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Thermal conductivity study of fiber-reinforced light weightconcreteusing natural fibers

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

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

I. INTRODUCTION

In the past few decades have seen the development of construction and to reduce the energy eco-friendly construction is carriedout, in order to protect the environment. In this context, this paper proposes a new insulation material based on natural fibres fromrenewable sources, as well as a higher level of availability at the national level. With the increase in the population of the world inthe 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 fornew 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 thisregard,there isa greatneedofinsulationmaterialswith lowthermal conductivityaswellastherequired strengthoftheconcrete.

Thermal insulation, concrete, materials or combinations of materials that will be used to provide resistance to the flow of heat, itmust have a low thermal conductivity, for use in the construction industry, representing a temperature gradient, have a significantinfluence on the heat exchange between the interior of the building and the surrounding area. The thermal properties of concretecan be defined as the effect of the heat and the high temperature of the concrete. The thermal conductivity is a measure of thethermal conductivity and capacity of the concrete. watt per meter kelvin is a unit of measurement of the thermal conductivity. Inorder to be considered an insulating layer, a layer in the structure of a building element must have a thermal conductivity of lessthan0.065(W/mK)[4].

Fiber-reinforcedconcrete,itisdesignedtoreducethedensityoftheconcrete,andimprovethefireresistance,thermalconductivit y, and absorption of energy. Fiber-reinforced concrete, that is used mainly to cover the cracks that develop in theconcrete, and the increase of the plasticity of the concrete elements. Natural fibers have a lower density (1.2–1.6 g/cm3) than thatofglassfiber(2.4g/cm3),whichensurestheproductionoflightercomposites[10].Bastfibrescanfulfilthemainfunctionoftheinsulation because of their porous structure and the low bulk density of the fibre leading to trapping of a large amount of airbetween the fibres in the insulation [3]. Natural fibres can be produced at a low cost and low power levels, the use of local labour,andtechnology.Inaddition,theincreaseofthefibercontentincreases,theporosityoftheconcrete,sothatthethermalconductivity can be reduced by the addition of fibers. The influence of fiber content and temperature on specific heat capacity ofcomposite was similaras thethermalconductivity[11].

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

II. MATERIALS AND METHODS

Materials

Materials that are utilized in concrete should be tested as per relevant standards in order to attain better performance, quality, anddurability. Various test has been conducted as per Indian standards on Cement, fine aggregate, and their physical and chemicalproperties were analysed. Quality of the binding property in cement depends on its composition and the fineness. OPC 53 gradecement 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 sameas the cement the specific gravity and fineness property are measured. FA showed the maximum reduction of thermal conductivityat 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 finenessmodulusofM-Sand,Specificgravity,waterabsorptionandbulkdensityofM-Sand.VermiculiteispartiallyreplacedwithM-Sand where the ratio of exfoliated vermiculite aggregate to the concrete and the vermiculite grade can be varied to the propertiessuch as strength and insulation as required for the concrete. Mortars produced using expanded vermiculite aggregate shows a goodperformanceinterms ofpreservationofmechanicalstrengthtoelevatedtemperature[2].Waterabsorptionof mortar wasincreased when the expanded vermiculite dosage as partial sand replacement wasincreased [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 hempwool is an excellent insulator, it can be applied as an environmentally friendly insulation material. Hemp has a true potential toreduce greenhouse gases emissions. Lignin in hemp fibers begins to decompose at 160°C and continues to decompose up to400°C[6].Sisal fiber is used as a reinforcing natural fiber for building materials. Sisal fibres are composed of three mainconstituents: cellulose,hemicellulose,and lignin.The quantity oflignin contentsinthe plantfibersprovidesathermal barrier[7].

