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Study on thermal conductivity of fiber-reinforced light weight concrete using natural fibers

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ABSTRACT

Light weight concrete has lower thermal conductivity and lower coefficient of thermal expansion. This project aims to develop an Eco-friendly thermally insulated light weight concrete by using fibers. Hemp and sisal are natural fibers which plays a major role in the reduction of thermal conductivity. Vermiculite is a naturally available material which can be used for light weight concrete furthermore provides good thermal insulation. Reducing the thermal conductivity by adding fibers in different proportions (1%,1.5%,2%) in a concrete where Vermiculite is partially replaced with fine aggregate and Fly ash is partially replaced with cement in which it shows reduction in thermal conductivity and also it can be used for light weight concrete. The thermal conductivity of the concrete is tested for different mix proportions. Then the mechanical property and durability of the concrete are tested for different proportions. The thermal conductivity of the fiber reinforced light weight concrete is tested and the results shows that when the amount of fiber increased the thermal conductivity is low. Thus, the low thermal conductivity is obtained by natural fibres. The mechanical strength of the different proportions of mixes are carried out and results shows that the increase in fiber reduces the strength. The plate and wall panel are analyzed in Abaqus for the control mix and low thermal conductivity fiber reinforced light weight concrete mix which gives the minimum thermal conductivity and appropriate strength. The results from these experiments are found out that the natural fibers and vermiculite can be a good solution for thermally insulated Eco-friendly building construction.

Keywords— Thermal conductivity, Natural fibres, hemp fiber, sisal fiber, vermiculite, fly ash, fiber reinforced concrete, light weight concrete

1. INTRODUCTION

In the past few decades have seen the development of construction and to reduce the energy eco-friendly construction is carried out, in order to protect the environment. In this context, this paper proposes a new insulation material based on natural fibres from renewable sources, as well as a higher level of availability at the national level. With the increase in the population of the world in the past few years, the demand for the improvement of the standard of living of the majority of these people has also increased, there is a strong demand for new apartment buildings, and improvements to the existing housing stock in the next few years, which in turn leads to an increase in the use of limited resources, and an increase in the level of greenhouse gas emissions. In this regard, there is a great need of insulation materials with low thermal conductivity as well as the required strength of the concrete.

Thermal insulation, concrete, materials or combinations of materials that will be used to provide resistance to the flow of heat, it must have a low thermal conductivity, for use in the construction industry, representing a temperature gradient, have a significant influence on the heat exchange between the interior of the building and the surrounding area. The thermal properties of concrete can be defined as the effect of the heat and the high temperature of the concrete. The thermal conductivity is a measure of the thermal conductivity and capacity of the concrete. watt per meter kelvin is a unit of measurement of the thermal conductivity. In order to be considered an insulating layer, a layer in the structure of a building element must have a thermal conductivity of less than 0.065 (W/mK)[4].

Fiber-reinforced concrete, it is designed to reduce the density of the concrete, and improve the fire resistance, thermal conductivity, and absorption of energy. Fiber-reinforced concrete, that is used mainly to cover the cracks that develop in the concrete, and the increase of the plasticity of the concrete elements. Natural fibers have a lower density (1.2–1.6 g/cm³) than that of glass fiber (2.4 g/cm³), which ensures the production of lighter composites [10]. Bast fibres can fulfil the main function of the

insulation because of their porous structure and the low bulk density of the fibre leading to trapping of a large amount of air between the fibres in the insulation [3]. Natural fibres can be produced at a low cost and low power levels, the use of local labour, and technology. In addition, the increase of the fiber content increases, the porosity of the concrete, so that the thermal conductivity can be reduced by the addition of fibers. The influence of fiber content and temperature on specific heat capacity of composite was similar as the thermal conductivity [11].

