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Introduction of sustainable and green materials in building construction for the wellness of the environment from an ethical and financial standpoint

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Vienna, 24.03.2022

Affidavit

I, **TOM BOBEN PUTHOOR, BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "INTRODUCTION OF SUSTAINABLE AND GREEN MATERIALS IN BUILDING CONSTRUCTION FOR THE WELLNESS OF THE ENVIRONMENT FROM AN ETHICAL AND FINANCIAL STANDPOINT", 76 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

Construction of buildings is an inevitable part of an expanding city or for the developing infrastructure of a country. As a result of the high rate of construction works that are happening around the world, harmful carbon emission continues to rise and cause a serious threat to our ecosystem. Therefore, we must consider the materials that are used in the construction process that causes carbon emission and replace them with materials that are more eco-friendly.

In this paper, we take into consideration two conventional materials that are used in construction, Ordinary Portland cement and fiberglass insulation. And replace them with their green and sustainable alternatives Ferrock and Hempcrete.

Ferrock is an iron-based binding compound that is used to bind different waste materials for carbon-negative building materials. Iron dust is a waste from the Iron industry that normally is discarded used along with small quantities of limestone, recycled glass (source of silica) and Oxalic acid.

Hempcrete is a bio-composite material that consists of hemp hurds (shives), lime and sand. The lime-based binder undergoes a carbonation process in which CO_2 is absorbed.

Every phase in Ferrock and Hempcrete production will be assessed and studied and will be compared with that of Ordinary Portland Cement (OPC) and Fiberglass. Both these alternatives will be compared with their conventional predecessors based on their carbon dioxide emission, compressive test, Thermal conductivity, cost, and applications.

Keywords:

Ordinary Portland Cement, ferrock, hempcrete, glass fiber, compressive strength, thermal conductivity, environmentally friendly materials.

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1.0 Introduction

Today, new inventive approaches for reducing greenhouse gases in the atmosphere, such as carbon dioxide, are promoted. Climate change has motivated experts in a variety of sectors to look for fresh solutions in this respect. Concrete is the fourth most significant source of carbon emissions. It is also known as the "basis of modern civilisation." Environmental concerns such as air pollution, skin illness, respiratory difficulties, global warming, climate change, and so on are caused by the massive generation of carbon dioxide in the environment. More than eight tons of CO_2 are emitted for every ton of cement produced. As a result, the environment is becoming increasingly polluted. So, in this thesis, we look at how eco-friendly materials like ferrock and hempcrete may be used to replace cement and glass fiber.

Ferrock's main constituent is iron dust, a by-product from the iron mill that is destined for the trash because it cannot be recovered traditionally and extracting iron from this powder is too expensive. While it dries, the iron dust combines with carbon dioxide and rust to form an iron carbonate matrix, which forms Ferrock.

Hempcrete, also known as hemp-lime concrete or a hemp-lime biocomposite is a carbon-storing composite building material that works through both carbonation and photosynthetic mechanisms. Hempcrete is made out of hemp shiv, a waste product from the manufacture of hemp fiber, and a lime-based binder. Hempcrete has a high resistance to heat conductivity, making it a viable substitute for fiberglass insulation.

Following are the main research questions:

1. What is the relation between Carbon dioxide emission and the use of conventional building material?
2. Will replacing conventional building materials with sustainable and green substitutes be possible?
3. To what extent these new materials can be used?
4. From a financial standpoint is it practically possible to replace OPC in construction and fiberglass for insulation purposes?
5. How are eco-friendly buildings beneficial to health and the environment?

In this thesis work, we study the manufacturing process and associated carbon emissions related to it. This study will help engineers to design and manufacture building using eco-friendly materials. And even able to provide long term health benefits to the people living in such buildings.

1.1 Structure of Thesis

Firstly, the chapter 3 looks into the study of all four construction materials which we focus in this thesis. Here we understand the necessary ingredients required to manufacture different construction materials, their composition, carbon emission associated with the manufacturing, compressive strength test, thermal conductivity test and their results. We referred to different articles and collected the most information in this chapter to get a deeper knowledge of the materials. In addition, some applications of these materials are included in this chapter.

Secondly, in chapter 4 we compare the different materials focused in this thesis based on main three factors that include Carbon emission, compressive strength and thermal conductivity. And we sort the materials from the highest to the lowest value. Here we can understand the average value of each material and the factors that affect those values. From this value, we can understand why the material with the highest value alone does not make it the most suited for construction.

Thirdly, in chapter 5 we take some of the cost and related information collected on each material from the internet and other sources. Unfortunately, they are not accurate data. The purpose of this chapter is just to get an understanding of the average price of materials and the cost of installation. As there are a lot of factors that affect the price of materials like availability of the materials, market demand, service providers in location, availability of manpower, skills to work with each material and so on, the price varies with locations. Here we take some average value of materials in the U.S.A to get a rough understanding.

Fourthly, in chapter 6 we collected some data on the history of different materials so that we can understand how long each material has been used around the world, how did they come to be in use, and how different cultures contributed to its development. Here we can see that some conventional materials have been used for centuries. It takes a lot of effort to make a change to something that has been traditionally accepted and followed around the world.

Fifthly, in chapter 7 we can see the Limitations of this study, where some of the reasons on the inaccuracy of data collected and explained are given.

Finally, chapter 8 concludes the contents, here we discuss in detail the reasons why some of the conventional building materials should be replaced and what are the factors that obstruct its implementation.

2.0 Fundamentals

2.1 Sustainable materials

Sustainable materials are materials used throughout our consumer and industrial economy that can be produced in required volumes without depleting non-renewable resources and without disrupting the established steady-state equilibrium of the environment and key natural resources (Rutgers, 2010).

2.2 Green materials

Green materials are defined as non-toxic materials are materials that do not cause harm to the environment, to the users of the material or to the producers of the material. They improve occupancy health, lower cost, and conserve energy and water use and waste products. Green Materials are composed of renewable, rather than non-renewable resources. Green materials are environmentally responsible because impacts are considered over the life of products (Lynn M. Froeschle,1999).

2.3 Compressive strength

Compressive strength is the ability of the material or structure to carry the loads on its surface without any crack or deflection.

Unit of measuring: MPa (megapascals)

2.4 Thermal conductivity

Thermal conductivity is a measurement of a material's ability to conduct energy when heated.

Unit of measuring: W/m/°C or W/m/°K (watts per meter per degree Celsius(or Kelvin))

2.5 R-Value and U-Value

When we consider heat transfer through conduction, R-value measures resistance to heat transfer and U-value measures the rate of heat transfer. The lower its U-value, the better the product’s ability to resist heat conduction.

Therefore, U-Value is the mathematical reciprocal of R-Value: $U=1/R$ & $R=1/U$.

3.0 Study of Materials

3.1 Ordinary Portland Cement (OPC)

Figure 1: Ordinary Portland Cement

Portland cement is the most popular form of cement used as a basic ingredient in concrete, mortar, stucco, and non-specialty grout all over the world. Joseph Aspdin created it from other varieties of hydraulic lime in England in the early 1800s, and it's commonly composed of limestone. It's a fine powder made by calcining limestone and clay minerals in a kiln, crushing the clinker, and mixing with 2 to 3 percent gypsum (Civil Keeda, 2021). There are several varieties of Portland cement. Ordinary Portland cement (OPC) is the most popular, however white Portland cement is also available. Its name comes from the fact that it looks like Portland stone, which was produced on the Isle of Portland in Dorset, England. Portland cement is one of the lowest-cost materials commonly employed throughout the previous century due to the low cost and broad availability of limestone, shales, and other naturally occurring components used in it. Concrete made from Portland cement is one of the most adaptable building materials on the planet.

3.1.1 Cement manufacturing procedure

Raw materials that are required for cement manufacturing consists of limestone, clay and sand. Which can cover the elements like calcium, silicon, iron and aluminium.

Raw materials	**Elements covered**
Limestone (CaO)	Calcium
Clay (Al_2O_3) and sand (SiO_2)	Silicon, Aluminium
Iron Ore (Fe_2O_3)	Iron

Table 1: Main raw materials for cement manufacturing and elements covered

Cement plants are located near the limestone quarries and raw materials and transferred using conveyor belts.

In addition to the main raw materials mentioned above some other raw materials are also required in small quantities for cement manufacturing like shale, fly ash, mill scale and bauxite. The materials are crushed in crushing quarries into the size of small gravels. The raw material from the quarry is analyzed to see it has the required proportion of limestone and clay (Limestone 80%, Clay 20%) before the grinding process. The raw mix is then ground to fine powder and are stored.

The preheated materials are then heated up to 1450°C in kiln, which is a huge rotating furnace. At this high temperature chemical reaction takes place and limestone releases the carbon dioxide (CO_2). Through a chemical reaction between calcium (Ca) and silicon dioxide (SiO_2) the primary constituent of cement, calcium silicate (Ca_2O_2Si) is formed. Different components in the manufactured cement include tricalcium and dicalcium silicate(Ca_2SiO_4), tricalcium aluminate ($Ca_3Al_2O_6$) and tetra calcium aluminoferrite ($Ca_4Al_2Fe_2O_{10}$). When the materials reached the lower part of the kiln, it forms the shape of clinker. Clinker is then passed out of kiln and cooled using forced air. Cooled clinker is then crushed into very fine powder which is considered as cement. During crushing gypsum ($CaSO_4$) is added in small percentage which helps in controlling the setting of cement (Engineering Intro.,2012).

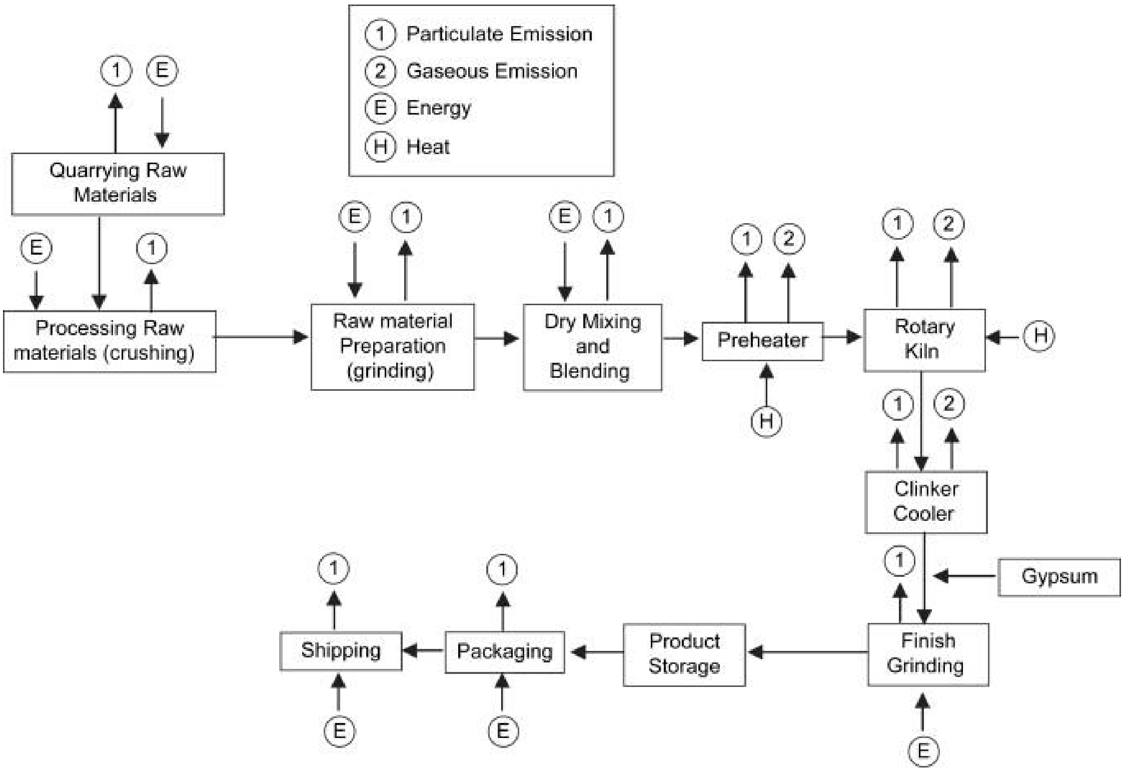

Figure 2: Cement manufacturing flowchart (Hutzinger Deborah N, 2008)

During the production of concrete, cement is mixed with water and aggregates. Cement water mixing results in an exothermic reaction and hardening of chemical components of cement. Which in turn acts as a strong adhesive agent that binds the aggregates together to form a hard solid structure.

3.2 Ferrock

Ferrock is an iron-based compound made of 95% recycled materials to be used as an eco-friendly substitute for Ordinary Portland Cement (OPC) (Lanuza Alejandro.et.at.,2017). The main ingredient of ferrock is steel dust, which is a by-product of steel manufacturing, and silica from recycled glass. Fly ash can also be used instead of silica. During the production process, the iron within the steel dust will react with the CO_2 and rusts to form iron carbonate. That means any carbon produced during production can easily be offset by the amount of airborne carbon used up to produce the final product, making ferrock a carbon-negative alternative to OPC (Dincer Ibrahim.et.al.,2020).

Figure 3: Ferrock (flywheel.netdna-ssl, 2021)

3.2.1 Ferrock manufacturing procedure

For the manufacturing of ferrock, clay and limestone are used but they are used in smaller proportion compared to that of cement manufacturing. Ratio of limestone and clay used are eight to ten percent. Eighty percent of the mixture is composed of low value waste products like metallic iron powder which is a by-product of the shot blasting or steel manufacturing industries. This fine powder is usually discarded to be used for landfills. These ingredients are mixed with a source of silica, such as fly ash or recycled glass. They are blended to for a uniform mixture after the addition of oxalic acid to facilitate the chemical process. Even though oxalic acid is added in very small percent it plays an important role in the precipitation and mineralization of iron. Oxalic acid helps to prevent iron oxidization and has the ability to absorb CO_2 by creating iron oxalate. While reacting with Ferrock mixture it reacts and transforms into a bonded carbonate molecule and cannot emit harmful gas to the atmosphere (Lanuza Alejandro.et.at.,2017).

