

# IMPACTS DU RECYCLAGE SUR LES ASPECTS THERMO- MÉCANIQUES DU PET

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Mines Paris Tech (CEMEF)



Journée Industrielle

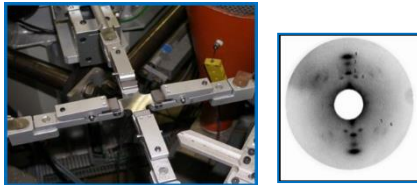
# Recyclabilité des polymères

Filière de recyclage du PET

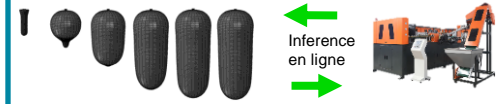
13 décembre 2022 - Mines Paris - PSL



THESE Laurianne Viora  
CEMEF, 3 ans  
« *Comportement thermo-mécanique et microstructure induite, Soufflabilité* »

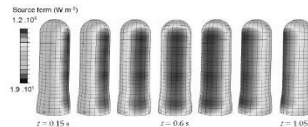


POST-DOC  
William Han  
CMAT, 18 mois (sept. 2022)



**Jumelage numérique**

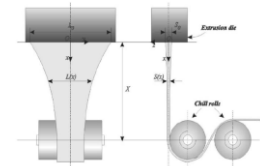
POST-DOC Anh-Duc  
Le  
ICA, 9 mois  
« *Modélisation du comportement thermique* »



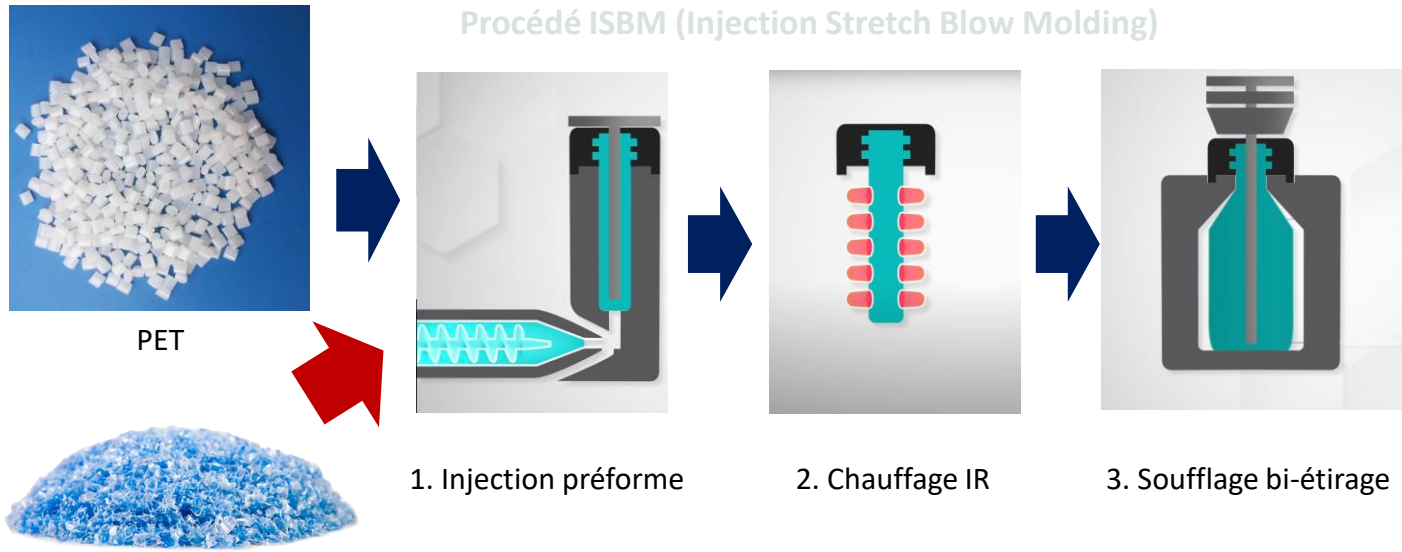
STAGE Marie Combeau  
C2MA, 6 mois  
« *Processabilité, microstructure et propriétés finales* »



STAGE  
C2MA, 6 mois (2023)



