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Enhancing the Compressive Strength of Thermal Energy Storage Concrete by Using Paraffin Wax and Waste Copper Slag

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ENHANCING THE COMPRESSIVE STRENGTH OF THERMAL ENERGY STORAGE CONCRETE BY USING PARAFFIN WAX AND WASTE COPPER SLAG

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Abstract- :- The phase change materials is trending in the engineering sciences in order to enhance the thermal comfort of buildings. Several methods introduced to reduce the building energy consumptions. Phase change materials has been capable to store and release energy, introduced in the environment. PCM_s property makes them to store energy when environment temperature is high and release energy during cold environment. Investigation of this paper is to enhance the thermal heat storage capacity without losing other properties of concrete. Partial Replacement of paraffin wax as Phase change material is with cement and waste copper slag with fine aggregates. Paraffin wax percentage (0%, 2.5%, 5% and 7.5%) and copper slag percentage (10%, 15%, 20%) employ in the concrete. Result revealed that increase in compressive strength shown up to 5% addition of paraffin wax after that falling off in the strength, flexural strength up to 2.5% there is increase and after that significant reduction was shown. Split tensile strength is increasing at 2.5% and further decreasing. The strength loses after 2.5% in all three cases as there is high performance concrete and cement quantity was reduced (compressive, Split tensile and Flexural strength reduced) and paraffin wax quantity increased (good for thermal properties enhancement). Therefore mechanical strength of PCM concrete can be improved further also by adding plasticizer into the high performance PCM concrete and more addition of paraffin wax can be used to enhance the thermal performance of the concrete.

Keywords – Phase Change Material, Concrete, Paraffin Wax, Waste Copper Slag, Compressive Strength, Split, Concrete Mix Design

I. INTRODUCTION

Phase change materials are used for heat storage as their behaviour with temperature shows the phase change from solid to liquid depends upon the environment temperature like in summer they absorb energy and in cold times they release energy meant to be better comfort inside the building. As for better comfort inside the buildings, needs basic amount of energy. By this energy consumption by building can be reduced and load bearing by the building also reduced. In summer we more dependent on electrical equipment's like Air conditioning we can reduce this by using phase change material in the concrete by this cost of the building can be reduced. Some researches demonstrated that different organic materials can be used and their applications on concrete [8] Internal structure of the PCM_S changes when phase change materials goes from one state to another that is solid to liquid or liquid to solid. Three types of PCM_s are there Organic, Inorganic, and Eutectic. Copper slag is used to enhance mechanical properties of the concrete in replacement of fine aggregates. Recent researches demonstrated that copper slag is best replacement of fine aggregates for better strength in high performance concrete [1]

Organic Phase Change Material

Organic materials originally derived from living organisms and having carbon-based compounds. Organic PCMs have the ability to absorb large quantity of heat and release during phase change process at a certain temperature. Molecules of organic material contain carbon and hydrogen or hydrocarbons and organic material soluble in

organic solvent, nature is combustible and chemical reaction takes place at slower rates. Some examples are Paraffin Wax, fatty acids and Polyethylene Glycol.[8] This research concludes the organic phase change material have inherent properties of heat storage capacity due to this property organic phase change material gained acceleration and is use in present context of the phase change material concrete.

1.1.1 Paraffin

Paraffin wax is one of them having crystalline flammable substance extracted from coal, petroleum, distillates of wood. Paraffin having straight chain n alkanes $CH_3–(CH_2)–CH_3$. This chain release large amount of thermal heat. More the chain length there is change in both melting point and thermal heat increase. Paraffin is less expensive, safe, predictable, reliable and non-corrosive. Type 2 Paraffin wax is used in or research as per IS CODE 4654 **[9]**. Paraffin wax have good thermal heat storage capacity as this is used in candle making. It is an organic material and can be used in concrete. Some researcher demonstrated that paraffin can be used in low cost water tight admixtures where compressive strength is ignored **[10]**

1.1.2 Non Paraffin

Non paraffin have the highly varied properties. Recent studies identified different types of organic materials and fatty acids, glycols and Alcohol's which is suitable for energy storage Error! Reference source not found.. The identified materials are flammable and cannot be exposed into the environment at high temperature. High heat of fusion is seen in fatty acids as compared to paraffin also show freezing and melting behaviour with no super cooling.

