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Research Article

Mechanical and Thermal Properties of Shale Ceramsite Concrete: Experimental Study on the Influence Law due to Microencapsulated Phase-Change Material Content and Phase-Change Cycle Numbers

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The addition of microencapsulated phase-change materials (MPCM) to concrete will inevitably cause changes in the mechanical and thermal properties of concrete, and this is vitally important for the safety and energy saving of concrete building components. In this research, shale ceramsite and shale ceramics sand were used as the main raw materials to produce lightweight aggregate concrete (LWAC) mixed with MPCM. In order to investigate the effect of MPCM content and phase-change cycle numbers on the mechanical and thermal properties of MPCM-LWAC, two groups of MPCM-LWAC specimens were prepared. One group consists of specimens containing 2.5%, 5.0%, 7.5%, and 10% MPCM, respectively, and they are used to reveal the change law of tensile strength, compressive strength, enthalpy, and specific heat capacity of LWAC integrated into MPCM. The other group includes specimens with the same MPCM content, but the specimens are subjected to different phase-change cycle numbers of 50, 100, 150, and 200 at the environment temperature of −10–60°C to study the thermal properties of MPCM-LWAC. Findings from the experimental results include the following: (1)The tensile and compressive strengths of MPCM-LWAC concrete are negatively correlated with the MPCM content, while the enthalpy and specific heat capacity are positively correlated with the MPCM content. When the MPCM content reaches 10%, the compressive and tensile strengths of MPCM-LWAC decreased, respectively, by 45.49% and 52.63% than the LWAC without MPCM. (2) Under heating and curing condition, the corresponding maximum specific heat capacity of LWAC with 10% MPCM is 328.35% and 249.50% higher than the LWAC without MPCM, respectively, and the average specific heat capacities increase 71.21% and 44.94%, respectively. (3) The melting enthalpy of MPCM-LWAC is slightly larger than the curing enthalpy, and the difference is more noticeable with the increase of MPCM content. In addition, when the number of phase-change cycle is below 200, the compressive strength and splitting tensile strength of MPCM-LWAC decrease by less than 5%, and the specific heat capacity decreases by less than 1.33%. Hence, it concludes that shale ceramsite concrete with MPCM has promising application prospects.

1. Introduction

Reduction in energy consumption has major significance for the mitigation of global warming. Three sectors of transportation, industry, and construction together account for 97.88% of the global energy consumption. Particularly, the construction sector alone accounts for approximately 30% of the total energy consumption. Energy used for refrigeration and heating to maintain indoor comfort temperature is one of the major parts of building energy consumption [1, 2].

The use of fossil fuels to maintain indoor comfort temperature increases the emission of harmful gases. Hence, renewable energy is a prime option to boost the energy efficiency of buildings, such as solar energy, wind energy, and geothermal energy. However, the intermittent characteristics of these renewable energies limit their applications, except for phase-change materials (PCM). PCM has been the present hotspot in the field of building energy saving materials due to its unique advantages, especially large heat storage per unit volume, absorbing and releasing heat under constant temperature [3–5]. More importantly, PCM maintains good thermal stability when they are added to building materials.

PCM undergo phase changes according to the change of ambient temperature, which is accompanied by the absorption and release of heat. When the ambient temperature is greater than the minimum phase-change temperature of PCM, it transforms from solid to liquid and absorbs heat from the environment, causing the ambient temperature to decrease. When the ambient temperature is less than the maximum phase-change temperature, it transforms from liquid to solid and releases heat into environment, raising an increase of the ambient temperature. This endothermic and exothermic process under different ambient temperatures helps adjust the amplitude of the ambient temperature fluctuation. Therefore, embedding PCM into building materials can significantly increase the thermal inertia of building materials and prevent excessive abrupt changes in indoor temperature.

Scholars around the world have carried out extensive research on the application of PCM in the field of building materials, such as adding PCM into concrete, mortar, gypsum, and wood. [6–9]. Among them, PCM concrete can not only be used as a structural material in different building structures but also be utilized as a functional material to maintain indoor comfort temperature, which shows a good application prospect in the field of building energy conservation [10, 11].

At present, scholars have carried out substantive researches in many aspects, such as the development of PCM, addition methods of PCM, and mechanical and thermal properties of energy storage concrete [12–14]. According to these research findings, PCM commonly used in construction field are organic and inorganic solid-liquid PCM with phase transition temperature between 10 and 30°C, such as paraffin wax and hydrated salt. However, for inorganic PCM, its application is limited in the construction field due to the two serious shortcomings of undercooling and phase separation.

For solid-liquid PCM, some serious problems were encountered in the process of repeated solid-liquid conversion, such as leakage, interaction between PCM and concrete matrix, and reduced heat transfer efficiency. In order to solve these problems, shaped phase-change aggregate [15], macro-PCM [7], and micro-PCM [13] came into being. MPCM is a new type of composite materials, composed of solid-liquid PCM particles wrapped by stable polymer film. MPCM not only provides a very high heat transfer area but also avoids leakage of PCM [16, 17]. Moreover, adding MPCM to concrete can improve the energy storage capacity of concrete material, but exists a negative effect on the mechanical properties. Pilehvar et al. [18] investigated the effects of curing time, phase state, and PCM content on the compressive strength of silicate concrete and geopolymer concrete through experiments. They found that the compressive strength of PCM geopolymer concrete was larger than that of PCM silicate concrete under the same conditions. Hunger et al. [19] measured the thermal conductivity and specific heat capacity of PCMconcrete by using the method of transient hot wire and homemade improvised device for studying the effect of MPCM content on the thermal properties. Their finding is that the increase of MPCM content will decrease the thermal conductivity and increase the specific heat capacity of concrete, thus beneficial to improve the thermal performance of concrete. However, scanning electron microscope (SEM) images exposes the problem that MPCM may be destroyed in the mixing process, which will cause the paraffin to penetrate into the concrete matrix. Ouni et al. [20] added different amounts of MPCM to Portland cement concrete and found that the addition of MPCM to concrete improved the heat storage capacity of concrete.

Good mechanical and thermal stability are the most fundamental premise for the development and utilization of PCM-concrete. The above literatures indicates that the energy storage concrete in raw material selection and production technology is different. The energy storage capacity of present concrete containing PCM lacks reasonable comparisons. However, the mechanical and thermal properties of different types of PCM-concrete are quite different. Therefore, it is necessary to further study the mechanical and thermal properties of energy storage concrete with application prospect.

In this research, MPCM-LWAC partition wall is regarded as the research background. Shale ceramsite, shale ceramics sand, MPCM, and Portland cement as the main raw materials are used to prepare MPCM-LWAC specimens. A series of experiments on mechanical and thermal properties of MPCM-LWAC were carried out to study the effects of MPCM content and phase-change cycle numbers on the tensile strength, compressive strength, enthalpy, and specific heat capacity of MPCM-LWAC. Under the heating and curing condition, a comparative study was conducted to reveal the change law of mechanical and thermal properties of MPCM-LWAC with MPCM content and phase-change cycle numbers. The above research lays a foundation for the development and application of MPCM-LWAC partition wall.

