SCCT Annual Concrete Seminar 2015

Concrete: From Production to Recycling

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Preparation and Characterization of Phase Change Material for Thermal Energy Storage in Buildings

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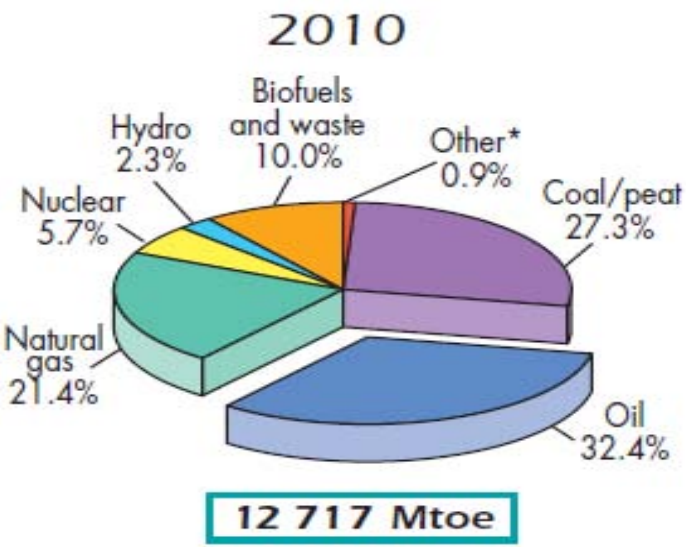
Background

Energy Consumption

- Global Issues
  - The energy demand increases as the growth of economic.
  - The conventional fossil energy sources are exhausting
  - The usage of fossil fuel is related to emission of harmful gases making people worried about environment issues.



World total primary energy supply by fuel in 2010 (Agency, 2012)

- Building Sector
  - It is the dominant energy consumers around the world with a total of 30% share of the overall energy consumption.
  - The energy demand for buildings have increased very rapidly due to population growth enhancement of building services and thermal comfort levels.*

*L. Perez-Lombard, et al. A review on buildings energy consumption information, Energy and Buildings 40 (3) (2008) 394–398.

Background

Energy Issue:

- Carbon audit (system control)
- Green label (system control)
- Use of replacement materials with lower embodied CO_2 emission (materials)

Research Direction (Topic):

2009 Role of Building Materials, global warming/Urban Heat Island effect (SCCT)

- Possible Alternative Materials on reduction in CO_2 Emissions in Building Design
- Review contribution of building finishes materials on Urban heat island effect
- Characterise building finishes materials in terms of their total energy released after heat

2011 Study of Rice Husk Ash as Green Cement Replacement Materials (Green Construction Materials, workshop Nami/HKIE Mat'ls divn)

2013 Study of Fine Recycled Glass in Concrete as filler and Cement Replacement Materials (SCCT)

2015 Study of Phase Change Materials (potential application in Buildings)

Background

Publications: Study of Phase Change Materials

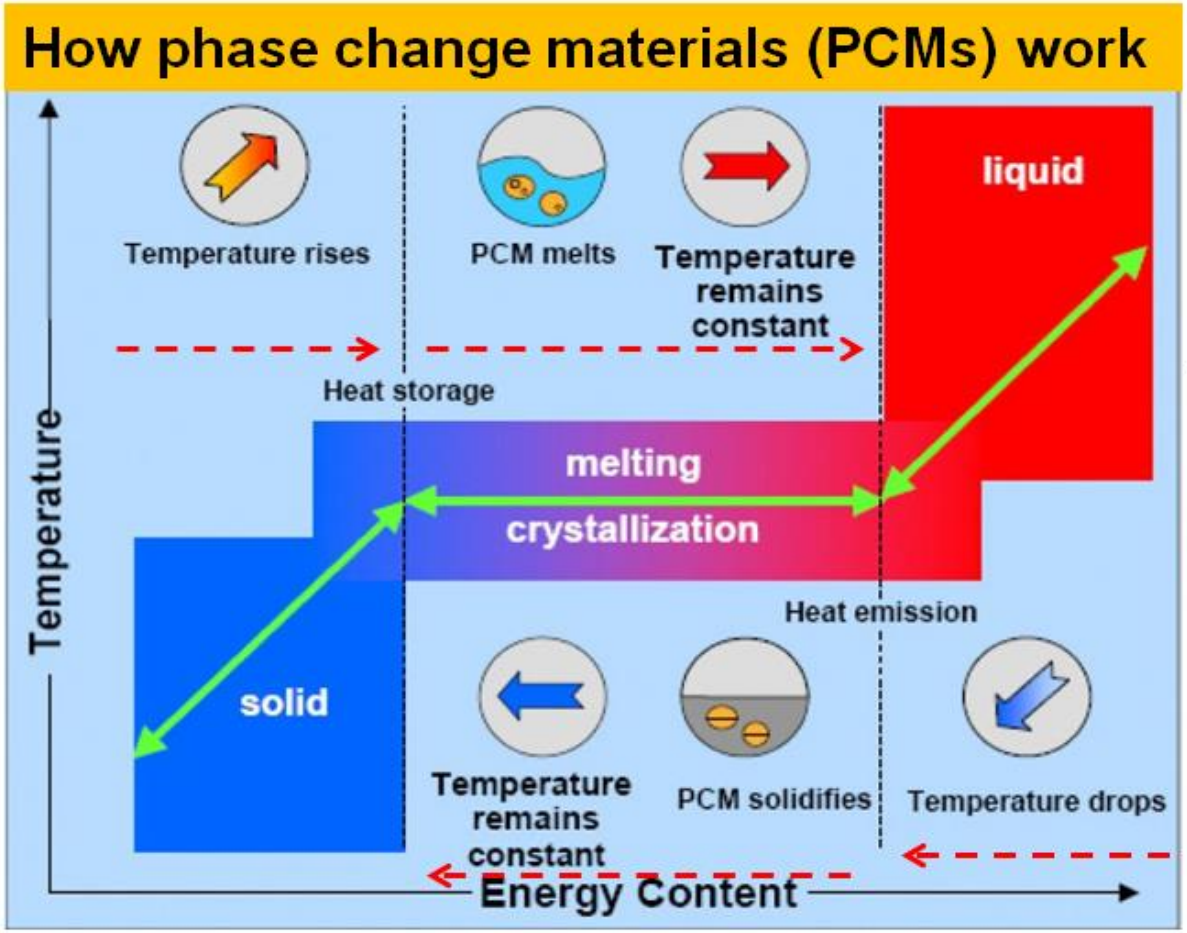
Memon, S.A., Cui, H.Z, Lo, Y.T. and Li, Q.S. (2015), Development of structural–functional integrated concrete with macro-encapsulated PCM for thermal energy storage. Applied Energy 150 (2015) 245–257.

Lo, Y.T., Memon, S.A., Barbhuiya, S.A., Xu, W, (2013), Development of form-stable composite phase change material by incorporation of dodecyl alcohol into ground granulated blast furnace slag., Energy and Buildings., July, 62: 360-367.

Memon, S.A., Lo, Y.T., Shi, X., , Barbhuiya, S., and Cui,H.Z. (2013), Preparation, characterization and thermal properties of Lauryl alcohol/Kaolin as novel form-stable composite phase change material for thermal energy storage in buildings., Applied Thermal Engineering, 59: 336-347.

Memon, S.A., Lo, Y.T., Cui, H.Z, and Barbhuiyaca, S. (2013), Preparation, characterization and thermal properties of dodecanol/cement as novel form-stable composite phase change material. *Energy and Buildings* , 66: 697-705.

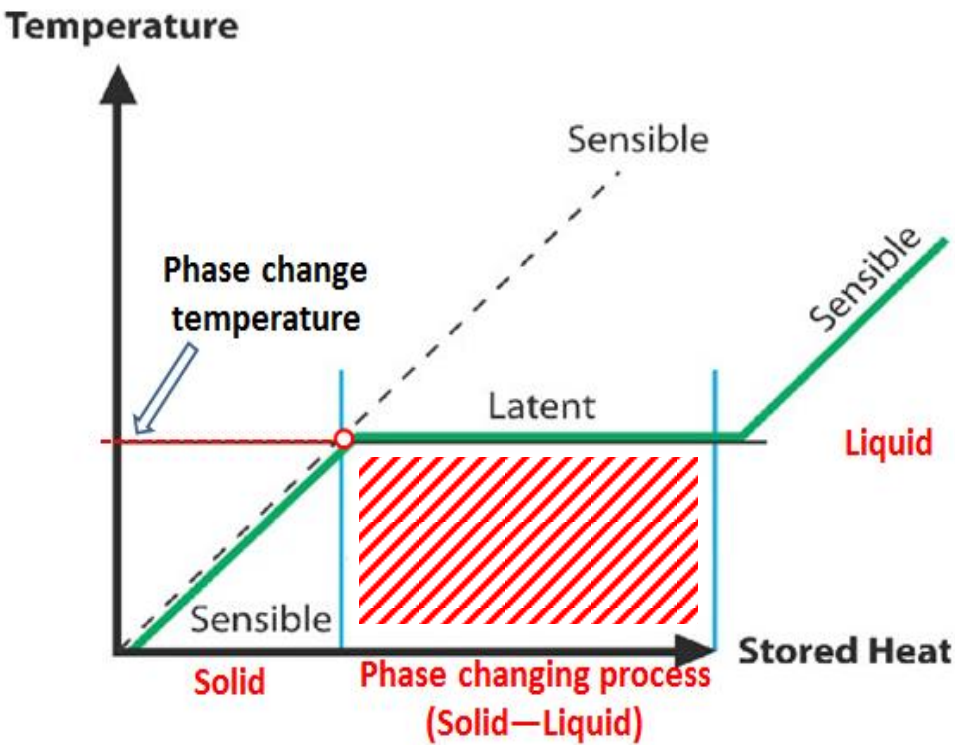
Background

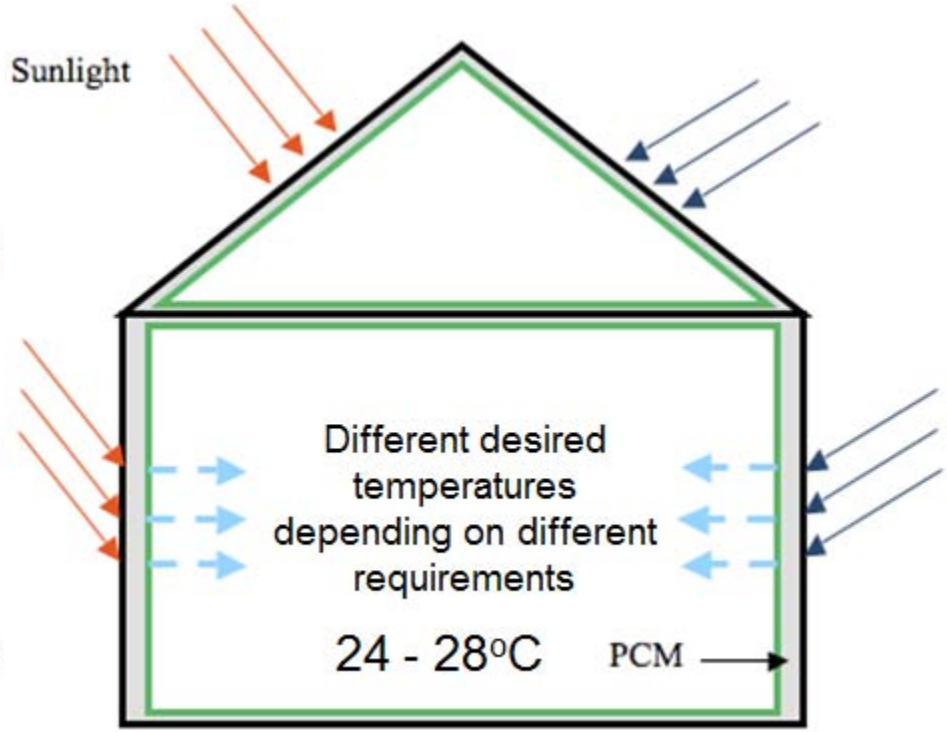


- **Phase change material (PCM)** works on the principle that as the temperature increases, the material stores energy with phase changing from solid to liquid phase within a defined temperature range; and then, when the temperature decreases, it releases heat with phase changing from liquid to solid phase.

Solution

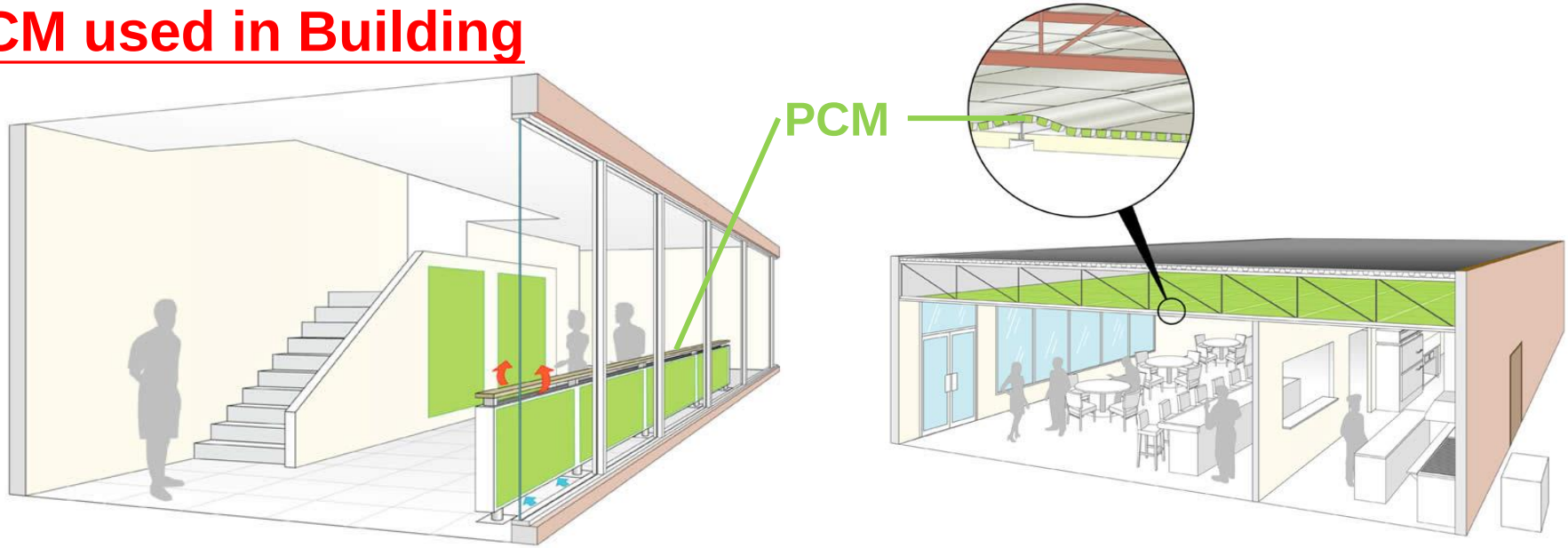
Combination of Building Materials and PCMs



