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Paraffin as a Phase Change Material in Concrete for Enhancing Thermal Energy Storage

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Abstract. Phase change material (PCM) for thermal energy storage (TES) is the material that can absorb energy during heating process as phase change takes place and release energy to environment during cooling process. Nowadays, energy consumption trends in construction building show a significant increase. It is important for reducing energy consumption in building by decreasing the energy demand and providing thermal human comfort inside the building. The objectives of this research are to determine the optimum percentage of PCM in concrete affected by time to achieve high thermal storage performance and evaluate the mechanical properties in different percentage of PCM concrete. Various percentage of 0%, 5%, 10% 15% and 20% of PCM concrete added with Ground Granular Blast Slag (GGBS) as filler were prepared and tested after 7 and 28 days of curing process. The result shows the thermal storage energy effective when integration with PCM in concrete. Besides, the compressive strength, water absorption and density measurement decrease with increasing amount of PCM. In conclusion, 5% of PCM with 30% GGBS added in concrete resulted in better thermal energy storage and compressive strength compared to other percentages of PCM concrete samples.

1. Introduction

Thermal energy storage (TES) is defined as the capable to store heat energy with the help of sensible heat storage or latent heat storage material. Latent heat materials are considered as phase change material (PCM) which is interchange solid and liquid state known as phase change. Therefore, PCM can act as insulator in concrete wall to prevent solar heat entering the building. When cement wall added with PCM material as a construction material in building, it will produce high performance of heat energy storage material. The thermal properties and heat transfer of this TES material will stimulate thermal energy storage in concrete. Phase change material (PCM) as a latent heat storage was use as application in building show had high potential can be used in passive cooling and heating strategies in Europe [1].

Moreover, it has been found that PCM helps indoor temperature to be reduced to maintain desirable temperature for a longer period of time [2]. Thus, PCM can be a useful way to improve the building thermal performance. When the temperature increases at a certain melting point, the PCM will start to absorb the heat from outside which it phases changed from solid state to liquid state. However, when



the temperature decreases, the PCM will release energy away and turn back to solid state from liquid state. Paraffin is a type of organic PCM. Paraffin is a white or colourless soft solid, derivable from petroleum, coal or oil shale. In this research, paraffin is chosen as the phase change material to investigate the thermal storage capacity in building.

2. Experimental Procedures

2.1. Raw Materials

Paraffin is the hydrocarbons which having the general formula C_nH_{2n+2} , C being a carbon atom and H is a hydrogen atom. The mixture of solid straight-chain hydrocarbons ranging in melting point from about 48 °C to 66°C. The paraffin used with size not more than 1mm. Besides, the chemical composition of ground granulated blast furnace slag (GGBS) is identically to the Portland cement. It is produced from the blast furnaces. Replacing Portland cement with GGBS can increase the strength of concrete. 30% GGBS can achieved the highest strength in concrete compared to others percentage of GGBS [3].

2.2. Mix Design and Process

The grade of concrete is 35. The concrete mix design calculation is shown in appendix A. The proportion of coarse aggregates and fine aggregates are 65% and 35% of the total proportion of aggregates in concrete mixture. The water-cement ratio is 0.45. All the mix design for GGBS ratio was fixed at 30% of the total weight of cement replacement since the 30% of replacement is the limit and best percentage of replacement to reduce heat hydration and increase strength of concrete [3], [4]. Besides, there are 5 different percentages of paraffin added in proportion to dry materials concrete including 0%, 5%, 10%, 15%, and 20% [5].

For the concrete mixing process, the dry materials such as coarse aggregates, fine aggregates, GGBS, paraffin, and OPC cement were mixed together. Then, the water will be added into the dry mixtures. After the mixture reaching the proper consistency, the fresh concrete was poured by three layers into the cubic moulds and compact it by the rod with dropping the rod. After casting of specimens, the specimens were left inside the room at room temperature for 24 hours. Then, the specimens were immersed in the water tank which filled with water for 7 and 28 days.

2.3. Testing and Analyzing

The thermal energy storage (TES) test was according to EN ISO 9659-1:1993, the stimulation of change between day and night by periodical illumination is used in this experiment. The experiment will be examined the situation with two layered PCM concrete samples represent as the walls of the building materials. Besides, the compressive strength is determined according to BS 1881-116:1983. The compressive strength of concrete is used to test the capable of the concrete samples to resist the forces by compressing it when the weight is applied until concrete samples failure. Moreover, the density measurement test was determined according to BS EN12390-7. The density for 28th day after curing process of concrete specimen is determined. The density was calculated at 28th day of specimen taken out from the water. The density of different percentage of specimens are calculated and compared. The method for determination of water absorption was according to BS 1881-122. The different percentages of PCM in concrete with cubic size samples were obtained and tested at 28th day.

