

June 29, 2022  
Armelle Chabot  
MAST-LAMES  
Univ Eiffel

# Overview of research on pavement debonding studies

International UNH-UGE collaboration first step



1

**“Linking our two universities and fostering long-term synergistic partnerships”** E. Dave, Nantes (France), Nov17, 2021



2

# Université Gustave Eiffel

**New concept of National University that brings together 5 partners to the University UPEM near Paris**

**Ambition from 1<sup>st</sup> January 2020:**  
to become, in a 10 years period, a major actor in the design and evaluation of engineering and monitoring innovation solutions for future urban area  
**Research, Training, Partnership**

**Mobilization of relevant disciplines:**  
Civil engineering and materials, Architecture, urban planning, transport, environmental sciences, economy, geography, mathematics and digitalization sciences, social sciences, history

3


## KEY FIGURES

- 17 000 students  
(40% on vocational training courses or graduate level apprenticeships),
- 500 doctoral students,
- 1 200 researchers, teaching researchers and teachers,
- 1 300 administrative and technical staff.

## LOCATIONS

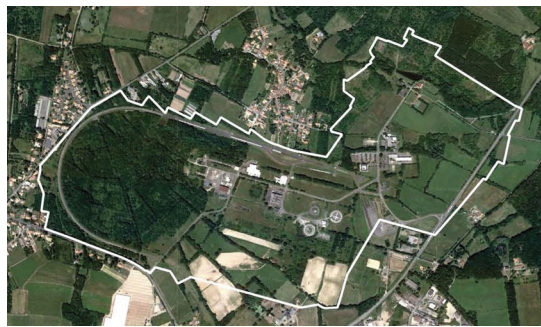
**7 Campus**

4




**Nantes Campus**  
(145 ha)

< 40 PhD students  
280-320 staff in 12 research teams






COLLÈGE DOCTORAL PAYS DE LA LOIRE

SCENES DE L'INGENIERIE ET DES SYSTEMES




FR CNRS 2488 Institut de Recherche en Sciences et Techniques de la Ville





5/35





5

## LAMES research team (from MAST Dpt.)





**APT facilities**  
Track length 120 m  
Maximum speed 100 km/h  
Traffic : 500 000 loads/month





<https://www.youtube.com/watch?v=nGihMk1hFZw>


**The 3 pillars of LAMES:**

- ✓ **A: Survey (non destructive testing)**
- ✓ **Modeling**
- ✓ **E: Testing pavement infraStructures**

**+ MIT (material) research team**



6/35



6

## Outline

- Introduction
- Debonding phenomenon in multi-layered
- Interface Debonding Lab Testing in Pavements
- Future Direction:

Interface Characterization and Multi-material optimization  
in aim to reduce urban heating in pavements

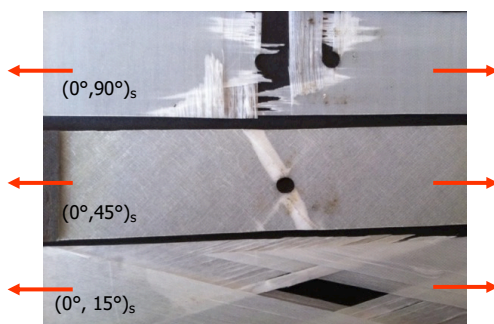
7

## My « knowledge »: Fracture in multi-layered systems

Composites (from 1989)



Pavement (from 1999)



(TP ENPC, Chabot 1997)



8/35

8

## Outplane interface stresses → Edge effect

**Tension exemple**

**Bending exemple**

(Pouteau et al., 2002)

N = 50 | I : 0.24 | L : 0.25 | e1 : 0.05 | e2 : 0.05

9/35

9

## Multi-particle Model of Multi-layer Materials (M4)

Chabot PhD thesis (1997) (Chabot & Ehrlacher, 1998)

- ✓ Polynomial approximation per layer  $i$  in  $z$  for  $\sigma_{ij}$
- ✓ Hellinger-Reissner formulation (Reissner, 1950)

**Objet 3D : Volume**

Layer  $i+1$

$$\tau_{\alpha}^{i,i+1}(x, y) = \sigma_{\alpha 3}(x, y, h_i^+)$$

$$v^{i,i+1}(x, y) = \sigma_{33}(x, y, h_i^+)$$


---

Layer  $i$

$$N_{\alpha\beta}^i(x, y) = \int_{h_i^-}^{h_i^+} \sigma_{\alpha\beta}(x, y, z) dz$$

$$Q_{\alpha}^i(x, y) = \int_{h_i^-}^{h_i^+} \sigma_{\alpha 3}(x, y, z) dz$$

$$M_{\alpha\beta}^i(x, y) = \int_{h_i^-}^{h_i^+} (z - \bar{h}_i) \sigma_{\alpha\beta}(x, y, z) dz$$


