Study on the Thermal Properties of Mortars with Partial Cement Replacement by Barite and Ceramic Waste Powder

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ABSTRACT: Buildings consume 40% more power to maintain good thermal comfort for users of the building. Several efforts are being made to reduce this energy. Hence different materials have been recommended to give good thermal comfort inside the building and also contribute to lower the CO_2 emission.

In this study, strength and thermal properties of cement mortars with partial replacement of cement by ceramic waste powder and barite powder are studied. The cement is replaced partially with varying dosages of ceramic waste powder and barite powder i.e., by 10%, 20%, 30%, 40% and 50%. Compressive strength and thermal properties like thermal conductivity is found out by hot-wire method and specific heat is found out by half open dynamic method. A MatLab code is developed based on cyclic admittance method to obtain thermal characteristics like decrement factor and time lag. Also thermal performance analysis of a building wall is done using COMSOL software wherein plastering material for wall is the cement mortar that was developed with partial replacement of cement by ceramic waste powder and barite powder. XRD test is conducted to know the phases developed after hydration.

From experimental investigation and analysis in software, CC20 mix has the lowest thermal conductivity of 0.177 W/m-K and specific heat of 1009 J/Kg-K. From MatLab code, its decrement factor came out to be 0.026 and time lag of 4.82 hours. From thermal performance analysis of building wall, CC20 as the plastering material showed best results by attaining a temperature of 26°C at the inner surface of the wall when the outer surface of the wall is subjected to a temperature of 34.2°C.

KEYWORDS: Barite, Ceramic Waste, Decrement factor, XRD test, Mortar.

I. INTRODUCTION

Cement is the most widely used man made material in the world. It is the primary component of the concrete mixture. Even though it occupies only 10-15 % of the total volume of the concrete mixture, it is the critical material structure that after reacting with water combines and binds together all the other constituents. Its huge popularity is due to its numerous advantages that it has like low cost, wide applicability and general availability. But its popularity also carries with it huge risk to environment. It not only contributes to the carbon footprint but also due to its high thermal conductivity, it becomes inefficient in thermally insulating the building. Hence partial or full replacement of cement is considered a sustainable solution toward decreasing the environmental impact of cement production and will also contribute to sustainable concrete.

The production of cement involves the consumption of large quantities of raw materials, energy, and heat. Cement production also results in the release of a large amount of solid waste materials and gaseous emissions.

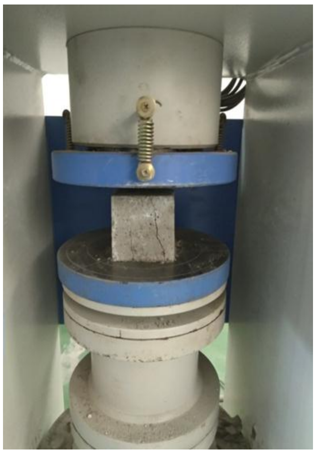
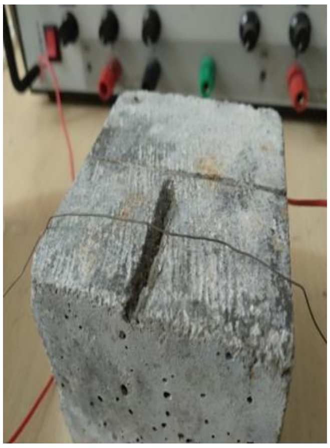
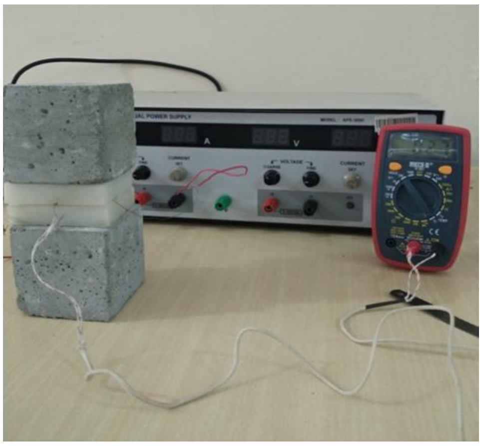
There are numerous ways to reduce the environmental impact of concrete and conserve energy. One of the ways is to use the supplementary cementitious material. Since production of cement is energy intensive and also contributes to carbon footprint , substituting it with other materials that are by-products of industrial process can be a good option. The best known of such material is Fly ash. It is a residue of coal combustion which is an excellent cementitious material. It also improves certain properties of concrete such as durability. Ground Granulated Blast Furnace Slag (GGBFS) is another cementitious material that is a by-product of steel industry. We can rely on recycled materials also for the substitution of cement or aggregates in the concrete mix.Indian ceramic production is 100 million ton per year. About 15 to 30% waste is generated in the ceramic industry from the total production which is not recycled in any format in the present day. They are dumping the waste in nearby pit or vacant spaces. This leads to serious environmental and dust pollution. As the ceramic waste is being piled up every day, pressure is build up on the ceramic industry to find a solution for its safe disposal. Thus employment of ceramic waste powder in various sectors of industry especially construction industry will help in protecting the surrounding. This will result in growth of eco-friendly concrete. In addition to protecting the surrounding, it has many other advantages like reduction in the use of other raw materials, conservation of energy as it is a reused material.