2. Materials and Methods

2.1. Basic Properties of Raw Materials

2.1.1. Lightweight Aggregate. In this research, shale ceramsite with diameters of 8–20 mm and 5–8 mm was selected to be mixed as lightweight coarse aggregate (LWCA) by a mass ratio of 4 : 6, and shale ceramic sand with diameters of 3–5 mm and 1–3 mm was chosen to be mixed with a mass ratio of 4 : 6 as lightweight fine aggregate (LWFA). Basic properties of lightweight aggregate are shown in Table 1.

Table 1: The properties of lightweight aggregate.

Shale ceramsite	Size (mm)	Packing density (kg/m3)	Water absorption of 1 h (%)	Cylinder pressure strength (MPa)
LWCA	8~20	641	4.50	4.37
	5~8	795	3.63	6.43
LWFA	3~5	857	3.27	7.37
	1~3	930	—	—

2.1.2. Microencapsulated Phase-Change Materials (MPCM). MPCM with polymethyl methacrylate as the shell material and n-octadecane as the core material is produced by Hebei Ruo-sen Technology Co., Ltd. Experiment was carried out to investigate the micromorphology of MPCM by using scanning electron microscopy (SEM). From the SEM image of MPCM (Figure 1), it can be found that MPCM with a diameter of 1–3 um is spherical. In addition, the thermal properties of MPCM were investigated by conducting differential scanning calorimeter (DSC) test. The DSC curve of MPCM is shown in Figure 2, which presents clearly the change curve of heat flux with temperature during the melting and curing process. The phase transition temperature range of MPCM is from 24.9°C to 28.9°C in the melting process. On the contrary, its phase transition temperature range is from 20°C to 25.1°C during the curing process.

2.1.3. Cement. Cement with the grade of P.O 42.5 is a commercial ordinary Portland cement. According to General Portland Cement (GB175-2007), the physical properties and quality of cement were detected, as shown in Tables 2 and 3. The compressive strength of the cement for 3 d and 28 d is 27.2 MPa and 54.9 MPa, and its flexural strength is 5.7 MPa and 8.8 MPa, respectively.

2.1.4. Water. Tap water was used as the test water. It needs to emphasize that chemical admixtures such as fly ash, air entraining agent, and water reducing agent were not used in the preparation of MPCM-LWAC to avoid chemical reaction between such admixtures and MPCM.

2.2. Mix Proportion Design. The strength of MPCM-LWAC specimens prepared in this study is less than 10 MPa due to lightweight partition wall as the research background. According to the Technical Specification for Lightweight Aggregate Concrete (JGJ51-2002), the sand ratio and water-cement ratio are determined to be 0.65 and 0.6, respectively. Meanwhile, the MPCM content meeting the strength requirements should not be more than 10% [21]. The mixture ratio of MPCM-LWAC is selected as given in Table 4 to satisfy these conditions. MPCM-LWAC-0.0% was designed as a control experiment. MPCM-LWAC specimens were prepared by replacing the LWFA with the same amount of MPCM. The cubic concrete specimen has the size of $100 \times 100 \times 100\ \text{mm}^3$.

3. Experimental Procedures

3.1. Mechanical Test. In order to ensure that MPCM-LWAC can meet the strength requirements of lightweight partition wall, it is necessary to determine the tensile and compressive strengths of MPCM-LWAC and study its influencing factors. The tensile and compressive strengths of MPCM-LWAC with MPCM content of 0%, 2.5%, 5.0%, 7.5%, and 10.0% and phase-change cycle numbers of 0, 50, 100, 150, and 200 were determined by using a microcomputer-controlled electro-hydraulic servo pressure testing machine.

3.2. Thermal Tests

3.2.1. Testing Program. Differential scanning calorimeter (DSC) based on power compensation was used to test enthalpy and specific heat capacity of MPCM-LWAC with MPCM content of 0%, 2.5%, 5.0%, 7.5%, and 10.0% and the same items of MPCM-LWAC with phase-change cycle numbers of 0, 50, 100, 150, and 200, respectively. Figure 3 gives the process of making specimen and test instruments.

3.2.2. Calculation Principle of Enthalpy. DSC test is based on power compensation, and it can reflect the change of enthalpy of the sample by monitoring the power difference between the sample and the reference (sapphire) [22]. DSC curve with the abscissa of time or temperature and the ordinate of heat flow can be obtained by DSC test. The main feature of power compensation DSC test is that the sample and reference have independent heaters and heat sensors. The temperature difference between the sample and the reference is equal to 0°C by adjusting the heating power of the sample, so that the heat flow rate can be directly calculated from the compensated power using

$$\Delta W = \frac{\mathrm{d}Q_s}{\mathrm{d}t} - \frac{\mathrm{d}Q_r}{\mathrm{d}t} = \frac{\mathrm{d}H}{\mathrm{d}t}, \tag{1}$$

where ΔW is the compensated power; $dQ_s/\mathrm{d}t$ is the heat supplied to the sample per unit time; $dQ_r/\mathrm{d}t$ is the heat supply per unit time of the reference object, and $dH/\mathrm{d}t$ is the rate of change in enthalpy.

The heat absorbed or released per unit mass of PCM in the process of phase transformation is known as the phase-change enthalpy, which is equal to the change in enthalpy of

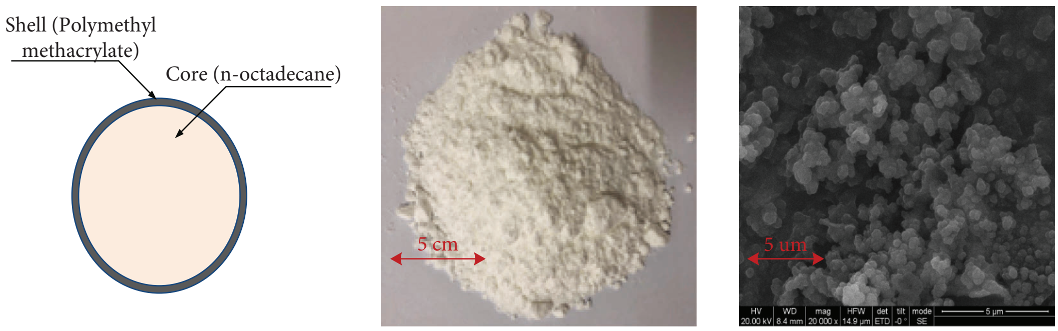

Figure 1: Morphology picture of MPCM.

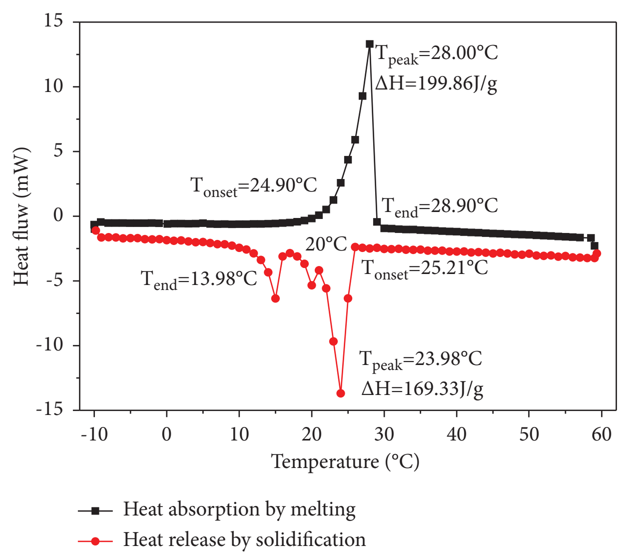

Figure 2: Heat flux curve with temperature during its melting and curing process.