**Modélisation mécanique de la mise forme, Stabilité dimensionnelle**



### Variabilités de la matière première

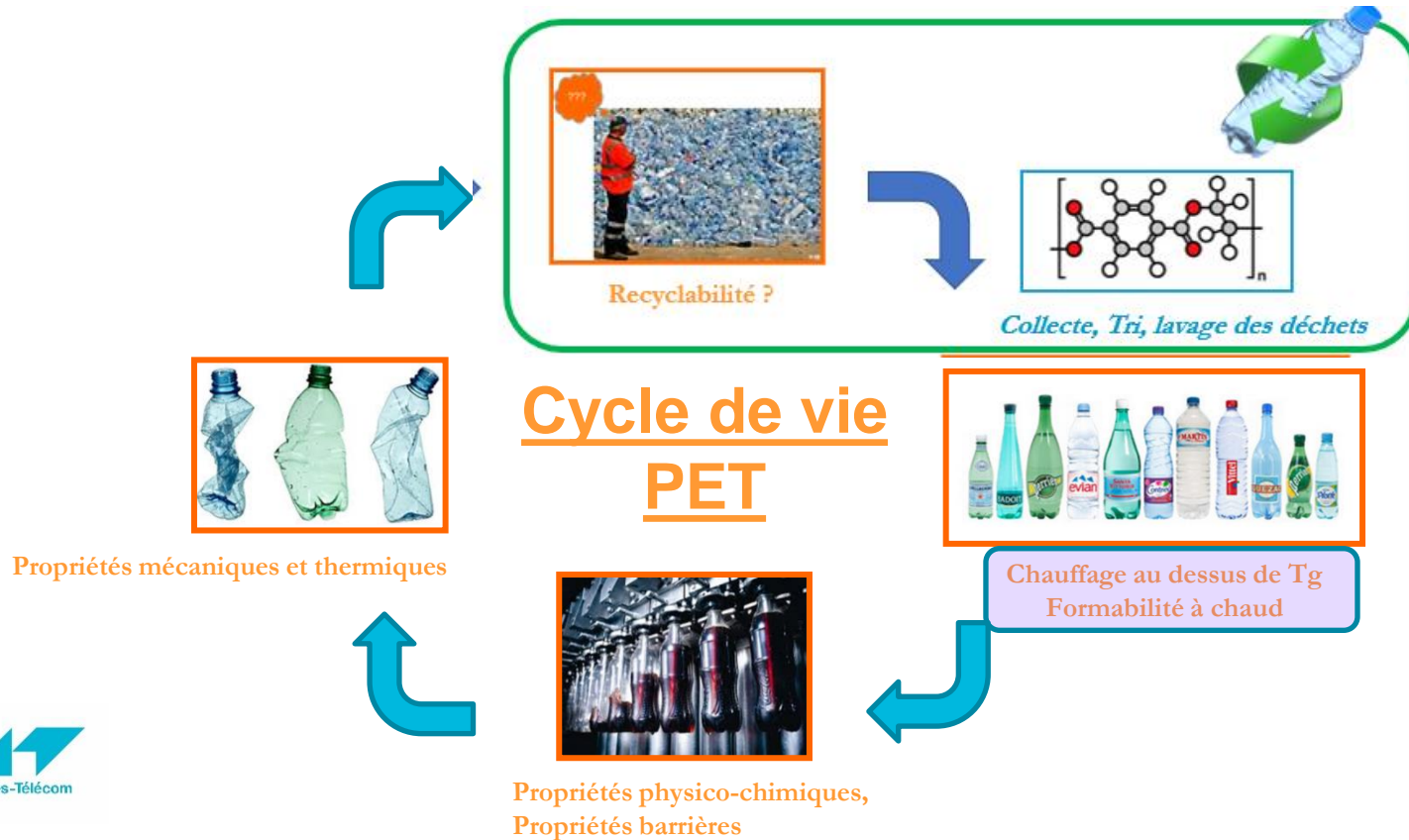
PET recyclé

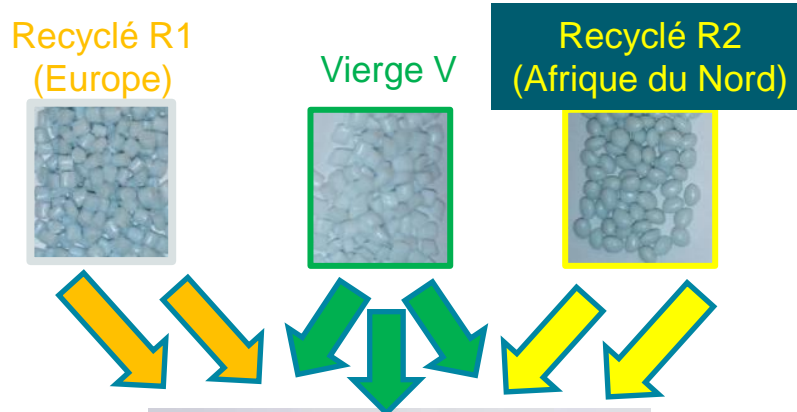
- Diversité des gisements
- Multiple cycles de recyclage
- Taux de recyclage



