Multi-objective Bayesian optimization for intumescent coating

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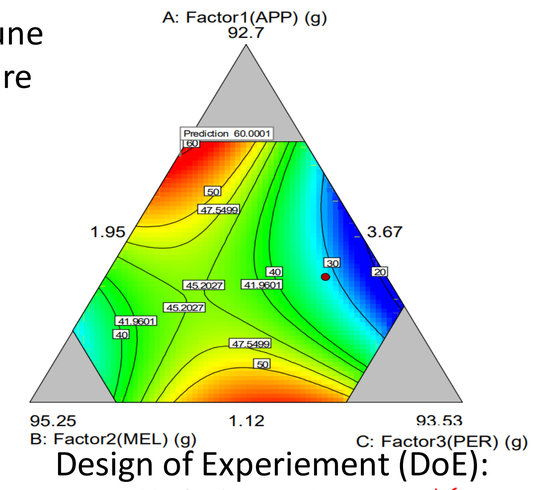
Aims/objectives

Wood is more and more used in buildings = sustainable materials compared to concrete and steel

Intumescent coating most commune system to protect wood against fire in structures

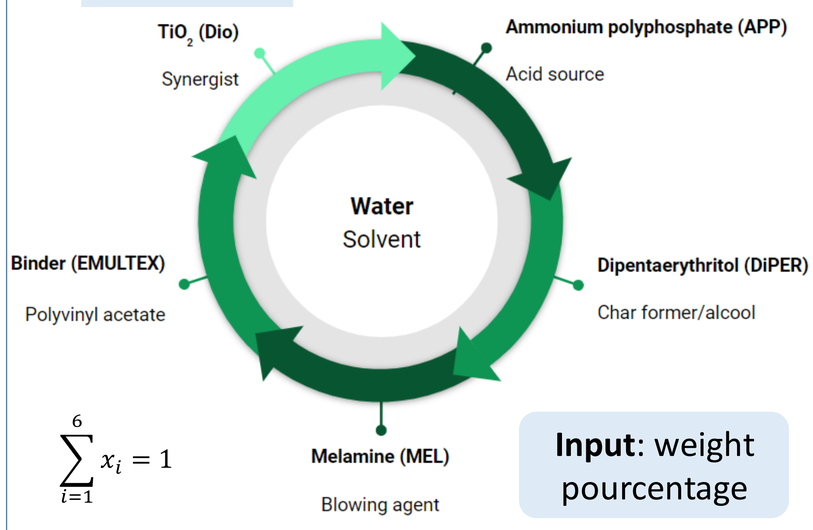
Intumescent coatings react => an expanded structure limiting heat and mass transfer



Design of Experiement (DoE):

- High dimension ✗
- Multi-objective ✗
- Noisy observation ✗

Input



$$\sum_{i=1}^{6} x_i = 1$$

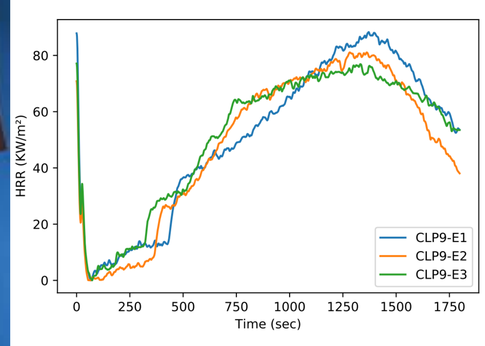
Input: weight pourcentage

Output

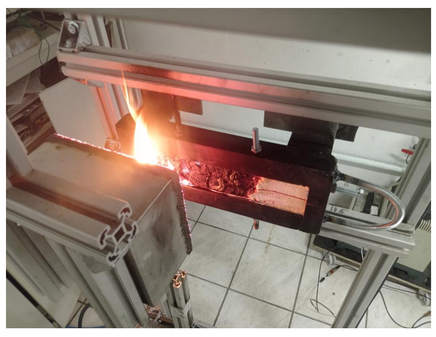
- Heat flux: 50 KW/m²
- Test time: 30 min