There are different types of Ceramic products like wall and floor tiles, brick and roof tiles, table and ornamental ware, refractory products , sanitary ware, etc,. Ceramic waste may come from two source. The first source being the ceramic industry and this waste is classified as non-hazardous. They can be waste from thermal process and waste from manufacture of ceramic products, bricks, roof tiles. The second source of ceramic waste is from Construction and demolition activity. Barite is a mineral composed of Barium Sulphate. It is the main source of Barium. It gets name from Greek word "barys" which means heavy. This is due to the high atomic weight of barium. It has specific gravity of 4.5 which is extraordinary for a non-metallic material. Because of its high specific gravity, it is widely used in different sectors of industry. Barite of size 0-100 microns is basically used in concrete. It is a clean, smooth , unresponsive and inexpensive naturally available material. It is non toxic and non reactive material. It can be one of the best alternative for partially replacing cement in concrete and cement mortar.

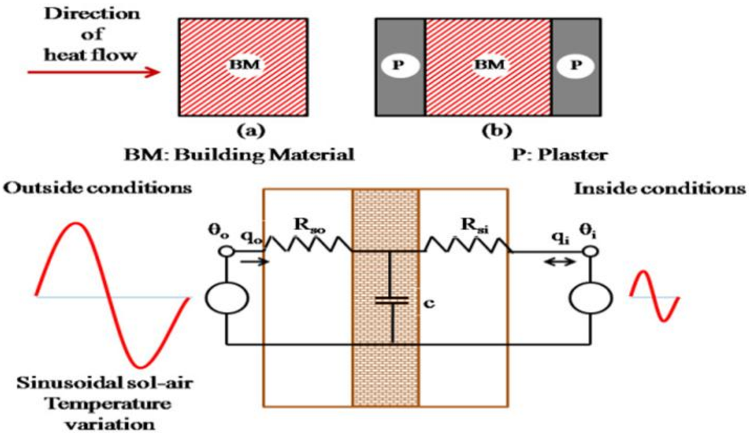
II. Methodology

III. **Objective No.**	**Statement of the Objective**	**Method/ Methodology**	**Resources Utilised**
1	Literature review	Referring relevant journal papers and reference books	Journals/Books
2	Basic material testing	Laboratory test procedures and code books	Raw materials like cement, ceramic waste powder, barite powder, sand, water and different equipments.
3	Study of Strength, Thermal properties and XRD test	Compressive strength test, Hot wire method for Thermal conductivity, Half Open Dynamic method for Specific heat and XRD test	Lab equipments, fabricated equipments, XRD equipment and mortar cubes
4	Study of Thermal characteristics	To code in MatLab to determine Decrement factor and Time lag	MatLab software
5	Factors affecting Thermal characteristics	Density and Apparent porosity	Mortar cubes
6	Thermal performance analysis of building wall	Heat transfer analysis for a wall in COMSOL	COMSOL Multiphysics Pvt Ltd software

Compressive Strength Test ,Thermal Conductivity And Specific Heat Test:

Experimental setup for measuring thermal conductivity of mortar cubes

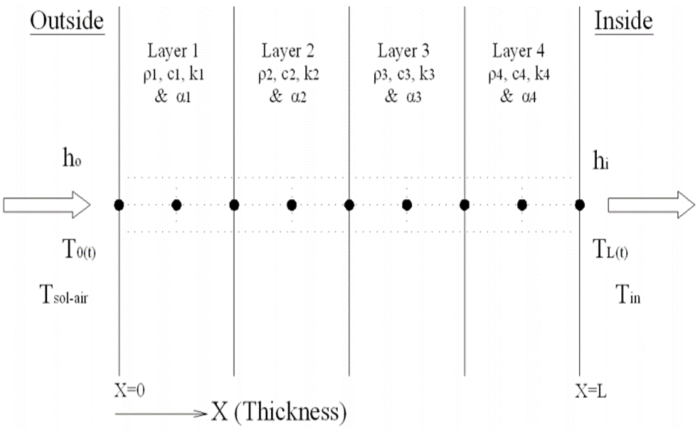
Experimental setup for measuring specific heat of mortar cubes

Effect Of Density And Porosity On Thermal Properties Of Mortar Cubes

increase in porosity will decrease the thermal conductivity. To know the porosity, water absorption test was conducted wherein cubes after water curing of 7 days and 28 days were used for testing. After 7 days and 28 days of curing, the cubes are taken out and dried in room temperature for 24 hours. After 24 hours, they are weighed. This weight is noted down as dry weight of cube before immersion . They are then immersed in water and kept for 48 hours. It is taken out after 48 hours. Any excess water is removed from the surface by wiping it with clean cloth. They are weighed and the weight is noted down as wet weight after immersion. The measured water absorption percentage is expressed as the increase in weight as percentage of dry weight. The main aim here was to know percentage of voids present and that would be filled with water. This gives the porosity of the material because by knowing the increase in mass of the sample we get to know how much of voids in the sample are empty.

