Fire Behavior and numerical simulation of facade elements for buildings

Comportement au feu et simulation numérique d'éléments de façade pour le bâtiment

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Project

- ANR project FRENETICS (Fire REsistaNce of External Thermal Insulation Composite Systems)

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CATALOGUE

- Context
- Objective
- Methodology
- Test at small-scale
  - TGA
  - STA
  - Thermal conductivity ***k***
- Test bench
  - Configuration of bench
  - Fire test
- Numerical Simulation
- Conclusion

Context

Increasing energy performance → Increasing building insulation

External Thermal Insulation (ETI)
plastic (PE, EPS, PIR. etc)

RT 2012 and 2020

- Limiting the thermal bridges between environment and building interior space
- Increasing the fuel mass

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Objective

- Describe the thermal decomposition process of ETI elements at small-scale
- Characterize the flame-façade interaction and propagation at intermediate-scale
- Studying some flame retardant coating for the fire protection and building a digital model which can be used in large scale

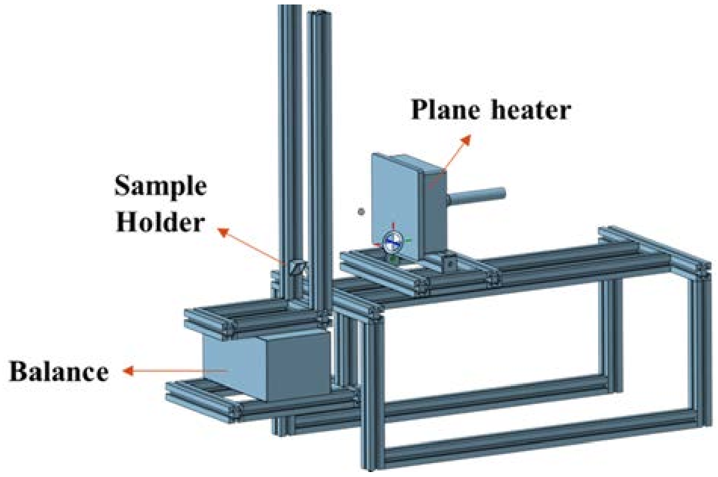
Methodology

- At the lab-scale:

Investigation of thermal decomposition of ETI by TGA-FTIR, DSC and Hot disc.

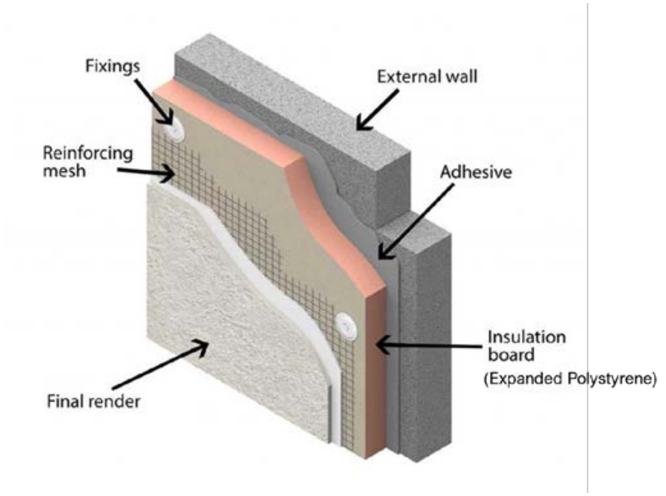
- New insulation material is developed by introducing flame retardants.
- At the intermediate-scale:

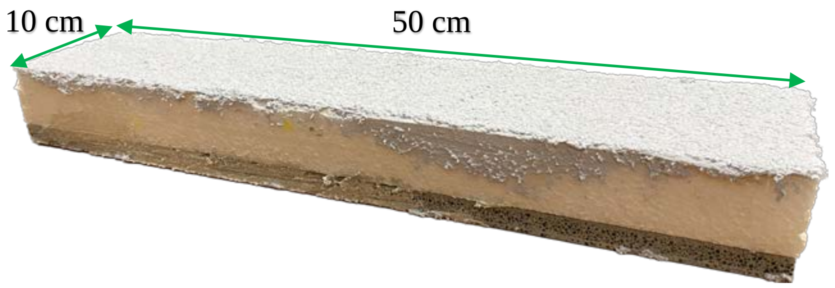
A test bench, with a horizontal and rotational motion, is developed to study the fire-façade interaction under controlled heat condition.

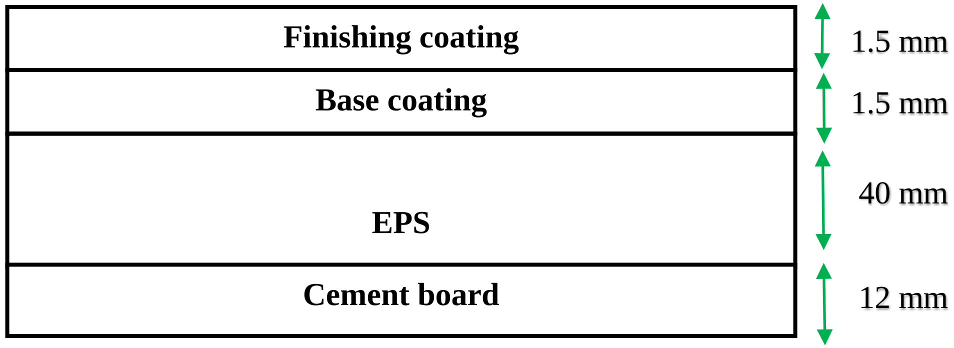


- A numerical model of bench test is developed in COMSOL Multiphysics.

External Thermal Insulation (ETI)







