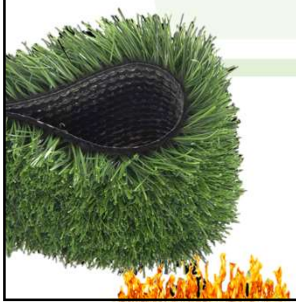
Interreg France-Wallonie-Vlaanderen GRASS

Université de Lille

UMET Unité Matériaux Et Transformations

centralelille ENSCL

UNDERSTANDING OF THE FIRE BEHAVIOUR OF ARTICIAL GRASS - NEW APPROACHES



Sophie DUQUESNE
Centrale Lille Institut,
ENSCL, France

European Meeting on Fire Retardant Polymeric Materials, 29 August-1 September 2021, Budapest, Hungary.

MONDAY, 30th of August 2021

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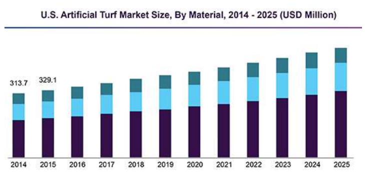
Artificial turf

Market and uses

European artificial turf market:
45 million m²/year.



Sports fields

Landscaping (outdoor, balconies,…)

Indoor use (kid playground, event hall, …)

Advantages: Cost savings

- Less maintenance
- Usable in all weather conditions
- Durability
- No need to mow, to use water and pesticides

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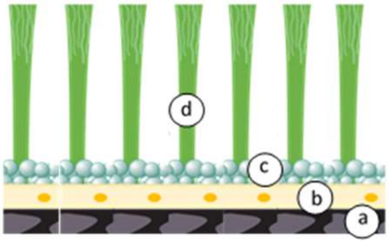
Artificial turf: sports structures

Complex and multilayered material



- a : Backing (PP / PET)
- b : Sand
- c : Performance layer (infill)
- d : Straight pile (PE)

Mainly composed of organic materials

→ Highly flammable
→ Dense and toxic smokes

Playground, Alaska, April 2017

Synthetic sport turf, Westfields, March 2011

Deliberately set fire causes extensive damage to artificial turf field next to Nanaimo school

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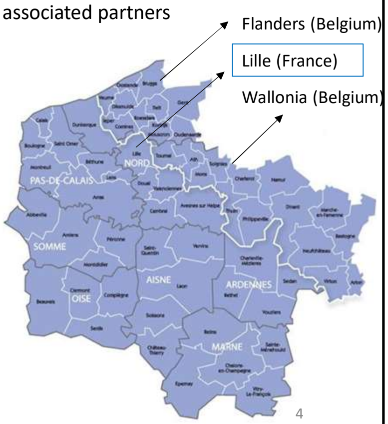
Artificial turf: fire behaviour

The GRASS project

http://www.interreg-grass.eu/

- European cross-border project France - Belgium
- Co-financed by the European Regional Development Fund (ERDF)
- 4 main partners
- Several associated partners



Main goals:

1. Increase awareness of public and stakeholders of difference between natural and artificial grass
2. Improve the fire retardancy and eco-friendliness of artificial turf

What are the main steps?

- Better understanding of the fire behaviour of artifical grass
- Develop new fire retardant solutions taking into account the durability and ecological aspect as well as the industrial feasibility
- Develop high throughput screening technics to evaluate the fire behaviour of such materials

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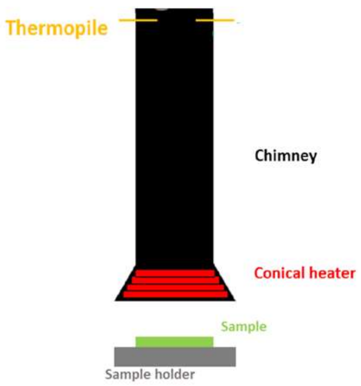
Fire testing: Mass Loss Calorimeter (MLC)



Mass Loss Calorimeter test

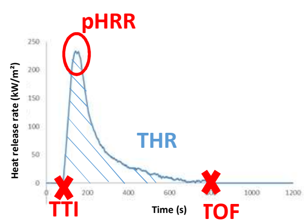
Bench-scale reaction-to-fire test which provides a forced-flaming combustion scenario; with an external heat radiative flux

