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Investigation of thermal properties in synthetic fiber reinforced lightweight concrete

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ABSTRACT

The work investigates the basic possibilities to form a fiber reinforced lightweight concrete which posses worthy thermal insulation since on vogue. Thermal conductivity, supreme attention of thermal property that affects heat transfer in concrete by conduction. In general, achieving light weight concrete brings down the thermal conductivity and dead load of the structure. The transforms in FRLWC are primarily related to the density which is correlated to the total porosity. 0.5%, 1% and 1.5% of polypropylene fiber and glass fiber are used in order to enhance the overall concretes characteristics and in a view to restrict the initial crack propagations. Furthermore, weight and thermal conductivity possibly descended by replacing fine aggregate with several materials with low specific gravity (1% of coco-peat powder, 6% perlite, 30% of GGBS and 10% gypsum) which also enhances the workability of fresh mix. M15 grade of concrete specimens are casted and tested for its strength characteristics and thermal property and results with the above-mentioned percentages of fibers and compared for its optimum composition after validation studies. Wall panels of control mix and optimum composition (1% of glass fiber) are modelled and analyzed using the software ABAQUS 6.14-1 and its results are analogized.

Keywords— *Fiber reinforced light weight concrete, GGBS, Gypsum, perlite, Coco peat, glass fiber, polypropylene fiber, thermal conductivity and Thermal resistivity.*

1. INTRODUCTION

The intention of work is to form thermally insulated fiber reinforced light weight concrete (FRLWC) using GGBS, Gypsum, Perlite and coco peat. If light weight concrete (LWC) is used as blocks for the wall the dead load of the structure can be reduced and also resists the heat entering the building, as the % of air voids present in the concrete make it as a thermal insulating material [6]. Thermal insulation is a booming idea in order to restrict the huge electricity consumption in buildings by preventing heat exchange in the surrounded envelope. It can be achieved with the material of less than 0.2w/mk conductance. Thermal conductivity is the propensity of a material to absorb heat. The proportion of heat loss has direct effect on energy consumption of structures. Concrete with abated thermal conductivity considered to be the one to perform as satisfactory thermal insulating material. Thermal-insulated space stay warm in winter and cool in summer since it regulates proper heat flow. On adding further advantage weight and extra pressure of structure get reduced as it is LWC when compared with materials like bricks. In order to achieve the desired property, a light weight aggregate perlite which also posses low thermal conductance is used [14,15,16]. Materials possessing low specific gravity influence on achieving low density [7]. Gypsum is utilized because it is easily obtainable, ecologically sound, thermal and fire resistance [9]. Coco peat powder is an organic dreg from the coir industry which has dominance in reduction of thermal conductance and density has been selected as a replacement. The increase in percentage of poly propylene fiber (PPF) and glass fiber (GF) in light weight concrete decreases the workability, improve shrinkage, early tensile strength and reduce the growth of initial cracks but PPF increased the number of pores of the concrete structure and elevated temperature resulted in numerous cracks [5,13]. To boost mechanical properties and to diminish crack propagation fibers are used in FRLWC. Thermal properties can be made sound with increase in porosity hence minimal amount of foam is being induced to the FRLWC. Compressive strength test, tensile strength test and thermal conductivity test are done in a view to identify their performance in strength and thermal aspect. Heat transfer of the material is represented through the software ABAQUS 6.4.1, commercial software for FEM analysis [4].

2. MATERIALS USED

As per the IS12269:2013 code standards the OPC 53 grade of cement with specific gravity 2.92 is taken with standard consistency 32%, Table-1 ascertains the chemical composition of cement. The GGBS and Gypsum are typically used to restrain the temperature hike in large concrete pours [2]. The gypsum in this research is used to produce self-compacting, lightweight composites with improved thermal and mechanical properties. Table-2 shows the chemical composition of gypsum. The M-sand is essential inert granular material, compare to river sand it also gives high strength to the concrete and causes less effect to the environment. Coco peat/coco pith is a trivial material procured from coir industries which is used as the partial replacement for fine aggregate (FA). The incorporation of coco peat in concrete causes construction expense diminution, light weight concrete and thermally sound etc. The perlite is a lighter amorphous volcanic glass material which has magnificent insulating attributes hence typically implemented as loose-fill in masonry construction [14,15]. The primary intention of the work is to examine the integration prospect of the usage of coco-peat and perlite granules to substitute a part of a fine aggregate to achieve the target mean strength. Polyvinyl acetate coated roving glass fiber (E-type glass fiber) is incorporated to achieve the light weight concrete to produce a strong composite material having improved tensile and impact properties, the water resistance, mechanical properties [2,3,5]. It also produces the concrete with considerable abated thermal conductivity and post cracking behaviour. Table-3 shows the properties of glass fiber. And polypropylene fiber (synthetic fiber) inclusion in concrete decreases the thermal conductivity by its hydrophobic nature, addition increase the air voids when the water is dried out and causes the more air voids thus slower the transfer of heat thus lower thermal conductivity was obtained [4,5]. Table 4 shows the properties of polypropylene fiber. Table 5 shows the physical properties of materials taken.

