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Strength Characteristics of Concrete Containing Glycerine as Phase Change Material

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ABSTRACT

Glycerine is well established as a Phase Change Material (PCM). But very little is known about its effects on the structural performance of the resulting concrete. In this paper Glycerine is added at 0 %, 2.5 %, 5.0 %, 7.5 % and 10 % by weight of water and the fresh and hardened properties such as compressive strength at 7, 28, 56 and 90 days and sorptivity are experimentally evaluated. The fresh concrete produced showed a drastic reduction of slump with increasing percentage replacement with 74% reduction at 10% addition of Glycerine compared to the control mix. Further, the compressive strength also showed a drop in strength by 34.5% with respect to control mix for 10 % addition of Glycerine. The compressive strength determined at 7, 28, 56 and 90 days showed an optimum Glycerine content of 7.5% on all days. The sorptivity values are found to decrease with increase in amounts of Glycerine. The percentage reduction of sorptivity values from 2.5 % Glycerine to 10 % Glycerine was found to be approximately 6 %. It is thus concluded that addition of Glycerine to concrete results in a more watertight concrete compared to the standard concrete.

Keywords - Glycerine, Phase Change Material, physical and mechanical properties, durability.

1. INTRODUCTION

The problem of global warming was something we were currently addressing. Global warming posed a serious threat to our planet and would have a variety of detrimental environmental repercussions. Emissions of greenhouse gases (GHG), in particular CO2 emissions, were the cause of this warning. People feel uneasy because of this topic all around the world. To create a comfortable environment, they would explore for alternatives like using fans and air conditioners. Everything needed to be powered by electricity [1]. From a social, economic, and environmental perspective, it was evident that the current patterns of energy production and consumption were unsustainable. When energy demand increases, greenhouse gas emissions also increase, pushing up energy costs and accelerating global warming. Carbon dioxide (CO2) Energy-related emissions are anticipated to triple in 2050 if no action is done, which would increase demand for fossil fuels and exacerbate supply security challenges [1].

The need for energy to keep buildings at a comfortable temperature is one of the largest issues facing administration and government. When there are temporal gaps between the supply of energy and its consumption, thermal storage is necessary to ensure the continuation of a thermal process in energy systems [2]. Future generations will face serious problems as a result of excessive electrical energy use. The majority of the technology that will be produced in the future will require electrical energy, therefore this is why. Also, the air conditioner was pricey and consumed more electrical energy. The majority of people, especially those in rural areas, could not afford it.

On account of population growth and the depletion of natural energy resources, energy conservation is crucial. In the majority of nations [1-2] that contribute to the global warming issue, buildings are responsible for 30% of greenhouse gas (GHS) emissions and one-third of all energy usage. The serious threat posed by global warming to our planet has a significant impact on the environment, particularly on our ability to live comfortably. The combination of an air conditioner and a fan is a recommended solution for living in a pleasant environment. This entire process required the use of electrical energy. The thermos-physical characteristics of the building material have a significant impact on the energy needed for cooling and heating a building that involves thermal comfort [3].

