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RESEARCH ARTICLE

STUDY ON MECHANICAL AND THERMAL PROPERTIES OF WATER HYACINTH CEMENT COMPOSITES

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Abstract

This study investigates the mechanical and thermal properties of a novel cement composite incorporating water hyacinth, an abundant and under-utilized aquatic plant. The water hyacinth fibers were treated and mixed with cement to create a composite material. Various ratios of water hyacinth to cement were tested to optimize the composite's properties. The mechanical properties, including compressive strength, tensile strength and flexural strength were evaluated using standard testing methods. The thermal properties were assessed by measuring the thermal conductivity and specific heat capacity of the water hyacinth cement composites. The test results indicate that the water hyacinth cement composite exhibits promising mechanical strength and improved thermal insulation compared to conventional cement. This research suggests that water hyacinth, often considered a problematic invasive species, could be effectively utilized in sustainable construction materials.

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Introduction:-

Weeds are plants that invade the space and nutrients of other plants. Water hyacinth is one such weed which grows abundantly in most of the water resources like ponds, lakes etc. It spread across the south-eastern U. S. It is one of the 100 most invasive weeds. Hence a suitable application is to be found for this weed.

The materials that are generally being used for thermal insulation are Petrochemicalls like polyurethane, expanded polystyrene and extruded polystyrene. These materials are harmful to the environment. An ecofriendly approach needs to be developed. So, thermal insulation boards using water hyacinth can act as a solution for both these problems. Environmentally friendly ago-based thermal insulator made from water Hyacinth fiber (aquatic weed) with cement as binder was developed. For this reason, the thermal behavior of the water hyacinth and cement composite was studied.

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Thermal insulation:

Thermal insulation is the reduction of heat transfer (i.e., the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence**.** Petrochemicals like expanded polystyrene, extruded polystyrene are widely used for the purpose of thermal insulation. But they are in- organic, non-renewable materials which are harmful to the environment. Hence an organic and sustainable substitute is required in the place of these.

Water hyacinth:

It is an intrusive aquatic weed which grows abundantly in many water bodies like lakes ponds, etc., It is categorized as a floating surface aquatic weed. It is present in 70% of lakes and ponds. Its growth cannot be contained easily. Water hyacinth has many negative impacts on the ecosystem, hydrology, etc. Water hyacinth plant causes depletion of dissolved oxygen in the water resources thereby decreasing the livelihood of the river or lake. It also creates the major problem to the means of water navigation. The presence of this aquatic weed affects the irrigation systems. The petioles of water hyacinth plant are spongy and they have high porosity in its internal structure and thereby they have very low thermal conductivity values. Hence these can be used for purpose of thermal insulation.

Pulp particles:

The water hyacinth particles that pass through the 2.36 mm sieve are known as pulp particles. The water hyacinth plant is cleaned, dried and the petioles were separated. They are then crushed manually and sieved through the 2.36 mm sieve. The size of the

Table 1.1:

Chemical compounds	Percentage composition
Cellulose	52.2
Hemicelluloses	16.78
Lignin	9.42
Ash	12.14
Moisture	9.46

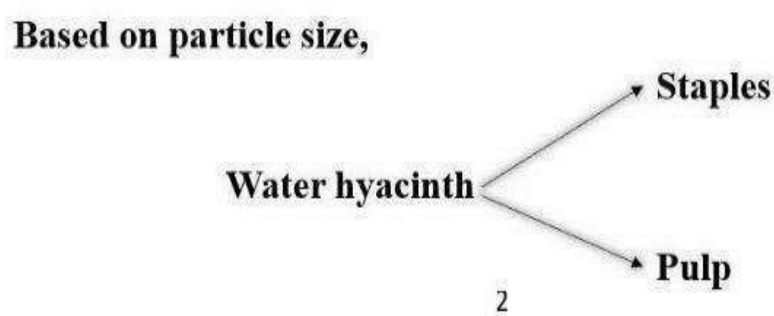


Figure 1:-

pulp particles are less than 2.36 mm. When these particles are used in making a board, the density is higher and porosity is lesser due to the excelling particle size distribution and better filling of voids present between the particles in the composite.

Staple particles:

The water hyacinth plant particles that are retained in the 2.36 mm sieve are known as staple particles. The water hyacinth plant is cleaned, dried and the petioles are separated. They are then crushed manually and sieved through 2.36 mm sieve. The particles that are retained are considered as the staple particles and their size is more than 2.36 mm. When these particles are used in making boards, the density is lower and porosity is lesser due to the presence of more voids present in the composite after casting of specimen.

Binder:

It is a material or substance that holds different materials together to form a cohesive unit by adhesion or cohesion. The bonding can be due to mechanical or chemical action. It can be organic or inorganic in nature. In this project we use cement as binder to hold the water hyacinth particles together.

Figure 2. 1.1:- Pulp And Staple.

Cement:

It is a powdery substance made by calcinations of lime and clay which can be used to make mortar or concrete. It is a binder used in construction which sets and hardens and adheres to other materials thus binding them together. When cement is mixed with fine aggregate, we obtain mortar. When mixed with sand and gravel, concrete is obtained.

Sustainable development:

It is the principle of meeting development goals while also sustaining the ability of nature to provide resources and services on which the economy and society depend. It is the method of development in which the right to live of the future generations is not affected or negotiated with.