Finishing coating
Base coating
} Incombustible

EPS Expanded Polystyrene Combustible

Constitution of coating – Analyse XRF

Finishing coating → 68%Si, 14%Al, 9%Ca, 6%Mg

Base coating → 53%Ca, 24%Si, 11%Al, 7%Ti

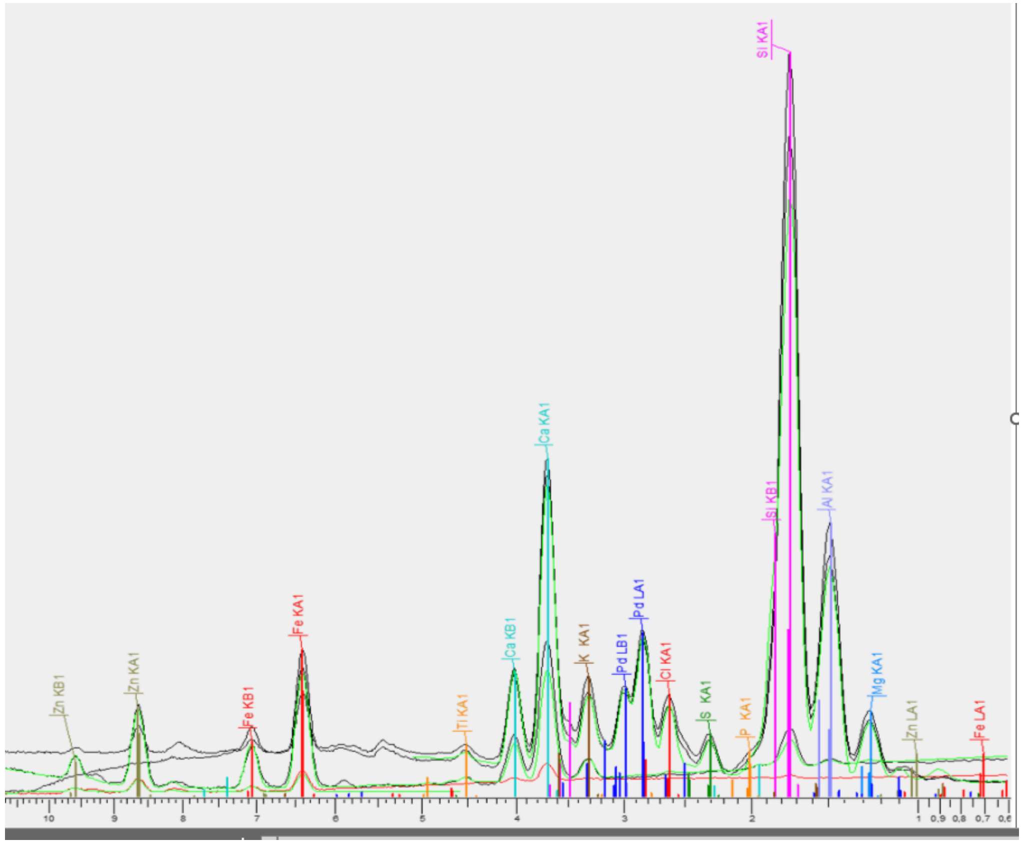


Fig.1 XRF spectrum of base coating

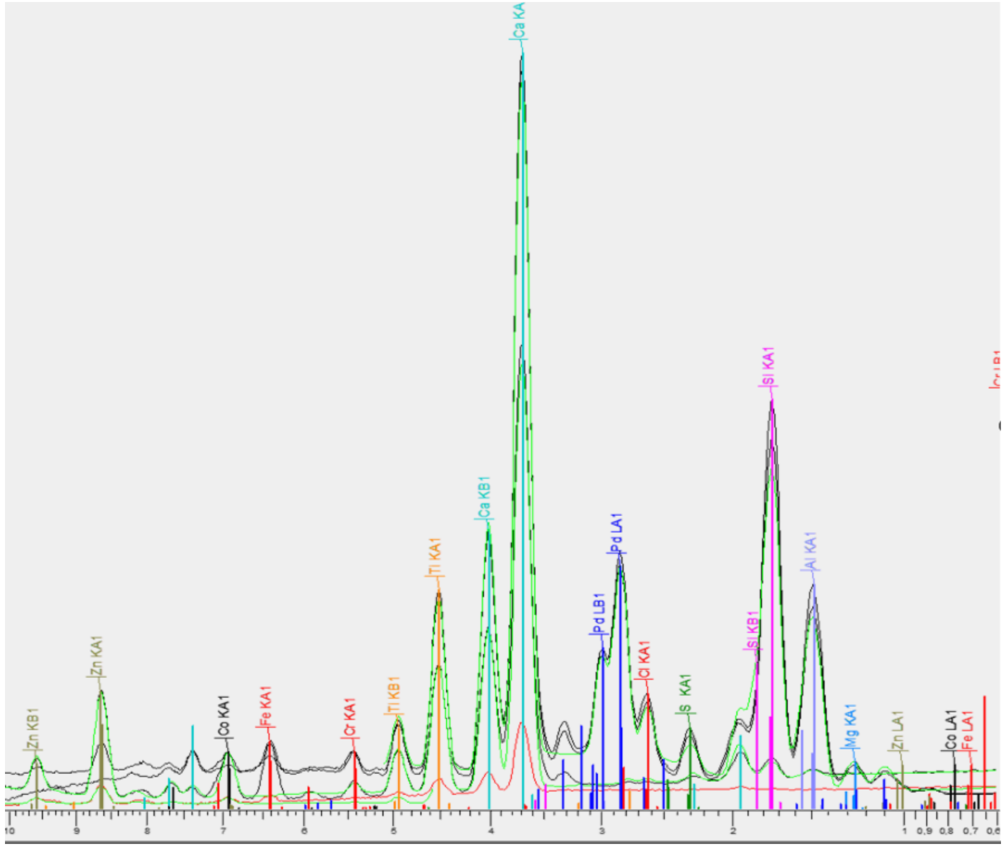


Fig.2 XRF spectrum of finishing coating

1 TEST AT SMALL-SCALE

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Curves TGA

EPS	
E_a	177,619 kJ/mol
$Log(PreExp)$	11,996 Log(1/s)
n	1,184
θ	1,004

Finition	Step1	Step2
E_a	79,901 kJ/mol	356,130 kJ/mol
$Log(PreExp)$	4,988 Log(1/s)	16,782 Log(1/s)
n	2,491	2,252
θ	0,463	0,536

