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Review of the Impact of Incorporation of Phase Change Materials on the Compressive strength of Concrete

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ABSTRACT

In a quest to reduce the high energy consumption by buildings, several initiatives have evolved in which the incorporation of phase change materials (PCM) into building materials has been shown to be effective by the science community. PCM are capable of capturing and releasing heat thereby maximizing the temperature supply. However, the incorporation of PCM into concrete have negative impacts on its strength due to the properties of the PCM. This review explored the effect of the use of PCM in concrete on its compressive strength with a focus on the role of the properties of PCM and methods of incorporation. Information gathered from the open literature shows that there's a reduction in the compressive strength of concrete with the incorporation of PCM, and the trend continues with an increase in the amount of PCM. However, with proper optimization and incorporation method, a negligible or acceptable reduction in compressive strength can be obtained while enhancing the thermal properties of the concrete

1. Introduction

Buildings consume a high amount of energy which is mostly from the heating and cooling of space. The consumption of this high energy also leads to a huge amount of carbon dioxide being emitted into the atmosphere. In order to reduce buildings energy consumption and detrimental emissions into the atmosphere, phase change materials (PCM) can be incorporated into building materials. PCM are capable of increasing the thermal storage of building materials, thereby resulting in a reduction in energy usage for heating and cooling. Concrete is a versatile and the most used material in the construction industry stands as the best carrier for PCMs in buildings. Incorporation of PCM into concrete will lead to enhancing its thermal properties which will consequently lead to a reduction in the energy consumption of a building.
Though the incorporation of PCMs into concrete has been found to enhance its thermal properties, there's a detrimental effect on other properties of concrete such as its mechanical properties. The induction of more voids with the inclusion of PCM has been found to reduce the compressive strength of concrete (Lecompte et al., 2015). Also, improper adhesion of the PCM with other components in the matrix alongside the properties of PCM, and incorporation methods have been found to alter the compressive strength of concrete (Cui et al., 2015). This reduction in strength has also been reported for concrete with alternative binders such as geopolymers (Shadnia et al., 2015).

With most review on PCM focused only on its thermal properties, this paper aims to explore briefly the experimental results present in open literature on the effect of incorporation of PCM in concrete on its compressive strength. Only compressive strength is explored in this article because it is the main mechanical property of concrete, and other mechanical properties can be related to it.

2. Phase Change Materials

PCM possess high latent heat capacity which gives them the ability to store a large amount of energy during phase change. During heat storage and release; these materials change from solid to liquid and vice versa. PCMs can be incorporated into concrete through direct mixing with components of concrete and impregnation into porous aggregate or concrete elements.

3. Effect of PCM on Compressive Strength

The compressive strength of concrete is its most important mechanical property and it is affected by the concrete's composition. Introduction of PCM into concrete and an increase in the amount of PCM introduced leads to a decrease in its compressive strength (Hunger et al., 2009). Reduction in strength has been attributed to PCM's low stiffness and strength which lowers the overall hardness of the concrete. It will be observed from **Figure 1** that more reduction in strength occurred when PCM was incorporated as an addition into concrete rather than as replacement by volume of the fine sand. More decrease in strength with the addition method has been ascribed to be as a result of the dilution effect of a non-binder into the concrete matrix (Pania and Yunping, 2012). Therefore, the introduction of PCM by partial replacement of sand is a more efficient method. The method of incorporation of PCM has also been found to affects its strength, most especially when

the PCM cracks into the fresh concrete mixture during mixing (Hunger et al., 2009). Incorporating PCM as the last component during mixing has been found to result in a less detrimental effect on the compressive strength (Lecompte et al., 2015; Pani and Yunping, 2012;).

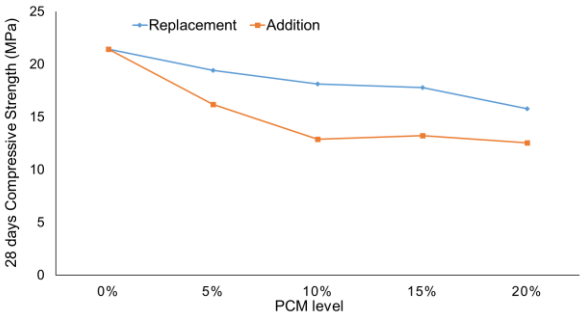

Figure 1: Effect of PCM incorporation regime on the compressive strength of concrete (Data from Pani and Yunping, 2012)

A similar reduction in compressive strength was observed incorporation of PCM in both OPC concrete (OPCC) and geopolymer concrete (OPC) as shown in **Figure 2**. However, GPC exhibited higher strength at all replacement levels compared to that of OPCC

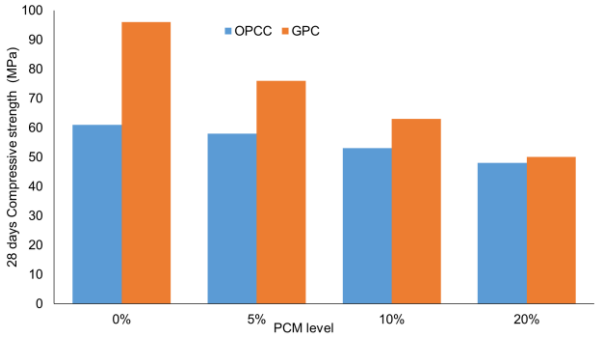

Figure 2: Effect of PCM level on compressive strength of OPCC and GPC (data from Pilehvar et al., 2017)

In an early study by Hawes (1991) using paraffin wax (PW) as PCM in concrete, he recorded higher strength more than control when the PW was used in the solid state. However, when the PW was in a liquid state; a similar strength to control was achieved. This indicates that the physical state of the PCM also influences the compressive strength of concrete. Failure pattern of composites containing PCM under compression as also be found to be different to those of conventional concrete. The spherical nature of encapsulated PCM along with its low tensile strength has been reported to cause this type of contrasting failure pattern.

3. Conclusion

Despite the overall goal of incorporation of PCM into concrete is to improve its thermal properties, more attention must be placed on not sacrificing the concrete's strength as it determines its serviceability to a great extent. Therefore, based on this review, the following main conclusions can be made:

1) Incorporation of PCM into concrete leads to a reduction in strength. The compressive strength of concrete incorporating PCMs is mainly affected by the quantity of PCM incorporated and the incorporation method
2) The use of GPC as a carrier for PCMs can complement for the strength loss of OPCC
3) Despite the reduction in compressive strength of concrete with the incorporation of PCM, a structural grade concrete can still be achieved with proper optimization that will minimize the strength loss.

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