Waste management:

It includes activities and actions required to manage waste from its production to disposal. It involves the collection, transportation and treatment and disposal of waste. It also involves the monitoring and regulation of processes, laws, technologies and mechanisms.

QGIS:

The expansion of QGIS is Quantum Geographic Information System. It is a free and open-source cross platform desktop geographic information system application that supports viewing, editing and analysis of geo spatial data. It allows composing and exporting geographical maps. shapefiles, coverages,

Scope:

- To find a suitable use for the water hyacinth plant and to reduce its menace in the water bodies like lakes and ponds.
- To know the spread of the so-called invasive aquatic weed water hyacinth in Tamil-Nadu and to plot its abundance with the help of QGIS.

To achieve a sustainable alternative solution for the problem of thermal insulation in the construction industry.

Objective :

- To mark the spatial extent of lakes containing water hyacinth plant in Tamil Nadu
and to show its abundance using QGIS
- To study the mechanical & thermal properties of Water Hyacinth cement composite by optimizing the proportion of various particle sizes of water hyacinth.
- To use ago-based material (water hyacinth) effectively in thermal insulation in order to attain sustainable development

Literature Review :

1. Juby Mariam Boban et.al. "Incorporation of Water Hyacinth in concrete", International Journal of Engineering Research and Technology (IJERT) Vol. 6 Issue 05 May 2017.

In this paper, the water hyacinth fibres (WHF) were used as a replacement for fine aggregate in concrete with variation percentage of addition. As a first step in the process, the water hyacinth plant is cleaned to remove dirt and then sundried for one day. The plant is cut for the length of 5mm (for better stability) in order to get fibres of uniform length. The various percentage of WHF added to replace the fine aggregate in the concrete are : 0%, 0.5%, 1%, 1.5%, and 2%. The different sizes of specimen (cube, cylinder) were casted as per the requirement of each testing. At first the compressive strength test and split tensile strength test were conducted for all the proportions on 7th day and 28th day of curing. Among various tried ratios, 0.5% gives the maximum results. Hence the sorptivity test, rebound hammer test, water absorption test and heat resistance test were done for 0.5% only. Also, the results were compared with the properties of normal concrete. The author suggests various structural applications for the WHF incorporated concrete. They are: 1) This concrete can be used in marine structures as it having more water absorbing capacity. This indicates that the concrete has low permeability than that of normal concrete. If it is used in high exposure areas, the concrete can regain the absorbed water and cut-off the permeability; 2) This concrete can be used in the construction of retaining wall as it possesses crack resisting capacity and provides better stability against the soil pressure. Low sorptivity value shows that the proposed concrete has resistance towards freezing thawing reactions. A protective coating of WH incorporated concrete can be used in the place where the structure is exposed to high heat as it provides better heat resistance than that of normal concrete; 3) WH incorporated concrete can be used in the foundation for machine operating room as it provides higher strength than conventional concrete. The author concludes the paper by saying that the usage of water hyacinth in the concrete as the replacement for fine aggregate make the structure durable and provides low weight buildings.

2. Suchanya Viwatsakpol and Greg Heness, "Mortar Reinforced with Water Hyacinth Fiber", Department of Materials Engineering, Kasestsart University (2021).

In this literature paper, water hyacinth plant is used as a reinforcing material in the mortar and it is tested for compressive strength and bending strength. The plant was cleaned and oven dried on 50℃ for 4 nights. Some samples were treated with the sulphur which increases the workability of the mortar and decreases the brittleness of the tile and the cube specimen. The plant was used in five different ways such as, crushed dry fiber (CDF), long dry fiber (LDF), milled dry fiber in 2 sizes-<20 mesh (#20-MF) and <40 mesh (#40-MF). The WHF is mixed in 3 different ratios –1%, 3% and 9% by mass. The two categories of specimens were casted with sand and without sand in the mortar matrix. The specimen was casted as a cube for compressive strength test and tile for bending strength test. The water cement ratio was fixed as 0.485 and cement to sand ratio was 2.75. The bonding between the water hyacinth particles and the cement and sand particles were analysed.