Chart-1:Vermiculite

Chart-2:SisalFiber

Chart-3: Hemp Fiber

Table 1:PropertiesofCement

Parameters	Results
Specific gravityofcement	2.92
Standardconsistency	32%

Table2:Properties ofFlyAsh

Parameters	Results
Specific gravityofflyash	2.22
Standardconsistency	29%

Table3:PropertiesofM-Sand

Parameters	Results
SpecificgravityofM-Sand	3.19
Finenessmodulus	4.60
Water Absorption	0.45%
BulkDensity	2010.60Kg/m^3

Table4:Properties ofvermiculite

Parameters	Results
SpecificgravityofVermiculite	5.04
Finenessmodulus	1.20
Water Absorption	4.83%
BulkDensity	680.80Kg/m^3

MixProportions

Mix proportionsarecalculated and theresultsare tabulated anditiscalculated usingIScode

Mixproportionsofconcretewithoutvermiculite

Table 5:Mixproportionswithoutvermiculite

Designparameters	Results
Target mean strength	15N/mm^2
Water cement ratio	0.5
Watercontent	165kg/m^3
Cementcontent	231kg/m^3
Fly Ash content	99kg/m^3
Fine aggregate content	2215.13kg/m^3
Admixture content	3.6kg/m^3
Materialsfor6 cube(150mm x 150mm x150mm)	Cement 5.61kg Flyash 2.406 kgFine aggregate 53.82 kgWater 4.01kg Admixture 0.087kg

Materials for 6 cylinderdiameter–150mm;height-300mm	Cement 8.81kg Flyash 3.78 kgFine aggregate 84.52 kgWater 6.3 kg Admixture 0.137kg
Materials for 1 plate300mmx300mmx25 mm	Cement 0.062kg Flyash 0.26kgFine aggregate 5.98 kgWater 0.44kg Admixture 0.010kg

Mixproportionsofconcretewithvermiculite

Table 6:Mixproportionswithoutvermiculite

Designparameters	**Results**
Target mean strength	15N/mm^2
Water cement ratio	0.5
Water content	165kg/m^3
Cementcontent	231kg/m^3
Fly Ash content	99kg/m^3
Fine aggregate content	2082.22kg/m^3
Vermiculitecontent	49.99kg/m^3
Admixture content	3.6kg/m^3
Materialsfor6 cube(150mm x 150mm x150mm)	Cement 5.61kg Flyash 2.406 kgFineaggregate50.59kg Vermiculite 1.21kg
	WaterAdmixture 4.01kg 0.087kg
Materialsfor6cylinder diameter–150mm; height -300 mm	Cement 8.81kg Fly ash 3.78kg Fine aggregate79.45kg Vermiculite 1.90 Water 6.3kg Admixture 0.137kg
Materialsfor1plate 300mmx300mmx 25mm	Cement 0.062kg Fly ash 0.26kg Fine aggregate5.62kg Vermiculite 0.134 Water 0.44kg Admixture 0.010kg

Castingofthe specimens

For the purpose of determining the compressive strength and tensile strength of the light weight fibre reinforced concrete, cubespecimens 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 carriedout with the square plate specimen of dimension 300mm x 300mm with the thickness of 25mm. The specimens are casted in thecasting yardusingthemixdesignandreplacementpercentages offibre byfollowingsteps:

Preparationofthemould,mixing,pouringofconcrete,compaction ofconcrete,demoulding and curing.

