Examination of the properties of concrete with paraffin phase change material

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Abstract: Nowadays, numerous problems, including the environmental problem caused by fossil fuels, have led to greater attention to the optimal use of energy and the development of renewable energy. One of the most important parts of using energy efficiently is storing it. The application of phase change materials (PCMs) in concrete. PCMs are materials capable of storing and releasing energy based on the temperature of the environment in which they are situated. This capability makes them provide heat during cold times, and absorb heat when the temperature is higher. This paper illustrates the study on implementation of Paraffin Wax in concrete with partial replacement of fine aggregate. The total weight of fine aggregate is replaced with 10% and 20% of Paraffin Wax to study the temperature changes in thermocol box with one side wall. The thermal stability and compressive strength were tested in the period of 7, 14 & 28 days after curing. The results revealed that the combination of PW enhances the thermal stability with desirable strength for PCM implemented concrete.

Index Terms – Concrete, Phase Change Materials (PCMs), Paraffin Wax, Compressive Strength, Flexural Strength, Concrete Mix Design, Fresh Concrete, Harden Properties

1. Introduction

1.1 Introduction

Concrete, the virtually most utilized construction materials globally, is found to also have several limitations and challenges. Among these issues are depleting natural raw materials sources, high energy consumption, and increasing production cost. On the other hand, the cost of running buildings is extremely high due to high energy consumption for cooling and heating spaces within the building. About one-third of the energy consumption for most countries can be attributed to that consumed by buildings. Therefore, in order to reduce the running cost for (Vakhshouri, 2019) (Rafiza Abd Razak1, 2019) buildings and improve the sustainability of our environment, it is pertinent to find innovative alternatives to reduce the energy consumption of buildings. (A. Adesina a, 2019)

The last two decades have seen a rapid develop and research on the use of phase change materials (PCMs) in concrete to improve the energy efficiency of buildings and thermal comfort for its residents. PCMs are thermal storage materials capable of releasing and storing when they change from one state to another (i.e. solid to liquid and vice versa) depending on the temperatures to which they are subjected. There exist different types of PCMs depending on the required application, however, the common type used in concrete is the organic one. Organic PCMs are preferable for concrete because they are economical and possess a high heat of fusion when compared to other types of PCMs.

Organic phase change materials become the research focus because in its phase change process the parvafacise phenomenon is hard to happen, and it is easy to be overcooled Paraffin wax has good performance of thermal energy storage, phase transformation temperature can be adjusted and it can be processed into shapes, etc. So paraffin wax has been widely used in building's envelope.

1.2 Phase Change Materials

A phase-change material (PCM) is a substance which releases or absorbs sufficient energy at phase transition to provide useful heat or cooling. Generally the transition will be from one of the first two fundamental states of matter - solid and liquid - to the other. The phase transition may also be between non-classical states of matter, such as the conformity of crystals, where the material goes from conforming to one crystalline structure to conforming to another, which may be a higher or lower energy state.

1.3 Why Paraffin Wax is PCM?

Paraffin wax is high-molecular-mass hydrocarbons with a waxy consistency at room temperature. Paraffin are made up of straight chain hydrocarbons. The melting point of paraffin is directly related to the number of carbon atoms within the material structure with alkanes containing 12-40 C-atoms possessing melting points between 6 and 80 degrees centigrade. These are termed 'pure paraffin' and should not be confused with paraffin waxes. Paraffin waxes contain a mixture of hydrocarbon molecules with various carbon numbers with lower melting points and poorer latent heats than pure paraffin. Paraffin waxes are often considered a low-grade PCM.

1.4 Aim and Objectives

Aim: Examination of the properties of concrete with paraffin phase change material

Objectives:

1. To evaluate the impact of paraffin wax inclusion on the mechanical properties of concrete, such as compressive strength and flexural strength

2. To investigate the effect of temperature in open exposure to sunlight of concrete with and without PCM

2 Literature Review

1. A.Adesina, P.O. Awoyera, A. Sivakrishna, (Aug 2019) " Phase change materials in concrete: An overview of properties"

From this paper we can find that the properties of PCM in concrete and how it changes with change in percentage of PCM. Advances in material technology in the last two decades have shown that the incorporation of phase change materials (PCMs) into the most used building material in the world (i.e. concrete) is one of the ways to tackle the building energy problem. Phase change materials are capable of absorbing and releasing energy based on the temperatures they are exposed to.

