Studies on Impact of Phase Changing Material on Concrete for Enhancing Thermal Comfort

Mohd Ehtesham Azam [1], Mohd Ishaq khan [2], Mohammed Shahnawaz [3], Touseeq Anwar wasif [4]

[1, 2, 3] UG Student, Department of Civil Engineering
[4] Asst Professor of Civil Engineering
ISL Engineering College, Hyderabad, Telangana

Abstract - *The current trend in materials science in civil engineering is to examine the application of new technologies to improve thermal and energy performance. This tendency is exacerbated by the necessity for a building sector-wide sustainable development plan. The incorporation of a Phase Change Material (PCM) in cement used for building construction is evaluated in this article. The ability of PCMs to absorb and replenish energy is their defining feature. By embedding PCMs into the materials used in building construction, this property might be leveraged to conserve energy. Thermal energy storage systems (TES) with Phase change materials (PCM) offer attractive means of improving the thermal mass and the thermal comfort within a building. PCMs are latent heat thermal storage (LHTS) materials with high energy storage density compared to conventional sensible heat storage materials. Concrete incorporating PCM improves the thermal mass of the building which reduces the space conditioning energy consumption and extreme temperature fluctuations within the building. The heat capacity and high density of concrete coupled with latent heat storage of PCM provides a novel energy saving concepts for sustainable built environment. Microencapsulation is a latest and advanced technology for incorporation of PCM in to concrete which creates finely dispersed PCMs with high surface area for greater amount of heat transfer.*

The aim for this project was to determine the strength and durability characteristics of high strength structural concrete by using phase change materials, which will give a better understanding on the properties of concrete. The various proportions of phase changing material (0%, 10%, 20%, 30%) gives various result for 7thday, 14thday and 28thday of compressive strength test gives test result as compared to conventional concrete.

Key Words: Thermal energy storage systems (TES); Phase change materials (PCM); latent heat thermal storage (LHTS); Phase change material (PCM)

1. INTRODUCTION

Many developing nations have seen a surge in electricity consumption in the last decade, necessitating the construction of energy-efficient buildings. Construction sectors in emerging nations utilise a significant amount of energy, accounting for roughly 40% of total output [1,2]. Thermal energy storage systems (TES) are a potential option for energy conservation since they may store energy for later use with either sensible thermal energy storage materials or latent heat storage materials. Latent heat is the energy necessary to alter the phase of a substance [3-5]. Steel, masonry, and water are examples of current TES materials used in the building industry. These materials are sensible heat storage materials that store thermal energy when the temperature of the material is elevated. Latent heat storage materials are known as phase changematerials (PCM), and they preferably have a solid liquid phase change [6, 7]. A phase change material (PCM) is a substance having a high heat of fusion that can store and release huge quantities of energy by melting and solidifying at a specific temperature. When a substance transforms from solid to liquid or vice versa, heat is absorbed or released [8, 9]. As a result, PCMs are categorised as latent heat storage (LHS) units. The incorporation of phase into the building system has the potential to boost the thermal storage capacity of the building envelope. PCMs may store energy at a constant or almost constant temperature, which is referred to as the PCM's phase transition temperature [10]. Cementitious materials, which are the most often used building materials, have a large potential for producing high performance heat storage materials. The heat transmission behaviour and thermal characteristics of this composite material are characterised by stimulation of thermal energy storage in concrete [11]. In the built environment, Phase Change Materials (PCM) can be utilised to limit interior temperature shift by storing latent heat in a material's solid-liquid or liquid-gas phase change[12, 13]. PCMs can store up to 14 times more thermal energy per unit volume than traditional thermal storage materials [14]. Heat is practically isothermally absorbed and released, and it is utilised to minimise the energy consumed by traditional heating and cooling systems by minimising peak loads [15, 16]. Organic and inorganic PCMs have both been employed in construction applications. Organic compounds are further subdivided into paraffins and non-paraffins[17,18]. These organic PCMs have desired features such as cohesiveness, chemical stability, non-reactivity, and recyclability [19-26]. However, in the solid form, these organic materials have a low heat conductivity. Inorganic compounds, on the other hand, have a large latent heat absorption capacity and are non-flammable. Inorganic PCMs have a higher thermal energy storage capacity and are less expensive than organic PCMs [27-29].

