Supporting Information

Bio-based sunflower carbon/polyethylene glycol shape-stabilized phase change materials for thermal energy storage

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1. Figures

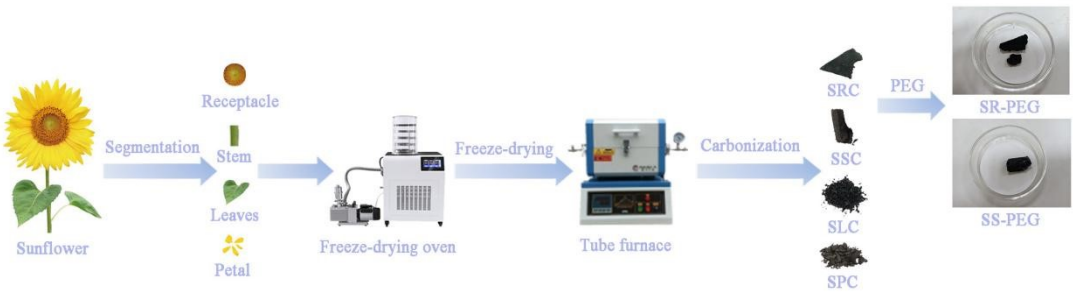

Fig. 1. The flowchart for the preparation of shape-stabilized phase change materials.

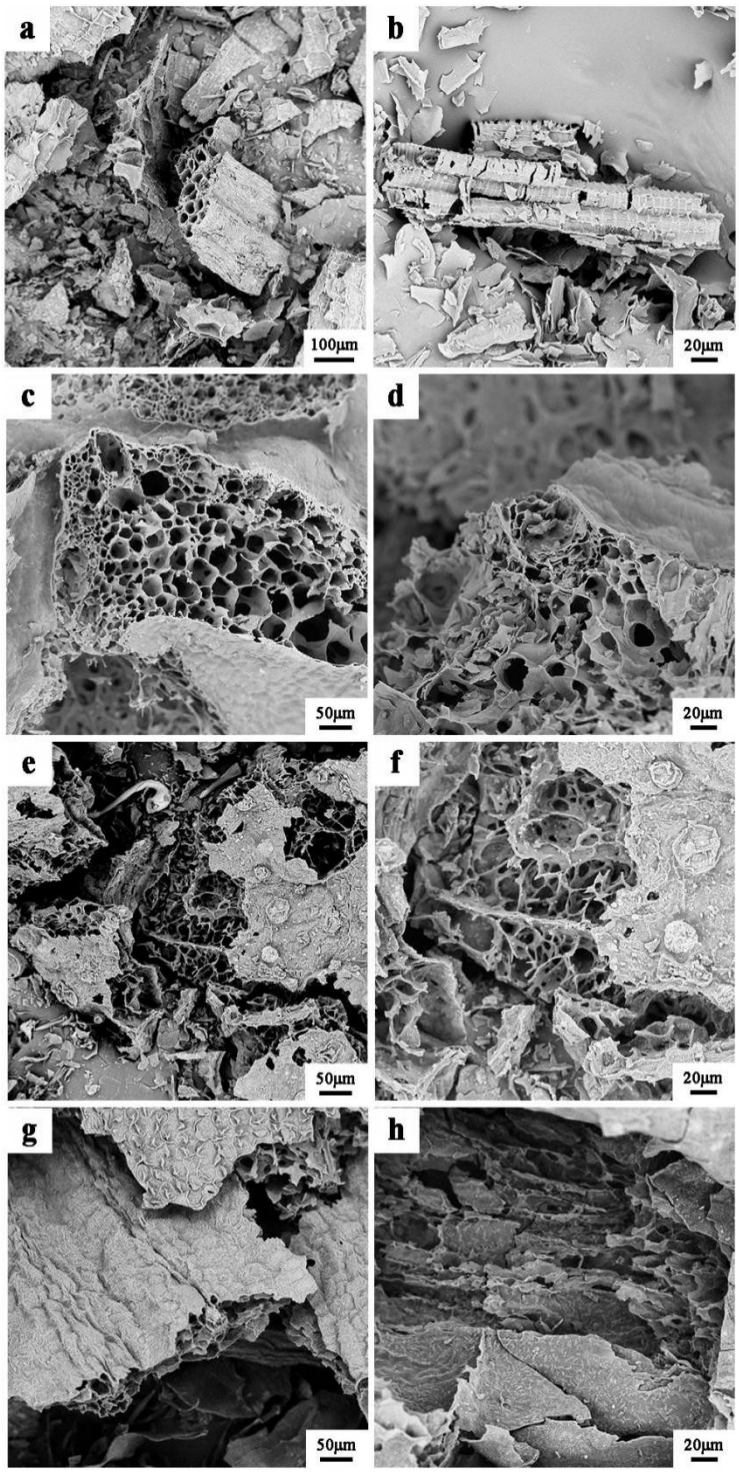

Fig. 2. SEM images of primary carbon in various parts of sunflower: (a~b) SSC; (c~d) SRC; (e~f) SLC; (g~h) SPC.