The utilization of naturally available vermiculite (light weight material) is a good source of construction material which can be used effectively [8]. vermiculite can be used in light weight concrete and plaster for its good thermal insulation, fire resistance and good sound insulation[1]. Thus, a fiber-to-light reinforced concrete, was made using a natural fibre with a partial replacement of vermiculite, and to obtain a heat-insulation. The thermal properties of concrete can be improved by increasing the porosity, so that the foam is to be used for the enhancement of the thermal conductivity, as well as the reduction of the weight of the concrete. The small size and uniform pore size allow you to increase the stability of the foam, thus allowing the improvement of the thermal insulation of the thermal conductivity for all of these mixtures, as well as the representation of the heat and with the help of the software (ABAQUS 6.4.1). Abaqus, a commercial finite element analysis is a complex one. It is used to solve the highly non-linear, transient, dynamic and quasi-static analyses, as well as thermal analysis.

2. MATERIALS AND METHODS

2.1 Materials

Materials that are utilized in concrete should be tested as per relevant standards in order to attain better performance, quality, and durability. Various test has been conducted as per Indian standards on Cement, fine aggregate, and their physical and chemical properties were analysed. Quality of the binding property in cement depends on its composition and the fineness. OPC 53 grade cement is used for this study as it is the most preferred building and construction material which can improve the tensile strength. Specific gravity and fineness property of cement are calculated. Fly ash is used as the partial replacement of cement in which same as the cement the specific gravity and fineness property are measured. FA showed the maximum reduction of thermal conductivity at 30% replacement [9]. Fine aggregate is an inert granular material which is considered as an essential ingredient of a concrete. size and shape of the aggregate greatly influences the properties of the concrete. Physical properties are defined as their fineness modulus of M-Sand, Specific gravity, water absorption and bulk density of M-Sand. Vermiculite is partially replaced with M-Sand where the ratio of exfoliated vermiculite aggregate to the concrete and the vermiculite grade can be varied to the properties such as strength and insulation as required for the concrete. Mortars produced using expanded vermiculite aggregate shows a good performance in terms of preservation of mechanical strength to elevated temperature [2]. Water absorption of mortar was increased when the expanded vermiculite dosage as partial sand replacement was increased [5]. The physical properties of M-Sand are also calculated. Hemp fibre and sisal fibre are used in the concrete with different proportions as 1%,1.5%,2%. As hemp wool is an excellent insulator, it can be applied as an environmentally friendly insulation material. Hemp has a true potential to reduce greenhouse gases emissions. Lignin in hemp fibers begins to decompose at 160°C and continues to decompose up to 400°C[6]. Sisal fiber is used as a reinforcing natural fiber for building materials. Sisal fibres are composed of three main constituents: cellulose, hemicellulose, and lignin. The quantity of lignin contents in the plant fibers provides a thermal barrier [7].



Chart-1: Vermiculite



Chart-2: Sisal Fiber



Chart-3: Hemp Fiber

Table 1: Properties of Cement

Parameters	Results
Specific gravity of cement	2.92
Standard consistency	32 %

Table 2: Properties of Fly Ash

Parameters	Results
Specific gravity of fly ash	2.22
Standard consistency	29 %

Table 3: Properties of M-Sand

Parameters	Results
Specific gravity of M-Sand	3.19
Fineness modulus	4.60
Water Absorption	0.45%
Bulk Density	2010.60 Kg/m ³

Table 4: Properties of vermiculite

Parameters	Results
Specific gravity of Vermiculite	5.04
Fineness modulus	1.20
Water Absorption	4.83%
Bulk Density	680.80 Kg/m ³

2.2 Mix Proportions

Mix proportions are calculated and the results are tabulated and it is calculated using IS code

2.2.1 Mix proportions of concrete without vermiculite

Table 5: Mix proportions without vermiculite

Design parameters	Results
Target mean strength	15 N/mm ²
Water cement ratio	0.5
Water content	165 kg/m ³
Cement content	231 kg/m ³
Fly Ash content	99 kg/m ³
Fine aggregate content	2215.13 kg/m ³
Admixture content	3.6 kg/m ³
Materials for 6 cube (150mm x 150mm x 150mm)	Cement 5.61 kg Fly ash 2.406 kg Fine aggregate 53.82 kg Water 4.01 kg Admixture 0.087 kg
Materials for 6 cylinder diameter – 150mm; height -300 mm	Cement 8.81 kg Fly ash 3.78 kg Fine aggregate 84.52 kg Water 6.3 kg Admixture 0.137 kg
Materials for 1 plate 300mm x 300mm x 25mm	Cement 0.062 kg Fly ash 0.26kg Fine aggregate 5.98 kg Water 0.44 kg Admixture 0.010 kg