Parameters:

- Flux : 25 kW/m²
- Distance : 35 mm

Measured values :

- Heat release rate (HRR)
- **Peak of heat release rate (pHRR)**
- **Total heat release (THR)**
- **Time to ignition (TTI)**
- **Time of flame out (TOF)**



All measurements performed at least twice
Acceptable error of 10 % for HRR, pHRR and THR; 15% for TTI

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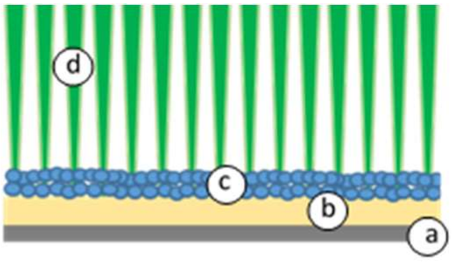
Artificial turf: Sports structures

1. **Determine the contribution of each component on the fire behaviour of the complete structures**



Complex and multilayered material:

a : Backing (PP)

b : Sand

c : Performance layer (infill)

d : Straight pile (PE)

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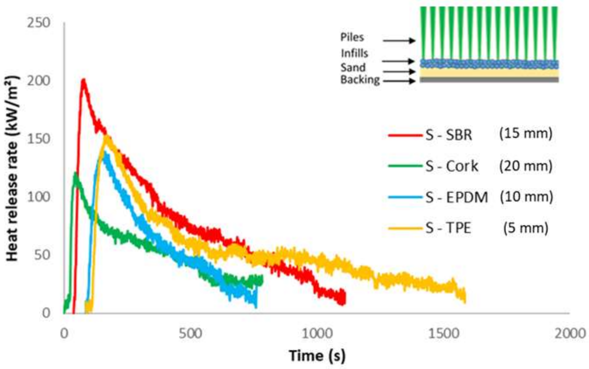
Fire behaviour: Complete structures

Fire behaviour of the complete structures (S):



Infills	TTi (s)	pHRR (kW/m²)	THR (MJ/m²)	TOF (s)
S – SBR	40 ± 4	201 ± 21	82 ± 2	981 ± 30
S – Cork	23 ± 1	121 ± 10	36 ± 1	523 ± 22
S – EPDM	86 ± 1	143 ± 4	41 ± 3	617 ± 75
S – TPE	86 ± 14	154 ± 1	82 ± 4	1739 ± 30

- **Worst fire behavior** according to the **THR : *S+TPE*** *and* ***S+SBR***
- **Worst fire behavior** according to the **pHRR : *S+SBR***

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Results submitted for publication in Fire and Materials

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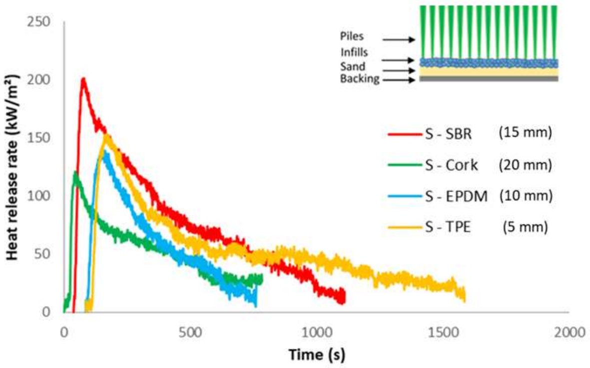
Fire behaviour: Complete structures

Fire behaviour of the complete structures (S):