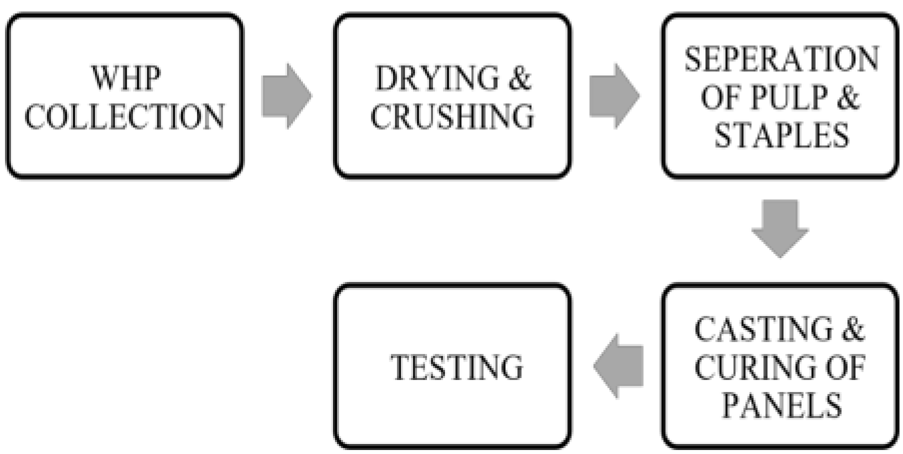
Methodology & Materials:-

Sample Collection

The samples of water hyacinth plant were collected from **KEELAKUYIL KUDI LAKE, Madurai**. The water hyacinth plant forms a complete mat over the water surface. The latitude and longitude of the lake is 9.1853° N, 77.8728° E. Various steps were taken for the removal of water hyacinth as it turns down the possibilities of usage of the lake water for household and other purposes. But all the steps were gone useless as it grows recurrently after every rainy season. If the water is free from this encroaching aquatic weed, the lake water can meet-out the part of water scarcity prevailing over the locality throughout the year. So, this work is proposed to meet the problem that happening around the locality by the water hyacinth plant.

Composite Processing

The mapping of aerial extent of the water hyacinth plant is discussed in



CHAPTER 4 – ANALYTICAL STUDY-QGIS.

The various process of preparation of water hyacinth-cement composite such as casting, curing and other tests are explained in CHAPTER 5 – EXPERIMENTAL STUDY.

Experimental Work:

1. **General:**

In this chapter, the process of casting, curing and the procedures of all the tests that has been done is discussed in detail.

2. **Mixing:**

First the appropriate amount of cement, pulp and staple particles were mixed thoroughly to get uniform dry mix. Then it was added with calculate amount of water to form a homogeneous mixture. Then it was placed in the mould and the surface was neatly finished to get uniform surface. No specific compaction procedure is used here.

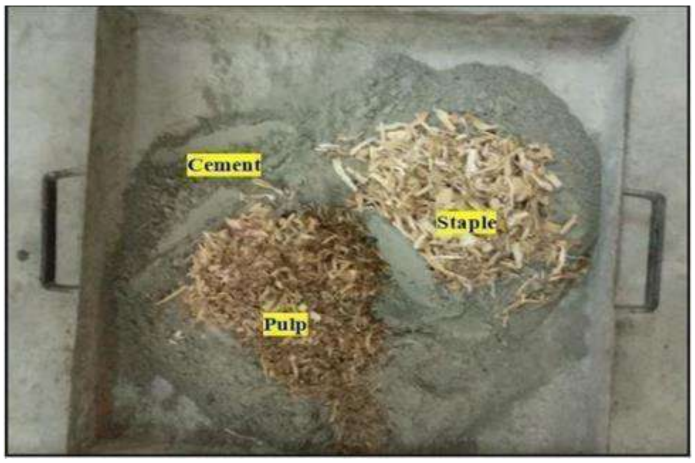
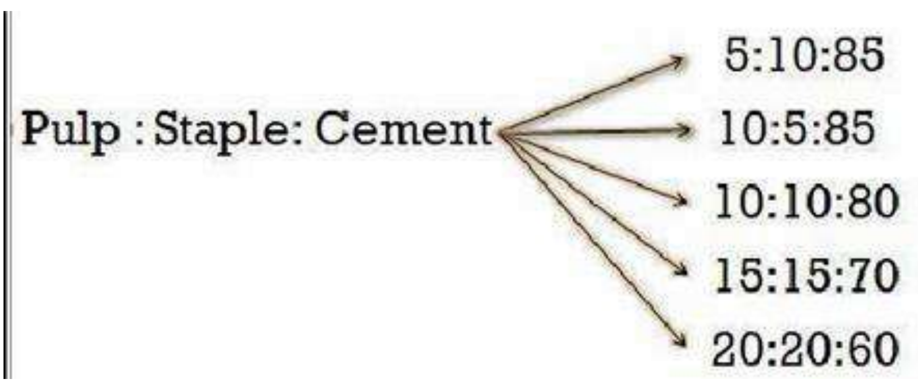


Figure 4.1:- Mixing of materials.

The water hyacinth-cement composite was casted in five different ratios by varying the quantity of pulp, staple and cement. The ratios are considered as follows:



Three specimens were cast for each test in each ratio. The water to cement ratio is chosen as 0.45.

Dry Volume = 190mm x 90mm x 90mm = 0.001539 m^3

Wet Volume = 1.3 x Dry Volume = 0.0020007 m^3

Volume of pulp = 12 x 0.018 = 0.216 kg

Volume of staple = 12 x 0.018 = 0.216 kg

Volume of cement = 12 x 1.05 = 12.6 kg

Volume of water = 12 x 0.47 = 5.64 lit

Casting:

The water hyacinth plant was sun dried for 15 days and then casted.

Figure 4.2:- Casting.

The specimens were casted and left in the mould for 24hrs and on the next day, they were demoulded from the mould and left for curing. In this project work, accelerated curing was used.

Curing:

Conventionally, the quality of concrete is calculated in terms of its 28 days compressive strength.

Testing:

- **Bulk density test:**

Bulk density is the ratio of the weight of specimen to its volume. After the curing, the specimens were sun dried to eliminate the water absorbed during the curing. Then it was weighed using the electric balance. The volume is calculated as it is same as that of the volume of the mould. Also, it was verified with the measured volumes.

$$\text{Bulk density} = \frac{\text{Weight of specimen}}{\text{Volume of Specimen}}$$

Bulk density of the specimen depends on the bulk density of the materials used in the process of manufacture of that specimen. Addition of water hyacinth influences the density of the specimen.