2.2.2 Mix proportions of concrete with vermiculite

Table 6: Mix proportions without vermiculite

Design parameters	Results
Target mean strength	15 N/mm ²
Water cement ratio	0.5
Water content	165 kg/m ³
Cement content	231 kg/m ³
Fly Ash content	99 kg/m ³
Fine aggregate content	2082.22 kg/m ³
Vermiculite content	49.99 kg/m ³
Admixture content	3.6 kg/m ³
Materials for 6 cube (150mm x 150mm x 150mm)	Cement 5.61 kg Fly ash 2.406 kg Fine aggregate 50.59 kg Vermiculite 1.21 kg

	Water	4.01 kg
	Admixture	0.087 kg
Materials for 6 cylinder diameter – 150mm; height -300 mm	Cement	8.81 kg
	Fly ash	3.78 kg
	Fine aggregate	79.45 kg
	Vermiculite	1.90
	Water	6.3 kg
	Admixture	0.137 kg
Materials for 1 plate 300mm x 300mm x 25mm	Cement	0.062 kg
	Fly ash	0.26kg
	Fine aggregate	5.62 kg
	Vermiculite	0.134
	Water	0.44 kg
	Admixture	0.010 kg

2.3 Casting of the specimens

For the purpose of determining the compressive strength and tensile strength of the light weight fibre reinforced concrete, cube specimens of 150mm x 150mm x 150mm and cylinder specimens of 150mm diameter with a height of 300mm is casted. Compression test and split tension test are conducted on the specimens for 7 days and 28 days. Thermal conductivity test is carried out with the square plate specimen of dimension 300mm x 300mm with the thickness of 25mm. The specimens are casted in the casting yard using the mix design and replacement percentages of fibre by following steps:

Preparation of the mould, mixing, pouring of concrete, compaction of concrete, demoulding and curing.

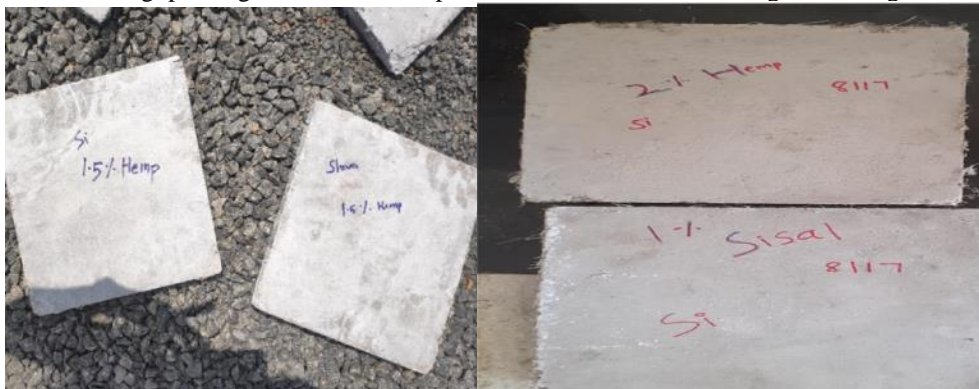


Chart 4: De-moulded specimen

2.4 Test Method

2.4.1 Thermal Conductivity Test

Thermal conductivity invokes to the intrinsic ability of a material to transfer or conduct heat. Heat propels along a temperature gradient, from an area of high temperature to an area with a lower temperature. This transfer will continue until thermal equilibrium is landed. There are two methods in thermal conductivity test they are steady state method and transient method.