Table 1: Cement chemical composition

Constituents	CaO	Al_2O_3	SiO_2	Fe_2O_3	MgO	K_2O	Na_2O	So_3
Percentage %	66.67	4.5	18.9	4.9	0.87	0.43	0.12	2.5

Table 2: Gypsum chemical composition

Constituents	CaO	MgO	P2O5	F	Organic matter	Na2O + K2O	SiO2 + Insoluble residue in HCl	Al_2O_3 + Fe2O3	SO3
Percentage %	32.4	0.06	0.25	0.2	0.02	0.05	0.8	0.22	45.6

Table 3: Properties of Glass fiber

Diameter of the filament	8 to 10 μm
Number of filaments in a strand	204
Tensile strength of the fiber	2.06 to 2.75 $\times 10^3$ N/mm^2
Modulus of elasticity for glass	6.89 to 7.58 $\times 10^4$ N/mm^2
Coating on the fibers	Polyvinyl acetate
Density	2.54g/cm3
Poisson's ratio	0.22

Table 4: Properties of polypropylene fiber

Diameter of the filament	12μm
Tensile strength of the fiber	0.45 to 0.5 $\times 10^3$ N/mm^2
Modulus of elasticity for glass	3.5 GPa
Density	0.9 g/cm3
Specific gravity	0.9 to 1

Table 5: Physical properties of materials

Properties	**Cement**	**GGBS**	**Gypsum**	**M-Sand**	**Coco peat**	**Perlite Granules**
Specific gravity	3.138	2.97	2.7	3.19	0.67	0.341
Standard consistency (%)	0.32	0.3	0.34	-	-	-
Water absorption (%)	-	-	-	0.45	1.82	1.51
Bulk density	-	-	-	2010.6 kg/m^3	179.21 kg/m^3	220.57 kg/m^3
Fineness modulus	-	-	-	4.6	2.39	4.34

Table 6: Mix Design

Materials	**Cement**	**GGBS**	**Gypsum**	**M sand**	**Coco peat**	**Perlite**	**Water**	**Admixture**
Control mix(M1)	198	99	33	2242.3	-	-	165	3.6
Mix with replacement (M2)	198	99	33	2085.3	4.76	14.38	165	3.6

Table 7: Experimental Test results

Mix	**Mix proportions**	**Compressive strength (N/mm2)**	**Tensile strength (N/mm2)**	**Density (kg/m3)**
M1	Control mix	10.92	1.23	2095.18
M2	1% coco peat 6% perlite	6.3	1.42	1791.72
M3	M2 + 0.5% PP	6.89	1.73	1786.28
M4	M2 + 1 % PP	11.2	2.34	1781.68
M5	M2 + 1.5% PP	10.17	2.16	1729.37
M6	M2 + 0.5% GF	6.88	1.52	1779.4
M7	M2 + 1 % GF	11.75	2.31	1747.89
M8	M2+ 1.5% GF	10.06	2.15	1730.37

3. EXPERIMENTAL INVESTIGATION

3.1 Compressive strength test

Compression test ascertained in Fig-1 is the primary beneficial properties of concrete. As a primitive construction material, it is essential for concrete to resist compressive stress. It is also locations where tensile and shear strengths are also primarily considered. This compressive strength is used to estimate the required property. 150mm x 150mm x 150mm cubes are done by mixes in table 6, tested and reported in Table-7.

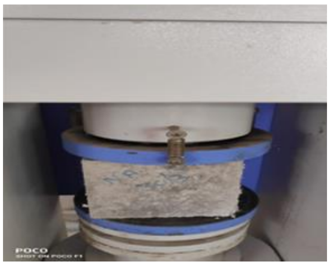


Fig. 1: Compressive strength test

3.2 Tensile strength test

Split cylinder test, an indirect method to find tensile strength is used since it is hard-won to apply uniaxial tension. Concrete is not expected to resist direct tension as it is brittle. Specimen develops cracks as the tensile force applied exceeds its tension capacity. Specimen used – 150mm x 300mm picturized in Fig-2.