Ingredients	**Percentage (by weight)**	**Specifications**
Iron dust	60%	Waste metallic iron powder with a median size of 19.03µm
Fly-ash	20%	Class F fly-ash
Limestone	10%	Powder form median particle size of 0.7µm
Clay	8%	Powder form
Weak organic acid	2%	Oxalic acid has been used as catalyst

Table 2: Ferrock ingredients and its proportion (Lanuza Alejandro.et.at.,2017)

Chemical reaction:

$$Fe+2CO^2+H^2O \rightarrow Fe^2+2HCO_3+H^2 \uparrow$$

$$Fe^2+2HCO_3 \rightarrow FeCO_3+CO_2+H_2O$$

Net reaction is:

$$Fe+CO_2+H_2O \rightarrow FeCO_3+H_2 \uparrow$$

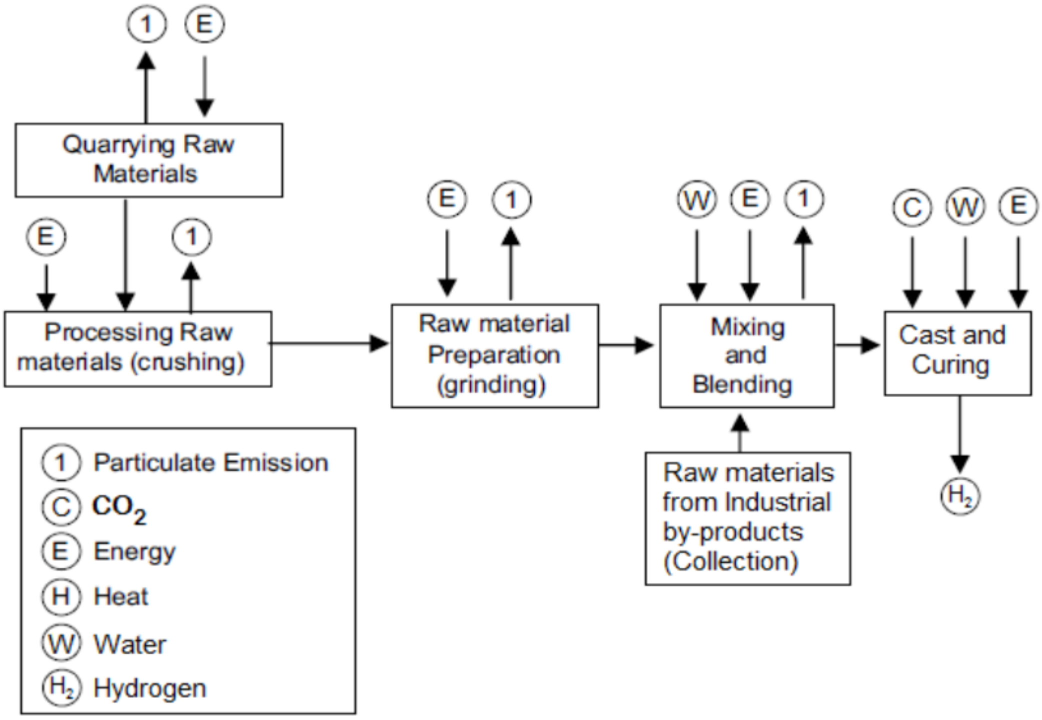

Figure 4: Ferrock manufacturing flowchart (Karuppasamy.et.al., 2018)

Mixing the aggregates with water and compressed carbon dioxide, iron oxide is chemically changed to iron carbonate and hydrogen gas is formed as a by-product. Fully cured ferrock contain 8 to 10% captured CO_2 by weight. Ferrock is therefore carbon negative unlike Portland cement, which during manufacture is a major source of CO_2 and other air pollutants (D.S.Vijayan.et.al., 2019).

3.2.2 Compressive strength test

The capacity of a material or structure to carry stresses on its surface without cracking or deflection is known as compressive strength. Concrete's compressive strength is determined by a number of elements, including the water-cement ratio, cement strength, the quality of the concrete ingredients used, and quality control during the manufacturing process. The compressive strength of concrete for typical construction ranges from 15 to 30 MPa (The Constructor, 2009).

3.2.3 Test on ferrock specimen

The mix proportion are taken by varying the concentration of oxalic acid (4,6,8,10 and 12 moles). The ratio of ferrock mortar used was 1:3 with water solid ratio 0.3. Mix proportions of ferrock is shown in table 02. Cubes were casted for determining the compressive strength of ferrock. The moulds if size 50mm x 50mm x 50mm were used. After the casting the blocks are removed from the mould after 24 hours from the time of mixing and immersed in curing tank (Mouli Prashanth, 2019).

Mix	Ferrock(Kg/m^3)	Fine Aggregate (Kg/m^3)	Oxalic Acid (Moles)	Oxalic Acid (Kg/m^3)
M1	390	1170	4	42.12
M2	390	1170	6	63.18
M3	390	1170	8	84.24
M4	390	1170	10	105.3
M5	390	1170	12	126.3

Table 3: Mix proportions of specimen for compression testing (Mouli Prashanth, 2019)

Mix	Compressive strength (MPa) 7 Days	Compressive strength (MPa) 28 Days
M1 – 4 MOLES	32.17	45.03
M2 – 6 MOLES	33.68	48.12
M3 – 8 MOLES	34.60	50.21
M4 – 10 MOLES	36.37	53.14
M5 – 12 MOLES	36.15	52.26

Table 4:Test results of hardened ferrock concrete (Mouli Prashanth, 2019)

Compression tests were performed on the ferrock block at 7 and 28 days respectively. And the results are shown in table 04. From the table it is clear that the compressive strength of Ferrock is twice than that of conventional Ordinary Portland Cement (OPC).

3.2.4 Applications of ferrock

Ferrock is relatively chemically inactive which makes it a suitable to be used in highly active environments like salt waters, therefore it can be used in marine constructions, sea walls, piers, structural piling, foundation and other structures exposed to sea waters (Ilvy Bonnefin, 2017).

The application of ferrock varies based on the coarse size of aggregates added to it. By using a coarse grit aggregate it can used to make slabs, blocks and other precast forms which are used in general applications. By using fine aggregate ferrock can be pressed into shape without cracking into plaster or mortar. And by using rebar or similar reinforcements is it is possible to construct large structures. One of the main advantages of ferrock is its shorter cure time which gives an advantage for tight construction schedules to save time. The environmental durability of ferrock makes its application in the manufacturing of pipes that are used for wastewater removal (Lanuza Alejandro.et.at.,2017).

By using Ferrock for large scale constructions like houses, roads, railways and other similar. We get buildings that absorbs the harmful carbon dioxide.The material can also withstand temperature over 600°C. therefore when it is turned into foam it is an excellent candidate for fireproofing or insulations.

Ferrock also has a bit of flexibility, which means it can withstand more pressure and movement. Concrete is completely solid, and a slight movement can weaken the structure. This feature of ferrock makes it an ideal material to be used in areas where seismic activity (earthquakes) is high (Builder space, 2021).

3.3 Hempcrete

Hempcrete consists of hemp hurds and lime binder. Therefore, it is also called Hemp-lime It is a bio-composite building materials used for construction and insulation. The hemp stalk is composed of 50% carbon by dry weight. Hempcrete is a carbon-negative building material because CO_2 absorbed in the growing process of the hemp is more than the CO_2 produced in the manufacturing of binder. A large portion of the CO_2 emitted in the manufacturing of lime (calcium hydrate) is also reabsorbed as it cures and reverts to limestone (calcium carbonate). A hempcrete wall of 30 cm can trap around 40Kg of CO_2 per m^2 wall (Dincer Ibrahim.et.al.,2020). It has low density, good thermal, acoustic insulation properties and can passively regulate humidity. Unfortunately, due to its low compressive strength and modulus of elasticity, hempcrete cannot be used as a direct load bearing material but can be used as an infill material (Agnita Mukherjee, 2012).

Figure 5: Hempcrete Block (unyzeHemp, 2021)

3.3.1 Hempcrete manufacturing procedure

The hemp stalks (hemp straw) without layers are crushed in hammer mill to reduce its particle size around 40±5 mm in dimension. The binder used for Hempcrete can be hydrated lime, natural hydraulic lime, or a mixture of both. Hydrated lime is made from pure limestone and carbonated by absorbing CO_2. Hydraulic lime contains limestone with clay impurities and when mixed with water it will have a binding reaction (Tarun Jami.et.al., 2019).

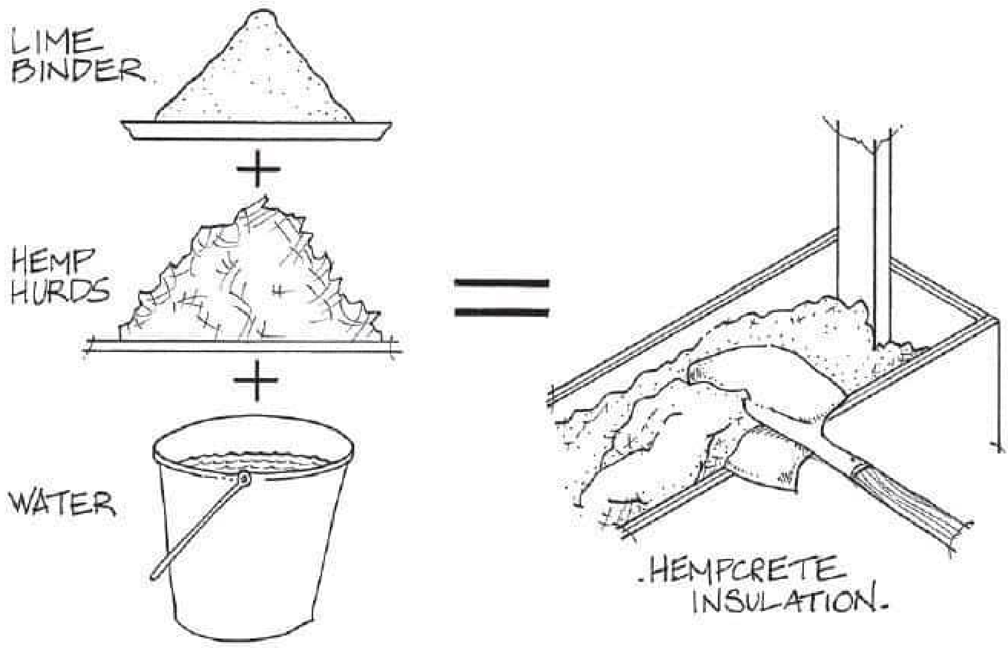

Figure 6: Hempcrete manufacturing basic overview diagram (greenhomegnome.com, 2017)

Water plays different roles during curing of hempcrete.

Hydration reaction:

Water is supplied during hydration reaction. Hydrated lime consists of dicalcium silicate (C_2S) and tricalcium silicate (C_3S) which reacts with water (H_2O) to form calcium silicate hydrate (C-S-H) and bulk calcium hydroxide ($Ca(OH)_2$).

$$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO\ .\ 2SiO_2\ .\ 3H_2O + Ca(OH)_2$$

This reaction is faster in the case of C_3S (few hours) and slower (few days) in the case of C_2S.

Carbonation reaction

Water is produced during the carbonation reaction. The bulk calcium hydroxide ($Ca(OH)_2$) which is obtained from hydration of quick lime or other hydraulic lime reacts with the carbon dioxide (CO_2) to form calcium carbonate ($CaCO_3$) and water (H_2O).

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

This is very slow reaction and occurs over several years (Lubos Gregor, 2014).

3.3.2 Compressive strength

When a load is given to a material, the phrase compressive strength refers to the resistance it provides without altering its form or shape or failing. It is one of the most significant material features to consider while constructing a building.

The commercial hemp wall has a compressive strength of 0.1 to 0.2 MPa, which varies somewhat since hemp is a natural product. This is just around a tenth of the value of concrete blocks. When cement is applied to hemp concrete blocks, the strength of the blocks appears to improve. It can be utilized in places with strong seismic activity since it is a low-density material that is somewhat resistant to cracking under movement.

Because of the imprecise arrangement of shives, the high flexibility of aggregate, and the porous character of Lime-Hemp Concrete (LHC), it has a low compressive strength. It has a low Young's modulus and compressive strength as a result of these features. As a result, LHC in its current state cannot be employed as a load-bearing material. Higher compressive strength and stiffness are required for load-bearing applications.

Compaction can greatly improve the compressive strength of hempcrete. By lowering the binder content, the material's mechanical strength can be improved, as well as its ability to withstand deformation before failure. It was discovered that a mix with a higher density might perform better in terms of compressive strength and that a higher density is associated with a higher level of compaction (Tarun Jami.et.al., 2019).

3.3.3 Compressive test

3.3.3.a Aggregates and binder

Using a grinding technique, hemp shives have been completely removed from the fibres. This biobased aggregate has a low bulk density (approximately 110 kg/m3) due to its porous nature. The aggregate's capillaries have a diameter of 10 to 50 m on the interior. As a result, it has a high capacity for water absorption, up to 270 percent in just a few minutes. Shives have a particle density of roughly 280kg/m3. The shive particles are porous because their walls are mostly made of cellulose, which has a density of 1465 kg/m3. A lime-based binder was used. It consists of 75% hydrated lime $Ca(OH)_2$, 15% hydraulic lime, and 10% pozzolana. Its specific density is 2450Kg/m^3.

3.3.3.b Mix designs

One of the materials used in the tests comes from Chanvribloc® trade blocks. The provider hasn't revealed its exact composition, but it's mostly made up of hemp, shiv, and hydraulic binder. It has a dry density of 340 kilograms per cubic meter (A. Youssef.et.al., 2015).

M1 and M4 are two LHC mixtures that were created. M1 has a higher binder content but is less compressed than M4. M4 is stronger than M1 in the compaction direction due to its increased compactness in the hardened state.

The capillary and malleable nature of shiv adds to the mixing difficulty as compared to standard concrete. There are two steps in the mixing phase:

Step 1: Using a planetary Hobart mixer, mix the shive with water for 4 minutes at 140 rpm.

Step 2: Add the lime and mix at 140 rpm for 4 minutes.

During the first phase, the shives entirely absorb the water. As a result, the second phase is similar to combining dry particles. As the aggregates are compressed in the compression cell, water is released. Because most of the water available is needed for lime wetting and hydration near the end of compaction, the amount of water required should be estimated as a function of binder concentration. W/B is the water to binder mass ratio, which for each LHC combination is 0.55. The Binder to Shiv mass ratio is B/S. A steel cylinder with an inner diameter of 100mm, a stationary lower punch, and a moving top punch make up the compression cylinder. The upper punch's piston is coupled to a 250kN press that is equipped with force and displacement transducers. The cylinder wall is 10mm thick, ensuring a radial pressure of 10MPa (A. Youssef.et.al., 2015).

	M1	M4
Shiv (S) [kg/m^3 of LHC]	215	500
Binder (B) [kg/m^3 of LHC]	387	270
Water (W) [kg/m^3 of LHC]	213	148
W/B	0.55	
B/S	1.8	0.54
Green density [kg/m^3]	816	920
Green compactness [-]	0.52	0.6
Compactness In the hardened state [-]	0.37	0.55

Table 5: Studied mixtures (A. Youssef.et.al., 2015)

The mixture put into the cylinder has a starting apparent volume that is 3 to 4 times the end compacted apparent volume. For each species, the ultimate height was set at 200mm. Every test is performed at the same 1mm/s upper punch speed. The specimen reaches certain compactness termed green compactness at the end of the compression stage (Table 5). Due to the difference in specific gravity between water, shiv, and lime, compactness is essentially the most important measure to characterize the compaction condition. The specific gravities of the elements in this investigation are 1465 Kg/m3 for the shiv walls and 2450 Kg/m3 for the binder.