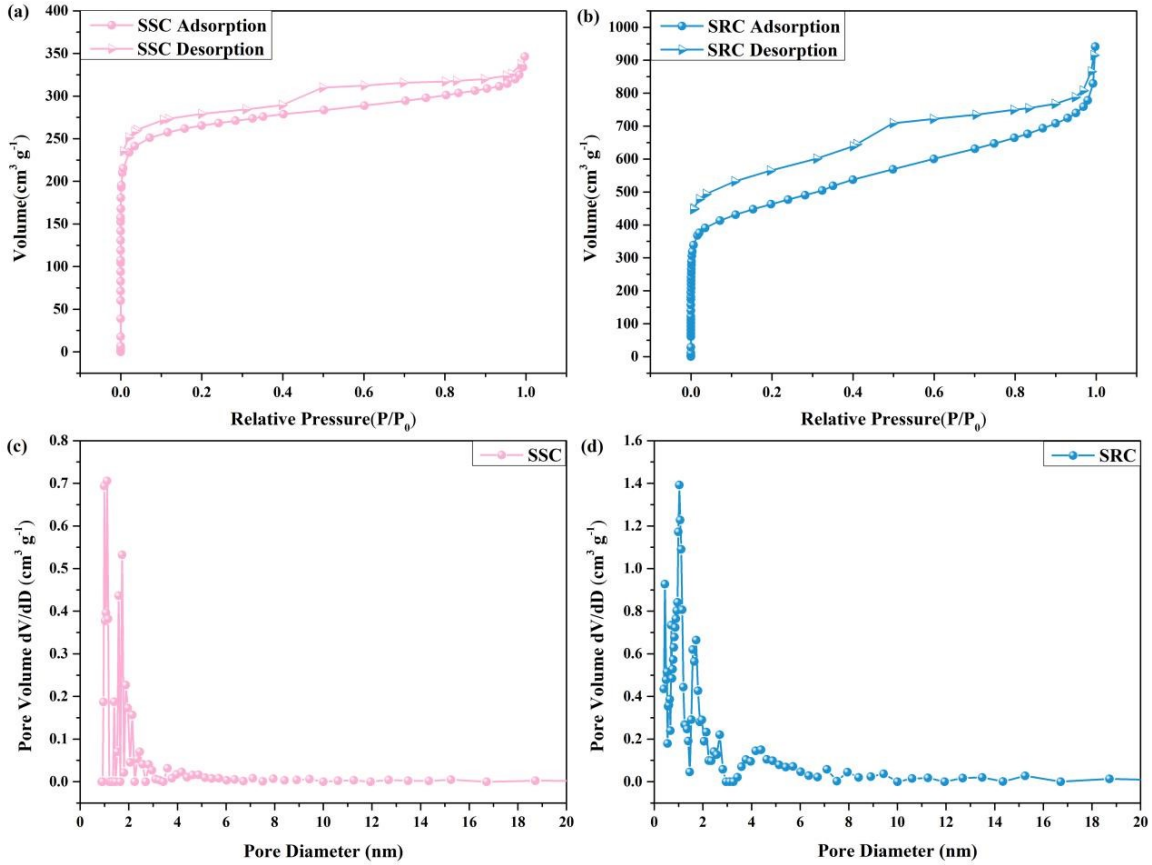

Fig. 3. Nitrogen adsorption/desorption isotherms: (a) SSC and (b) SRC, and DFT desorption pore size distribution: (c) SSC and (d) SRC.

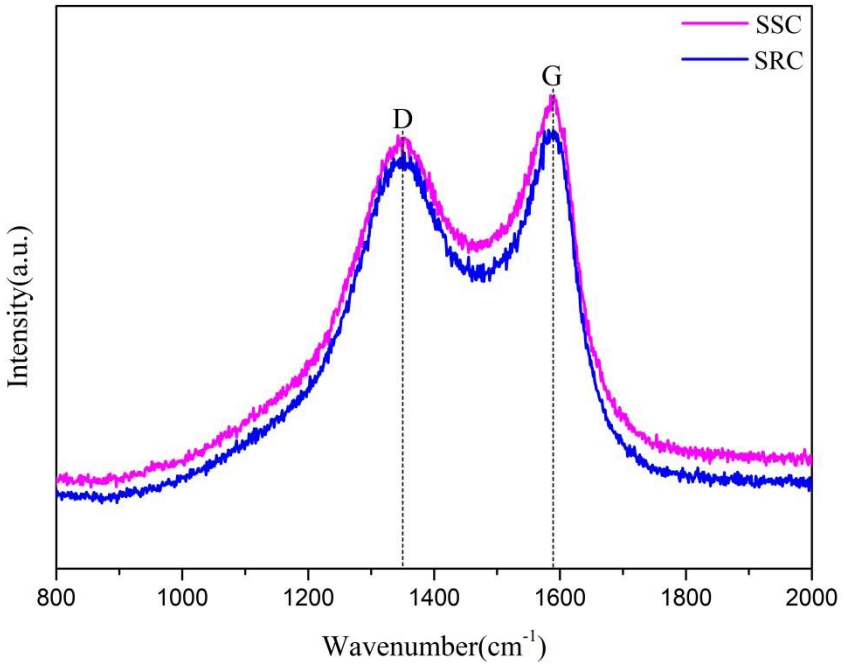

Fig. 4. Raman spectra of SSC and SRC.