3 Fire tests → 4 performance outcome

Horizontal mass loss cone



1 - Total heat released (THR)
2 - Time of ignition (ti)



CFE 1/3 scale

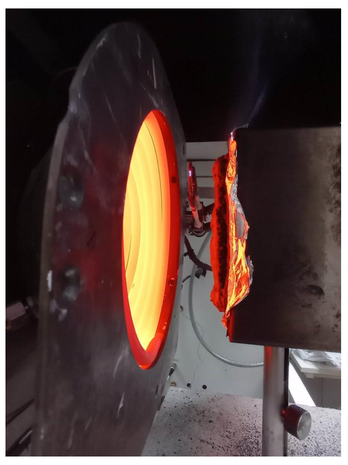
The flame propagation is evaluated using a lab-made by small scale

CFE radiant panel test (similar to the ISO5658-2)

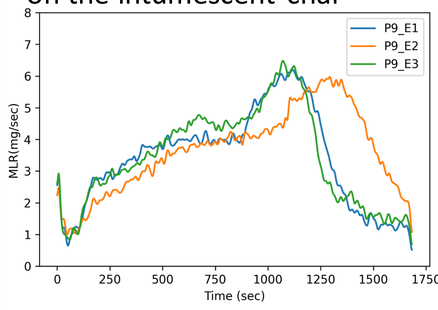
3 - distance of degradation

Determination of distance of degradation *via* image segmentation (K-means clustering)

Vertical mass loss cone



Vertical → more representative of fire in a building and impact gravity on the intumescent char

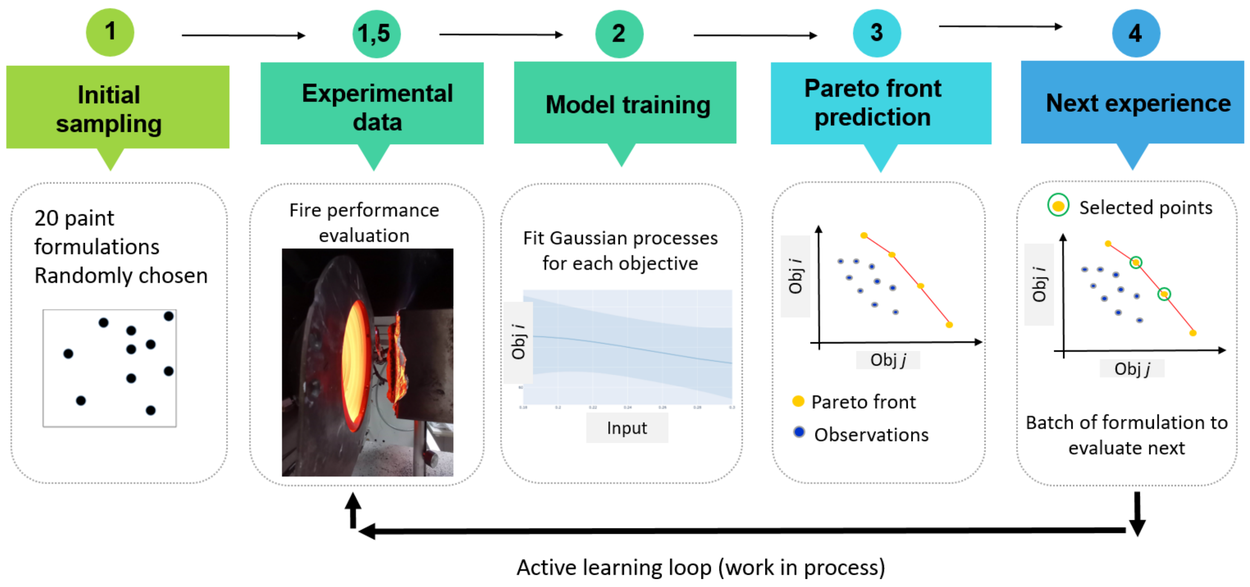


4 – Median of the mass loss rate

- Heat flux: 50 KW/m²
- Test time: 30 min

Pipeline

Bayesian optimization (BO) is a sequential model-based approach that efficiently explores and exploits the search space to find the optimal solution of a black-box function with limited evaluations. BO can be used for noisy and small dataset.