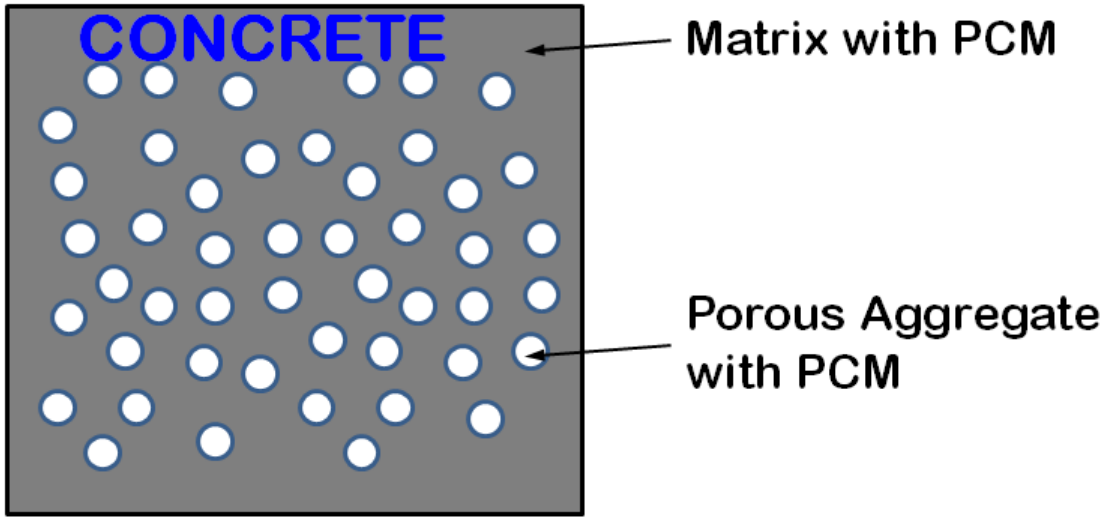


- Phase change material (PCM) has a large latent heat, It absorb or release large amount of latent heat in a narrow phase change temperature range, thus to regulate the indoor temperature of buildings.
- Different desirable indoor temperatures can be achieved in buildings by using PCM with suitable selected phase change temperatures.

PCM used in Building

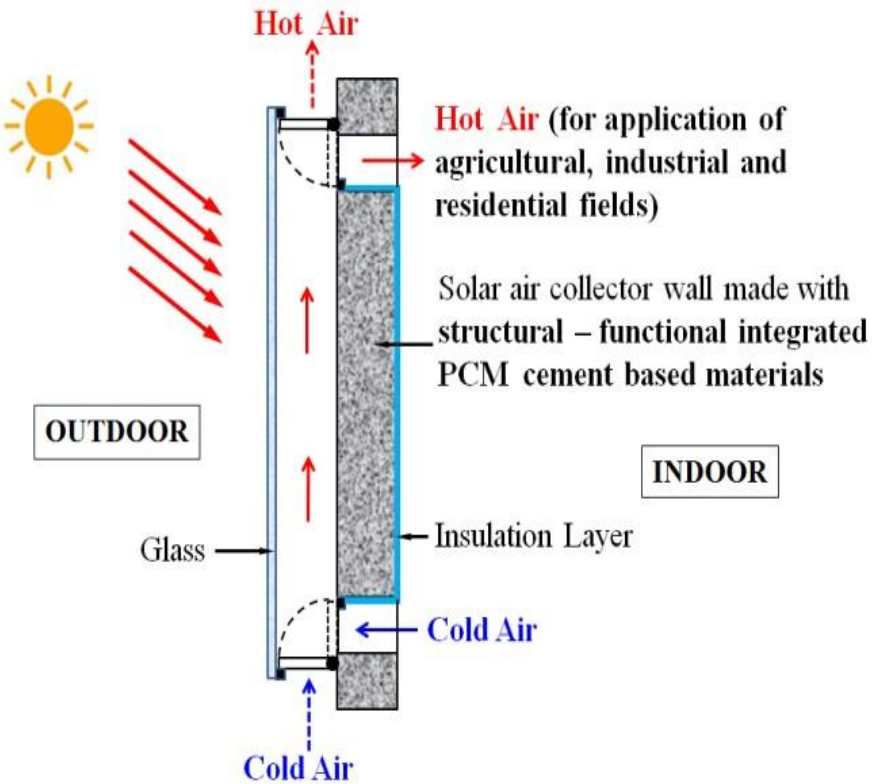


- More and more PCMs have been used in building, such as, interior walls. ceilings.

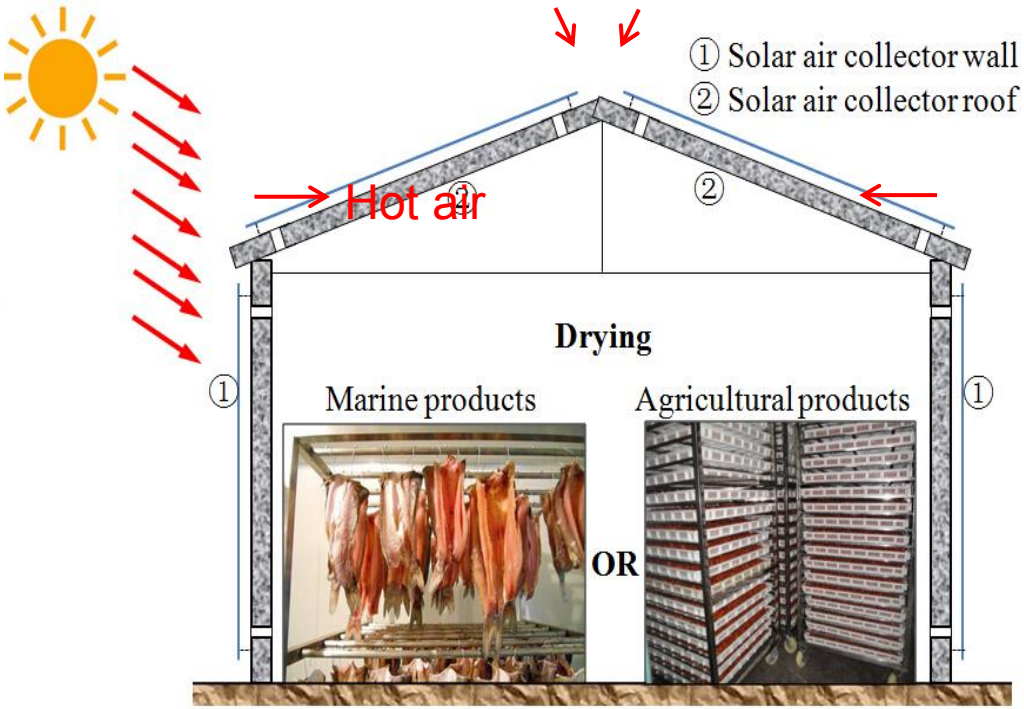


- Thermal energy storage concrete is prepared by integrating PCM with it.

Functional Structural PCM Wall

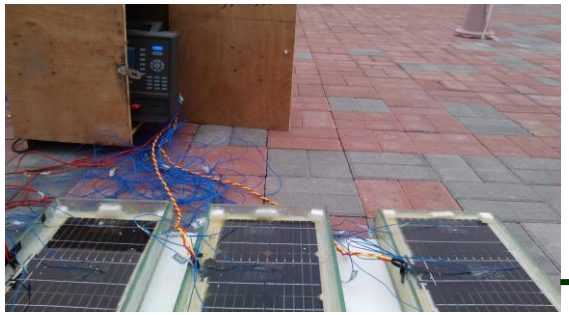


Solar air collector system

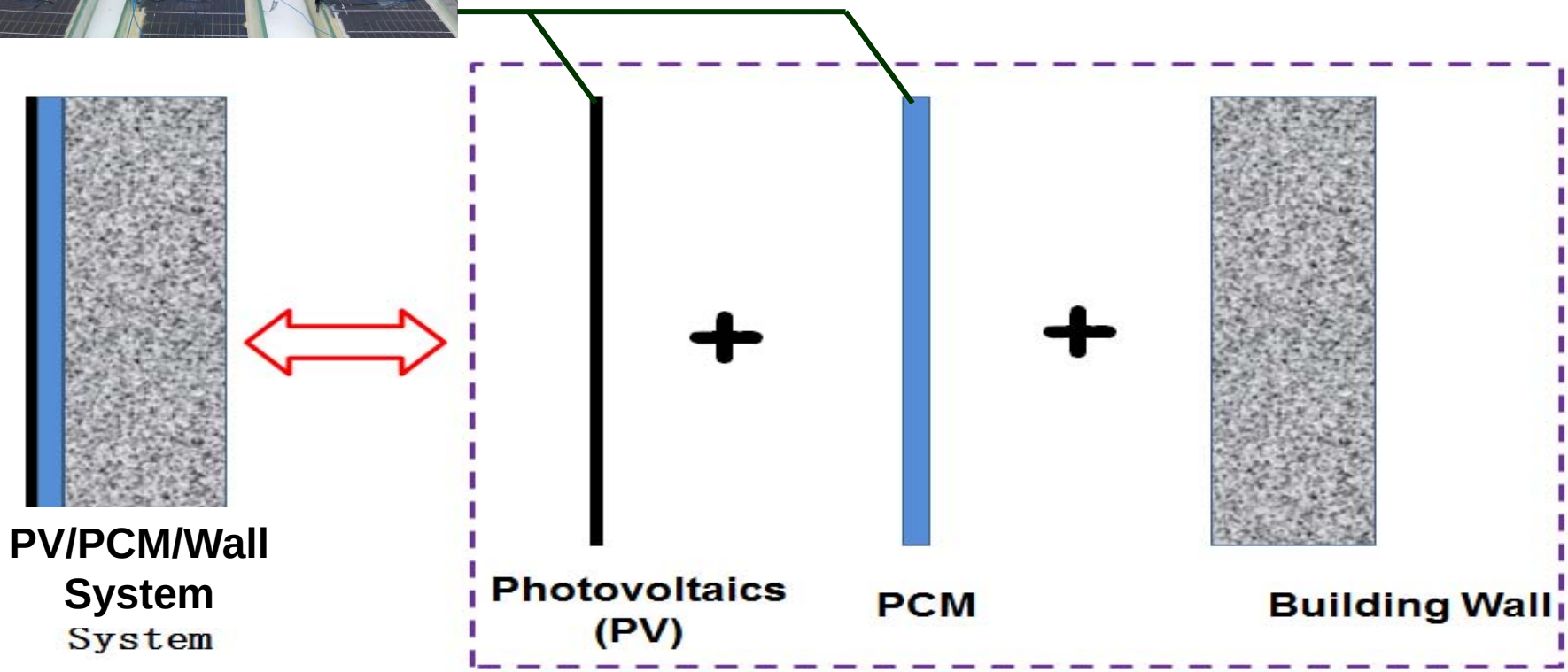


Solar air collector system used in wall and roof for drying in industrial building

Photovoltaics (PV) /PCM Composite Wall System



- Combining the characteristics of PV, PCM and building wall. PV/PCM composite wall system (a) store solar energy (b) increasing the efficiency of PV panel (c) regulate indoor temperature.



Laboratory Study

- **Part 1: Form-stable composite PCM**

  PCM in Mineral Admixture and Cement

  - PCM - Kaolin (KO)
  - PCM - Ground granulated blast furnace slag (GGBS)
  - PCM - Cement (CE)

- **Part 2: Macro-encapsulated PCM**

  PCM in Porous Lightweight Aggregate

  - Paraffin – Ceramisite Lightweight Aggregate Concrete

➢Part 1: Form-stable composite PCM

PCM in Porous Mineral Admixture and Cement

➢ Selection of PCM

Lauryl Alcohol (LA)	Paraffin
•Phase change temperature in Human comfort zone	
•High latent heat storage capacity	
•Economical	
	•Chemically inert
	•Non-corrosive
	•Innocuous (not harmful)

LA

Paraffin

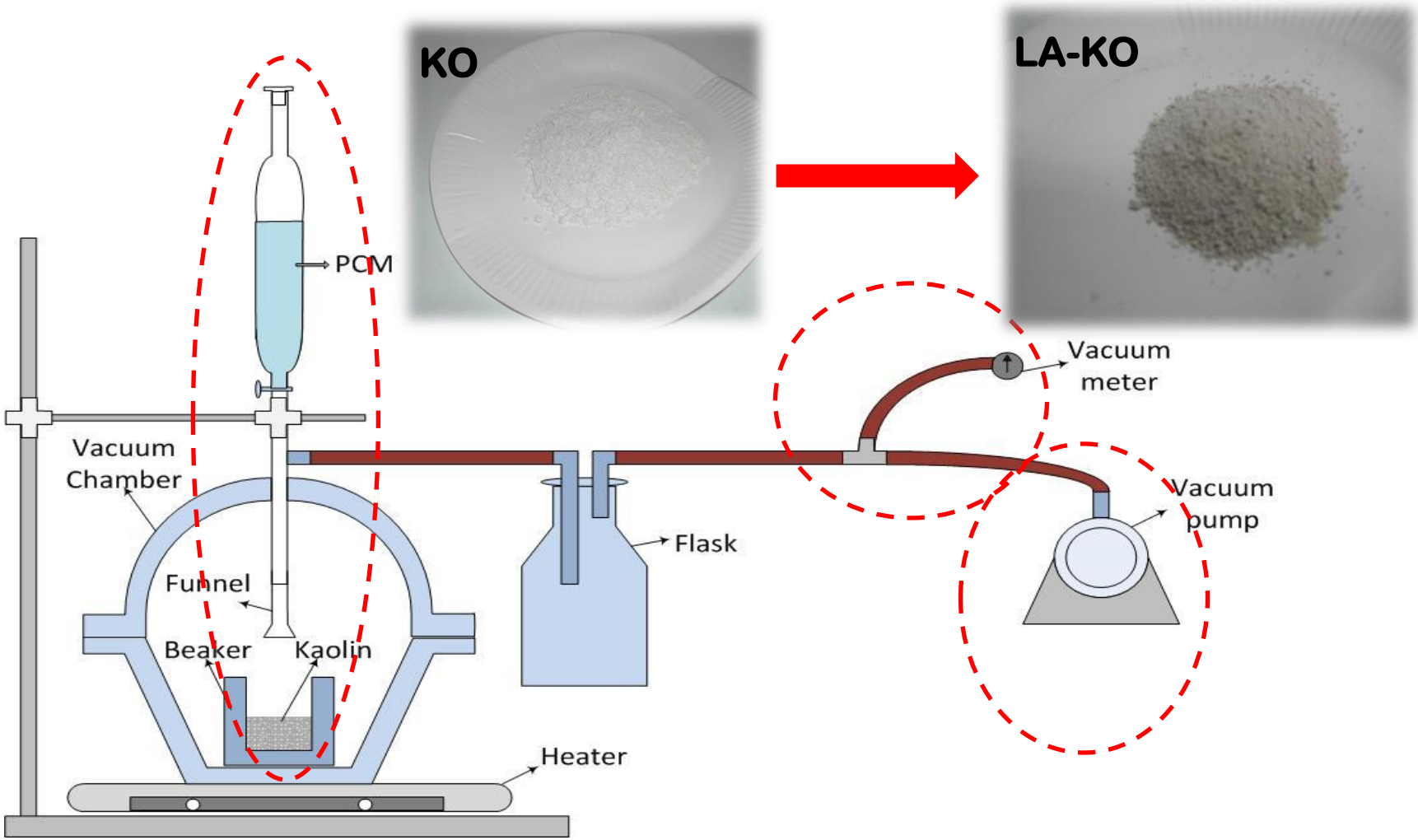
➢ Porous Mineral Admixture & Cement

- **Kaolin (KO)**
  - World production 28Mtonnes/year, China's share 11%
- **Ground granulated blast furnace slag (GGBS)**
  - China produces 30Mtons/year, Use in concrete 7Mtons/year
- **Cement (CE)**