Table 2: Physical properties of cement.

Testing items	Specific area (m^2/kg)	Standard consistency	Setting time (min)		Soundness	Compressive strength (MPa)		Flexural strength (MPa)	
			Initial set	Final set		3 d	28 d	3 d	28 d
P·O42.5	327	27.2	162	213	Qualified	27.2	54.9	5.7	8.8

Table 3: Quality testing of P·O42.5 cement.

Testing item	Loss on ignition (%)	SO_3 (%)	MgO (%)	Chlorine ion content (%)	Alkali content (%)
P·O42.5	0.34	2.81	2.30	0.023	0.52

Table 4: Mix proportion of MPCM-LWAC specimens by using the method of equal mass substitution.

Specimens	Water (kg/m^3)	Cement (kg/m^3)	LWAC (kg/m^3)	LWFA (kg/m^3)	MPCM (kg/m^3)	Water-cement ratio	Sand ratio
MPCM-LWAC-0.0%	187.0	311.7	455.5	845.800	0.000		
MPCM-LWAC-2.5%	187.0	311.7	455.5	824.655	21.145		
MPCM-LWAC-5.0%	187.0	311.7	455.5	803.510	42.290	0.60	0.65
MPCM-LWAC-7.5%	187.0	311.7	455.5	782.370	63.435		
MPCM-LWAC-10%	187.0	311.7	455.5	761.220	84.580		

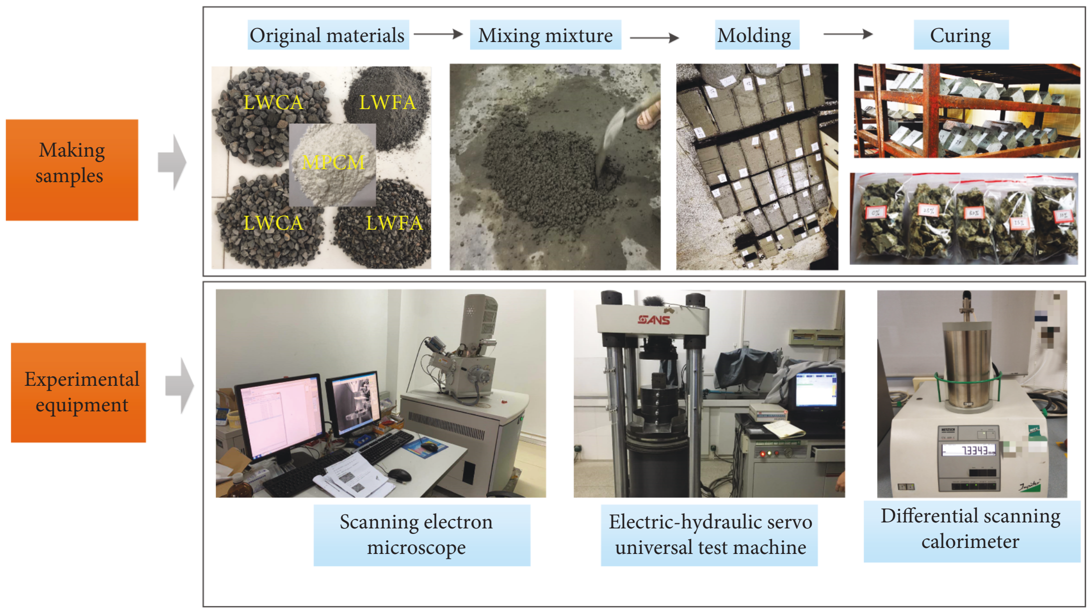

FIGURE 3: Specimen making and experimental equipment.

the system in the process of phase transformation in quantity. Therefore, the enthalpy of tested sample can be calculated according to equation (2).

$$\Delta H = \int_{t_1}^{t_2} \frac{dH}{dt} dt, \quad (2)$$

where ΔH is the enthalpy of PCM, t_1 and t_2 are the start time and end time of DSC peak respectively, and dH/dt is the rate of change in enthalpy.

3.2.3. Calculation Principle of Specific Heat Capacity. Specific heat capacity of tested sample was determined by using the comparative method (Figure 4). The DSC curves of empty crucible, sapphire, and the sample were tested from T1 to T2 under the same experimental conditions. The DSC curve of the empty crucible was taken as the baseline. According to the DSC curve position of sample and sapphire, the calculation formula of specific heat capacity of sample was deduced:

$$C_p = \overline{C}_p \cdot \frac{\overline{m}}{m} \cdot \frac{y}{\overline{y}}, \quad (3)$$

where C_p and $\overline{C}_p$ are the specific heat capacity of sapphire and the sample to be determined, respectively, J/g•°C. m and $\overline{m}$ are the mass of sapphire and sample to be determined, respectively, g. y and $\overline{y}$ are the range differences between the sample to be determined and sapphire on the ordinate.

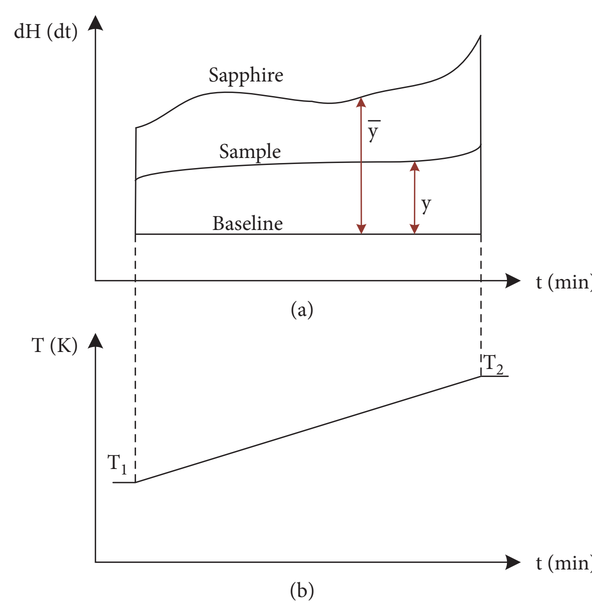

FIGURE 4: Calculation principle diagram of specific heat capacity based on the DSC curve.