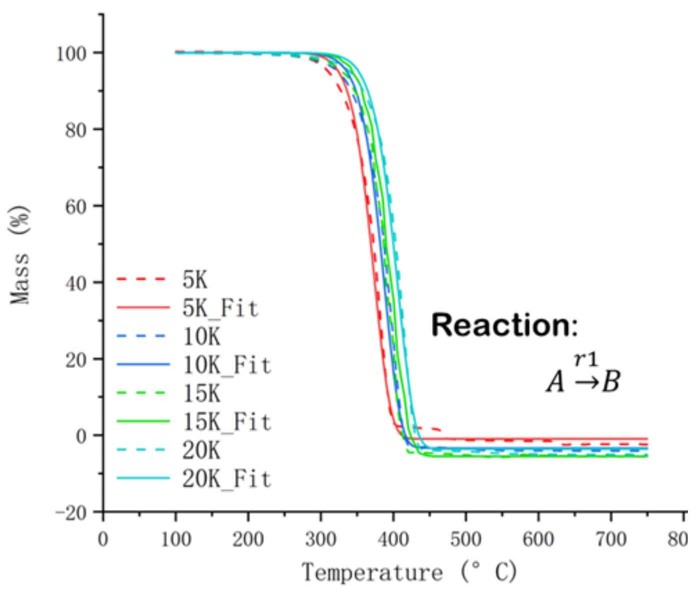


Fig.3 TG fit curves of EPS in air

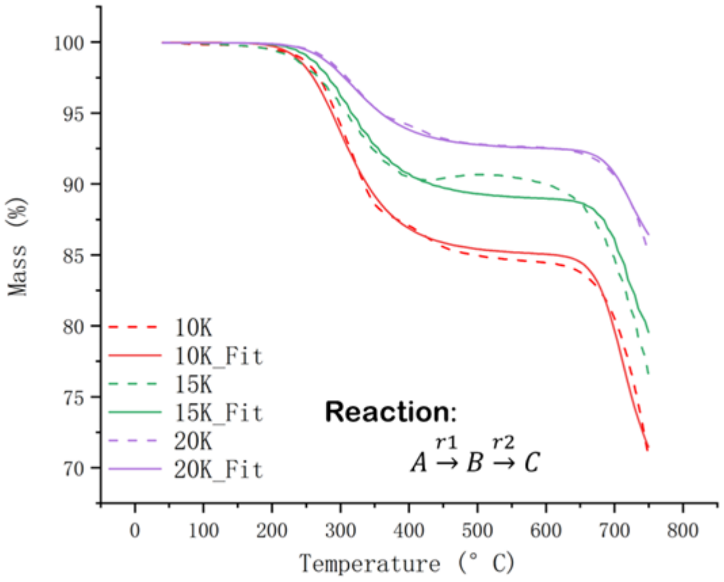


Fig.4 TG fit curves of final render in air

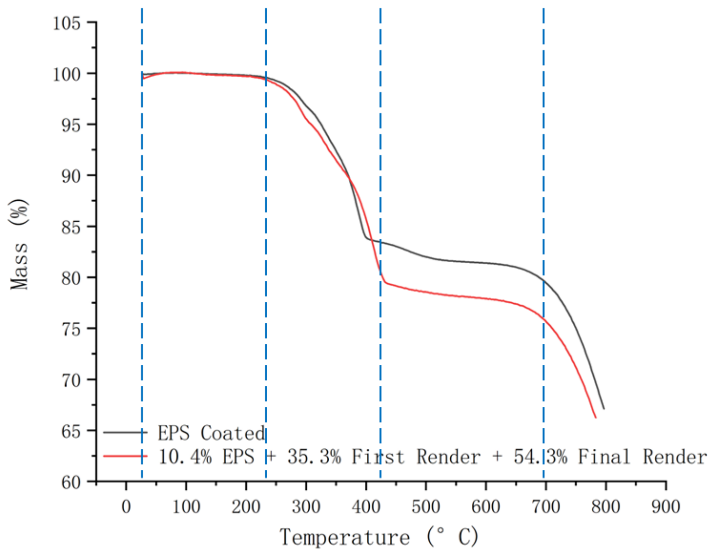


Fig.5 Comparison of TG tested and TG calculated

Curves STA

Step	Enthalpy (J/g)	Onset Temperature(°C)	Mass Loss(%)
M	160.8	T_i = 44	-
		T_f = 125	
1	-603.1	387.3	98.22

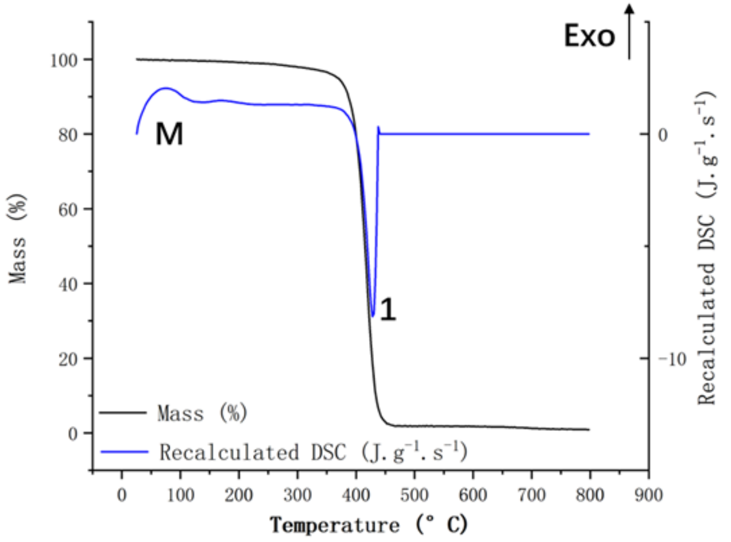


Fig.6 STA curves of EPS in 10K/min in nitrogen

Step	Enthalpy (J/g)	Onset Tenperature(°C)	Mass Loss(%)
1	-98.48	184	6.17
2	-82.16	395.7	15.56
3	-438.8	750.1	16.37