1.1 Phase change Materials

The smart materials constitute a large variety of materials: magnetic shape memory, self-healing materials, piezoelectric materials, etc Materials that have one or more properties which can be significantly changed in a controlled fashion by external stimuli, such as stress, moisture, temperature, pH, electric or magnetic fields. This research focuses on phase change materials (PCMs) as a type of smart materials. PCMs exhibit a high enthalpy of fusion. Indeed, compared with sensible heat storage materials, latent heat storage materials present a higher energy storage density, per unit of temperature gradient, while requiring less mass of material. Over a limited temperature range, a PCM can change its physical state. Even some PCMs are suitable for building incorporation (thermal insulation, building envelope, walls, slab ceiling. Building's temperature ranges between 0◦to55◦ approximately depending on the geographic location. Many research projects focused on the application of PCMs in building construction.

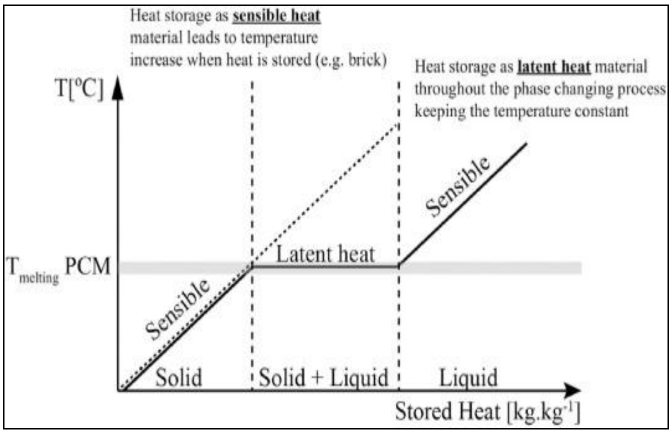

Fig -1: Heat transition regions of PCM

2. LITERATURE REVIEW

Alam et al., (2016) studied characteristic strength of recycle aggregate concrete with partial replacement of cement with silica fume. They reported that adhered mortar on recycled coarse aggregate produces porous and rough nature of surfaces, which help in developing better bond. But for achieving required workability, the water absorption for recycled coarse aggregate is more than natural aggregate, they further reported that the recycled aggregate concrete has less workability as compared to the concrete made of natural aggregate; this is due to the porous and rough surfaces of the recycled aggregate.

Corominas and Etxeberria (2016) studied effects of using recycled concrete aggregates on the shrinkage of high performance concrete. They reported that the plastic and drying shrinkage became higher as the quality of RCA decreases.

Laneyrie et al., (2016) studied the influence of recycled coarse aggregates on normal and high performance concrete subjected to elevated temperatures of 750 °C and reported that the residual performances for the recycled concretes were generally similar to but slightly worse than those observed for the reference concretes. Also the presence of non- cementations impurities accelerates the damage of concretes with temperature.

AmithaJayalath (2017) states that Latent heat storage materials with solid liquid phase change or Phase Change Materials (PCMs) provide a promising solution in developing efficient thermal storage systems for buildings. The thermal mass of the building structures can be increased with the incorporation of PCMs into building materials. it will enhance the occupants comfort and reduce the consumption of energy for space conditioning.

ZakariaDakhli (2019) states that phase Change Materials (PCMs) integration in building materials reduces the need for air conditioning use in summer and brings comfort and well-being throughout the seasons. This research study proved that PCM incorporation in cement material enhances its thermal efficiency by adding a new feature: "thermal absorption feature". The latter absorbs energy to restore it when needed (day vs. night).