4. Analysis of Experimental Result

4.1. Mechanical Properties Analysis of MPCM-LWAC

4.1.1. Effect of MPCM Content on Tensile and Compressive Strengths of MPCM-LWAC. The tensile and compressive strengths of MPCM-LWAC with different MPCM content are shown in Figures 5 and 6. From Figures 5 and 6, it can be found that the tensile and compressive strengths of MPCM-LWAC decreased with the increase of MPCM content. Compared with MPCM-LWAC-0.0% specimen, the tensile strength of MPCM-LWAC-2.5%, MPCM-LWAC-5.0%, MPCM-LWAC-7.5%, and MPCM-LWAC-10.0% specimen decreased by 10.66%, 21.31%, 34.84%, and 45.49%, and their compressive strength decreased by 8.27%, 22.3%, 49.62%, and 52.63%, respectively. The functional relationship showing the influence of MPCM content on the tensile and compressive strengths conforms with

$$\sigma_c = -1.46\varepsilon_{\text{MPCM}} + 26.85, \quad (4)$$

$$\sigma_t = -0.11\varepsilon_{\text{MPCM}} + 2.45, \quad (5)$$

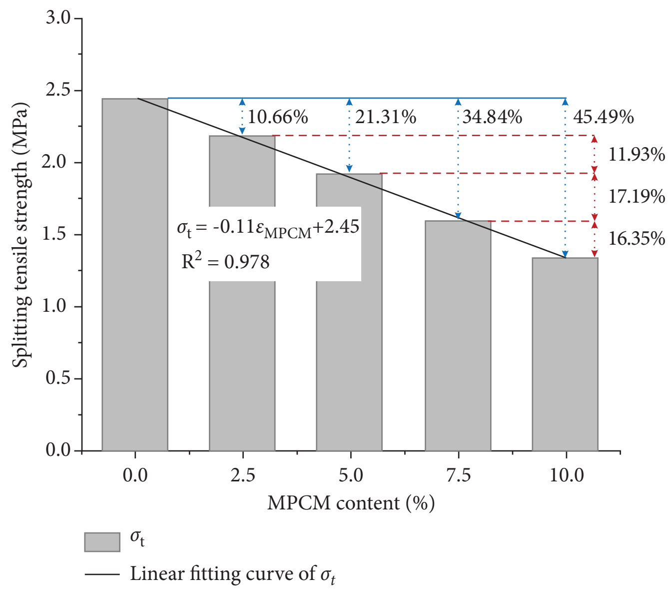

FIGURE 5: The relation curve between splitting tensile strength and MPCM content.

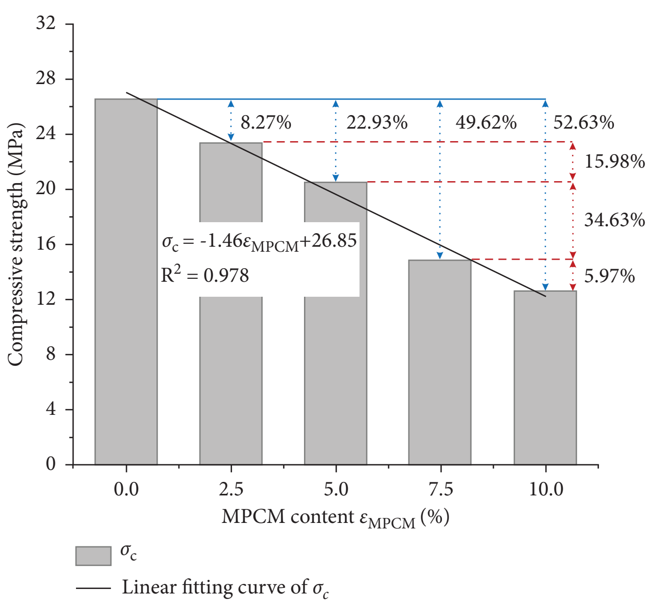

FIGURE 6: The relation curve between compressive strength and MPCM content.

where σ_c and σ_t are the compressive strength and tensile strength of MPCM-LWAC, respectively, MPa; $\varepsilon_{\text{MPCM}}$ is mass fraction of MPCM content, %.

4.1.2. Effect of Phase-Change Cycle Numbers on Tensile and Compressive Strengths of MPCM-LWAC. Figures 7(a) and 8(a) show the change law of compressive and tensile strength of MPCM-LWAC with the number of phase-change cycle. Figures 7(b) and 8(b) show the change amount of compressive and tensile strength of MPCM-LWAC specimen subjected to different phase-change cycle numbers.

According to Figures 7(a) and 7(b), the compressive strength of MPCM-LWAC-0.0% specimen undergoing phase-change cycle numbers of 50, 100, 150, and 200 varied by decreasing −0.38%, 0.77%, 0.38%, and 1.14%, respectively. The compressive strength of MPCM-LWAC-5.0% specimens decreased by −0.47%, −0.09%, 0.46%, and 1.93%, respectively. The compressive strength of MPCM-LWAC-10.0% specimens decreased by 0.58%, 1.75%, 2.92%, and 3.51%, respectively. When the MPCM content was 2.5% and the phase-change cycle numbers was 200, the compressive strength variation decreased the maximum value of 3.72%.

From Figures 8(a) and 8(b), after the specimen subjected to phase-change cycle numbers of 0, 50, 100, 150, and 200, the splitting tensile strength variation of MPCM-LWAC-0.0% specimen decreased by 0.81%, 0.41%, 0.81%, and 1.22%, respectively. The variations of the tensile strength of MPCM-LWAC-5.0% specimens decreased by 0.51%, 1.02%, 2.03%, and 3.04%, respectively. The compressive strength variations of the MPCM-LWAC-10.0% specimens decreased by 1.44%, 2.16%, 2.88%, and 4.32%, respectively. When the MPCM content was 7.5% and the phase-change cycle numbers were 200, the splitting tensile strength variation decreased the maximum value of 4.90%.

According to the above results, it can be concluded that the compressive strength and splitting tensile strength of MPCM-LWAC exhibit decreasing trend with the increase of phase-change cycle numbers. However, the decreasing amount for both strengths are not more than 5%, which is not enough to affect the normal use of the material.

4.2. Analysis of Thermal Properties of MPCM-LWAC

4.2.1. Effect of MPCM Content on Enthalpy of MPCM-LWAC. Figures 9(a) and 9(b) are the DSC curves of MPCM-LWAC specimens with different MPCM contents.

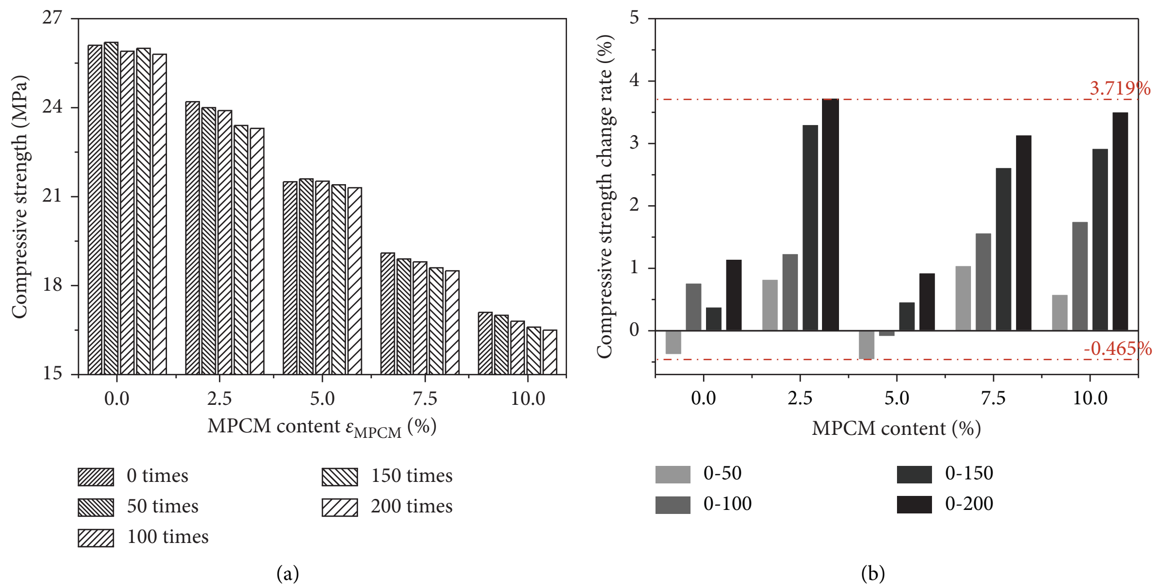

FIGURE 7: The relation curve between the numbers of phase-change cycle and compressive strength with the numbers of phase-change cycle. (a) The change law of compressive strength. (b) The change law of compressive strength variation.