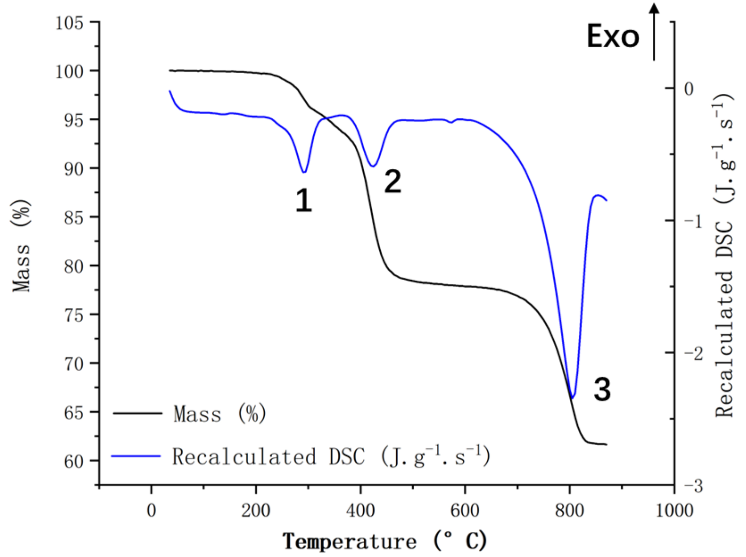


Fig.7 STA curves of ETI in 10K/min in nitrogen

Curve of thermal conductivity *k*

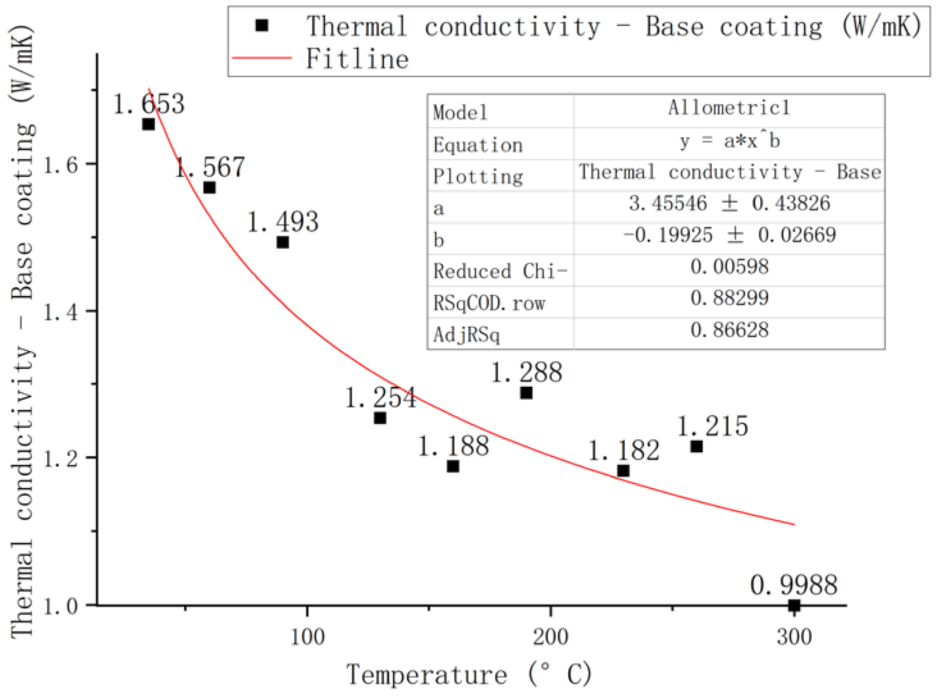


Fig.8 ***k*** curve of base coating versus time

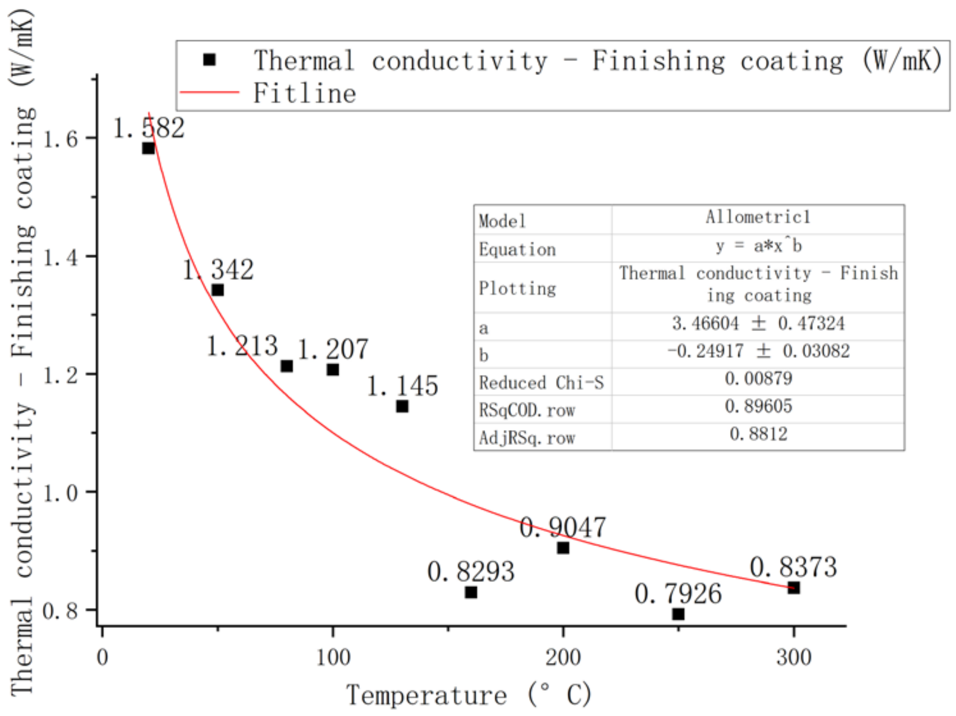
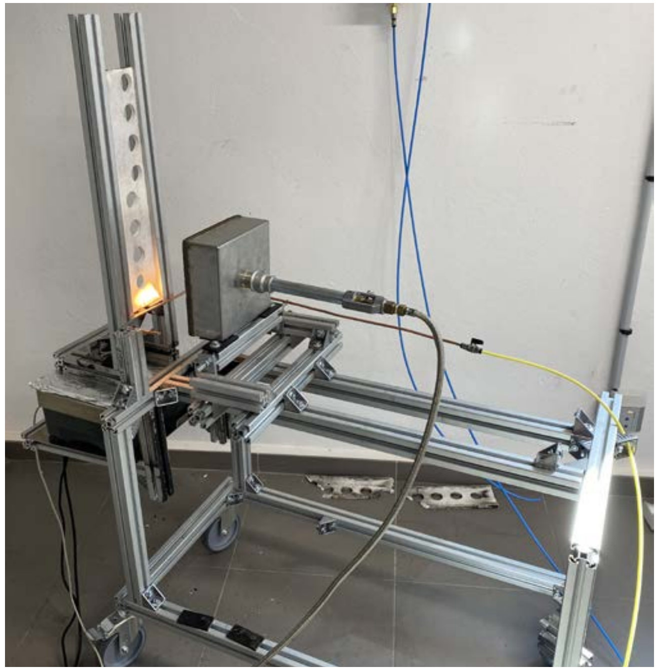


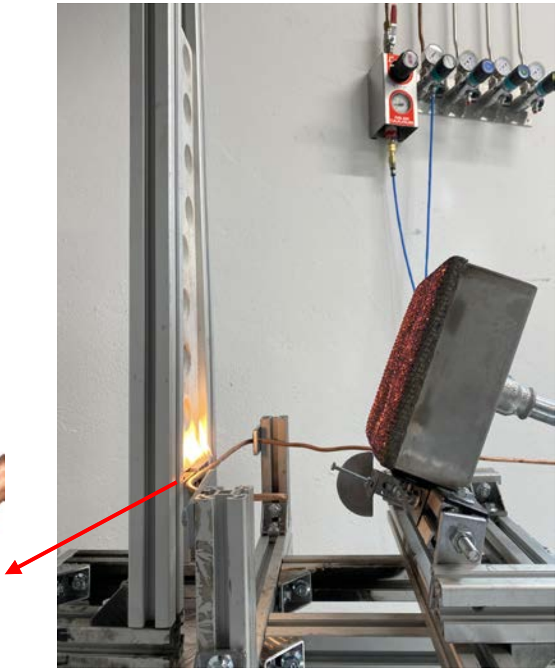
Fig.9 ***k*** curve of finishing coating versus time