---

Layer  $i-1$

$$\tau_{\alpha}^{i-1,i}(x, y) = \sigma_{\alpha 3}(x, y, h_i^-)$$

$$v^{i,i+1}(x, y) = \sigma_{33}(x, y, h_i^+)$$

10/35

Chabot A., Ehrlacher (1998) Modèles Multiparticulaires des Matériaux Multicouches M4\_5n et M4\_(2n+1)M pour l'étude des effets de bord. Comptes-rendus aux 11ème Journées Nationales sur les Composites (JNCl1), Arcachon, 3: 1389-1397. Ed. AMAC

10

## Dedicated pavement analysis

Tran PhD thesis (2004) & Nasser PhD thesis (2016)

Material	Thickness (m)	Young's modulus (MPa)	Poisson's ratio
BBSG	$e^1=0.08$	$E^1=5400$	$\nu^1=0.35$
GB3	$e^2=0.15$	$E^2=9300$	$\nu^2=0.35$
GC3	$e^3=0.23$	$E^3=23000$	$\nu^3=0.25$
Soil	-	$E=120$	$\nu^4=0.35$

$v^{2,3}(x) = \sigma_{zz}(x, h_2^+) = \sigma_{zz}(x, h_3^-)$

Interface 2,3 Normal stress

Chabot, A., Tran Q. D., Ehrlicher A., 2007. A modeling to understand where a vertical crack can propagate in pavements. In Proc. *Advanced Characterization of Pavement and Soil Engineering Materials*, 1: 431-440.  
 Nasser H., Chabot A., 2018. A Half-analytical Elastic Solution for 2D Analysis of Cracked Pavements. *Advances in Engineering Software*, 117: 107-122.

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11

## Bond Criteria ?

Homogeneous elastic material:  $\lambda = 1/2$

$$\bar{\sigma} = \frac{K_I}{\sqrt{r}} f_I(\theta) + \frac{K_{II}}{\sqrt{r}} f_{II}(\theta) + \dots$$

$$\underline{U}(x_1, x_2) = \underline{U}(O) + k r^{\lambda} \underline{u}(\theta) + \dots$$

Figure 10.4 - Modes de sollicitations d'une fissure (dessins de Bill Bocquet).

The critical value  $k_c$  depends on the opening  $\omega$  of the notch, it must be experimentally determined. The factors  $k$  and  $k_c$  are strongly dependent of the singularity and in particular of the exponent  $\lambda$ . Units for

For a bi-material, it is worst,  $\lambda$  is a complex number!

$E_1, \nu_1$

$E_2, \nu_2$

Point stress?

Average stress?

Energy release rate -> fatigue...: Paris law?

$$G(\bar{\sigma}, \bar{u}) = - \frac{\partial E_p(\bar{\sigma}, \bar{u}, a)}{\partial a}$$

$G < G_c$

England AH, 1965. A crack between dissimilar media. *Journal of Applied Mechanics*: 32:400-402.  
 Williams ML, 1959. The stress around a fault or crack in dissimilar media. *Bull Scismol Soc Am*, 49:199-204.

12/35 Université Gustave Eiffel

12

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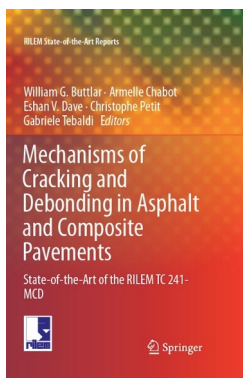
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14

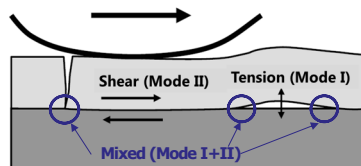


## Chapter III – Interface Debonding Behavior



### 2 MODE I – OPENING MODE

- 2.1 Tensile Bond Test (TBT)
- 2.2 Tensile Notch Bond Test (TNBT)



After Raab & Partl (2004)

### 3 MODE II – IN PLANE SHEAR MODE

- 3.1 Shear Bond Test SBT (without normal stress)
- 3.2 Shear Bond Test SBT (with normal stress)

### 4 MODE III – OUT PLANE SHEAR MODE

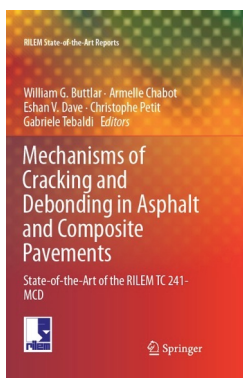
### 5 MIXED MODE (I + II)

- 5.1 Three point bending test
- 5.2 Four point bending test
- 5.3 Composite specimen interface test (CSIC)