Compactness in the fresh state is equal to the sum of the solid and liquid volume fractions. The volume of a solid in a liquid is divided by the total volume of the sample. Because the liquid phase is presumed to be physically related to lime and shiv at the conclusion of the compression process, it is included. This assumption is valid as soon as the water content is minimal, guaranteeing that no free and draining water exists in the sample. Also, be sure there was no mass loss during compression. For 72 hours, each specimen is kept at a height of 200mm. This step is required to guarantee that the lime is just slightly hydrated, preventing capping and elastic release of the specimen when it is pushed out of the die. The LHC blocks are then housed in a controlled environment with a temperature of 201°C and a humidity of 705 percent. To prevent the release of viscoelastic material During maturation, M4 blocks must also be clamped. Some water is used for hydration of lime during specimen aging, and a substantial proportion is thereafter dissipated. The compactness of the samples then declines, which occurs more frequently when the paste content is high (Tronet P., 2014).

3.3.3.c Cubic sample manufacturing

Two cubic specimens are machined from each hardened LHC cylinder block, each with a 7cm edge. One comes from the top and the other from the bottom of the cylinder.

Figure 7:Location of cube sample to be machined in the cylinder (A. Youssef.et.al., 2015)

Each compression test (M1, M4, and Chanvribloc®) and each test with shiv pattern parallel and orthogonal to the compression direction are measured using five cubic specimens. The density of each specimen was determined by weighing it.

Under a 500kN press equipped with axial force and displacement sensors, compressive behavior is monitored in a normal compression. During compression, four LVDT transducers are additionally positioned to measure the transverse strain. The compressions are monotonic, and the experiments are carried out by applying stress on the cubs in both parallel and orthogonal directions to the compaction axis.

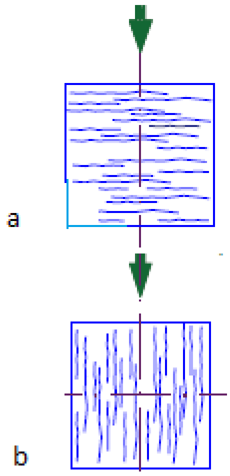

Figure 8: a) Simple compression parallel with compaction process b) Simple compression orthogonal to compaction process (A. Youssef.et.al., 2015)

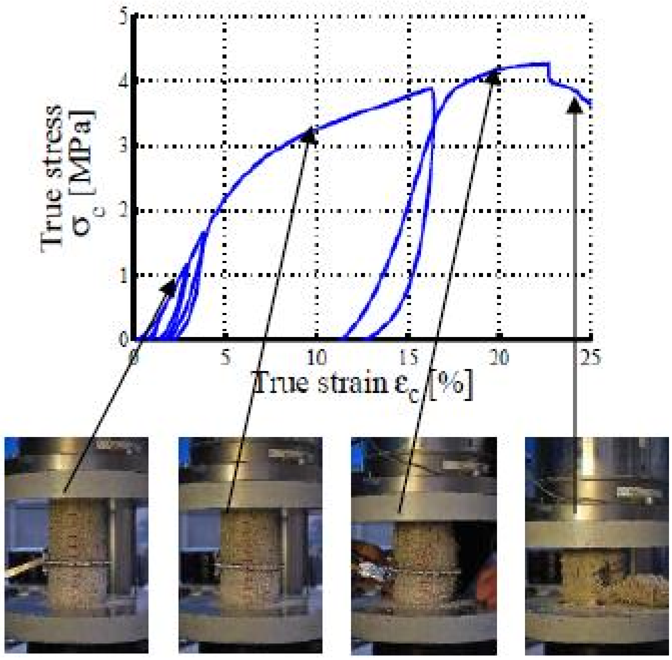

Figure 9:Compression curve for strength and characterization of hardened compacted LHC cylinders (A. Youssef.et.al., 2015)

Hempcrete with a high binder concentration or porosity is often brittle, with compressive strength equal to the highest load applied during the test. Studies on crushed cylinders reveal a distinct pattern, more akin to stiff foam (Figure 09). With a broad plastic hardening zone, the mixtures are more ductile.

3.3.3.d Test Results

Density of the cube samples in the hardened state

		Density [kg/m³]	Top/Bottom Ratio
M1	Top	660	1.15
	Bottom	574	
M4	Top	895	1.17
	Bottom	765	
Chanvribloc®		340	-

Table 6:Average density of different mix designs (A. Youssef.et.al., 2015)

Every cube specimen's density was measured. The values in the table are the averages of at least five different specimens. Heterogeneity arises between the top and bottom parts of the compacted LHC specimen due to friction during the molding and compression process, with the same size order for M1 and M4. The cylinder compression cell's wall carries a portion of the compressive load during the compaction process. The mixture is then subjected to lower pressure at the bottom of the cylinder than in the top. As a result, the bottom section has a lesser level of compaction (Tronet.et.al., 2014).

3.3.3.e Compressive behaviour

The usual curves when compression is performed in the opposite direction of compaction can be seen in figure 10a. Every combination exhibits aplastic behavior, indicating the highest level of stress. The M1 and M4 specimens shatter during the experiment. This discovery suggests that the shive layers, which were initially parallel to the major stress, buckle and collapse. The compressive stress is simple to identify in these curves because it corresponds to the peak of the stress-strain curve. Table 07 shows the average compressive strengths calculated from the findings of the whole testing program. When simple compression is performed in the same direction as manufacturing compaction, the curve shown in Figure 10b is common. The shive layers are perpendicular to the primary stress in this situation. It's tough to obtain a readable compressive strength and characterize the strength of each sample directly from these graphs. According to research (Tronet.et.al., 2014), there is a stress parameter that may be used to compare curves and characterize the strength of each sample. The yield stress, as shown in Figure 11, is this parameter.

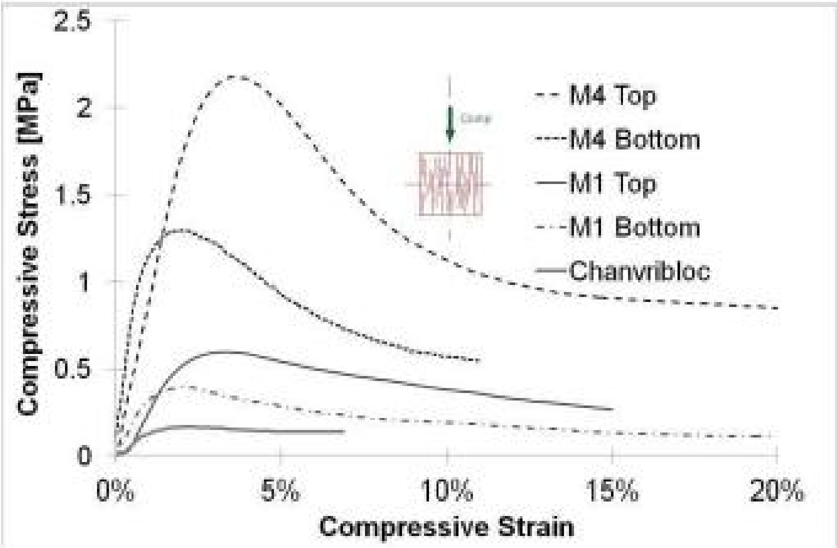

Figure 10a: Parallel

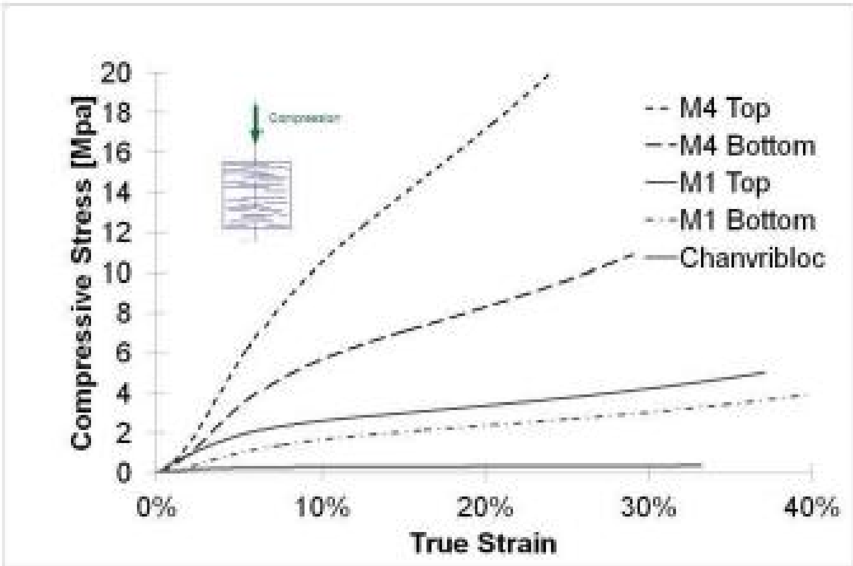

Figure 10: a&b: Compressive behavior parallel and Othogonal to fabrication load (A. Youssef.et.al., 2015)

Figure 10b:Orthogonal

		Compressive strength σ_c [MPa] (CO)	Yield stress σ_y [MPa] (CP)	Yield stress σ_y obtained on cylinders by [Tronet 14b] [MPa] (CP)
M1	Top	0.72±0.36	1.9±0.3	1.4
	Bottom	0.31±0.16	1.18±0.14	
M4	Top	1.62±0.51	6.87±0.58	4.7
	Bottom	1.3±0.07	4.3±0.85	
Chanvribloc®		0.13±0.06	0.27±0.12	-

Table 7:Behaviour of different mix designs, Compressions parallel to compaction load direction (CP) and compressions orthogonal to compaction load direction (CO). (A. Youssef.et.al., 2015)

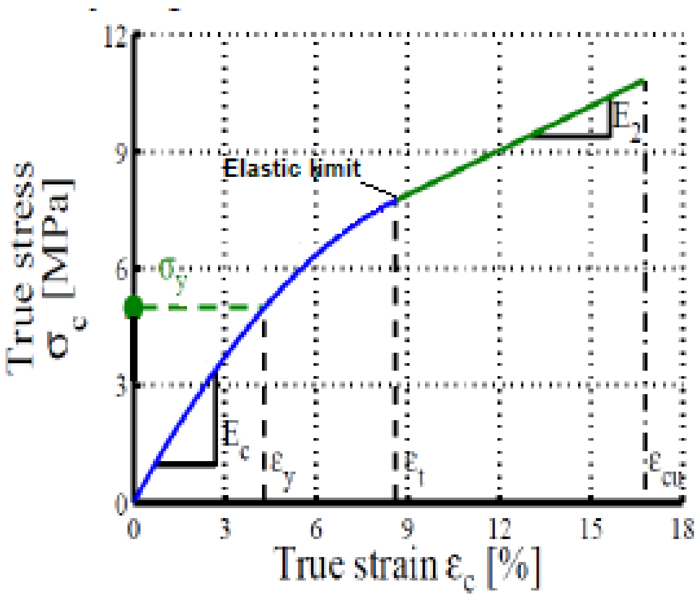

Figure 11: Yield stress conducted with simple compression in compaction direction (CP). The blue line represents elastic deformation and green line represents ductile deformation

Compressions orthogonal to the manufacturing direction have a lot of dispersion (CO). The findings should be compared to the shiv layers' defaults and tensile behavior. There is also a pattern of association between compressive strength and density. It indicates that even when there is less binder, the transverse compressive behavior of the shiv (M4) stays superior. The increased compressive strength is most likely owing to the porosity constraint, which results in a more rigid behavior as compactness decreases. In compressions parallel to the compaction load direction, the yield stress is always larger than in compressions orthogonal to the compaction load direction. By contrasting the results of the stress test with the findings of the stress test (Tronet.et.al., 2014). The cylinder's resistance is near to the resistance of its weakest region, which is connected with the cube taken from the bottom. Within the same block, friction along the compaction cell causes mechanical behavior to vary. To decrease this problem and assure greater uniformity of precast parts, such a compaction method must be technically enhanced. Because of the samples' unstable and changeable transverse behavior, as well as their low compressive strength, they are difficult to lay transversally as a load bearing material, even in a supporting wall.

Supplementary testing on different sizes of commercial hempcrete blocks have revealed that there is no size effect in this length range. The curves are identical in form. It's possible that the size has no influence when compared to the specimens' aspect ratio.

3.3.4 Thermal properties

3.3.4.a Composition of the selected hemp concrete

Name	Notation	Binder composition (% by weight)	Binder: hemp: water ratio		
			B	H	W
Builder's mix	BM	70% CL90, 20% NHL3, 10% PC	2	1	3.1
Commercial mix	CM	100% commercial binder	2	1	2.9
GGBS	G	70% CL90, 30% GGBS	2	1	3.1
GGBS + WR	G + WR	70% CL90, 30% GGBS, 0.5% methyl cellulose	2	1	3.1
Metakaolin	M	80% CL90, 20% metakaolin	2	1	3.3
Metakaolin + WR	M + WR	80% CL90, 20% metakaolin, 0.5% methyl cellulose	2	1	3.1

Table 8: Composition of Hemp concretes, binder composition and binder : hemp : water ratio (% by weight) (R. Walker.et.al., 2013)

The only difference between the six blends was the binder makeup (Table 08). Because each binder has a distinct water need based on its composition, the water content could not be maintained at a constant level. As a result, the water content of each concrete was determined by achieving uniform workability across all concretes. There is currently no test that can be used to determine the workability of hemp concrete (R.Walker.et.al., 2013).

3.3.4.b Specimen preparations

The mixing was done in two batches in a big pan mixer taking a mixing time of around 7 minutes. The dry binder was combined by hand before adding 75 percent of the total mixing water and mixing for 2.5 minutes to make a slurry. After that, the hemp and the remaining water were progressively added. Because density has such a large impact on concrete qualities, it was carefully monitored. A certain amount of concrete was weighed to achieve a dry density of 360 kg/m3. The concrete was poured in a single layer into cling-film-lined timber moulds and gently pressed to achieve a density equivalent to that of a normal wall structure. The samples were transferred to a curing room at 16°C±3°C temperature and 55%±10% relative humidity after the mold was removed. Low mixing water content and dry curing conditions prevented binder hydration, affecting the commercial binder's performance (Walker R.et.al., 2013). Permeability, capillary action, and specific heat capacity were all tested using four 100 mm cubes. Each mix had one wall (1m wide X 900 mm high X 300 mm thick) that was shuttered and tamped into place every 300 mm, similar to standard on-site wall construction (Table 09). The walls were tamped by hand, and the density varied depending on the concrete compaction, as described in. With a protective covering, the walls were cured outside for a year. This was followed by a 6-week curing period in the laboratory before the thermal conductivity was measured (U-value).