3. Results and Discussion

3.1. Thermal Energy Storage

Based on the result obtained in Figure 1 and Figure 2, it can be seen that the temperature quickly increases while the temperature between the concrete panels and the temperature inside the calorimetric chamber changes slowly. After turning off the lamp, the outside temperature decreases quickly. The temperature changes periodically by switching on and off the light source about every 10 minutes with a temperature wave is generated by about 4°C. Solidification and melting of PCMs in every cycle and night cooling is important to achieve full performance of the PCM storage [6].

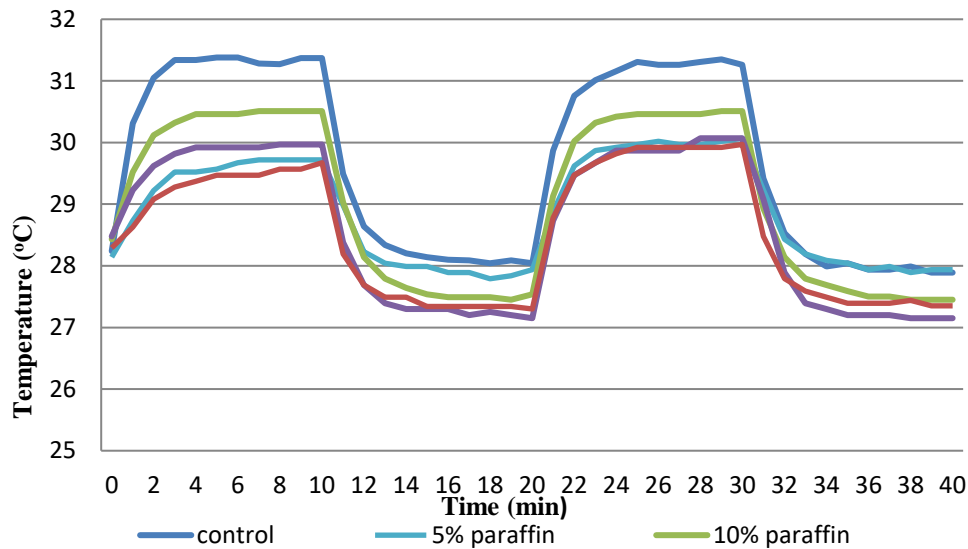


Figure 1. Outer surface concrete temperature versus time in different paraffin in concrete on 7 days.

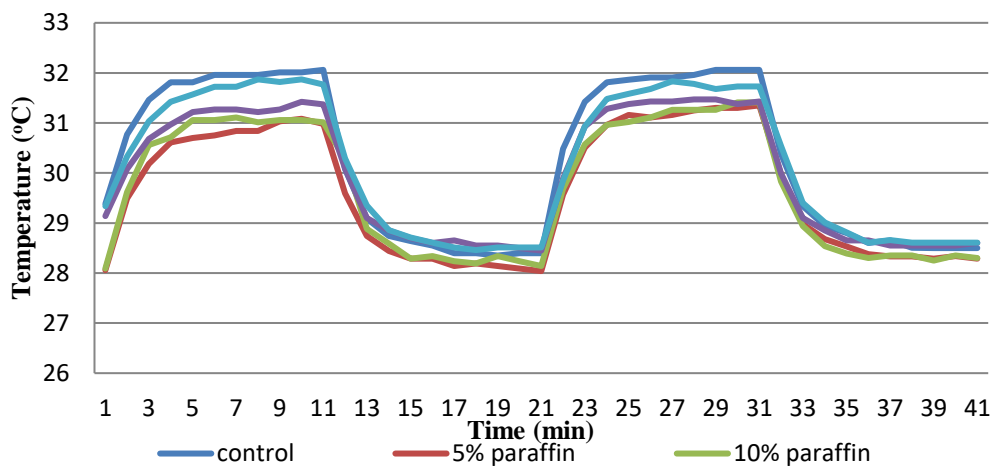


Figure 2. Outer surface concrete temperature versus time in different paraffin in concrete on 28 days.