2.4.1.1 Heat Flow Meter: The thermal conductivity is dogged by means of heat flow meters (HFM) with the plate technique for insulators. HFM 446 *Lambda Eco-Line* is a new standardized method for the evaluation of thermal conductivity.

2.4.1.2 Procedure: Sample for testing the thermal conductivity is located in the socket (between top and bottom hot plate).A temperature gradient is set between two plates through the material to be measured. By means of two highly definite heat-flow sensors in the plates. To measure the flow of heat that enters and exits the material, respectively. If the state of equilibrium of the system is reached and the heat flow is constant, the thermal conductivity can be computed and displayed.

2.4.1.3 Thermal Conductivity Test Results

Table 7: Thermal Conductivity Values

Mix	Mix proportions	Thermal conductivity (w/mk)	Thermal resistance
M1	Control mix	0.265	0.094
M2	6% of vermiculite	0.232	0.107
M3	M2 + 1% HF	0.221	0.113
M4	M2 + 1.5 % HF	0.217	0.114
M5	M2 + 2% HF	0.157	0.158
M6	M2 + 1% SF	0.182	0.136
M7	M2 + 1.5 % SF	0.178	0.140
M8	M2 + 2% SF	0.161	0.155

Table 7: shows that the thermal conductivity of the specimen, shows average results of control mix along with the 6% vermiculite and fibres of 1%, 1.5%, 2%.

2.4.2 Compression Strength Test

Compression strength is one of the most important and useful test for concrete. concrete is employed to resist compressive strength. The compressive strength is used estimate the required strength.

Compressive Strength Results:

Table-8: Compressive Strength values

Mix	Mix proportions	Compressive strength (N/mm ²)								Compressive strength (N/mm ²)
		7 days				28 days				
		Cube 1	Cube 2	Cube 3	avg	Cube 1	Cube 2	Cube 3	avg	
M1	Control mix	4.11	4.08	4.39	4.19	9.37	9.14	9.77	9.42	9.42
M2	6% of vermiculite	4.11	3.67	4.02	3.63	4.91	6.88	7.64	7.64	7.64
M3	M2 + 1% HF	4.51	4.27	5.49	5.09	11.66	11.56	12.58	11.93	11.93
M4	M2 + 1.5 % HF	5.34	3.93	4.64	4.63	11.92	10.39	10.95	11.08	11.08
M5	M2 + 2% HF	4.09	4.98	3.98	4.35	10.17	11.42	10.46	10.68	10.68
M6	M2 + 1% SF	5.06	4.02	3.33	4.13	10.42	11.11	11.29	10.94	10.94
M7	M2 + 1.5 % SF	4.27	4.76	4.89	4.64	9.42	10.55	10.2	10.05	10.05
M8	M2 + 2% SF	3.23	4.36	4.22	3.93	10.64	10.07	9.12	9.94	9.94

Table 8: shows that the compressive strength of the specimen, shows average results of control mix along with the 6% vermiculite and fibres of 1%, 1.5%, 2%.

2.4.3 Tensile Strength Test

The tensile strength of the concrete is dogged by indirect test method (split cylinder test) due to difficulty in employing uniaxial tension to a concrete specimen. Moreover, the concrete is very weak in tension due to its fragile nature. In this respect, therefore, it will not withstand a direct tension.

Table 9: Tensile strength values

Mix	Mix proportions	Tensile strength (N/mm ²)								Tensile strength (N/mm ²)
		7 days				28 days				
		Cylinder 1	Cylinder 2	Cylinder 3	avg	Cylinder 1	Cylinder 2	Cylinder 3	avg	
M1	Control mix	1.31	1.0	1.04	1.11	1.83	1.96	1.45	1.78	1.78
M2	6% of vermiculite	0.74	1.07	0.96	0.92	1.09	1.50	1.35	1.58	1.58
M3	M2 + 1% HF	1.47	1.15	1.63	1.41	2.40	1.84	2.45	2.23	2.23
M4	M2 + 1.5 % HF	1.59	1.10	1.15	1.28	1.86	2.49	1.69	2.05	2.01
M5	M2 + 2% HF	1.31	1.15	1.10	1.18	2.41	1.56	1.72	1.89	1.89
M6	M2 + 1% SF	0.81	1.08	1.20	1.03	2.27	1.97	2.0	2.08	2.08
M7	M2 + 1.5 % SF	1.16	0.95	0.92	1.01	1.62	1.73	1.86	1.73	1.73
M8	M2 + 2% SF	1.04	1.23	0.70	0.99	1.45	1.72	1.04	1.40	1.40

