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DESIGN AND APPLICATION OF CONCRETE BRICKS USING PHASE CHANGE MATERIALS

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Abstract

Brick made of concrete is an effective way of making a strong first impression. The use of concrete bricks seems to have more advantages than its viewable qualities. Cancelling the exterior unwanted noise, acting as an effective barrier from outside traffic noise or any flying airplane passing overhead and many other different disruptions. The other benefit of the concrete brick is the low maintenance and fire protection. Exterior walls made of concrete bricks have improving thermal mass qualities.

Phase Change Material are those type of material having high heat of fusion as compared to the conventional material. The incorporation of such material in building materials has catch my research interest because of the concern of alarming global warming and the ability of this material to help in reduction of consumption of energy in building because of the thermal storing capacity the PCM material has and increase indoor comfort of a building.

This paper presents the testing of concrete bricks which have phase change material in them and comparing it with the conventional concrete bricks. The PCM enhanced concrete bricks were casted at 5% of pcm by weight of concrete brick and were used to make a room so that the temperature could be observed at certain timings. In the process of casting, different placing alignments of PCMs in concrete bricks were used to get optimum advantage from the material. The paper shows that there was temperature variation of average of 4 to 6 degree between the PCMs enhanced concrete bricks room as compared to the conventional concrete brick room. The compressive strength decreases up to 2% which is in an acceptable range limit.

Keywords: Phase change material (PCM); Thermal storage; Sustainable; Building energy conservation; Energy storage.

I. INTRODUCTION

A. Background

One third of energy usage in many countries is due to the building energy consumptions. This tells us that sustainability is the most important criteria for the building industry. With the development of new technology, many ways have been brought up to reduce energy consumption of buildings, and one of these methods is the development of phase change

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materials. What it does is it can absorb or release energy at different temperatures, and hence when they are added to concrete, helps reducing energy consumption. One very important characteristic of building materials is thermal mass, and concrete being good at storing thermal energy is a very good carrier for PCMs.

B. Phase Change Materials

Phase change material is a substance which absorbs/releases energy during transitioning of its phase. This change that happens, is between the two phases of solid and liquid. When a phase change material at phase change temperature is melted/solidified, it stores or release large amounts of energy, larger than the sensible heat. When a material changes its phase from solid to liquid or vice versa, energy is absorbed or releases, hence phase change materials may also be known as Latent Heat Storage (LHS) materials.

Umberto Beradi in his paper (Properties of PCMs for building applications) which was published in Energy & Building (2019) mention the properties and suitability of PCMs to the field of building applications. According to him Paraffins of organic and non-paraffins are considered suitable in incorporating with gypsum and concrete and also Microencapsulated Phase Change Materials is considered to be helpful in the increment of the compressive strength that is reduced due to the introduction of PCMs[1]. Coming to the thermal properties like the latent energy storage and the thermal mass is highly improved. Thermal storage and conductivity increase when done high conductive coating of PCM as they have efficiently high heat storage capacity.

Various studies have been explained, published so far about the thermal storage properties and advantages as well as disadvantages with application of micro encapsulated phase change materials PCMs. Guangjian Peng, Guijing Dou, Yiheng Sun explained in his paper about the enhancements of PCMs in the field of building by microencapsulation and the thermal energy storage properties of the microencapsulated PCM [2]. The future in thermal storage field are the phase change materials and are having lots of attention. The microencapsulation's plays wonders by enhancing the thermal & mechanical performances in the phase change materials by sufficiently increasing the transfer area for heat transfer and leakage prevention. that the pcms has a wide variety and different applications worldwide in different section. They can be used in the fabrication of composite material and polymers. Shell materials has different type mainly three. Thermal capacity of PCMs is a wonder and can be used in high or low buildings, textiles etc. The usage of PCMs in medicines is important and valuable indeed a good application. Use with the solar energy it can be a useful alternative asset and also for the storage from solar-thermal or from electrical-thermal.