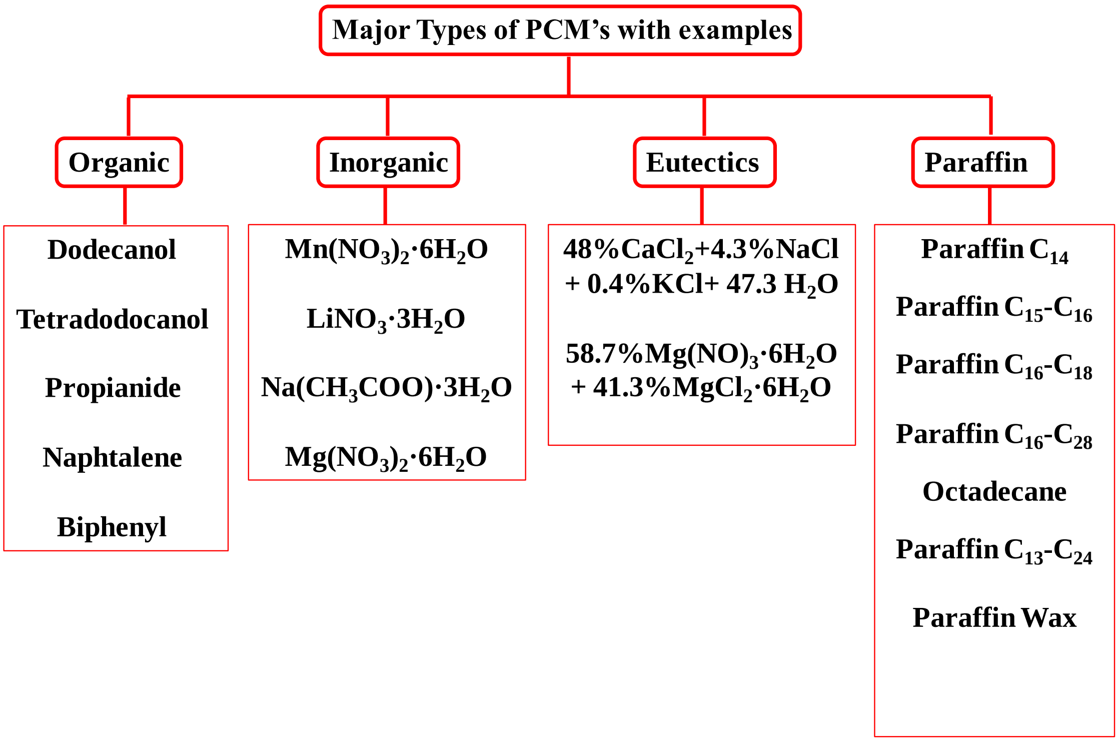

Fig. 1 Major types of PCM's with examples [14]

Conduction, convection, and radiation are the three mechanisms by which heat transfer, a vector quantity, happens [4]. A material's capacity to conduct heat is indicated by its thermal conductivity [5]. The thermal conductivity values of the construction materials affect how much energy a building uses [6]. In comparison to all other building materials, including plastic, wood, and steel, concrete is utilised in construction materials twice as often [7]. Buildings' energy consumption and heat transport are reduced by concrete with low thermal conductivity [8].

Despite these answers and demand, sustainable building development is generally gradual. The best method for the building sector to achieve its sustainability goals is to integrate a number of benefits, such as greater health and productivity, improved indoor environments, and higher energy efficiency, into the planning and construction phases of a project [9]. This study was carried out to investigate the thermal conductivity performance of a lightweight concrete block with the various applications of cooling agent. The goal was to find the best method and solution to solve the thermal problem without the use of electrical energy and in an environmentally friendly manner.

Phase-Change Phase change materials are special kinds of substances that use latent heat to store and release heat (PCMs). PCMs were used as thermal energy storage to allow buildings to control temperature during a cycle of 24 hours in order to change and release the heat. PCMs were one of the most effective management strategies for controlling building temperature throughout the daily cycle. These chemicals were classified as PCM in the initial classification of materials for thermal energy storage, suggesting that they were functional and widely utilised. The main goal of using phase change materials (PCMs) in free cooling was to lessen overheating inside buildings due to their great thermal capacity to absorb considerable amounts of heat and wide range of melting temperatures [10]. In order to control the temperature inside the area, PCMs were utilised as an alternative to air conditioning and as a means of reducing the need for regular heating and cooling [11]. The melting point of PCM must be very close to the application temperature, high specific heat must be taken into account for the PCM, and high thermal conductivity in the solid and liquid phases must be taken into consideration to support charging and discharging processes in the storage system used [12]. The four states of material phase transitions are solid-solid, solid-liquid, gas-solid, and gas-liquid. Because the other variants had technical restrictions, only the solid-liquid variety had been utilised for building cooling or heating [13]. There was a wide variety of PCMs on the market with different melting point ranges. The most common classification of PCMs are organic, in organic and eutectic as presented in Fig. 1 [14].