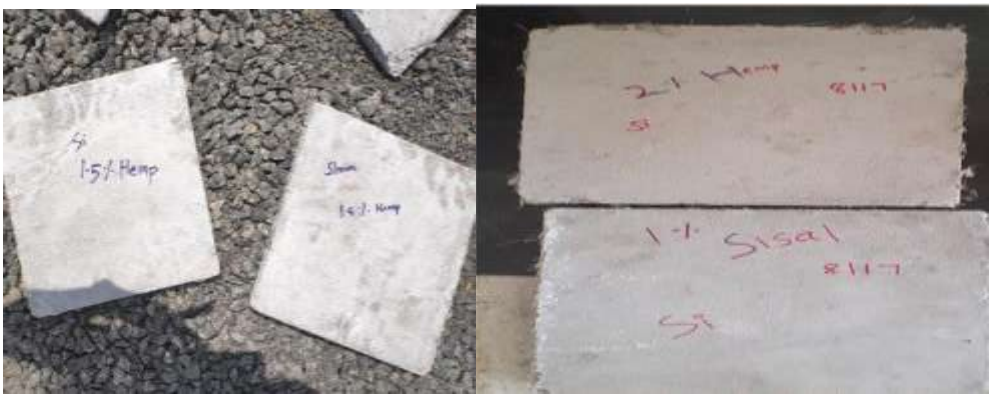

Chart4:De-mouldedspecimen

Test Method
ThermalConductivityTest
Thermal conductivity invokes to the intrinsic ability of a material to transfer or conduct heat. Heat propels along a temperaturegradient, from anareaof high temperature to anareawith alower temperature. Thistransfer will continueuntil thermalequilibrium islanded.There aretwo methodsinthermal conductivity testtheyare steady state method and transient method.

Heat Flow Meter: The thermal conductivity is dogged by means of heat flow meters (HFM) with the plate technique forinsulators.HFM446LambdaEco-Lineis anew standardizedmethod forthe evaluationofthermalconductivity.

Procedure: Sample for testing the thermal conductivity is located in the socket (between top and bottom hot plate).Atemperature gradient is set between two plates through the material to be measured. By means of two highly definite heat-flowsensors in the plates. To measure the flow of heat that enters and exits the material, respectively. If the state of equilibrium of thesystem is reached andtheheatflowis constant,thethermalconductivitycan becomputedand displayed.

ThermalConductivityTestResults

Table7:ThermalConductivityValues

Mix	**Mixproportions**	**Thermalconductivity (w/mk)**	**Thermalresistance**
M1	Controlmix	0.265	0.094
M2	6%ofvermiculite	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

Table7:showsthat thethermal conductivity ofthespecimen,showsaverageresultsofcontrolmixalongwiththe 6%vermiculiteand fibresof1%,1.5%,2%.

CompressionStrengthTest

Compressionstrengthisoneofthemostimportantandusefultestforconcrete.concreteisemployedtoresistcompressivestrength.Thecompressivestrengthis usedestimate therequiredstrength.

CompressiveStrengthResults:

Table-8: CompressiveStrength values

Mix	Mixproportions	Compressive strength(N/mm^2)								Compressivestrength (N/mm^2)
		7 days				28 days				
		Cube1	Cube2	Cube3	avg	Cube1	Cube2	Cube3	avg	
M1	Controlmix	4.11	4.08	4.39	**4.19**	9.37	9.14	9.77	9.42	**9.42**
M2	6%ofvermiculite	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% vermiculiteand fibresof1%,1.5%,2%.

TensileStrengthTest

The tensile strength of the concrete is dogged by indirect test method (split cylinder test) due to difficulty in employing uniaxialtensiontoaconcretespecimen.Moreover,theconcreteisveryweakintensionduetoitsfragilenature.Inthisrespect,therefore,itwillnotwithstandadirecttension.

Table9:Tensilestrengthvalues

Mix	Mixproportions	Tensilestrength (N/mm2)								Tensile strength(N/mm2)
		7 days				28 days				
		Cylinder 1	Cylinder 2	Cylinder 3	avg	Cylinder 1	Cylinder 2	Cylinder 3	avg	
M1	Controlmix	1.31	1.0	1.04	**1.11**	1.83	1.96	1.45	1.78	**1.78**
M2	6%ofvermiculite	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 andfibresof1%,1.5%,2%.

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 of320 to1920kg/m^{3}as perACI213,2001.

Table10:Density ofTheSpecimens

Mix	Mixproportions	Density(kg/m3)			
		Cube1	Cube2	Cube3	Avg
M1	Controlmix	1934.81	1914.07	1988.14	**1945.67**
M2	6%ofvermiculite	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 fibresof1%,1.5%,2%mixes.

WaterAbsorptionTest
Absorption testing is a famous method of determining the water-tightness of concrete. Method for Determination of WaterAbsorption,measurestheamountofwaterthatpermeatesintoconcrete samples when submersed.

Table-11:waterabsorptionvalues

		Waterabsorptiontest									
Mix	Mixproportions	Wetweight			Dryweight			Waterabsorption			
		Cube1	Cube2	Cube3	Cube1	Cube 2	Cube3	Cube1	Cube2	Cube3	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%ofvermiculite	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% vermiculiteand fibres of1%,1.5%,2%mixes.

