Modelling of the swelling behaviour of a fire retarded material under a cone calorimeter

Manon Fleurotte[1,3], Abdenour Amokrane[1], Olivier Autier[1], Gérald Debenest[2], Gaëlle Fontaine[3], Serge Bourbigot[3]

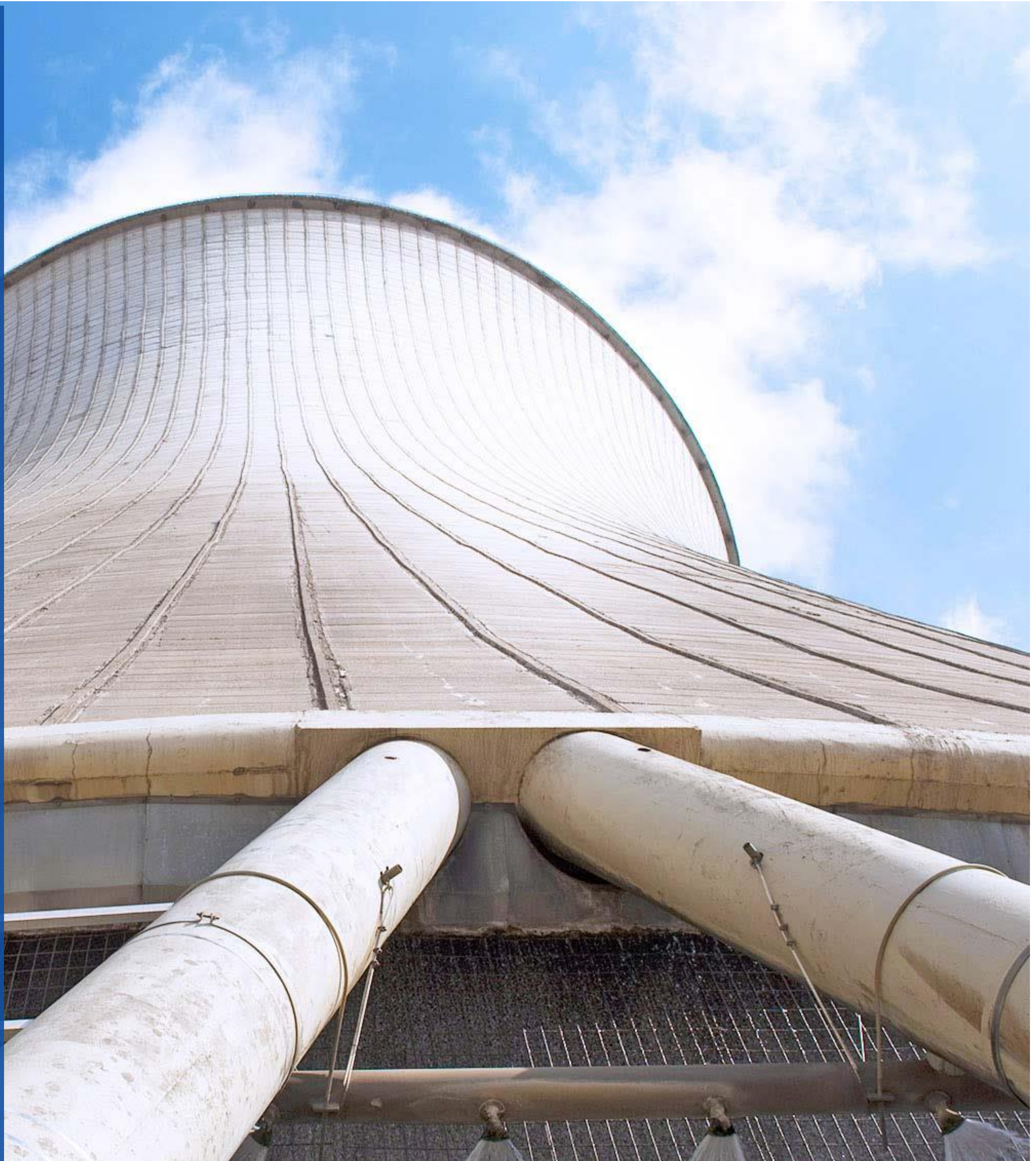
[1] EDF (Electricité de France), Lab Chatou, France