Kaolin (KO)

GGBS

Preparation of PCM (Lauryl Alcohol/Kaolin)

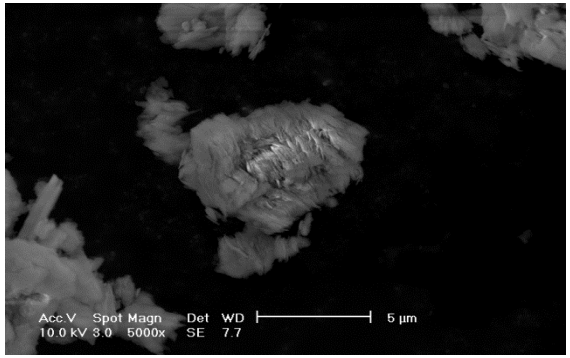


Schematic of Vacuum Impregnation setup

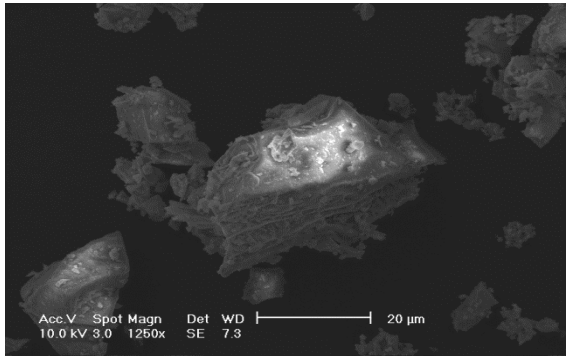
Morphology

– Environmental scanning electron microscope(ESEM)

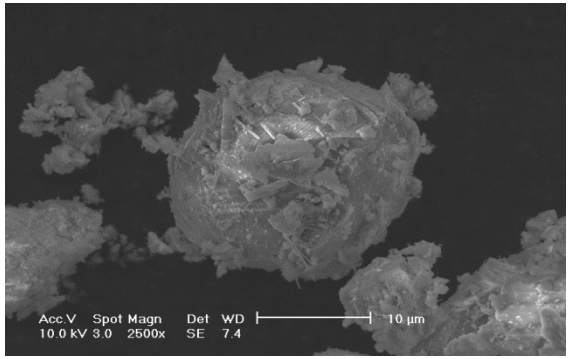
Kaolin



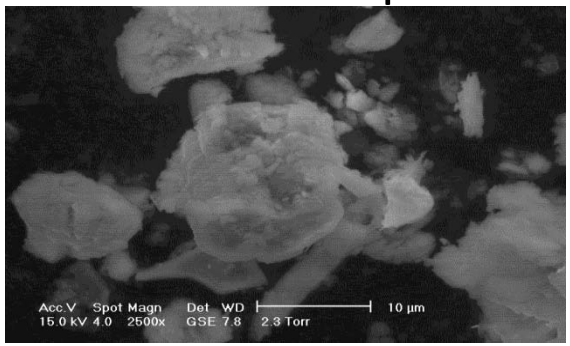
GGBS



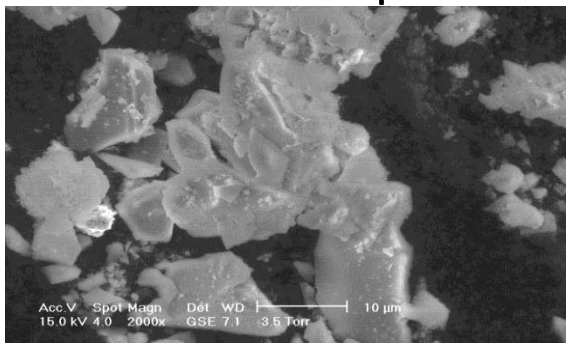
Cement



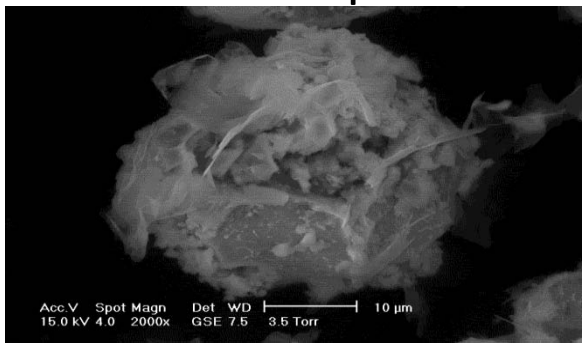
LA-Kaolin composite



LA-GGBS composite



LA-CE composite



LA= 24%; Paraffin = 18%

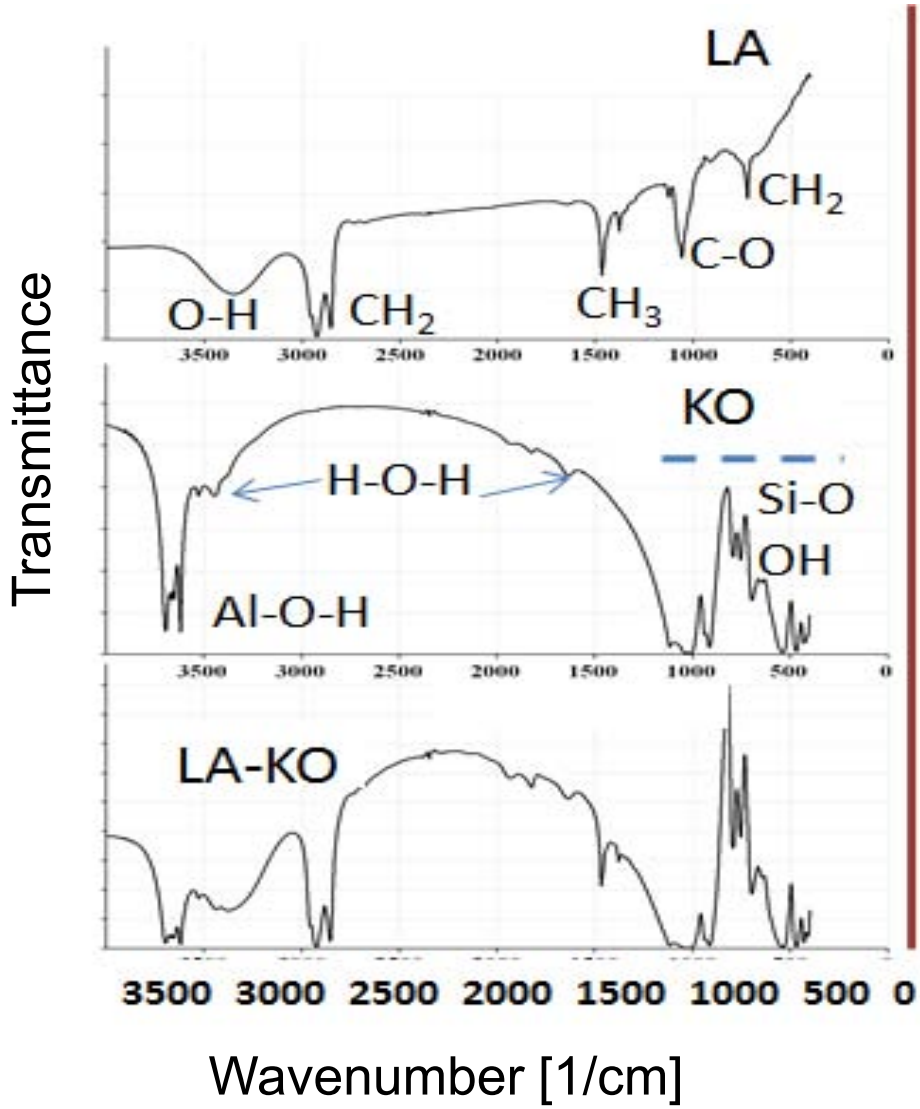
LA=11%; Paraffin = 9%

LA= 9%; Paraffin = 7%

- PCM was successfully held by the porous structure through capillary force and surface tension of the materials. KO has the best absorbing capacity of PCM.

Chemical Compatibility

- Fourier transformation infrared spectrum analysis (FT-IR)

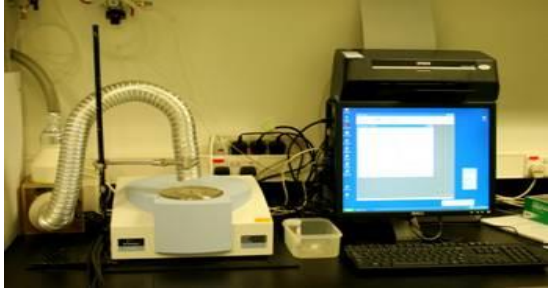


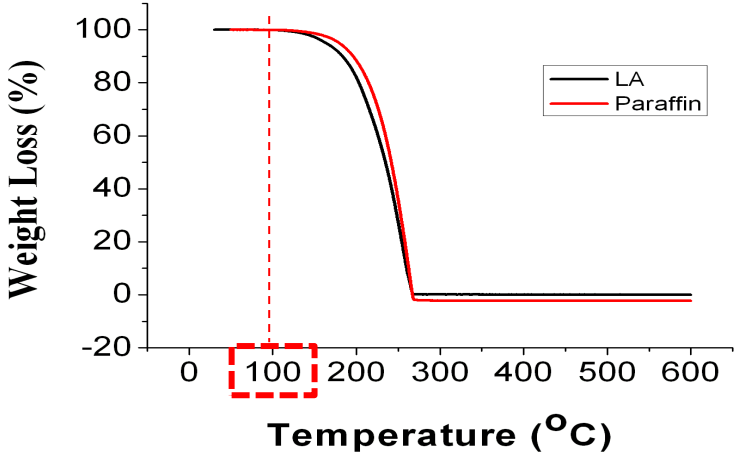
- The peak in the FT-IR spectrum correspond to different functional group. Without new peaks appear, the interaction between components of the composite PCM of LA-KO is physical in nature – Chemically compatible. So the composite mothed of LA-KO is only physical absorption.

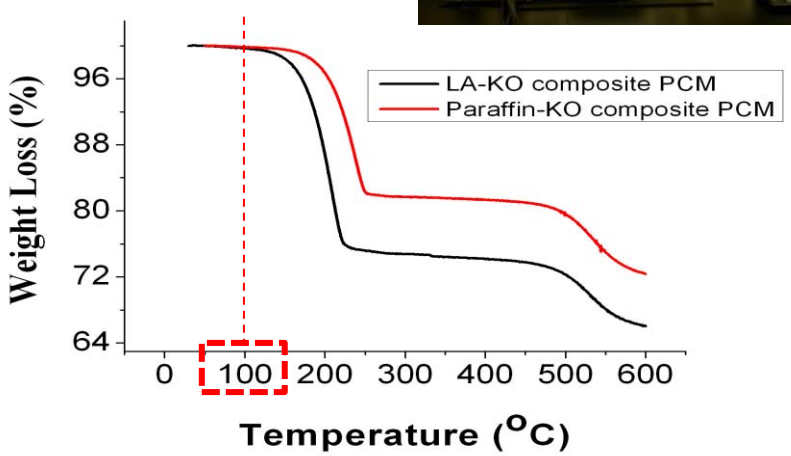
- Also, according to the test result, LA and paraffin both are chemically compatible with KO, GGBS and cement.

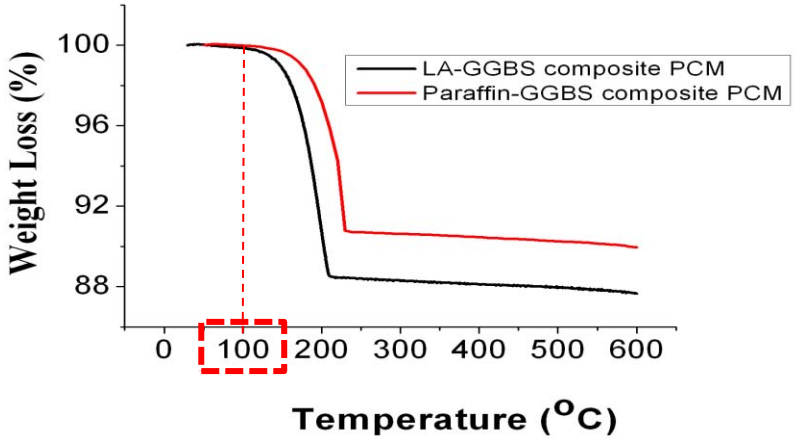
Thermal stability

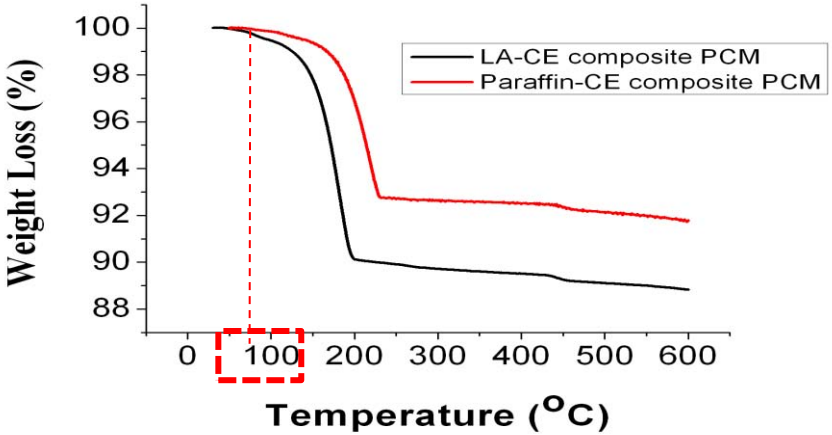
– Thermal gravimetric analyzer(TGA)