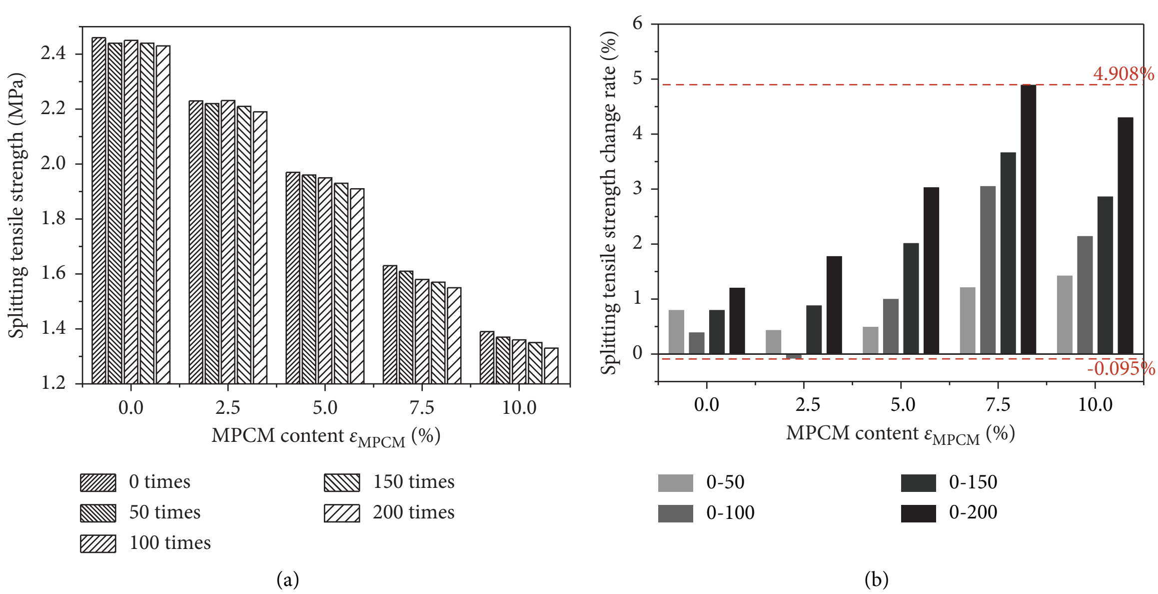

FIGURE 8: The relation curve between the numbers of phase-change cycle and splitting tensile strength with the numbers of phase-change cycle. (a) The change law of splitting tensile strength. (b) The change law of splitting tensile strength variation with the numbers of the phase-change cycle.

It can be seen from Figures 9(a) and 9(b) that the phase-change temperature range and calorimetric signal shape displayed on the DSC curve of MPCM-LWAC depend on the DSC curve of MPCM (Figure 2). In addition, there are two obvious differences between DSC curves in the melting and curing process. One is that there are two peaks in DSC curves during the curing process, which are caused by the solid-liquid phase transformation of MPCM. Other is that the peak temperature of MPCM-LWAC in the curing process lags behind its peak temperature in the melting process.

The melting enthalpy and curing enthalpy of MPCM-LWAC with different MPCM contents were calculated according to (2). As can be seen from Figure 10, the melting enthalpy and curing enthalpy of MPCM-LWAC are positively correlated with the MPCM content. The mixture of LWAC with MPCM does not affect the enthalpy of MPCM.

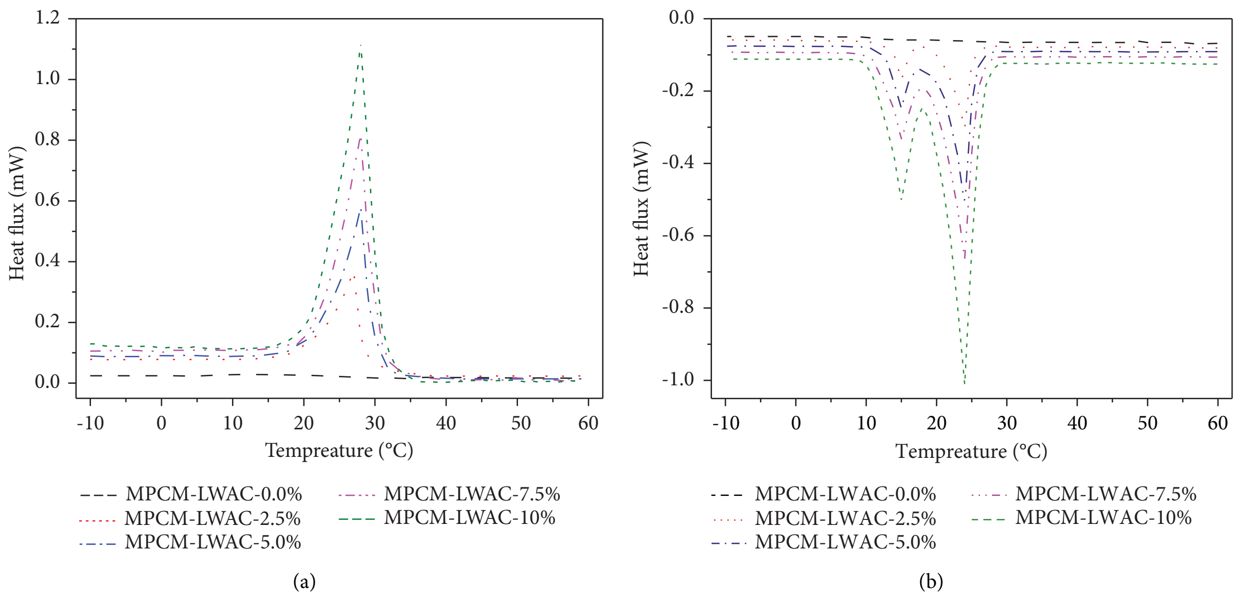

Figure 9: DSC curves of MPCM-LWAC with different MPCM contents. (a) Heat absorption by melting. (b) Heat release by solidification.

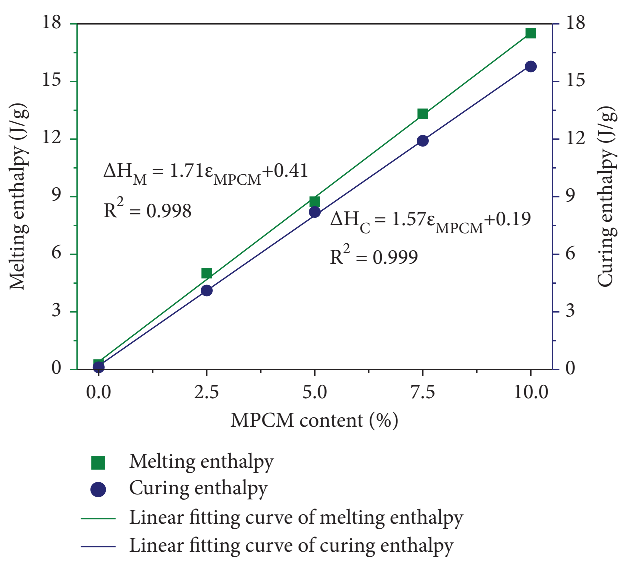

Figure 10: Effect of the MPCM content on melting and curing enthalpy.

