L'exploitation
et la maintenance
des infrastructures

PN - ANR MOVE
DVDC
DURÉE DE VIE DES CHAUSSÉES

IREX
Institut pour la recherche appliquée
et l'expérimentation en génie civil

Study of the damage in bituminous mixtures induced by freeze-thaw cycles

TRAN Duc Thang, SAUZEAT Cédric , DI BENEDETTO Hervé
Uni. Lyon / ENTPE / LTDS

POUTEAU Bertrand
Eurovia

UNIVERSITÉ DE LYON
ENTPE
L'école de l'aménagement durable des territoires
LTDS

EUROVIA
VINCI

MINISTÈRE
DE LA TRANSITION
ÉCOLOGIQUE
Liberté
Égalité
Fraternité

Restitution publique des résultats
7 novembre 2023, ENTPE, Vaulx-en-Velin

AGENCE NATIONALE DE LA RECHERCHE
ANR

Presentation Outline

Introduction – Context

Material and Specimens

Conditioning

Thermomechanical tests

Results

Conclusion



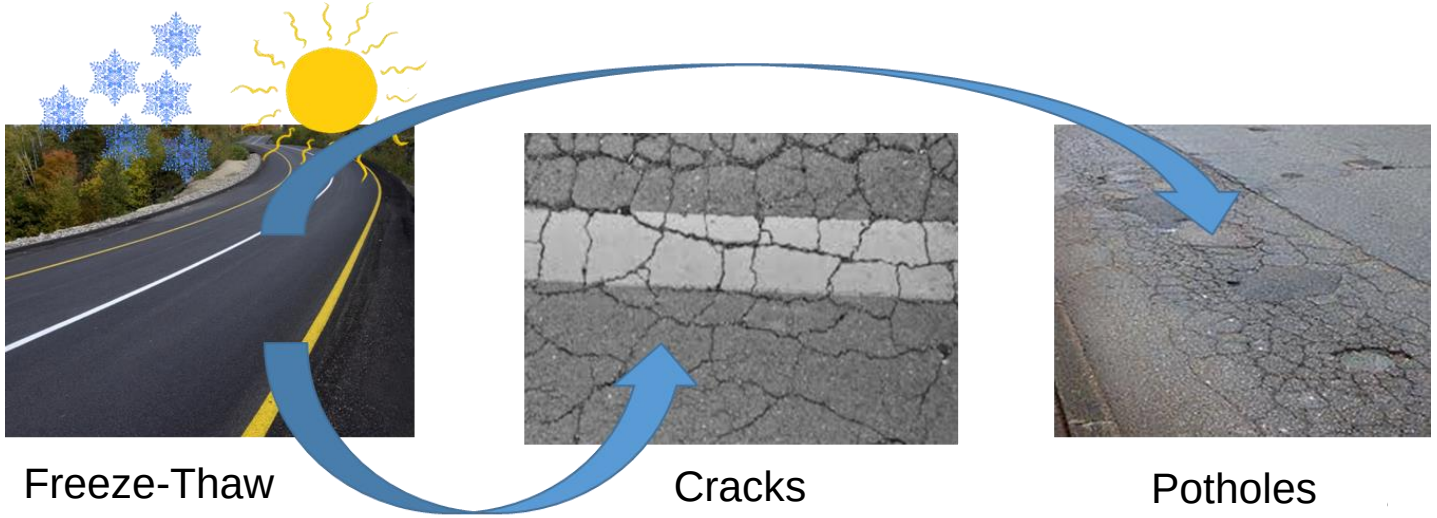
Context

1. Pavement damage mechanisms

1.5 Winter damage

Duc Thang TRAN PhD thesis

« Investigating the effect of freeze-thaw cycles on the behaviour of bituminous mixes »

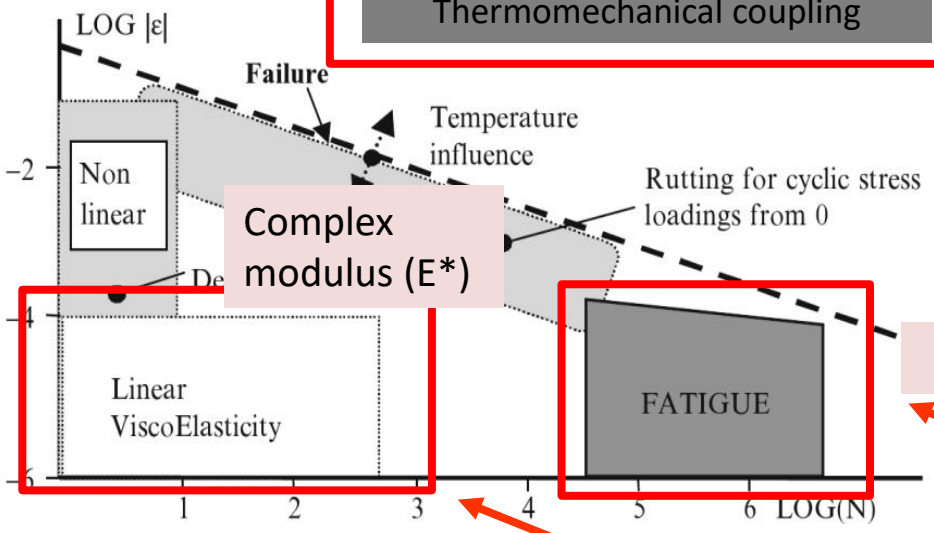




PhD objectives

Thermomechanical coupling

Thermal Stress Restrained Specimen Test (TSRST)