2. Amir Reza Vakhshouri (2019) "Paraffin as Phase Change Material"

In this chapter of the book attempts to briefly discuss paraffins and their unique role in thermal energy storage systems as phase change materials. Among the many ways introduced for energy storage, thermal energy storage, including latent heat, is among the most interesting. This storage is done with materials called phase change materials (PCMs). These materials store the energy in the form of latent heat at constant temperature during the phase transition, discussed in this chapter, and release the same stored energy in the crystallization process.

3. Adeyemi Adesina (Jun 2019) "Use of phase change materials in concrete: current challenges"

Sustainability awareness in the building industry has increased in recent years, and several initiatives have been developed. One of the areas gaining attention recently is the application of phase change materials (PCMs) in concrete. PCMs are materials capable of storing and releasing energy based on the temperature of the environment in which they are situated. This capability makes them provide heat during cold times, and absorb heat when the temperature is higher. As concrete is the most used building material in the world, the use of PCMs in concrete will be a great way to widen the application of PCMs.

4. Mohamed Teggar, Kamal A. R. Ismail (Feb 2022) "A Comprehensive Review on Phase Change Materials and Applications in Buildings and Components"

The review shows the wide penetration of PCM in the building sector supported by intense research and development activities. As a result many certified PCM-based products are available in the market. It is hoped that this review can be of help to researchers, developing engineers, and architects working in the area. Phase change materials (PCMs) have shown their big potential in many thermal applications with a tendency for further expansion.

5. Azain Sayekar , Akshay Mali , Nagesh Wadekar (2019) "A Review on PCM Heat Exchanger Using Paraffin Wax"

The main aim of our project is experimentally investigating the feasibility of an expanded paraffin wax phase change material (PCM) heat exchanger operating as a condenser in an instant air source. The temperature distribution and volume expansion of an expanded paraffin wax were investigated and tested under different inlet water flow rates.

6. D. Zhou, C. Y. Zhao, Y. Tian1 (2022) "Review on thermal energy storage with phase change materials (PCMs) in building applications"

Thermal energy storage with phase change materials (PCMs) offers a high thermal storage density with a moderate temperature variation, and has attracted growing attention due to its important role in achieving energy conservation in buildings with thermal comfort. Various methods have been investigated by previous researchers to incorporate PCMs into the building structures, and it has been found that with the help of PCMs the indoor temperature fluctuations can be reduced significantly whilst maintaining desirable thermal comfort.

7. Pania Meshgin and Yunping Xi (Feb 2021) "Effect of Phase-Change Materials on Properties of Concrete"

This paper presents the results of an experimental investigation of using phase change materials (PCMs) in portland cement concrete. The objective of this study is to improve the thermal properties of concrete as a structural material. A compression test, flexural test, drying shrinkage test and thermal conductivity test were conducted. PCMs are used in concrete mixtures as both sand replacement and additives.

4. Methodology

3.1 Introduction:

The application of phase change materials (PCMs) in concrete. PCMs are materials capable of storing and releasing energy based on the temperature of the environment in which they are situated. This capability makes them provide heat during cold times, and absorb heat when the temperature is higher. As concrete is the most used building material in the world, the use of PCMs in concrete will be a great way to widen the application of PCMs. The Paraffin Wax (PW) is used as PCM in concrete.

This paper illustrates the study on implementation of Paraffin Wax in concrete with partial replacement of fine aggregate. The total weight of fine aggregate is replaced with 10% and 20% of Paraffin Wax to study the temperature changes in thermocol box with one side wall. The thermal stability and compressive strength were tested in the period of 7, 14 & 28 days after curing. The results revealed that the combination of PW enhances the thermal stability with desirable strength for PCM implemented concrete.

The aim of this paper is to explore briefly the effect of PCMs on major properties of concrete that indicates its viability to be used for large scale applications. The properties explored are the fresh, mechanical and durability properties

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3.2 Material Used

3.2.1 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).

3.2.2 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.

3.2.3 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.

3.2.4 Paraffin Wax

Paraffin wax are also known as petroleum wax obtained from coal, petroleum and shale oil. Paraffin wax are odourless and bluish white substances which are having specified characteristics of being solid at room temperature and begin to melt above (approximately) 37°C. Such paraffin wax can be used as a partial replacement in the concrete which provides heat energy storage in colder seasons of building.