Melting enthalpy of MPCM-LWAC is slightly larger than its curing enthalpy, and the difference is more obvious with the increasing amount of MPCM.

4.2.2. Effect of Phase-Change Cycle Numbers on the Enthalpy of MPCM-LWAC. DSC test was carried out to measure specific heat capacity of MPCM-LWAC with the different phase-change cycle numbers of 0, 50, 100, 150, and 200. The specific heat capacity of MPCM-LWAC was calculated according to (3) (here, specific heat capacity refers to the average of the specific heat capacity at each temperature point). The calculation results are shown in Figure 11. From Figure 11, the maximum and minimum enthalpy of MPCM-LWAC with different MPCM contents were obtained.

Undergoing 0, 50, 100, 150, and 200 phase-change cycle numbers, the variation in enthalpy of MPCM-LWAC with different MPCM contents of 2.5%, 5.0%, 7.5%, and 10% during the melting process are 7.16%, 9.49%, 6.57%, and 3.94%, respectively. The variation in enthalpy during the curing process are 6.22%, 3.11%, 5.30%, and 1.16%, respectively. This suggests that when the phase-change cycle numbers are less than 200, the phase-change cycle has little influence on the latent heat.

Under different phase-change cycle numbers, the enthalpy obtained by DSC test has no obvious and regular trend. That is, the enthalpy of MPCM-LWAC may increase or decrease with the increase of phase-change cycle numbers. The reason for this phenomenon is that DSC test requires the sample to be uniform. However, it cannot be guaranteed that the MPCM content contained in each group of samples is fixed, nor that the content of other components is consistent.

4.2.3. Effect of MPCM Content on Specific Heat Capacity of MPCM-LWAC. The specific heat capacity of MPCM-LWAC is calculated according to (3), and the results are shown in 12.

Comparing Figures 12(a) and 12(b), the specific heat capacity of MPCM-LWAC-0.0% always stays within the range of 1.210 ± 0.05 J/g°C during the whole process of heating and curing, which suggests that temperature has little effect on the specific heat capacity of MPCM-LWAC-0.0%.

Within the phase transition temperature range (20–30°C), the specific heat capacities of MPCM-LWAC-2.5%, 5.0%, 7.5%, and 10% increase rapidly, and the increase of specific heat capacity is proportional to the MPCM content, which is determined by the phase-change characteristics of MPCM. The specific heat capacity of MPCM-

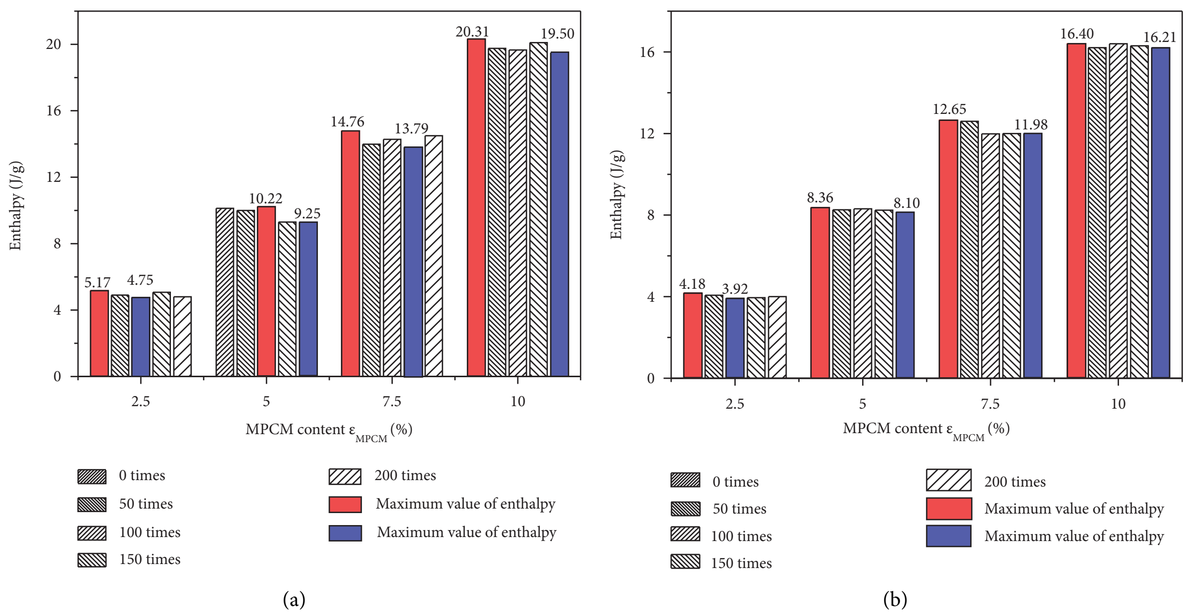

Figure 11: Effect of the phase-change cycle numbers on the enthalpy of MPCM-LWAC. (a) Heat absorption by melting. (b) Heat release by curing.

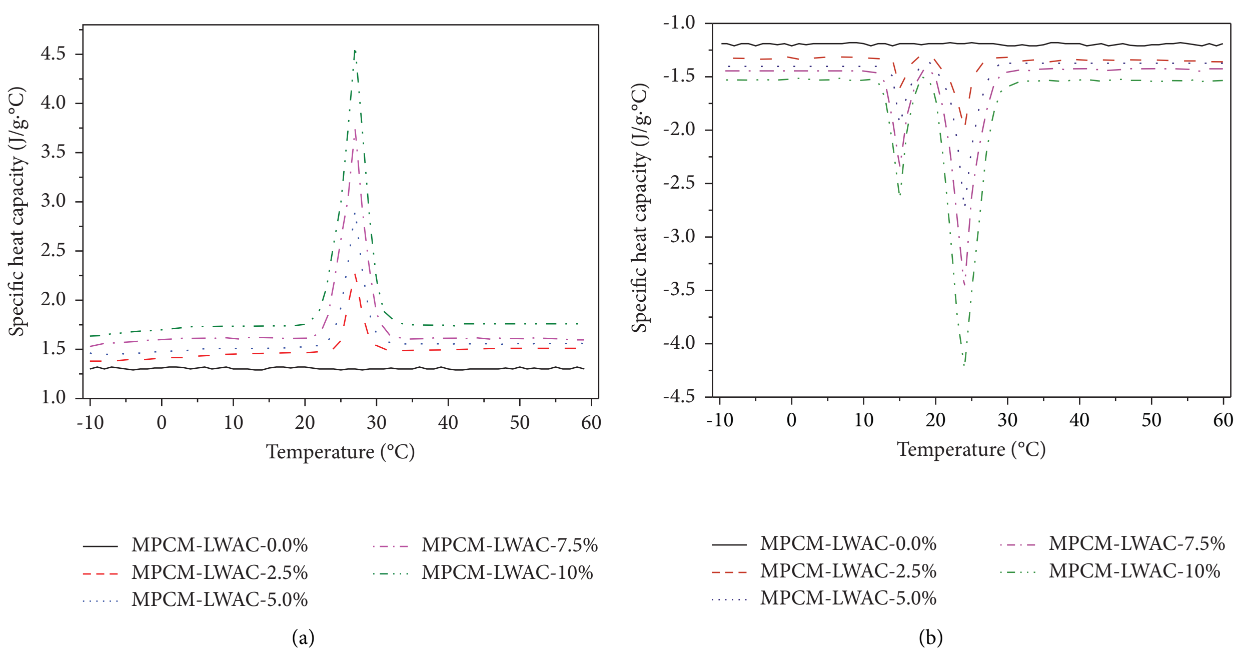

Figure 12: Curve of specific heat capacity of MPCM-LWAC with temperature. (a) Heat absorption by melting. (b) Heat release by solidification.