Fig. 2: Split tensile strength test

3.3 Density

Density is a quantification of concretes compactness. It depends on typical properties of the material. Here it is a lightweight concrete. Hence density ranges from 320 to1920kg/m3 tabulated in Table-7 as per ACI 213, 2001.

3.4 Thermal conductivity

Thermal conductivity, an intrinsic ability to transfer heat in a material. Also illustrated as heat/time/area through a plate of thickness and its unit is w/mk. Heat in a material drift along a heat gradient until it reaches an equilibrium. The rate of heat transfer leans on magnitude of temperature gradient. Thermal resistance, resistance to heat flow and the reciprocal of thermal conductance, hence higher value of it means material is at better insulation. Thermal conductivity feasibly measured by either steady state method or transient method. Here, heat flow meter a specific steady state method is adopted and measured values are listed in Table-8 with plate specimen divulges in Fig-3 of size 300mm x 300mm x25mm.

Fig. 3: Thermal conductivity plate specimen

3.5 Heat flow meter

HFM 446 Lambda Eco-Line is a new standardized plate method displayed is Fig-4 for determination of thermal conductivity of insulators. Sample to be tested placed in the socket (between top and bottom hot plates) A temperature gradient is set between two plates through the material to be measured. By virtue of two immensely precise heat-flow sensors in the plates. The heat transfer through the material is measured. If equilibrium occurs and heat value stands constant, the thermal conductivity is value in w/mk is displayed.

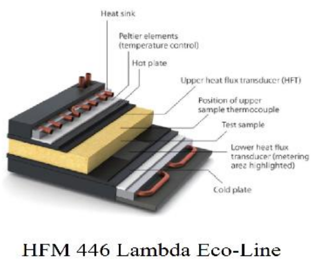


Fig. 4: HFM 446 Lambda- thermal conductivity test

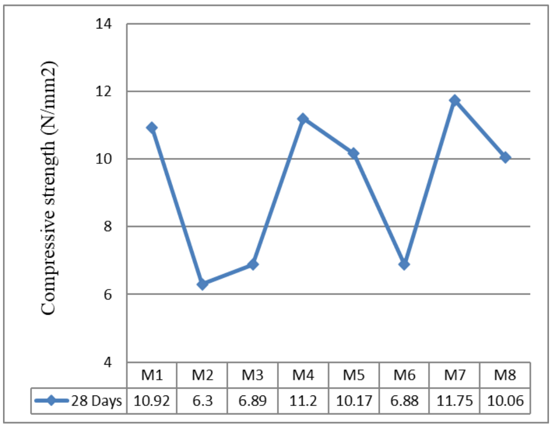
Table-8: Thermal conductivity and resistance values

Mix proportions	Thermal conductivity (w/mk)	Thermal resistance (w/mk)
Control mix	0.269	0.092
M2 + 0.5% PP	0.225	0.11
M2 + 1 % PP	0.215	0.116
M2 + 1.5% PP	0.27	0.092
M2 + 0.5% GF	0.306	0.081
M2 + 1 % GF	0.136	0.183
M2+ 1.5% GF	0.224	0.111