2 Research Significance

The thermal performance of heat storage concrete is very important for energy consumption in buildings. By using high heat storage PCM in structure can enhance the thermal properties of the structure. Addition of PCM in to the structural material enhances the thermal performance but on the other hand it effect on decrease in mechanical performance which should not be ignored and for that copper slag is used which is best suitable replacement of fine aggregates . For the enhancement of mechanical performance without losing thermal performance copper slag is used same properties as that of fine aggregates.

3 Experimental Procedure

3.1 Materials

In this research ordinary Portland cement was used. Well graded sand acting as a fine aggregates having water absorption 0.3% and specific gravity 2.63 was used in this research. Coarse aggregates was used having specific gravity 2.63, their crushing value by percent was 22, and water absorption percentage was 0.7%. 12.5 was the maximum size of coarse aggregates. Locally available Paraffin wax of TYPE 2 is used in the research as per the Indian Standard IS: 4654, wax starts melts from 45^{o}c to 75^{o}c. the maximum ash content percent by mass was 0.03, 0.5 was the exceeding limit of oil content % by mass and whit in colour was the paraffin wax. Copper slag used as the replacement of coarse aggregates having the same properties as that of coarse aggregates, 2.63 g/cm^3 was the specific gravity, crushing value 21%, 12% was the impact value and water absorption percentage was 0.4.

3.2 Preparation of PCM Concrete

Direct method technique used in this research as the percentages (2.5%, 5% and 7.5%) was calculated as per the designed target strength and then PCM material, Paraffin wax was used in the mixing process (replacement with cement) for thermal enhancement and copper slag (replacement with Fine aggregates) was used for enhancement of compressive strength of Phase Change Material Concrete as copper slag have the same properties like fine aggregates that's why used as replacement for better results.

Mix Design of PCM Concrete

Mixing ratios of concrete were prepared for the target strength, 40 MPa. The ordinary Portland cement was replaced with paraffin wax in 3 proportions that is 2.5%, 5% and 7.5% by weight of cement and fine aggregate replaced with waste copper slag in 3 proportions that is 10%, 20% and 25%. Three mixtures were prepared and tested, study the effect of Paraffin wax and copper slag on the mechanical performance (Compressive, flexural and split tensile strength) and thermal property like heat storage capacity of PCM

concrete. (**Error! Reference source not found.)** describes the mix design of PCM concrete.

3.3 Testing Method

3.3.1 Thermal properties of PCM concrete

Adiabatic temperature rise test was conducted on the hard concrete of both the specimen that is normal concrete and PCM concrete, to study the absorption of latent heat and release by the both specimen. The maximum temperature were given to the concrete was 110^{o}c from one side and temperature was checked by temperature gun. As the paraffin wax melting temperature was 45^{o}c to 75^{o}c. This process was conducted for 2 hour and after each 5 minutes the temperature was checked on all the sides with the temperature gun. After 2 hour hard specimen were taken out and placed and room temperature and again temperature was checked after each 5 minute. Through this we got to know that how much heat is absorbed by the specimen at maximum temperature and how much heat is sustained inside the PCM concrete. Comparison was checked between the normal concrete and PCM concrete. Below **Fig. 1** graph shows the heat absorbed by the specimen containing Phase change material concrete and normal concrete.

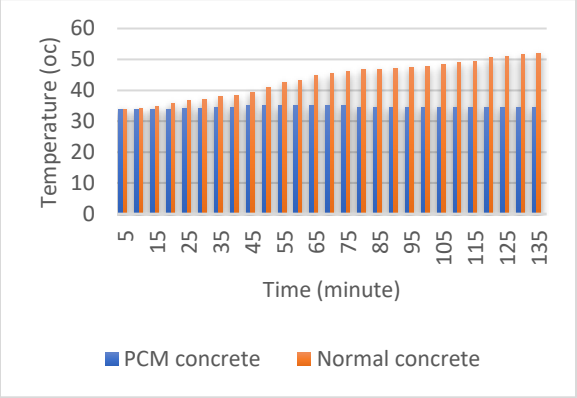

Fig. 1 Absorbed temperature b/w normal and PCM concrete

3.3.2 SEM/EDS Technique

Microstructure of the hard concrete were analysed using scanning electron microscope which helps to study the microstructure of the concrete. Powder sample was subjected to SEM analysis. When the compression testing part was done then the sample/cube was crushed and collected the sample for SEM analysis. As per lab machine requirements powdered form is needed for the test on that particular specimen of both concrete without PCM, and concrete with PCM.