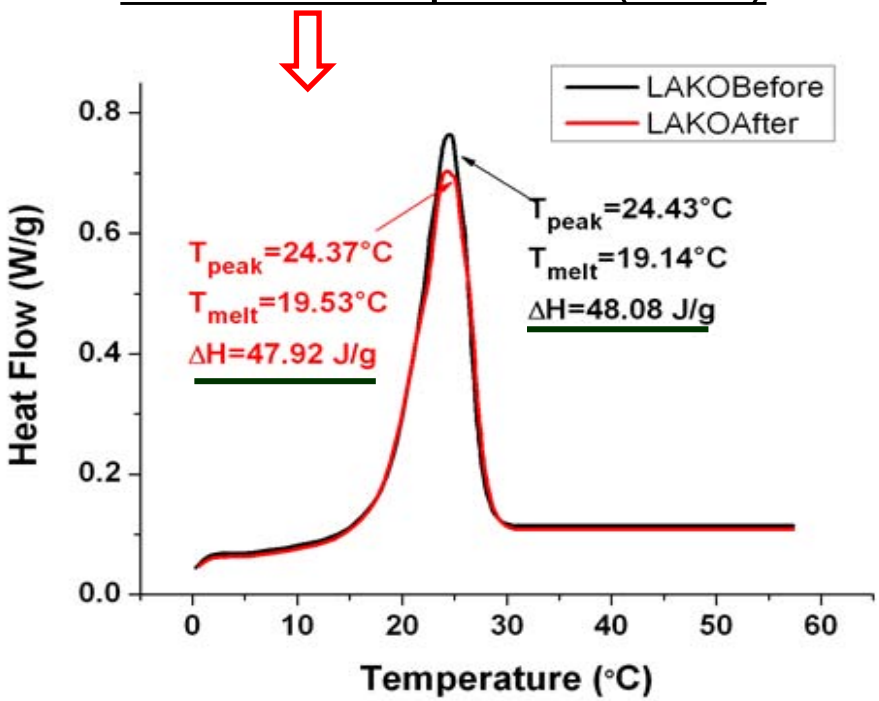


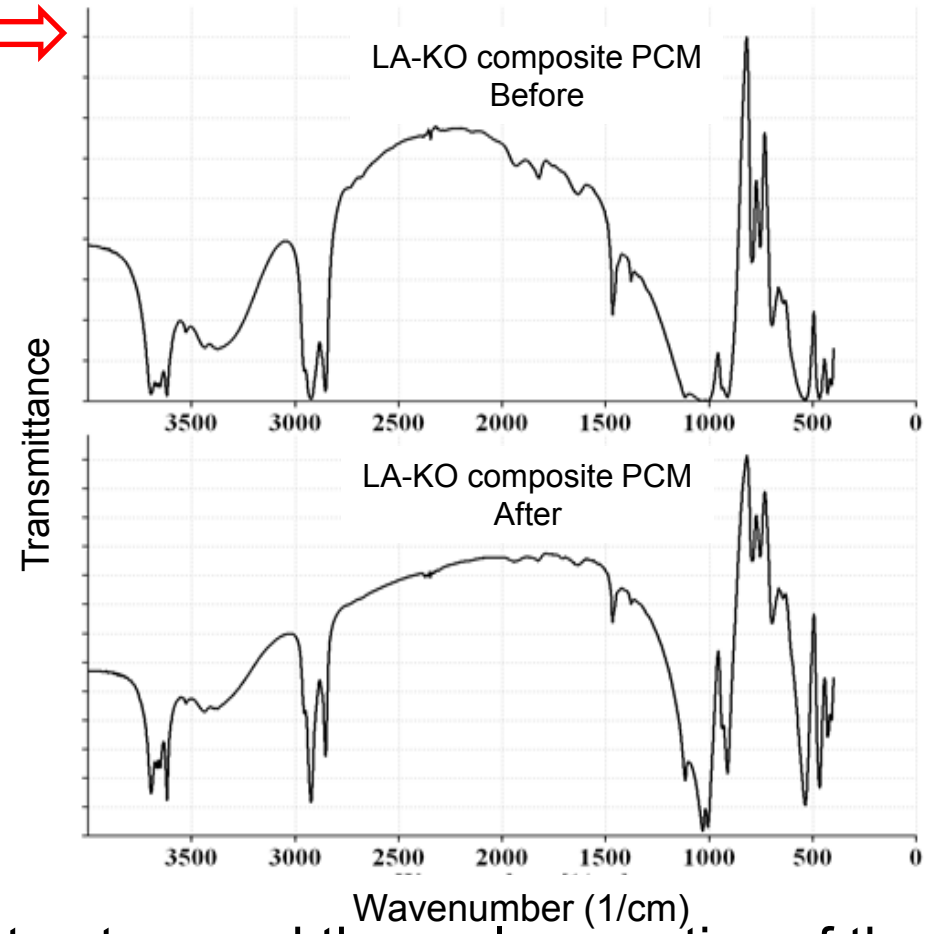


- When the test temperature is below 100°C, no obvious weight loss was observed. So the composite PCMs are thermal stable in its working temperature (<=100°C).

Thermal reliability

- The composite PCM is necessary to be thermally reliable over large number of melting and freezing cycles.
  - Chemical compatibility (FT-IR)
  - Thermal Properties (DSC)

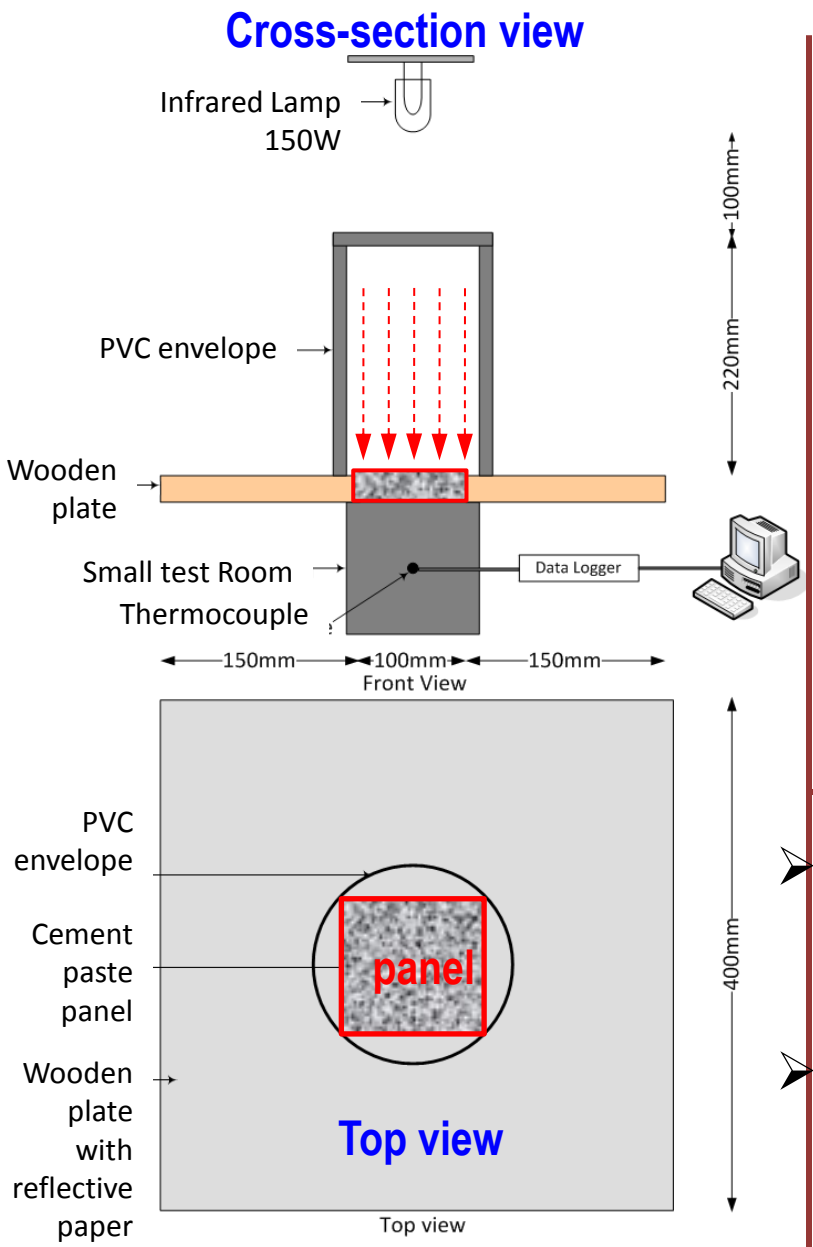


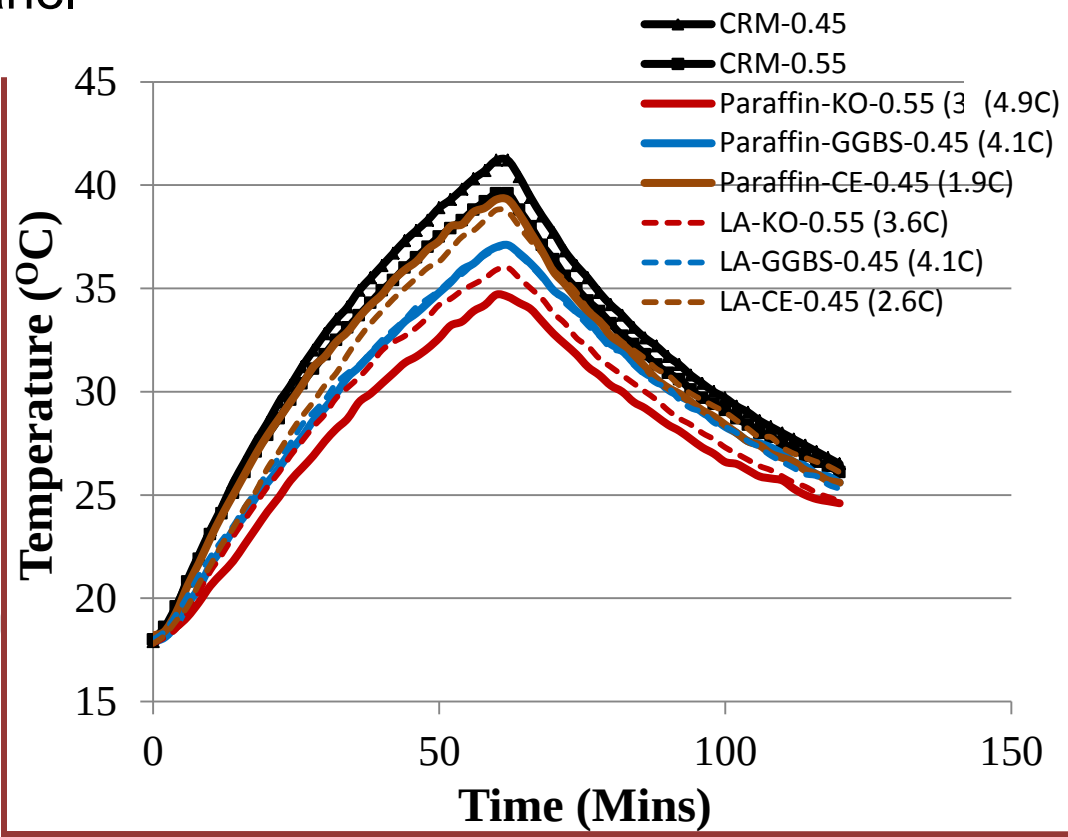


- The test results indicate chemical structure and thermal properties of the composite PCM don't change after numbers of thermal cycles (18-26°C).

Thermal performance

– Energy storage cement paste panel

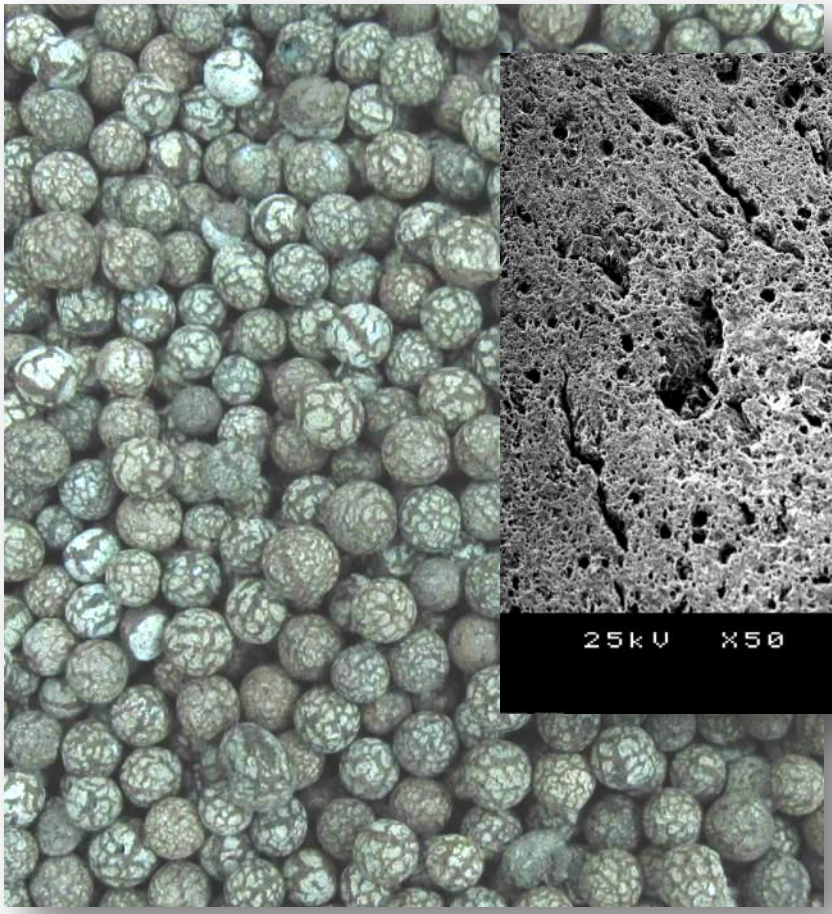




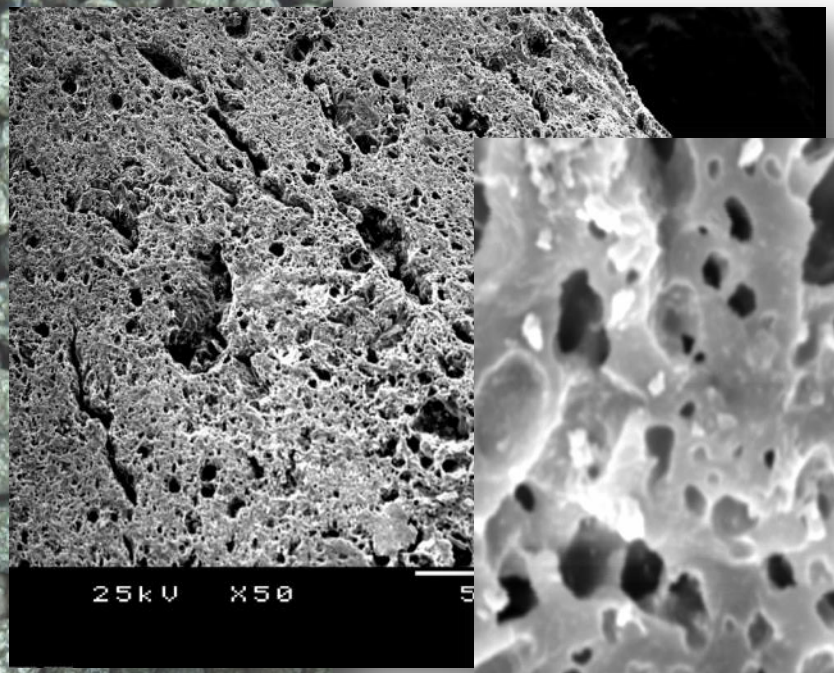
- PCM panels test showed reduced indoor temperature, right-shifted temperature curves and reduced temperature fluctuations.
- Form-stable composite PCMs are Potential Thermal energy storage materials for Building applications.