### Impacts sur le procédé de mise en forme

- Propriétés thermo physiques et optiques
- Propriétés thermomécaniques

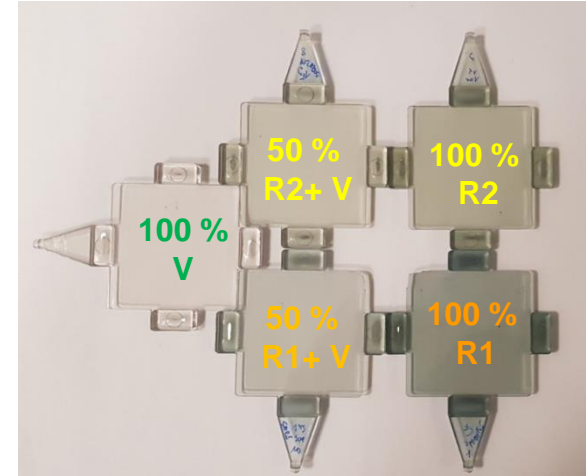




Mélange Mélange

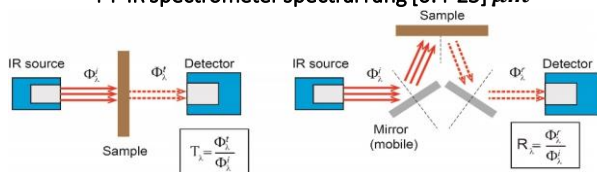
Préformes injectées

Virgin PET RAMAPET N180

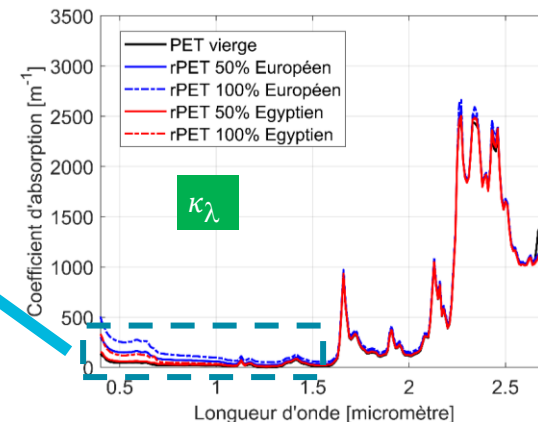
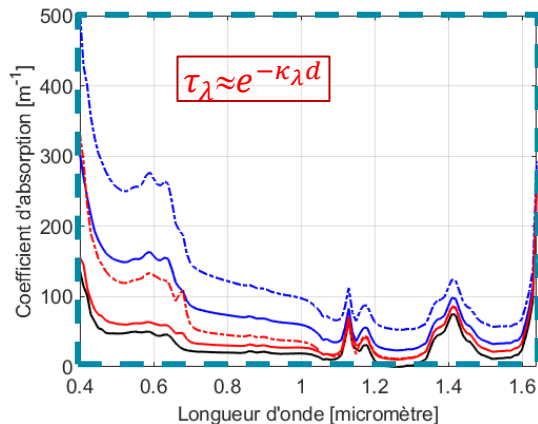
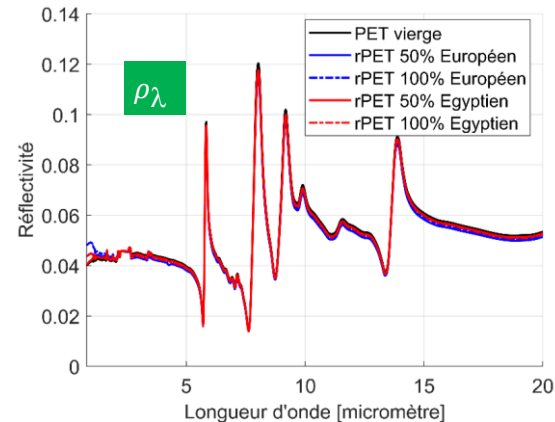
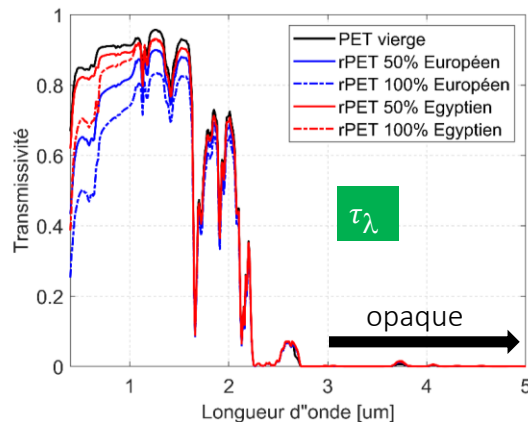


Plaques injectées

FT-IR spectrometer spectral rang [0.4-25]  $\mu\text{m}$



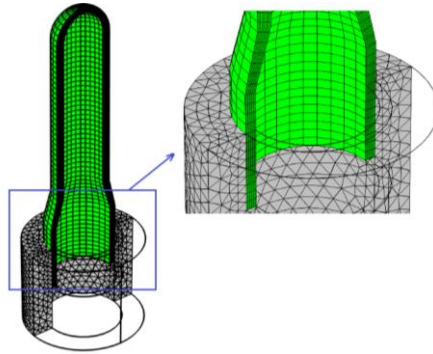
Measurements of  $\tau$  and  $\rho$



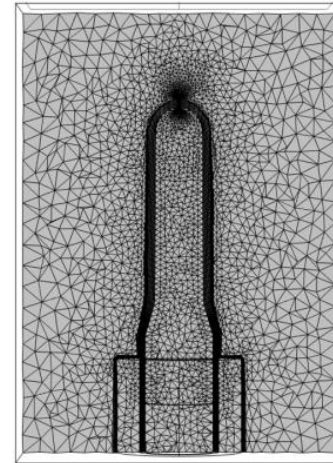
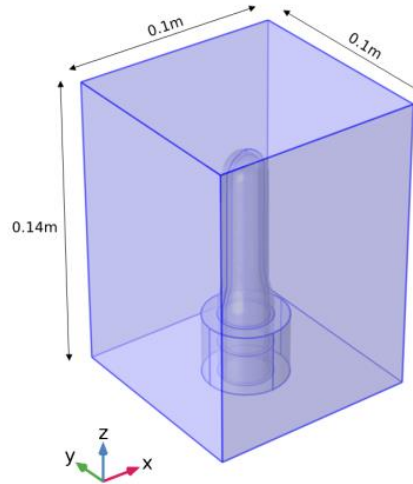