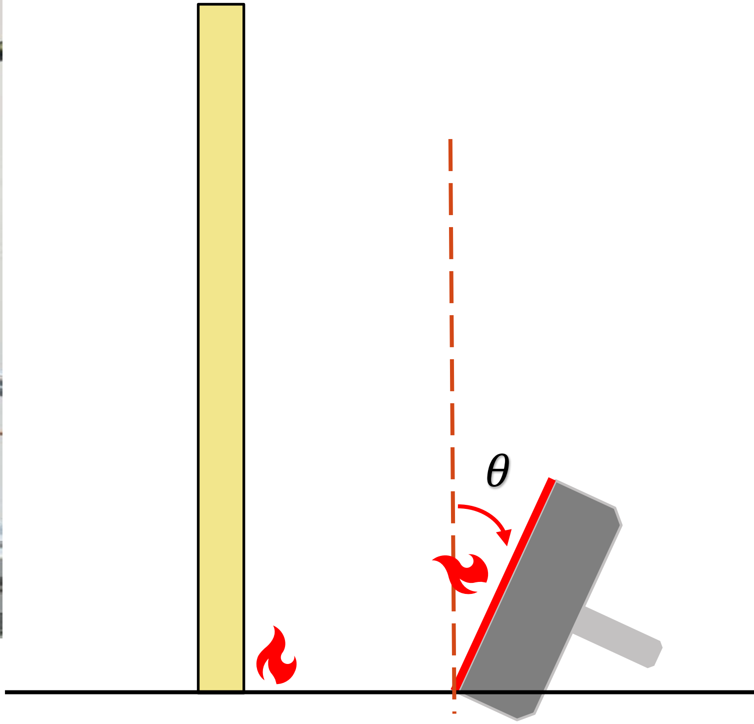
2

TEST BENCH

Test bench configuration



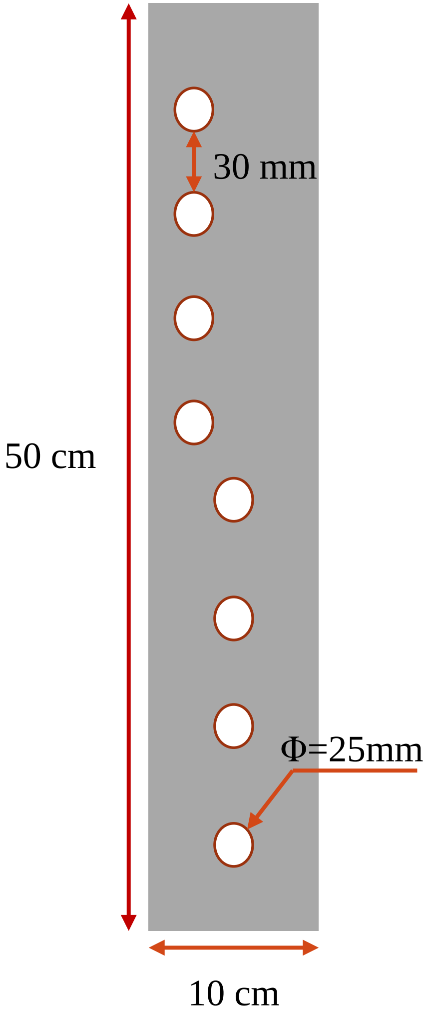




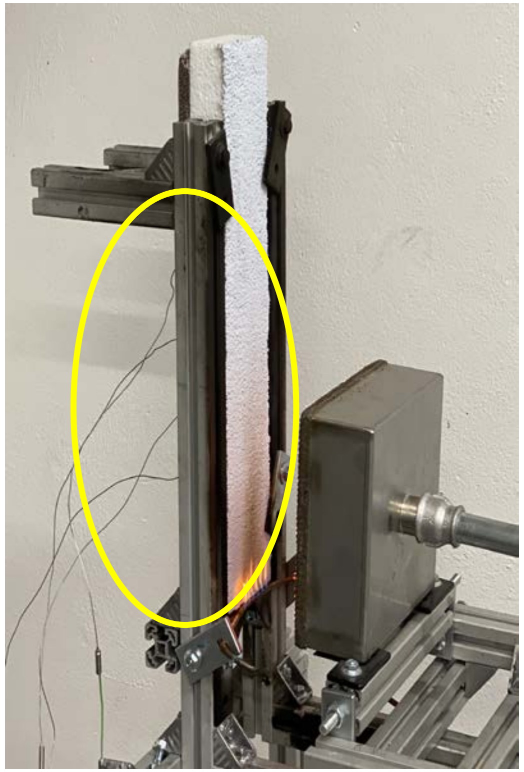
The lower edge of facade and the radiator as well as the igniter are at the same level – External heat source scenario