Bulk density of a material is the ratio of its weight to volume. The bulk density of specimen depends on its constituent materials. The calculation of the bulk density for the specimens of the specified five ratios is as follows:

Proportion (P:S:C)	5:10:85	10:5:85	10:10:80	15:15:70	20:20:60	UNIT
Length	0.25	0.25	0.25	0.25	0.25	m
Breadth	0.25	0.25	0.25	0.25	0.25	m
Thickness	0.015	0.015	0.015	0.015	0.015	m
Weight of Sample, W	1.59	1.56	1.25	1.195	1.14	kg
Volume of Sample, V	0.0009375	0.0009375	0.0009375	0.0009375	0.0009375	M^3
Density of the Sample	1696	1664	1333.33	1274.67	1216	Kg/m

Table 4.1: Calculation of bulk density.

- **Water absorption test:**

In this test the cured specimen is sundried until the surface is fully dry. Then it is fully immersed in water which is at room temperature for a period of 24 hours. The specimen is then taken out and its weight is measured. It is taken as W1. The specimen is then kept in an oven and its weight is periodically measured. When it attains constant weight, the specimen is taken out of the oven. This weight is taken as W2. The noted weights are applied in the following formula to get the water absorption capacity for the specimen.

$$\text{Water Absorption} = \frac{(W1-W2)*100}{W2}$$

Proportion (P:S:C)	5:10:85	10:5:85	10:10:80	15:15:70	20:20:60	UNIT
Weight of Saturated sample, W1	1.839	1.831	1.326	1.044	1.254	kg
Weight of Dried sample, W2	1.674	1.613	1.07	0.825	0.825	kg
Formula for Water Absorption	$=\frac{(W1-W2) * 100}{W2}$					
WA	9.86	13.52	23.93	26.55	27.83	%

Table 4.2: Calculation of Water Absorption capacity.

- **Flexural strength test:**

This test is used to determine the breaking load of clay roofing tiles and cement concrete flooring tiles. In this test a double lever system with a ratio of 1:12 is provided for applying the load. The lower lever is supported on a ball bearing and carries a counter-balance weight and a receiving pan. The lead shots flow through a supply pipe to a receiving pan.

The loading roller along with the yoke according to the specimen thickness. The bearing rollers are kept in the centre according to the specimen and the specimen is then placed in the centre. The loading roller is then adjusted such that it is in contact with 33 the specimen. The specimen is then loaded by starting the flow of the lead shot. This is done by operating the shutter lever by pressing it down. When the specimen fails the lever strikes hard on the shutter and the flow of lead shots is stopped. The loading pan is removed and the lead shots collected in the pan are weighed. By multiplying the weight by twelve the actual load at which the specimen failed is obtained.

Proportion (P:S:C)	5:10:85	10:5:85	10:10:80	15:15:70	20:20:60	Unit
Weight of ball + container	6.94	7.62	5.82	4.73	4.008	Kg
Weight of container	1.15	1.15	1.15	1.15	1.15	Kg
Weight of ball	5.79	6.47	4.67	3.58	2.858	Kg
Force applied	56.7999	63.4707	45.82	35.198	28.03698	N
Length of the specimen, L	250	250	250	250	250	mm
Breadth of the Specimen, b	250	250	250	250	250	mm
Thickness of the specimen, t	15	15	15	15	15	mm
Formula =	$=1.5 \times \frac{PL}{b * t * t}$					
Modulus of Rupture	0.76	0.78	0.62	0.58	0.52	MPa

$$\text{Modulus of rupture} = 1.5 * \frac{P * L}{b * t * t}$$

Table 4.3: Calculation of Flexural Strength.

Three-point flexure test is done in this project work. It measures the bending strength of the specimen. The table given below explains the calculation of the Modulus of rupture.

- **Thermal Conductivity Test:**

The two knobs of hot and cold plate temperature setting are kept at its extreme anticlockwise direction and the apparatus is switched on. The area of the sample is entered as the value for AREA parameter and thickness of sample is entered as input to the THICKNESS parameter. It is the measured rate of electrical energy input to central heater of hot plate. It is the measured rate of electrical energy input to central heater of cold plate. Instantaneous measured temperature achieved in central section of hot plate assembly. Instantaneous measured temperature achieved in central section of cold plate assembly. The sample is then placed between the hot and cold plate assemblies. The necessary PC software is installed and connected

with the apparatus. The knobs are rotated in the clock-wise direction to achieve the desired watt setting for hot plate assembly and cold plate assembly. The apparatus automatically comes into operation and LCD displays all four parameters. The data will automatically be transferred to the Pc software. The test is then started by pressing the START TEST button. After 3-4 hours the hot and cold plate assemblies will attain stable temperatures. When the 'Final Result Ready' message is displayed the readings can be noted. Thermal insulation is indirectly proportional to the thermal conductivity of the material. The thermal conductivity values for the tested specimen are as shown in the table below:

Proportion (P:S:C)	**5:10:85**	**10:5:85**	**10:10:80**	**15:15:70**	**20:20:60**	**Unit**
Power Input to the hit plate	195.3	184.5	199.9	195.5	201.56	W
Thickness of the Sample	0.015	0.015	0.015	0.015	0.015	M
Length of the Sample	0.25	0.25	0.25	0.25	0.25	M
Breadth of the sample	0.25	0.25	0.25	0.25	0.25	M
Area of the Sample	0.0625	0.0625	0.0625	0.0625	0.0625	m
Hot plate Temperature	231.3	220.2	237.4	233.5	235.4	ºc
Cold plate Temperature	122.9	130.7	130.8	133.6	129.8	ºc
Formula for Thermal Conductivity	$= \frac{\text{Power input to hot plate x Thickness of Sample}}{\text{Area of sample x (Hot plate Temperature – Cold plate Temperature)}}$					
Thermal Conductivity	0.145	0.146	0.143	0.139	0.134	W/mK

Table 4.4: Calculation of Thermal conductivity.