## Logiciel commercial COMSOL Multiphysics®

Maillage préforme



Géométrie et maillage utilisés pour le calcul CFD

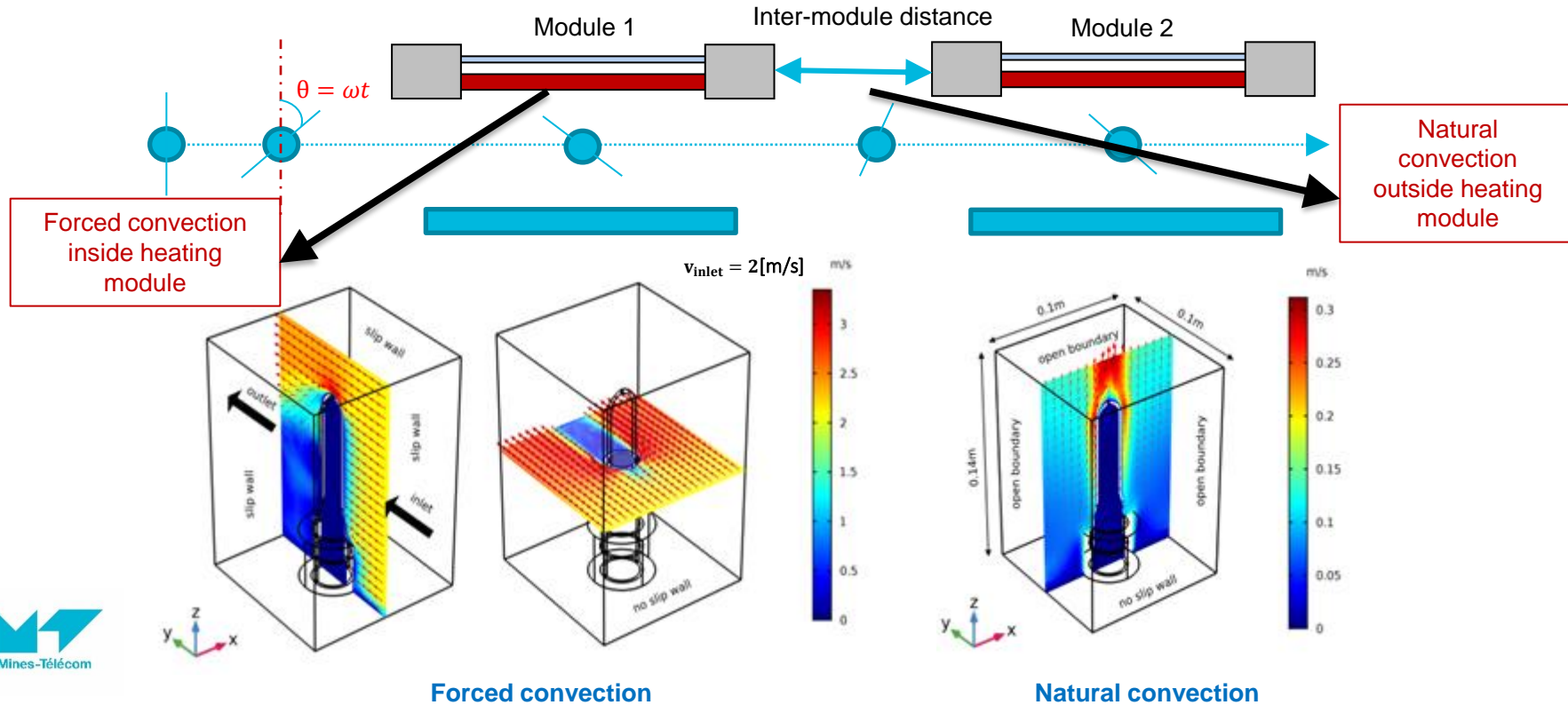


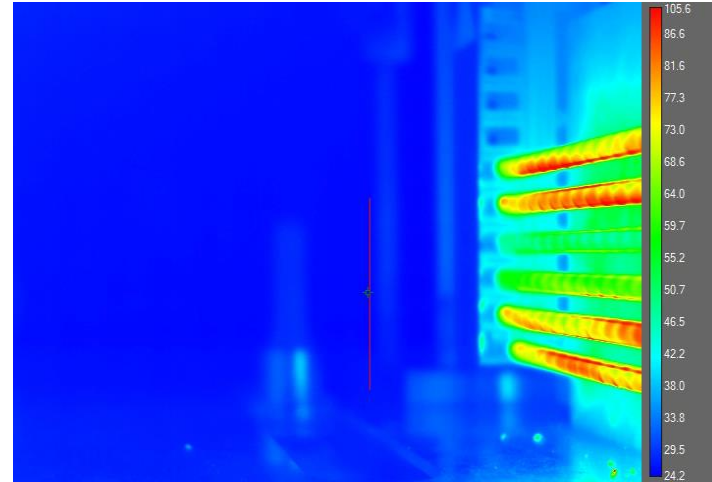
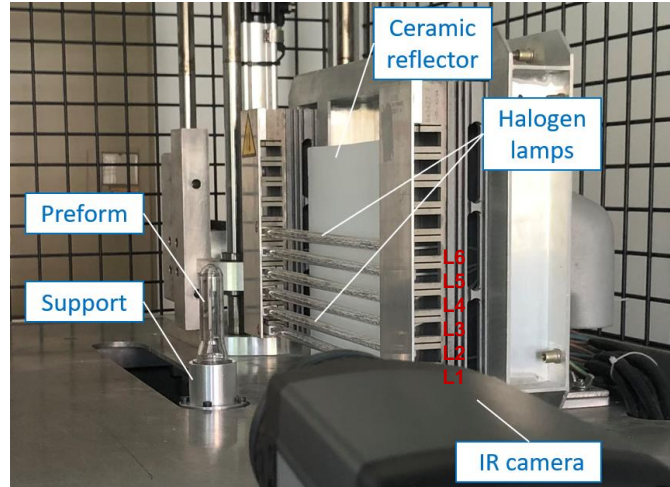
267069 elements

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) - \nabla \cdot q_r$$

Terme source  
radiative (**logiciel  
interne RAY-HEAT**)



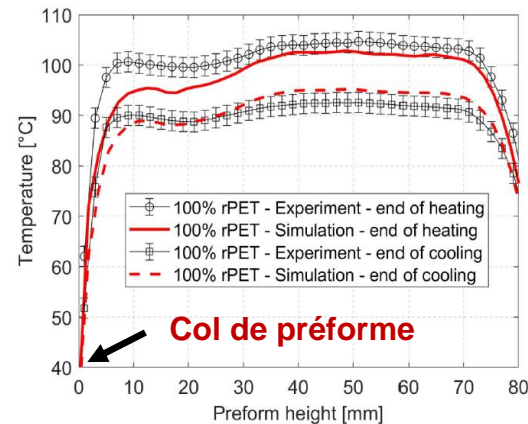
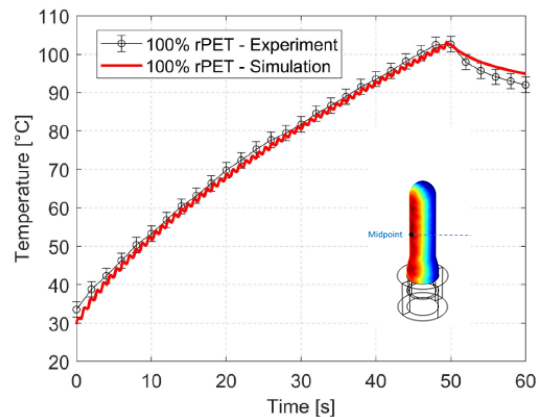
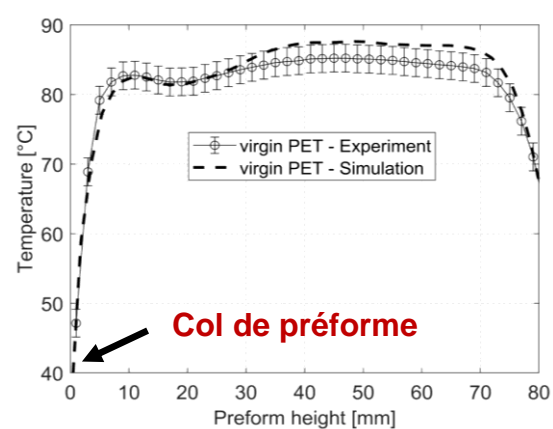
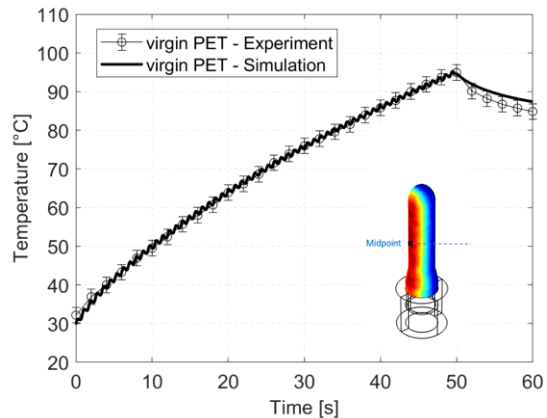