➢Part 2: Macro-encapsulated PCM

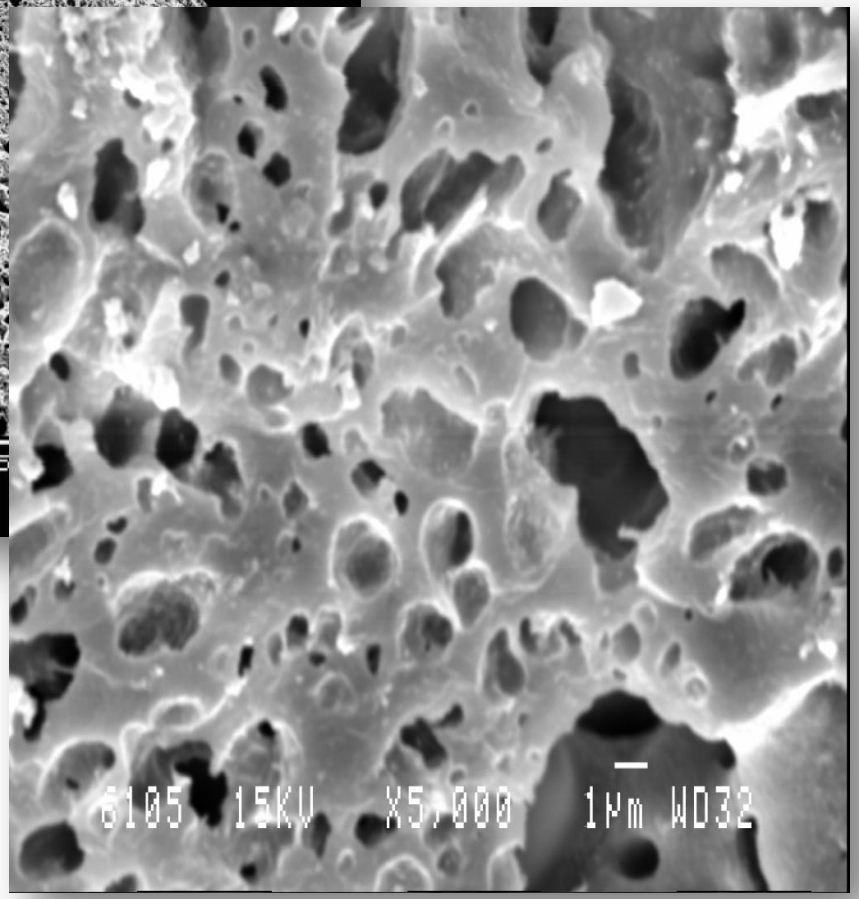
PCM in Porous Lightweight Aggregate



X 50

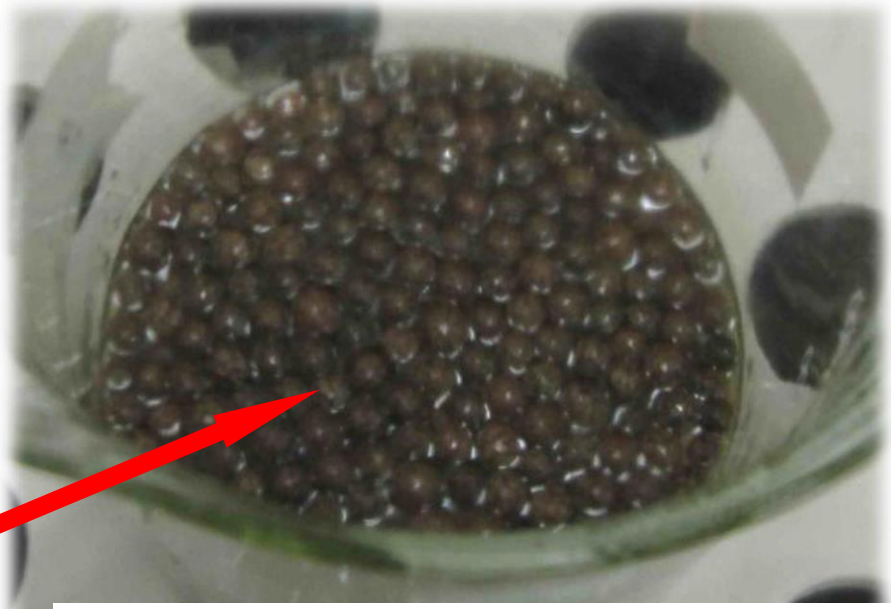


X 5000



- Ceramic porous lightweight aggregate as carrier of macro-encapsulated PCM.

Preparation of PCM-LWA composite



The PCM: paraffin

Phase change temp.: 24 ℃

Latent heat: 103 J/g.

Left：Vacuum impregnation set-up

Right：LWA in the melted paraffin

- Use vacuum impregnation method to obtain the macro-encapsulated PCM.

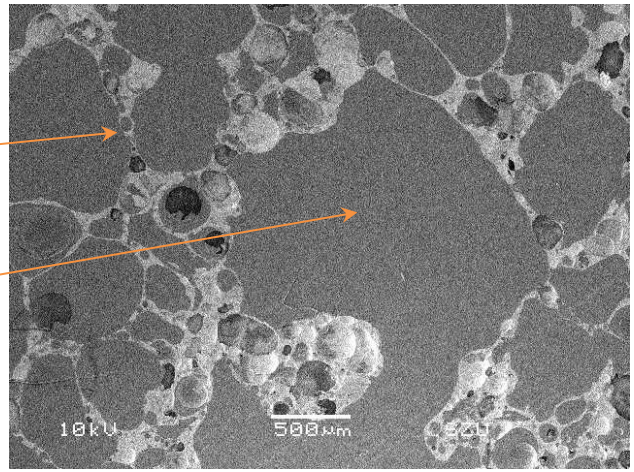
Macro-encapsulated Paraffin-LWA

Properties of the LWA, ceramisite	
Density	600kg/m3
Porosity (MIP)	77.75%
Water absorbing capacity by simple immersion (1hr)	18%
Water absorbing capacity by vacuum immersion (1hr)	73.85%
PCM absorbing capacity by vacuum immersion (1hr)	70%

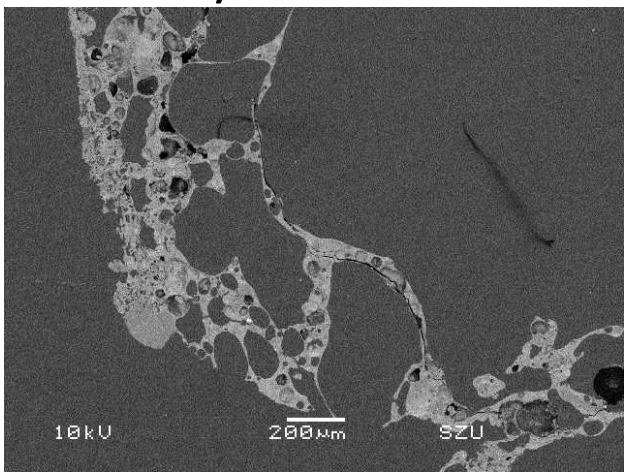
Synthetic LWA

LWA skeleton

LWA pores



LWA core

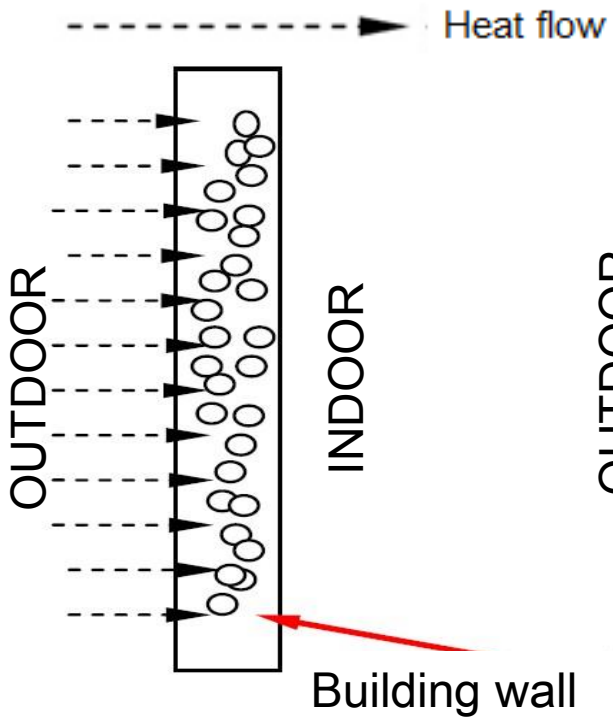


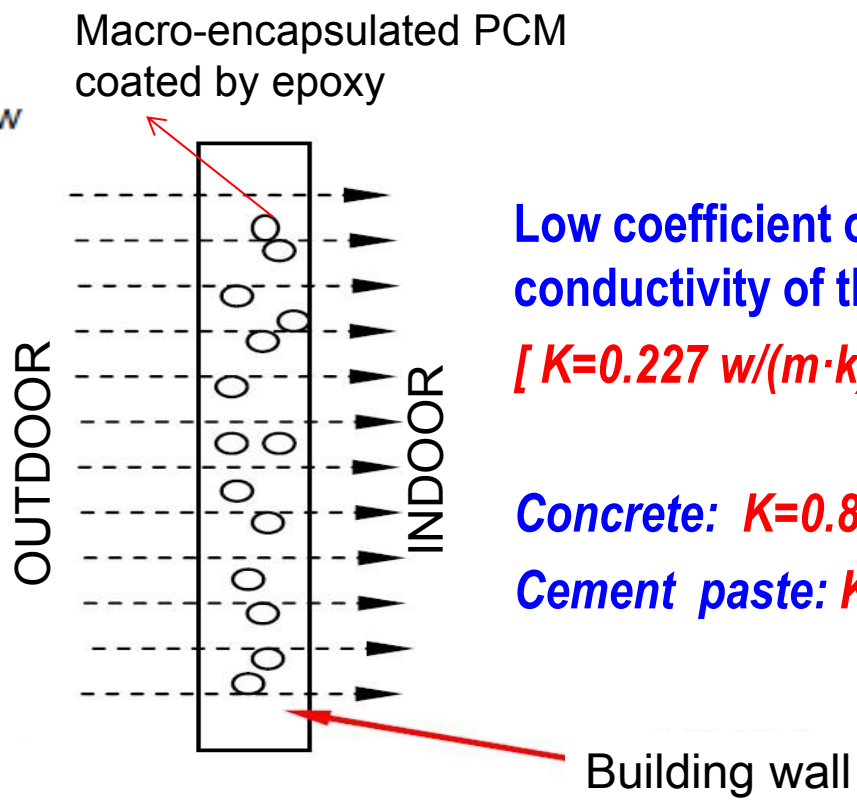
Boundary of LWA

- The maximum mass percentage of the PCM absorbed is about 70%. Compared with PCM absorbed in the form-stable PCM, it is very high.

- Since paraffin had no effect on hydration reaction, the leak paraffin (if any) adhering on the aggregate surface will pose problem to cement hydration and lower the mechanical strength of concrete.
- PCM-LWA trial coated with epoxy

Limitation: poor thermal conductivity of epoxy





Low coefficient of thermal conductivity of the epoxy sealer

[K=0.227 w/(m·k)]

Concrete: K=0.886 w/(m·k)

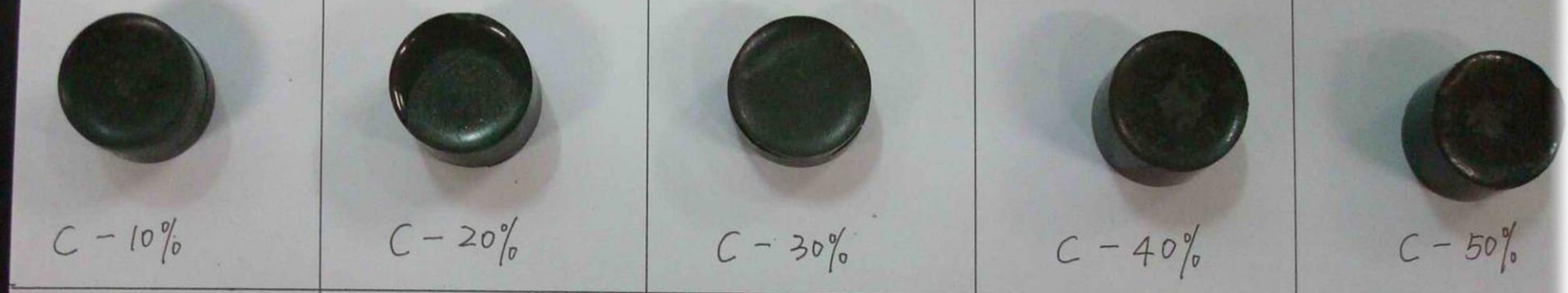
Cement paste: K=0.912 w/(m·k)

Ideal Working Model for PCM

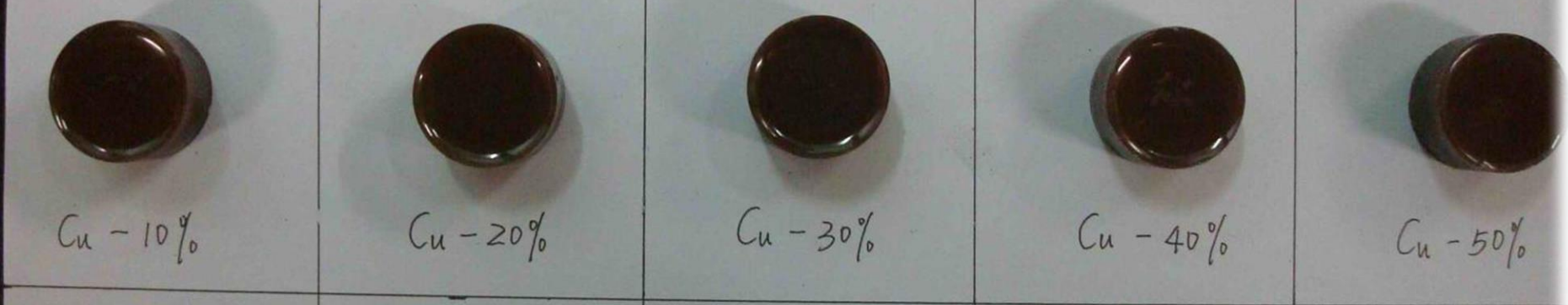
Real Working Model for PCM

- Low coefficient of thermal conductivity of the epoxy coat affected heat storage since heat can't get through the epoxy layer into the PCM inside the aggregate.