Results and Discussion:

General:

To know the quality of water hyacinth bricks, following tests were carried out as per Indian Standard Code (IS) in laboratory as well as in field. According to the results obtained from the various tests, quality of bricks is determined and discussed. All the test results of water hyacinth bricks achieved is compared to normal clay bricks. The following brick test is conducted for the project.

- **Bulk Density Test:**

Proportion (P:S:C)	**5:10:85**	**10:5:80**	**10:10:80**	**15:15:70**	**20:20:60**
Density of the sample (kg/m^3)	1696	1664	1333.33	1274.67	1216

Table 5.1: Result of bulk density.

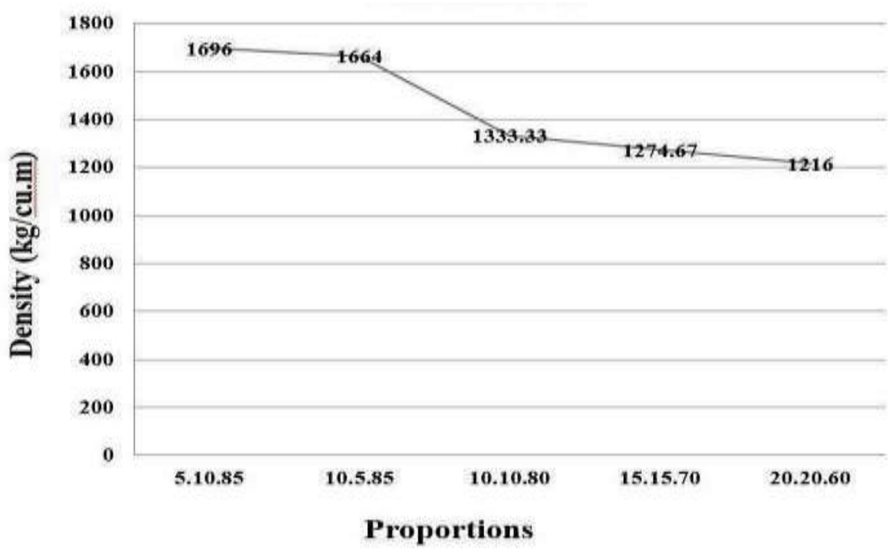


Figure 5.1: Graph of bulk density.

Discussion:

The bulk density of the specimen decreases with increase in the quantity of the water hyacinth particles in the composite. Also, the bulk density increases with increase in cement content. Hence the value of bulk density for the ratio (P:S:C) 5:10:85 is 1696 kg/m3 and for ratio of 20:20:60 the value is 1216 kg/m^3. The percentage decrease in the bulk density values is 39.5%. This is due to porous nature of the petioles of the water hyacinth plant.

Water Absorption Test:

Proportion (P:S:C)	5:10:85	10:5:80	10:10:80	15:15:70	20:20:60
Water Absorption (%)	9.86	13.52	23.93	26.55	27.8

Table 5.2: Result of water absorption

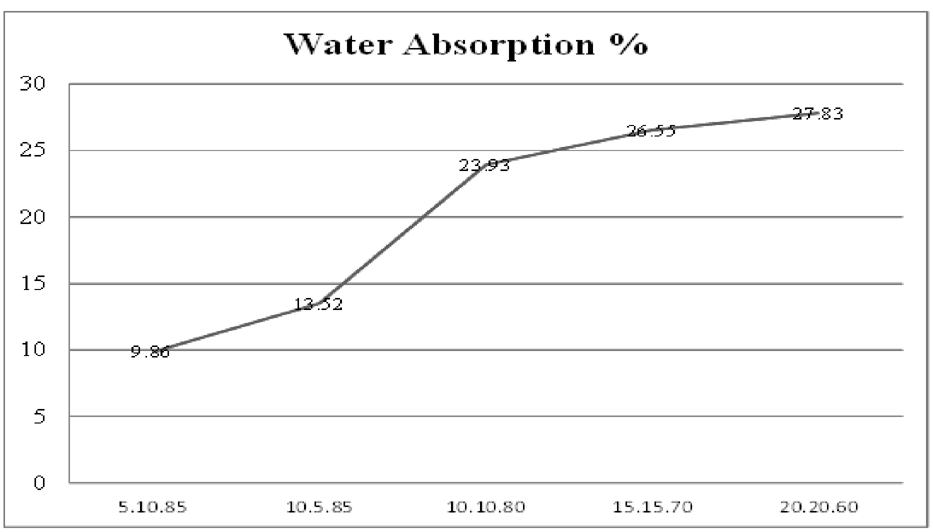


Figure 5.2 : Graph of water absorption.