Fig.1: Crushed paraffin wax

3.3 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 M30 grade concrete

Materials	Quantity in Kg (for 1m^3)
Cement	682.33
Fine aggregate	569
Coarse aggregate	1102
Water	307

Table -1: Materials of concrete and its quantity

Materials	Proportion
Cement	1
Fine aggregate	0.75
Coarse aggregate	1.5
Water	0.45

Table -2: Materials of concrete and its proportion

Sr. No.	Description	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (lit)	Paraffin Wax (Kg)
1.	Compressive Strength Test	2.30	1.2	3.72	1.035	0
2.	Flexural Strength Test	9.9	8.20	15.90	4.5	0

Table -3: Mix proportion for conventional concrete

Sr. No.	Description	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (lit)	Paraffin Wax (Kg)
1.	Compressive Strength Test	2.30	1.08	3.72	1.035	0.120
2.	Flexural Strength Test	9.9	7.38	15.90	4.5	0.82

Table -4: Mix proportion for 10% paraffin wax replacement concrete

Sr. No.	Description	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (lit)	Paraffin Wax (Kg)
1.	Compressive Strength Test	2.30	0.96	3.72	1.035	0.24
2.	Flexural Strength Test	9.9	6.56	15.90	4.5	1.64

Table -5: Mix proportion for 20% paraffin wax replacement concrete

3.4 Experimental investigation

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.

3.4.1 Fresh properties

1. **Concrete Slump Cone test:**

The slump cone test for the conventional and paraffin wax incorporated concrete were to performed to obtained slump value. So we can find out the workability of concrete.

The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It can also be used as an indicator of an improperly mixed batch. The test is popular due to the simplicity of apparatus used and simple procedure. The slump test is used to ensure uniformity for different loads of concrete under field conditions.

3.4.2 Hardened properties

1. **Compressive strength test:**

Compressive strength is the capacity of material or structure to resist or withstand under compression. The Compressive strength of a material is determined by the ability of the material to resist failure in the form cracks and fissure.

In this test, the push force applied on the both faces of concrete specimen and the maximum compression that concrete bears without failure is noted.The compression strength test of the specimens reached their desired strength on the 28th day of curing.

2. **Flexural strength test:**

Flexural test evaluates the tensile strength of concrete. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending. The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading).
As same as compression strength test we are taking flexural strength test of the paraffin wax incorporated concrete specimens on 7^{th}, 14^{th} and 28^{th} day of curing period

2. **Temperature Test:**

The surface temperature test of the wall specimens was done based on the comparative records. Wall specimens are cast in thermocol box as one side of thermocol box is removed and wall specimens are casted. As the thermocol is good insulator and bad conductor of heat. Thermocol box is bad conductor of heat so it does not allow the entry of heat from the walls of thermocol box so for our experimental investigation we used thermocol box.

These prepared thermocol boxes with conventional concrete wall and the paraffin wax mixed concrete wall was placed in open exposure to sunlight. The experimental observation is done from morning 9am to evening 8pm. The thermal measurement was done by the small instrument known as Thermometer.

4. Results and discussion

4.1. Fresh Properties

4.1.1. Concrete Slump Cone test

The slump cone test for the conventional and paraffin wax incorporated concrete were to performed to obtained slump value. So we can find out the workability of concrete.

The slump cone test for the conventional and paraffin wax incorporated concrete were performed and the below slump values were obtained respectively as shown in Table 8. The workability of concrete was high in all the proportions of the concrete manufactured.

Sr. No.	Type of concrete	Value of slump (mm)
1.	Conventional concrete	100
2.	10% Paraffin Wax Incorporated Concrete	110
3.	20% Paraffin Wax Incorporated Concrete	120

Table -6: Slump cone test result

Fig.2. Slump cone test

4.2 Hardened Properties

4.2.1 Compressive Strength Test:

Compressive strength is the capacity of material or structure to resist or withstand under compression. The Compressive strength of a material is determined by the ability of the material to resist failure in the form cracks and fissure.The compression strength test of the specimens reached their desired strength on the 28th day of curing.

The paraffin wax incorporated concrete specimens reached their attained strength showing that the strength decreases as the amount of paraffin wax composition increases respectively as shown in Table 7 and chart 1.