III. ANALYTICAL STUDY

A steady-state coupled temperature-displacement analysis can be performed in ABAQUS (Standard). In steady-state case, it isconvenientfor changing loads and boundary conditionsof the material through the stepand for obtainingthe definite solutions.Bydefault,theinitialtemperatureofallnodesiszero.Modelerscanspecifynonzeroinitialtemperatures.Boundaryconditionscan be used to prescribe both temperatures and displacements at nodes in fully coupled thermal-stress analysis. The materials in afully coupled thermal-stress analysis must have both thermal properties, such as conductivity, and mechanical properties, such aselasticity. The various steps involved in finite element analysis are modelling of the wall element, material assignment, sectionassignment ,step, boundary condition ,heat flux, mesh and job . then the analysis results are displayed after these steps. The plateandwallpanel forthecontrolmix andtheminimumthermal conductivitymixproportionareanalysesusing ABAQUSsoftware.

ControlSpecimen

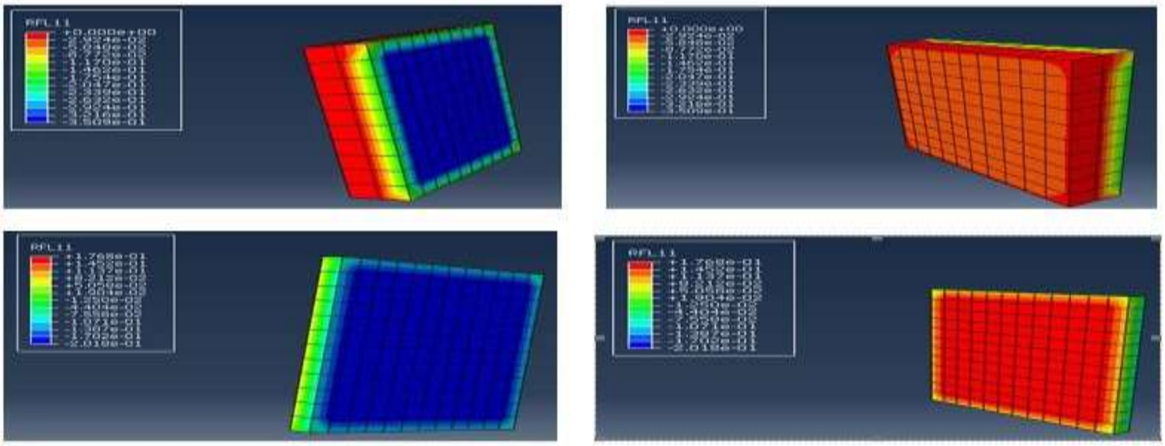

Chart5:HeatTransferAnalysis forControlSpecimen

2%HEMPFIBRE

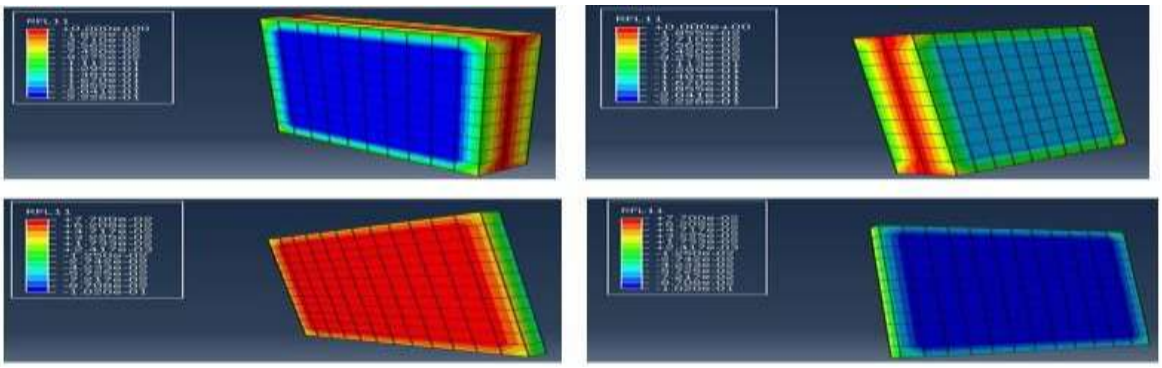

Chart6:HeatTransferAnalysisforMIX 5(2% Hempfibre)