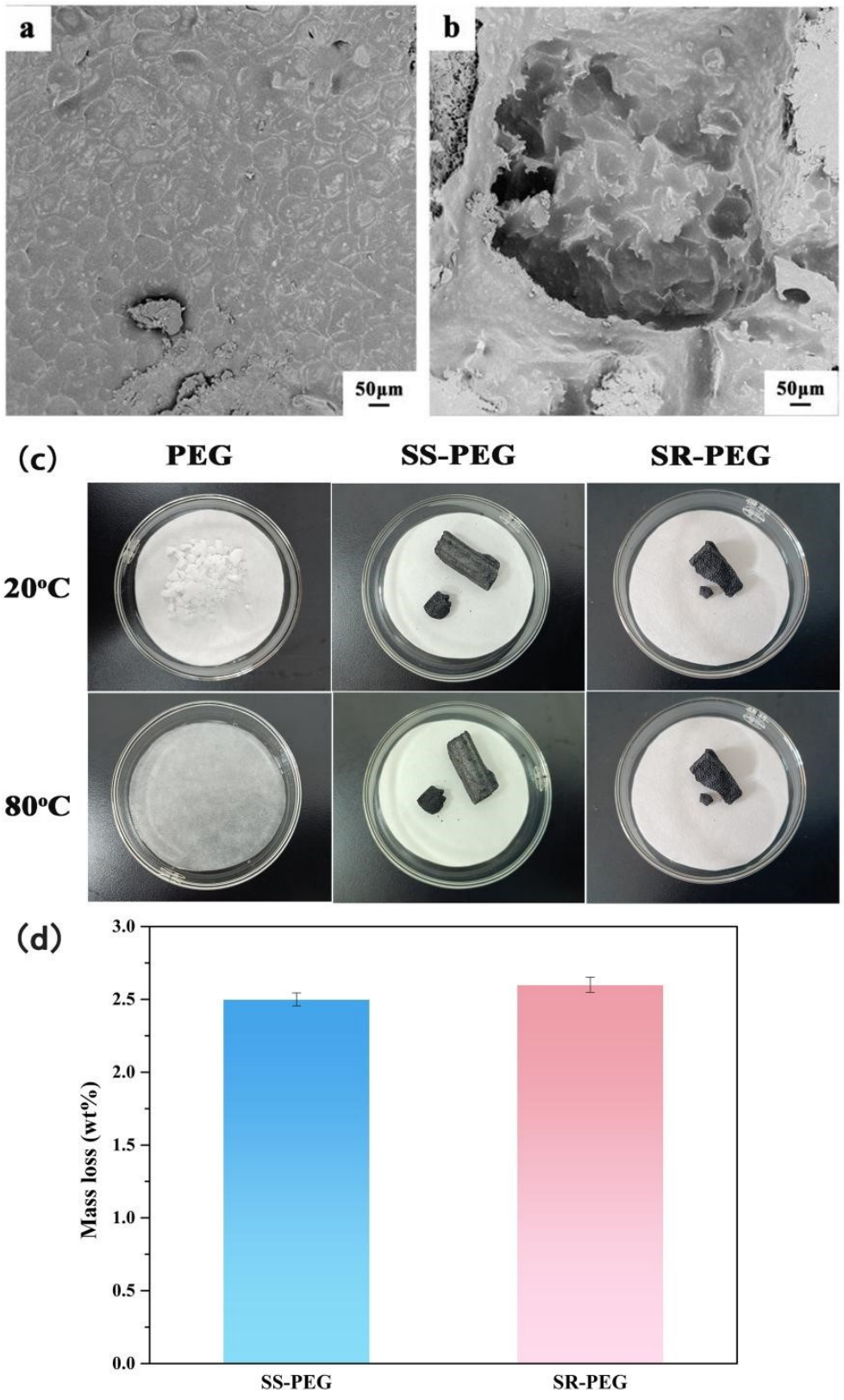

Fig. 5. SEM images of shape-stabilized phase change materials: (a) SS-PEG and (b) SR-PEG, and (c) leakage macroscopic morphology of PEG, SS-PEG and SR-PEG under 80 ℃ for 30 min.