TPE

Cork

Results submitted for publication in Fire and Materials

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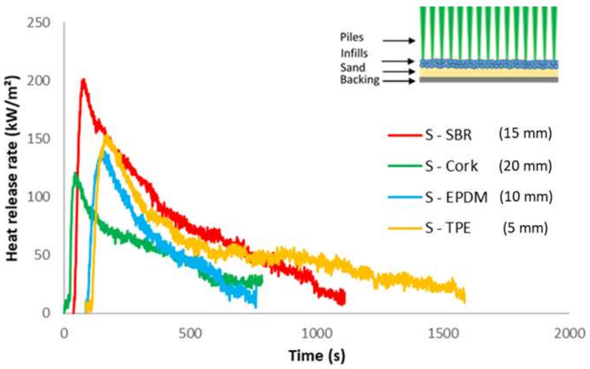
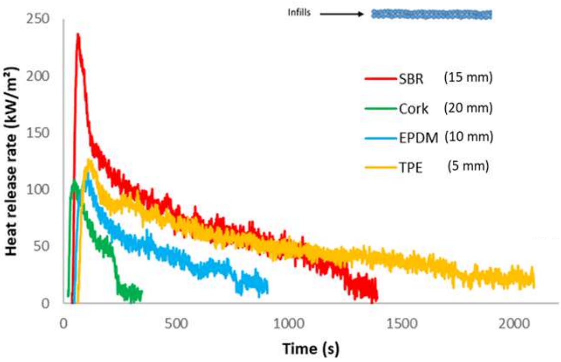
Fire behaviour:

Comparison of the fire behaviour of the complete structures (S) and of the infill alone:





- In terms of pHRR and THR, **TPE and SBR have the worst behavior while cork has the best one**.
- **Major contribution of infill** in the fire behavior.

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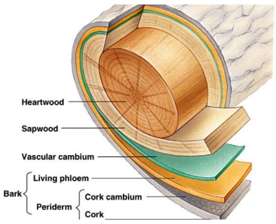
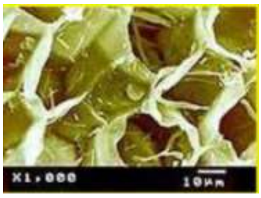
What is Cork ?





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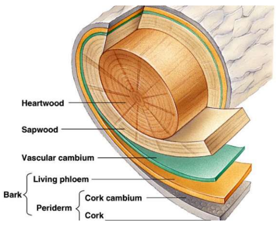
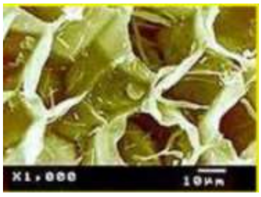
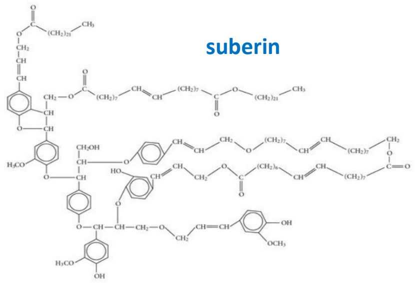




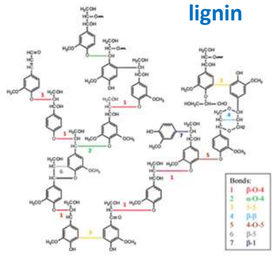
The average chemical composition of cork is:

- **Suberin (45%)** – the main component of the cell walls; responsable for the resilience
- **Lignin (27%)** – the binding compound
- **Polysaccharides (12%)** – components of the cell walls; define the texture of the cork
- **Tannins (6%)** – polyphenolc coumpounds responsable for colour
- **Ceroids (5%)** – hydrophobic compounds that ensure the imperviousness of cork
- Mineral, water, glycerine and others remaining compounds

suberin



lignin



Cork modification: Phosphorylation process

Objectives: Enhance the fire behaviour of cork granules
Increase the charring phenomenon of cork

Polymers for Advanced Technologies. 2008;19:628-635
European Polymer Journal, vol. 84, pp. 652–667, 2016

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Strategies:

Low durability, risk of leaching, ...

Surface modification ✗

Bulk modification ✓

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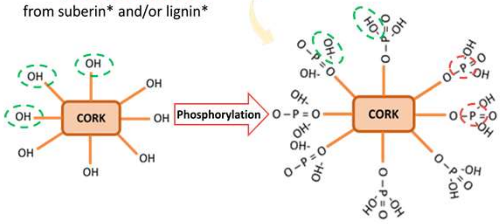
Grafting phosphorus moieties onto cork

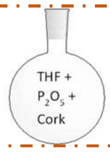
→ reactions with the **free hydroxyl groups** from suberin* and/or lignin*

P_2O_5, H_3PO_4, ...