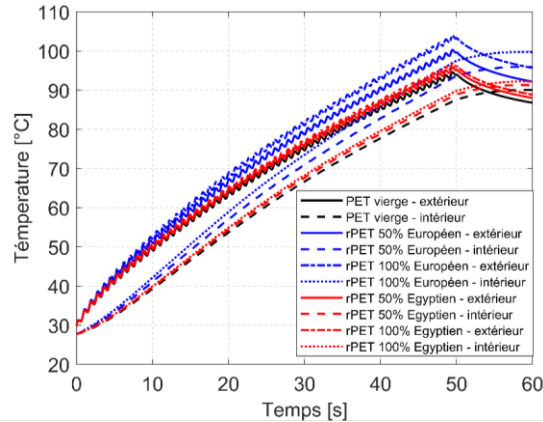


IR camera FLIR A655sc  
 Spectral range:[7.5-14] $\mu$ m  
 Emissivity of PET:0.94  
 Frequency:2 frames/s  
 Precision:  $\pm 2^{\circ}\text{C}$

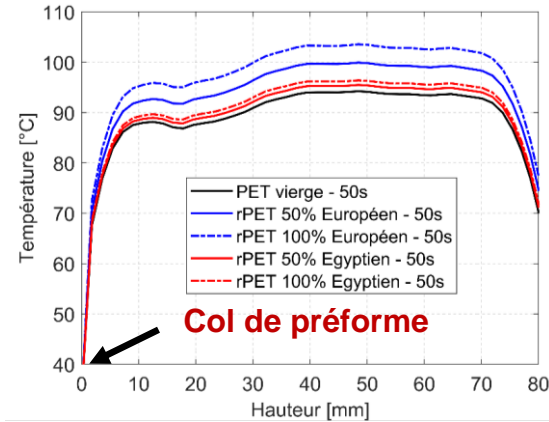
Rotational speed=1,15 rps  
 Translation velocity=0,18 m/s  
**Heating time = 50s**  
**Cooling time = 10s**

Parameter	Symbol	Unit	Lamp 1	Lamp 2	Lamp 3	Lamp 4	Lamp 5	Lamp 6
Electrical power	$P_e$	W	1000	1000	450	300	750	900
Filament temperature	$T_f$	K	2433.4	2433.4	2035.9	1858.6	2281.9	2376.7
Quartz temperature	$T_q$	K	675.9	675.9	584.9	547.3	640.2	662.4
Filament power	$P_f$	W	838.4	838.4	352.0	223.0	615.6	749.1
Quartz power	$P_q$	W	57.6	57.6	35.3	27.8	48.2	54.0



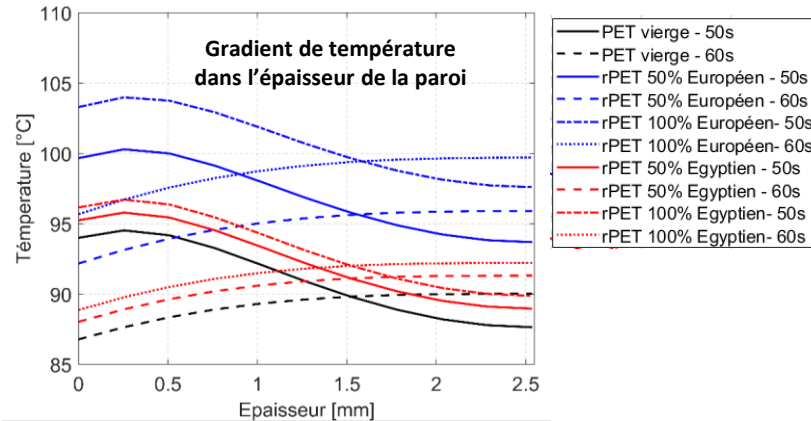


Température temporelle d'un point au mi-hauteur de la préforme



Profil de température longitudinal de la préforme

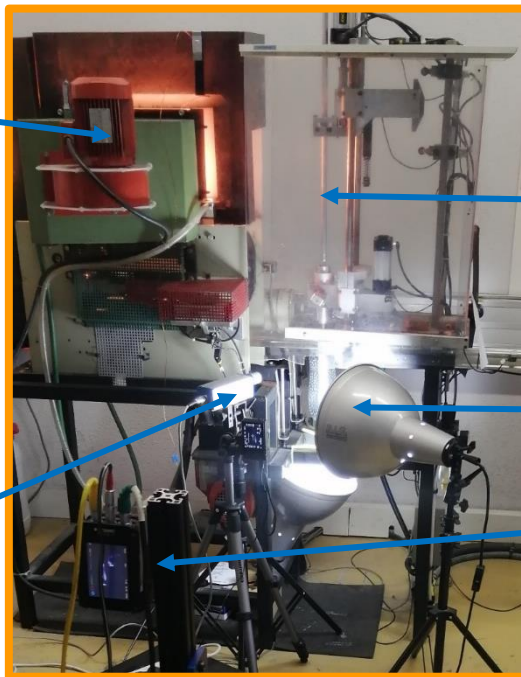
rPET Eu 100% > rPET Eu 50% > rPET Eg 100% > rPET Eg 50% > PET vierge



