Mechanical and thermal properties of phase change energy storage concrete

Yichao Zhang, Zhongren Zhang, Jinghai Zhou*, Ying Wang
School of Civil Engineering, Shenyang Jianzhu University, Liaoning100168, China

*Corresponding author e-mail: lunwenww@sina.com

Abstract. Phase change energy storage particles have excellent thermal properties. The phase change energy storage concrete prepared by adding phase change energy storage particles to concrete has excellent mechanical properties and thermal properties of concrete. Choosing appropriate phase change materials and mix proportion can effectively reduce the energy consumption of concrete buildings on the premise of meeting the requirements of compressive strength. In this paper, the mechanical and thermal properties of phase change energy storage concrete are reviewed, and the existing problems are analyzed, and the future development trend is prospected.

1. Introduction
With the development of our society and the improvement of people's living standards, people pay more and more attention to the comfort of living environment. At present, in China, the energy consumption of buildings accounts for 30% of the total energy consumption of the whole society, which is expected to rise to 35% by 2020. Compared with some developed countries whose climate conditions are similar to ours, the energy consumption per unit area of buildings in our country is three times of theirs [1-2]. Improving the use efficiency of building energy is an important and priority for governments all over the world. Building energy conservation can not only reduce greenhouse gas emissions, but also make economic development more sustainable [3].

As one of the most widely used building materials in the world, concrete has the advantages of strong plasticity, low cost, high strength and durability, but its thermal performance is poor, thermal conductivity is large, and it is easy to cause energy loss, which is not conducive to building energy saving. Phase change energy storage particles are used to encapsulate composite phase change materials by some experimental methods, which can not only keep the original thermal properties, but also improve the leakage and stability of composite phase change materials [4-6]. Adding phase change energy storage particles to concrete in a certain proportion can reduce the thermal conductivity of concrete, improve the heat storage capacity of concrete, and reduce the energy loss of concrete buildings in use [7-8]. At the same time, in the preparation stage, reduce the peak temperature of hydration, delay the time when the hydration temperature reaches the peak, and reduce the risk of cracks due to temperature stress [9-11]. This paper summarizes the research progress of phase change concrete in mechanical and thermal properties, summarizes the existing problems, and prospects the future research direction of phase change concrete.
2. Study on mechanical properties of phase change energy storage concrete

Phase change material is a kind of material whose state changes with the change of external temperature. When the state of material changes, phase change material can store energy and release energy. The phase change process of phase change material is a standard physical change process, that is, the phase change process of phase change material. Therefore, a lot of latent heat is absorbed and released during the phase transformation of phase change materials. The material form of phase change material changes with the change of external temperature. Take the solid-liquid phase change material as an example. When the external temperature is higher than the melting point of the phase change material, the phase change material changes from solid to liquid, which absorbs and stores a lot of latent heat (energy) during the melting process; when the external temperature is lower than the freezing point of the phase change material, the phase change material changes from liquid to solid, which releases a lot of latent heat (energy) during the solidification process. The energy stored or released in the process of phase change is called the latent heat of phase change. The latent heat of phase change material is equal to the enthalpy change value, so the latent heat of phase change is also called the enthalpy of phase change. The phase change temperature range of phase change materials is small, but when phase change materials play the role of phase change, the temperature of phase change materials themselves remains unchanged or the temperature changes slowly, so there will be a wide range of temperature changes, and a large number of phase change latent heat transfer in the process of phase change, which is a characteristic of distinguishing sensible heat materials and insulation materials. Mechanical properties are the most important properties of concrete as building materials. Because some phase change energy storage particles are added into concrete, the strength of concrete is bound to be affected. At present, the preparation of phase change energy storage concrete is mainly based on the replacement of coarse aggregate or sand by phase change energy storage particles in proportion. Xu et al. [12] prepared phase change energy storage particles with diatomite as the matrix to absorb paraffin, and added 10%, 15%, 20% and 30% of the cement mass to the cement-based composite. The results showed that the maximum reduction rates of 28 day compressive strength, flexural strength, dry shrinkage strain and thermal conductivity of the composite were 48.7%, 47.5%, 80.7% and 33.6% respectively. Liu Fuzhan et al. [13] prepared phase change energy storage particles by adsorbing paraffin with expanded perlite. The results show that when the ratio of composite phase change material to sand is not more than 50%, the compressive strength of phase change concrete is less than that of reference concrete. Dehdezi et al. [14] studied the microstructure of concrete containing 0.5%, 1%, 3% and 5% powder phase change energy storage particles. The results showed that the shell of phase change energy storage particles was destroyed during the process of concrete mixing and compaction. Narain et al. [15] mixed 20% phase change energy storage particles into each volume of concrete. The test results show that the compressive strength of concrete decreases by 25%. Considering the workability and surface void, the maximum content of phase change energy storage particles should not exceed 15% of each volume of concrete. Chaimiao et al. [16] prepared phase change energy storage particles with octadecane encapsulated in steel ball, and prepared phase change concrete with 25%, 50% and 75% of phase change energy storage particles instead of coarse aggregate. The test results show that the compressive strength will decrease with the increase of replacement rate, but the minimum strength still exceeds 40MPa.