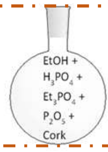


Protocols

n°1

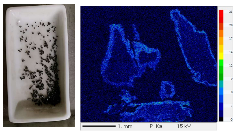


n°2



Characterizations

Raw cork / Modified cork
- Sligth ↗ (≈+4%) of carbon residue



- Up to **+11%** of the carbon residue
- Uniform thin layer grafting of phosphorus

Conclusions

Minor improvements ✗ — ↗ **significant carbon residue at 600°C.** ✓

THF ✗ — **Optimization of the formulation.**

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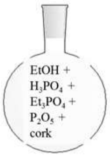
Phosphorylation of cork: optimisation and up-scaling



Good compromise "synthesis time / results".
- Increase in the **carbonaceous residue of ≈ 6%.**
- Increase in **thermal stability.**
- **Uniform grafting** in thin layers of phosphorus.
- **High production yield** (89%).

Cork (g)
$V_{H_3PO_4}$ (mL)
V_{EtOH} (mL)
$V_{Et_3PO_4}$ (mL)
$m_{P_2O_5}$ (g)
Temperature (°C)
Time (h)
Agitation
Wettability

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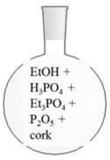

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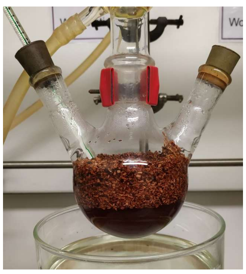
"Large" scale production for fire tests.

Cork (g)	80
$V_{H_3PO_4}$ (mL)	400
V_{EtOH} (mL)	400
$V_{Et_3PO_4}$ (mL)	270
$m_{P_2O_5}$ (g)	8.8
Temperature (°C)	45
Time (h)	24
Agitation	550 rpm
Wettability	Excellent

Upscaling:



250 mL - 12 g of cork

Scaling-Up

Dimensional analysis modelling

2 L - 80 g of cork

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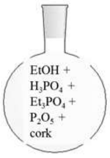

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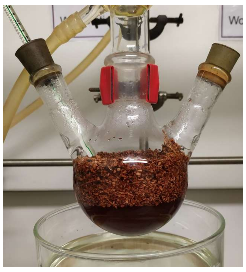

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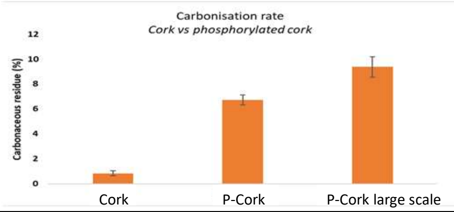

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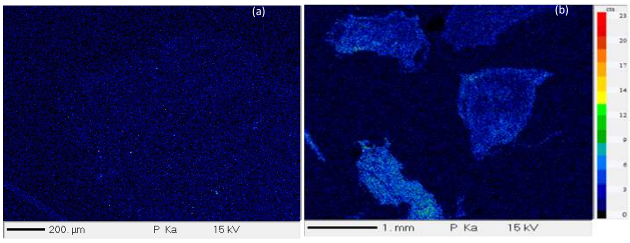
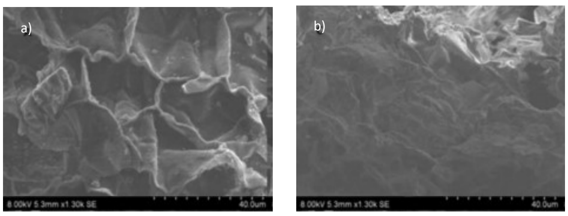
Modified cork: morphology and thermal stability