In Multi-objective optimisation there is typically no single best solution. The Pareto front is the set of solutions where no other solution can improve one objective without sacrificing another. It represents the optimal trade-off between conflicting objectives, providing a range of solutions, to guide decision-making.

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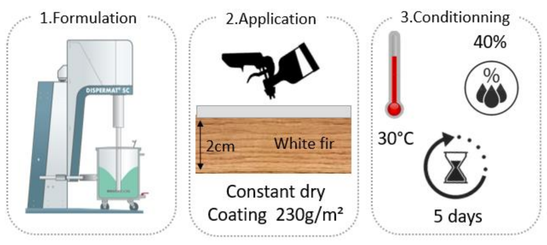
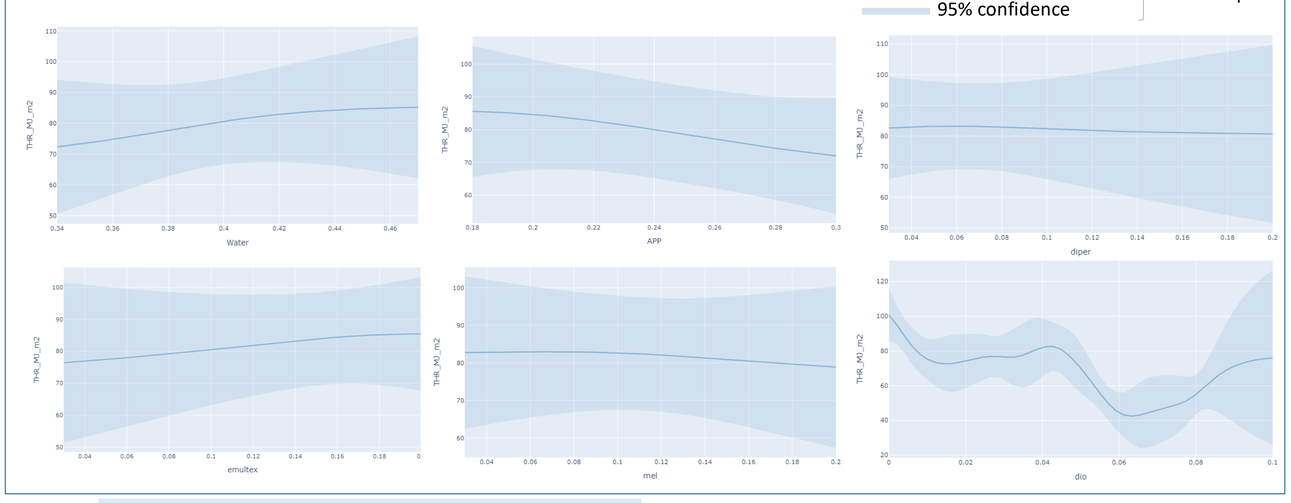


Experimental protocol

1. The coating formulations were obtained a dispersion using a high-speed disperser
2. A constant dry mass is applied on white fir
3. The sample is conditioned at 30°C, 40% RH during before the fire testing

Prediction



Metric evaluation

Metric	THR	Ti	Median of MLR	Distance of degradation
Mean absolute percentage error (MAPE)	13%	17%	3%	2%
Coefficient of correlation	0,67	0,73	0,89	0,67
Fisher exact test p value	0,011	0,011	0,0005	0,32

Error bar: 95% confidence
Model evaluation technique: Leave one out cross-Validation (LOOCV)

Conclusion/perspective

- Intumescent is an efficient method to protect wood against fire in a building
- Designs of experiment are very efficient but require high amount of data
- The performance of the coating is evaluate by 3 fire tests giving 4 parameters of performance
- Multi-objective Bayesian Optimisation has been chosen to find the optimum configuration of the paint (pareto front) and minimize the number of samples

Outlooks

- Number evaluation until a satisfactory approximation of the Pareto front is obtained
- Comparison between different sampling for initial points

References

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