[2] Institut de Mécanique des Fluides de Toulouse (IMFT)–Université de Toulouse, CNRS-INPT-UPS, Toulouse, France

[3] Univ. Lille, CNRS, INRAE, Centrale Lille, UMR 8207–UMET–Unité Matériaux et Transformations, Lille, France

RésoFeux
SCIENCES DES INCENDIES

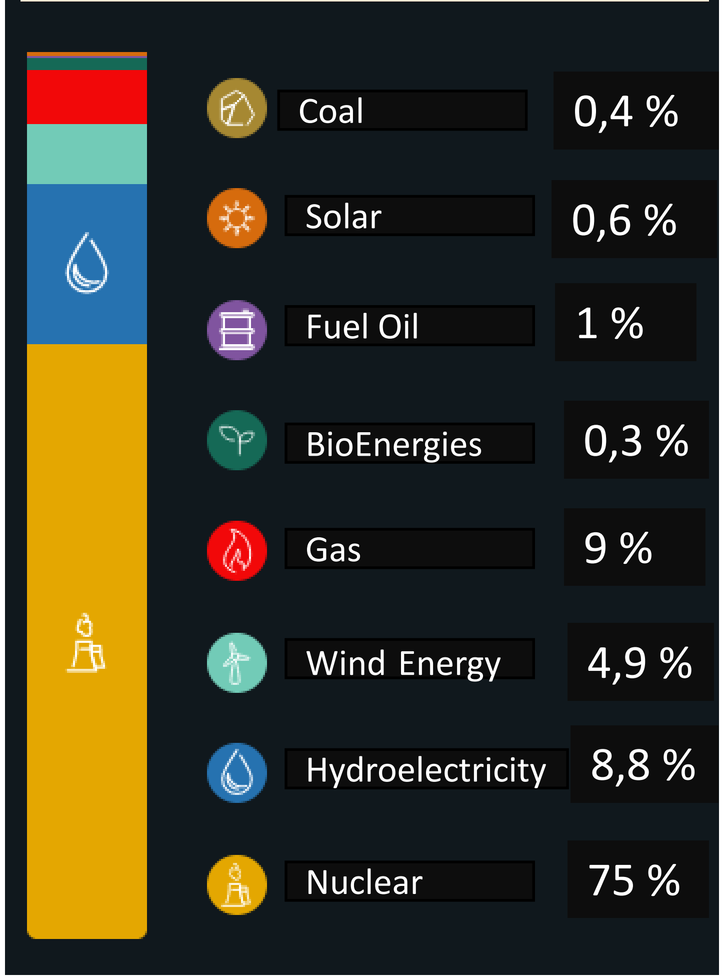
EDF R&D Lab Chatou, 06/07/2023



Context

- EDF (Electricité de France) : a French multinational electric utility company owned by the French state.
  - EDF operates a diverse portfolio of at least 120 gigawatts of generation capacity in Europe, South America, North America, Asia, the Middle East, and Africa
  - In 2009, EDF was the world's largest producer of electricity. One of the largest in the world today.
- Electricy production in France :
  - Almost 100% produced by EDF
  - ~ 75 % from nculear energy
- Fire hazard
  - Most likely risk facing a Nucear Power Plant (NPP)
- Issues
  - Public safety, protect the environment
  - Plant safety
  - Availability
- Electrical cables may constitute a fuel for fire hazard
  - High heat load: hundreds of kms of cables in a NPP
  - Complex fuel: nature of material