coming to the nature of PCM Branko Šavija talked about how PCM can be use to control the cracking in concrete that are usually caused due to reinforcement corrosion, mechanical loads, shrinkage, thermal deformations, and freezing and thawing [3]. By using PCM, concrete cracking can reduce as PCM temperature variations can be minimized; therefore, avoiding thermal cracking. In warm climates, incorporation of PCM has an additional benefit that goes beyond the early age behaviour. Since PCMs typically

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remain active, they will go through a phase change every time their phase change temperature is passed. Therefore, they could contribute to reducing thermal fatigue in structures exposed to temperature variations, such as concrete pavements. Branko Šavija also explained about the effects of PCM on concrete properties. Addition of concrete can alter the mechanical properties and can cause a reduction in compressive strength of concrete [3]. Therefore, the quantity of PCM that is permitted to be added in concrete should have a limit. Addition of PCM in concrete also affects thermal properties.

II. METHODOLOGY

Below is the given procedure method we have used:

Step 1: Collection of data of updated techniques: In getting the information regarding this task, we went through different research papers that were related to our topic across different sites and platform and studied them thoroughly so that the work can done smoothly and efficiently also it will help to know about the latest methods. All the research papers have been added into the literature review section as references.

Steps 2: Identify the techniques for improvement: After gathering all the techniques, all of them were fully examined and their application in the real world as well as their feasibility as well as usability was considered. Overall Impact of any given technique was also considered which would affect in this step on the process.

Step 3: Shifting for Improvement: Once after considering the most suitable technique for the process, we assembled them in a step-by-step process to manufacture the PCM enhance concrete bricks. In manufacturing the we are considering using different PCM alignment placement for better gains that could be expected. The building dimensions of the rooms for the conventional and PCM enhanced concrete bricks were set.

Step 4: Compatibility with other techniques: Other techniques were also considered for example taking the pcm by volume and the impact of these such technique had on the enhance pcm as well conventional structure of concrete bricks. We checked how these techniques may reduce the compressive strength, workability, temperature change variation etc. The behaviour of all such technique were to be studies deeply and thoroughly whether they are better than the technique we have initiated with or how good they would have been worked by introducing the PCM in concrete.

Step 5: Final changes and Overall impact: After considering all the different techniques we evaluated the work on how it is different from the basic process of the manufacture. It was done so that we could know the overall impact our technique will have on the process and we can determine the future testing chances comparing them with conventional ones and understanding the effect being shown.

Step 6: Experimentation: Performing experimental comparative analysis between the standard concrete samples of bricks to the enhanced PCM concrete brick samples. Also, in the temperature of the different room of standard and PCM enhanced concrete bricks. Further in the step the collection of variation of data in the experiment is done.

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III. EXPERIMENTAL PROGRAM

A. PCM FS29:

FS29 is an organic chemical based PCM having nominal freezing temperature of 290C. It stores thermal energy as latent heat in its crystalline form. On changing phase this latent heat is released or absorbed, allowing the ambient temperature within the system to be maintained.

FS29 is constituted of the right mix of various additives allowing equilibrium between solid and liquid phases to be attained at the melting point. It has been shown that using certain amount of pcm in concrete can increase the thermal capacity of the concrete. It has a negative effect on the compressive strength of the concrete but is in under a acceptable range.5% of pcm by weight is considered as the suitable amount to introduce in concrete bricks to increase the thermal capacity and keeping the compressive strength under check. The pcm can be added into the concrete bricks with different variation in alignment of the pcm in the brick. It can be centric, diagonal or on the edges.

TABLE I

PROPERTIES OF FS29

Property	Nominal Value
Melting Temp (℃)	29.0
Freezing Temp (℃)	28.0
Latent Heat (kJ/kg)	160
Liquid Density (kg/m3)	952
Solid Density (kg/m3)	1040
Liquid Specific Heat (kJ/kgK)	2.1
Solid Specific Heat (kJ/kgK)	2.7
Liquid Thermal Conductivity (W/mK)	NA
Solid Thermal Conductivity (W/mK)	0.45
Base Material	Organic
Congruent Melting	Yes
Flammability	Yes

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Thermal Stability (Cycles)	~2000
Maximum Operating Temperature (℃)	120
Flash Point (℃)	200