4.3 X-RAY DIFFRACTION (XRD)

The type of non-destructive test for concrete is X-Ray Diffraction (XRD) used to analyse the crystalline structure of material present in the concrete. By this information of chemical composition will be find to check that what kind of materials was used in the concrete. Unknown materials and minerals were checked by this technique (XRD**). Figure 2** the XRD analysis of waste copper slag and paraffin wax in concrete.

4. Result and Discussions

4.1 Compressive Strength

The specimen having dimensions 150x150x150mm subjected to the compression testing machine having 2000 KN capacity as per the Indian Standard IS 516-1959**.** This test was performed on specimen after completion of 28 days curing. To obtain the average compressive strength for each mix there were 3 specimen casted and were tested, tested results were shown in **Fig. 3** When paraffin and copper slag were incorporated into the normal concrete at different proportions PCM concrete will reduce the strength significantly. 2.5% addition of Paraffin wax and 10% Copper slag shows the equal result to the normal concrete strength, after adding 5% and 7.5% paraffin and copper slag 20% and 30% shows significantly reduction in compressive strength. Therefore further increasing of Paraffin wax and Copper Slag it reduces the mechanical properties of PCM concrete. The possible reason for the significantly reduction in compressive strength was (i) direct method of introduction of the paraffin wax into the concrete this leads to the PCM concrete shows porous in nature. (ii) In the replacement of cement of high strength concrete some plasticizer must be used to fulfil the replacement of concrete. [1] Study shows the increase in the strength of concrete up to addition of 50% copper slag into the high strength concrete. Comparison of compressive strength between normal concrete and PCM concrete shown in **Fig. 3.**

ID	Cement	C.A	F.A.	Water	Paraffin wax	Copper Slag
	Kg	kg	kg	kg	gm	gm
Normal concrete	7.0125	14.0425	8.506	2.525	-	-
2.5% PCM, 10% CS	6.837	14.0425	7.565	2.525	175.3	850
5% PCM, 20% CS	6.662	14.0425	6.806	2.525	350	1700
7.5% PCM, 25% CS	6.486	14.0425	6.381	2.525	526.87	2125

Table 1 *Mix Design of Concrete*

4.2 Split Tensile Strength

The specimen having dimensions 150mm diameter and 3000mm length subjected to same compression machine having load capacity 2000 KN. After completion of 28 days curing period split tensile test were performed on the specimen. For each mix 3 specimen were casted and tested for the average of split tensile value. As compared to normal concrete the PCM concrete specimen shows the significant reduction in the split tensile test. Further addition of Paraffin wax and copper slag reduces the split tensile strength of PCM concrete. Error! Reference source not found.. Shows the comparison of split tensile strength between normal concrete and PCM concrete

4.3 Flexural Strength

Flexural strength Comparison between normal concrete and PCM concrete, for each proportions three specimens were casted and tested after curing period of 28 days. Then average is taken of three specimens. This same process is continued in both the cases of normal concrete and PCM concrete. PCM concrete shows significant reduction in the strength after addition the Paraffin wax in percentages from 2.5%, 5% and 7.5%, copper slag 10%, 20%, 25% into the concrete. As comparative to 2.5% and 5% almost both are nearer but after addition more paraffin that is 7% there is reduction in strength of 21.09 as compared to the 2.5% and 5% which is almost equal that is 28.97 and 28.63. Fig**. 2** shows the comparison between normal concrete and PCM concrete.