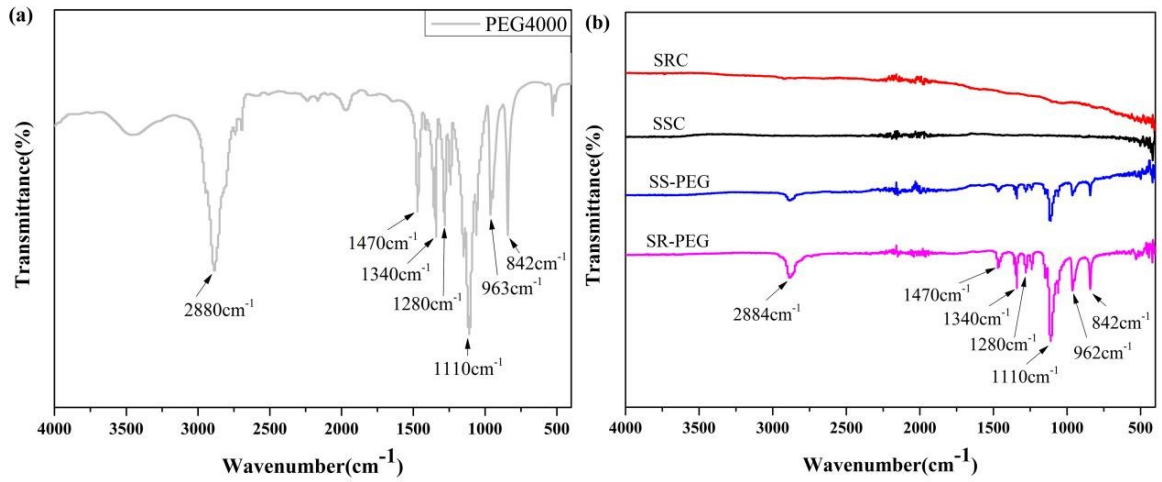

Fig. 6. Infrared spectra of PEG4000, various carbon materials and shape-stabilized phase change materials: (a) PEG4000; (b) SSC, SRC, SS-PEG and SR-PEG.

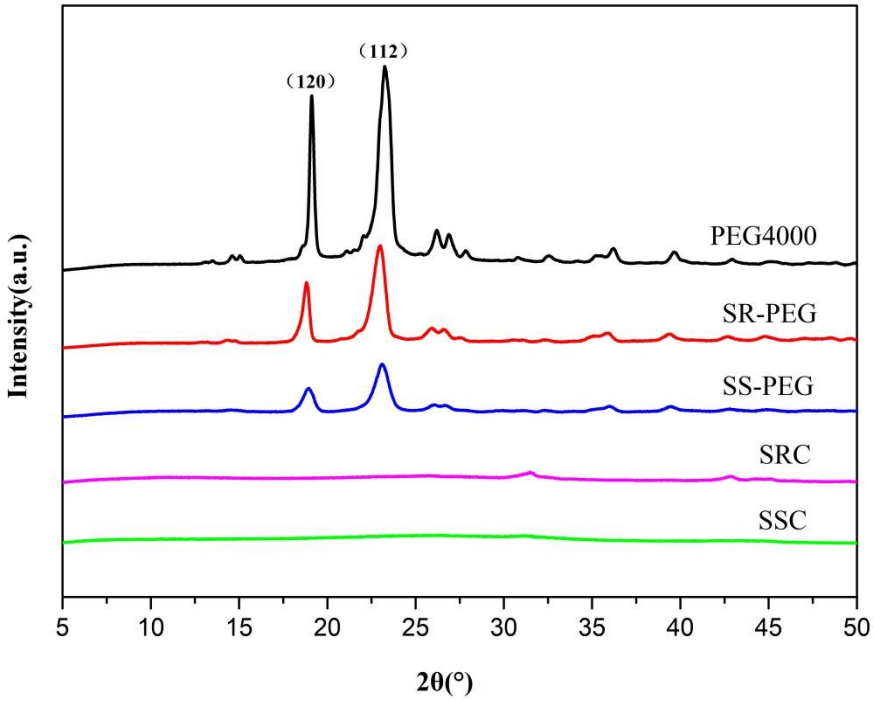

Fig. 7. XRD patterns of PEG4000, SSC, SRC, SS-PEG and SR-PEG.