15/35

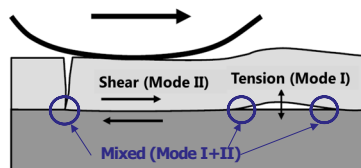


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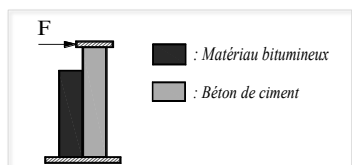
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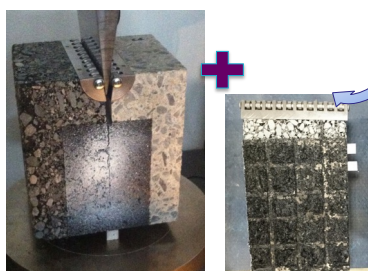
16/35



## Bond Criteria ? Fracture energy?



Pouteau PhD thesis (2004)  
Fatigue tests



Gharbi PhD thesis (2018)  
With or without fiber grids

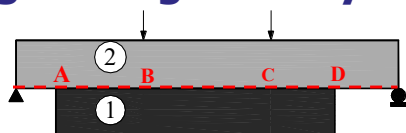


Thèse (Hun, 2012)  
Static test in (or not) a water bath

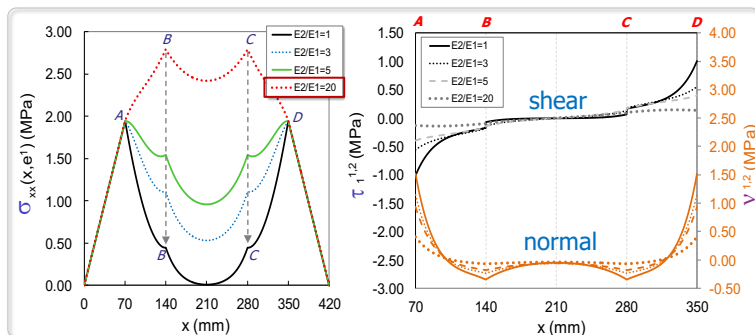
17/35

17

## Bending case: geometry & $E_2/E_1$ Hun PhD thesis (2012)



Tension stress at the Bottom of layer2      Interface 1,2 stresses



Energy release rate using VCCT,  $G_{VCCT}$

$$G_{VCCT}(a) = G_I(a) + G_{II}(a)$$

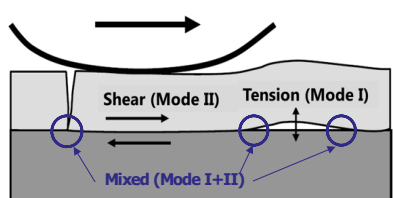
- $G_I$  function of  $(v^{1,2}(x_a))^2$
- $G_{II}$  function of :  $(\tau_1^{1,2}(x_a))^2$  and!  $Q_1^1(x_a) \cdot \tau_1^{1,2}(x_a)$

18/35

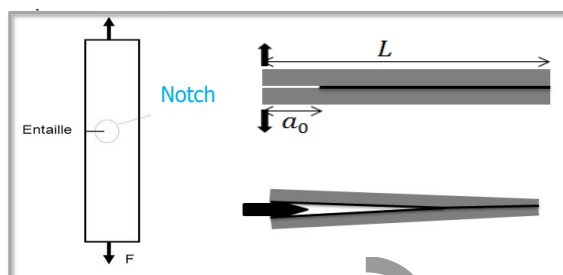
Chabot A., Hun M., Hammoum F., 2013. Mechanical analysis of a bond test between layers of composite pavements *CBM*, 40:1076-1088. doi: 10.1016/j.conbuildmat.2012.11.027

18

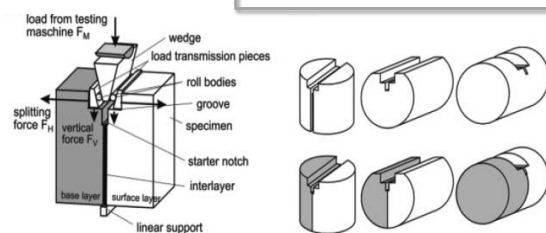
## Tensile Notch Bond Test (mode I)



After Raab & Partl (2004)



Wedge Splitting Test (WST)



Tschegg, E. K., 1986. Equipment and appropriate specimen shapes for tests to measure fracture values, AT No. 390328, Austrian Patent Office, Vienna, Austria.