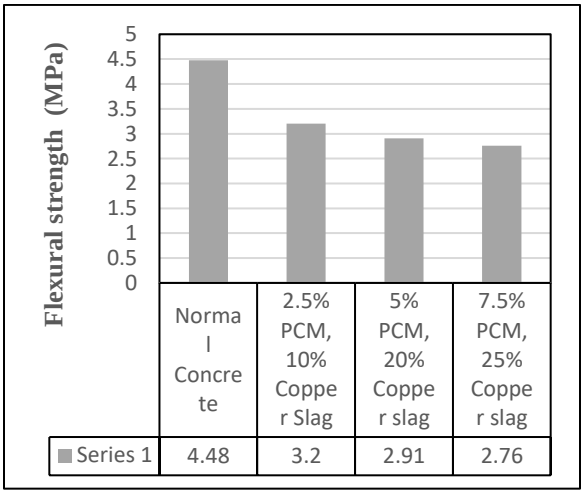

Fig. 2 Combined effect of Paraffin Wax and Copper Slag on Flexural strength

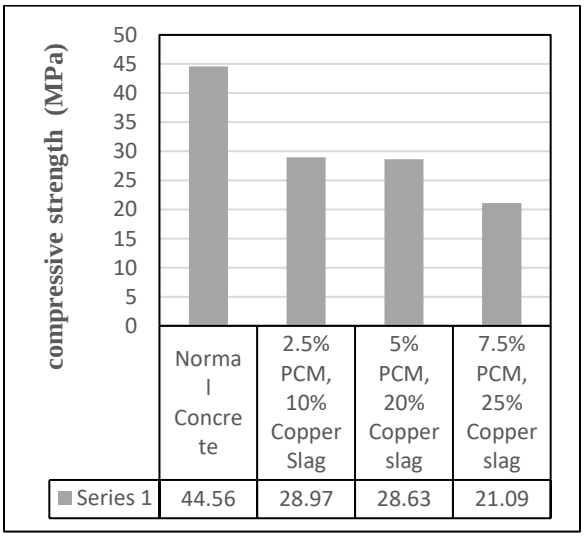

Fig. 3 Combined effect of Paraffin Wax and Copper Slag on Compressive strength

Element	Mass %	Atom %
O	13.53	26.20
Al	15.33	17.60
Si	24.68	27.23
Ca	8.85	6.84
Ti	13.98	9.04
Fe	23.22	12.88
Cu	0.43	0.21
Total	100	100

Table 2 Chemical elements present in PCM concrete

4.4 Micro Structural Analysis Micro structure of the PCM concrete was analysed at the micro level by using SEM. EDS Analysis of Phase change material concrete shown in Error! Reference source not found.. All elements present in the specimen are shown in the Error! Reference source not found.below. EDS was performed on the crushed specimen and analysis were done for the chemical composition in the specimen.

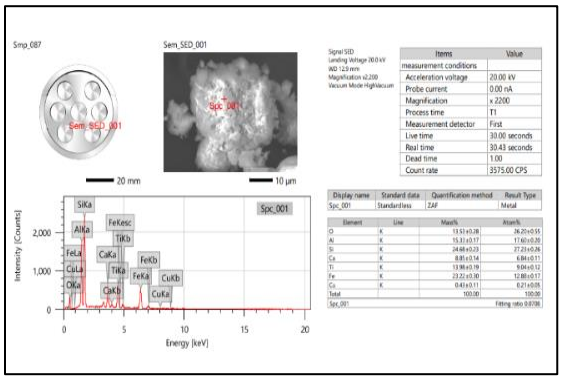

Figure 5 EDS Analysis of PCM concrete

4.5 Adiabatic Temperature rise Analysis

PCM specimen and normal specimen was subjected to the heater and placed on that specimens were tested continuous heat were given to the specimens from lower side until the heat is constant, constant temperature is after 5 minutes which was 310^{O}c after each 1 minute temperature of specimen was checked with the help of temperature gun this process continuous to 1 hour as PCM specimen temperature remain constant after 40 minutes means paraffin wax starts absorbing heat and other side temperature remain constant, paraffin wax started changing its phase from solid to liquid. Further specimen was taken out and place in room temperature and after that same temperature was checked until comes to room temperature whole process was same checked on the normal concrete in which no addition was done. Analysis between normal concrete and PCM concrete were given in