3. MATERIALS AND METHODS

3.1 CEMENT

Cement is a binder which binds sand and gravel produces concrete. Cement mixed with fine aggregate to form mortar. Cement used in construction usually inorganic often calcium carbonate or lime based formed by a process known as calcination generate calcium oxide is then grounded with small amount of gypsum to form ordinary Pozzolana Cement (OPC).

3.2 FINE AGGREGATE

These fine aggregates are those natural sand particles passing 4.75 mm sieve and predominantly retained on 75μm sieve. the increased round shape of grains increases the workability. The fine aggregate has the purpose of filling the voids in coarse aggregate and to act as workability agent.

3.3 COARSE AGGREGATE

Coarse aggregate are obtained by crushing natural rock which are retained on 4.75 mm sieve provide strength to the entire structure and enormously increases volume of concrete. It influences durability hardness and other mechanical properties of concrete.

3.4 PARAFFIN WAX

Paraffin wax are also known as petroleum wax obtained from coal, petroleum and shale oil. Paraffin wax are under alkane group with mixture of hydrocarbon molecules with general formula C_nH_{2n+2}.

Paraffin wax are odorless and bluish white substances which are having specified characteristics of being solid at room temperature and begin to melt above (approximately) 37oc. Such paraffin wax can be used as a partial replacement in the concrete which provides heat energy storage in colder seasons of building.

Fig -2: Paraffin wax

3.5 MIX DESIGN

Mix designing of concrete is the process of determining absolute properties of cement, sand and aggregate for concrete to achieve required strength in structure where such concrete is being used. Mix design can be stated as concrete mix**.**

Design mix of M20 grade concrete

Table -1: Materials of concrete and its quantity

Materials	Quantity
Cement	411.85 kg/m^3
Fine Aggregate	622.22 kg/m^3
Coarse Aggregate	1235.56 kg/m^3

Table -2: Materials of concrete and its specific gravity

Materials	Specific Gravity
Cement	3.1
Fine Aggregate	2.55
Coarse Aggregate	2.65

Table -3: Materials of concrete and its proportion

Materials	Proportion
Cement	1
Fine Aggregate	1.5
Coarse Aggregate	3
Water	0.4

Table -4: Percentage of paraffin wax replacement and equivalent aggregate weight of fine aggregate

Sl. No.	Percentage of paraffin wax	Aggregate weight of paraffin wax (kg/m^3)	Aggregate weight of fine aggregate (kg/m^3)
1.	0%	0	622.22
2.	10%	62.22	560
3.	20%	124.44	497.78
4.	30%	186.66	435.56

4. EXPERIMENTAL INVESTIGATIONS AND RESULTS

Several Investigation are made in the implementation of phase changing materials in building construction material which inferred various results. Paraffin Wax is the major phase changing material in this experiment which is used as a partial replacement of fine aggregate.

4.1 WORKABILITY TEST

Concrete Slump Test is a measurement of concrete's workability, or fluidity. It's an indirect measurement of concrete consistency or stiffness. A slump test is a method used to determine the consistency of concrete.

The pH value should be lies between 6 to 9. The water/ cement ratio normally ranges from 0.25 to 0.5. Here the water/cement ratio is fixed as 0.4. The slump test shows that slump fomed is zero slump. The concrete in the compaction factor test resulted is 0.78.

Fig -3: Slump cone test

4.2 COMPRESSIVE STRENGTH TEST

In M20 grade concrete, the paraffin wax (10%, 20% and 30%) is replaced with aggregate weight of fine aggregate. The incorporation of different proportion of paraffin wax showed different results when compared to normal concrete cubes.

The slump value of freshly prepared PW Concrete was almost same when compared to normal concrete. The compressive strength of hardened concrete is checked on 7th, 14th, 28th days. The results are shown in the table below.