2. MATERIALS

This section is devoted to describe the physical and chemical characteristics of the ingredients used in the manufacture of concrete incorporating Glycerine.

Cement: OPC 53 grade confirming IS 12269-2013 [15] was used in this work. The physical properties of cement used in the construction of slabs are presented in Table. 1.

Table 1 Physical Properties of OPC-53

Fineness (%)	2.09
Le Chatelier Soundness (mm)	8
Specific Gravity	3.15
Consistency (mins)	30
Setting Time (mins)	102 (IST), 255 FST
Compressive strength (MPa)	28 (3 Days), 40 (7 Days), 57 (28 Days)

The chemical properties following IS 12269-2013 [15] were also evaluated and are presented in Table 2.

Table 2 Chemical Properties of OPC-53 (%)

Loss on ignition	3.1
CaO	66.72
SiO2	18.93
Al2O3	4.57
Fe2O3	4.90
MgO	0.83
K_2O	0.45
Na_2O	0.12

Coarse Aggregates: Basalt aggregates which were available from a nearby quarry and confirming to IS 2386-1963 (Revision 2016) [16] and 20 mm down particle size was used. To ensure complete elimination of deleterious materials such as silt, dust and, unsound particles detrimental to concrete, the aggregates were thoroughly washed with tap water and dried in the air for 24 hours. The physical properties of coarse aggregates (CA) are mentioned in Table 3. River sand confirming to IS: 383-2016 [17] was used in this work, with particle size distribution as shown in Fig. 2.

Fine Aggregates: River sand confirming to IS: 383-2016 [17] was used in this work, with particle size distribution as shown in Fig. 2.

Glycerine: Glycerine is a water-soluble, colourless, odourless, viscose liquid. Glycerine is one of the phase change materials (PCM). It is the most important by-product during the production of biodiesel and its yield was considerably high. Glycerine plays an accelerating role of reaction to the surrounding. Its melting point is 17.9°C and latent heat is 198.7kJ/ kg

Table 3 Properties of coarse aggregate and fine aggregate confirming IS 2386-1963(Revision 2016) [16]

Coarse Aggregate	
Property	**Values**
Aggregate crushing value,%	20.62
Aggregate impact value,%	10.48
Los Angles abrasion value, %	12.08
Bulk density, kg/m^3	1623
Fineness modulus	6.3
Water absorption, %	0.45
Flakiness index,%	6.9
Elongation index, %	11.5
Specific gravity	2.66
Fine Aggregate	
Bulk density, kg/m^3	1532
Fineness modulus	2.48
Water absorption, %	0.57
Specific gravity	2.62

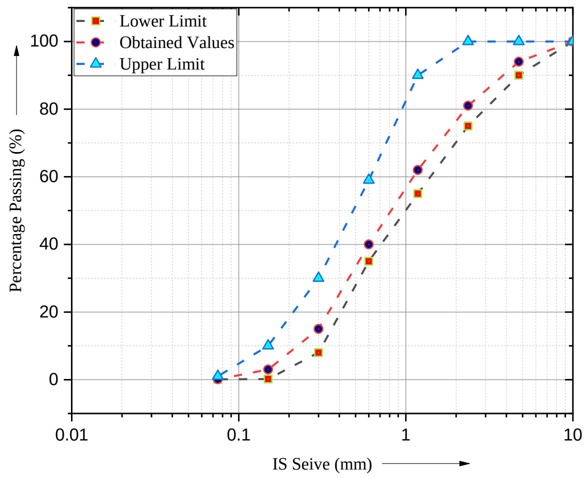

Fig. 2 Particle size distribution of sand

3. TECHNIQUES

This section describes the mix proportioning, casting, curing and the various tests performed on concrete specimen and procedures incorporated in the present work.