The 5% paraffin in concrete had the lowest temperature obtained in peak temperature, that means highest level of latent heat storage of paraffin. Similarly, the peak temperature decreasing also mainly result from the sensible heat storage and also effected in the inside temperature decreasing. The 5% paraffin in concrete which was the best in heat reducing performance, showed the reduction of temperature by around 3°C compared to other percentage of paraffin concrete which is around 3.5°C.

Besides, the temperature of the 5% paraffin concrete did not change during 18-20 minute. It is believed that the heat transfer to the paraffin took place during this period. Then there was a temperature rise with significantly increase at about 20-22 minutes. The sudden increase in temperature indicated the completion of phase transition of PCM.

The results showed the peak temperature is lower when addition of paraffin into the concrete. It is due to the integration of paraffin to the concrete causing decrease in thermal conductivity. A reduction of thermal conductivity will affect the rate of heat to absorb and release. The reduction in thermal conductivity is due to increased air content in concrete and voids content when increasing the percentage paraffin in concrete [7].

3.2. Compressive Strength

From Figure 3, GGBS concrete had lower strength at the early ages, however long term strength will be increased [8], [9]. Both the trend lines at days 7th and 28th are decreasing from 0% of paraffin added in concrete until 20% of paraffin with constant 30% GGBS replace cement content. It showed that the compressive strength of the concrete samples decreased as the percentage of paraffin increased. This is due to the inhomogeneity of the mixture. Paraffin can be in solid and liquid phase which will not react with the concrete mixture [10] and more pores observe at high percentage of paraffin in concrete. It shows that the addition of paraffin does not contribute to the strength development, but paraffin can maintain a good thermal storage material.

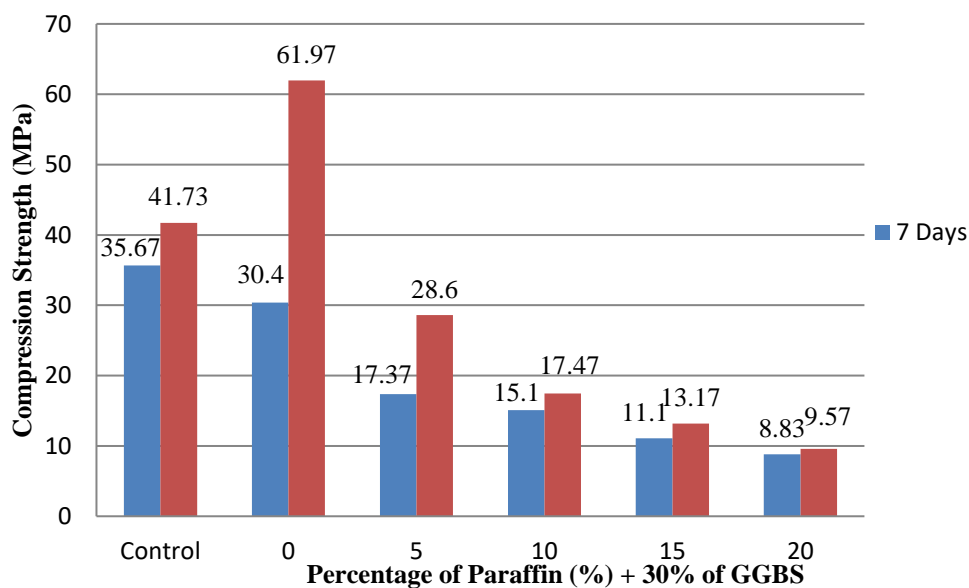


Figure 3. Compressive strength of concrete with addition paraffin at various percentage on 7 and 28 days.

3.3. Density

Figure 4 showed that the density of concrete samples decreasing when the percentage of the paraffin increasing in the concrete sample. It is because the paraffin in concrete containing high porosity values than the control concrete samples and containing air and voids in the concrete samples [11]. Besides, paraffin contains low specific gravity, thus density of concrete with high contain of paraffin were less density compared to normal concrete samples.