Electricty production in France in 2022



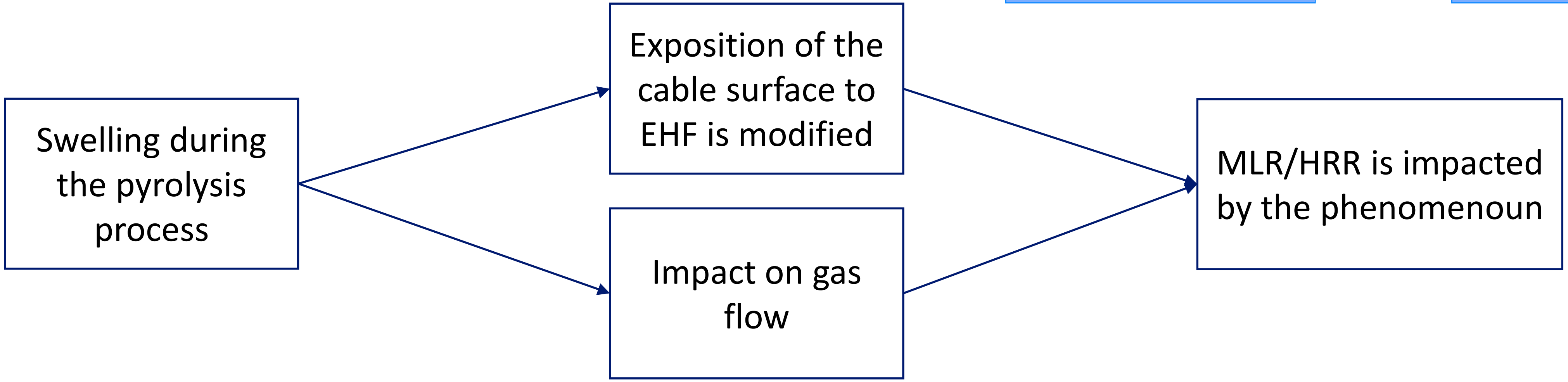
Cables are undergoing deformation during the pyrolysis process

- Some materials used for the fabrication of electrical cables: **PVC** (*polyvinyl chloride*), **EVA/ATH** (*ethylene vinyl acetate containing aluminum trihydroxide*), **PE/ATH** (*polyethylene containing aluminum trihydroxide*)
- These materials are swelling during their thermal decomposition process
- This phenomenoun has an influence on the whole process, and on the MLR/HRR

PVC cables deformation observed under a cone calorimeter

Before

After



→ Need to acount for the deformation phenomenoun in the pyrolysis model to be predictive on the MLR/HRR prediction

Summary

1. Context
2. Deformation Model and Validation
3. Conclusion

- Litterature review of existing models
    - Existing models are not adapted: different application, order of complexity
    - We selected the model of *Zhang et al*[1]
    - Model developped for the modelling of coatings' swelling
- Need to be adapted for our application
- Modifying the model to add some important physical aspects
- The modified model was implemented in the pyrolysis code Gpyro and validated on cone calorimeter experiments, including:
    - Thickness evolution in function of time
    - MLR
    - Back surface temperature
    - Denisty evolution in function of time

[1] Y. Zhang, Y.C. Wang, C.G. Bailey, A.P. Taylor, Global modelling of fire protection performance of an intumescent coating under different furnace fire conditions, Journal of Fire Sciences. 31 (2013) 51–72.

❑ Model adapted to represent the EVA/ATH material

- Model based on the law of perfect gases
- Swelling is linked to the expansion of gases in the solid matrix
- Thickness was observed to increase after the first reaction.
- No more increase of the thikness with the second reaction

$$\frac{\partial z}{\partial t} = \frac{\beta R}{a P_0 M_1}\left(T \frac{\partial m_{G_1}}{\partial t} + m_{G_1}\frac{\partial T}{\partial t}\right)$$

$$z_t = z_{t-\Delta t} + \Delta t \frac{\partial z}{\partial t}$$

Reaction scheme of EVA/ATH material :

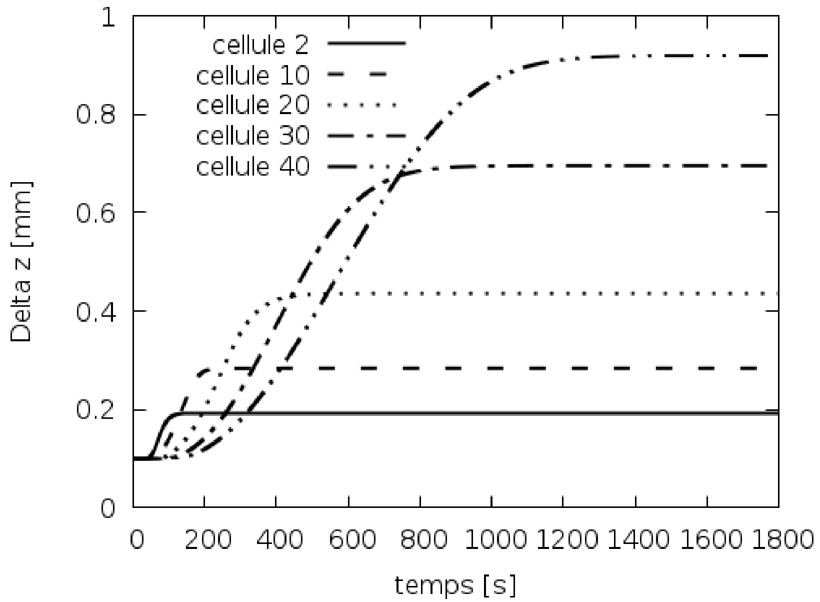
$$EVA/ATH_v \rightarrow 0.794\ EVA/ATH_i + 0.206\ G_1$$