Graphite (Carbon powder) *K=398 W/mK*



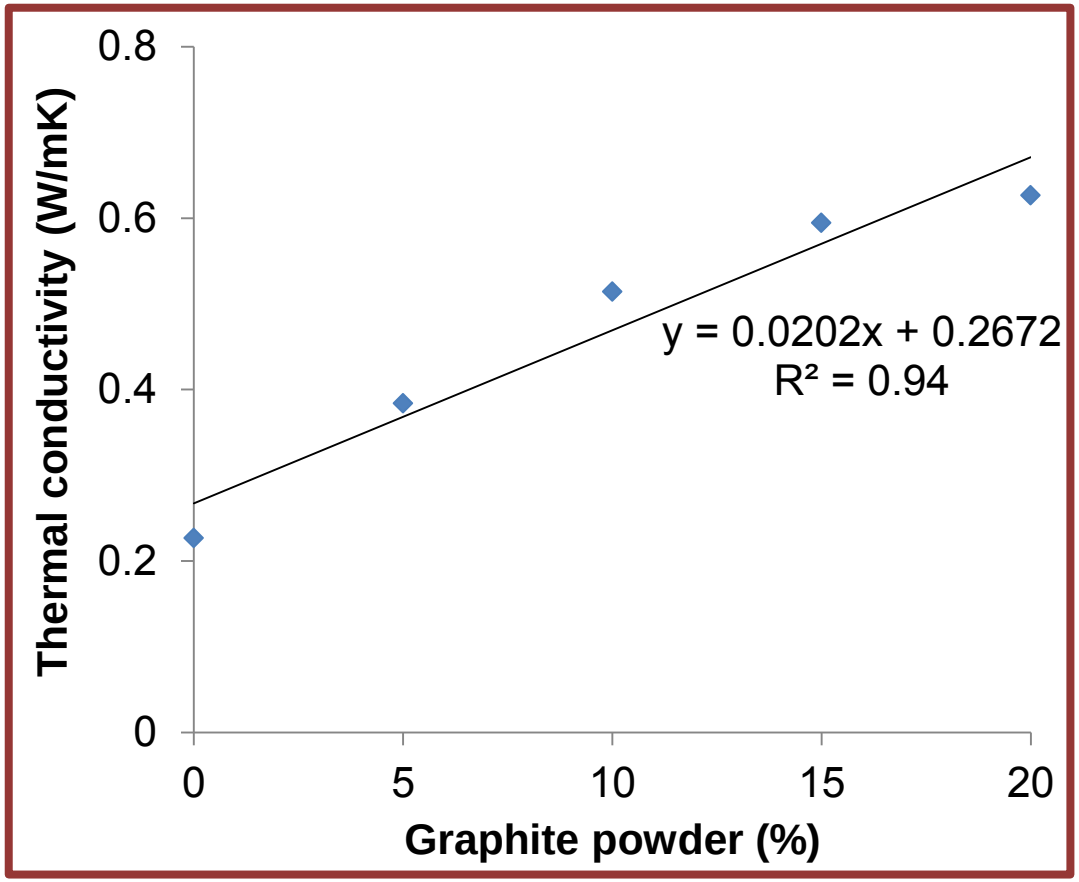
Copper powder *K=401 W/mK*



Control samples

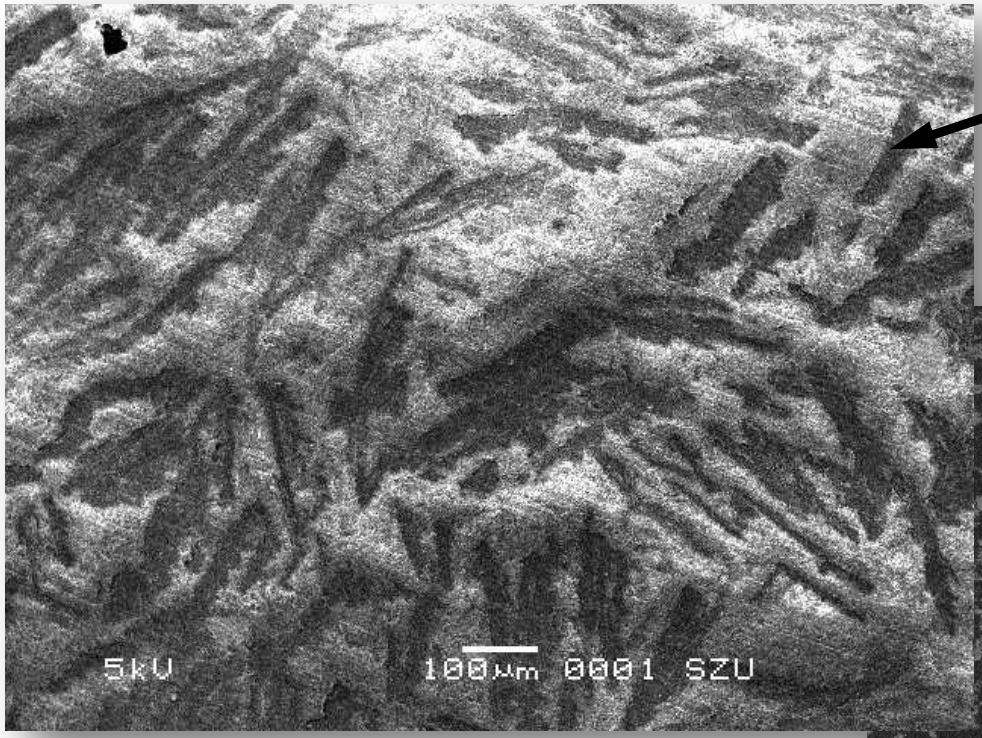
- Graphite and copper powder that with high thermal conductivities were added into epoxy in order to improve thermal conductivity.

Thermal conductivity tester



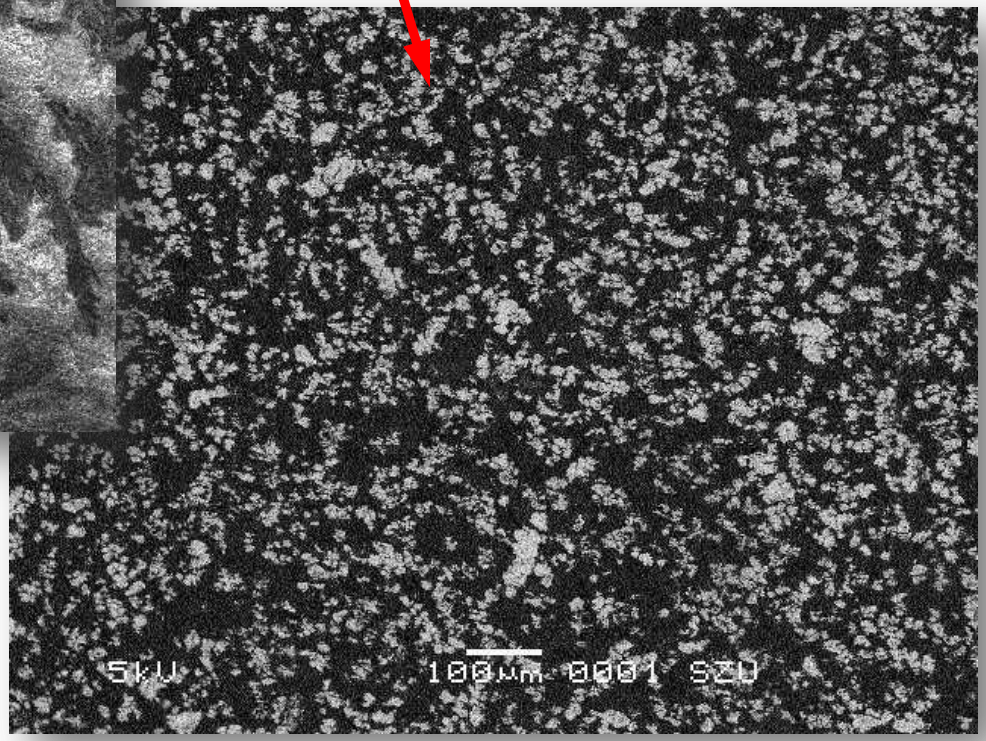
- Test results show that graphite has better thermal modification than copper powder.
- When 20 wt% of graphite powder is added to epoxy, the thermal conductivity would increase to 0.627 W/mK.

Surface Morphology



Graphite (Flake)

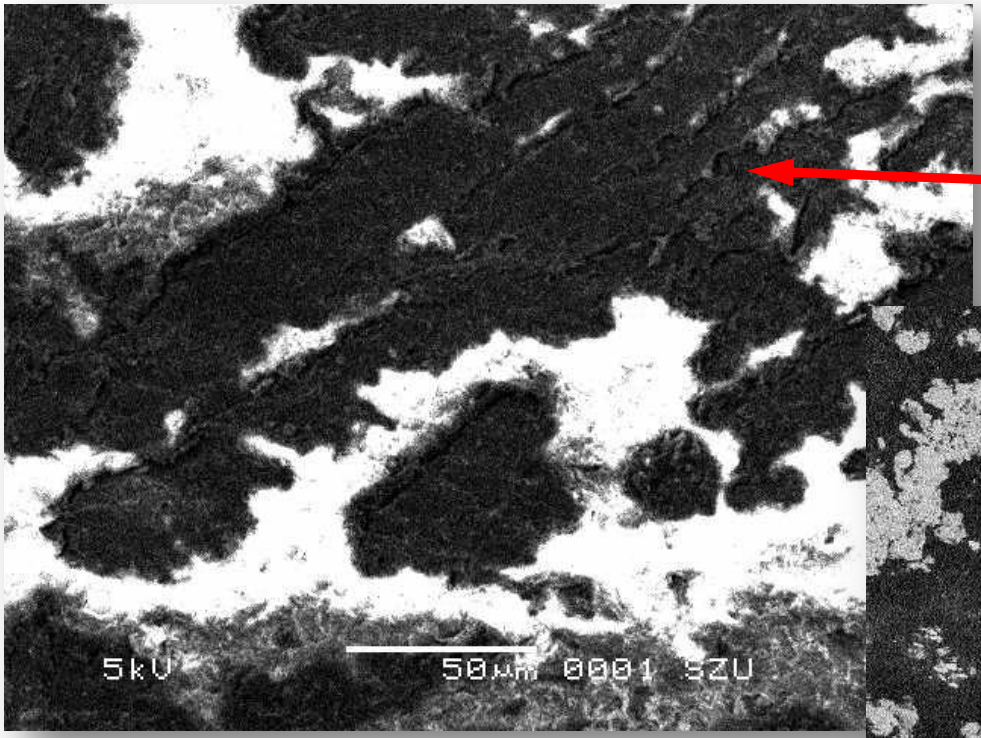
Copper powder (particle)



30% graphite（100X）

30% copper powder (100X)

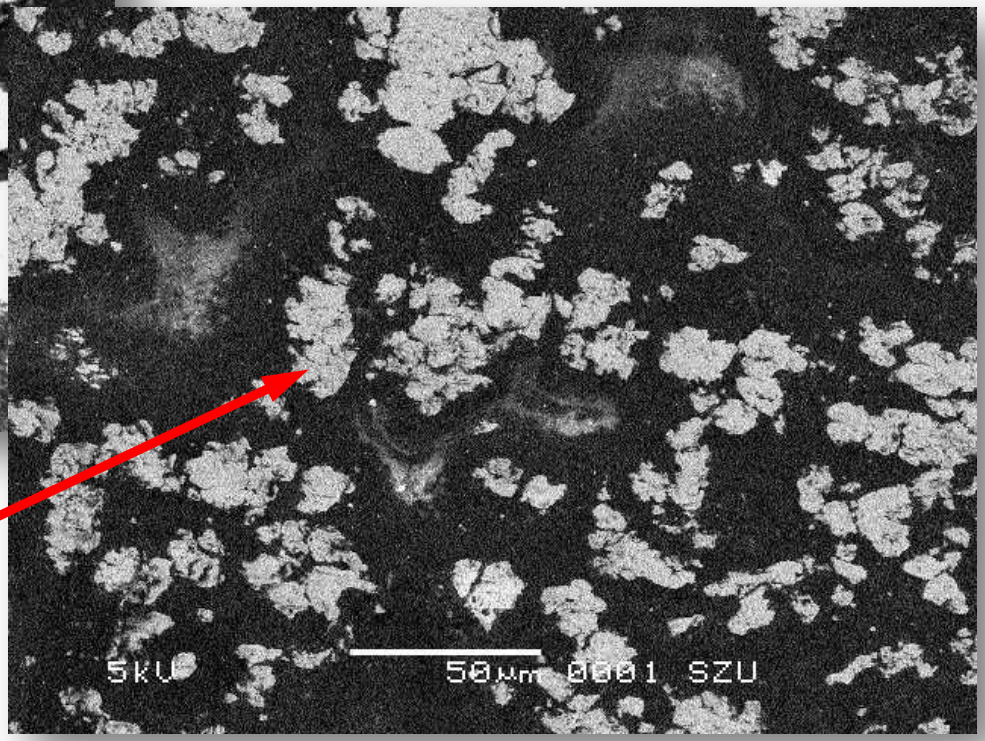
Surface Morphology



30% graphite （500X）

Graphite (connective)