Name	Notation	Approximate density (kg/m^3)
Builder’s mix	BM	627
Commercial mix	CM	627
GGBS	G	565
GGBS + WR	G + WR	569
Metakaolin	M	508
Metakaolin + WR	M + WR	531

Table 9: Density of walls

3.3.4.c Thermal conductivity

The thermal conductivity of the walls was determined by measuring their thermal transmittance (U-value) using a Hukseflux TRSYS01 measurement device and Loggernet software for in situ measurements in accordance with ISO 9869 and ASTM C1155. The two opposing ends were fitted with hemp concrete walls and a 300 mm (6X50 mm) thick PIR insulation board was used to create an enclosed room. A radiator heated the inside of the chamber, which was regulated by a thermocouple temperature sensor that activated a switch. The average temperature inside and outside was 27°C and 16°C, respectively. The builder's hemp concrete wall was used as a control throughout the tests, while the other walls were tested for two weeks each. Despite being permitted to cure for 13.5 months previous to testing, the walls were likely not completely dry at the time of testing (they lost a further 10 percent water in the following 3 months). The average daily U-value observed in the range of 0.3 to 0.7 W/m2 K was used to compute the U-value of each wall (R. Walker.et.al., 2013).

3.3.4.d Results

The typical U-values of the 300 mm hemp concrete walls (as shown in Table 10) range between 0.39 and 0.46 W/m2 K and rise with density. Other authors (Daly P.et.al., 2010) reported values in the range of 0.22–0.89 W/m2 K for 300 mm thick walls. The density has an impact on thermal characteristics. Cerezo discovered a link between rising hemp concrete density and increasing heat conductivity, and generated an empirical relationship (Eq. (1)) for hemp:binder:water ratios of 1:1:2, 1:2:3, and 1:2.5:3.6 for roof, walls, and render mixes, respectively (Cerezo V, 2005).

Conductivity = 0.0002 x (density) + 0.0194 → (1)

Figure 12 depicts the relationship between thermal conductivity and density of the hemp concretes studied. The values obtained by applying the relationship provided by are also shown (Cerezo V, 2005). The thermal conductivity of the concretes appears to be slightly lower than that indicated by the connection above. Thermal conductivity increases with density, and the type of binder has no statistically significant effect on thermal conductivity, according to the findings. These findings contrast with those of Gourlay and Arnaud, who discovered that heat conductivity changes greatly depending on the type of binder (Gourlay E.et.al., 2010). It's likely that the difference in hydraulic content between the lime–pozzolan and partly hydrated commercial binder (R. Walker.et.al., 2013) in this study isn't as significant as in Arnaud's binders. It's also possible that discrepancies in performance are hidden by moisture content in the walls and certain measurement method inaccuracy.

Type	Density	U-Value (W/m^2K)	Thermal conductivity (W/mK)	Coefficient of varience	Measurement error (%)	Difference in value predicted by Cerzo (W/mK))
BM	627	0.46	0.138	6.8	14.6	0.0068
CM	627	0.46	0.138	3.0	16.2	0.0068
G	564	0.42	0.126	5.5	13.6	0.0062
G + WR	569	0.43	0.129	7.2	11.8	-0.008
M	508	0.39	0.117	7.8	13.6	0.008
M + WR	531	0.41	0.123	4.0	11.8	0.01

Table 10:U-value of hemp concrete walls. BM – builder's mix, CM – commercial mix, G – GGBS binder, G + WR – GGBS binder with water retainer, M – metakaolin binder, M + WR – metakaolin binder with water retainer (R. Walker.et.al., 2013).

Surprisingly, metakaolin concretes deviate the least from projected values, and water retainer concretes differ less than identical concretes without water retainers (Fig. 12). As a result, the findings imply that metakaolin has a slightly higher thermal conductivity than water retainers at a given density, and that water retainers increase conductivity.

Because air has a low thermal conductivity, it was assumed that increasing hydraulic content (the number of hydrates filling air voids) would enhance thermal conductivity. However, although the findings are not statistically significant, they show that increasing hydration lowers heat conductivity.

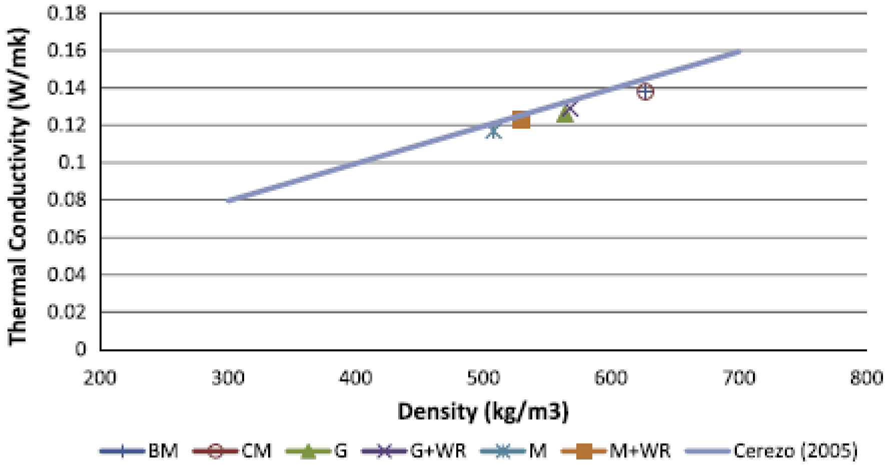

Figure 12: Relationship between density and thermal conductivity of hemp concrete walls and the relationship established by Cerezo (R. Walker.et.al., 2013)

3.3.5 Applications of hemp in building construction and other fields

Hempcrete in building construction

Many present environmental challenges might be solved by using hemp in building. The main benefit of utilizing hempcrete in buildings and structures is that it absorbs carbon dioxide from the air and creates a greenhouse-free environment to live in. Cannabis is believed to sequester around 249 kg of CO2 every ton of hemp used. Hempcrete is a fire-resistant material that is thermally stable. Another significant benefit of utilizing Cannabis is that it is an effective pesticide and insect repellent, ensuring that the wood is less susceptible to harm and has a long lifespan. Hemp walls have a high insulating power, which reduces energy consumption expenditures by half. For example, if traditional walls have an R-value of 12–15, hempcrete has an R-value of 30 for a 12-inch wide wall, which is nearly double1. The capacity of a substance to resist heat passage from one side to the other is measured by its R-value. Currently, hemp plaster is sold under the brand names Hempcrete, Canobiote, Canosmose, and Isochanvre by a number of building enterprises. Hempcrete is utilized as an interior coating for restoring existing stone walls, as well as for floor slabs and ceiling insulation. The concentration of hemp hurds and lime mix varies depending on the function. Further study and analysis of hemp-lime as a construction material should be encouraged, given the possible positive environmental effects, including the possibility for carbon sequestration and the economic benefits to the manufacturing, rural, and construction sectors (Karche T. et.at., 2019).

Hemp as food

Hemp has been utilized as a food source from roughly 3000 years ago, when it was a major food source for the Chinese and Nepalese. Hemp, on the other hand, lost favor as a food source as emphasis focused on its hallucinogenic characteristics, and its production became prohibited. Hemp was revitalized as a highly nutritious source of food when nutritionists investigated it. The inclusion of edestin, a hemp seed protein, contributes to the distinctive nutritional quality. Hemp seeds have the greatest concentration of this protein in the whole plant world. It has the highest amount of alpha-linoleic acid (ALA) and is an excellent source of healthful fat, especially for individuals who do not eat fish or eggs (Abedi E.et.al., 2014). Hemp seed also includes phytosterols, which aid in lowering cholesterol levels by eliminating fat build-up in the arteries. As the nutritional benefits of hemp seed have been more widely recognized, a slew of new products have hit the market. Hempseed butter, hempseed oil, hemp milk, and hemp flour are only a few of them.

Hemp butter, like almond and peanut butter, is a pure pulverized form of hempseed nut. The hue of hemp butter is somewhat greenish since it is derived from hemp seeds, which contain chlorophyll. It can be prepared at home or in a professional setting. Hemp butter has gotten a lot of positive feedback, and people seem to like it and think it's tasty. It's used in smoothies, salad dressings, and even as a sandwich spread. Edible hempseed oil is also gaining favor as a healthy alternative in smoothies. It's poured over meals or used in salad dressings and sauces. It's also possible to take it as a supplement. The oil comes in a black, opaque container that must be kept refrigerated at all times. Hemp milk, a new product that has gained a lot of traction, maybe manufactured at home by mixing the seed nuts with water in a 3:1 ratio and filtering it. The milk has a high nutritional content as well as therapeutic characteristics that can aid in health maintenance3. Hemp flour is used in baked items that contain other processed ingredients. The use of hemp as food is a relatively new innovation, and people seem to like it (Karche T. et.at., 2019).

Medicinal uses of hemp

Hemp's medicinal value has been widely recognized since the beginning, even before official documentation. For over 6000 years, people have written about their experiences with hemp. These documents have been extremely helpful in disseminating information about its medical use. The usage of cannabis was originally documented around 1000 BC in medical documents such as 'Sushrita.' Furthermore, hemp has allusions in Indian literature such as Tajnighuntu and Rajbulubha for its usage in the treatment of numerous disorders linked to phlegm clearing and gas releasing. In addition, these works discuss the use of cannabis to improve mental acuity and eloquence, as an appetite stimulant, in the treatment of gonorrhea, and as a general tonic (Bouloc, 2013).

An Israeli scientist discovered physical proof of the usage of hemp. He discovered hemp plant remnants in the bodies of young women who died during delivery 1600 years ago (Martin et al., 1993). Hemp was also utilized in medical concoctions in Arabic medicine, in addition to Indian medicine. Hemp was thought to be useful in the treatment of epilepsy. Chamberlin's epileptic son was healed by hemp plants, according to the documented records in the Arabic pharmaceutical book Al-badri from 1464 BC. Queen Victoria's doctor utilized hemp to relieve labor pains and dysmenorrhea in the nineteenth century (Baker et al., 2003). The use of hemp to assist delivery is also recorded in Egyptian papyri. Hua T'o, the pioneer of Chinese surgery, recorded and reported the use of hemp as an analgesic when combined with wine between 117 and 207 AD, finding it to be a suitable anesthetic for patients (Nahas, 1973).

All of the information shown above demonstrates hemp's enormous medical value. Rabies, epilepsy, anxiety, rheumatism, and even respiratory problems like bronchitis and asthma may all be cured with hemp (Li, 1974). The plant was utilized for a variety of reasons, including analgesic (neuralgia, headache, and toothache), anticonvulsant (epilepsy, tetanus, and rabies), hypnotic, and tranquilizer, according to historical sources (anxiety, mania, and hysteria). Hemp was also used as an anesthetic, anti-inflammatory (rheumatism and other inflammatory diseases), antibiotic (topically for skin infections, erysipelas, and tuberculosis), antiparasite (internal and external worms), digestive, appetite stimulant, diuretic, aphrodisiac or anaphrodisiac, antitussive, and expectorant (bronchitis, asthma) (Baker et al., 2003) The THC component of hemp has been found to have a substantial influence on appetite stimulation in cancer and AIDS patients (Amar, 2006).

As a result of hemp's medicinal potential, new fields of study into hemp as a pharmaceutical product have opened up. Many formulations were created as pharmaceutical companies grew more familiar with the qualities of hemp and its unique components. Hemp joined the pharmaceutical industry in 2003, and several global conglomerates moved their emphasis to hemp medications. GW Pharmaceuticals banded together to form exclusive marketing deals. Certain drugs have now been authorized by the FDA (Food and Drug Administration) and are available for purchase in pharmacies. However, in the next years, these drugs will become more widely used, and they will be more readily available on the market (Karche T. et.at., 2019).

Hemp application in the automotive industry

Plastics, fibers, foam, glass, and rubber residues account for 25% of vehicle trash by weight, making disposal a serious concern in waste management. The world has finally agreed to take steps in the correct way to protect the environment from the internal combustion engine and to manage trash. The fibrous hemp that inspired the use of hemp in the vehicle business dates back to circa 1940, when Henry Ford, founder of Ford Motor Co., created a hemp-based car plant (Peças et al., 2018). Later, as technology advances, the automobile sector has demonstrated a strong interest in employing hemp fibers to create moulded materials and products that are a good substitute for fiberglass (Marsh, 2003). Furthermore, automobiles constructed of hemp could be simply buried at the end of their lives, where microbes would naturally eat them.

Hemp woody fibers can be utilized as a glass fiber alternative (Garcia-Jaldon et al., 1998). The use of hemp to make vehicle parts is still new, but as the benefits of hemp's industrial uses become clearer, several states and nations throughout the world are supporting its usage in the automotive industry. Raw hemp bales are processed into fibrous sheets, which are then fed into machinery that makes vehicle door panels. Flex form Technology and Johnsons Controls have developed a hemp-based automobile door lining. The sheets of nonwoven hemp fibers are coated with glue and pressed into the desired shape, similar to maps. Hemp, according to Hemp Inc., might build a stronger automobile panel and be an excellent replacement for petroleum-based plastics and fibers.

James Meredith, a researcher from Warwick University in the United Kingdom, presented a study in 2012 in which he investigated the specific energy absorption (SEA) of three natural composites: unwoven hemp, woven flax, and woven jute. He determined that hemp resisted the most SEA, demonstrating that it can bear enormous pressure despite its low bulk (Meredith et al., 2012). Hemp appears to be a feasible alternative for fiberglass in automotive panelling, according to these tests.

BMW and Mercedes are now using hemp composites in high-end models, and BMW is showcasing automobiles such as the upcoming electric and hybrid supercar as a concept car that is partially made of hemp polymers. Canadian motive Industries used hemp to create the Kestrel automobile. It is around 2500 pounds in weight and comes at a very reasonable price. The car's body is composed entirely of hemp and is 100% impact resistant. The bodyshell's impact resistance was demonstrated by passing a crash test. Unlike steel, the panel returned to its original form. It outperforms glass fiber in terms of mechanical characteristics, weight, and efficiency (Karche T. et.at., 2019).

3.4 Fiberglass

Glass-reinforced plastic, also known as glass-fiber reinforced plastic, is commonly referred to as fiberglass. Fiberglass is sometimes referred to as GFK, which stands for Glasfaserverstärkter Kunststoff in German. Fiberglass is a fiber-reinforced polymer comprised of plastic with glass fiber reinforcement that is typically woven into a mat. The plastic can be either thermosetting (epoxy, polyester, or vinylester) or thermoplastic (epoxy, polyester, or vinylester). Fiberglass is a lightweight, robust material that is utilized in a variety of items. It's not as strong or rigid as carbon fiber, but it's less brittle, and the raw ingredients are far less expensive. It has superior bulk strength and weight than many metals, and it can be shaped into more intricate forms (EDUCALINGO, 2021).