Source: Company Specification

TABLE II

MIX DESIGN FOR PCM ENHANCED CONCRETE BRICKS

Material	Details
Design	M25
Cement	Portland Cement
Water	Water/Cement ratio=0.44
Sand	Fine
Aggregates	Coarse 60%, Fine 40%
PCM	FS29, 5% per weight of concrete

Source: self

B. Steps of introducing the pcm in the concrete bricks

The following steps were taken to mix the pcm with concrete tiles

1. Create a mixture of concrete and prepare the mould of brick by oiling them with kerosene oil. The dimension of the mould should be of standard size that is (20cm X 10cm X 10cm)

2. Take the weight of mould and set it as zero point for weighing the brick

3. Put the concrete into the mould and starting spreading it so that I can get all the spaces

4. Introduce the pcm of 5% by weight into the mould.

5. Wrap the pcm in a geofibre so that it won’t displace easily and will stick together

6. Align the pcm in different manner. It can be centric, diagonal or on the edges.

C. Steps of making the room of standard and PCM enhanced concrete bricks and installation of device for temperature measurement.

1. Two rooms of 2.5sqft has to be built. The first one should be of standard bricks and the second one will be on pcm enhanced concrete bricks.

2. Use the standard bricks to build the walls of the room and after building the walls cover the top with a thick plywood board and a plastic sheet. It will work as a roof for the room.

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3. Similarly the process will be the same for the second room except each layer of the concrete bricks will have pcm of different alignments for example the 1st layer will be a centric pcm concrete brick, the second will be the one with edges and lastly the 3rd will be with the diagonal PCM. This series will go so on until the desire dimensions are achieved.

4. A temperature measuring device is installed in the center of the roof of both the rooms.

5. Taking the readings from the device at a specific time during the day of both the rooms.

IV. Testing

A. Compressive strength

To determine the effect of PCMs on the compressive strength of the concrete, Ultimate Testing Machine was used. The testing was performed in the following ways:

- The concrete cube having dimension 15cm x 15cm x 15cm is removed from water at the end of required curing time and wiped.
- The dimension of the specimen was taken to the nearest 0.2m and the bearing surface of the UTM was cleaned.
- Then the cube was placed in the machine so that the load is applied to the opposite sides of the cube cast.
- The specimen is aligned centrally in the base and the movable portion is gently rotated.
- Then we applied the load gradually so that shock would not occur, at a rate of 140kg/cm^2/minute.
- The maximum load was then recorded.

Fig 1. Compressive test machine **(Source: Self)**

B. Water absorption test

- The specimen is dried in a ventilated oven at 105 ^oC to 115 ^oC and then cooled at room temperature and its weight was taken.
- Once the specimen was completely dry, it was immersed in the clean water for 24 hours at room temperature.

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- After the completion of 24 hours, the specimen was removed, wiped with a damp cloth and weighted.
- After 3 minutes, the new weight of the specimen was taken.

Fig 2. Concrete bricks in water for Water absorption
Source: Self

C. Temperature test

- Two rooms, one made of normal standard concrete bricks and the other made of PCM enhanced concrete bricks.
- With the help of the temperature sensor shown in the picture, the temperature difference in both of the rooms is measured.
- The temperatures are measured at the interval of 4 hours every day for 3 weeks.

Fig 3. Temperature measuring device source: self

Fig 4. Two rooms with temperature measuring devices source: self

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V. Results and Discussion

A. Compressive Strength:

TABLE III

Compressive Strength test

No. of Days	Standard concrete (N/mm^2)	PCM enhance concrete (N/mm^2)	% change
7	16.73	16.34	2.3
	16.79	16.37	2.5
	16.84	16.43	2.4
14	22.45	21.88	2.5
	22.53	22.03	2.2
	22.64	22.11	2.3
28	23.95	23.44	2.1
	24.08	23.52	2.3
	24.17	23.63	2.2

The result provided in the table 5.1 shows that the use of PCM is generally decreasing the strength of the concrete by 2 to 2.5%. Figure 5.1 shows the graph pattern of comparison done between conventional or standard concrete with the PCM enhanced concrete.