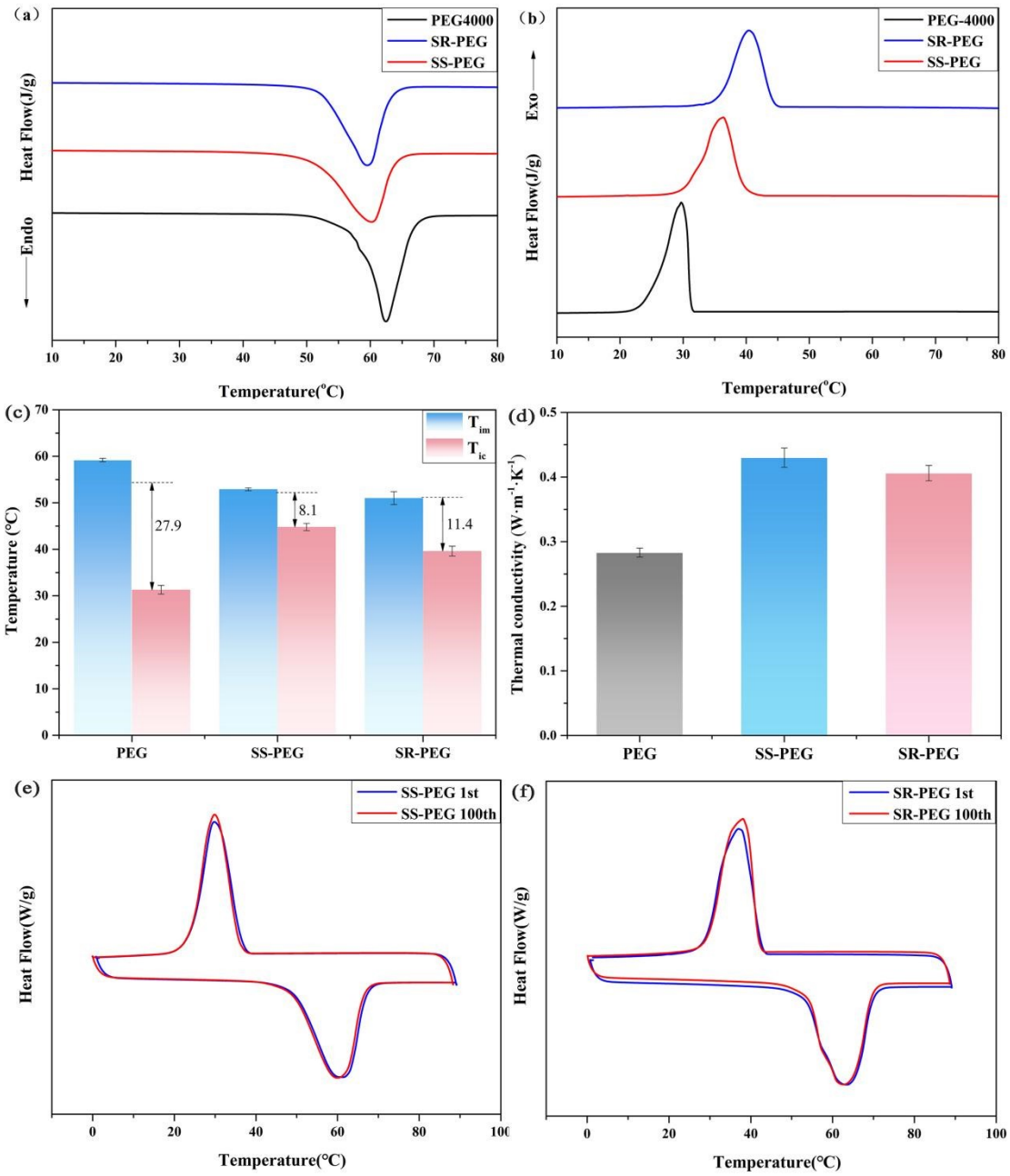

Fig. 8. DSC curves of PEG4000, SS-PEG and SR-PEG: (a) melting curve, (b) crystallization curve; (c) Melting and crystallization temperature of PEG4000, SS-PEG and SR-PEG; (d) The thermal conductivity of PEG, SS-PEG, and SR-PEG; DSC curves of composite PCMs after 100 thermal cycles: (e) SS-PEG, (f) SR-PEG.

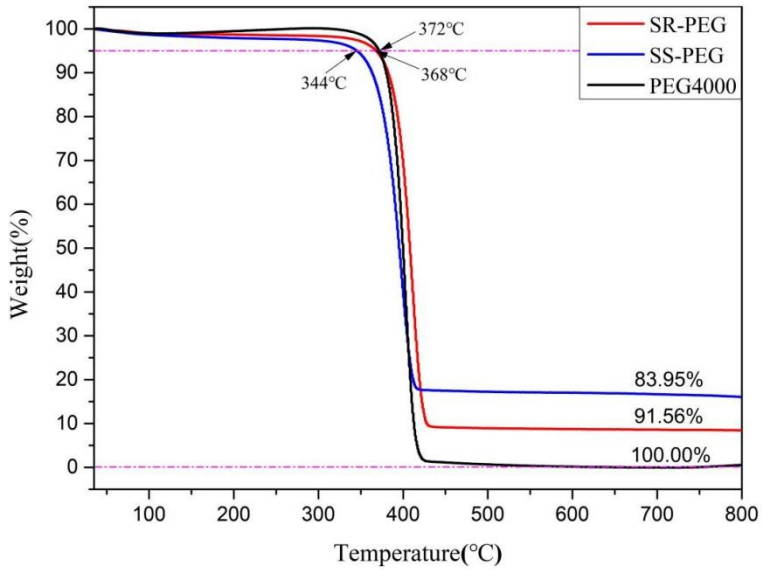

Fig. 9. TGA curves of PEG4000, SS-PEG and SR-PEG.