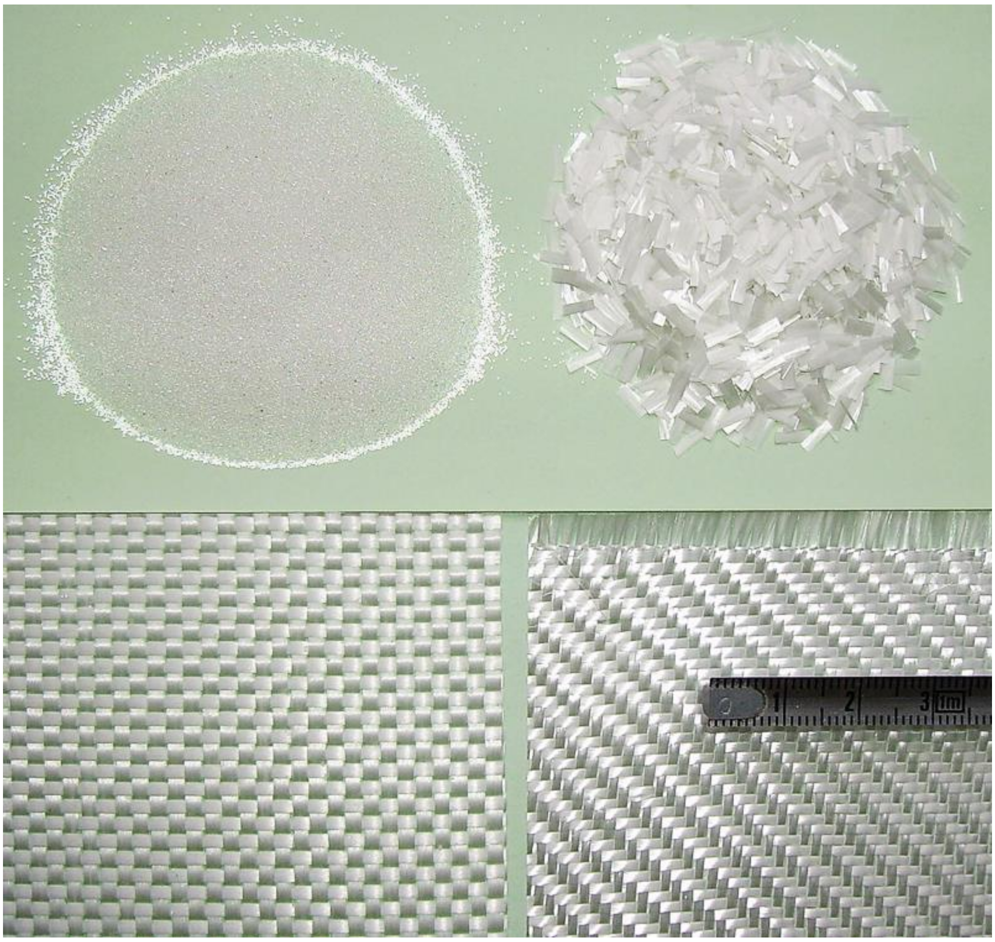

Figure 13: Fiberglass (educalingo.com, 2021)

Glass fibers are one of the most adaptable industrial materials currently available. They can be easily made from basic elements that are nearly limitless in supply (Lowenstein K. L.,1975). All of the glass fibers mentioned in this article are made from silica-based materials. They have desired fiber qualities like as strength, flexibility, and stiffness, as well as important bulk properties such as hardness, transparency, chemical resistance, stability, and inertness. Glass fibers are used to make structural composites, printed circuit boards, and a variety of other specialty items (Wallenberg F. T., et.al, 2001).

3.4.1 Fiberglass manufacturing

The direct production approach is preferred in current glass fiber manufacturing plants. Raw ingredients are kept separately in the silos and accurately metered to the mixing tank before being transferred to the batch silo to be charged to the furnace. This system is computer-controlled and sealed, preventing dust from entering the atmosphere.

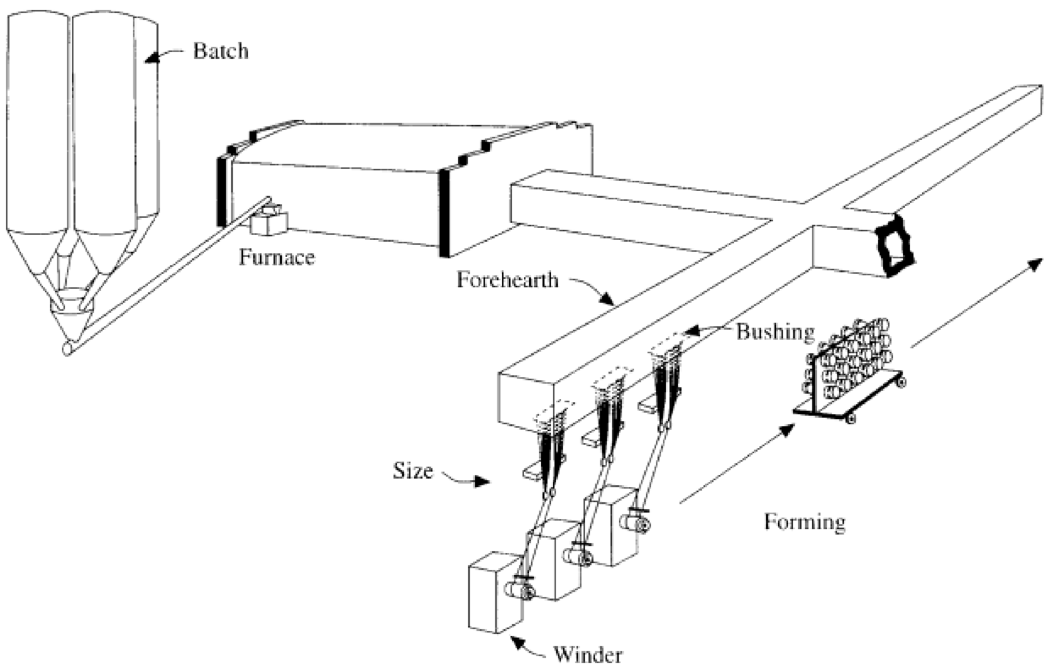

Figure 14: Continuous fiberglass manufacturing process(High strength glass fibers, AGY 2006)

Sand is used to make silica, clay is used to make alumina, colemanite or boric acid is used to make boron oxide, and limestone or calcite is used to make calcium oxide. E-glass furnaces are typically rectangular, with a short exit channel that connects to a narrow forehearth channel where fiber-forming takes place Figure 14.

In today's market, there are two generic forms of E-glass. The current E-glass has a boron oxide content of 5 to 6% by weight. To remove boron from the off-gases of boron-containing melts, strict environmental rules necessitate the installation of expensive emission abatement devices. It is also necessary to utilize boron-free E-glass, which is more ecologically friendly. Because these melts don't contain boron, they don't release it into the environment during processing. As a result, Fiberglas (Owens Corning Corp., Toledo, OH) has launched Advantex, a boron-free E-glass product. There are two types of commercial boron-containing E-glass. The quaternary SiO2-Al2O3-CaOMgO phase diagram is used in one commercial form, whereas the ternary SiO2-Al2O3-CaO phase diagram is used in the other. In the ternary SiO2-Al2O3-CaO system, commercial E-glasses contain a minor quantity (0.6 wt%) of MgO that is not intentionally added but produced as a by-product (or tramp) from other constituents. Commercially accessible boron-free E-glass, on the other hand, is generated from the quaternary SiO2- Al2O3-CaO-MgO phase diagram (Wallenberg F. T., et.al, 2001).

Dense chromium oxide, which is resistant to the corrosive molten E-glass, is the ideal refractory material for the furnace's wall. Zircon blocks and another layer of clay blocks bake the refractory. Natural gas is often utilized as a source of energy to generate heat at a temperature of roughly 1600°C and to melt raw materials as they are fed into the furnace. The electrodes and bubblers at the bottom of the furnace cause convection of the glass on the top of the melt during the development of the E-glass and as it flows to the furnace exit, the developed gasses are removed and the chemical processes are completed (Cevahir Arif, 2017).

As molten E-glass exits the furnace, it passes via the forehearth channel and into the bushing, where fiber is created. The bushing looks like a synthetic fiber spinneret, but it's rectangular and built of a platinum and rhodium alloy to endure the high temperature and corrosivity of molten E-glass Figure 15. The presence of rhodium in the bushing alloy enhances the hardness and rigidity of the bushing, extending its lifetime. The bushing is electrically heated to improve temperature control and fiber uniformity as they pass through thousands of tips and nozzles. The nozzles' diameters range from 0.75 to 2.0 mm, and the linear speed of the winder or chopper pulling the fibers can reach 60 m/s (Thomas J. L., 2007).

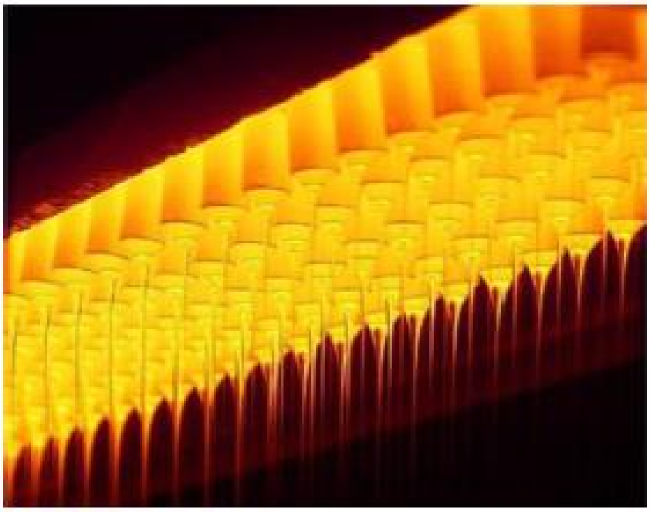

Figure 15: Flow of fiberglass from bushing (Cevahir Arif, 2017)

Fiber sizes can be adjusted by varying the winder or chopper speed or the bushing's output capacity, resulting in fibers of various diameters. Table 11 shows the names of fibers of various diameters.

Letter designation based on design	Average diameter (μ)
D	5.33
E	7.32
G	9.50
H	10.67
J	11.75
K	14.19
M	15.86
N	17.38
T	23.52

Table 11: Letter designation-based glass fiber diameter (Hearle JWS, 2000)

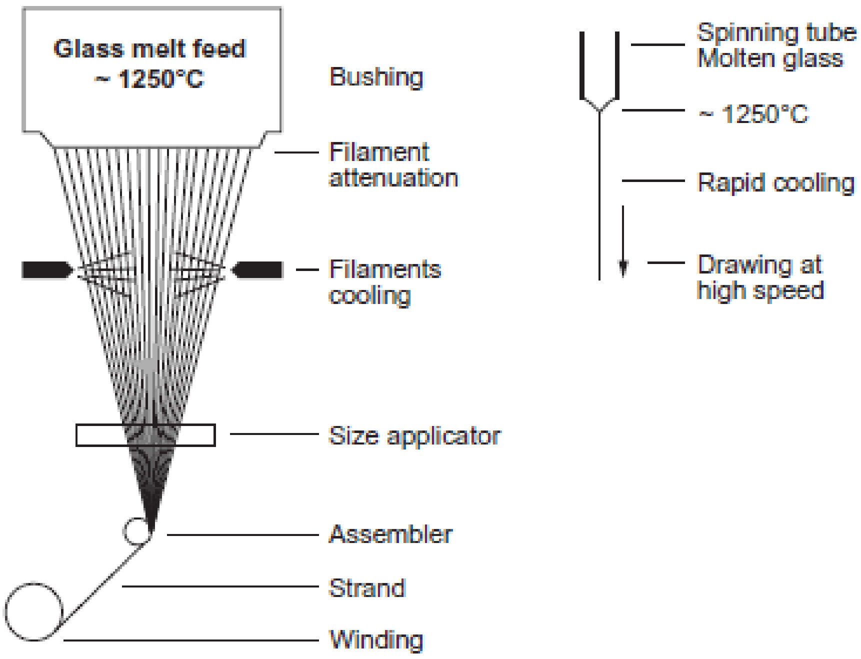

Figure 16: Continuous filament forming process (Wallenberger F.T., 2010)

By circulating cool air and spraying water as soon as the liquid glass exits the tip of the nozzle, it is quickly quenched. When the glass reaches the size applicator, which is a few meters beneath the bushing, it will be completely solidified (Fig. 16).

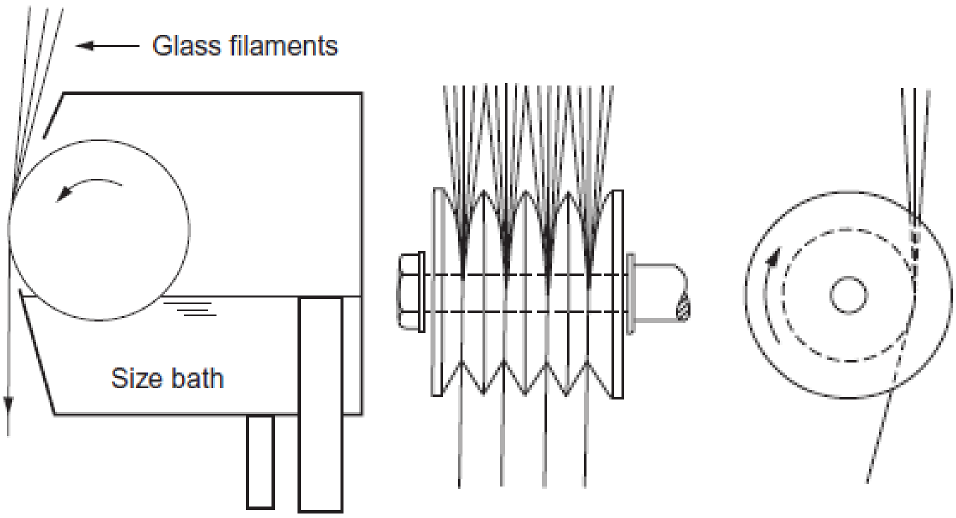

Figure 17: Applicator (Cevahir Arif, 2017).

A roller or a belt applicator is used to apply the aqueous size to the glass surface at this step. The glass filaments can be collected through split shoes, which are commonly rotatable grooved disks since they are wetted by water and size (Fig 17).

Traditionally, attenuated glass fibers are wound on a collet, which is a cylinder driven by a winder. Typically, the fibers are coiled on a paper or plastic tube that is slipped onto the collet. The tube's purpose is to make it easier to handle the formed cakes. The collet's rotation speed is the most important factor in determining the fiber diameter in its final form. The diameter of the filament is also affected by the temperature adjustment of the bushings. The traverse, which places individual strands to the collet in such a way that the cake has an even build-up and the strands can be coiled easily after drying, is another crucial feature of the winder (Cevahir Arif, 2017).

3.4.2 Emissions from glass fiber and glass production in production general

3.4.2.a E-glass production

In addition to CO2, SOx (Sulphur oxides), and thermal NOx (Nitric oxides), the manufacturing of E-glass releases CO2 and SOx from batch material degradation (Dai Q. et.al., 2015). Furthermore, the boron-containing batch material produces greater PM emissions (Particular matter) than float glass. Up to 15% of the additional boron content in the furnace is anticipated to volatilize and react with other species in the exhaust gas to create particles (Wallenberger 2010).

Within the stage of raw material processing (melting and refining), process emissions (energy consumption from fossil fuels and decarbonization of raw materials) account for 50% of total greenhouse gas emissions and 40% of total greenhouse gas emissions. Raw material production accounts for 22% of greenhouse gas emissions, energy generation accounts for 17%, and fossil fuel production accounts for 11% of greenhouse gas emissions during the glass manufacturing process (GlassFibreEurope, 2016).