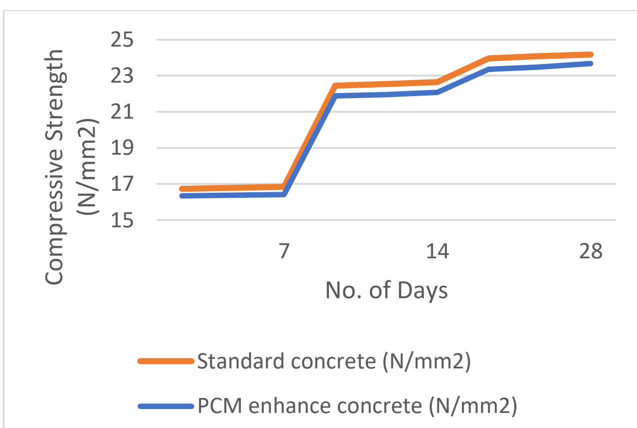

Fig 5. Compressive strength comparison between standard and PCM enhanced concrete Source: Self

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B. Water Absorption:

TABLE IV

WATER ABSORPTION TEST

Type of brick	Water Absorption %	
	Sample A	Sample B
Standard concrete brick	14%	15%
PCM enhanced concrete brick	16%	17%

As per the Farid. (2004) that the use of PCM in concrete increased porosity, accounting for increase in the water. Absorption of the concrete bricks in which PCM has been used.[8]

C. Temperature Variation

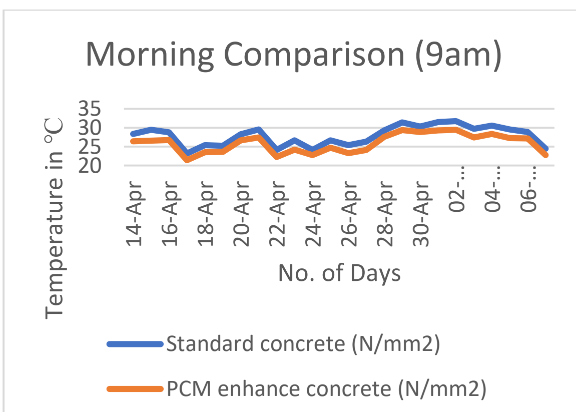

Fig 6. Morning Comparison between standard concrete bricks room v/s PCM enhanced concrete bricks room. Source: Self

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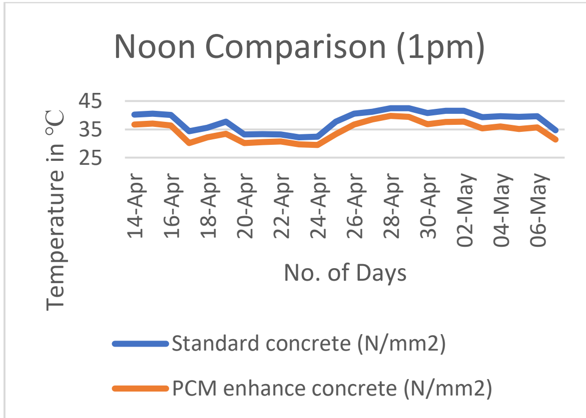

Fig 7. Noon Comparison between standard concrete bricks room v/s PCM enhanced concrete bricks room. Source: Self

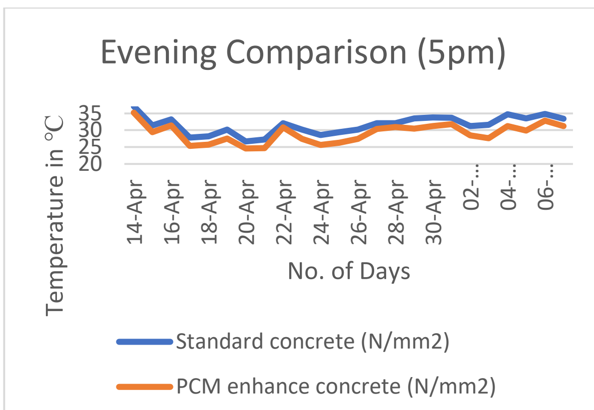

Fig 8. Evening Comparison between standard concrete bricks room v/s PCM enhanced concrete bricks room.