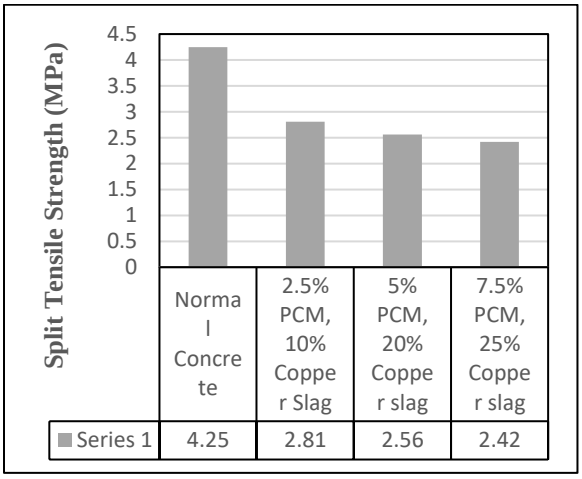

Figure 4 Combined effect of Paraffin Wax and Copper Slag on Split Tensile Strength

4 Conclusion

- In this study paraffin wax and copper slag is used to improve performance of concrete. Copper slag replaced normally available aggregates in concrete mixes in proportions of 10%, 20% and 25% by volume. Paraffin wax replaced cement in concrete mix in proportions 2.5%, 5% and 7%. Mechanical and thermal properties were analysed based on compressive strength test, flexural strength test, tensile strength test and adiabatic temperature rise test. In addition with these test, micro structural analysis (SEM) performed on the specimen to study the effect of addition of Paraffin Wax and Copper Slag in to the concrete