The average direct greenhouse gas emissions due to molten glass production at the furnace stage (504 kg eq CO2/ton of molten glass) can be compared to the average value calculated for the EU-ETS benchmark of 540 kg eq CO2/ton of molten glass, and the benchmark value of 406 kg eq CO2/ton of molten glass.

Inputs	Batch preparation	Melting and refining	Forming	Post-forming
Natural gas (MMBtu/ton)	---	6.5	---	3.28
Electricity (MMBtu/ton)	1.15	---	2.00	---
Sand (ton/ton)	0.393	---	---	---
Limestone (ton/ton)	0.395	---	---	---
Kaolin (ton/ton)	0.327	---	---	---
Refined B_2O_3 (ton/ton)	0.0666	---	---	---
Water (gal/ton)	---	---	960	---
Emissions				
CO_2 (g/ton)	---	157671	---	---
NO_x (g/ton)	---	2217	---	---
PM (g/ton)	---	105	---	---
SO_x (g/ton)	---	679	---	---

*1 MMBtu = 28.263682 m^3 of natural gas at defined temperature and pressure.

1 MMBtu = 293.07107 kWh

1 gallon = 3.8 litres

Table 12: Life cycle inventory and emissions during E-glass manufacturing (Dai Q. et.al., 2015)

More than 90% of greenhouse gas emissions released during CFGF (Continuous filament glass fiber) manufacture come from carbon dioxide. The second-largest source is methane. Both gases account for nearly all greenhouse gas emissions in the system under study (GlassFibreEurope, 2016).

3.4.2.b Float glass production

Emissions of numerous criterion pollutants are produced during the manufacture of float glass. Because the batch preparation process works with fine ground particles, it produces particulate pollution (PM). The PM emission from batch preparation is believed to be low since most current mixing vessels are fitted with filter systems that essentially catch-all PM emissions (Scalet et al., 2013). Batch materials degrade and release CO_2 throughout the melting process (Reactions 1, 2, 3). Stoichiometric calculations are used to determine the amount of CO_2 released. Because of the high temperature in the furnace, nitrogen in the air combines with oxygen to form thermal

NOx (Reaction 4), which begins to occur at temperatures over 760°C and continues to form until the available oxygen is exhausted at temperatures above 1300°C. As a result of the thermal breakdown of Na2SO4 (Reaction 5), which is utilized as a refining agent, SOx is also released during the melting and refining process (Wallenberger F.T., 2010).

$CaCO_3 \rightarrow CaO + CO_2(g)$	(1)
$Na_2CO_3 \rightarrow Na_2O + CO_2(g)$	(2)
$CaMg(CO_3)_2 \rightarrow CaO + MgO + 2CO_2(g)$	(3)
$N_2(g) + O_2(g) \rightarrow 2NO(g)$	(4)
$2Na2SO_4 \rightarrow 2Na2O + 2SO_2(g) + O_2(g)$	(5)

Chemical reactions during float glass production and associated emissions (Dai Q. et al., 2015)

By assuming state-of-the-art abatement methods, the regulated emissions from the melting and refining of float glass are reported (Scalet et.al., 2013). Because the reported emissions include emissions from natural gas combustion in the furnace (Scalet et al., 2013), the process emissions are estimated by subtracting the natural gas combustion emissions calculated using 2014 GREET emissions (Dai Q. et al., 2015), factors for industrial natural gas boilers, from the reported emissions by the company (Scalet et.al., 2013). The sole source of worry from the forming and post-forming processes is the SO2 sprayed on the hot ribbon before it enters the lehr to protect it from the rollers. The SOx emissions, as a result are predicted to be 18-36 grams per ton of glass produced (Scalet et al 2013)

3.4.3 Thermal conductivity of fiberglass

Thermal conductivity refers to a material's capacity to conduct heat. Each substance has its own unique thermal properties. Fourier developed the idea of heat conductivity in 1822. The fundamental heat conduction equation is "For a homogeneous material, the local heat flow is proportional to the negative local temperature gradient," according to Fourier (Gooch J.W., 2011).

3.4.3.a Manufacturing methods for test specimen

There are a variety of laminating processes to choose from. To remove manual lamination variability and extend production runs, many automated and semiautomated manufacturing procedures have been developed. The semi-automated methods use matched die moulding, which allows for precise thickness and glass content control and results in a mould with two excellent surfaces. There are two types of lamination techniques based on the mold used to laminate the composite material. There are two types of molding processes: open mold and closed mold.

We employed the hand lay-up technique, which is an open moulding method, to produce the composites product in this inquiry, which includes a wide range of items such as boats, tanks, housing for auto components, and many more. The moulding surface is first coated with gel coat. After the gel coat has set, roll stock glass fibre is applied. Pouring, brushing, spraying, or rolling the laminating resin on is an option. To solidify the laminate, completely wet the reinforcement, and eliminate entrapped air, paint rollers or squeegees are utilized. When it's required, low-density core materials are also incorporated (Chaturvedi S. K.,et.al., 2014).

3.4.3.b Materials used for the specimen

1. E-glass fiber (50%)
2. Epoxy resin
3. Aluminium Oxide (Al_2O_3)
4. Silica Oxide (SiO_2)

3.4.3.c Compositions for the specimen

Five specimens were manufactured with different composition (Chaturvedi S. K.,et.al., 2014).

a. 50% Resin + 50% Fiber
b. 30% Resin + 20%Al_2O_3 + 50% Fiber
c. 25% Resin + 25%Al_2O_3 + 50% Fiber
d. 30% Resin + 20%SiO_2 + 50% Fiber
e. 25% Resin + 25%SiO_2 + 50% Fiber

3.4.3.d Specimen manufacturing process

Hand lay-up molding is used to make pieces of any size, including technical elements with a few square feet of surface area and swimming pools as large as 1600 square feet (about 150 m2). However, this approach is typically confined to the production of components with basic forms that only require a smooth look on one face (the other face being rough from the molding operation). It's best for small and medium volumes that don't require a lot of molds or equipment.

The contact molding process entails gradually adding these materials to a mold surface:

1. Release Agent
2. Gel Coat
3. Layer of liquid thermosetting Resin with a viscosity of 0.3 to 0.4 Pa-s and moderate reactivity,
4. Layer of reinforcement (glass, aramid, carbon, etc.) in the form of chopped strand Mat or woven Roving The reinforcement is impregnated by hand with a roller or a brush.

To achieve the appropriate thickness of the structure, this technique is repeated for each layer of reinforcement (Chaturvedi S. K.,et.al., 2014).

3.4.3.e Experimental setup on thermal conductivity

Thermal conductivity measurements are conducted in a steady-state environment. Thermal conductivity tests are performed using ASTM E1530 disc-shaped specimens having a diameter of 50mm and a thickness of 10mm. On one side of the specimen, a known continuous heat is delivered. The temperature of the top and bottom surfaces of the specimen were measured using thermocouples mounted on the top and bottom of the specimen when thermal equilibrium was reached and the system approached steady state. The thermal conductivity was calculated using one-dimensional Fourier's law of conduction with the quantities of heat provided, temperatures, and thickness (Chaturvedi S. K.,et.al., 2014).

$Q= -KA\, dT/dx= (KA (T_1- T_2))/L$ (1) (Gooch J.W., 2011)

Where,

Q= Heat transfer rate (W)

K= Thermal conductivity (W/m °C)

A=Area (m2)

T1= temperature at bottom surface of the sample (°C)

T2= Temperature at top surface of the sample (°C)

L= Thickness of the sample

dT/dx = Temperature gradient

3.4.3.f Test Results

Thermal conductivity of E-glass fiber reinforced epoxy composite with different composition (Chaturvedi S. K.,et.al., 2014).

a. Without filter (Resin and fiber): 3.2 W/m°C
b. With filter 20% Al_2O_3: 1.48 W/m°C
c. With filter 25% Al_2O_3: 1.91 W/m°C
d. With filter 20% SiO_2: 1.52 W/m°C
e. With filter 25% SiO_2: 1.16 W/m°C

According to the findings, composites filled with 20% Al_2O_3 and 25% SiO_2 had low thermal conductivity. This could be due to the fact that when materials are heated, a slow chemical reaction occurs in Al_2O_3 and SiO_2 that releases a small amount of water, which resists heat flow and suggests that there is a fundamental difficulty in transferring heat from the composite to the fibers.

3.4.4 Applications of fiberglass

Applications in building insulation

Fiberglass has been the most used insulating material in recent years. Fiberglass is able to decrease heat transmission due to the method it is made, which involves weaving thin strands of glass into an insulating substance. It's commonly used to make two types of insulation: blankets (batts and rolls) and loose-fulfill, but it's also available in rigid boards and duct insulation. Medium and high-density fiberglass batt insulation materials are now available, with somewhat higher R-values than regular batts. Denser insulation is designed for locations with limited hollow space, such as cathedral ceilings.

Fiberglass insulation has R-values ranging from 2.9 to 3.8 per inch and is non-flammable. Furthermore, it is a low-cost kind of insulation, making it the preferred choice. Installing it, however, necessitates taking safety precautions. When working with fiberglass, it's crucial to use safety glasses, masks, and gloves (UNIDO, 2017).

Used in manufacturing bulletproof armor

Bullet-Resistant Fiberglass is a layered, reinforced structural polyester laminate that has unique bulletproof properties. Bullet-resistant sheets of fiberglass, pressed between steel plates at high pressure and temperature, delaminate when a bullet penetrates, distorting and flattening the projectile and dispersing the energy. As the bullet enters the high-strength glass fibers, more energy is consumed (Total Security Solutions, 2004).

Applications in dentistry

Periodontal splints, fixed partial dentures, endodontic posts, orthodontic appliances, and other indirect restorations are increasingly using fiber reinforced composites (FRCs) to replace metallic restorations. Due to their superior capabilities in tension and flexure, fiber reinforcement in FRCs often offers the composite structure with higher biomechanical performance. Because of its chemical resistance and inexpensive cost, the E-glass fiber is now the most often used fiber. A growing amount of attention is being dedicated to improving its clinical performance. In addition, numerous procedures are used to strengthen the bond between the fiber and the matrix. For the clinical applications of FRCs, oral circumstances provide unique requirements and obstacles. The biomechanical qualities of dental materials are extremely important in dentistry, and as a result, research on E-glass fiber reinforced composite systems is ongoing. The biocompatibility of FRCs is typically good, and their toxicity isn't a problem (Zhang M.et.at.,2012).

For medical use

Endoscopic examination and supplemental therapy of human organs by transmitting light beam, light irradiation of blood to dilute the blood, and light cure of filling teeth are some of the medical uses of optical glass fiber.

It's designed to be used with medical bandages and prosthetic bones. The glass fiber is braided into a belt, the unique resin is impregnated as a bandage, and the bone is wrapped around the wound to replace the problems and negative effects of the plaster. Composite prostheses are also often used. Fiberglass composite artificial bones are currently being developed. Some non-toxic composite materials with bone bioactivity have been studied in animals and shown to have optimum biocompatibility and bonding strength with the original bone, which is higher than stainless steel, and they are predicted to be employed.

Glass fiber composite items connected to human health, such as sanitary pumps used in food factories, milk factories, hospitals, medicines, and so on, account for around 8% of the global yearly production of various types of composite breathing gas cylinders (CORE-TEX, 2021).

4.0 Comparison of Materials

4.1 Comparing Carbon Emission

When we take into consideration all the four building materials that are taken for study in this thesis, OPC is found to be the material that contributes the majority to the total carbon emission. One of the main reasons is because they are widely used and used in large quantities. They have been used for a long time and the world is used to its production, distribution, and installation. From a highly developed country to the least developed country OPC is a material they are familiar with. Powdered limestone is heated and mixed with a variety of ingredients to create a clinker, which is then used to manufacture cement. CO2, which makes about 40% of the weight of limestone, is emitted during this process. The fundamental chemistry of cement manufacture is responsible for up to 60% of cement's carbon emissions, making carbon release difficult to avoid. The production of every tonne emits up to 622 Kg of carbon dioxide into the atmosphere (Brogan C.,2021).

In this study, glass fiber production seems to be responsible for the second most carbon emission. But compared to that of OPC the quantity in which they are used is less. If the mould is available, it is much easy and cheap to produce parts using fiberglass. They are available and are in use all around the world. In addition to carbon emission, it also produces sulphur oxides, nitric oxides, and particular matter. The production of every tonne emits up to 504 Kg of carbon dioxide into the atmosphere (GlassFibreEurope, 2016).

Now we can take into account both materials Ferrock and Hempcrete which are used to replace OPC and Fiberglass. Even though a slight amount of CO2 is emitted during the hemp-lime mixing, considering the amount of CO2 absorbed during the growth of hemp plant and during the time after the production of hempcrete in carbonation reaction, the amount of carbon emission can be considered negative. Cannabis which is used in hempcrete can absorb around 249 kg of CO2 per ton of hemp used (Karche T. et.at., 2019). And for Ferrock during its manufacturing, mixing the aggregates with water and compressed CO2 will turn Iron oxide to Iron carbonate (rust) and hydrogen gas is produced. Thus, a fully cured Ferrock contains 8 to 10 percent CO2 by weight. Therefore, we can say Ferrock is a carbon-negative material (D.S. Vijayan.et.al., 2019).

4.2 Comparing Compressive Strength

Here we compare only OPC, Ferrock and Hempcrete, as they can be used as a binding material for construction. Among the three materials that we focus on here for our study Ferrock is the one that has the highest compressive strength. And its strength can be further increased by using thicker wireframe which is used to create the required shape for the structure. But using thicker wireframe will naturally increase the total cost of the structure. It is not possible as the Ferrock is already an expensive material to work with if produced commercially. In addition to compressive strength, Ferrock has a bit of flexibility compared to that OPC concrete structure, therefore it makes it ideal to be used in areas of high seismic activity. The compressive strength of Ferrock is around 52.26MPa which is almost twice that of OPC concrete (Mouli Prashanth, 2019).

Then we have our traditional Ordinary Portland Cement concrete, which has already conquered the market for building construction binding material all around the world. It is produced cheaply as they are produced in large quantities. Cement concrete is reinforced using steel bars in order to withstand shear and tensile forces, as concrete has only high compressive strength and low tensile strength. The compressive strength of concrete is around 15Mpa to 30Mpa based on the grade of concrete and the aggregates used (The Constructor, 2009).

Archaeologists have established that hemp was used in the building for at least 1,500 years. It can be found in Central European wooden-framed structures. Hemp mortar has also been discovered in the abutments of ancient Merovingian bridges in France (Zuo Junyi, 2021). Hempcrete even though was used as a binding material, it doesn’t have a compressive strength close to the materials above. The compressive strength of hempcrete is around 1Mpa to 1.5Mpa based on the grade of aggregate and the amount of lime binders used. In most cases they are used along with load-bearing wooden frames as a filling material, seal gaps.

