Experimental investigation of light weight cementitious material for thermal insulation

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Abstract. Light weight – thermal insulation concrete has a growing demand in energy efficient building. It can be used in places where there is a requirement for thermal insulation in the form of tiles and weathering coarse for roof as well as in places where there is a need for thermal lining. For the preparation of light weight – thermal insulation concrete, a cement replacement mix consisting of Silica fume, Metakaolin, Egg shell powder, Alccofine were used along with different particle sizes of Cenospheres as a fine aggregate replacement. The test concrete samples were tested for their physical and mechanical parameters like compressive strength and its thermal conductivity were investigated. The light weight – thermal insulation concrete has a reliable compressive strength and a satisfactory thermal insulation property.

1. Introduction
Energy efficient buildings and low-cost buildings have become the need of the hour. The light weight low density concrete aids in both the essentials mentioned. Furthermore, the rising temperature and hot climate has increased the need for insulation for comfort. The physical, geometrical and thermophysical properties of the materials define the thermal behaviour of the element for various outdoor conditions. The propagation of heat through the elements depends on the element’s density and its thermal conductivity value [7]. The sustainability concept in buildings revolve around the idea of energy consumption and energy savings. The use of poor thermal insulating materials has led to the increase of energy consumption as the need for air conditioning increased. It was noted that 23% to 26% of total energy consumption was utilised just for air conditioning [8]. The insulating materials are expensive and there arises the requirement of skilled labour of the installation purposes. The simple way to increase the thermal resistance of any material is to introduce air gaps, it based on the fact that the thermal conductivity of air is less than the thermal conductivity of the concrete.[6] Due to the introduction of air gaps, the mechanical properties are slightly reduced. The low-density light weight material can be used as only a filler material and not as a load bearing element. As the low-density light weight concrete has lesser mechanical properties, we have prepared the element to be used in filling, cladding and lining. They can be used as wall tiles both external and internal cladding, used in roofing as well as thermal linings in furnace.

2. Materials
The low-density light weight concrete was prepared using cement with partial replacements of silica fume, metakaolin, ground granulated blast furnace slag, alccofine. The fine aggregates were modified...
with the use of cenospheres and egg shell powder. Special agents such as super plasticiser and air entraining agents were used to increase the workability of the concrete and to gain lower densities.

![Figure 1. Materials used in casting.](image)

2.1. Cement
The cement used was ordinary portland cement of grade 53 confining to the bureau of Indian standard code IS 12269 -1987(9). The specific gravity of the cement is 3.15 with a fineness of 5%. The initial setting time observed was 30 minutes.

2.2. Metakaolin
In the earth’s crust, there is a natural product called kaolinitic clay, which when heated to 600 to 900-degree Celsius will yield to metakaolin along with silica and mullite [2]. Metakaolin helps in increasing the mechanical properties of the concrete. It has an increased pozzolanic activity than other replacement material [3].

2.3. Silica Fume
Silica Fume of specific gravity 2.2 and surface area of 20000 m²/Kg was used as a partial replacement to cement. Silica fume increases the micro structure of the cementitious material and it has enhanced fineness and higher surface area compared to cement.

2.4. GGBS
Ground granulated blast furnace slag is obtained from iron manufacturing plants where is obtained as a by-product. GGBS is used in concrete to increase the durability parameters, they have high cementitious properties.

2.5. Cenospheres
Cenospheres are obtained from coal burning process as a solid residue. The property of cenospheres depends on the type of coal being used. The cenospheres are light in weight, these are attributed o their hollow structure and their lower density [1].
2.6. Alccofine
Alccofines are similar to silica fume, their microstructure attributes to their enhanced mechanical properties. They are more economical and they aid in polymerization process [10]

3. Experiments

3.1. Mechanical Property
The mechanical property for compressive strength of concrete was carried out. The concrete was designed for various trial mixes and optimum was tested and the results are tabulated in table 1.

| Specimen   | 7 - day | 14 - day | 28 - day |
|------------|---------|----------|----------|
| Specimen 1 | 3.54    | 7.95     | 8.86     |
| Specimen 2 | 3.46    | 7.87     | 8.93     |
| Specimen 3 | 3.57    | 7.93     | 8.84     |
| Mean       | 3.52    | 7.92     | 8.87     |

Figure 2. Test for Compressive Strength.