Mix Proportioning: Glycerine was added to the wet concrete mix with successive increments of 2.5 % by weight of up to 12.5 %. For brevity, notation presented in Table 4 is used for mixes containing different percentages of Glycerine. The mix proportions of concrete containing Glycerine was done based on IS: 10262:2019 [18] and presented in Table 5. A preliminary mix with a water-cement ratio of 0.40

resulted in a stiff mix which was not workable and the slump value was found to be only 25 mm. Hence, in order to make the fresh concrete workable, the water-cement ratio was increased to 0.50.

Table 4: Notation of mixes and their expansion

Notation	Expansion of Notation
M0	Concrete with 0% of Glycerine
M1	Concrete with 2.5 % of Glycerine
M2	Concrete with 5.0 % of Glycerine
M3	Concrete with 7.5% of Glycerine
M4	Concrete with 10% of Glycerine

Workability: Slump test in accordance with IS: 1199-2020 [19], was conducted on fresh concrete to investigate the workability. The fresh mix of concrete containing Glycerine appeared rich and cohesive. The test values of workability are presented in Table 6. The mix was designed for medium slump value in the range 75-100 mm, as per IS: 456-2000 [20]. For the control mix, the slump value was found to be 85 mm. Addition of Glycerine drastically reduced the slump and at a replacement percentage of 10%, nearly 74% reduction in slump value was observed.

Table 5: Design mix proportions of C20/25 concrete with varying % of Glycerine

Mixes	Cement	FA	CA	Water	Glycerine
M0	1	1.77	2.86	0.5	0.0
M1	1	1.77	2.86	0.5	4.8
M2	1	1.77	2.86	0.5	9.6
M3	1	1.77	2.86	0.5	14.4
M4	1	1.77	2.86	0.5	19.2

Mechanical Properties: A total of 140 samples of cubes with various percentages of replacements were casted for testing the compressive strength characteristics of concrete in accordance with IS: 516-1959 (Reaffirmed 2004) [21]. An average of 3 specimens for every mix was taken for 7, 28, 56 and 90 days and is presented in Fig. 3.

Table 6: Slump of fresh concrete with varying % of Glycerine

S.No.	Mixes	Slump (mm)
1	M0	85
2	M1	78
3	M2	65
4	M3	52
5	M4	40

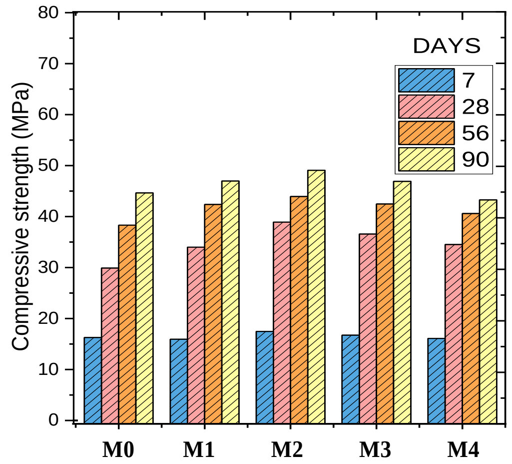

Fig. 3 Compressive strength of concrete containing varying % of Glycerine at 7, 28, 56 and 90 days

The compressive strength in MPa of M0 at 7 days was found to be determined at the age of 7 days at 16.22 MPa. The compression strength of M1, M2, M3 and M4 presented a nominal increase in strength of 0.74%, 0.92%, 0.87% and 0.74% compared to the control mix (i.e. NAC) respectively. The strength of M2 was seen to be the maximum compared to control mix at 7 days. At 28 days, the strength showed a sudden increment compared to the 7 days strength for all the mixes. This increment was maximum in case of M2 and was nearly double the corresponding value obtained at 7 days. After 28 days, i.e. at 56 and 90 days, the increase in strength of the mix was relatively less. Nevertheless, in all days, the maximum was obtained at M2. As the percentage of Glycerine further increased to 7.5 % and 10%, the strength decreased. Although even at 10% replacement levels, the 7 days strength was comparable to the control mix and at 28, 56 and 90 days, the strength was much more than the control mix.