IV. RESULTS AND DISCUSSION

4.1.ComparisonbetweenHempandSisalfibres

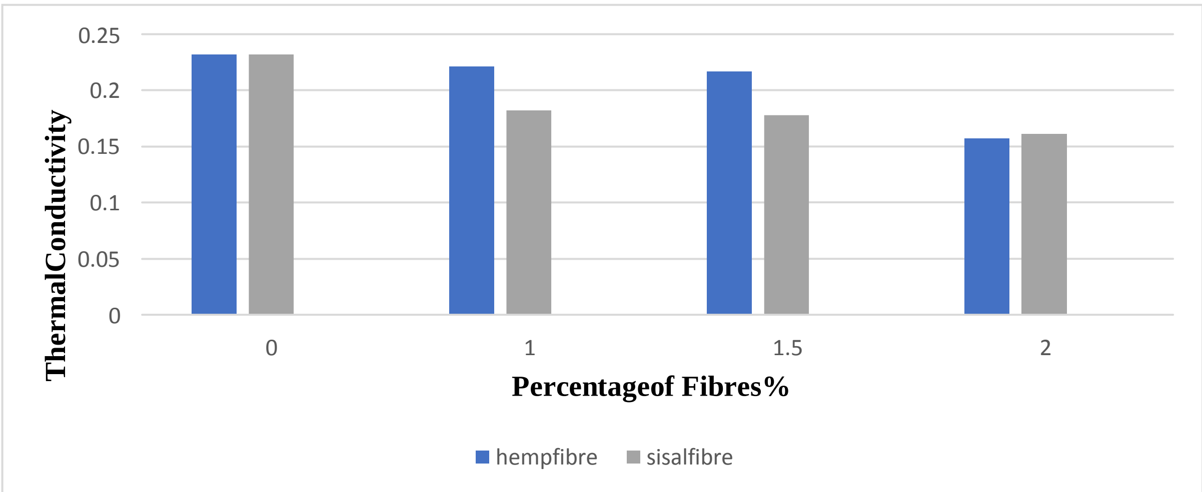

Chart 7:Bargraph Showing comparison between Thermal conductivity of fibres

Chart 7: shows the comparison between the thermal conductivity ofhemp and sisal fibres , from the results it is clearly shows thatthe2%ofhempandsisalfibrehasthelow thermalconductivity inwhich the2%ofhemp hastheminimumthermalconductivity.