3.2. Thermal Properties
The low-density light weight concrete was studied for its thermal properties. Equipment such as DSC (Differential Scanning Calorimeter) and Thermal conductivity measuring equipment was used in order to identify the behaviour of the concrete under various temperatures.

Figure 3. Tile specimen (left). Tile test specimen (right).
3.2.1. Conduction – Temperature measurement. Tiles were casted of size 300 mm X 300 mm having a thickness of 10mm. Based on the conduction plate size, the tile was cut to a size of 120 mm X 120 mm. The temperature was maintained at 180 degree – Celsius and the heat was transferred to the tile specimen through a conduction plate in radial manner. The temperature of both the conduction plate and the specimen was measured using infrared thermometer. The temperature readings were photographed, refer figure 4.

![Figure 4. Temperature reading under conduction plate.](image)

3.2.2. Thermal Analysis. Differential scanning calorimeter is used to find the melting point temperature ($T_m$) of the material. The material was finely grounded and made into powder form, 10mg of the powdered sample was placed inside the crucible of the DSC and the temperature was increased at 20$^\circ$C/minute up to 200$^\circ$C. The experiment was terminated at 200$^\circ$C because, at the application point of view we restricted it to be used in and as wall cladding and roofing material. The data obtained from DSC were tabulated in excel format, the same is deduced into a graph shown in figure 5.

![Figure 5. Graph showing various phases of the specimen material – Thermal Analysis.](image)
3.2.3. Thermal Conductivity. For the measurement of thermal conductivity and thermal diffusivity a machine – Laser Flash Analyser 467 HT was used. The temperature range of this machine is from 30 degree – Celsius to 900 degree – Celsius. The sample of size 10 mm X 10 mm with thickness of 2 mm was used. The sample specimen is shown in figure 6.

The LFA 467HT works on the principle of conversion of light source to heat source through black body radiation. For this purpose, the specimen was coated with graphite spray to induce a black surface so that the light is concentrated on the specimen which will then convert to heat energy. Sample holder is made of silicon carbide single crystal. The detector used is Indium Antimonide submerged in liquid nitrogen. The Xenon laser produced from argon gas is used as the light source.

![Graphite coated specimen](image)

**Figure 6.** Samples used in LFA 467HT.

![Laser Flash Analyser 467 HT](image)

**Figure 7.** Laser Flash Analyser 467 HT.
The thermal conductivity of the specimen depends on the specimen’s density. The density of the specimen was found to be 943 Kg/m$^3$ or 0.943 g/cc. The thermal conductivity of the specimen is given by,

$$\lambda = \alpha \cdot \rho \cdot C_p$$

Where $\lambda$ – Thermal conductivity, $\alpha$ – Thermal diffusivity, $\rho$ – Density, $C_p$ – Specific heat capacity.

The temperature was raised at 10 degree – Celsius. The thermal conductivity and thermal diffusivity are tabulated in table 2. For specific heat capacity, a reference sample, pyroceram 9606 was used from which the specimen’s specific heat capacity was obtained. The mean thermal conductivity was found to be 0.262 W/(m*K)

**Table 2. Thermal conductivity and Thermal Diffusivity.**

| Temperature/°C | Diffusivity/(mm$^2$/s) | Conductivity/(W/(m*K)) |
|---------------|-------------------------|------------------------|
| 30            | 0.385                   | 0.267                  |
| 40            | 0.379                   | 0.263                  |
| 50            | 0.373                   | 0.266                  |
| 60            | 0.369                   | 0.258                  |
| 70            | 0.364                   | 0.257                  |
| 80            | 0.36                    | 0.258                  |
| 90            | 0.357                   | 0.262                  |
| 100           | 0.353                   | 0.265                  |

**Figure 8.** Graph showing thermal conductivity of the specimen.
4. Conclusion
The low-density light weight concrete has a thermal conductivity of 0.262 W/(m*K) which is very low when compared to the conventional concrete of 1.9 W/(m*K). This shows that this concrete can be used in thermal insulation wherever required.

4.1. Future Studies.
The future studies involve in using this material as plastering with more workability. More studies to be conducted on this material at higher temperatures in order to use them in furnace lining. This light weight material can also be used as a filler material in dry walls so that the need for foam insulation can be avoided which is harmful for the health.

5. References
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