$$EVA/ATH_i \rightarrow 0.547\ EVA/ATH_c + 0.453\ G_2$$

❑ Influence of the porosity on the swelling process

- Adding a term in the expression of β to acount for the fact that the presence of the prorosity allows the gas to escpae more easily from the material

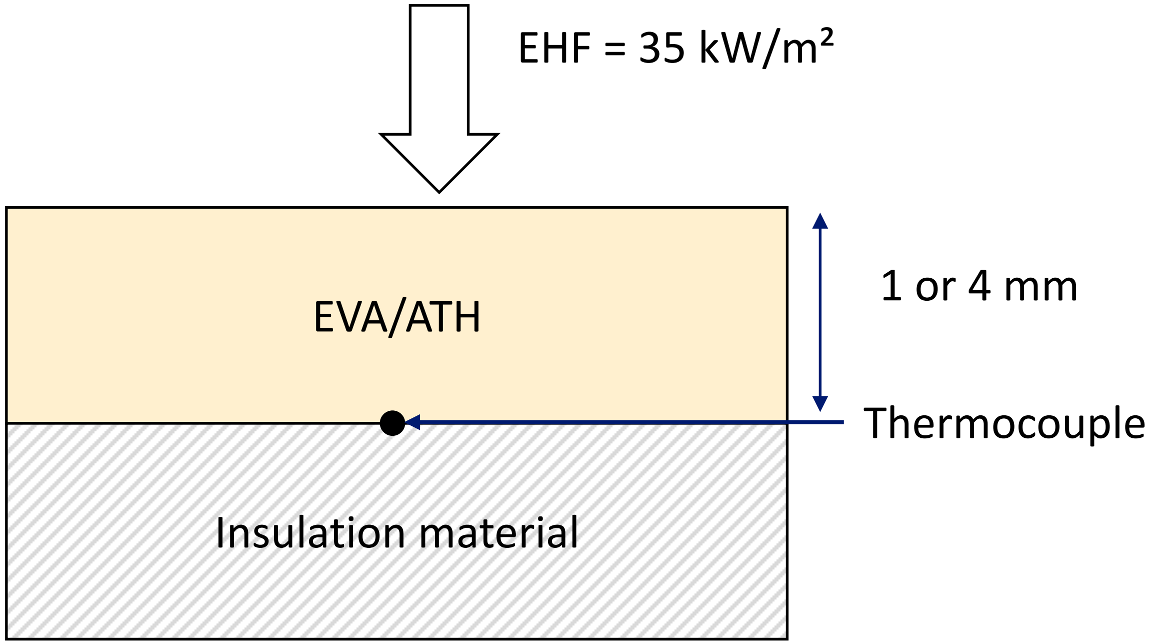
$$\beta = \left(\frac{T_{melt}}{T}\right)^{C_{trap}\frac{m_s T}{m_{s,0} T_0}} \frac{1-\Psi}{1-\Psi_0}$$



Thikness evolution without the porosity term

- Study of EVA/ATH samples
- Experiments under cone calorimeter

• Experiments have been performed under a cone calorimeter
• The experiments followed the ASTME906 procedure
• Repetability was verified