LWAC remains unchanged outside the phase transition temperature range.

The change trend of specific heat capacity of MPCM-LWAC with temperature is consistent with that of MPCM, and the horizontal coordinate of peak point is also the same as that of MPCM, which indicates that the phase-change characteristics of MPCM determine that of MPCM-LWAC.

4.2.4. Effect of Phase-Change Cycle Numbers on Specific Heat Capacity of MPCM-LWAC. Figures 13(a) and 13(b) are the effect of the phase-change cycle numbers on the specific heat capacity of MPCM-LWAC.

From Figures 13(a) and 13(b), it can be found that when the phase-change cycle numbers are less than 200, the phase-change cycle has little influence on the specific heat capacity.

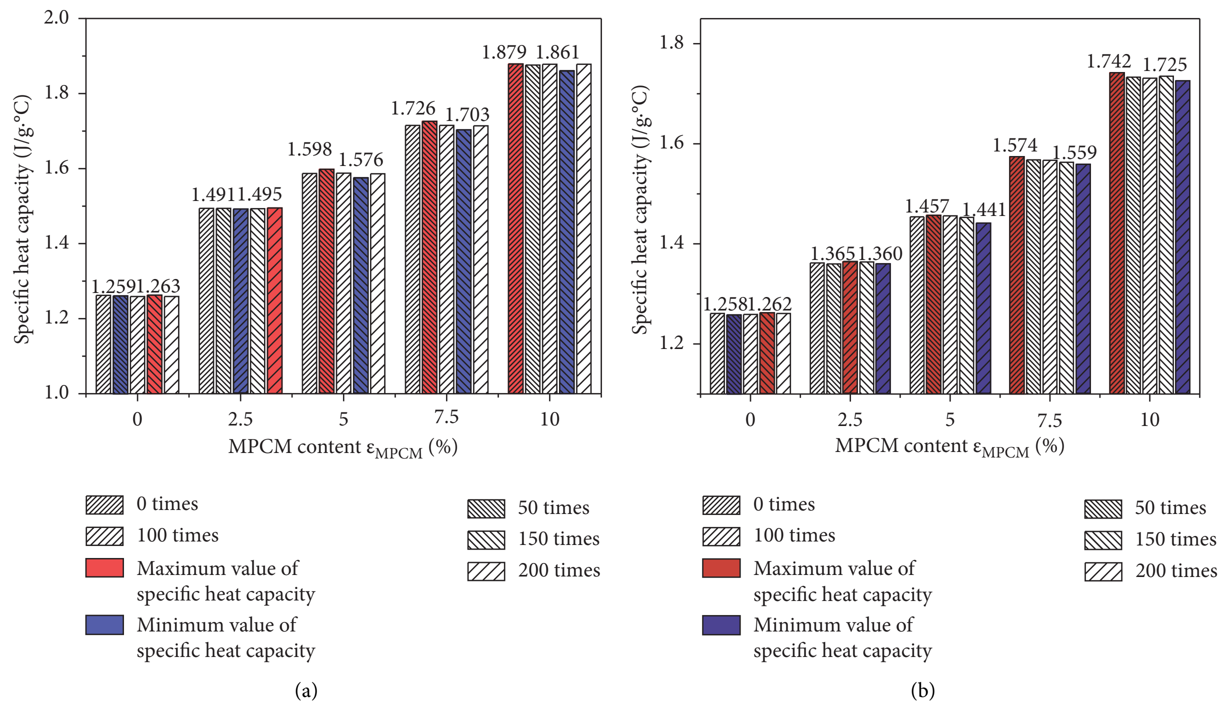

FIGURE 13: Effect of the phase-change cycle numbers on the specific heat capacity of MPCM-LWAC. (a) Heat absorption by melting. (b) Heat release by curing.

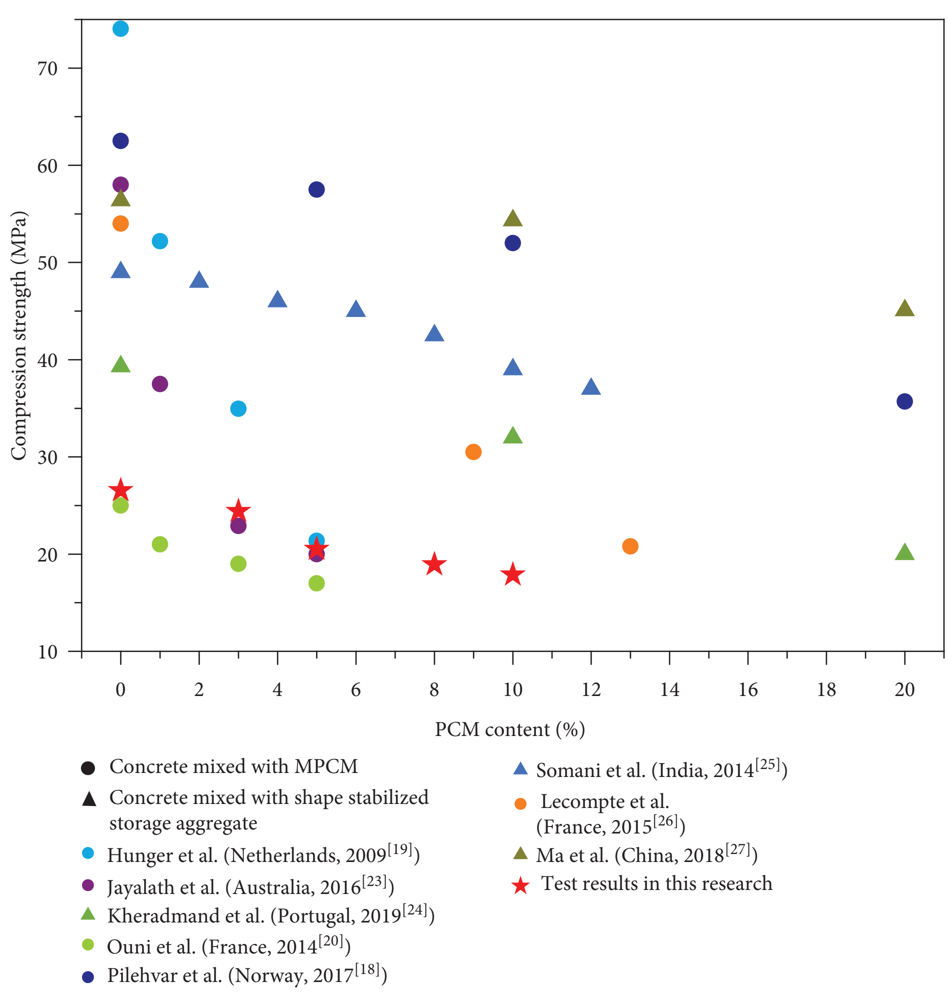

FIGURE 14: The relation curve between compressive strength and PCM content by different researchers.