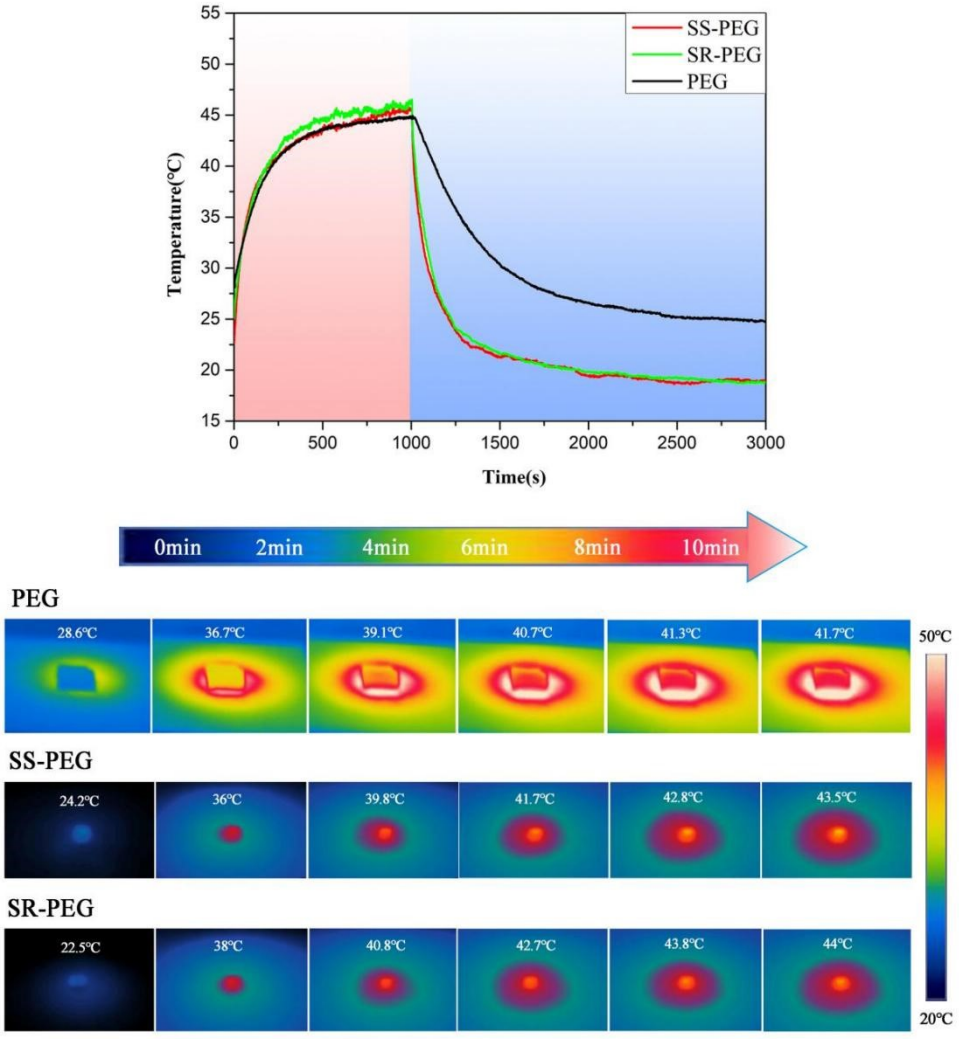

Fig. 10. (a) Temperature curves of PEG, SS-PEG and SR-PEG with time under xenon lamp; (b) Infrared thermal images of PEG, SS-PEG and SR-PEG during heating.

2. Table

Table 1 BET surface area and pore volume of SSC and SRC.

Samples	BET surface area (m^2/g)	Total pore volume (cm^3/g)	Micro pore volume (cm^3/g)	Mean pore size (nm)
SSC	1016.60	0.51	233.56	2.01
SRC	1637.00	1.27	376.10	3.10

Table 2 Enthalpy and phase transition temperature of PEG4000 and various shape-stabilized phase change materials.

Samples	T_{im} (°C)	T_m (°C)	ΔH_m (J/g)	T_{ic} (°C)	T_c (°C)	ΔH_c (J/g)	R (%)
PEG4000	59.2±0.4	62.5±0.2	187.4±0.3	31.3±1.1	28.5±1.2	174.3±0.5	-
SS-PEG	52.9±0.3	59.7±0.2	153.4±0.7	44.8±0.9	41.4±1.1	150.4±0.4	81.9
SR-PEG	51±1.5	60±1.1	171.5±0.2	39.6±1.2	36.7±0.6	166.5±0.2	91.5

Table 3. Thermal transition capacity and the loading of recently reported composite PCMs.

Supporting materials	PCMs	Latent heat (J/g)	Loading (%)	Ref.
Potato derived carbon	PEG4000	91.8	50.0	[51]
Potato derived carbon	PEG4000	158.8	85.4	[52]
Eggplant-derived porous carbon	PEG2000	149.0	90.1	[53]
Hemp-stem-derived biochar	PEG6000	170.44	88.62	[54]
Corncob-derived biochar	PEG6000	121.94	85.19	[55]
Boron nitride/polypyrrole/wood-based carbon	PEG6000	160	78.1	[56]
SSC	PEG4000	153.4	81.9	This work
SRC	PEG4000	171.5	91.5	This work

3. Uncertainty analysis of DSC and thermal constant analyzer

3.1. Uncertainty analysis of DSC

Selection of thermal analysis standards indium calibration to analyze the uncertainty of DSC instruments. According to the analysis of the measurement process of the differential scanning calorimeter, the uncertainty of the temperature indication error mainly comes from the following three aspects: (1) the uncertainty introduced by the standard substance calibration; (2) the uncertainty introduced by test repeatability; and (3) the uncertainty introduced by the instrumental system. The uncertainty of the calorimetric indication error mainly comes from the following four aspects: (1) the uncertainty introduced by the standard substance calibration; (2) the uncertainty introduced by test repeatability; (3) the uncertainty introduced by the weighing of the balance; and (4) the uncertainty introduced by the instrumental system.