4.3 Comparing Thermal Conductivity

Here among the four materials that are taken for study, we compare the thermal conductivity of only Hempcrete and Fiberglass insulation. Since they are both used as insulation materials in buildings to reduce energy consumption. With the right proportion of composite, the thermal conductivity of fiberglass insulation came achieved between 1.16 W/mK and 1.91W/mK (Chaturvedi S. K.,et.al., 2014). And for hempcrete wall of 300mm thickness, the thermal conductivity is around 0.2 W/mK (R. Walker.et.al., 2013) based on the difference in mixture and binder composition and also on the thickness of the material used. Based on the thickness of insulation material and thermal conductivity fiberglass can give much better insulation. But in addition to it, more layers of the wall has to be built which increases the cost of building. Hempcrete of the right thickness can give much better insulation to a building. It is called breathable material which means it helps to keep the air in the building clean and free from toxic gasses like in the case of fiberglass insulation. Both materials are fire-resistant and water-resistant. If properly installed hempcrete is termite resistant and will gain strength over time.

5.0 Data collected on each material from a financial standpoint

In this chapter, we take into consideration different factors like demand for the material, availability of raw materials and skill required to work with the material.

Ordinary Portland Cement

Cement prices in the United States reached roughly 124 dollars per metric ton in 2020, the highest level in recent years. Hydraulic cement becomes sticky and protects the hardened material from chemical assault through a chemical reaction between the dry cement materials and water. The US will import 15 million metric tons of hydraulic cement for use in 2020. Portland cement is one of the most prevalent forms of hydraulic cement. It may be found in concrete, cement, stucco, and grout. In the year 2020, the United States manufactured 89 million metric tons of Portland and masonry cement (Garside M., 2021).

Cement has high demand around the world and is widely available in the market. It requires high skill to work with the cement. Pouring concrete costs around $45 per hour of labour. There may additionally be a $60 delivery cost. Depending on the thickness of the slab poured, concrete costs anywhere from $26.29 to $33.166 per square meter. The labour will cost an extra $23.41 to $24.15 per square meter. Concrete slabs can be poured off-site or on-site. Smaller slabs, like as the hot tub foundation, may be poured elsewhere and delivered to your home with ease. On-site pouring is used for larger slabs, like a driveway (Daniel W.,2021).

Ferrock

Ferrock is an environmentally friendly concrete substitute. 95 percent of the materials needed to manufacture ferrock are recycled, so you won't be depleting natural resources as you would with concrete. However, the fundamental issue is that ferrock requires steel dust and silica, which are both by-products or waste from another operation. As a result, both goods are in short supply. Ferrock production is largely reliant on the production of other items. This means that ferrock producers are restricted in the amount of rock they can produce due to component availability. Making ferrock requires a lot of silica and metal shavings, which makes huge projects difficult. There are now just a few applications that Ferrock may be used. (Builder Space, 2022)

Ferrock may be used much like cement once it has been mixed. You may use it to pour into any mold or trowel. Finally, carbon dioxide gas is introduced to the mixture. The iron in the dust will rust when it absorbs CO_2 during this process.

Hempcrete

It is still difficult to build a house using hempcrete as they are rare and costly to produce. Furthermore, because of the difference in density, the amount of hemp necessary to create a unit volume of hempcrete is substantially larger than the amount of cement used in cement concrete. Furthermore, because hempcrete is not a load-bearing component of construction, it can only be utilized as a filler between wooden frames. As a result, the price of lumber reinforcements is factored into the total cost. The usual construction price per square meter adds $196 to the total cost. Even if the initial expenditures are very steep, the thermal insulation features of hempcrete can help save heating and cooling expenses in the long term (Sager J., 2019).

The construction of walls, ceilings and floors using hempcrete require a great deal of skills as there are different steps involved in it like foundation, structural frame, shuttering, mixing hempcrete and placing hempcrete. Even though there are difficulties in construction of building using OPC in construction the number of people who possess the skills are much more compared to those who knows to work with hempcrete, in turn there is an increase in labour cost.

Fiberglass

The cost of installation will vary depending on the location of the house, the amount of manpower required, and other considerations. The average cost of installing fiberglass insulation, on the other hand, ranges from $9.47 to $17.65 per square meter. For a 500 square meter area of your property, you may anticipate paying between $3219.17 and $6458.35, including labor.

Installing fiberglass insulation is not as complex as other home repair chores. Many homeowners will tackle the task on their own. Keep in mind, however, that bad installation is one of the most typical insulation drawbacks. In any case, you should budget between $25 and $50 per hour of work (Orentas G., 2022)

6.0 History of Materials

6.1 History of cement

The Japanese cement industry

Japan's cement industry began in 1875 with the first domestic cement manufacturer. It has undergone continuous technological progress, expanding and enlarging as the Japanese economy grew, to become world-class in cement quality and production technology in all aspects. In terms of production scale, the industry had 17 businesses and 30 plants as of April 2012, with a total clinker production capacity of 54.76 million tons. Seven major corporations with capital stock worth more than $10 billion and ten medium-sized companies with capital stock worth less than $10 billion make up the enterprise scale. Eleven of the 17 enterprises are specialized in cement manufacturing, while the remaining six companies are involved in a variety of industries, such as the chemicals industry (Shimoda T., 2016).

Cement production volume in Japan

The volume of domestic cement production peaked in 1979 at 87.94 million tons. Although this was followed by a negative trend in line with the slowing economy, there was some improvement starting in 1987. In 1996, there was a last-minute surge in demand before the consumption tax rate was raised, combined with a high need for rebuilding after the Great Hanshin Earthquake. Production volumes reached an all-time high of 99.27 million tons, thanks to a strong Asian export market. After that, there was a declining trend, with production being constant at 70 million tons since 2001. In 2008, the plateau came to an end, with a declining trend continuing. In 2014, production totaled 61.91 million tons, including clinker for export (Shimoda T., 2016).

Japanese domestic demand for cement

Throughout the post-war rebuilding and fast economic expansion, domestic demand for cement grew steadily. The production activity of materials industries such as electricity, steel, and coal began to rise as a result of public investment in basic infrastructures such as trains, highways, ports, and dams. Following that, capital investment mostly went into industrial industries including petrochemistry, electrical appliances, equipment, and vehicles. As a result, domestic cement consumption kept pace with Japan's rapid industrialization, which was catching up to the wealthy countries of the West.

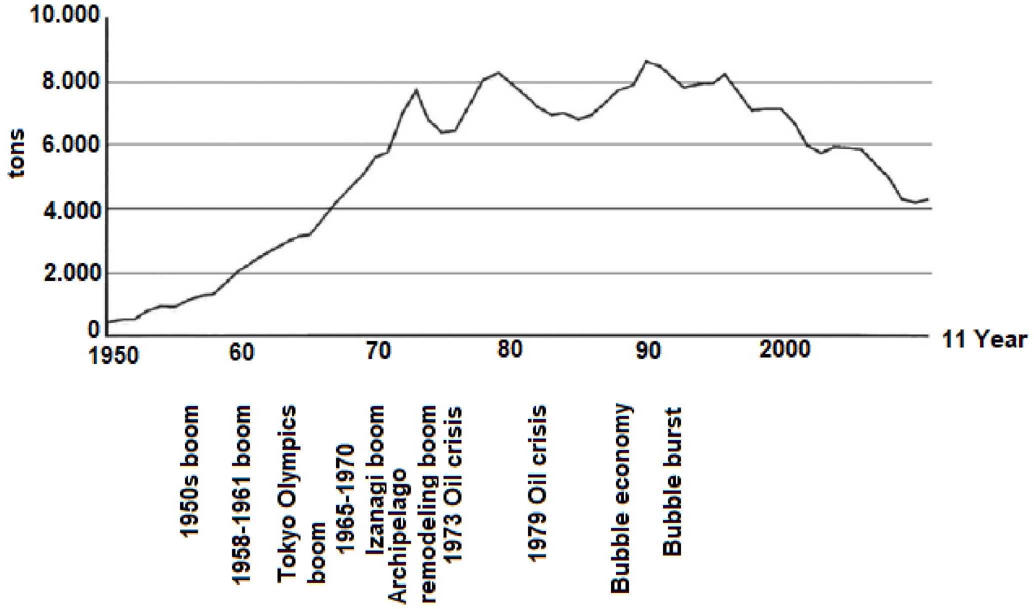

Figure 18: Trends in domestic cement demand in Japan (1950-2011) (Shimoda T., 2016)

With the first oil crisis, the expanding demand for cement came to a standstill (October 1973). Following a series of peaks and dips, a new high was reached in 1990, at the conclusion of the bubble economy. Demand peaked at 86.29 million tons that year, then continued to decline due to a lengthy recession, reducing to about 40 million tons more recently.

Domestic sales reached 45.9 million tons in 2014. In 2014, ready-mixed concrete accounted for 72 percent of domestic cement sales (excluding imports) by the demand sector, with precast concrete contributing for 12 percent. These two areas combined accounted for 84 percent.

Further investigation of cement final consumption by the market sector finds a nearly equal distribution of 51.0 percent:49.0 percent between the public and private sectors. Cement's domestic price is roughly ten thousand dollars per ton (2012, standard

Portland cement, Tokyo region), which translates to ten dollars per kilogram, a relatively low price for a chemical product, making it a strong performer among commodity prices (Shimoda T., 2016).

Cement exports and imports in Japan.

Japan's status as a significant cement exporter has remained unchanged. This is owing to its cost competitiveness, which stems from its large number of coastal cement factories and bulk shipping capability. In recent years, exports have stayed around 10 million tons (since 2010). In 2014, 9.11 million tons were produced, accounting for almost 15% of total domestic output. In the meanwhile, Japan's cement imports have remained stable at roughly 600,000 to 900,000 tons. Cement is a fully liberalized commodity, and the costs of cement manufacturing and delivery in Japan are competitive worldwide.

Expansion of Japanese cement industry overseas

Following WWII, the Japanese cement industry's international growth mostly consisted of the building of transfer facilities to ensure a stable export supply. With the development of cement factories and other substantial expenditures in the 1990s, foreign growth began in earnest. The growing Pacific Rim was the major focus of this international investment. As from 2012, Japan's overseas cement production bases would include two plants in Korea (14.76 million tons), seven plants in China (8.87 million tons), six plants in two Southeast Asian countries (11 million tons), four plants in California, and Arizona, USA (4.84 million tons), and one in the Pacific (200,000 tons), totaling 20 plants in six countries with an annual production capacity with around 40 million tons.

Japan has a large amount of garbage and by-products as a result of its economic expansion. However, challenges in finding new landfill sites in recent years have highlighted the topic of how to encourage recycling and limit the quantity of landfills in general. In this social context, the cement industry has gone beyond its existing role as "a basic construction materials industry" to become "a core industry in a resource-recycling society" by using the large volumes of waste and by-products as fuel and raw materials for cement manufacturing, an objective that is becoming increasingly important over time.

Based on existing cement production facilities and burning technologies, the cement industry has developed a comprehensive variety of waste and by-product recycling technologies, and today reclaims and reuses roughly 28.5 million tons of waste and by-products from other sectors (in 2012). This equates to around 21 million m3 when converted to volume.

Roman concrete

The first instances of Roman concrete may be found around the year 300 B.C. The Romans not only enhance the technical aspects of concrete, but they also gave it a name. The word "concrete" derives from the Latin concretus, which means "combined" or "grown together." The theater at Pompeii and the Roman baths were built with pozzolanic, hydraulic cement, which was created by the Romans around 75 B.C. The pozzolanic cement was made from a pulverized mixture of lime and volcanic ash containing silica and aluminum that was discovered at Pozzuoli, Italy, thus the name (Steiger R. W., 1995).

Figure 19: Patheon of Rome, Completed in A.D. 128. (Pinterest.ch, 2021)

Although unreinforced, Roman concrete still survives today and was widely utilized. Large volumes of concrete may be found in the Colosseum (finished in A.D. 82, Figure: 20) and the Pantheon (completed in A.D. 128, Figure 19). Concrete was also used to create the Basilica of Constantine and the foundations of the Forum structures.

The aggregate in the concrete of the Pantheon varies from heavy basalt in the foundations and 20-foot-thick lower walls, through brick and tuff (a stone derived from volcanic dust) in the higher walls, to the lightest pumice at the top of the 142-foot-diameter dome. The overall building is in good shape and remains in its original form today. Given that the builders had no knowledge of hydraulic lime chemistry, it is a remarkable achievement (Steiger R. W., 1995).

Figure 20:The Colosseum in Rome, Completed in A.D. 82. (nationalgeographic.org, 2021)

In their drive for less weight and thinner wall sections, Roman engineers attempted to strengthen concrete using metal strips and rods. It was unsuccessful, however, since the bronze had a faster rate of thermal expansion than the concrete, resulting in spalling and cracking.

Furthermore, even though the Romans employed concrete in many of their projects throughout their vast empire, transporting volcanic ash from Italy proved unfeasible. As a result, the pozzolan technique that had been so successful in Rome perished with the collapse of the Roman Empire in 476 A.D. For the following 1,300 years, lime mortars and concretes were employed in all concrete buildings (Steiger R. W., 1995).

British concrete technology

The Normans were supposed to have reintroduced the skill of manufacturing concrete to Britain, but recent excavations in Northampton have unearthed three Saxon concrete mixers dating from 700 A.D. (Figure 21). They were small bowls carved out of bedrock with a center post hole. The mixing was done by a beam rotating around a horizontal shaft with paddles attached to it. Humans and animals both contributed to the labor force.

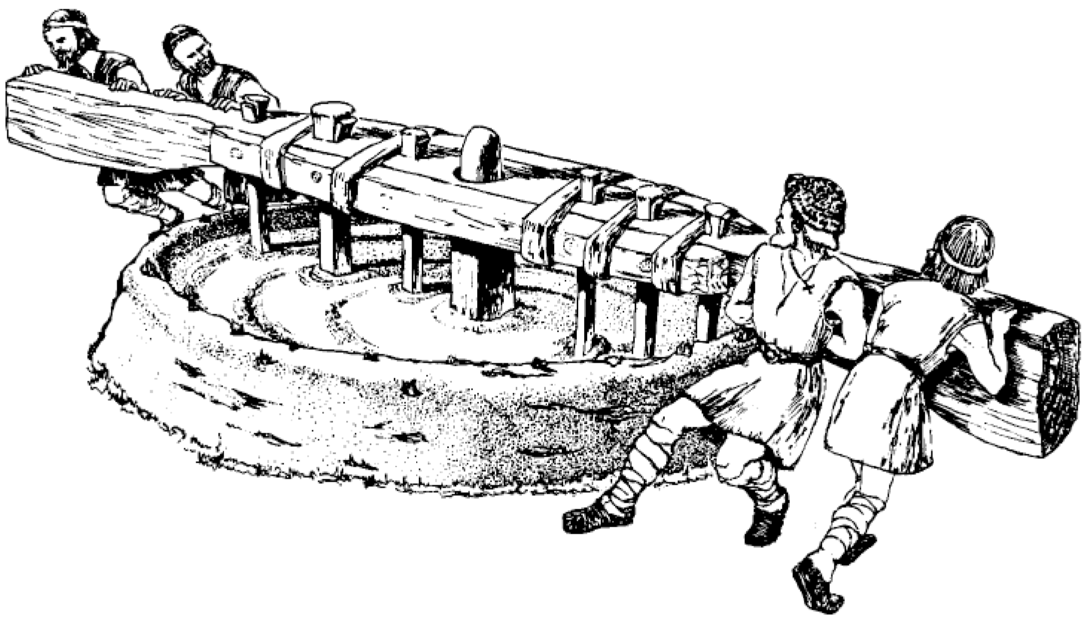

Figure 21:Saxon concrete mixer A.D. 700 (Steiger R. W., 1995)

The concrete work of the Saxons was limited, and it was the Normans that introduced more advanced concrete technology to Britain when they arrived in 1066. The stone front of Reading Abbey in Berkshire (dating from 1130) has been removed, revealing a concrete core that still exists today.