Measurement of test bench

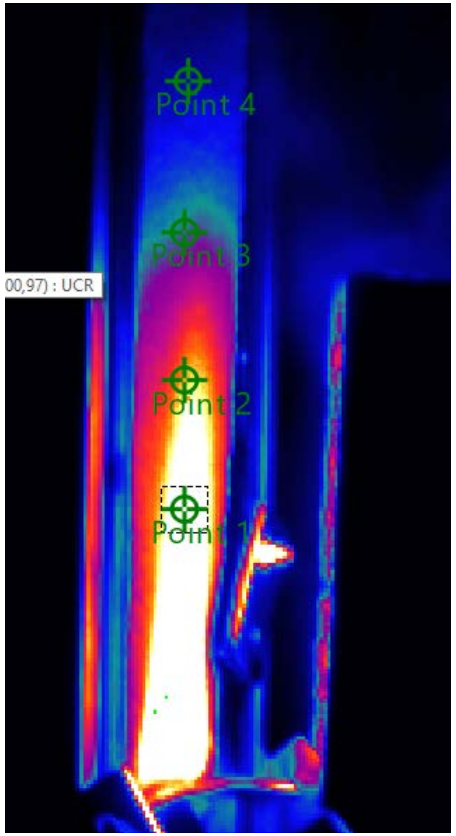
Heat flux calibration



Temperature monitoring

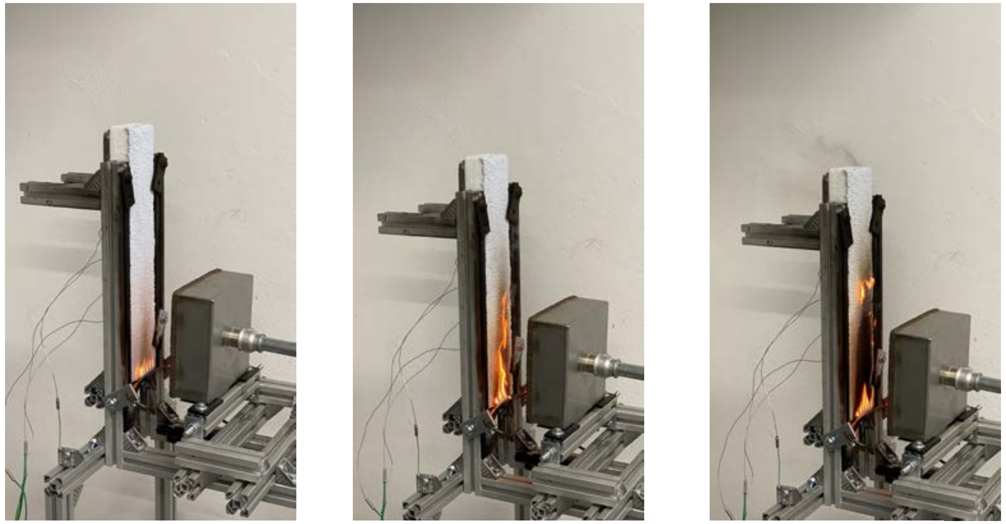


Thermal couple



IR Camera

Fire test of ETI STO – 0°,10cm, 43.2 kW/m²



Finishing coating
Base coating
EPS
Cement board

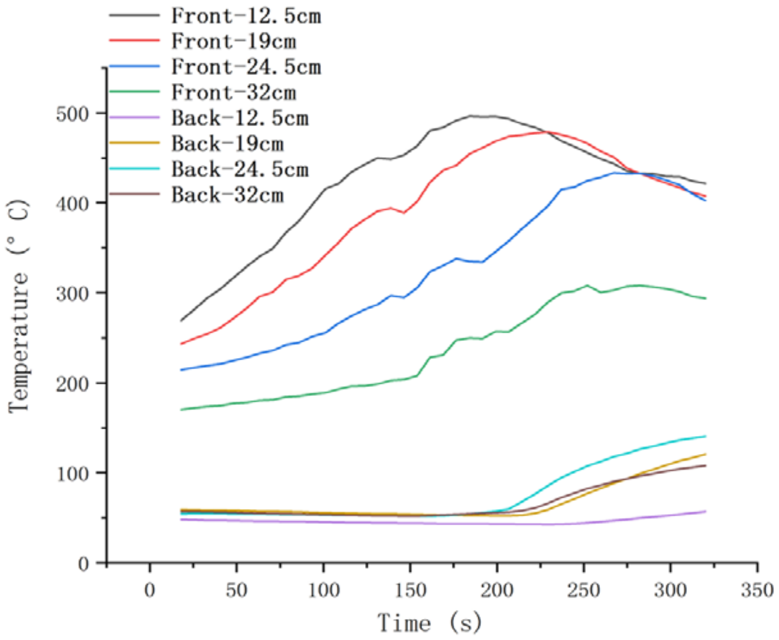


Fig.10 Temperature profile of ETI STO at front face and back face

Discussion of flame retardant application

- Mixture of finishing coating and FR
  - APP 766 – Base APP
  - ADEKA – Base piperazine phosphate

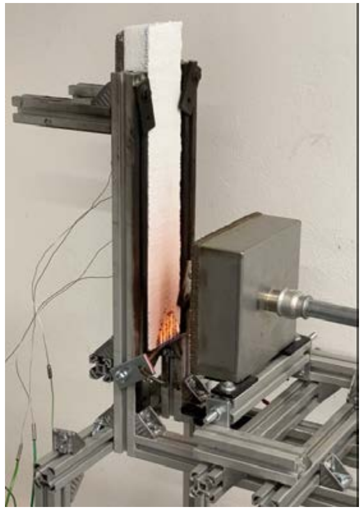
- Intumescent painting **FLAMEOFF**

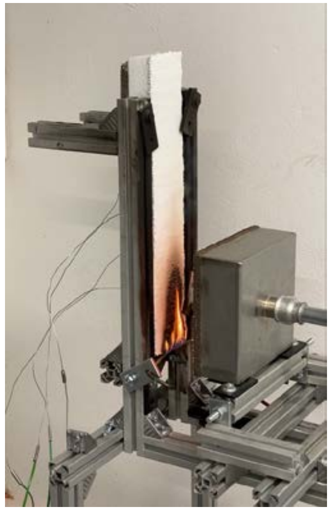
- Adding a FR layer **FLAMEOFF**

- Blending **expandable graphite** in the finishing coating

Fire test of ETI FlameOFF – 0°,10cm, 43.2 kW/m²

FlameOFF
Finishing coating
Base Coating
EPS
Cement board





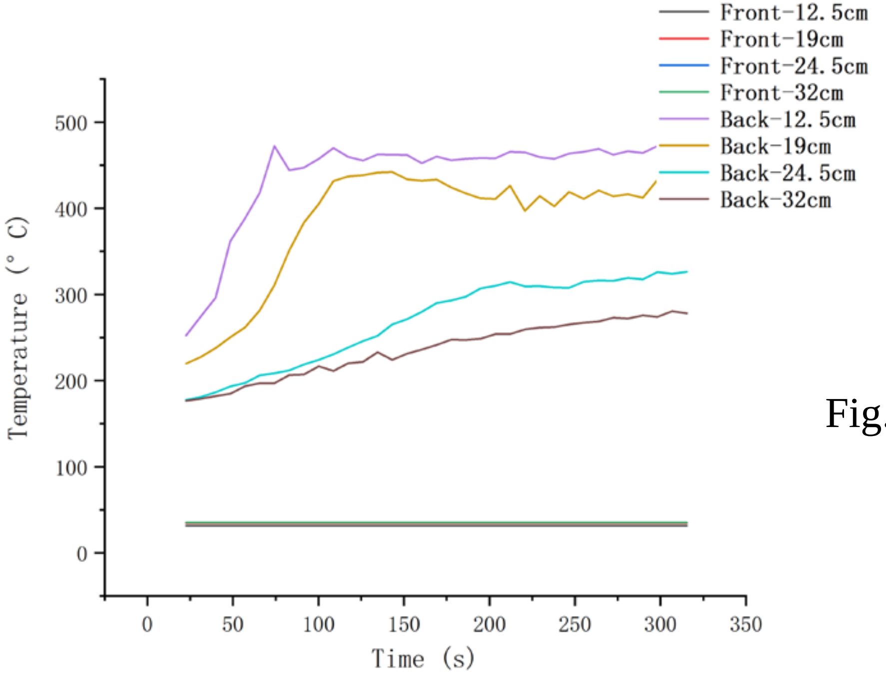
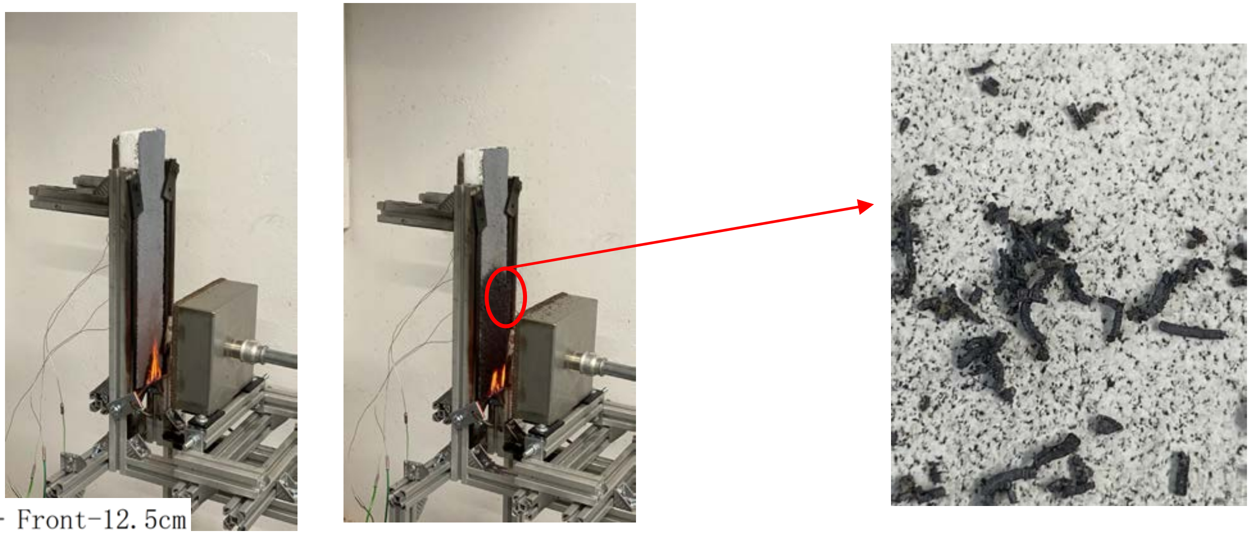