Sr. No.	Day	Conventional Concrete (n/mm^2)	10% Paraffin Wax Incorporated Concrete (N/mm^2)	20% Paraffin Wax Incorporated Concrete (N/mm^2)
1.	7th Day	19.40	19.08	19.00
2.	14th Day	29	26.85	24.25
3.	28th Day	35.48	30.32	27.00

Table -7: compressive strength test result

Fig.3. Compressive strength test

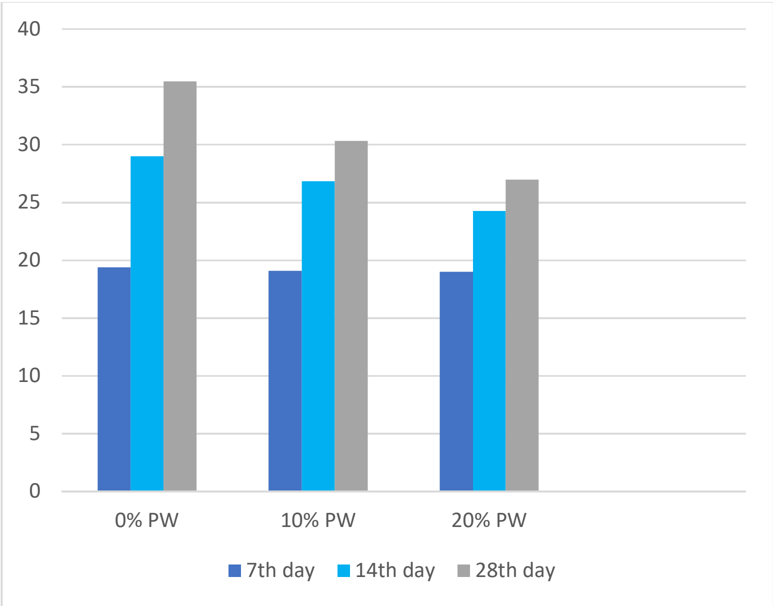

Chart.No. 1. Compressive strength test result

4.2.2. Flexural Strength Test:

The flexural strength test of the specimens showed the similar properties as the compression strength test i.e., the value of the strength decreases as the proportion of the paraffin wax increases and these proportions attained the required strength as shown in Table 8 and chart 2.

Sr. No.	Day	Conventional Concrete (Mpa)	10% Paraffin Wax Incorporated Concrete (Mpa)	20% Paraffin Wax Incorporated Concrete (Mpa)
1.	7th Day	3.30	3.1	2.90
2.	14th Day	3.41	3.20	2.95
3.	28th Day	3.50	3.28	3.10

Table -8: Flexural strength test result

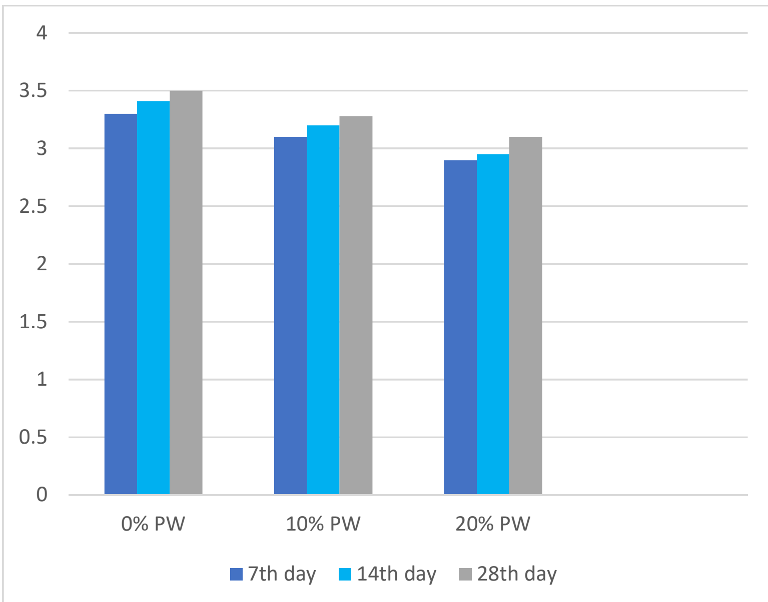

Chart. No. 2. Flexural strength test results

4.2.2. Temperature Test:

The surface temperature test of the wall specimens was done based on the comparative records. Wall specimens are cast in thermocol box as one side of thermocol box is removed and wall specimens are casted. As the thermocol is good insulator and bad conductor of heat. Thermocol box is bad conductor of heat so it does not allow the entry of heat from the walls of thermocol box so for our experimental investigation we used thermocol box.