Fig -4: Compressive strength apparatus testing concrete

Table -5: Compressive strength of concrete

Percentage of PCM (%)	7th day (N/mm^2)	14th day (N/mm^2)	28th day (N/mm^2)
0	16.95	22.19	33.21
10	16.78	21.47	31.54
20	16.56	20.84	30.05
30	15.32	19.03	28.52

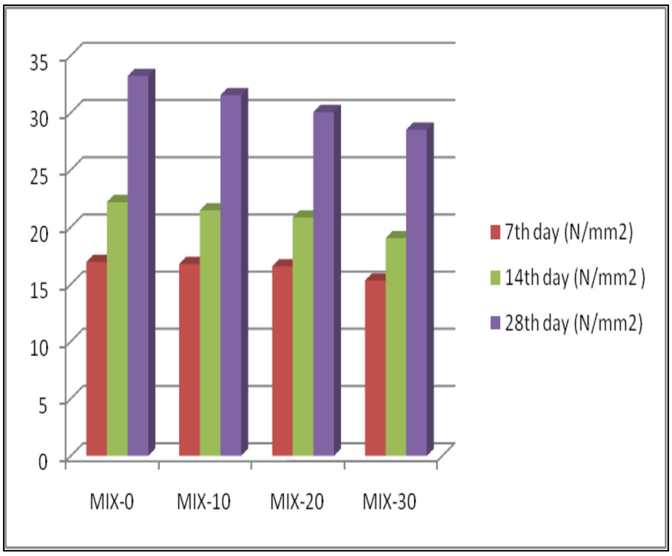

Chart-1: Compressive strength of the concrete with different proportion of concrete on 7th day, 14th day, 28th days

The compressive strength of various PCM concrete showed nearby values of ordinary M20 grade concrete when it is replaced with 10% of aggregate. Above 10% replacement of fine aggregate reduces the strength of the concrete. It shows that increases in paraffin wax in concrete decreases strength.

4.3 TEMPERATURE TEST

There were totally 2 cubes were casted with 10% PCM implemented M20 concrete with dimensions of 15cmx15cmx15cm. One of those cubes was plastered with paraffin wax incorporated cement mortar with ratio 1:6. The other cube was plastered with normal cement mortar with ratio of 1:4.

The observation is done on the thermal capacity and heat dissipation inside the casted cubes. The cubes had been placed in open exposure to sunlight. The experimental observation is done from morning 9am to evening 9pm. The thermal measurement was done by the small instrument known as Thermometer.

Table -6: Temperature at Different Time

Condition	Temp @ 9am	Temp @ 12pm	Temp @ 3pm	Temp @ 6pm	Temp @ 9pm
Without plastering	30.3°C	34.6°C	36°C	32.1°C	28.0°C
With plastering	31.9°C	32.0°C	34.9°C	32.3°C	31.3°C

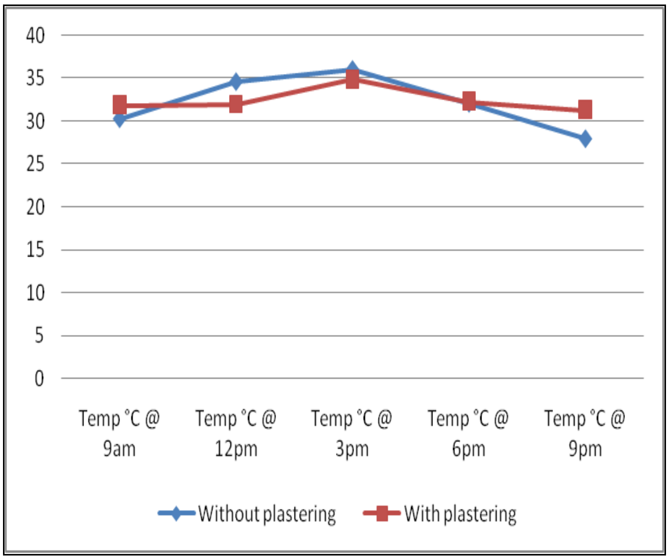

Chart-2: Temperature changes with respect to time

The surface temperatures were very low and provide thermal comfort over the other surfaces. Hence the result produced for this was good. It is observed that the constant temperature is maintained over a period of the time.