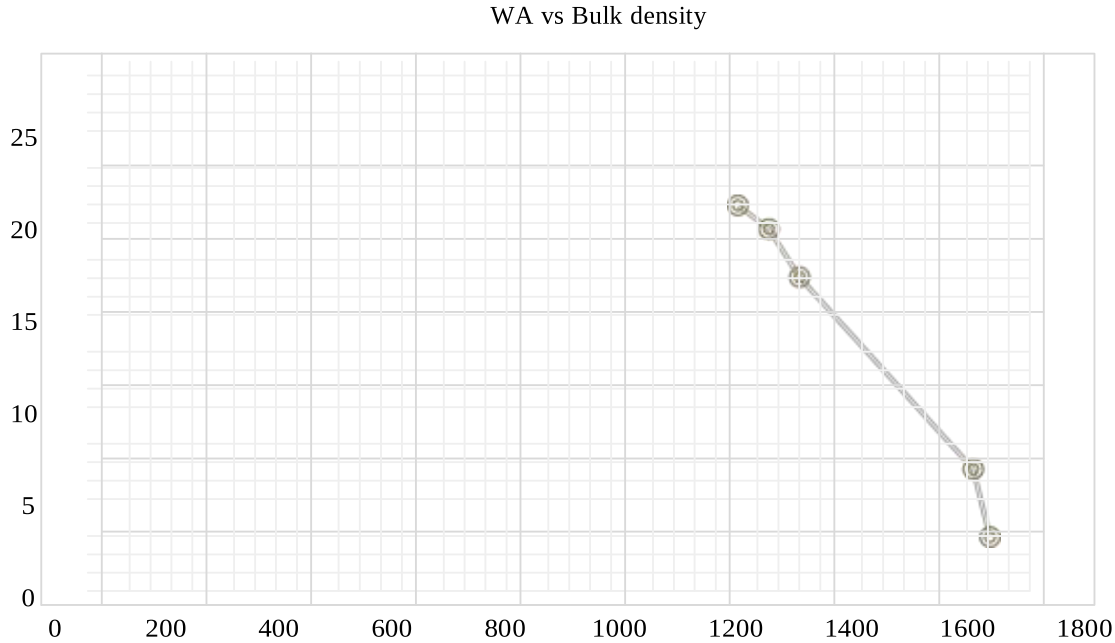


Figure 5.3: Graph of water absorption vs bulk density.

Discussion:

The hygroscopic capacity of the water hyacinth-cement composite increases with the increase in water hyacinth particles. Also, the density of the specimen is indirectly proportional water absorption capacity. The hygroscopic nature of plant fibres is responsible for the low density and high-water absorption capacity of the proposed composite specimen. With 5% difference in staple and pulp content increases the water absorption capacity by 27%. Hence, more water absorption in noted in the specimens with more water hyacinth particles. This may be due to the spongy and porous nature of the staple fiber particles. Decrease in cement content and increase in water hyacinth particles, decreases bulk density and increases the water absorption of the specimen.

Flexural Strength:

Proportion (P:S:C)	5:10:85	10:5:80	10:10:80	15:15:70	20:20:60
Modulus of rupture (MPa)	0.76	0.78	0.62	0.58	0.54

Table 5.4: Result of Flexural strength.

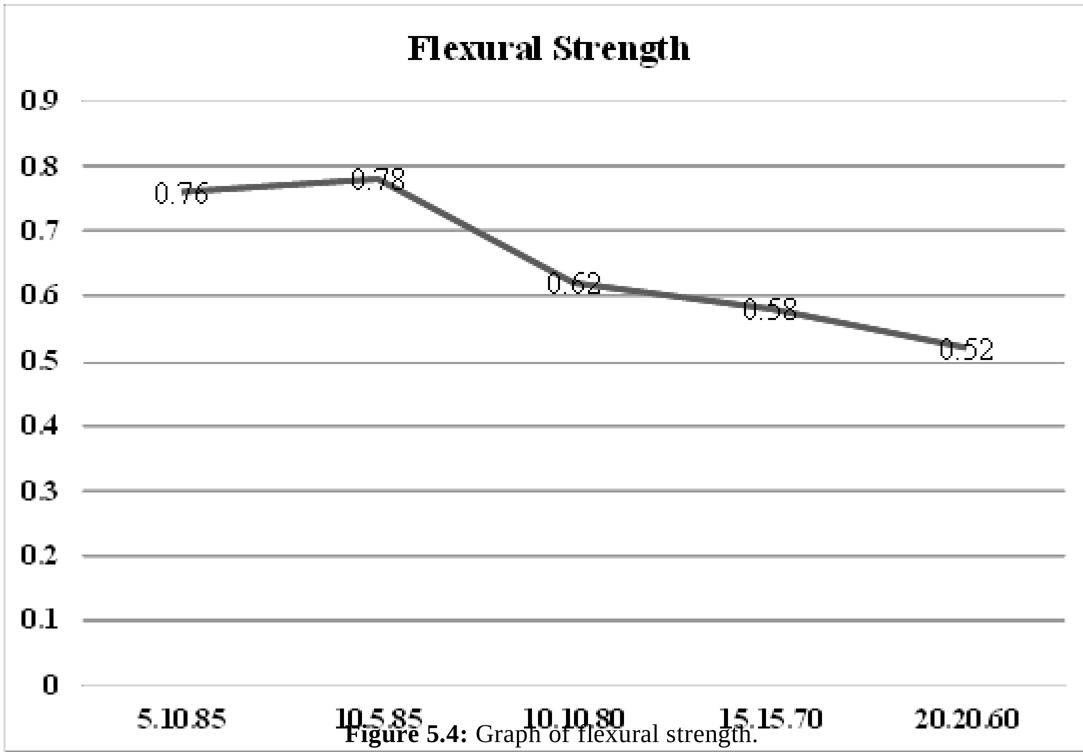


Figure 5.4: Graph of flexural strength.