Fig.11 Temperature profile of ETI FlameOFF at front face and back face

Fire test of ETI EG – 0°,10cm, 43.2 kW/m²

Finishing coating + Graphite
Base coating
EPS
Cement board



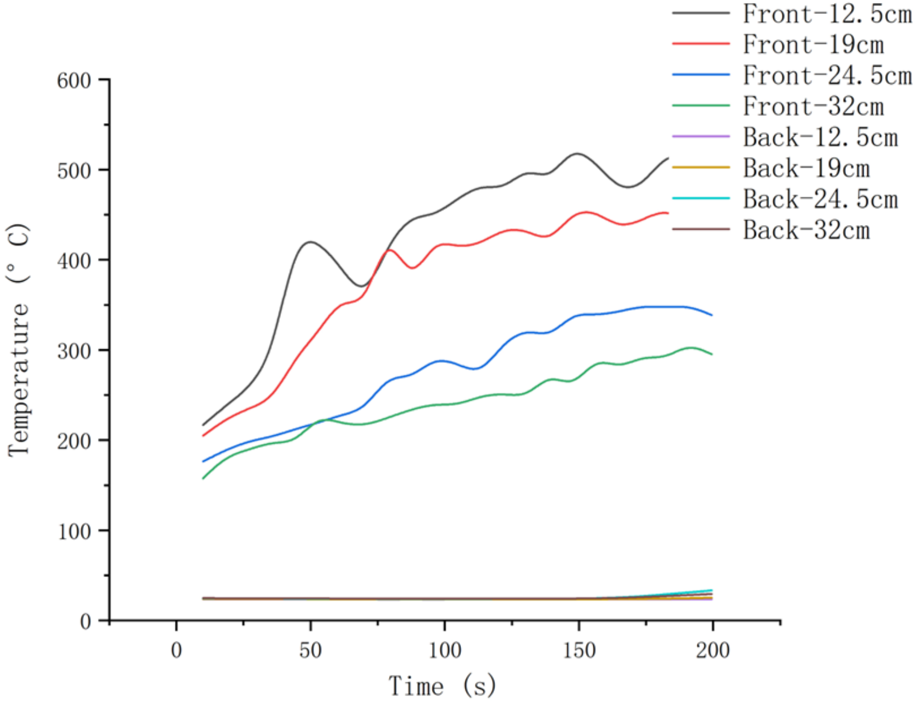


Fig.12 Temperature profile of ETI EG at front face and back face

Discussion of flame retardant application

- ➢ Mixture of finishing coating and FR
  - APP 766 ✗

  - ADEKA ✗

- ➢ Intumescent painting **FLAMEOFF** ✓

FlameOFF
Finishing coating
Base Coating
EPS
Cement board

- ➢ Adding a FR layer **FLAMEOFF** ✗

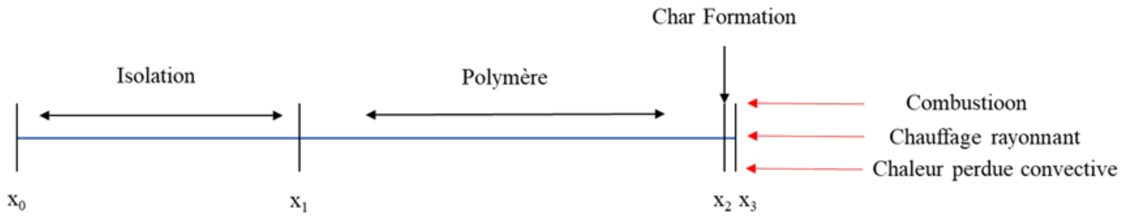
Finishing coating
FlameOFF
Base Coating
EPS
Cement board

- ➢ Blending **expandable graphite** in the finishing coating ✓

Finishing coating + Graphite
Base coating
EPS
Cement board

3 NUMERICAL SIMULATION

Simulation – Model Stalter*



In the pyrolysis reaction, the polymer mass is consumed and produces a fraction ***ϑ*** of gas.

$$Polymer \overset{k_0}{\rightarrow} \theta \cdot Gas + (1-\theta) \cdot Char$$

The reaction rate of polymer mass consumption :

$$\frac{\partial m_p}{\partial t} = -k_0 \cdot {m_p}^n$$

The rate constant for pyrolysis, $\boldsymbol{k_0}$, is described by the Arrhenius law :

$$k_0 = A_0 \cdot exp\left[\frac{-E_{A0}}{R \cdot T}\right]$$

$\boldsymbol{A_0}$, $\boldsymbol{E_{A0}}$ and ***n*** can be investigated using TGA

In reality, $\boldsymbol{x_2}$ would move to the left. By simplification, assuming that the polymer zone ($\boldsymbol{x_2}$-$\boldsymbol{x_1}$) is constant. So concentration (or density) changes over time.

$$r_p = \frac{\partial c_p}{\partial t} = -k_0 \cdot c_p$$

* Jr, David L Statler, and Rakesh K Gupta. “A Finite Element Analysis on the Modeling of Heat Release Rate, as Assessed by a Cone Calorimeter, of Char Forming Polycarbonate,” n.d., 7.