Sorptivity: In order to conduct the sorptivity test, three specimen of 30 mm slice was removed from three concrete cubes of size 100 mm x 100 mm x 70 mm. The age of these cubes was 90 days. The specimens were oven dried for three days at 55˚C and cooled in desiccators. To prevent the sorption of water from the sides and allow the sorption only from the bottom, epoxy resin was coated all along the sides. The specimens were immersed in tap water contained in pans maintaining a water level of 5 mm from the bottom of the pan. The schematic of the experimental set-up is shown in Fig.4. The mass of these specimens were measured accurately at regular time intervals after removing the excess water using absorbent cloth. Based on the data of absorbed volume of water, the slope of line fitted to the plot of cumulative absorbed volume of water per unit area of inflow surface versus square root of time was calculated. This is termed as the sorptivity co-efficient and is given by

$$f_{sc} = i / \sqrt{t}$$

Here, f_{sc} = sorpitivity coefficient, mm/√min.,

i = cumulative absorbed volume of water per unit area of inflow surface, mm and

t = elapsed time, min. For each test, the readings up to 16 min. were ignored to find the slope of best fitted curve.

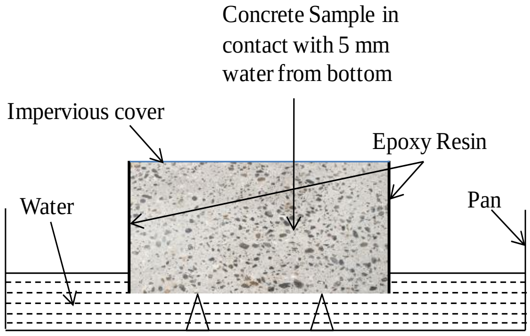

Fig. 4 Set-up for Sorptivity measurements

The results of the sorptivity test are presented in Fig. 5. The sorptivity values were found to decrease as the Glycerine percentage increased in concrete. An addition of 10% of Glycerine resulted in a reduction of sorptivity values by nearly 9% compared to control mix. The percentage reduction of sorptivity values from 2.5 % Glycerine to 10 % Glycerine was found to be approximately 6 %. It is thus concluded that addition of Glycerine to concrete results in a more watertight concrete compared to the standard concrete.

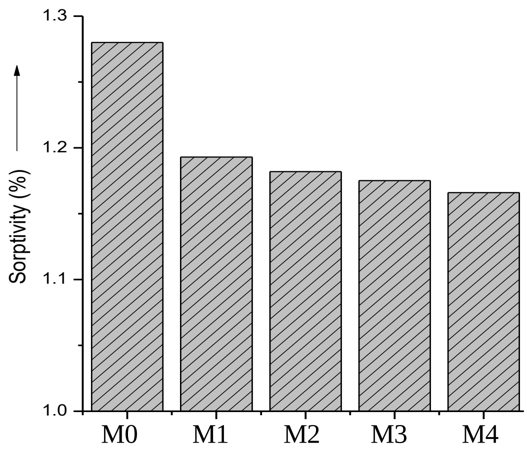

Fig. 5. Sorptivity values with varying % of Glycerine

4. CONCLUSION

The present experimental research focussed on the fresh and hardened properties of concrete incorporating Glycerine. It is selected as an additive to concrete as it is reported to be a suitable PCM. Further, not much literature is available on the strength and durability effects of its addition to concrete. Based on this work, the following conclusions can be drawn:

- The workability of the fresh concrete containing Glycerine was found to reduce drastically with the increase in its percentage.
- The compressive strength determined at 7, 28, 56 and 90 days showed an optimum Glycerine content of 7.5% on all days.
- The sorptivity values are found to decrease with increase in amounts of Glycerine. The percentage reduction of sorptivity values from 2.5 % Glycerine to 10 % Glycerine was found to be approximately 6 %. It is thus concluded that addition of Glycerine to concrete results in a more watertight concrete compared to the standard concrete.
- Additional tests on chemical effects on resulting concrete and durability aspects such as freeze and thaw, abrasion resistance, rapid chloride penetration test etc. could be conducted to further ensure the quality of resulting concrete.

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