Table 9: shows that the tensile strength of the specimen, shows average results of control mix along with the 6% vermiculite and fibres of 1%, 1.5%, 2%.

2.4.4 Density

The density of concrete is a evaluation of concretes solidity and it is the mass per unit volume, it bank on the type of concrete, typical properties of the concrete’s material. here it is a lightweight concrete. Hence density of the concrete can be in the range of 320 to1920kg/m³ as per ACI 213,2001.

Table 10: Density of The Specimens

Mix	Mix proportions	Density (kg/m ³)			
		Cube 1	Cube 2	Cube 3	Avg
M1	Control mix	1934.81	1914.07	1988.14	1945.67
M2	6% of vermiculite	1899.25	1857.77	1831.11	1862.71
M3	M2 + 1% HF	1931.85	1955.55	1848.88	1912.09
M4	M2 + 1.5 % HF	1905.18	1920	1928.88	1918.02
M5	M2 + 2% HF	1925.92	1946.66	1869.29	1914.06
M6	M2 + 1% SF	1810.37	1762.96	1638.51	1737.28
M7	M2 + 1.5 % SF	1922.96	1697.77	1780.74	1800.49
M8	M2 + 2% SF	1902.22	1703.70	1721.48	1907.15

Table 10: shows that the density of the specimens, shows average results of control mix along with the 6% vermiculite and fibres of 1%, 1.5%, 2% mixes.

2.4.5 Water Absorption Test

Absorption testing is a famous method of determining the water-tightness of concrete. Method for Determination of Water Absorption, measures the amount of water that permeates into concrete samples when submersed.

Table-11: water absorption values

Mix	Mix proportions	Water absorption test									
		Wet weight			Dry weight			Water absorption			
		Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Avg
M1	Control mix	6.67	6.6	6.9	6.53	6.46	6.71	2.14	2.16	2.83	2.37
M2	6% of vermiculite	6.64	6.65	6.324	6.41	6.27	6.18	3.58	6.06	2.33	3.99
M3	M2 + 1% HF	6.76	7.05	6.43	6.52	6.67	6.24	3.68	5.69	3.04	4.22
M4	M2 + 1.5 % HF	6.79	6.83	6.59	6.43	6.48	6.31	5.5	5.40	4.43	5.11
M5	M2 + 2% HF	6.93	6.97	6.52	6.5	6.57	6.32	6.61	6.08	3.16	5.28
M6	M2 + 1% SF	6.23	6.07	5.92	6.11	5.95	5.53	1.96	2.01	7.05	3.67
M7	M2 + 1.5 % SF	6.71	6.01	6.26	6.5	5.73	6.01	3.23	4.88	4.15	4.08
M8	M2 + 2% SF	6.53	6.06	6.11	6.33	5.75	5.81	3.1	5.3	5.16	4.52

Table 11: shows that the water absorption of the specimens, shows average results of control mix along with the 6% vermiculite and fibres of 1%, 1.5%, 2% mixes.

3. ANALYTICAL STUDY

A steady-state coupled temperature-displacement analysis can be performed in ABAQUS (Standard). In steady-state case, it is convenient for changing loads and boundary conditions of the material through the step and for obtaining the definite solutions. By default, the initial temperature of all nodes is zero. Modelers can specify nonzero initial temperatures. Boundary conditions can be used to prescribe both temperatures and displacements at nodes in fully coupled thermal-stress analysis. The materials in a fully coupled thermal-stress analysis must have both thermal properties, such as conductivity, and mechanical properties, such as elasticity. The various steps involved in finite element analysis are modelling of the wall element, material assignment, section assignment ,step, boundary condition ,heat flux, mesh and job . then the analysis results are displayed after these steps. The plate and wall panel for the control mix and the minimum thermal conductivity mix proportion are analyses using ABAQUS software.