III. Thermal performance analysis of building wall

For the practical application of the material, we are going to check the thermal performance of a wall. This is done in COMSOL. COMSOL is a general purpose simulation software for modelling designs, devices and processes in all fields of engineering and scientific research. The heat transfer through the walls is assumed to be one dimensional. Some of the wall consists of many layers of different materials with different thickness and different thermal properties



The general governing one dimensional transient heat conduction equation is as follows,

Where, k is thermal conductivity, ρ is the density and cp is the specific heat of the building materials. Two boundary condition and one initial condition is necessary to be specified. Convective boundary condition on both inside and outside surface of the wall are present (C, et al., 2013). The boundary condition at inside surface is given by,

where, h_i is the inside surface heat transfer coefficient , for still air its value is 9.36 $Wm^{-2}K^{-1}$ which is as per Indian standard 3792-1978.

The boundary condition at the outside surface is written as ,

$$k\left(\frac{\partial T}{\partial x}\right)_{x=L} = h_o[T_{sa}(t) - T_{x=L}(t)]$$

where, h_o is the outside surface convective heat transfer coefficient. It is given by the formula,

$h_o = 18.63\ V^{0.605}$ in $Wm^{-2}K^{-1}$ (for windward surface)

where, V = 0.25v for v > 2m/s or 0.50v for v < 2m/s

$T_{x=0}$ is the wall inside surface temperature, $T_{x=L}$ is the wall outside surface temperature and $T_{sol(t)}$ is the sol-air temperature (sol-air temperature)

COMSOL works on various formulas and concepts that are related to the analysis. Above formulas are applicable for thermal analysis of the wall. The study is Time-dependent and it is analysed under heat transfers in solids. A brick wall is considered with plastering of 15mm on both the sides. Thickness of the wall being 230mm (including plastering).

X-Ray Diffraction Test (XRD):

To perform material characterization and identifying hydration phases in Cement-mortar mix XRD test was conducted. This test is performed for cement mortar with partial replacement of cement by ceramic and barite which has shown optimum thermal conductivity and specific heat to provide thermal comfort of building.

IV. Conclusions:

From the experimental investigation and analysis in software , following conclusions are made when cement is partially replaced by ceramic waste powder and barite powder in cement mortar :

- Compressive strength decreases with increase in the percentage of replacement of cement by ceramic waste powder and barite powder.
- CC20 has the least thermal conductivity of 0.177 W/m-K which is 60 % lesser than RM that shows thermal conductivity of 0.449 W/m-K.
- CB20 shows the highest specific heat of 1313.733 J/Kg-K which is 15 % more than the specific heat of RM (i.e., 1143.698 J/Kg-K).
- The thermal conductivities of cement mortar with partial replacement of cement by barite powder increased from 7 days to 28 days because of the increase in density. More denser is the material , more is the thermal conductivity.
- Thermal conductivities of cement mortar with partial replacement of cement by ceramic waste powder decreased from 7 days to 28 days even though the density has increased from 7 days to 28 days. The possible reason for decrease in thermal conductivity is increase in porosity.
- Porosity of cement mortar made with partial replacement of cement by ceramic waste powder has increased from 7 days to 28 days. Hence, there is decrease in thermal conductivity for cement-ceramic mortar cubes.
- CC20 showed lowest decrement factor of 0.026 and highest time lag of 4.582 hours among all other cement mortar mixes.
- By thermal performance analysis of the wall, wall made with CC20 as the plastering material decreased the inside surface temperature of the

wall to 26°C when outside temperature was 34.2°C and room temperature was 25°C

- XRD analysis shows that that peak value of portlandite has decreased with the increase in percentage of replacement of cement by ceramic waste powder. The same is observed with peaks of CSH which is primarily responsible for strength of cement based materials. This accounts for decrease in strength of cement mortar with the increase in percentage replacement of cement by ceramic waste powder.

- XRD shows most of the components that were formed after hydration has alumina in one form or the other.

Future Directions:

- To improve the strength of mortar mixes without altering the thermal characteristics of the mixes

- A complete building can be modelled and its thermal performance analysis can be done

- Change in the microstructure of the cement mortar can be studied to justify the reasons for change in thermal conductivity when cement is partially replaced by ceramic waste powder and barite powder.

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