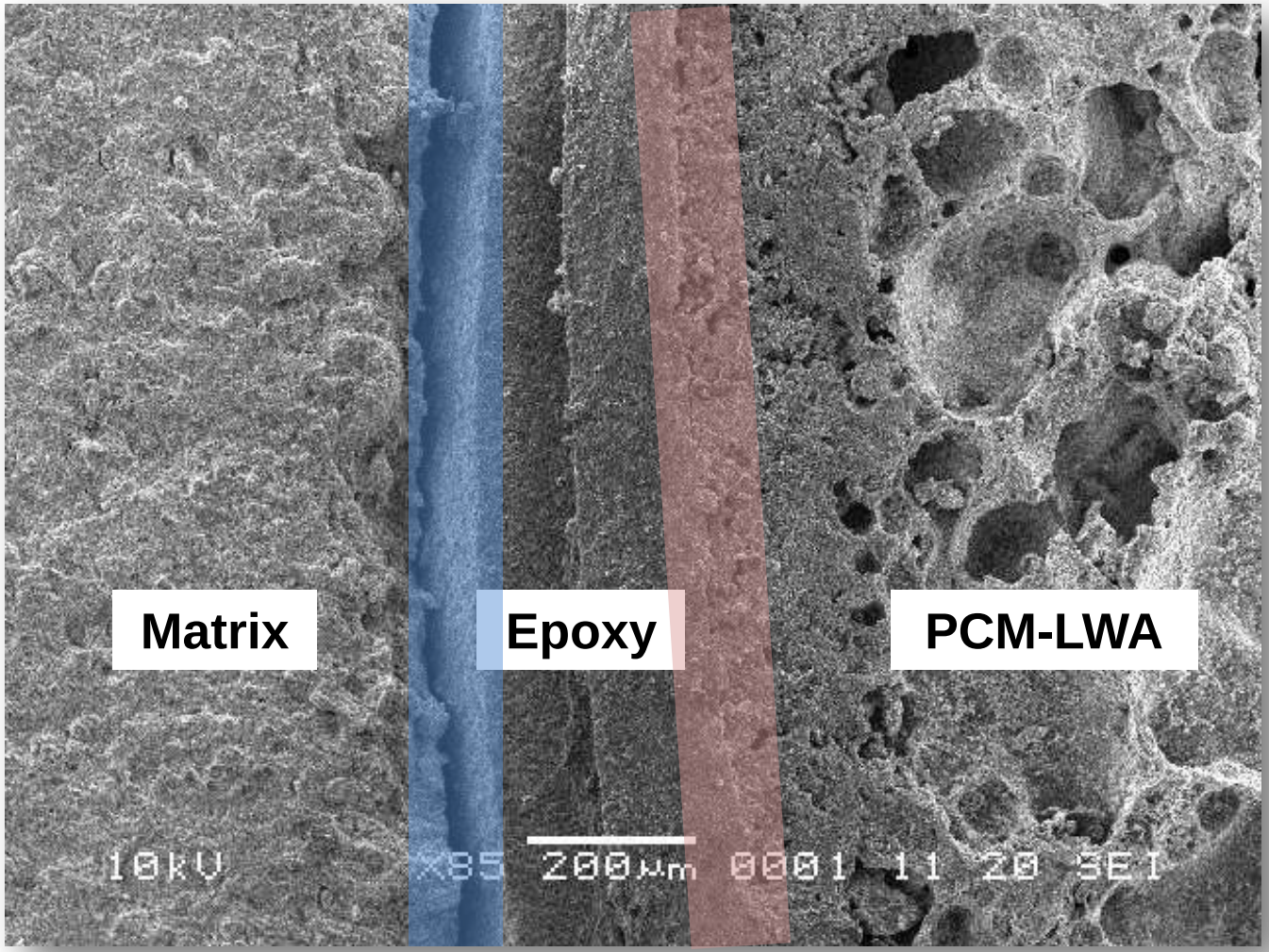
Copper powder (isolated)



30% copper powder (500X)

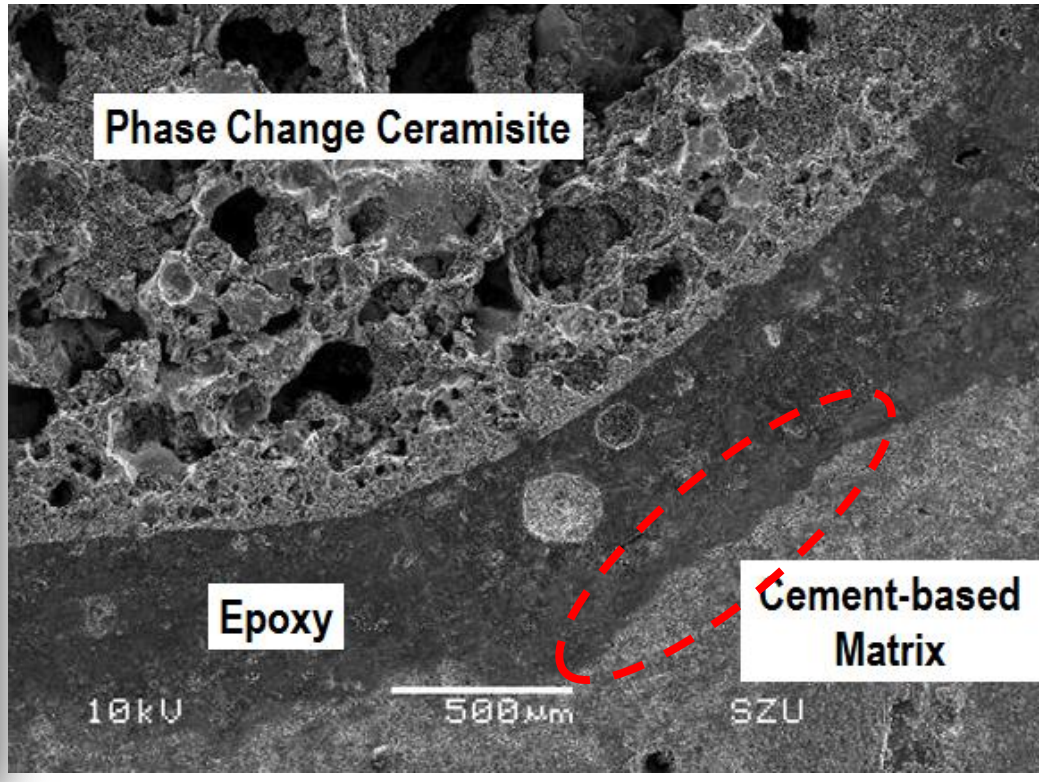
- Graphite with its inter connected flakiness shape achieve better thermal conductivity than copper.

Limitation: poor epoxy/cement interface



- The interface between LWA and epoxy is acceptable, but the interface between sealed epoxy and cement paste matrix is very poor.

Improving epoxy/cement Interface with Silica Fume



- Using **silica fume** to increase interface bond between PCM-LWA and cement-based matrix.

Preparation of Macro-encapsulated PCM-LWA

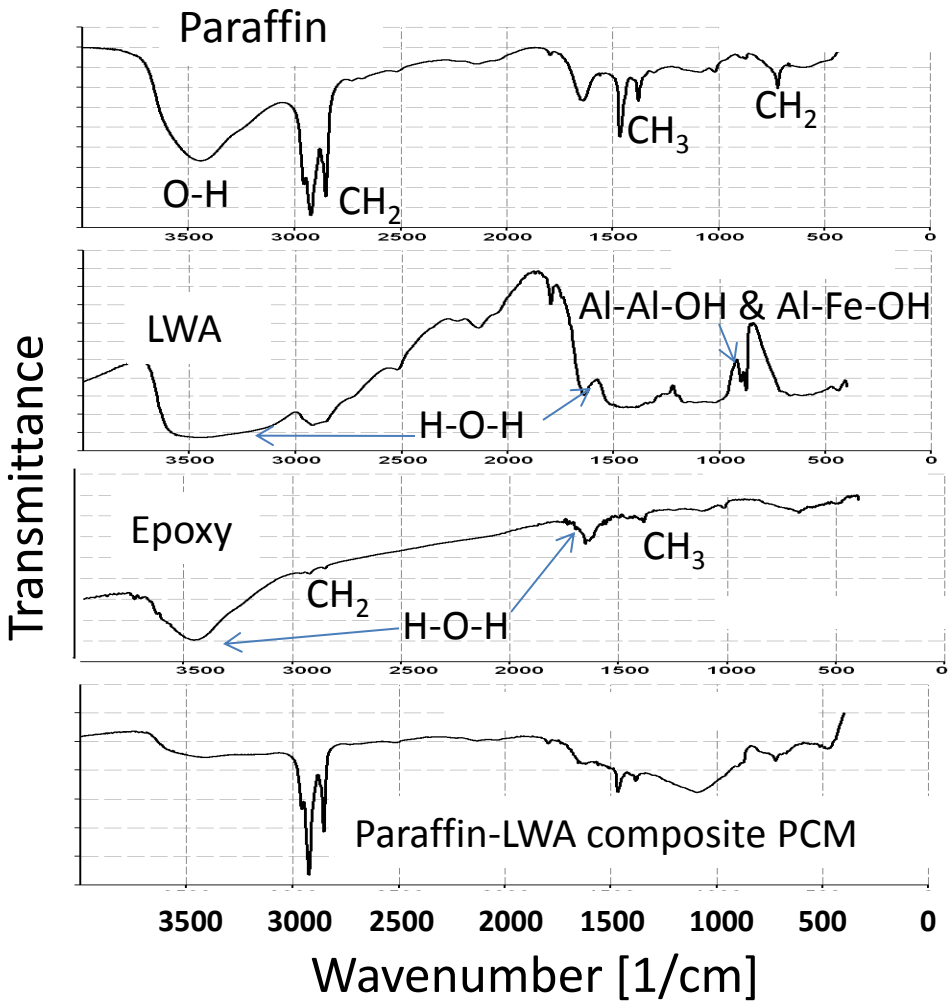
Paraffin-LWA

Modified Macro-encapsulated Paraffin-LWA

Surface Coat with **epoxy** and **graphite powder**

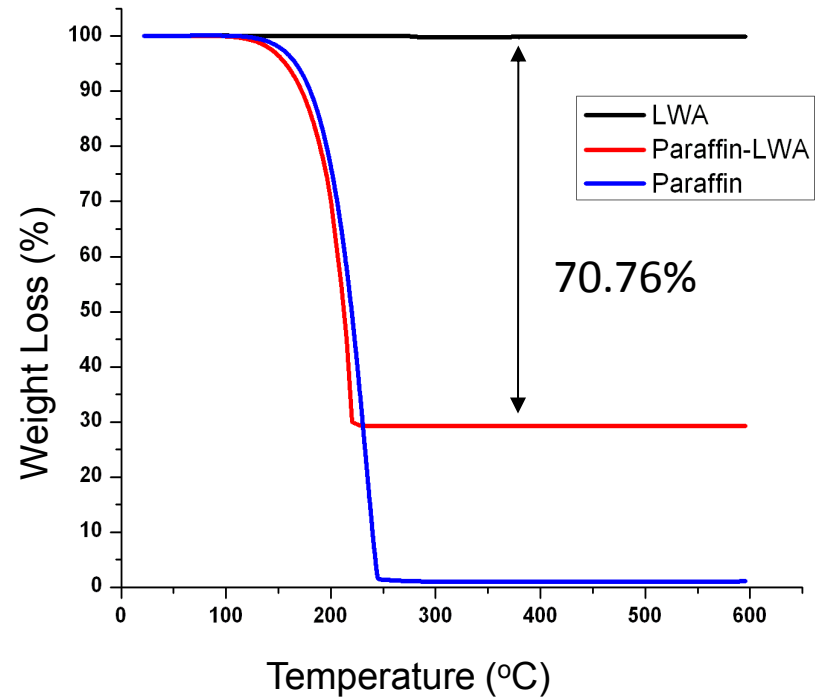
Surface Coat with **silica fume**

Chemical compatibility and thermal stability Check



Chemical compatibility (FT–IR)

- Macro encapsulated Paraffin-LWA is chemically compatible.

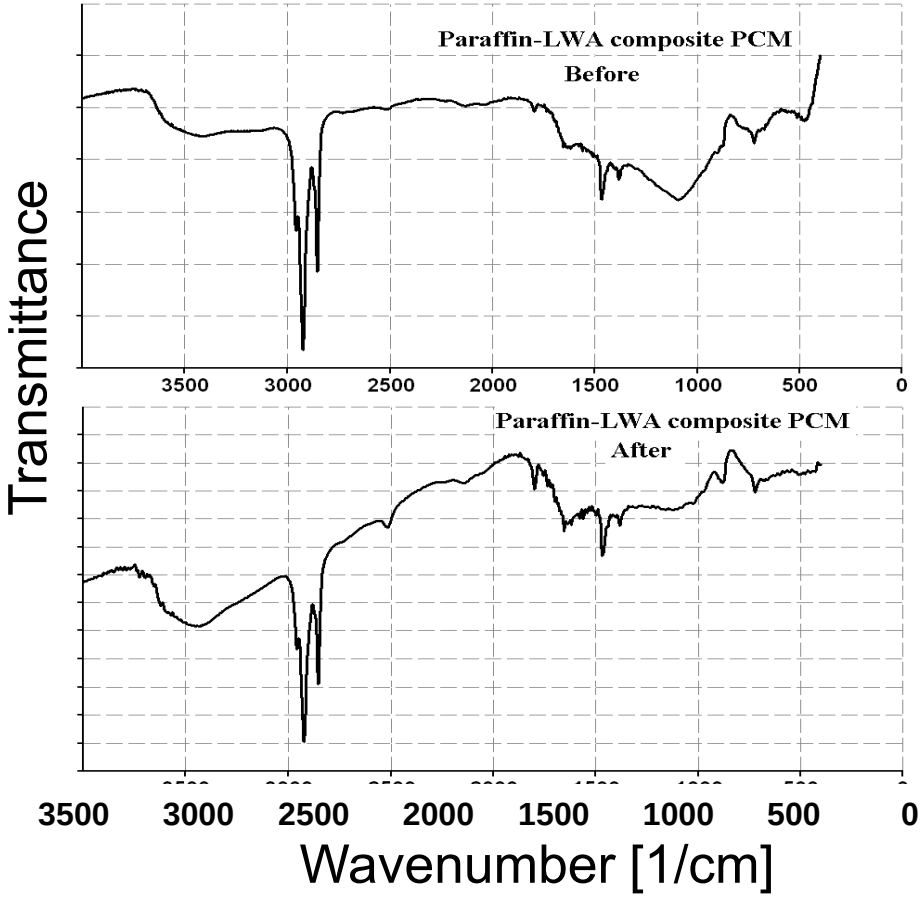


Thermal stability - TGA

- No weight degradation appears below 100°C, so the macro encapsulated Paraffin-LWA is thermally stable in its working temperature.