Control Specimen

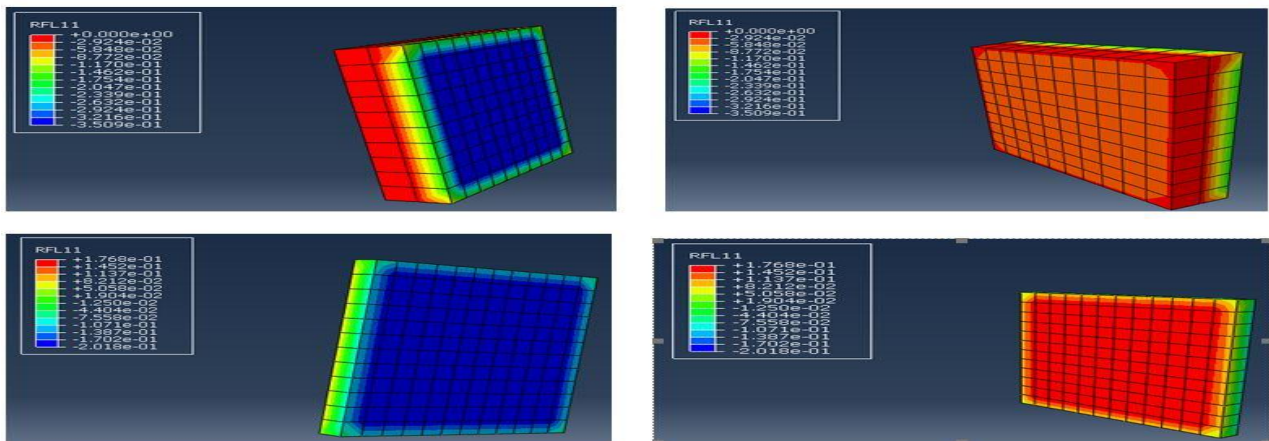


Chart 5: Heat Transfer Analysis for Control Specimen

2% HEMP FIBRE

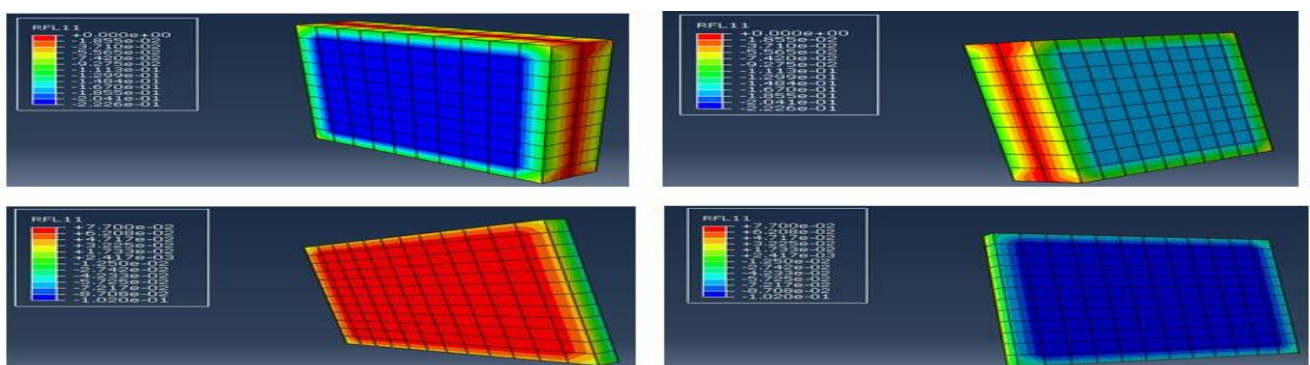


Chart 6: Heat Transfer Analysis for MIX 5 (2% Hemp fibre)

