Due to low bulk density, hempcrete has high transport and high storage costs. For example, hemp shiv was imported from the Netherlands, for the hemp house to be built in New Zealand with high transport costs [6].

The cost per square meter of a house built with traditional materials in the UK is £ 478, while a hemp house has a cost per square meter of £ 526. The cost of the hemp wall is £ 194 per square meter [69]. Hemp wall is 64% more costly than walls made with traditional materials [70]. To compare, the hempcrete market in France has grown by 400% in the past 10 years [71], where French farmers sell hemp shiv €80 per tons [72].

On the other hand, advanced building envelopes reduce the use of heating and cooling systems and reduce annual energy costs by reducing energy needs [73]. Using hygroscopic materials as building envelopes reduces the use of heating systems by 7 to 8% and cooling systems by 10 to 30%. Moisture buffering property and high thermal inertia of hempcrete provides at least 10% total energy saving, which reduced energy costs [74 - 76].

4.1.5. Life Cycle Assessment

Environmental assessment has been a core task for construction projects due to the rising recognition of environmental sustainability [77]. Life cycle assessment is a scientific assessment method to promote recourse saving and environmental protecting behavior [78]. The environmental impact of construction materials extends from the extraction of its raw materials to the management of the waste generated by its demolition [79]. According to the life cycle analysis, which is a method of evaluating the effects associated with the use of resources and all the effects of hempcrete on the environment, from the extraction of resources to the production of materials by measuring and evaluating, the lime binder used hempcrete has a beneficial effect on the environment [80, 81]. The use of hempcrete ensures that the energy used in buildings is reduced by 12-17%. In addition, the production and use of the lime hempcrete wall have a reverse effect on climate change; as the thickness of the lime hempcrete wall increases, the reverse effect on climate change increases [82].

The use of hemp in construction is promising to radically reduce the carbon footprint of buildings [83]. Approximately 1.8 tons of CO_2 are sequestrated for 1 ton of shiv used [84]. Approximately 1000 liters of shiv is used for one cubic meter of hempcrete and approximately 180 kg of CO_2 is locked on the 1m^3 hempcrete wall. Depending on the CO_2 emitted for the production of binders and the recarbonation of lime, 18 kg CO_2 is sequestrated to one cubic meter of hempcrete [85].

CONCLUSION

Considering the results in this study, hempcrete has not only a positive influence on the environment, global warming and climate change; it also provides comfort in the buildings. Excellent hygrometric behavior leads to indoor air quality and a comfortable indoor microclimate at the same time. Hempcrete exhibits low thermal conductivity, low density, low strength, high absorptivity and high moisture buffer capacity. The increased interest of researchers makes hempcrete more useful by obtaining more practical knowledge.

Hempcrete is ensuring a building envelope, which can be used in the wall, roof and floor. Although the water content in the hempcrete production cannot be standardized, mixture proportions should be calculated properly according to the application area, so as to avoid unexpected results.

Hempcrete production and use were inadequate until now in Turkey. Regulations should be created to promote hempcrete use in the buildings and contractors should be encouraged. Hemp plant, which has a lot of industrial use areas, will contribute to the production of new products and new technological developments.

Hemp is a suitable plant for growing in environments other than extreme desert climates and high mountain regions. The best growing conditions for hemp, however, are warm-weather areas with well-drained soil rich in organic material. Therefore, hemp agriculture should be expanded. Therefore, hemp plants can be cultivated in wide geography of the world.

Regulations should be created to promote hempcrete use in the building's construction and contractors should be encouraged. It is to be expected that researches related to hemp will increase in the coming period and used in the development of new products and technologies.

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CONFLICT OF INTEREST

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