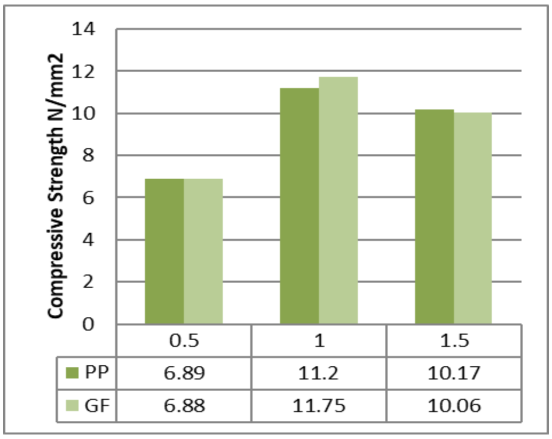
4. RESULTS AND DISCUSSIONS

4.1 Compressive strength test

The mechanical test results of compressive strength of fiber reinforced light weight concrete is presented in Fig-5 (a) and (b), the compressive strength of the control mix is compared with other mixes as seen in these figures, the compressive strength is decreased with replacement of coco peat powder and perlite granules with fine aggregate. And there is minor improvement in the replaced mix with the addition of fibers with 0.5% of weight of cement. The matrix with 1% and 1.5% of fiber inclusion, and compressive strength has been increased drastically when compared with 0.5% inclusion of fibers. But when compared with 1% and 1.5% of fibers, 1% fiber inclusion in the concrete matrix provides better results by the means of compressive strength and density. On comparing glass fiber reinforced concrete and polypropylene fiber reinforced concrete, it has to be concluded that glass fiber reinforced concrete shows better compressive strength at all ages. Which the results ascertained the length and quantity of fibers has an influence on the strength.



(a)

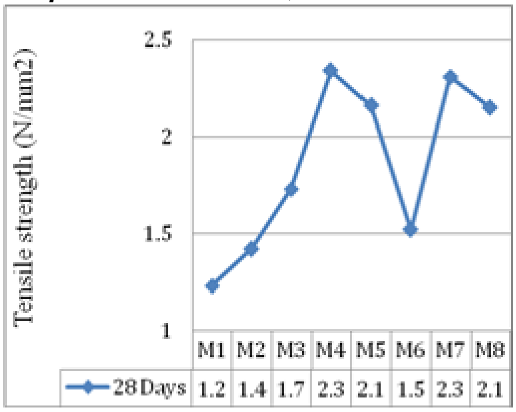


(b)

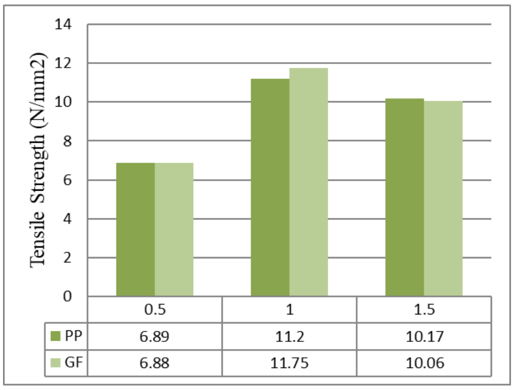
Fig. 5: (a) compressive strength results, (b) comparative results.

4.2 Split tensile test

The tensile strength is one of the basic and important property hence to obtain tensile strength. The fiber reinforced light weight concrete is not typically anticipated to resist the direct tension being with low tensile strength and brittle. However, assessing of tensile strength is indispensable to confirm the cracking load. The cracking is a evidence of tension failure. The results obtained for the split tensile test showed that the glass fiber reinforced light weight concrete exhibited greater dispersion contrasted with polypropylene fiber reinforced light weight concrete as depicted in Fig-6 (a) and (b). The specimen porosity and void fractions were the main reasons of a reduction in tensile strength. Hence with the addition of fibers tensile strength is observed to improve as it holds the concrete matrix and delays the tension expansion while applying the load. 1% of fibers is observed to be optimum in case of both fibers. On comparing polypropylene and glass fiber, 1% glass fiber reinforced light weight concrete showed better tensile strength.



(a)

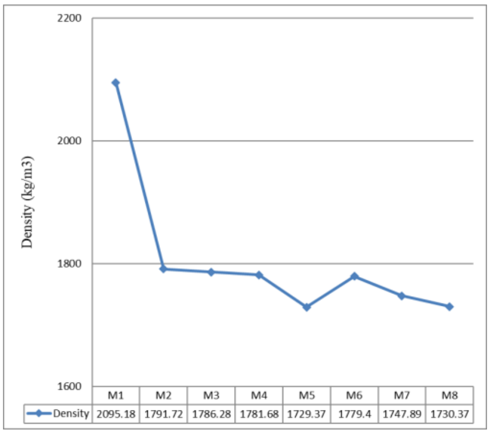


(b)

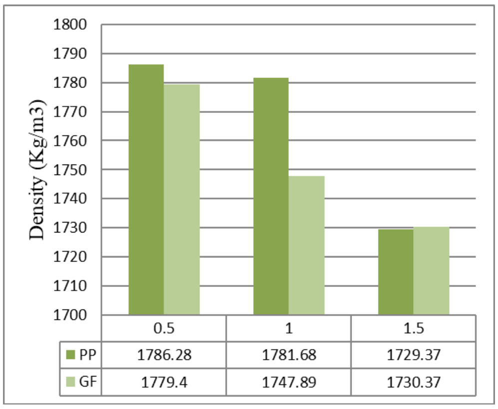
Fig. 6: (a) tensile strength results, (b) comparative results.