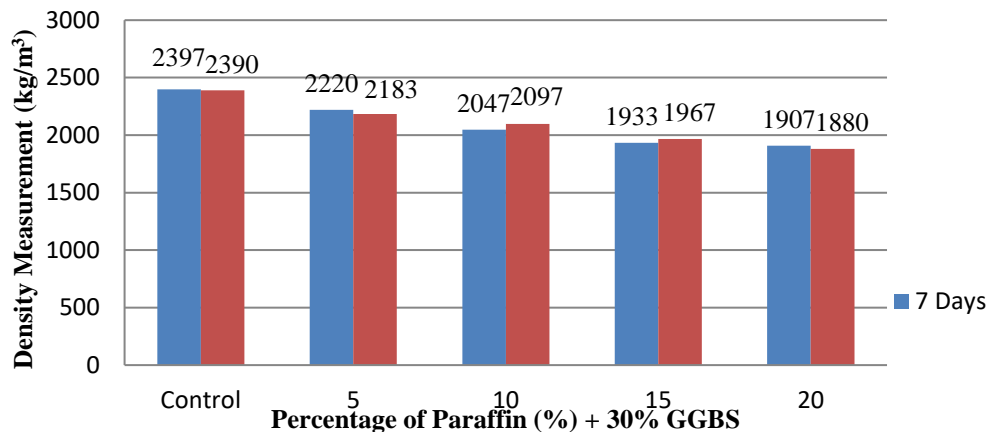


Figure 4. Comparison of the density measurement on different percentage of paraffin in concrete at 7 and 28 days after curing process.

Moreover, 20% of paraffin in concrete sample shows the density closely to be classified as lightweight concrete at 28th days. The density of unit weight concrete which determined in the dry state should not exceed 1840 kg/m³, and is usually between 1400 and 1800 kg/m³ [12]. Thus, the concrete sample contents more than 20% of paraffin can be used as internal wall for insulation purpose to achieve human thermal comfort without spending building energy use.

3.4. Water Absorption

According to the Figure 5, the trend line shows the percentage of water absorption is significantly decreasing until 10% paraffin in concrete. However, the water absorption value shows increasing when the percentage of paraffin in concrete is getting higher. The highest water absorption obtained is control concrete which is 1.79%. It observed that the paraffin concrete showed merely different when incorporation of paraffin in concrete more than 10%. It is because they undergoes the same transition of state of paraffin in concrete. The presence of paraffin in concrete leads to a decreasing in water absorption up to 79% when compared to control concrete due to partially or total occupation of the pores in concrete by the paraffin [13][14].

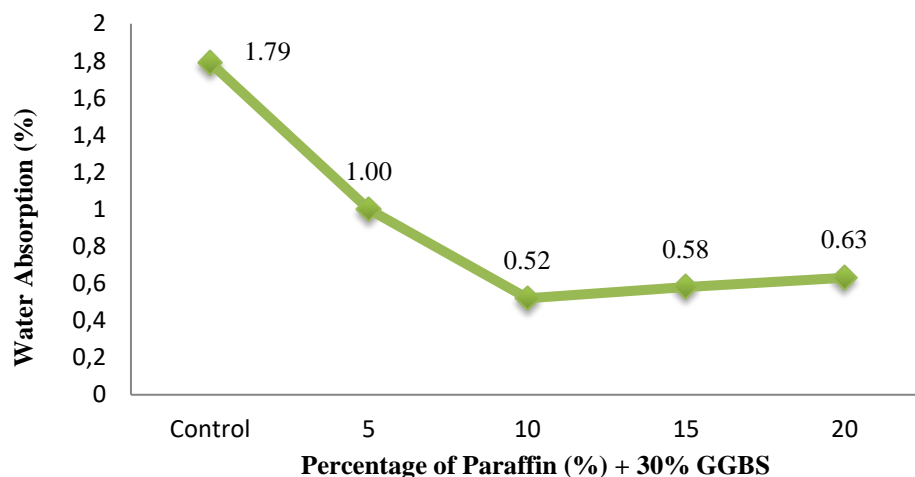


Figure 5. Comparison percentage of water absorption on different percentage of paraffin concrete on 28 days.

4. Conclusion

The various percentage of paraffin in concrete incorporating 30% GGBS in concrete samples were conducted to test the thermal energy storage, compression strength test, density measurement, and water absorption at 7 and 28 days. Based on the thermal results obtained, the 5% paraffin concrete achieve the highest thermal energy storage with lowest peak temperature obtained compared to other percentage paraffin. For the compressive strength test, the lower the percentage of paraffin in concrete, the higher the compression strength obtained. Moreover, the density is decreased when the percentage of paraffin in concrete is increased due to porosity of paraffin concrete increased. The water absorptions of the concrete were in the range of 0.5-2.0% which can be categorized as low. It can be concluded that 5% paraffin + 30% GGBS in concrete is the best percentage of paraffin in concrete. It is because it had highest thermal energy storage, high compression strength, optimized density and water absorption.

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