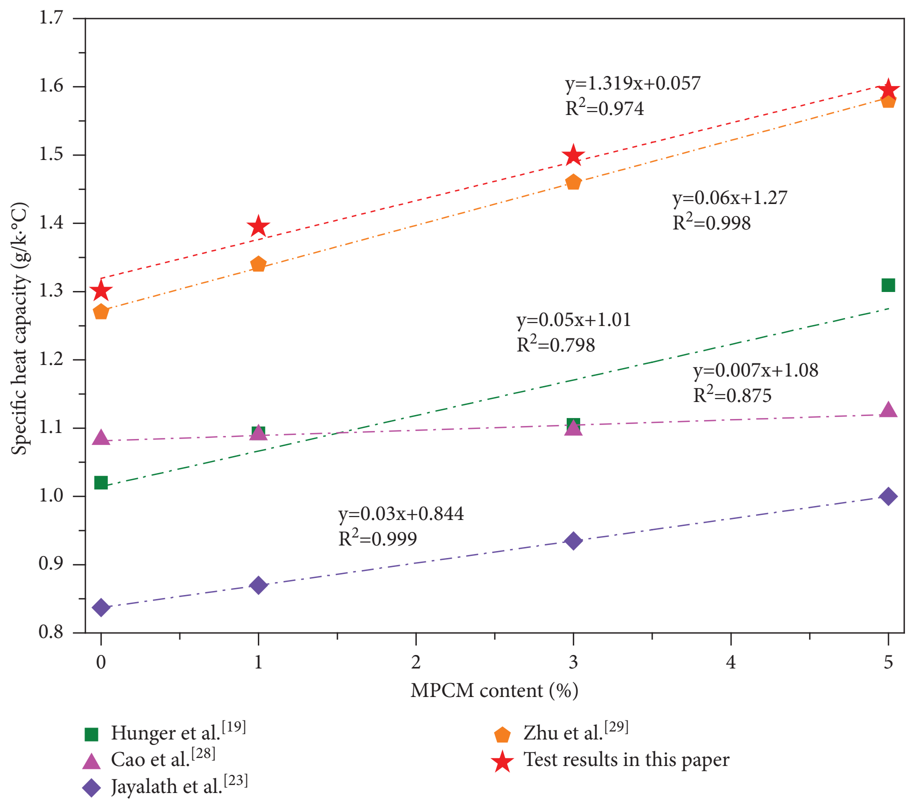

Figure 15: The relation curve between specific heat capacity and MPCM content by different researchers.

The maximum variation of the specific heat capacity is 1.33% (the specific heat capacity refers to the average of the specific heat capacity in the range of −10~60°C).

Based on the influence of the phase-change cycle numbers on the specific heat capacity of MPCM-LWAC, it is concluded that the MPCM-LWAC exhibits a good thermal stability, which is of great significance to the application of energy storage lightweight aggregate concrete.

5. Discussion

In order to reveal the influence of PCM content, preparation method and testing method on mechanical and thermal properties of PCM-concrete, experimental results from different scholars are summarized and presented in Figures 14 and 15, respectively, and they are compared with the results of this study.

From Figure 14, the compressive strength of PCM-concrete tested by different scholars has a wide range (varying from 17 to 75 MPa), which is mainly caused by the differences in raw material selection, mix ratio determination, and preparation process. The trend of experimental results in this study is similar with that of other researchers in Figure 14, namely, the addition of PCM will inevitably lead to the reduction of concrete compressive strength. Notably, the main difference between the research results of various scholars in Figure 14 is that the compressive strength of different PCM-concrete varies greatly. The MPCM-LWAC selected in this paper has lower strength, which mainly depends on the properties and content of raw materials.

There are three main reasons for the reduction of concrete strength caused by the addition of MPCM. The first reason is that the mechanical properties of MPCM are weaker than that of the replaced sand, the second reason is that the porosity of the MPCM-LWAC increases with the increase of MPCM content, and the third reason is that the larger the MPCM content, the stronger the aggregation effect of MPCM, causing uneven distribution of concrete compositions.

From Figure 15, the addition of PCM will inevitably lead to an increase in the specific heat capacity of concrete, and the increase is positively correlated with the amount of PCM. This phenomenon indicated that the PCM content greatly affects the specific heat capacity of PCM concrete. In addition, PCM shows good chemical stability in the hydration reaction of concrete mix. In terms of function, the larger the specific heat capacity of PCM concrete, the more beneficial it is to adjust the indoor temperature. Compared with the experimental results from other scholars in Figure 15, the MPCM-LWAC selected in this research has larger specific heat capacity.

According to literature [30], the strength of MPCM-LWAC in this research can be further improved by adjusting the cement grade, increasing the content of cement and sand rate, while keeping the specific heat capacity unchanged, which helps to expand the scope of application of this material.

6. Conclusion

Mechanical and thermal properties of shale ceramsite concrete with different MPCM contents and different phase-change cycle numbers have been investigated. The optimal mixture ratio is determined, and the MPCM-LWAC specimens with different MPCM content were prepared. Subsequently, the mechanical and thermal properties of MPCM-LWAC specimens were studied. The experimental results are as follows:

(1) The mechanical properties of MPCM-LWAC are negatively correlated with the MPCM content. The tensile and compressive strengths of MPCM-LWAC decrease linearly with the increase of the MPCM content. Compared with MPCM-LWAC-0.0% specimens, the tensile strengths of MPCM-LWAC-2.5%, MPCM-LWAC-5.0%, MPCM-LWAC-7.5%, and MPCM-LWAC-10.0% specimens decreased by 10.66%, 21.31%, 34.84%, and 45.49%, respectively. The compressive strengths decreased by 8.27%, 22.93%, 49.62%, and 52.63%, respectively.

(2) The enthalpy of MPCM-LWAC is positively correlated with the MPCM content. Outside the phase-change temperature range, the specific heat capacity of MPCM-LWAC does not change with the change of temperature, but inside the phase-change temperature range, the specific heat capacity of MPCM-LWAC changes greatly with the change of temperature.

(3) With the increase of phase-change cycle numbers, the compressive strength, tensile strength, and specific heat capacity of MPCM-LWAC gradually decrease, but the strength decrease percentage is less than 5%, and the maximum specific heat capacity decrease percentage is 1.33%, which is not enough to affect the normal use of the MPCM-LWAC.

(4) The mechanical and thermal properties of MPCM-LWAC are comprehensively revealed in this paper, which provides a basis for the use of this material as partition wall.

In further research, the mechanical and thermal properties of MPCM-LWAC are expected to improve by adjusting cement grade, cement and MPCM content, sand rate, etc. Such research studies help to optimize the mechanical and thermal properties and then to expand the application range of MPCM-LWAC materials.

Data Availability

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also form part of an ongoing study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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