4.3 Density

In this thesis the highest density 2095kg/m3, which is the density of control mix. On comparing control mix with fiber reinforced mix proportions 1% and 1.5% of the fiber reinforced concrete mixes shows lower densities ranges around 1700kg/m3 represented in Fig-7 (a) and (b) which falls under light weight concrete category. Hence addition of lighter aggregates such as perlite and cocopeat and foam decreased the density and fiber addition will slightly increase the density, hence here density cannot be reduced more than a certain extend.



(a)

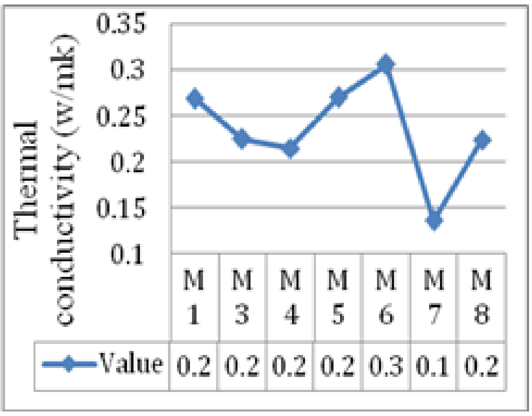


(b)

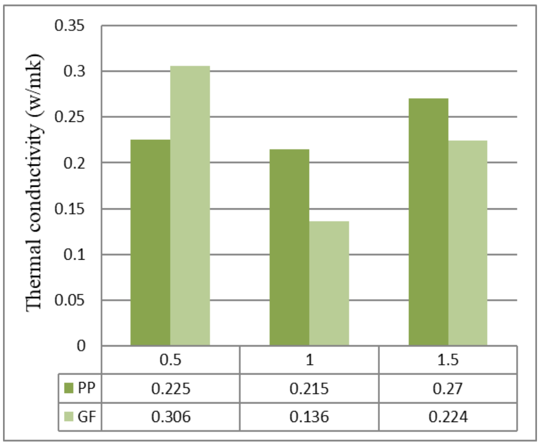
Fig. 7: (a) Density of all mixes, (b) comparative results

4.4 Thermal conductivity test

For thermal conductivity test concrete plate specimens of dimension 300mm x 300mm x 25mm has been casted and the test is performed. Thermal conductivity noted for control mix as 0.269 w/mK which the highest of all. The basic idea is to bring down thermal conductance of the concrete and to improve its thermal insulation property. It leans on type of materials, density and porosity of the concrete. From Fig-8 (a) and (b), For all the proportions of polypropylene fiber reinforced concrete, thermal conductivity value doesn't have any drastic changes only minor variations were observed whereas in glass fiber reinforced concrete, 0.5% has the highest value of thermal conductivity and 1% glass fiber inclusion had the least thermal conductivity of all the test results. Hence it is to be concluded that 1% glass fiber reinforced concrete has the best thermal insulation of all the proposed concrete mixes.



(a)

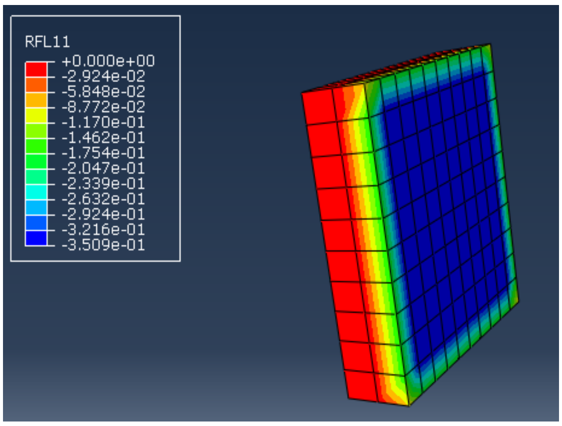


(b)

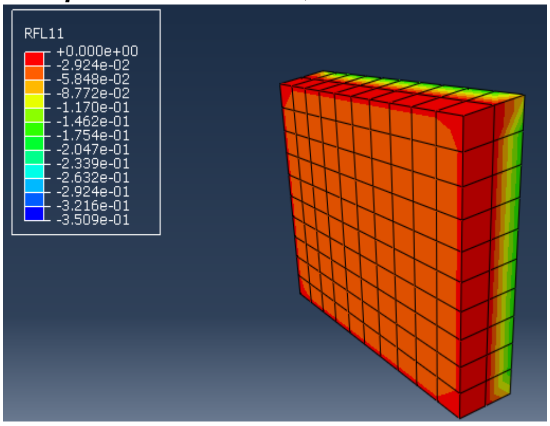
Fig. 8: (a) thermal conductivity results, (b) comparative results