3. Study on thermal properties of phase change energy storage concrete

Compared with ordinary concrete, thermal performance is the most important aspect of the improvement of phase change energy storage concrete. This performance can be seen from the most intuitive performance of thermal conductivity and specific heat capacity. Most studies show that the thermal conductivity of concrete decreases when phase change energy storage particles are added. Zhao Chengshou et al. [17] prepared phase change energy storage particles with silica encapsulated polyethylene glycol, and prepared phase change energy storage concrete with silica encapsulated polyethylene glycol instead of fine aggregate. The results show that the thermal conductivity of PCM is reduced by 35% and the specific heat capacity is increased by 62%. Dehdezi et al. [14] measured the
thermal conductivity of phase change energy storage concrete with 5% microencapsulated phase change energy storage particles. The results show that the thermal conductivity of phase change energy storage concrete is 0.71 W/(m·K), which is 36.6% lower than that of ordinary concrete. Cao et al. [18] studied the thermal performance of Portland cement concrete. The results show that the thermal conductivity of PCM in solid state is higher than that in liquid state. Fabiani et al. [19] used the transient plane heat source method to analyze the change process of the thermal conductivity and thermal diffusivity of the phase change energy storage concrete. The results show that the average thermal conductivity and thermal diffusivity of the concrete are reduced by the incorporation of the phase change energy storage particles.

4. Existing problems of phase change energy storage concrete
Paraffin is the most widely used phase change material at present because of its suitable temperature and low price. However, it is still expensive to use in phase change energy storage concrete, and the cost recovery cycle is too long. If phase change energy storage particles are used, the phase change materials need to be adsorbed or encapsulated, which is more expensive, and the manufacturing process is complex, so it is not suitable for mass production. It is expected that in the future, phase change materials with lower cost and faster cost recovery can be prepared, and the adsorption process of phase change energy storage particles can be improved to achieve the mass production.

Most of the research on phase change energy storage concrete is in the macro and micro stage, and the meso research is less at present. The meso research of phase change energy storage concrete is a bridge between macro and micro research. The lack of meso research will lead to the theoretical transition between macro and micro research is not smooth, and some phenomena cannot be explained from the mechanism. In the future, more scholars need to continue to study the meso research of phase change energy storage concrete and improve the multi-scale research of the whole phase change energy storage concrete.

5. Conclusions
This paper analyzes the research status of phase change energy storage concrete at home and abroad, and the existing problems are described on this basis. At present, there are many problems that need to be solved, such as poor mechanical properties, insufficient heat storage capacity, high cost and so on. To overcome the above problems and realize the large-scale practical application of phase change energy storage concrete is a main development direction in the future. The future development trend can be summarized as follows:

The preparation of phase change materials with lower cost and faster cost recovery can improve the adsorption process of composite phase change materials, reduce the cost of phase change energy storage concrete, and provide theoretical support for the large-scale practical application of phase change energy storage concrete. To increase the strength of the bearing matrix of the phase change material can improve the mechanical properties of the phase change energy storage concrete.

China has a vast territory, a wide latitude, a large distance from the sea, and a variety of terrain types and mountain ranges, resulting in a variety of climates. According to different environmental conditions in different regions, develop phase change energy storage concrete suitable for different environments. On this basis, improve its compatibility as much as possible, and prepare phase change energy storage concrete suitable for various environmental conditions.