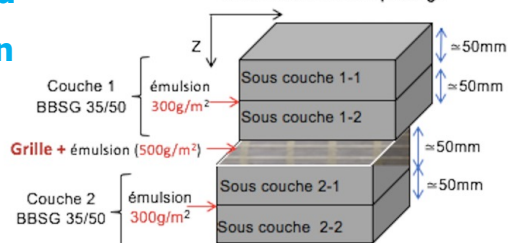
## Mode I interlaminar fracture characterization of pavements

PhD thesis (Gharbi, 2018)

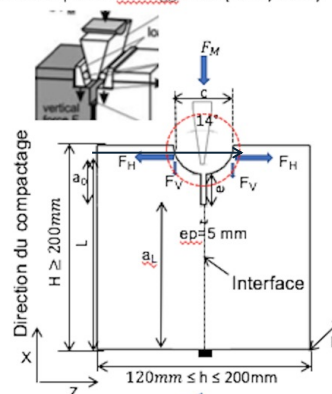
Adaptation of WST for extracted specimen



x Direction du compactage



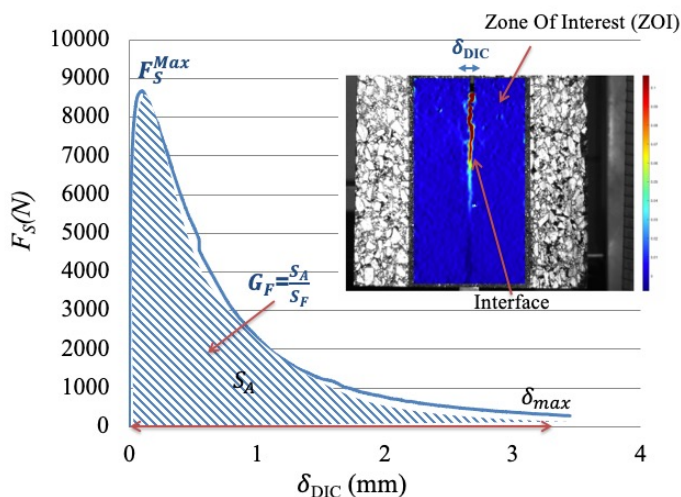
WST Adapté de Tschegg et al. (1995, 2012)



Gharbi M., Nguyen M.L., Trichet S., Chabot A., 2017. Characterisation of the bond between asphalt layers and glass fiber grid with help of a Wedge Splitting Test. *BCRRA2017*, CRC Press (Verlag) - doi: 10.1201/9781315100333-201

## Mode I interlaminar fracture characterization of pavements

PhD thesis (Gharbi, 2018)



21/35

Gharbi M., Chabot A., Geffard J.L., M.L. 2021. Interlaminar Mode-I Fracture Characterization Underwater of Reinforced Bituminous Specimens. *ISBM2020*, RILEM BookSeries, 27: 263-269. [https://doi.org/10.1007/978-3-030-46455-4\\_33](https://doi.org/10.1007/978-3-030-46455-4_33)

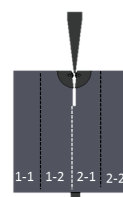
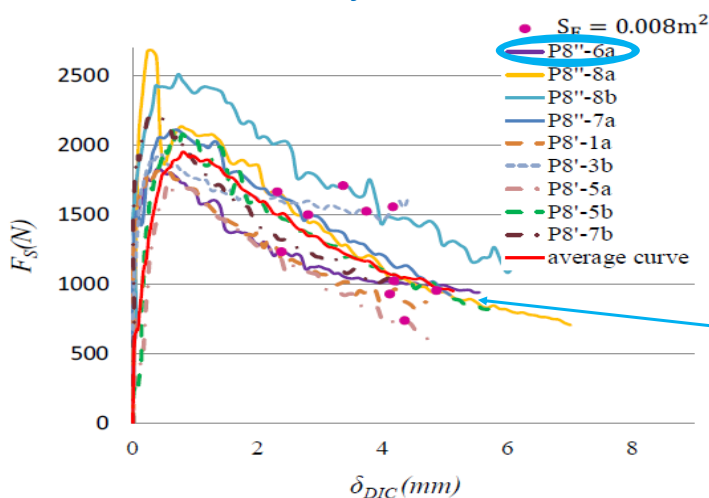
21

## Mode I interlaminar fracture characterization of pavements

PhD thesis (Gharbi, 2018)

### Force opening displacement curve results (asphalt material cases)

But for some cases, secondary delamination occurs

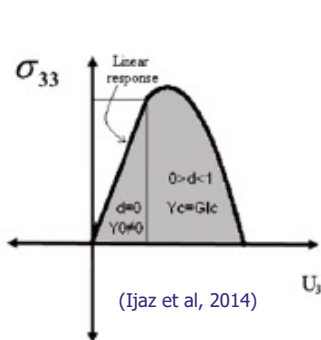


22/35

22

## Use of Viscohinte Model in Cast3M FEM (Gornet, 1999)

Damage modeling tacking into account a delay and different opening modes (I or mixed mode I+II) (Ladevèze et al., 1998)



$$\underline{Y}(t) = \sup_{\tau \leq t} \left[ \left( (Y_{d_n})^\alpha + (\gamma Y_{d_s})^\alpha \right)^{1/\alpha} \right]$$

$$\omega(\underline{Y}) = \left[ \frac{n}{n+1} \frac{Y - Y_0}{Y_c - Y_0} \right]^n$$