4. RESULTS AND DISCUSSION

4.1. Comparison between Hemp and Sisal fibres

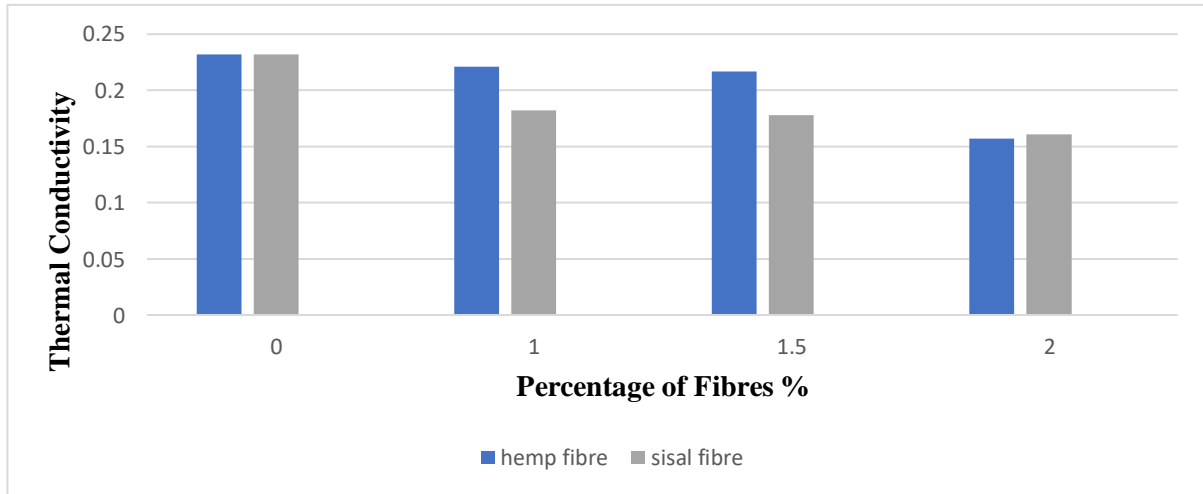


Chart 7: Bar graph Showing comparison between Thermal conductivity of fibres

Chart 7: shows the comparison between the thermal conductivity of hemp and sisal fibres, from the results it is clearly shows that the 2% of hemp and sisal fibre has the low thermal conductivity in which the 2% of hemp has the minimum thermal conductivity.