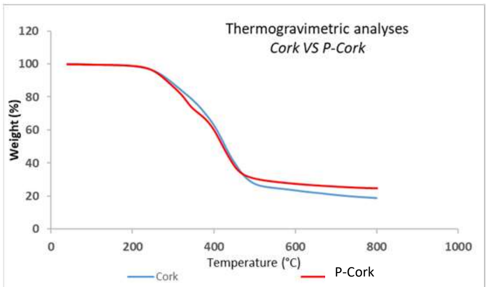


EPMA mapping of (a) virgin cork and (b) P-cork



SEM pictures of the (a) cork surface and of the (b) P-cork surface

Characterisations :
- Thermal stability (TGA), under N_2, 10°C/min



	Residue at 600°C (%)	Residue à 800°C (%)
Cork	23.2	18.5
P-Cork	27.4	24.7

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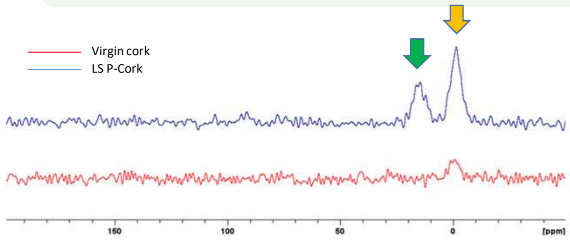
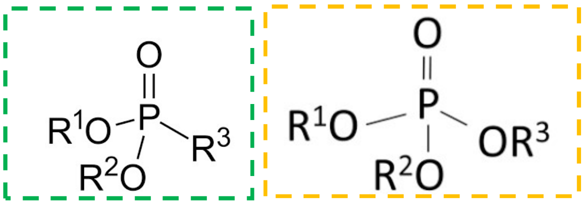
Modified cork: chemical characterisation

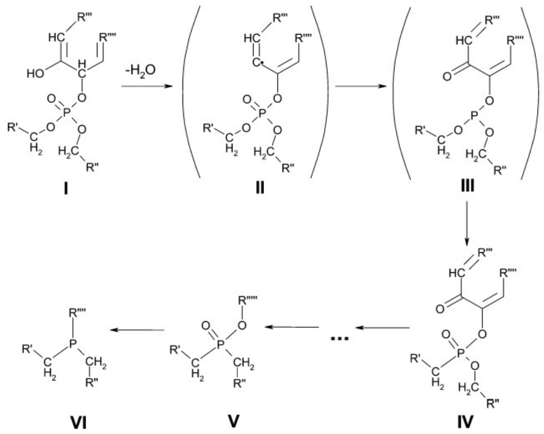


Solid state ^{31}P NMR spectra of virgin cork and LS P-cork

phosphonate

phosphate





Simplified scheme of Michaelis-Arbuzov-type reaction

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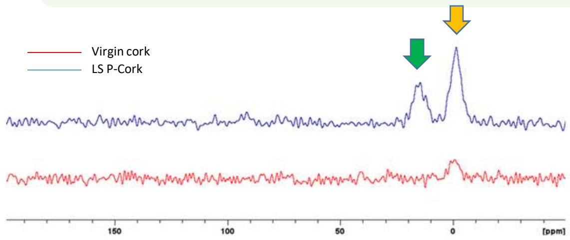

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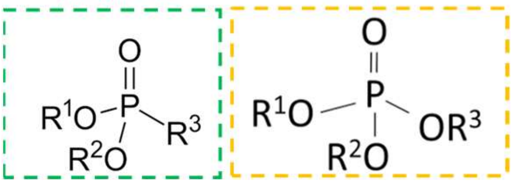

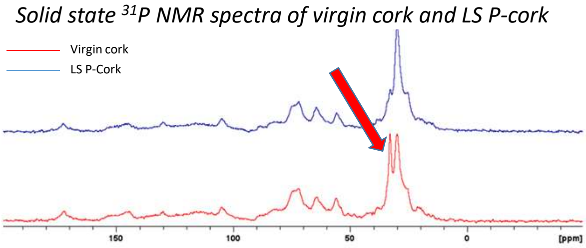

Solid state ^{13}C NMR spectra of virgin cork and LS P-cork

Peak (ppm)	Assignation
21	Ester groups of hemicelluloses
25 – 50	Waxes
25 – 33	Methylene carbons of suberin
56	Methoxy groups of suberin, lignin and hemicelluloses
65 – 105	Carbohydrate carbons (hemicellulose and cellulose)
110 – 155	Lignin aromatic carbons
172	Suberin ester groups
110 – 160	Lignin and polyphenols