**Parameters**

Raideurs d'interface : **kn, ks**

Energétiques : **Y0, Yc**

Retard : **k, m**

Mode I et II Contribution : **γ, α**

Fragilité d'interface : **n**

Damage speed:  $\dot{d} = k(\omega(\underline{Y}) - d)^m$

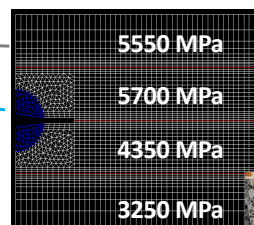
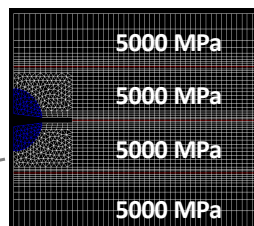
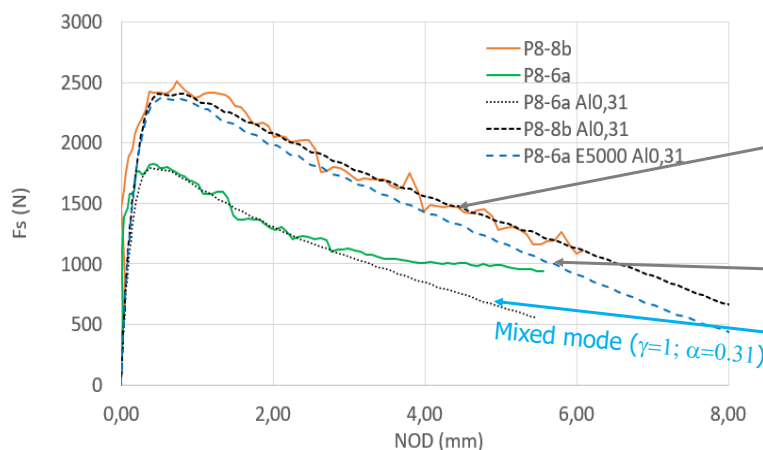
23/35

Ladevèze, P., Allix, O., Gornet, L., Lévêque, D., Perret, L., 1998. A computational damage mechanics approach for laminates: Identification and comparison with experimental results. *Studies in Applied Mechanics* 481-500.



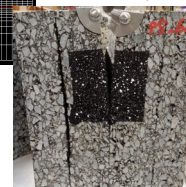
23

## Use of Viscohinte Model in Cast3M FEM (Gornet, 1999)



24/35

Lemartinel N., Chabot A., Dave E.V., Gornet L., 2022. CZM analysis of secondary debondings induced by wedge splitting testing of multi-layer specimens. *25ème Congrès Français de Mécanique*, Nantes, 29 août au 2 septembre 2022