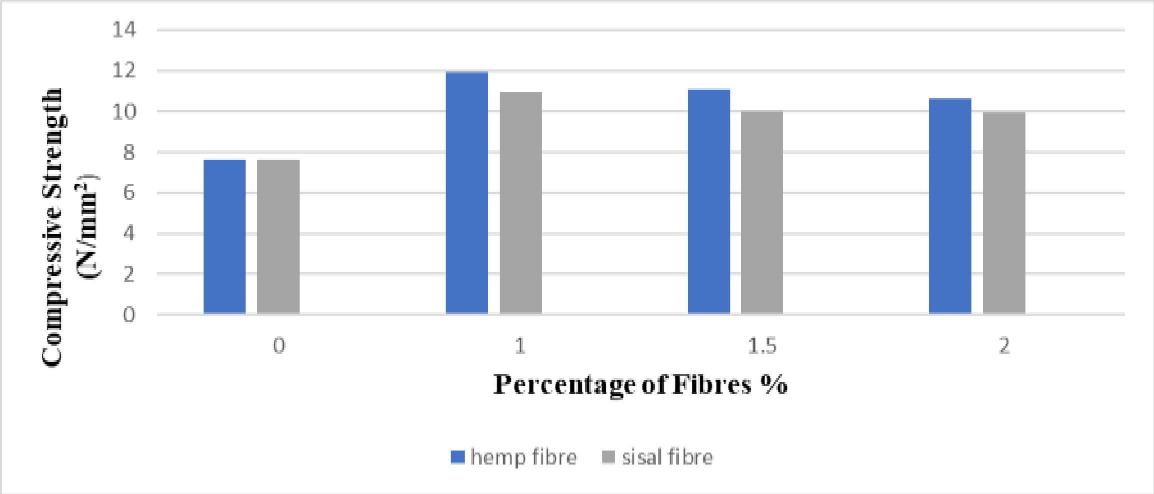

Chart 8:BargraphShowingcomparison betweencompressivestrength offibres

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

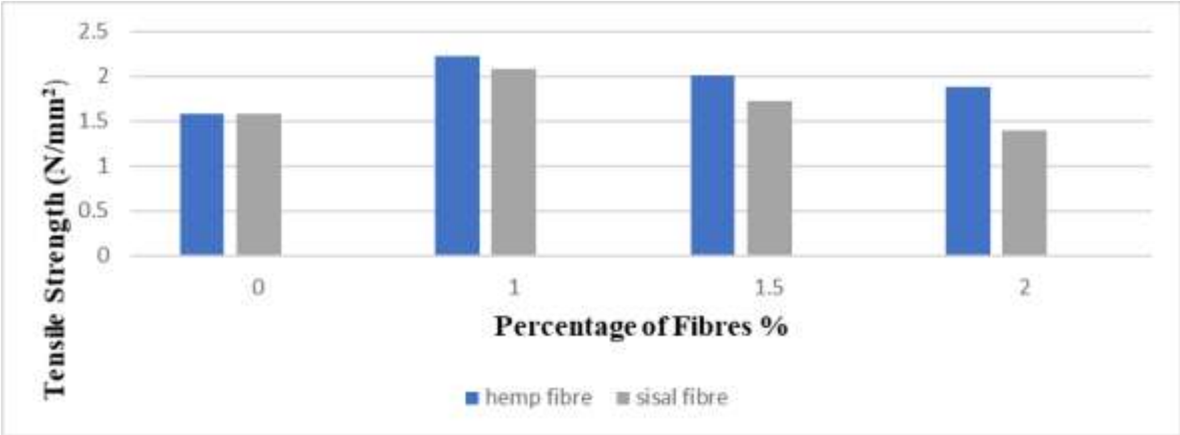

Chart 9:Bargraph Showingcomparisonbetween tensilestrengthoffibres

Chart-9: shows the comparison between the tensile strength of hemp and sisal fibres, from the results it is clearly shows that thereductioninthefibrecontentimprovesthestrength.Inwhichthe1%hemphasmorestrengthwhencomparetootherproportions andthemixwithvermiculitehasthelowest, strengthbythisitdeterminesthetensilestrengthisslightlyincreasedwhenfibre isadded.

V. CONCLUSION

- The conclusions obtained have been got from the study proves that the low thermal conductivity is obtained in fibre reinforcedlightweightconcrete.
- The thermal conductivity of the fibre reinforced light concrete is tested and the results shows that when the amount of fibreincreased the thermal conductivity is low. Thus the 2% of hemp fibre mix shows the very low thermal conductivity whencompared toothermixes.
- The compressive strength and tensile strength of the different proportions mixes are carried out and results shows that theincrease infibrereducesthestrength.
- Water absorption test is done as the durability test and the resultant values shows that they are based on the amount ofvermiculite andfibres added.

- The comparison is carried out with the normal light weight concrete and fibre reinforced light weight concrete, where the fibrereinforced lightweightconcreteas thelowthermalconductivity.
- Two wall panels for normal light weight concrete and 2% hemp fibre reinforced light weight concrete are designed inABAQUSandtheheattransferis studiedwhich arerelatabletoexperimentalstudy.
- Therefore,thesematerialsvermiculiteandfibreswhichisobtainedasnaturally availablematerialcanbeusedforlowthermalconductivity concreteandtherefore,they can be considered aseco-friendly and low-costconstructionmaterials.

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