Castles, such as the White Tower at the Tower of London, required a lot of concrete. The concrete foundation of Salisbury Cathedral (finished in 1265) with the highest spire in Britain is still in outstanding shape. Some cathedrals that were built with less durable materials lately needed substantial reinforcement operations to keep them from collapsing.

6.2 History of Ferrock

Ferrock was invented by Dr. David Stone, the founder of Iron Shell Media technologies while he was doing his Ph.D. at the University of Arizona Tucson in 2002 (Fordham Louise,2014). Ferrock was invented by accident while he was researching ways to prevent the iron from rusting and hardening. Even though he initially discarded the material later he came into realizing how it can be used as an environmentally friendly alternative to conventional cement.

6.3 History of Hemp

Despite the fact that the hemp plant has various applications, it became renowned because it was frequently used as a recreational narcotic. The hemp plant and its applications have been extensively documented throughout human history.

Hemp is the English word for the cannabis plant, originating from the ancient English haenep. Both haenep and cannabis are assumed to be derived from the Ancient Greek kánnabis, which originated roughly 2500 years ago from a much earlier term from the Ancient Iranian language.

Figure 22: Hemp Plant-Cannabis plant (images.unsplash.com, 2021)

Cannabis is divided into three types: Cannabis sativa, Cannabis indica, and Cannabis ruderalis. C. sativa and C. india, the first two, appear to be more closely related. Cannabis ruderalis differs from the other two in that it flowers after a specified number of days, regardless of the season. It also contains relatively little tetrahydrocannabinol (THC), the psychoactive ingredient that gives cannabis its high.

Hemp is a fast-growing plant with a branched structure at the top. It normally reaches a height of 1.5 to 4 meters. It also has a slender, hollow stem with a diameter of 4 to 20 centimetres. These figures may differ depending on the weather and the place where they are cultivated. The hemp plant's bast fibres, which are found in the stem and range in length from 1.2 to 2.1 meters, are exceptionally strong. They are categorized into distinct categories based on fineness, length, color, consistency, and strength.

The plant's inner wood or stem was never used extensively in the past, but that changed quickly in the modern world. They're used to make packing fillers, animal bedding, and hempcrete.

Cannabis sativa is one of the first known domestically farmed hemp plants, with evidence dating back to the Neolithic period. Hemp has been discovered to be utilized in a broad range of items across the world, including hemp seeds for oil and resins, food, fuel, medications, and cosmetics. Hemp fiber is used in the production of hand-wearing clothes, rope, and durable textiles like Salicloth (William Stanwix and Alex Sparrow, 2014).

Cultivation of Hemp in UK

The prohibition of the drug cannabis resulted in the banning of cultivation of all forms of the hemp plant and consequently unavailable for many non-drug-related uses. The cultivation of hemp in UK was outlawed in 1928's. Since 1930's efforts were taken into developing hemp plat which contains very little THC. Due to the success in this effort an industrial hemp plant has been widely available for some decades which contain little or no THC.

Industrial hemp refers to cultivars of *Cannabis sativa* which has been bred to have a THC content of 0.2 percent or less. The THC content of the drug-producing plant would be 10-15 percent depending on the method of cultivation and strain. These newly bred hemp plants have been legal to grow in the UK since 1993 and 1995 in Canada. Because the industrial hemp plant is similar in structure or looks identical to the drug- producing strains, in UK they need a special licence from the government (William Stanwix and Alex Sparrow, 2014).

History of Hempcrete

Hempcrete was developed in France in the mid-1980. During this time people were experimenting to find a suitable replacement deteriorated wattle and daub in in timber frames of medieval buildings. Due to the ill-advised repairs of the buildings during the post war period using Ordinary Portland cement an extensive damage was occurring. Using OPC to replace the vapour permeable earth and lime mortars and natural cements in historic buildings prevented the building fabrics from breathing. Leading retention of moisture within fabrics, which in turn damaged the timber frames.

Therefore, a replacement was developed which can not only preserve the vapour-permeable nature a building’s fabric, keeping it in good health but also provide insulation. The stem of the hemp plant showed high durability and composed of strong cellulose which is capable of going from wet to dry and vice versa indefinitely without degrading (William Stanwix and Alex Sparrow, 2014).

6.4 History of fiber-reinforced composites

We've been employing composites since the dawn of time. Back about 1500 BC, Egyptians and Mesopotamian immigrants-built homes out of a combination of mud and straw. In 1200 AD, the Mongols devised a composite bow, which they utilized to gain military superiority. After the confinement of plastics in the 1900s, the application of composites grew. The origins of contemporary fiberglass may be traced all the way back to the 1930s. After the invention of the first plastic, Bakelite, in 1907, the plastic business grew and other polymers such as vinyl, polyester, and polystyrene were produced. The first glass fabric was launched in 1935, marking the beginning of the FRP business. During World War II (1939-1945), the composite industry transitioned from the laboratory to mass manufacturing. Henry Ford utilized FRP composites in the vehicle sector in 1941. (Fransisko G.R., 2013).

Glass laminates were produced by the father of Composite "Gold Worthy" in 1942-1944. Glass fiber was used to make the first boat hull in 1946. More study on FRP composite was done in the 1960s and 1970s. FRP Composites were first used in the 1960s to manufacture airplane components such as spoilers, fairings, and floor boards. Carbon fibers with high potential strength were first presented in 1963 by W.Watt, L.N. Phillips, and W.Johnson. The composite industry began to urbanize and mature in the 1970s. A vacuum molding technique for the manufacturing of Fiber Reinforced Composite was patented by Group Lotus Car Ltd. in 1972. Due Point developed Aramid (Kevlar) fibers in 1973, which has a high impact strength. Gotch performed vacuum impregnation with a single solid tool and a silicone rubber diaphragm bag in 1978. In 1980 and 1985, he used vacuum pressure to conduct research with the silicone vacuum bag VARTM. From the 1980s through the 1990s, the primary goal of FRP composite production was to lower manufacturing costs. Covington and Bavmgardner stated in 1980 that they had developed prototype fiberglass helicopter rotor blades utilizing filament winding. The father of composite "Gold Worthy" created the pultrusion method in 1982. The Indian Institute of Composite Materials was founded in 1982. Resin transfer molding was first used to make vehicle bodywork in 1985, laser 28 decks in 1986, and boat hulls in 1987. Hold detailed the invention of a tape winding machine for manufacturing composite main motor blade components in 1986. The Advanced Composite Manufacturing Center was founded in 1987 to provide composite courses for research and development consulting. Centrifugal casting was first used to make big diameter cylindrical pipes in 1988. Boyce began using robots to wrap resin-impregnated fibers around pins for reinforcement prior to compression molding in 1989. The composite industry has expanded throughout the years for many processes since the notion of Fiber Reinforced Composite production began. There are four generations of composites that may be articulated: Glass-fiber reinforced composites were initially used in the 1940s by the first generation of composites. The second generation began using high-performance composites in the 1960s. During the 1970s and 1980s, the third generation was looking for new markets and properties in the composite world, and after the 1990s, the fourth generation was utilized. Biomimetic Materials, Nanocomposites, and Hybrid Materials (Alpa T.B.et.al., 2017).

6.5 History of glass fiber

Glassmakers have been experimenting with glass fiber manufacturing since antiquity, but Edward Drummond Libbey, who displayed a clothing fashioned from fabric combining silk and glass fiber in 1893, was the first to mass produce it (Lowenstein K. L.,1975). Russell Games Slayter received the first patent for glass wool manufacture in 1938. As a result of the good electrical insulating capabilities of the manufactured fiber, glass fiber products are referred to as electrical glass or E-glass. Glass fibers have been employed as insulators in US naval battleships since 1939. Furthermore, during World War II, the development of unsaturated polyester resin and glass fiber manufacturing was a driving factor in the creation of radar domes (Radom's) and structural elements of aircrafts employing the hand layup process. In 1953, General Motors began mass-producing the complete body of Chevrolet Corvette sport cars using glass fiber and the sheet molding compound (SMC) technology for the first time.

Glass fiber producers have spent millions of dollars to reduce waste due to advancements in technology, customer awareness, and government requirements. Glass fiber makers face a huge problem in reducing furnace emissions, which include dust, sulfur dioxide, and nitrogen oxides. The use of oxygen combustion has the advantage of lowering nitrogen oxide emissions into the atmosphere. To eliminate fluorine contamination and reduce air pollutants in the production process, glass manufacturers create fluorine- and boron-free glasses. New fibers with excellent mechanical strength and corrosion resistance are constantly being developed in response to industrial demands. S glass, ECR glass, boron-free glass, and a variety of other varieties of glassware are made in this way (Cevahir Arif, 2017).

6.5 History of Green buildings

Green building movement in the U.S.

The book "Silent Spring" by Rachael Carson is credited for kickstarting the green construction movement in the United States. The book sparked a national controversy about the government's unfettered use of pesticides including Dichloro-Diphenyl Trichloroethane (DDT) and other chemicals. This discussion had brought environmentalists from all over the country together, leading to the first Earth Day on April 22, 1970. The public awareness raised by this book can be referred to as the United States' first nationwide environmental movement. On a global scale, the inaugural Earth Summit was held in Stockholm, Sweden in 1972. It was established by the developed world to address the environmental repercussions of industrialization and is often regarded as the key defining event in international environmentalism. The Earth Summit brought together 113 countries, and it was determined to convene every 10 years to examine progress. There were several triumphs at the meeting, including the 26 principles of the UN Conference on Human Development Declaration, an action plan on the Human Environment, and an Environment Fund (Korkmaz.et.al., 2009).

Green building movement in Turkey

In many ways, green construction in Turkey has achieved an all-time high. Major commercial developments now display an awareness of environmental issues or a design based on sustainable principles, which was unheard of a few years ago. Green retrofitting is taking place in shopping malls and significant office buildings. The Turkish Ministry of Culture and Tourism has mobilized hotels and resorts with its Green Star program, which is based on recognized green building requirements, to cater to eco-conscious tourists. These recent initiatives, while little, signal the entry of green construction into Turkey's mainstream construction industry. In October 2007, the Turkish Green Building Association was founded with the goal of becoming a Green Building Council (GBC). Since then, the organization has been advocating for green buildings (Korkmaz.et.al., 2009).

Green building movement in India

The government's measures to promote sustainability in society, as well as the business sector's embrace of green building principles, are at the heart of the Indian green building movement. Unlike in the United States, where government policies were based on public pressure from environmental groups, the Indian government made important policy decisions in response to international events such as the OPEC oil embargo, the Brundtland Commission, and the Second Earth Summit (Korkmaz.et.al, 2009).

Among the countries studied historically in terms of their green building markets, the United States looked to be the pioneer in terms of green building guidelines acceptability and use. With the foundation of the Indian Green Building Council, India has likewise hastened its progress. Despite the fact that Turkey's green buildings are more visible than ever, more inter-development is required to enable large-scale production. The newly formed Green Building Association (emerging council) aims to convey global know-how to Turkey by leveraging the experiences of Green Building Councils around the world. An examination of the green construction movement in several nations over time revealed overlapping events and patterns. In addition, the establishment of green building committees in each country aided in raising awareness in both developed and developing countries. The next phase in this investigation is to look at the construction businesses in these countries, as well as their governments and universities, in order to better understand the motives and challenges to green building rules adoption. The goal of this project is to create a framework for developed and developing countries to use in order to embrace green building criteria (Korkmaz.et.al, 2009).

7.0 Limitations of this study/thesis

- The data or information collected are based on referring articles, thesis, books, and information available on the internet. There is no hands-on tests or experience with materials that are focused on this thesis.

- Data available on Hempcrerte and Ferrock are limited as they are not commonly used compared to that of conventional materials like OPC and Fiberglass.

- Information provided related to current price is not accurate as the price could varies with locations, availability of materials, demand of the materials and number companies available in a location that provide service. For this study we took the price of materials in the US as a rough value for comparison.

8.0 Conclusion

Based on this study we came to understand the manufacturing procedure associated with different materials, the raw materials required, and most importantly the carbon emission associated with each. And by replacing OPC and Fiberglass insulation with Ferrock and Hempcrete, we can reduce the emission of CO2 and associated harmful gas into the atmosphere causing climate change and negatively impacting the health of humans and other life forms. In fact, they not only reduce CO2 emission but also help clean the environment as they are carbon negative building materials.

Even though ethically replacing the conventional materials with a sustainable and green substitute is the right thing to do, there are limitations to implementing them on a large scale. Ferrock is a substitute for OPC focused in this thesis. Ferrock has much better compressive strength and is a carbon negative material, but one of the main raw materials required for the manufacturing of ferrock is Iron dust which is a waste product of the Steel Industry. In other words, the rate of production of the main component for Ferrock depends on the production of other steel products. So if we plan for mass production of Ferrock, there is a change of shortage of raw materials. And if we try to resolve this issue by buying steel and grinding them into dust, it will increase the cost of production drastically. Therefore, at the moment use of Ferrock is limited to only small-scale projects.

Hempcrete is a material that can be used both as a binder and an insulating material. Unfortunately, due to their low compressive strength, they cannot be used as a load-bearing component of a structure. Hempcrete can only be used as a filling material between wooden frames that can support the structure. Therefore, Hempcrete cannot be used as a substitute for OPC and its role in construction. But it can be used to replace conventional insulation materials like fiberglass. Since Hempcrete has good resistance to thermal conductivity it is a suitable sustainable and green substitute for most conventional insulation materials. They are carbon negative and eco-friendly materials manufactured from hemp shives and lime. Even though a house built from Hempcrete and wooden frames is more expensive than a conventional building, and the amount of hemp required to build the entire house is relatively high. In the long run, you can make up for it by saving on the cost of energy consumption. In addition to it, you can sell the amount at a much higher price even after a long time. Hempcrete is breathable, which benefits the building's inhabitants' health. While contemporary highly insulated buildings rely on airtightness to trap air within the lightweight insulation layer, it allows for natural ventilation throughout the building.

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List of Abbreviations

GGBS	Ground Granulated Blast-furnace Slag
HLC	Hemp-lime concrete
LHC	Lime-hemp concrete
OPC	Ordinary Portland Cement
PM	Particular matter
WR	Water Retainer

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