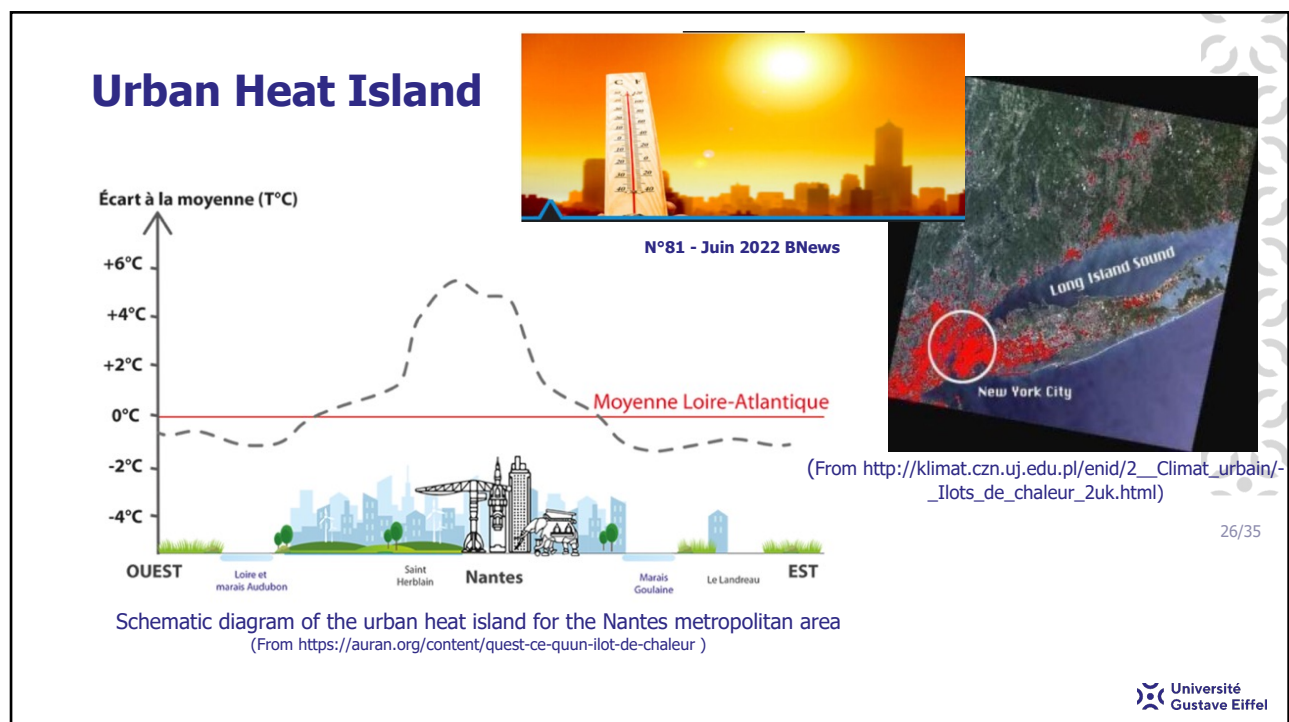
24

## Outline

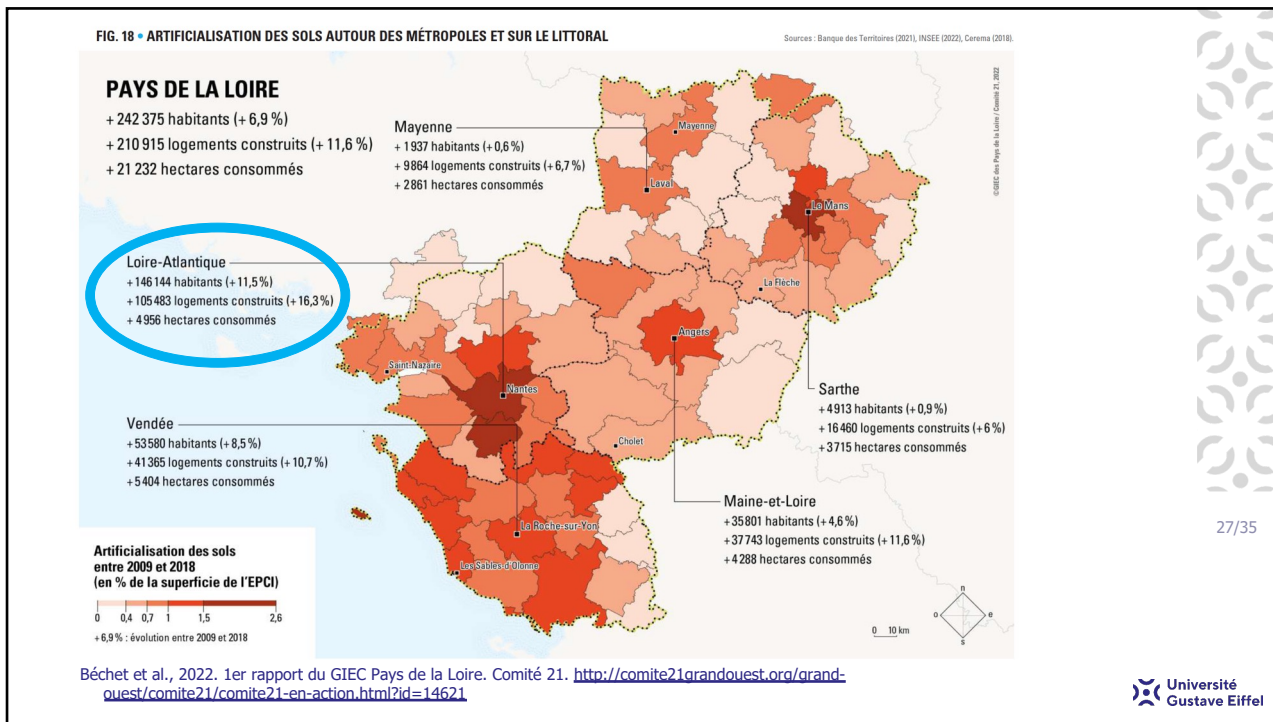
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