Four  
rayonnement  
infra-rouge



Pyromètre  
infra-rouge

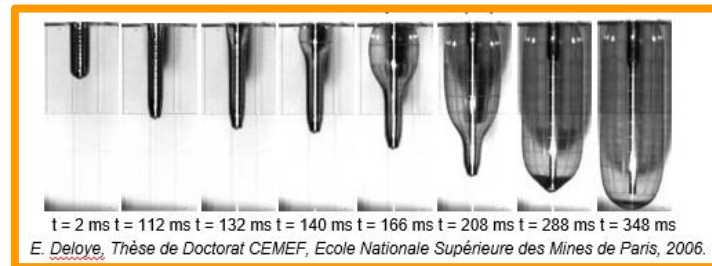


Canne  
d'étirage

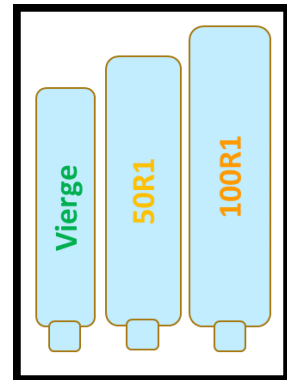
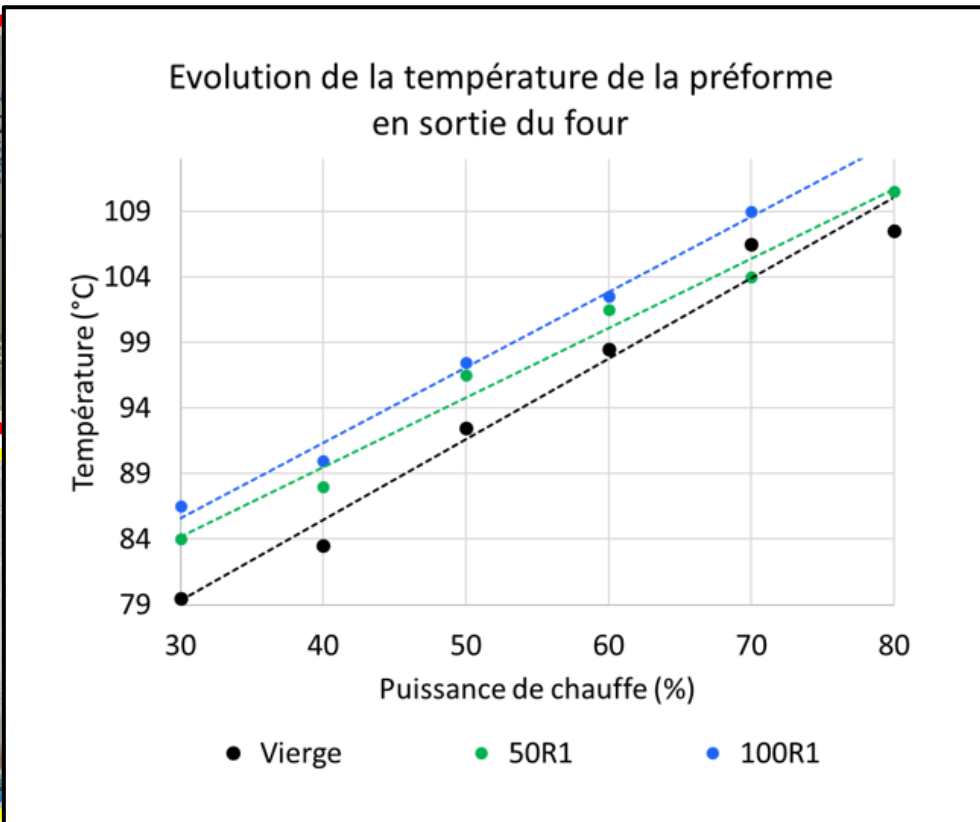
Eclairage