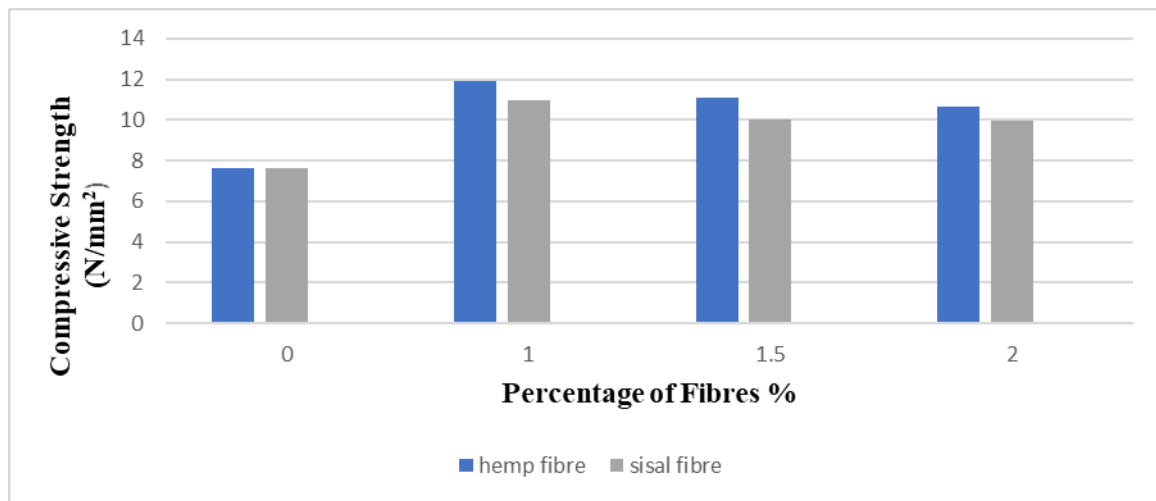


Chart 8: Bar graph Showing comparison between compressive strength of fibres

Chart 8: shows the comparison between the compressive strength of hemp and sisal fibres, from the results it is clearly shows that the reduction in the fibre content improves the strength. In which the 1% hemp has more strength when compare to other proportions and the mix with vermiculite has the lowest strength by this it determines the strength is slightly increased when fibre is added.

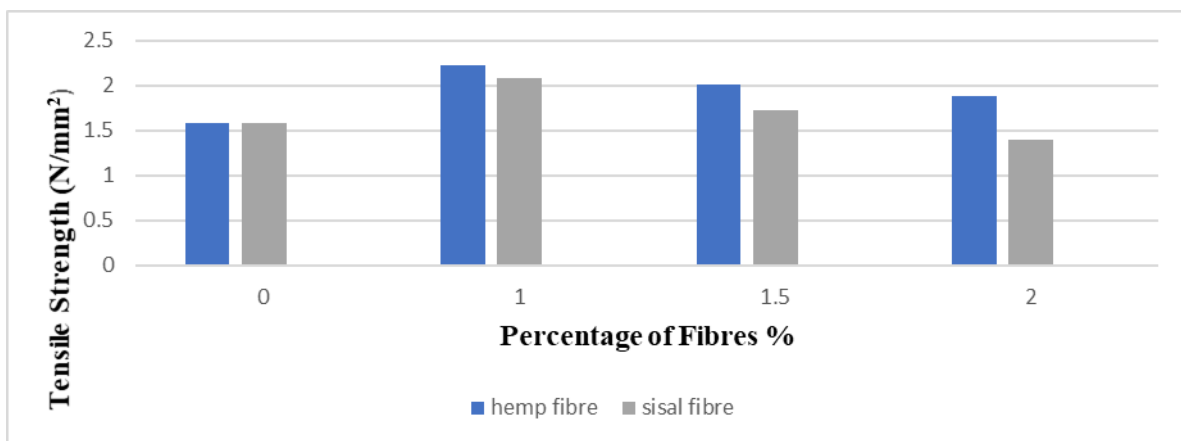


Chart 9: Bar graph Showing comparison between tensile strength of fibres

Chart-9: shows the comparison between the tensile strength of hemp and sisal fibres, from the results it is clearly shows that the reduction in the fibre content improves the strength. In which the 1% hemp has more strength when compare to other proportions

and the mix with vermiculite has the lowest strength by this it determines the tensile strength is slightly increased when fibre is added.

5. CONCLUSION

- The conclusions obtained have been got from the study proves that the low thermal conductivity is obtained in fibre reinforced light weight concrete.
- The thermal conductivity of the fibre reinforced light concrete is tested and the results shows that when the amount of fibre increased the thermal conductivity is low. Thus the 2% of hemp fibre mix shows the very low thermal conductivity when compared to other mixes.
- The compressive strength and tensile strength of the different proportions mixes are carried out and results shows that the increase in fibre reduces the strength.
- Water absorption test is done as the durability test and the resultant values shows that they are based on the amount of vermiculite and fibres added.
- The comparison is carried out with the normal light weight concrete and fibre reinforced light weight concrete, where the fibre reinforced light weight concrete as the low thermal conductivity.
- Two wall panels for normal light weight concrete and 2% hemp fibre reinforced light weight concrete are designed in ABAQUS and the heat transfer is studied which are relatable to experimental study.
- Therefore, these materials vermiculite and fibres which is obtained as naturally available material can be used for low thermal conductivity concrete and therefore, they can be considered as eco-friendly and low-cost construction materials.

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