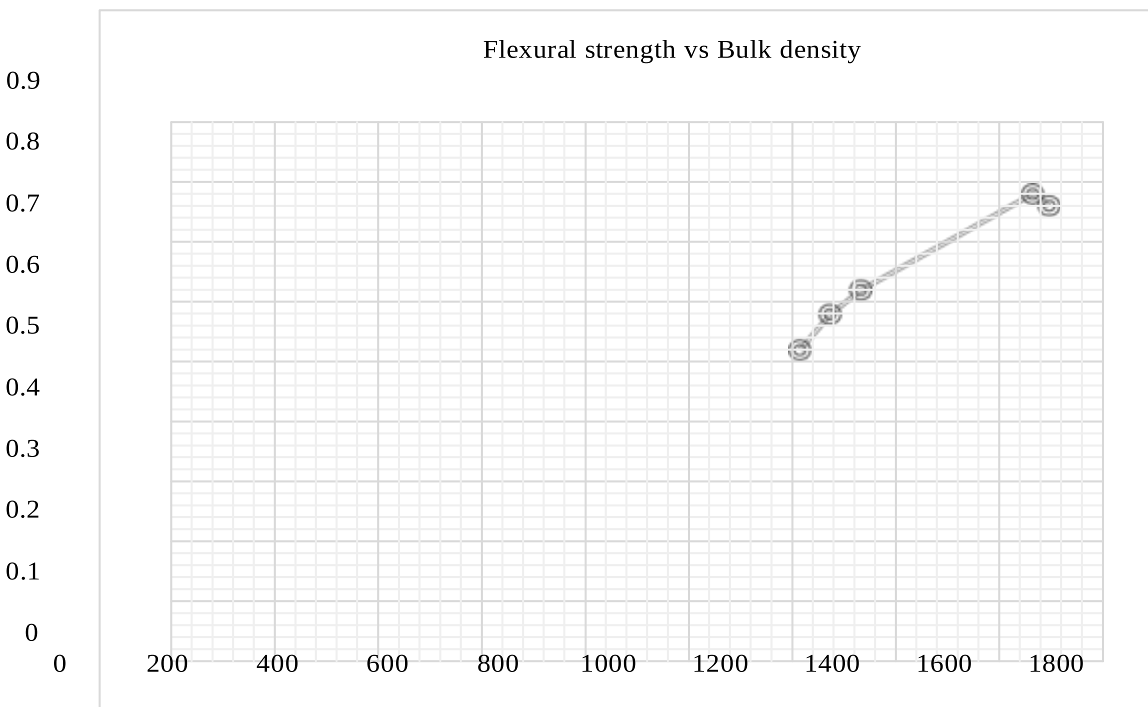


Figure 5.5: Graph of Flexural strength vs Bulk density.

Discussion:

The decrease in modulus of rupture value indicates the decrease in bending strength of the specimen. If the number of staple particles increases, flexure increases. Decrease in density of the specimen decreases the flexural strength. Flexural strength of the specimen increases with increase in water hyacinth particles. Increase in water hyacinth particles increases voids in the specimen, thereby reducing strength of the specimen. The values reduce from 0.76MPa to 0.52MPa with increase in water hyacinth particles. Increase in water hyacinth decreases bulk density and decreases flexural strength. Thus, flexural strength is found to be directly proportional to bulk density.

Thermal Conductivity Test:

Proportion (P:S:C)	5:10:85	10:5:80	10:10:80	15:15:70	20:20:60
Thermal Conductivity (W/mK)	0.145	0.146	0.143	0.139	0.136

Table 5.5: Result of thermal conductivity.