Caméra rapide

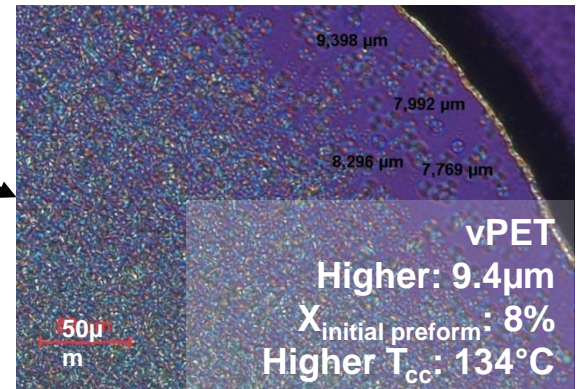
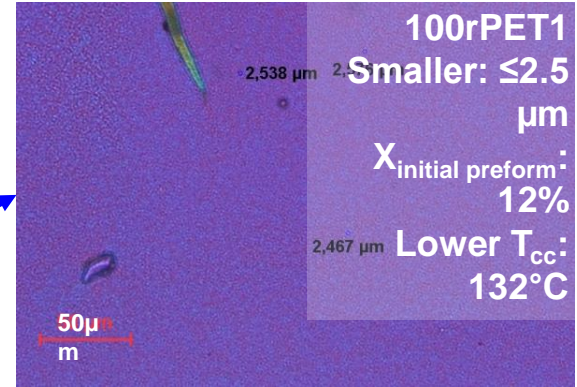
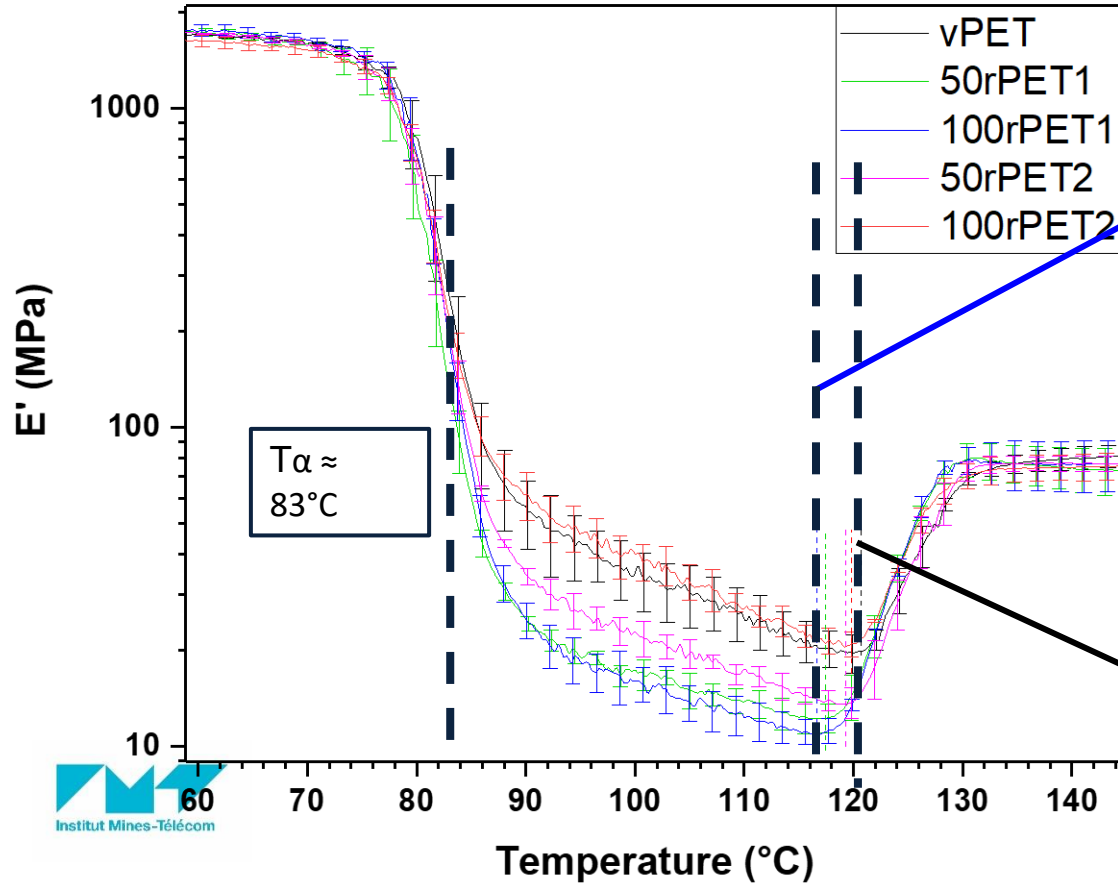
Prototype d'étirage  
soufflage libre