Simulation – Model Stalter*

- The mass balance of the gas during pyrolysis:

$$r_{G°P} = \frac{\partial c_G}{\partial t} - D_{poly} \cdot \frac{\partial^2 c_G}{\partial x^2} = \theta \cdot k_0 \cdot c_p$$

$$\frac{\partial c_G}{\partial t} - D_{char} \cdot \frac{\partial^2 c_G}{\partial x^2} = 0$$

- The heat balance in polymer:

$$\rho_{poly} \cdot Cp_{poly} \cdot \frac{\partial T}{\partial t} - k_{poly} \cdot \frac{\partial^2 T}{\partial x^2} = -\Delta H_0 \cdot k_0 \cdot c_p + \Delta H_e$$

- The heat balance in char:

$$\rho_{char} \cdot Cp_{char} \cdot \frac{\partial T}{\partial t} - k_{char} \cdot \frac{\partial^2 T}{\partial x^2} = 0$$

- Heating condition in surface:

$$\dot{Q}_{surface} = \dot{Q}_{heater} + \dot{Q}_{complémentaire} - h \cdot (T - T_{atm})$$

- Heat realease rate (HRR)

$$HRR = \Delta H_1 \cdot \left(-\frac{\partial c_G}{\partial x} \right) \Bigg|_{surface} \cdot D_{char}$$

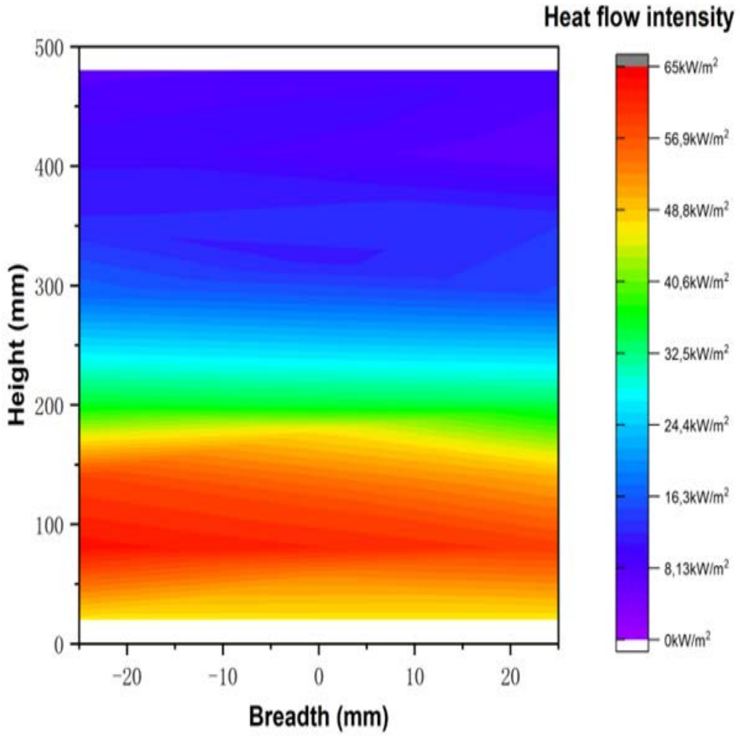
- Conversion rate

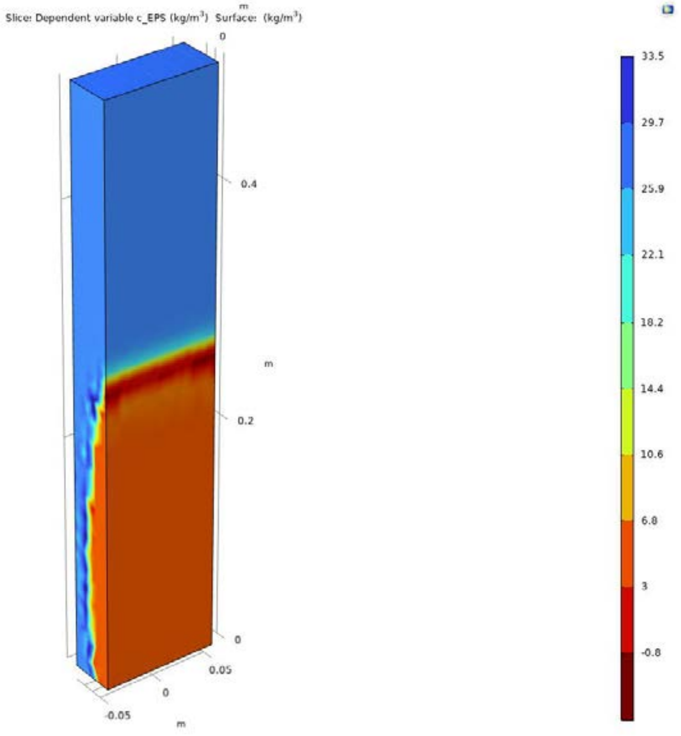
$$Polymer \xrightarrow{k_0} \theta \cdot Gas + (1 - \theta) \cdot Char$$

$$\theta_{poly} = \frac{c_{vg} - c}{c_{vg} - c_{final}}$$

Results of simulation

COMSOL





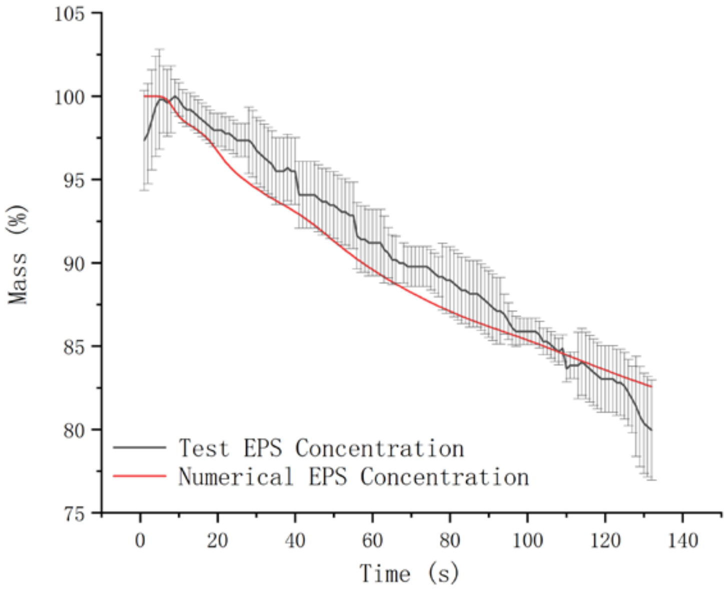


Fig.15 Comparison of mass loss

Fig.13 Distribution of heat flux on facade

Fig.14 Simulated EPS Concentration at 200s

Conclusion

- An original test bench at intermediate scale is introduced, equipped with a plane radiator movable horizontally and rotationally, to study the thermal decomposition and the flame propagation.

- The new insulation coating by adding FlameOFF or Expandable graphite works well in heat protection. Although, for EG, the mechanical properties of resulting char should be improved.

- With kinetic parameters investigated in small-scale, it is possible to define a pyrolysis model in calculation and using digital simulation, which contribute to understanding the observed phenomena.

THANK YOU