3.1.1. Uncertainty introduced by the standard substance calibration

Instrumental calibration of thermal analysis standard substance indium is a certified standard substance, standard substance certificate number GBW (E) 130182, is a class B uncertainty component. The melting temperature of the thermal analysis standard substance indium is 156.52 ℃, U = 0.26 ℃ (k = 2), and the heat of melting is 28.53 J/g, U = 0.30 J/g (k = 2), so the standard uncertainty introduced by the standard substance is $U_1(T_m)$ = 0.13 ℃, $U_1(\Delta H_m)$ = 0.15 J/g. The standard extended uncertainties U_{1rel} of the enthalpy of melting and melting temperature were 0.53% and 0.083%, respectively, given by the certificate of the standard substance.

Table 4 Melting enthalpy and melting temperature test results for indium.

Sample number	Mass	ΔH_m (J/g)	T_m (°C)
1	4.93	28.2	158.0
2	4.95	28.1	158.0
3	4.96	28.1	158.2
4	4.97	27.9	157.9
5	4.97	28.0	158.2
6	4.94	28.2	158.3
7	4.93	28.2	158.3
8	4.97	28.0	158.4
9	4.95	28.1	158.4

10	4.96	28.0	158.4
$\bar{x}$	4.95	28.1	158.2
s(x)	0.016	0.103	0.185

3.1.2. Uncertainty introduced by test repeatability

The uncertainty introduced by the repeatability of the calorific value belongs to the class A uncertainty. The enthalpy of melting and melting temperature of indium were measured several times under the same measurement conditions, and the results are shown in Table 4.The standard uncertainties U_2 introduced by the repeatability were calculated using Equation (1-2):

$$U_2(\Delta H_m) = \frac{s(x)_{\Delta H_m}}{\sqrt{n}} \quad (1)$$

$$U_2(T_m) = \frac{s(x)_{T_m}}{\sqrt{n}} \quad (2)$$

The relative standard uncertainties U_{2rel} were calculated using equation (3-4):

$$U_{2rel}(\Delta H_m) = \frac{U_2(\Delta H_m)}{\bar{x}} \quad (3)$$

$$U_{2rel}(T_m) = \frac{U_2(T_m)}{\bar{x}} \quad (4)$$

The calculation showed that the relative standard uncertainties introduced by the repeatability of the melting enthalpy and melting temperature of indium were 0.12% and 0.037%, respectively.

3.1.3. Uncertainty introduced by the weighing of the balance

The sample mass was weighed using an analytical balance with a division value of 0.01 mg. According to the certificate of calibration of the balance, the maximum permissible error is $\pm$ 0.005 mg in the range of 1 to 500 mg. The inclusion factor k = $\sqrt{3}$ is calculated based on the uniform distribution. The relative standard uncertainties U_{3rel} introduced by the weighing of the balance were calculated using Equation (5):

$$U_{3rel}(\Delta H_m) = \frac{0.005}{k\bar{x}_m} \quad (5)$$

The relative standard uncertainty introduced by the weighing of the balance is calculated to be 0.058%.

3.1.4. Uncertainty introduced by the instrumentation system

According to the performance of the DSC differential scanning calorimeter, the resolving power of temperature and heat is 0.01 ℃ and 0.01 J/g, respectively, and the half-widths of the intervals for temperature and heat are 0.005 ℃ and 0.005 J/g. Calculated according to a uniform distribution with an inclusion factor of k = $\sqrt{3}$, the

relative standard uncertainties U_{4rel} introduced by the resolving power of the instrument were calculated using Equation (6-7):

$$U_{4rel}(\Delta H_m) = \frac{0.005}{k\bar{x}_{\Delta H_m}} \quad (6)$$

$$U_{4rel}(T_m) = \frac{0.005}{k\bar{x}_{T_m}} \quad (7)$$

From the calculations, the standard uncertainties introduced by the instrumental resolving power for the enthalpy of melting and melting temperature of indium were 0.01% and 0.002%, respectively.