4.3.1 THERMAL CONDUCTIVITY TEST FOR PCM INTEGRATED CONCRETE

Thermal conductivity of pure cement (0% PCM integration) was found to be 0.7 W/mK.f 10% of PCM s integrated n cement, thermal conductivity dropped to 0.6 W/mK. With 20% of PCM integration, thermal conductivity continued decreasing till 0.56 W/mK. For 30% PCM, the value s 0.53 W/mK.

Table -7: Thermal Conductivity for various mix ratios

S.No	MIX	Thermal Conductivity (W/mK)
1	M1(0% PCM)	0.7
2	M2(10% PCM)	0.6
3	M3(20% PCM)	0.56
4	M4(30% PCM)	0.53

5. CONCLUSIONS

In this project it is concluded that the usage of Phase changing material in the building constructions can give a fine results. When paraffin wax or petroleum wax is incorporated with cement mortar, it gives temperature variation throughout the day. It is observed that in day time, the temperature is reduced and in night time, temperature is increased slightly. The temperature ranging from 2.7^{0}c to 3.5^{0}c is increased or decreased accordance to external temperature. When paraffin wax is mixed with concrete, it is observed that the wax accumulates into the voids of concrete during the curing process. The thermal conductivity of paraffin wax are usually 0.21 W/m^{0}c makes the concrete to swell out of wax at higher temperatures. If the paraffin wax is undergoing polymerization process and gets encapsulated it shows increased thermal conductivity and produces a better result. The surface temperature varies predominantly to lower and higher temperature when compared to normal conventional concrete.

Our outcomes of this project are:

- The need of external air conditioning or cooling is greatly reduced.
- Having a higher scope of more important tool for improving the thermal comfort in the domestic building.
- It can be utilized also in both residential and commercial buildings.
- To reduce the power supply for external air conditioner and maintain sophistic nature of occupants and buildings.
- It enables the development of sustainable Green buildings.

REFERENCES

[1] Abdelfatah A, Tabsh S and Yehia S (2011). Utilization of recycled coarse aggregate in concrete mixes, 5: 561-565.

[2] Abou-Zeid M N, Shenouda M N, McCabe S L and EI-Tawil F A (2005). Reincarnation of Concrete. Concrete Inter - national, 2: 53-59.

[3] Ajdukiewicz A and Kliszczewicz A (2002). Influence of recycled aggregates on mechanical properties of HS/HPC. Cement and Concrete Composites, 24:269 – 279.

[4] Alam M F, Sharma C R and Pandey V (2016). Study of characteristic strength of recycle aggregate concrete with partial replacement of cement with silica fume. International Journal of Innovative Research in Science, Engineering and Technology, 5:1-7.

[5] Anderson, Keith W, Jeff S, Uhlmeyer and Russel M (2009).Use of Recycled Concrete Aggregate in PCCP: Literature Search. Olympia: Washington State Department of Transportation. https://www.wsdot.wa.gov/research/reports/fullreports/726.1.p df.

[6] BIS: 10262-(2009) First revision. Concrete Mix Proportioning Guidelines.

[7] BIS: 10262-(2009). Recommended guidelines for concrete mix design. Bureau of Indian Standards, New Delhi, India.

[8] BIS: 383-(1970). Indian standard Specification for coarse and fine aggregates from natural sources for concrete. Bureau of Indian Standards, New Delhi, India.

[9] BIS: 456-(2000). Code of practice for plain and reinforced concrete. Bureau of Indian Standards, New Delhi, India.

[10] BIS: 8112-(1989). Indian standard 43 Grade ordinary Portland cement– specification. Bureau of Indian Standards, New Delhi, India.

BIOGRAPHIES

Mohd Ehtesham Azam
(UG Student, Department of Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)

Mohd Ishaq khan
(UG Student, Department of Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)

Mohammed Shahnawaz
(UG Student, Department of Civil Engineering,
ISL Engineering College, Hyderabad, Telangana)

Touseeq Anwar Wasif
(Asst Professor, Department of Civil Engineering,
ISL Engineering College, Hyderabad, Telangana)