TABLE V

No. of	**Standard concrete (N/mm^2)**			**PCM enhance concrete (N/mm^2)**		
Location: New Delhi	Mornin g (9am)	Noon (1pm)	Evening (5pm)	Morning (9am)	Noon (1pm)	Evening (5pm)
14-Apr	28.4	40.3	37.1	26.4	36.7	35.2
15-Apr	29.5	40.6	31.4	26.6	37.1	29.4

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16-Apr	28.8	40.1	33.2	26.8	36.4	31.4
17-Apr	23.2	34.4	27.8	21.4	30.2	25.3
18-Apr	25.4	35.6	28.2	23.5	32.2	25.7
19-Apr	25.2	37.8	30.2	23.6	33.5	27.5
20-Apr	28.3	33.2	26.7	26.7	30.2	24.6
21-Apr	29.6	33.3	27.2	27.4	30.5	24.7
22-Apr	24.1	33.2	32.1	22.3	30.8	30.8
23-Apr	26.7	32.2	30.2	24.2	29.7	27.4
24-Apr	24.1	32.5	28.6	22.8	29.5	25.6
25-Apr	26.7	37.8	29.4	24.7	33.4	26.3
26-Apr	25.4	40.6	30.2	23.3	36.7	27.4
27-Apr	26.3	41.3	32.1	24.1	38.5	30.4
28-Apr	29.3	42.5	32.1	27.6	39.8	30.9
29-Apr	31.4	42.5	33.5	29.4	39.4	30.5
30-Apr	30.3	40.8	33.8	28.9	36.8	31.2
01-May	31.5	41.6	33.7	29.3	37.6	31.8
02-May	31.8	41.6	31.2	29.5	37.8	28.5
03-May	29.7	39.3	31.6	27.4	35.4	27.6
04-May	30.6	39.7	34.7	28.4	36.1	31.2
05-May	29.6	39.5	33.5	27.3	35.2	29.9
06-May	28.9	39.7	34.8	27.2	35.7	32.8
07-May	24.5	34.7	33.4	22.8	31.4	31.2

The table 5.2 shows that there is an average variation of 2 degree to 4 degree in temperature between the two rooms depending upon the hour of the day. The highest variation is mostly during the time of noon at 1pm and the lowest is in the mornings or in the evenings. This can be due to the PCM high heat storing capacity. The latent heat of FS29 is 160Kg/KJ and due to this fact, it has high thermal storage capacity which helps in keeping the temperature low as compared to the temperature in the standard room. Given below are the graphical representation of the variation of temperature between the two rooms.

VI. Conclusion

It is concluded that the PCM is a material which releases and absorbs heat during phase transition provides heat and cool which in turn helps in minimizing the energy consumption. Therefore, lowering the energy consumption cost. According to our research and experiment we discovered various findings. They are:-

Around 2.5% reduction in compressive strength was seen when 5% PCM per volume of concrete was added. The maximum amount of PCMs that can be added to concrete mix is limited by the reduction of mechanical strength and the workability of PCM-concrete composite. In terms of concrete workability, the maximum amount of PCM that can be incorporated into concrete should not be higher than 6% by weight of concrete. Correspondingly, according to various studies, approximately around 3–5% by weight of concrete (which corresponds to approximately 10–12% by volume of concrete) is the maximum amount of PCM that can be incorporated into concrete to achieve the minimum recommended compressive strength.

The concrete surfaces incorporated with PCM had a temperature around 2-4°C lower than that of non-PCM-enhanced room depending on the time of the day.

The location of Pcm have major effect on the performance of PCM walls. Incorporation of Phase Changing Materials in Concrete.

1.) Adding PCM in centre of the concrete brick.

2.) Adding PCM on the edges of the concrete brick.

3.) Adding PCM diagonally in the concrete brick.).

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