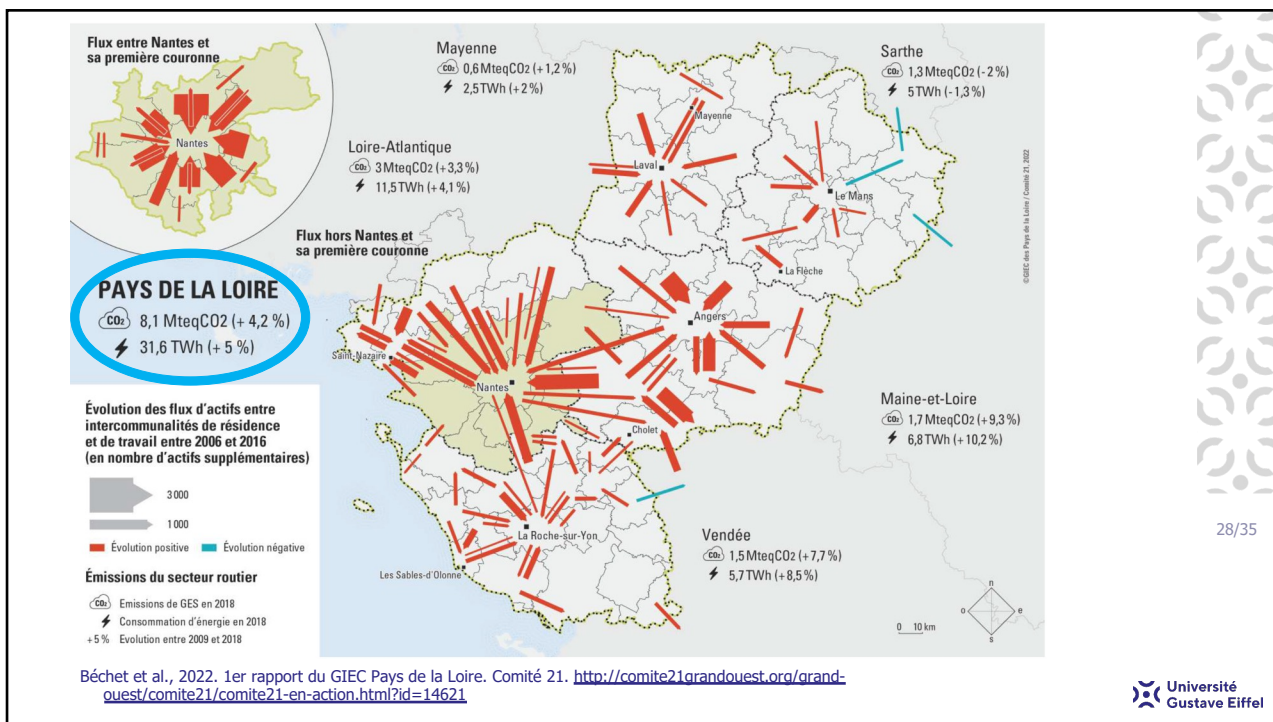
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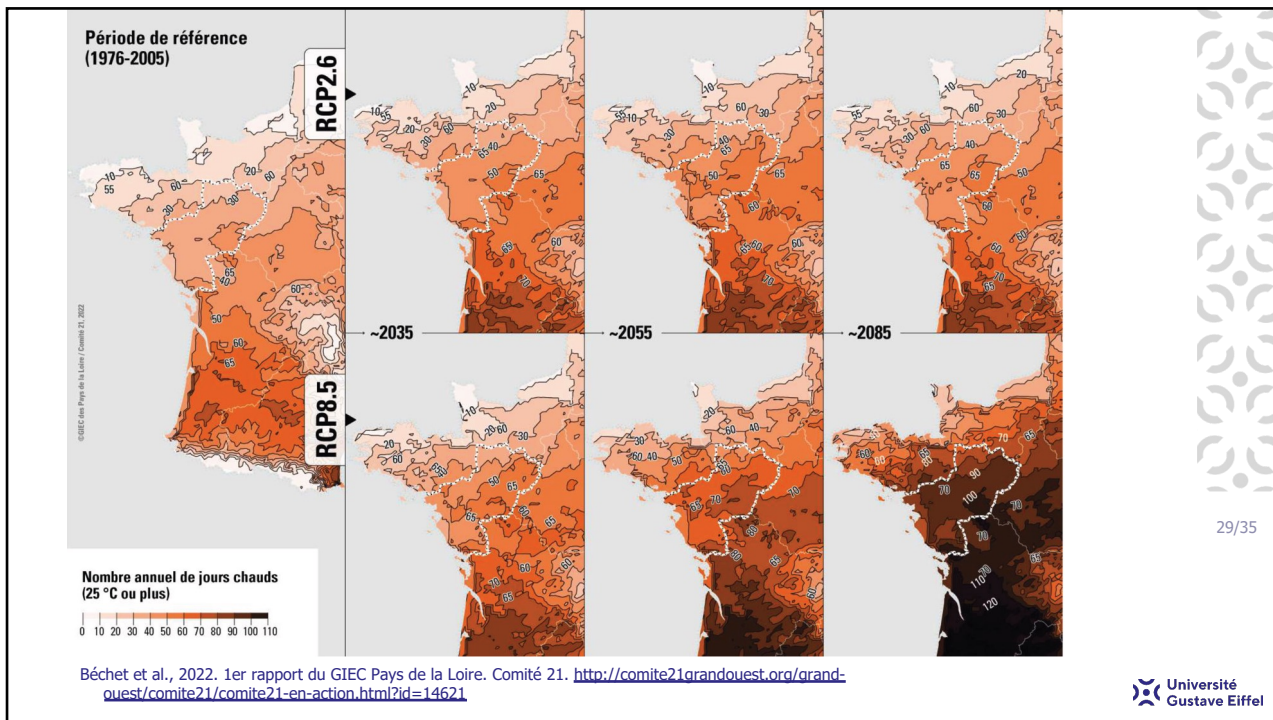
26