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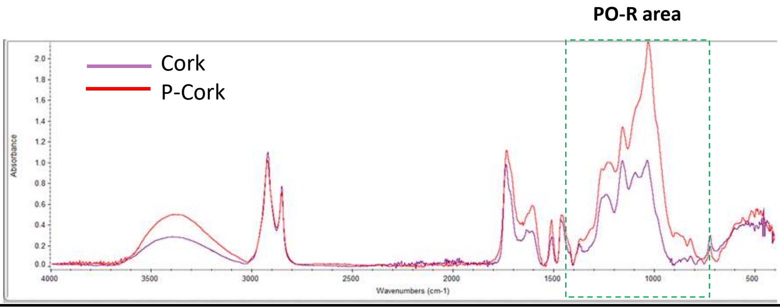
Modified cork: chemical characterisation

Characterisations :

- Infrared (IR)

ṽ(cm−1)	assignment	Corresponding bonding
1220-1260	ν CO	Aromatic ethers (formed during phosphorylation reaction).
1230-1260	ν PO-R	Presence of phosphonate.
1100-1200	ν PO-R	Elongation of the PO-C bond in the presence of phosphate (PO_4).
1030-1090	ν PO-R	PO-R bonds of phosphate groups (respectively $\nu_{as}PO_4$ et $\nu_s PO_3$)



Conclusion :

- Characteristic phosphorus bonds
  →Phosphorus compounds grafted during the phosphorylation reaction.

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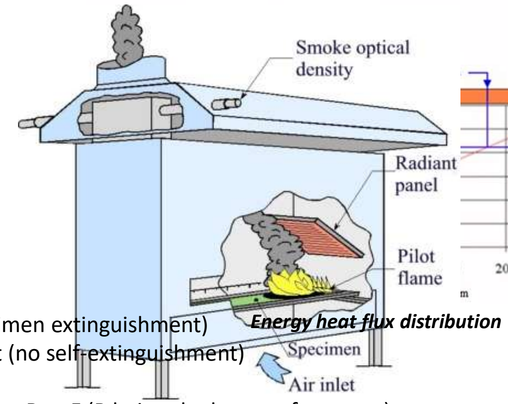
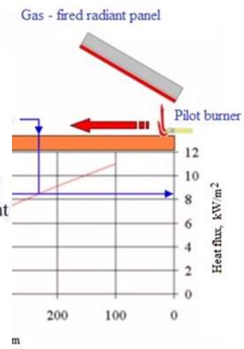
Regulations: Radiant panel test EN ISO 9239 – 1

Evaluation of the fire behaviour of floorings exposed to an energy flux gradient

- **Flame propagation** (burnt length)
- Max test duration : **30 min**
- Specimen size : (1050 x 230) mm²
- Smoke density (additional requirements)



Radiant panel test EN ISO 9239-1



Determination of the **critical heat flux (CHF):**

- Point where the flame stops to advance (specimen extinguishment)
- Position of the front flame after 30 min of test (no self-extinguishment)

Depending on the CHF - Ranking is obtained from B to F (B being the best performance)

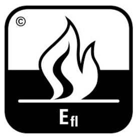
GRASS

Classifications : EN ISO 13501 – 1

Class of reaction to fire performance for floorings:

Class	Radiant panel test *EN ISO 9239 – 1*	Single – flame source test *EN ISO 11925 – 2**	Additional requirements
B_{FL}	CHF ≥ 8 kW/m²	Fs ≤ 150 mm dans 20 s	Smoke ≤ 750%.min (s1)
C_{FL}	CHF ≥ 4.5 kW/m²	Fs ≤ 150 mm dans 20 s	Smoke ≤ 750%.min (s1)
D_{FL}	CHF ≥ 3 kW/m²	Fs ≤ 150 mm dans 20 s	Smoke ≤ 750%.min (s1)
E_{FL}	No requirements	Fs ≤ 150 mm dans 20	No requirements
F_{FL}		No requirements	