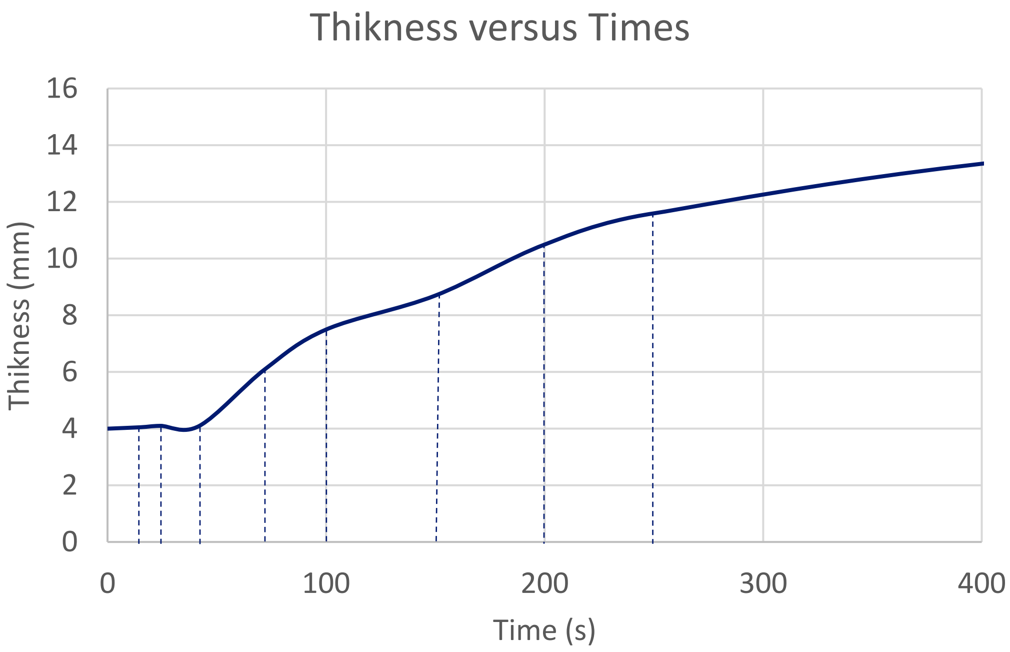


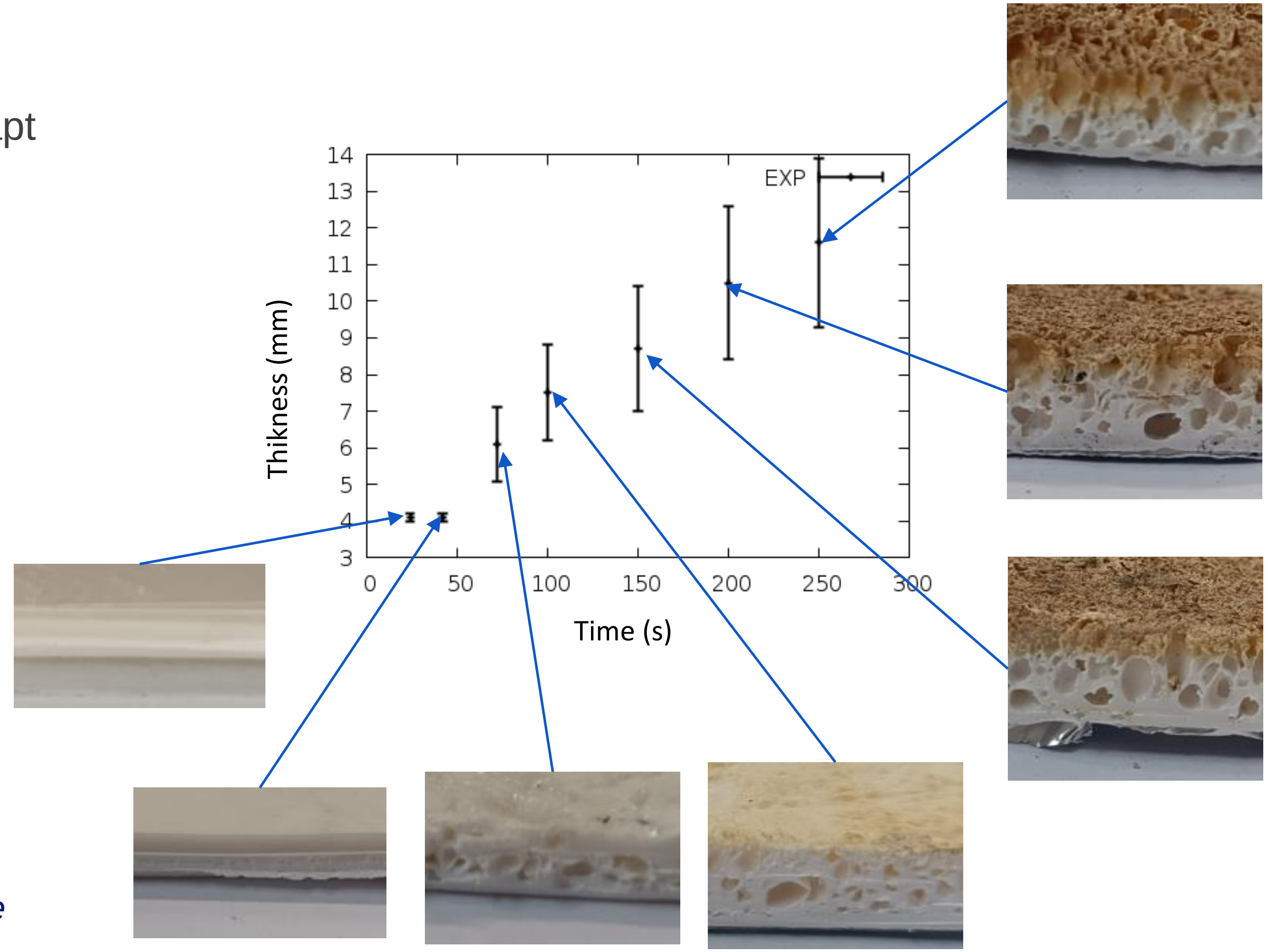
- Measurements

• Mass Loss
• Back surface temperature
• Thikness evolution with time
• Density evolution with time

❑ Measurements under a cone calorimeter

- First, repeatability was checkd on complete experiments
- Then, experiments were stopped at different times
- Measurement of thikness at each time
- Observation of the structure of the material, allowing to adapt the model