27



28



29

## UHI Solutions...

**Divers albédos de l'environnement urbain**

toit très réfléchissant	toit en tôle ondulée	peinture colorée	peinture blanche	bitume et gravier	tuyaux
0.60 - 0.70	0.10 - 0.15	0.15 - 0.35	0.50 - 0.90	0.03 - 0.18	0.10 - 0.35
autres	pelouse	goudrons	ciment	brique/pierre	
0.15 - 0.18	0.25 - 0.30	0.05 - 0.20	0.10 - 0.35	0.20 - 0.40	

**Paris**

**Lyon ... Los Angeles ...**

**Nantes ... Durham!**

30/35

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30

## Bending case with Discontinuities and climate change

31

## ≠T°C → Effect of ≠ E Ratio on Interface stresses

Dedicated M4-5nW analysis – Nasser PhD thesis (2016)

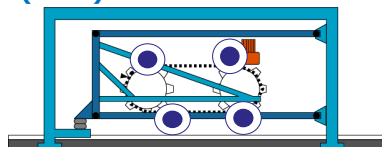
Nasser H., Chabot A., 2018. A Half-analytical Elastic Solution for 2D Analysis of Cracked Pavements. *Advances in Engineering Software*, **117**: 107-122.

32

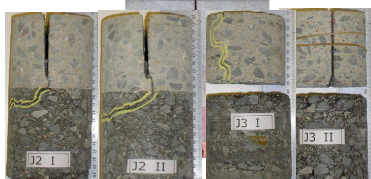


## Bond ALT for urban French roads

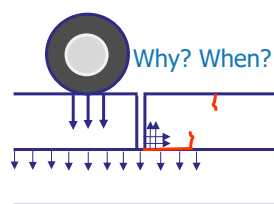
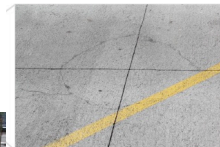
Pouteau PhD thesis (2004)



Rolling path



Cold T°C  
→ 3 materials? Hot T°C:  $E_{cc} \gg E_{ac}$



33/35

Chabot A., Pouteau B., Balay J.-M., De Larrard F., 2008. FABAC Accelerated Loading Test of Bond between Cement Overlay and Asphalt layers. *RILEM CP2008*, June 16-18, Chicago, US.



33

## Interface Characterization and Multi-material optimization in aim to reduce urban heating in pavements

The aim of this work is to propose some optimal solutions in terms of interfacial stress field for such assemblies regarding:

- Bibliographic work consisting of the listing of different materials, solutions and assemblies currently considered for UHI
- Numerical modelling (Cast3M, Abaqus, Scilab)
- 2D parametric studies of interfaces between multiple UHI road materials
- Lab testing taking into account thermal effect as well as the presence of water that further deteriorates interface integrity
- Life cycle assessment studies

Collaborative works between UNH & UGE for now

- 2 Master1 students:

Nathan Lemartinel (2021) from ECN (part of Nantes Univ) & Delin Soh (2022) from Nantes Univ

- 1 PhD UGE-UN co-tutelle student : Sadek Tormos (2022-2025/6)

- Collaborative discussions with IRSTV & UGE colleagues from Nantes (2021/22)

34/35



34

**Thank you for your attention!**



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Université  
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35

**SMARTPAVE**

<p><b>Resiliency to Climate Change</b></p> <ul style="list-style-type: none"> <li>• Adaptation Framework</li> <li>• Pavement Performance Modelling</li> <li>• Climate Projection and Downscaling</li> </ul>	<p><b>Life Cycle Assessment (LCA)</b></p> <ul style="list-style-type: none"> <li>• Climate-change Impacts in LCA</li> <li>• Pavement-Vehicle Interactions</li> <li>• Realistic Traffic Condition Considerations</li> </ul>
<p><b>SMARTPAVE: Safe and Resilient Urban Roadways</b></p>	
<p><b>Smart Sensing for Structural and Operational Condition Assessment</b></p> <ul style="list-style-type: none"> <li>• UAS Sensing Platforms</li> <li>• In-Situ and Vehicular Sensing Platforms</li> </ul>	<p><b>Educational Offering and Technology Transfer</b></p> <ul style="list-style-type: none"> <li>• Workshops, Seminars</li> <li>• Course Offerings</li> <li>• Ph.D. Cotutelle</li> </ul>

International Collaboration from I-site Future (Dave et al., 2020-23)



36