The measurement of temperature over time in conventional concrete and in paraffin wax incorporated concrete is shown in the below table 10 and chart 3.

Fig.11. Temperature test

Sr. No.	Time	Temp. in box of wall with conventional concrete (in °C)	Temp. in box of wall with 10% paraffin wax (in °C)
1.	9am	32	32
2.	10am	33.5	33.5
3.	11am	35	33
4.	12pm	38	37
5.	1pm	39.2	38.5
6.	2pm	39.8	39
7.	3pm	40	39.8
8.	4pm	38.1	39
9.	5pm	37	38.5
10.	6pm	34	35
11.	7pm	33	34.6
12.	8pm	32	34

Table- 10: Temperature Variation over time

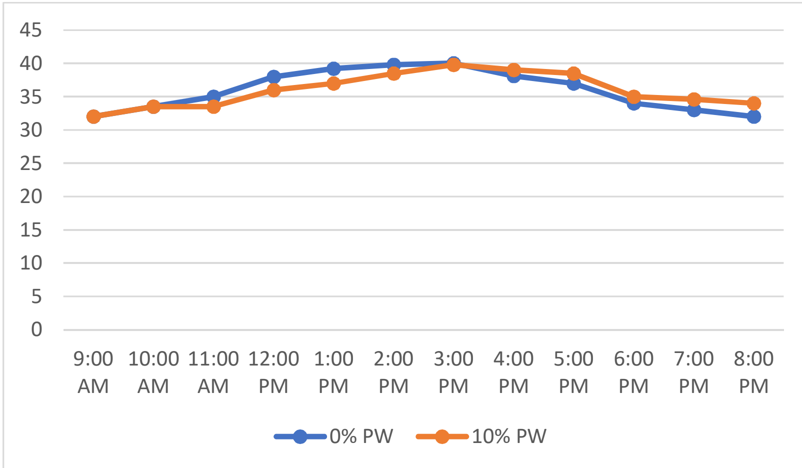

Chart. No. 3. Temperature variation over time

Fig.12. Temperature test specimens

5. Conclusion

This paper presents the effect of PCMs on various properties of concrete such as its fresh, mechanical and durability properties. Based on this overview, the following conclusions can be drawn:

1. The compressive strength of conventional concrete is 35.48 N/mm^2 and 10% incorporated paraffin wax concrete is 30.32 N/mm^2. Hence conventional concrete is 15% higher than 10% incorporated paraffin wax.

2. The compressive strength of conventional concrete is 35.48 N/mm^2 and 20% incorporated paraffin wax concrete is 27.00 N/mm^2. Hence conventional concrete is 25% higher than 20% incorporated paraffin wax.

3. The compressive strength of 10% incorporated paraffin wax concrete is 30.32 N/mm^2 and 20% incorporated paraffin wax concrete is 27.00 N/mm^2. Hence 10% incorporated paraffin wax concrete is 10% higher than 20% incorporated paraffin wax.

4. The flexural strength of conventional concrete is 3.50 Mpa and 10% incorporated paraffin wax concrete is 3.28 Mpa. Hence conventional concrete is 6% higher than 10% incorporated paraffin wax.

5. The flexural strength of conventional concrete is 3.50 Mpa and 20% incorporated paraffin wax concrete is 3.10 Mpa. Hence conventional concrete is 11% higher than 10% incorporated paraffin wax.

6. The flexural strength of 10% incorporated paraffin wax concrete is 3.28 Mpa and 20% incorporated paraffin wax concrete is 3.10 Mpa. Hence 10% incorporated paraffin wax concrete is 5% higher than 20% incorporated paraffin wax.

7. In this study, maximum strength was obtained by 10% paraffin wax incorporated concrete than 20% paraffin wax incorporated concrete, it is found that strength characteristics decreases with increase in paraffin wax.

8. 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.

9. The temperature at 8PM is about 32℃ in conventional concrete wall and temperature in 10% paraffin wax incorporated concrete is about 34℃. Hence the temperature difference is about 5% between the walls. The temperature ranging from 1.3℃ to 2℃ is increased or decreased accordance to external temperature.

10. There is a considerable temperature reduction without much change in mechanical properties of PCM concrete with respect to conventional concrete so it is feasible to use PCM material in high temperature areas.

Our outcomes of this project are:

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

6. References

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