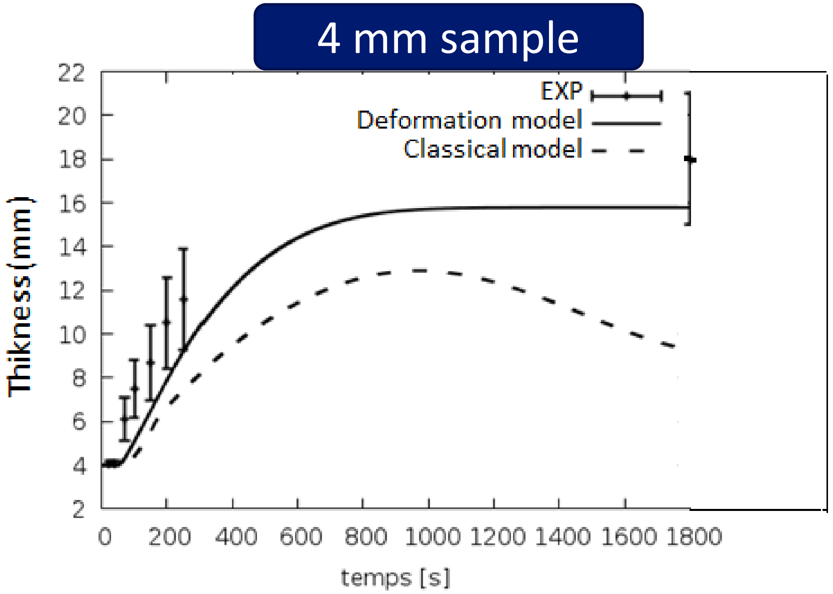


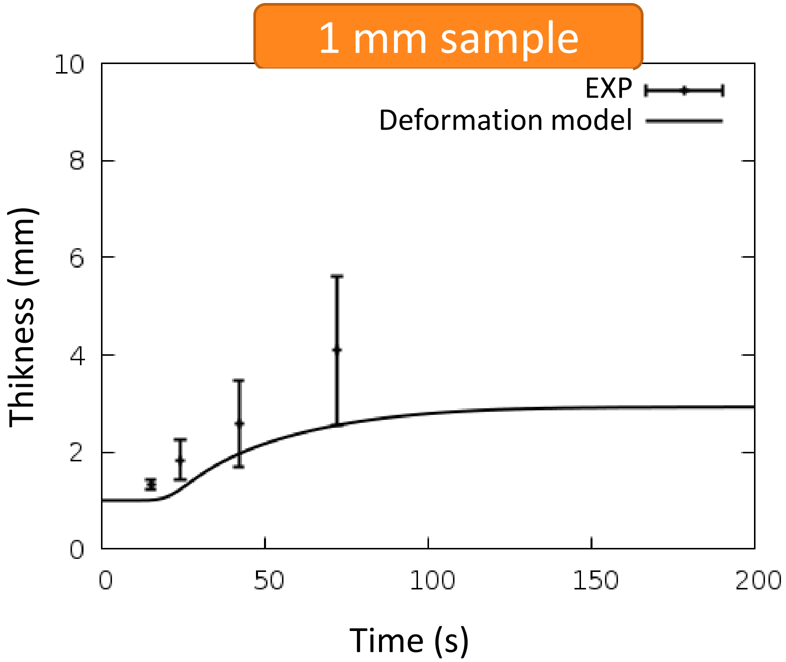
Times at which the cone calorimeter exp. were stopped to measure thikness and observe material structure:

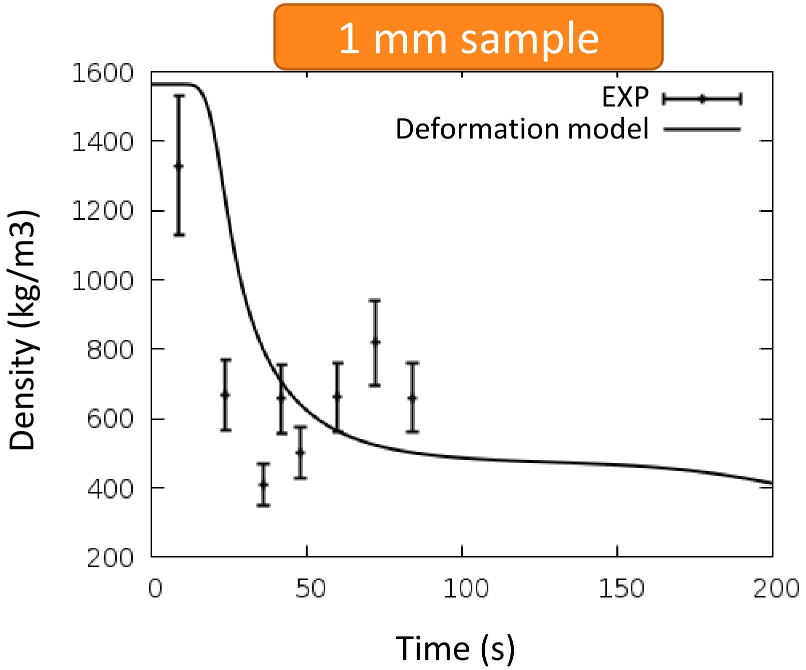
t (s) = 15, 24, 42, 72, 100, 150, 200 and 250

Some results

- Good agreement is obtained
- The deformation model is able to epredict the thikness and density with good accuracy
- Advantage:
  - No need to impose the density of the material and it evolution with time (compared to classical models used in the littérature)
  - Prediction of the thikness evolution







Summary

1. Context
2. Deformation Model and Validation
3. Conclusion

❑ For more details see our article :

Fleurotte M, Debenest G, Authier O, Fontaine G, Bourbigot S, Amokrane A. Modelling of the swelling behaviour of a fire retarded material under a cone calorimeter. Journal of Fire Sciences. 2023;41(4):136-166. doi:10.1177/07349041231177183

- A deformation model was devlopped and implemented in the pyrolysis code Gpyro
- The model is validated on cone calorimeter experiments
- The model obtained good results: good prediction of the thickness evlution with time as well as density evolution with time
- The model can easily be extended to other type of materials

Perspectives

- Further validation of the model: different operating conditions, other materials etc.
- Further predictibility: the C_{trap} (fraction of trapped gas - in the expression of β) parameter semms to have a real physical significance.
  - → So, now we intend to go further in the predictive modelling of this parameter

EDF

Thank you !