**Ignition time: 15 s*

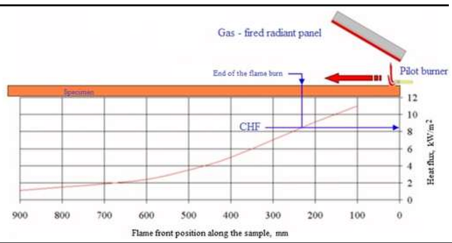


Outdoor applications

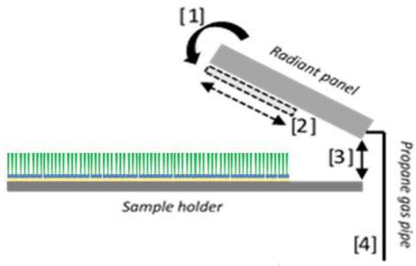
Indoor applications

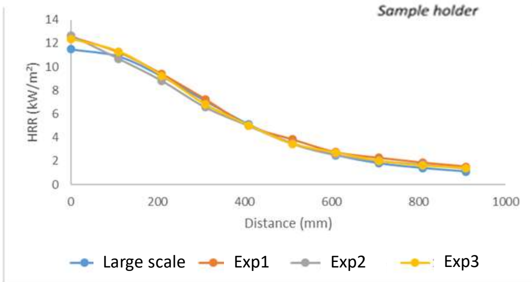
For indoor applications:

Minimum C : CHF ≥ 4.5 kW/m²
→ Burnt length about 420 mm max
→ Smoke rate S1 ≤ 750 %.min



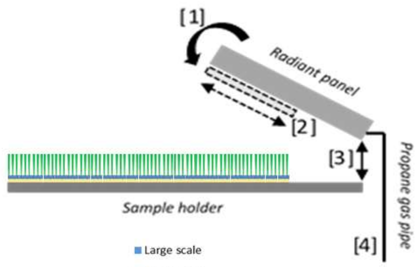
Small scale radiant panel : design

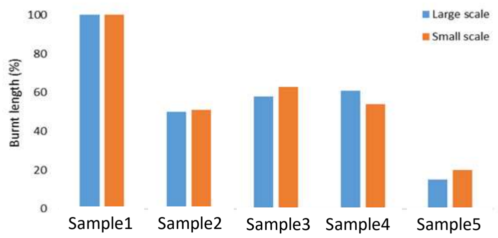




Results submitted for publication in Journal of Fire Sciences

Small scale radiant panel : validation





Results submitted for publication in Journal of Fire Sciences

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Fire test: small-scale radiant panel

P-Cork:

- Formation of a thick char at the surface.
- Excellent charring in contrast to virgin cork.
- Considering only the deeply degraded part, **flame propagation is lower than with virgin cork: Classification C_{FL}** (suitable for indoor use)

Parameters	Cork (20)	P-Cork (20)
% of length burned	54%	29%
Burning time	13 min 22 s	14 min 33 s
CHF after 30min (kW/m²)	2.66	7.13
Ignition time (s)	0 (immédiat)	0
Classification	**E_{fl} / F_{fl}**	**C_{fl}**
Smoke	S1	S1

Cork P-Cork

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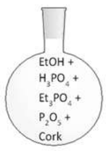
Conclusion

Fire behaviour

MLC
- Highlighting the **importance of the infill** on the fire behaviour of the structure.
- **Lower THR and pHRR for cork**.

Fireproofing strategy

- Bulk modification of cork granules by **phosphorylation** process.
- Choice of a protocol + optimization



$V_{H_3PO_4} = V_{EtOH} = 60$ mL
$V_{Et_3PO_4} = 40$ mL
$m_{P_2O_5} = 1.3$ g
Temperature: 45°C
Time: 24h

Results

- Improvement of thermal stability.
- **Significant reduction in burnt length + meeting class C in Small Scale Radiant Panel**
- Protection of the backing.

Outlook

- Further improve the fire properties of artificial turf structures by **also fireproofing the piles**.

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Interreg France-Wallonie-Vlaanderen

Université de Lille

UMET Unité Matériaux Et Transformations

centralelille ENSCL

M. Casetta

P. Bachelet

A. Paturel

Thank you for your attention.

Do you have any questions?

European Meeting on Fire Retardant Polymeric Materials, 29 August-1 September 2021, Budapest, Hungary.

Sophie DUQUESNE
Centrale Lille Institut, ENSCL, France

MONDAY, 30th of August 2021

Contact : sophie.duquesne@centralelille.fr