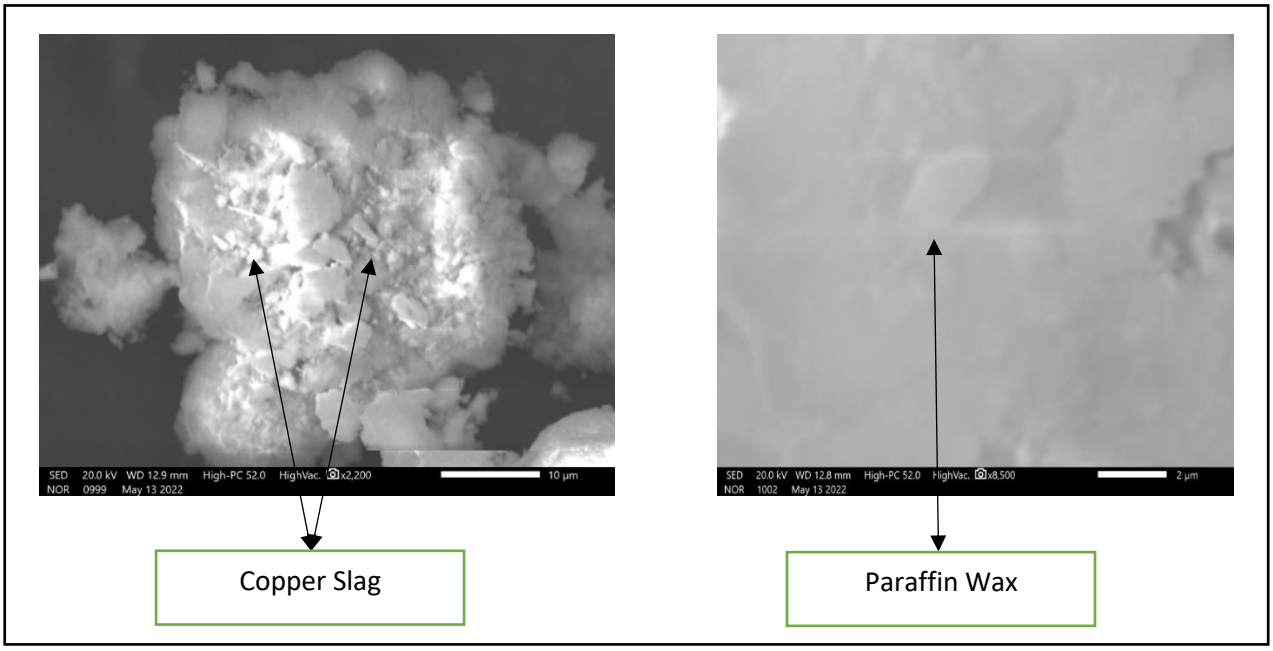

Figure 6 EDS analysis of PCM (Paraffin wax + Copper Slag) concrete

- The direct addition of Paraffin wax in to the concrete show good mechanical strength as the paraffin content significantly rise there is rise in thermal enhancement. But it leads to diminished the cracks occur in the concrete. As the paraffin wax started melting from 45^{o}c before melting cracks occur on the surface of concrete this leads to diminished of concrete strength.
- Copper slag replaced with the normal available fine aggregates shows good compressive strength they studied that up to 40% replacement of copper with fine aggregates will give good compression strength results. We used this reference for addition of copper slag in the PCM concrete give not too best result not too low results as shown in **Fig. 3.** This is may be because of replacement of cement as this is high strength concrete mix so when cement is replaced with Paraffin Wax. Further recommended is to addition of super plasticizer
- The performance of mechanical strength increase when no replacement was there, as when there is increase the paraffin wax and copper slag the mechanical behaviour of the PCM concrete diminished significantly. Compression strength of concrete at 28-days shows 44.56 MPa whereas PCM concrete compressive strength at 28 days range is 28.97.
- SEM, EDS and XRD analysis was done on the specimen, detailed elemental analysis was done on the specimen shown in above Error! Reference source not found., **Error! Reference source not found.** and Error! Reference source not found.
- Comparison between normal concrete and PCM concrete the temperature absorbed by the normal concrete was greater than PCM concrete as paraffin start melting when temperature rising above 45^{o}c then on the upper side temperature remain constant at 35.6^{o}c but as compared to normal concrete temperature start rising as the temperature increased. So paraffin shows adequate result.
- Further recommendations is to use super plasticizers for enhancing properties of concrete.
- Direct method of use of paraffin wax is not suitable for the PCM concrete as the paraffin wax is waxy in nature which when used in the mixing some of the wax is come on the surface of specimen on cement paste when vibrating on vibrator.
- If superplasticizer is used then more paraffin wax is used in the concrete for better results and can be used in high rise building keeping in mind the strength of concrete strength of the structure is more important factor if both factors fulfils then can be used in high rise building.

References

[1] Al-Jabri, Khalifa. (2006). Copper slag as fine aggregate for high performance concrete. 381-389. 10.2495/HPSM06037.

[2] Janarthanan, Anne. (2016). An experimental investigation on copper slag as replacement of fine aggregate in concrete. International Journal of Civil Engineering and Technology. 7. 282.

[3] Hawes DW, Feldman D. Absorption of phase change materials in concrete. Sol Energy Mater Sol Cell 1992;27(2):91–101

[4] Khudhair AM, Farid MM. A review on energy conservation in building applications with thermal storage by latent heat using phase change materials. Energy Convers Manage 2008;45:263–75.

[5] Kuznik, F., David, D., Johannes, K., Roux, J.-J. (2011) A review on phase change materials integrated in building walls, Renew. Sustain. Energy Rev. 15 379–391

[6] Ling, T. C., Poon, C. S. (2013). Use of phase change materials for thermal energy storage in concrete: An overview. Construction and Building Materials, 46, 55-62.

[7] Sharma A, Tyagi V, et al. Review on thermal energy storage with phase change materials and applications. Renewable and Sustainable Energy Reviews. 2009;13:318-345

[8] Dash, Lorina & Mahanwar, Prakash. (2021). A REVIEW ON ORGANIC PHASE CHANGE MATERIALS AND THEIR APPLICATIONS. International Journal of Engineering Applied Sciences and Technology. 5. 10.33564/IJEAST.2021.v05i09.045

[9] IS 4654: Paraffin wax : Bureau of Indian Standards

[10] Borhan, Tumadhir. (2006). PROPERTIES OF CONCRETE CONTAINING PARAFFIN WAX.