# INFLUENCE DE LA PUISSANCE DE CHAUFFE SUR LA SOUFFLABILITE

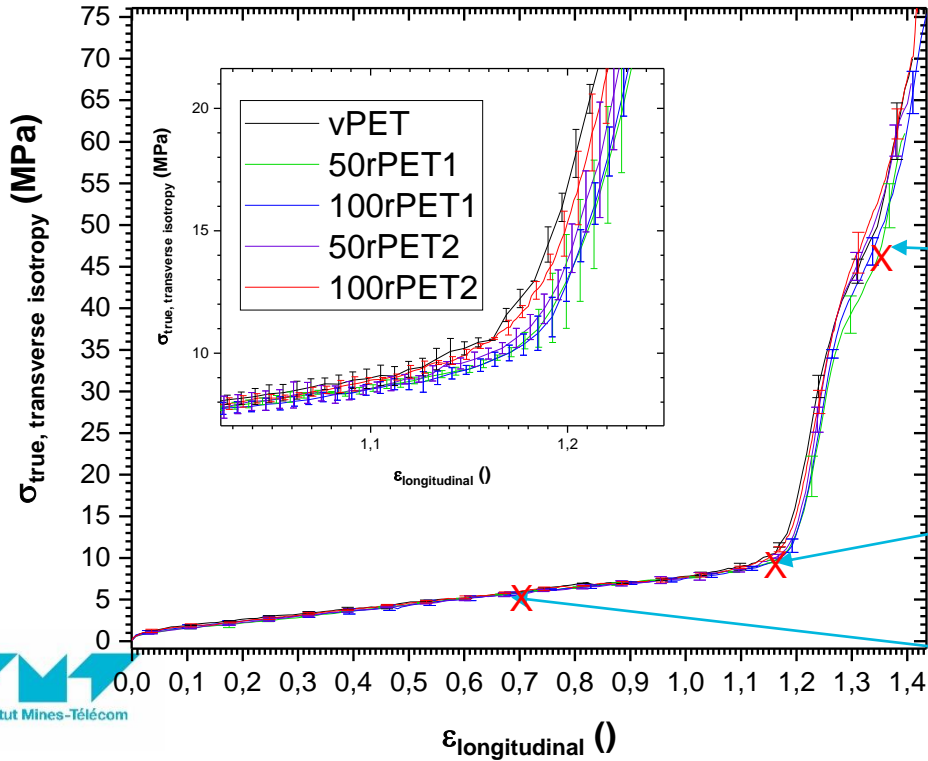




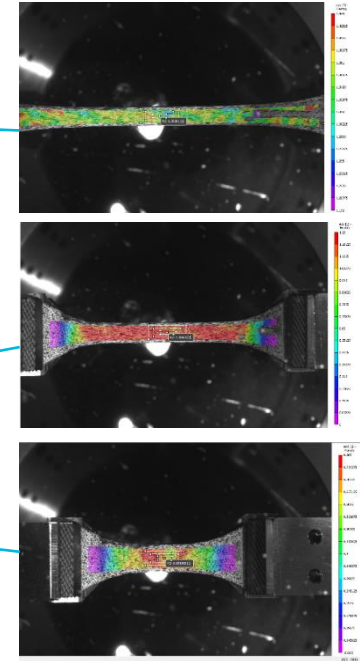




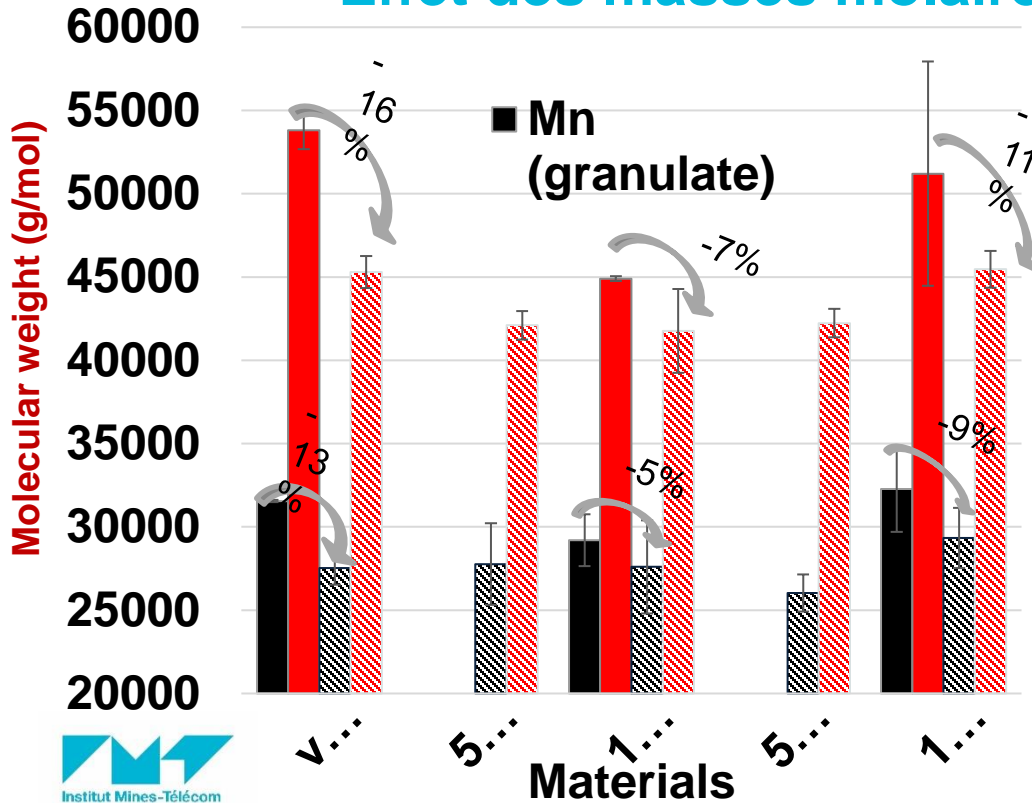
Couple (T°C, vitesse de déformation) : (83°C; 0.03s<sup>-1</sup>)



Mesure locale de champs de déformation



## Effet des masses molaires ?



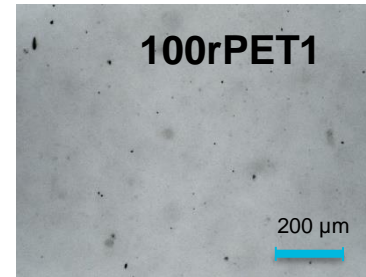
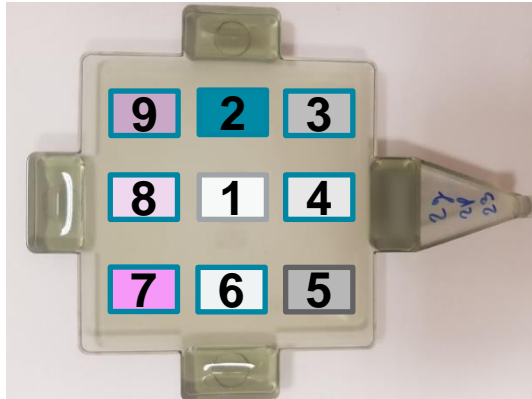
**INSA**  
VALOR

*imp*  
Ingénierie des Matériaux Polymères

Granulates: - 2 measurements for vPET and 100rPET1  
- 8 measurements for 100rPET2  
Plates : 3 measurements for each material

- $M_w(\text{vPET}) = M_w(\text{100rPET2}) > M_w(\text{100rPET1})$
- Plus grande dispersité avec 100rPET2

## Effet des contaminants ?



*Exemple de prise de vue obtenue par microscopie optique*

- Homogénéité des contaminants d'une zone à l'autre
- $\text{cont}(\text{vPET}) < \text{cont}(100\text{rPET}2) < \text{cont}(100\text{rPET}1)$

Material	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Moy
vPET	158±48	163±51	156±59	173±86	168±72	146±56	155±59	143±46	154±74	157±10
100rPET 1	670±133	659±149	735±121	654±108	683±188	680±106	747±92	730±123	713±115	697±35
100rPET 2	530±103	540±96	527±80	572±102	566±52	484±77	584±91	605±65	590±94	555±38

X4.4 (arrow from Z9 to Moy)  
X3.5 (arrow from Moy to Z9)

# MERCI DE VOTRE ATTENTION

## Contact :

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[Christelle.Combeaud@minesparis.psl.eu](mailto:Christelle.Combeaud@minesparis.psl.eu)