5. ANALYTICAL INVESTIGATION

A steady-state coupled temperature-displacement analysis can be performed in ABAQUS (Standard). In steady-state heat transfer method, arbitrary is consigned by modelers called "time" scale to the step. This is appropriate for modifying loads and BC's by the step and for interpretation to highly nonlinear (but steady-state) cases. As default, the initial nodal temperature set as 0. Modelers can particularize non-zero initial temperatures. Boundary conditions feasibly adapted to stipulate both temperatures and displacements at nodes in any heat transfer analysis. For performing such analysis materials must posses with the thermal properties, such as conductivity, and mechanical properties, such as elasticity, defined. In case of including thermal expansion as a basic property definition possibly thermal strain will occur. Analytical results of control mix (M1) and optimum mix (1% GF) are presented in Fig-9.



(a)



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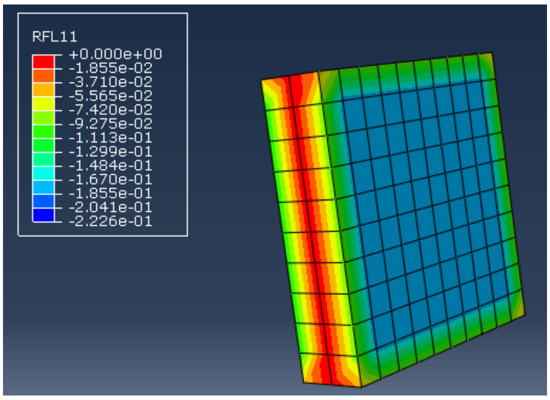
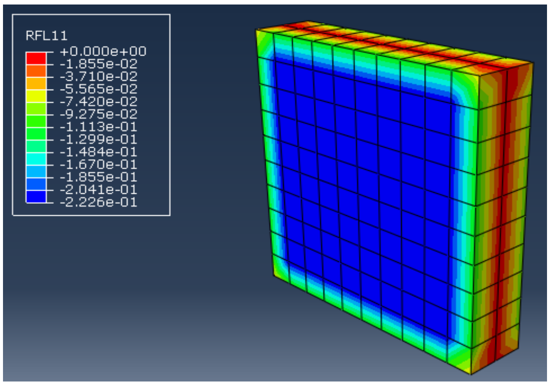


(c)



(d)

Fig-9: (a) control mix-surface 1, (b) control mix- surface 2, (c) optimum mix – surface1, (d) optimum mix surface 2.

6. SUMMARY AND CONCLUSION

This work presents a detailed investigation on the thermal behaviour of FRLWC. An ample experimental exploration is undertaken for different mixes (3 proportions of each) polypropylene fiber and glass fiber. The proportions are 0.5%,1% and 1.5%. According to the experimental results mix 5 (i.e., 1% Glass fiber) has good performance by all means. Primarily it has low thermal conductivity, proper density with comparatively good compressive and tensile strengths than all other mixes. The demeanor of the submitted concrete is investigated using experimental and analytical methods to gain a thorough understanding. Analytical models were developed using ABAQUS/CAE 6.14-1, for representing the heat transfer of the concrete. The following conclusion is made,

- Density of the concrete relies on the proportion of coco peat, perlite and fiber content.
- Increasing coco peat content beyond 1 %, it turns down the strength of concrete and holds utmost amount of water reasoning constant dampness in the concrete.
- Increasing the volume of fiber does not increase necessarily the thermal conductivity of the concrete. Since here the thermal conductivity depends on the density and porosity.
- Introducing very small quantity of foam in the concrete considerably reduce the thermal conductivity.
- 0.5% of both polypropylene fiber and glass fiber does not make any positive changes to the concrete. Whereas 1% and 1.5% of both the fibers showed better strength results.73
- In the perspective of thermal conductivity glass fiber performed better when compared with polypropylene fiber and the glass fiber’s optimum replacement percentage is found to be 1% since it manifested the minimal thermal conductivity of all the other proportions and the control mix.
- Thermal analysis performed using ABAQUS 6.14-1 for the wall panel which showed the heat transfer pattern which is relatable to the experimental results.

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