Acknowledgments
This work was financially supported by Innovation Team of Liaoning Institutions of Higher Learning (LT2019011), and National Natural Science Foundation of China (51678374).

References
[1] Outline of the 13th five year plan for housing and urban rural development.
[2] Qiu Baoxing. Further accelerating the pace of green building development: Interpretation of
China's green building action plan [J]. Urban Development Research, 2011, 18 (7): 1-6.

[3] M. Hunger, A.G. Entrop, I. Mandilaras, H.J.H. Brouwers, M. Founti. The behavior of self-compacting concrete containing micro-encapsulated phase change materials [J]. Cement and Concrete Composites, 2009, 31 (10): 731-743.

[4] Yang Q, Zhu B, Wu X. Characteristics and durability test of magnesium phosphate cement-based material for rapid repair of concrete [J]. Materials and Structures, 2000, 33 (4): 229-341.

[5] Jaworski M. Thermal performance of building element containing phase change material integrated with ventilation system-An experimental study [J]. Applied Thermal Engineering, 2014, 70 (1): 665-674.

[6] Latibari S T, Mehrali M. Synthesis, characterization and thermal properties of nanoencapsulated phase change materials via sol-gel method [J]. Energy, 2013, 61: 664-672.

[7] Zhou Jianmin, Zhang Dong, Wu Keru. New technology of building energy conservation phase change energy storage building materials [J]. Building Materials and Application, 2003 (4): 10-12.

[8] A. Jayalath, R. San Nicolas, M. Sofi, R. Shanks, T. Ngo, L. Aye, P. Mendis. Properties of cementitious mortar and concrete containing micro-encapsulated phase change materials [J]. Construction and Building Materials, 2016, 120: 408-417.

[9] Y.R. Kim, B.S. Khil, S.J. Jang, W.C. Choi, H. Do Yun. Effect of barium-based phase change material (PCM) to control the heat of hydration on the mechanical properties of mass concrete [J]. THERMOCHIMICA ACTA, 2015, 613, 100-107.

[10] Shi Wei, Zhang Xiong, Juergen D. Temperature control performance of phase change energy storage mass concrete [J]. Journal of Tongji University, 2010, 38(4): 564-568.

[11] Zhou Shuangxi, Rong Maoge, Zuo Sheng. Temperature control performance of composite phase change energy storage materials in mass concrete [J]. Journal of East China Jiaotong University, 2013, 30 (4): 30-34.

[12] Xu B, Li Z. Paraffin/diatomite composite phase material incorporated cement-based composite for thermal energy storage [J]. Applied Energy, 2013, 105 (2): 229-237.

[13] Liu Fuzhan, Wang Yu. Experimental study on phase change concrete for building energy conservation [J]. Comprehensive Utilization of Fly Ash, 2011 (3): 32-35.

[14] P.K. Dehdizi, M.R. Hall, A.R. Dawson, S.P. Casey. Thermal, mechanical and microstructural analysis of concrete containing microencapsulated phase change materials [J]. International Journal of Pavement Engineering, 2014, 14, 1-14.

[15] J. Narain, W. Jin, M. Ghandehari, E. Wilke, N. Shukla, U. Berardi, T. El-Korchi. Design and application of concrete tiles enhanced with microencapsulated phase-change material [J]. Journal of Asian Architecture and Building Engineering, 2016, 22(1): 05015003.

[16] Chai Miao. Research and development of steel ball phase change energy storage concrete with integrated structure and function [D]. Shenzhen: Shenzhen University, 2015.

[17] Zhao Chengshou, Ni Xuping, Han Guobin. Study on the preparation and heating rate of polyethylene glycol phase change energy storage concrete [J]. New building materials, 2015 (12): 17-20.

[18] V.D. Cao, S. Pilehvar, C. Salas-Bringas. Microencapsulated phase change materials for enhancing the thermal performance of Portland cement concrete and geopolymer concrete for passive building applications [J]. Energy Conversion and Management, 2017, 133: 56-66.

[19] C. Fabiani, A.L. Pisello. Coupling the transient plane source method with a dynamically controlled environment to study PCM-doped building materials [J].Energy and Buildings, 2018, 180: 122-134.