3.1.5. Synthetic uncertainty

The components of the standard uncertainty are uncorrelated, and the synthesized uncertainties U_{Srel} were calculated by equation (8-9):

$$U_{Srel}(\Delta H_m) = \sqrt{U^2{}_{1rel}(\Delta H_m) + U^2{}_{2rel}(\Delta H_m) + U^2{}_{3rel}(\Delta H_m) + U^2{}_{4rel}(\Delta H_m)} \times 100\% \quad (8)$$

$$U_{Srel}(T_m) = \sqrt{U^2{}_{1rel}(\Delta T_m) + U^2{}_{2rel}(T_m) + U^2{}_{4rel}(T_m)} \times 100\% \quad (9)$$

From the calculations, the synthesized uncertainties for the enthalpy of melting and melting temperature of indium were 0.55% and 0.09%, respectively.

3.1.6. Extended uncertainty

Taking the inclusion factor k is 2 and the confidence probability of 95%, the extended uncertainty of thermal conductivity is calculated by using equation (10):

$$U = kU_{Srel} \quad (10)$$

Calculations showed that the extended uncertainties of the enthalpy of melting and melting temperature for this DSC were 1.1% and 0.18%, respectively.

During the testing process, if it is ensured that the sample material is of the same quality each time it is placed in the sample, there will be a patchwork of several small pieces, which will result in multiple peaks when the temperature is raised or lowered. Therefore, it was ensured that the samples were placed in one piece at a time, which would result in the mass of the material not being quantified and thus increase the testing error. The samples were tested again and it was ensured that the enthalpy and temperature range of all the materials was $\pm$ 10%.

3.2. Uncertainty analysis of thermal constant analyzer

Since the thermal constant analyzer does not have a standard substance for routine calibration, polyethylene glycol was used directly as the test material. The sources of uncertainty components and their analysis are as follows. (1) The

uncertainty introduced by test repeatability. (2) The uncertainty component introduced by instrumentation system. (3) The uncertainty component introduced by sample temperature. According to the requirements of the instrument, the temperature of the measurement room is controlled at 25 ± 2 ℃, and the measurement is started after the temperature of the sample and the probe are equilibrated. Therefore, the uncertainty introduced by the sample temperature is negligible. (4) The uncertainty introduced by instrument input power and test time. The same instrument input power and test time are used for repeated tests, which are controlled by the computer, so the uncertainty introduced by the instrument input power and test time is negligible. (5) The uncertainty introduced by the probe resistance has been included in the instrument system uncertainty component.

Table 5 Test results of thermal conductivity of polyethylene glycol.

Sample number	*Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)*
1	0.290
2	0.283
3	0.280
4	0.281
5	0.279
6	0.284
7	0.283
8	0.283
9	0.281
10	0.282
$\bar{x}$	0.283
s(x)	0.003

3.2.1. Uncertainty introduced by test repeatability

The uncertainty caused by test repeatability belongs to class A uncertainty [JJF1059.1-2012]. Under the same conditions, the same standard block PEG for 10 tests, the average value as the test results, test results shown in Table 5. The standard uncertainty U_A introduced by repeatability was calculated using equation (11):

$$U_A(x) = \frac{s(x)}{\sqrt{n}} \tag{11}$$

The relative standard uncertainty U_{Arel} was calculated using equation (12):

$$U_{Arel}(x) = \frac{U_A(x)}{\bar{x}} \times 100\% \tag{12}$$

3.2.2. Uncertainty introduced by the instrumentation system

The uncertainty introduced by the instrument system belongs to class B uncertainty [JJF1059.1-2012]. The thermal constant analyzer thermal conductivity testing accuracy is $\pm$ 3%, obeying a uniform distribution. Using the equation (13) to calculate the standard uncertainty U_{Brel} introduced by the instrument system:

$$U_B(x) = \frac{a}{k} \tag{13}$$

Where a is $\bar{x}$ multiplied by the thermal conductivity test accuracy of the thermal constant analyzer. Taking the inclusion factor k is $\sqrt{3}$.

The relative standard uncertainty U_{Brel} was calculated using equation (14):

$$U_{Brel}(x) = \frac{U_B(x)}{\bar{x}} \times 100\% \tag{14}$$

3.2.3. Synthetic uncertainty

The components of the standard uncertainty are uncorrelated, and the synthesized uncertainty U_{Crel} is calculated by equation (15):

$$U_{Crel}(x) = \sqrt{U^2_{Arel}(x) + U^2_{Brel}(x)} \times 100\% \tag{15}$$

3.2.4. Extended uncertainty

Taking the inclusion factor k is 2 and the confidence probability of 95%, the extended uncertainty of thermal conductivity is calculated by using equation (16):

$$U = kU_{Crel} \tag{16}$$

The data from Table 5 was substituted into the above equation. The results showed that the extended uncertainty of the thermal conductivity of the thermal constant analyzer was 3.53%. Therefore, the uncertainty results for the thermal conductivity of SS-PEG and SP-PEG were 0.43 $\pm$ 0.015 and 0.406 $\pm$ 0.014, respectively. In order to ensure the reliability of the data, each sample was examined against three samples to obtain the average value and its actual range of values, which are shown in Table 6 and are within the uncertainty range of the instrument.

Table 6 Thermal conductivity of PEG, SS-PEG and SR-PEG.

Samples	*Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)*
PEG4000	0.283±0.007

SS-PEG	0.43±0.015
SR-PEG	0.406±0.012