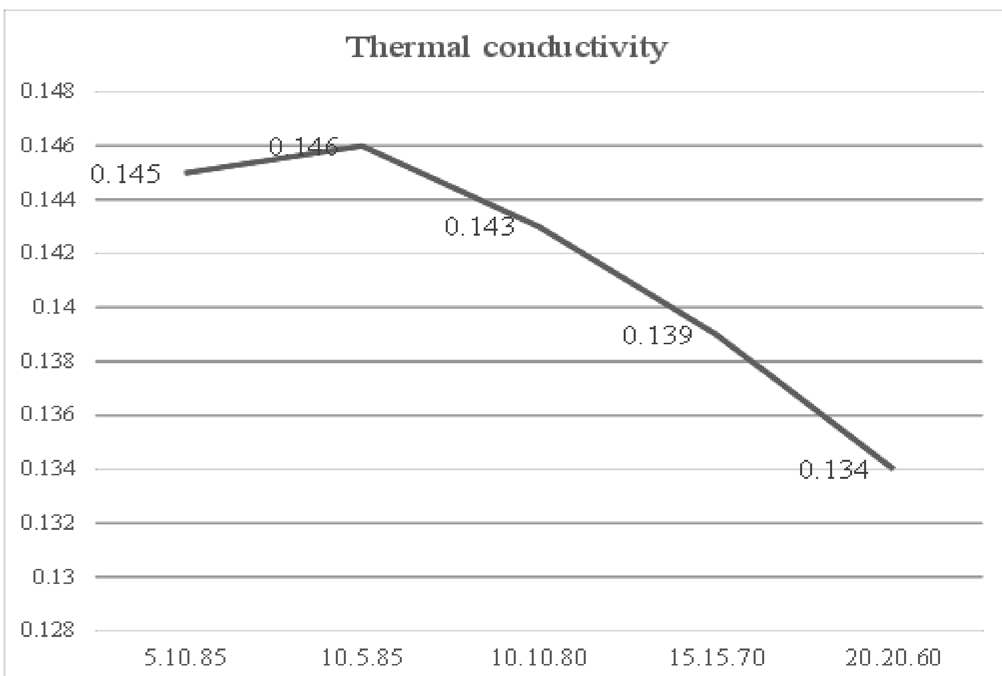


Figure 5.6: Graph of thermal conductivity

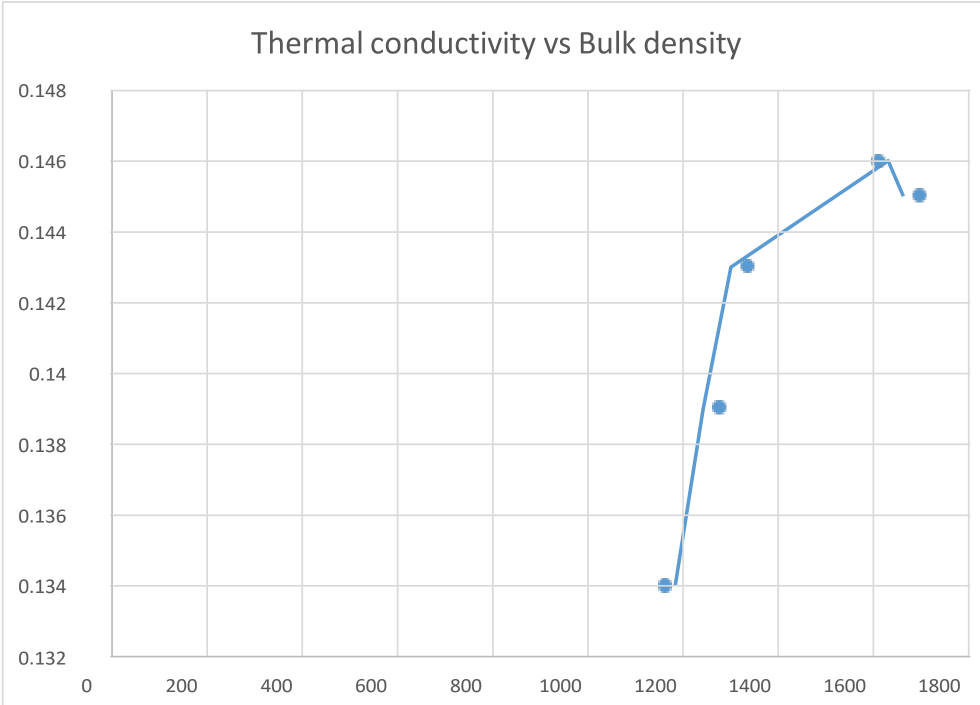


Figure 5.7 Graph of thermal conductivity vs bulk density

Discussion:

Thermal conductivity value decreases with increase in water hyacinth plant.
Main reason for the decline in the values is the spongy nature of the water hyacinth petioles. We know that thermal conductivity is inversely proportional to thermal insulation. Thus, higher the water hyacinth particles, higher will be the thermal insulation. Here, the second graph shows that the thermal conductivity is directly proportional to the bulk density of the specimen. The thermal conductivity of a tile made of cement paste is 1 W/mK. The results obtained in this experiment ranges from 0.145 W/mK to 0.134 W/mK for various proportions which is appreciably low. This clearly shows that the specimen added with water hyacinth particles insulates heat appreciably

Conclusion:

- Incorporating a higher percentage of water hyacinth in the cement brick composition increases its water absorption capacity. The provided ratio of 20:20.60 suggests the highest absorption capacity observed. This value is 27.83% greater compared to the ratio of 5:10:85.
- The values of the thermal conductivity test indicate that the addition of water hyacinth to cement reduces the thermal conductivity of the specimen to a great extent.
- The ratio 5:10:85 is 28% higher the water absorption and lower the bulk density
- The thermal conductivity value of 20:20:60 was observed as 86% lesser than the thermal conductivity value of cement. Hence, it can be used as thermal insulation.
- The flexural strength of ratio 5:10:85 is 0.76Mpa was observed. bulk density is directly proportional to flexural strength; thus, the bulk density will increase.

- For the best use of water hyacinth brick **20:20:60 ratio** is best for thermal insulation, high water absorption and low flexural strength. It can be best thermal insulation property material.
- **Further studies can be made to increase its strength** and to reduce its water absorption capacity.

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