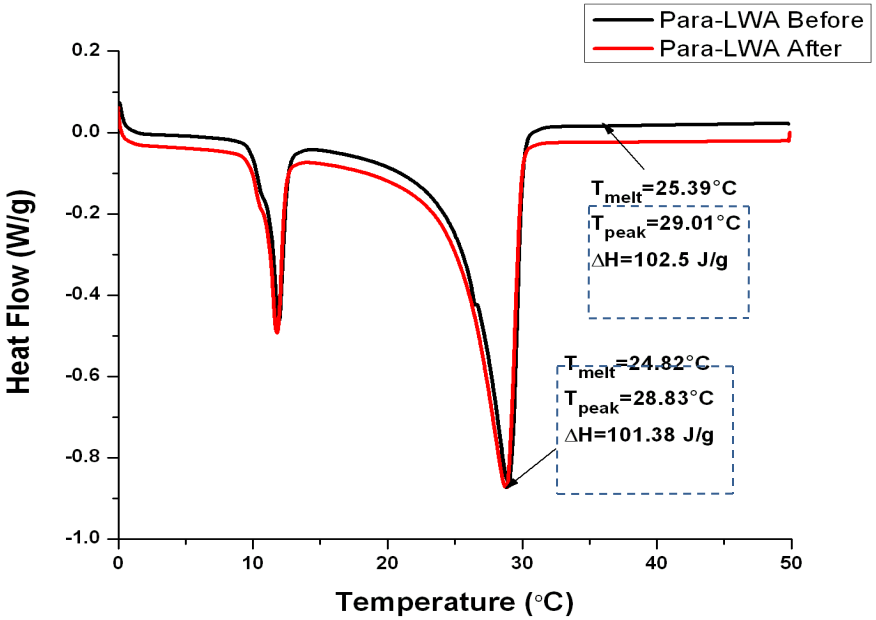
Thermal reliability – 1000 cycles

Chemical compatibility (FT–IR)



- Macro encapsulated Paraffin-LWA is thermally reliable in terms of chemical compatibility.

Thermal Properties - DSC



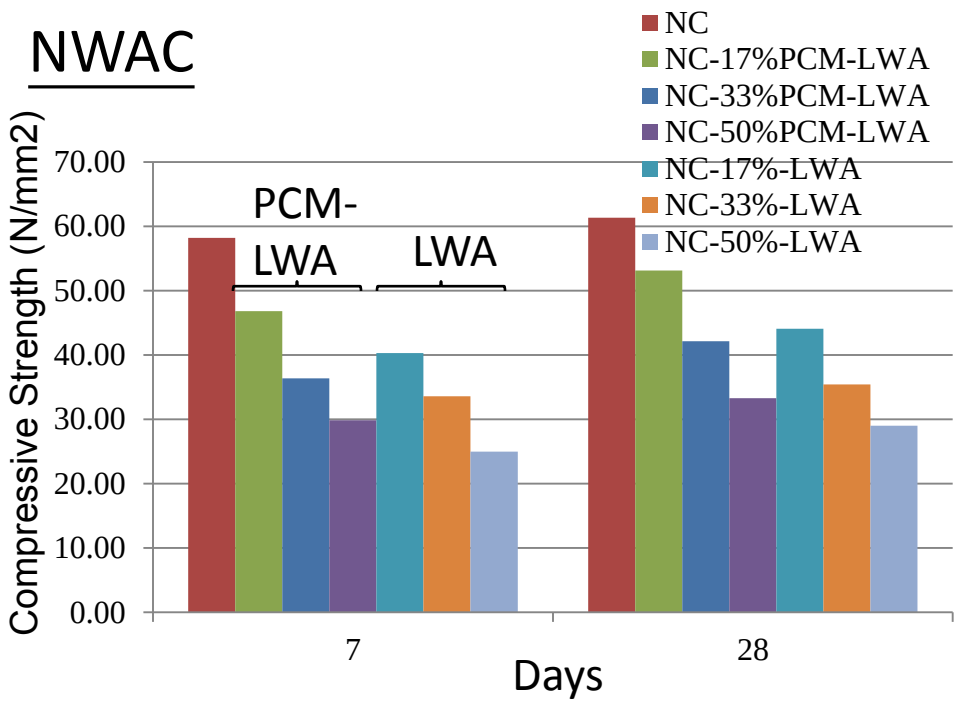
- Phase change temperature range of Paraffin-LWA is about 24-30 °C.
- It is thermally reliable in terms of phase change behavior, the difference in thermal properties before and after thermal cycles is small.

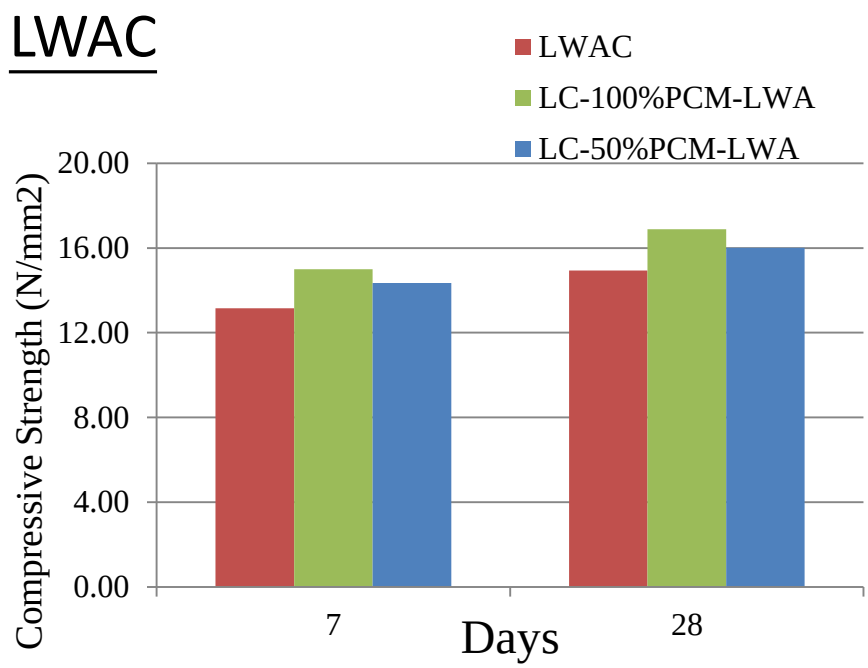
Mix proportion of Thermal Energy Storage Concrete

- Compared NWAC and LWAC with and without Paraffin-LWA

	Mix designation	Cement (kg/m³)	Water (kg/m³)	Sand (kg/m³)	NWA (kg/m³)	LWA (kg/m³)	PCM-LWA (kg/m³)
1	NC	400	140	787	1087	-	-
2	NC-17%LWA	400	140	787	910	43	-
3	NC-33%LWA	400	140	787	728	85	-
4	NC-50%LWA	400	140	787	546	126	-
5	NC-17%PCM-LWA	400	140	787	910	-	80.08
6	NC-33%PCM-LWA	400	140	787	728	-	160.16
7	NC-50%PCM-LWA	400	140	787	546	-	240.24
8	LC	400	140	507	-	316	0
9	LC-100%PCM-LWA	400	140	507	-	0	600
10	LC-50%PCM-LWA	400	140	507	-	158	300

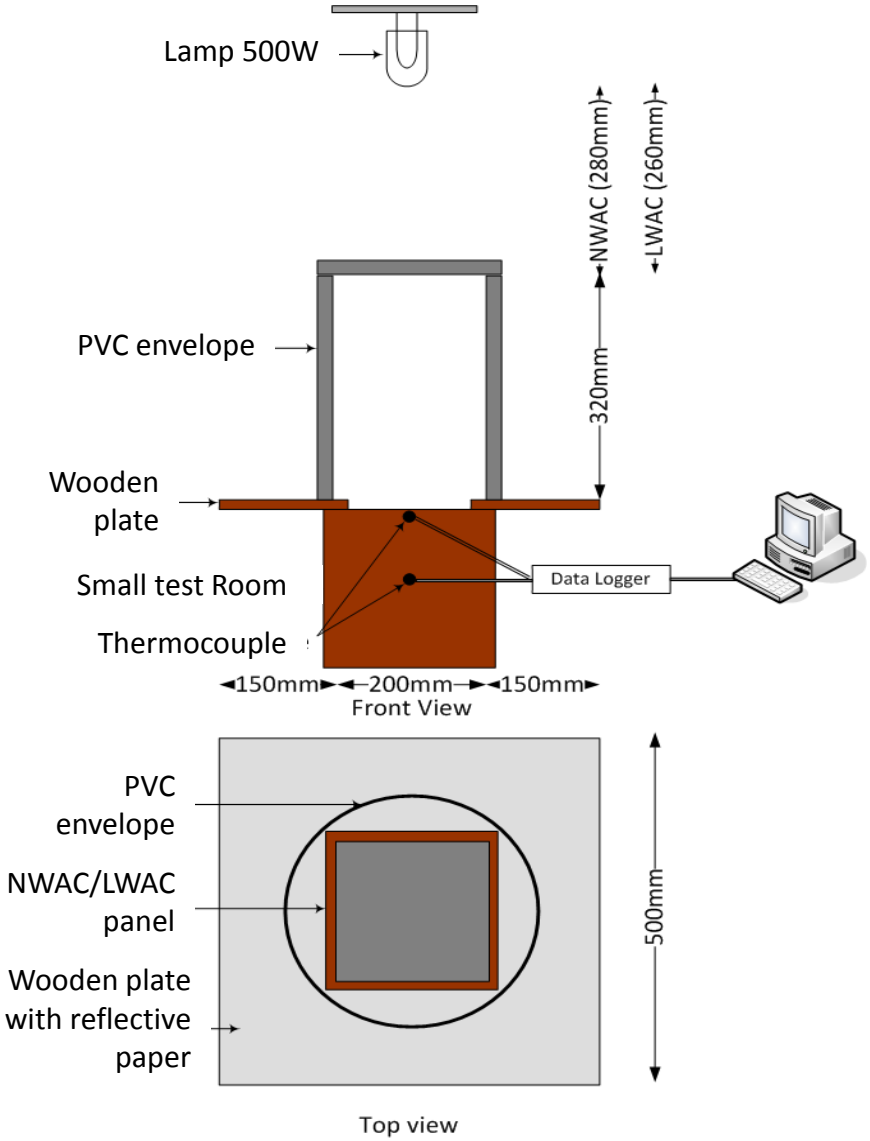
Compressive Strength of NWAC and LWAC

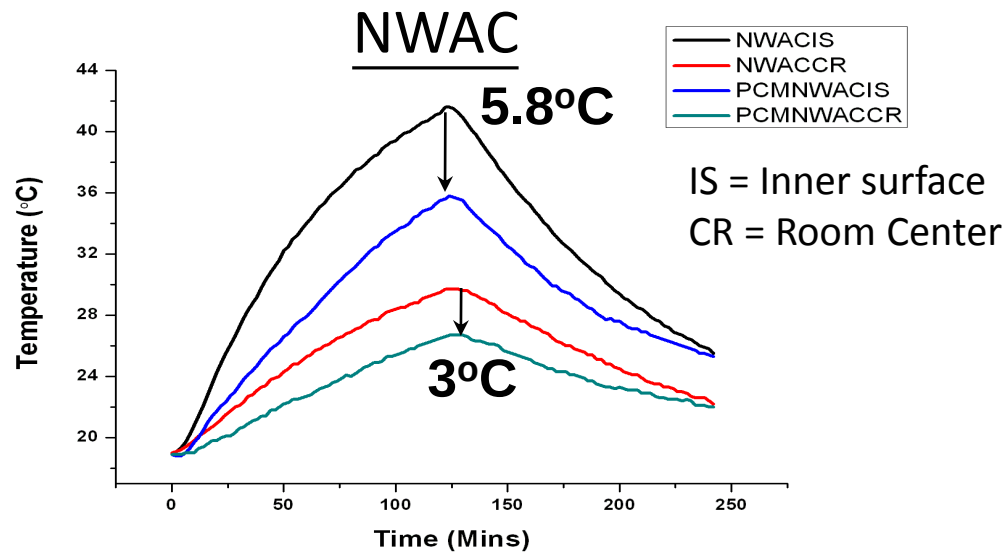


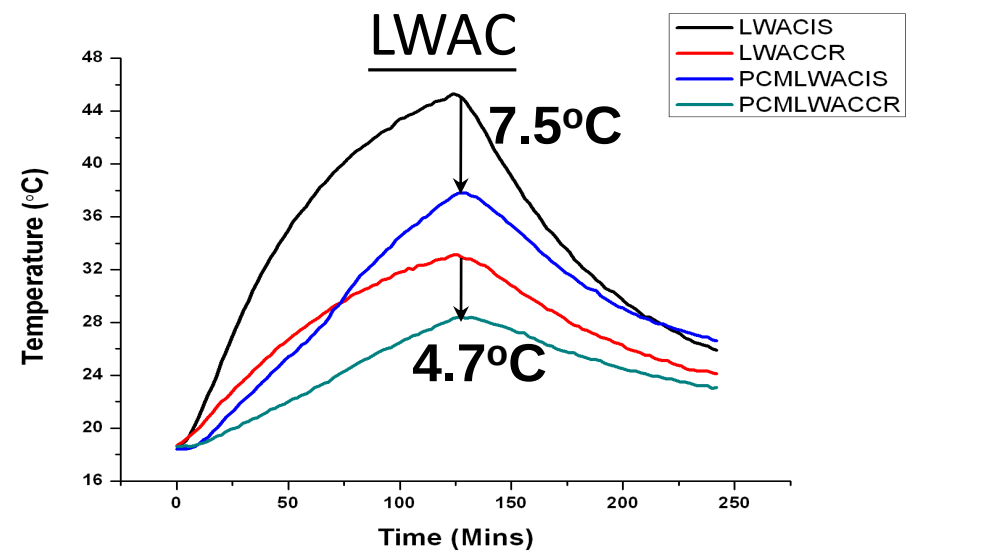


- The compressive strength after 28 days of NWAC with PCM-LWA is 33 - 53 Mpa.
- The compressive strength of LWAC with 50% and 100% PCM-LWA is larger than 16 MPa, higher than mix without PCM-LWA.

Thermal performance – NWAC & LWAC (Indoor test)







- Indoor temperature of the test chamber with energy storage concrete panel show lower indoor temperature.

Conclusions: Form-stable composite PCM

- PCMs can be vacuum impregnated into pores of mineral admixture or cement. Kaolin has the best storing capacity of PCM.
- Lauryl Alcohol and paraffin are both chemically compatible with KO, GGBS and cement.
- The form-stable composite PCMs are thermal stable and thermal reliable.
- The macro-encapsulated Paraffin-LWA also a chemical compatible, thermal stable and thermal reliable PCM material for thermal energy storage applications in buildings.
- The compressive strength after 28 days of NWAC with PCM-LWA is 33 - 53 MPa, which has an opportunity for structural purpose.
- The compressive strength of LWAC with 50% and 100% PCM-LWA is larger than 16 MPa, higher than mix without PCM-LWA.
- Indoor temperature of the test chamber with energy storage concrete panel show lower indoor temperature.

Conclusions: Macro-encapsulated PCM

- The macro-encapsulated Paraffin-LWA is chemical compatible, thermal stable and thermal reliable.
- The compressive strength after 28 days of NWAC with PCM-LWA is 33 - 53 MPa, which has an opportunity for structural purpose.
- The compressive strength of LWAC with 50% and 100% PCM-LWA is larger than 16 MPa, higher than mix without PCM-LWA.
- Indoor temperature of the test chamber with energy storage concrete panel show lower indoor temperature.
- Macro-encapsulated PCM-LWA is a promising candidate for thermal energy storage applications in buildings

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Concrete: From Production to Recycling

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Preparation and Characterization of Phase Change Material for Thermal Energy Storage in Buildings

Thank You !

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