Complex modulus (E*)

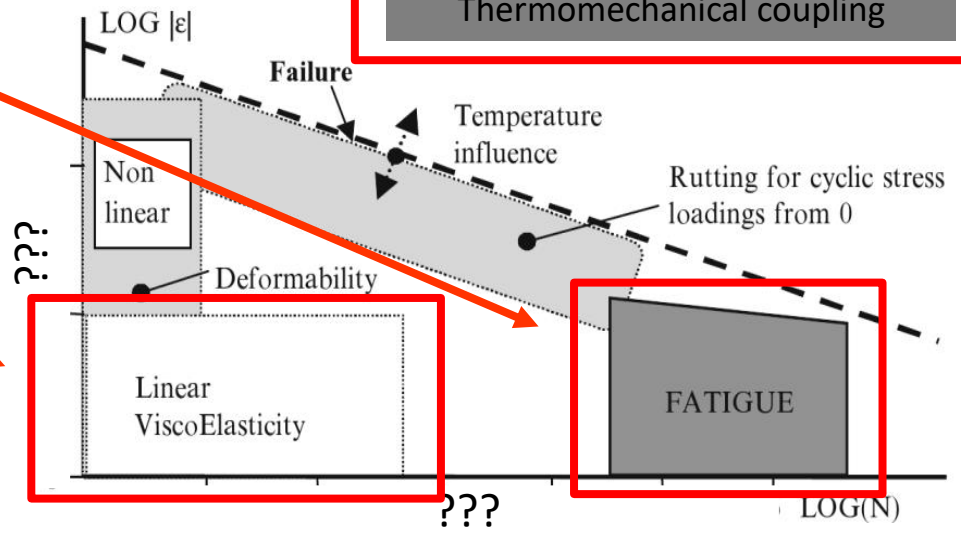
Fatigue test

Effects of
- Water
- Freeze-Thaw cycles
- Ageing

?

Damage

Thermomechanical coupling





Material : BBSG 0/10mm (class 2), bitumen 50/70, aimed %void 8%

Step 1 : Samples preparation

Material
- Unaged
- Aged

« RILEM » method
4h @ 135°C
+ 9 days @ 85°C

→ Slabs compacted with a rolling wheel compactor

→ Specimens cored in the slabs

→ Specimens stored

After 2 weeks, measurement of mass m_0 & volume V_0 → %void TEV_0

→

Step 2 : Conditioning

→ Specimens selected according to TEV_0

→ Specimens conditionning

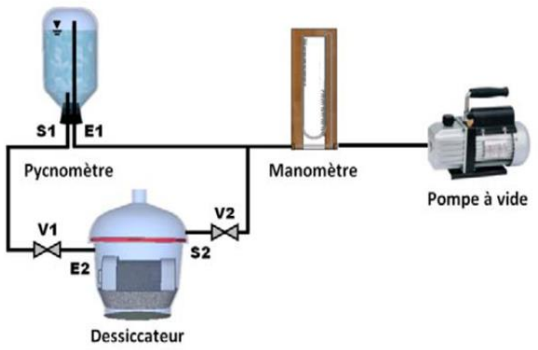
During conditioning, mesureament of mass & volume

Step 3 : Thermomecanical tests

→ Complex modulus, Thermal Stress Restrained Specimen Test (TSRST), Fatigue



Vacuum saturation

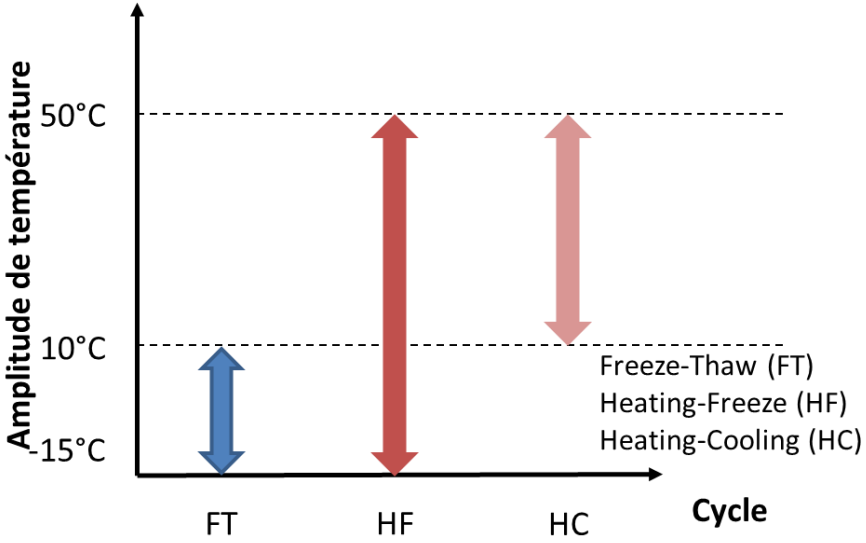


Specimen in a plastic bag with 10cl water

Freeze-Thaw cycles (12h)

Cycles number : 10 ou 50

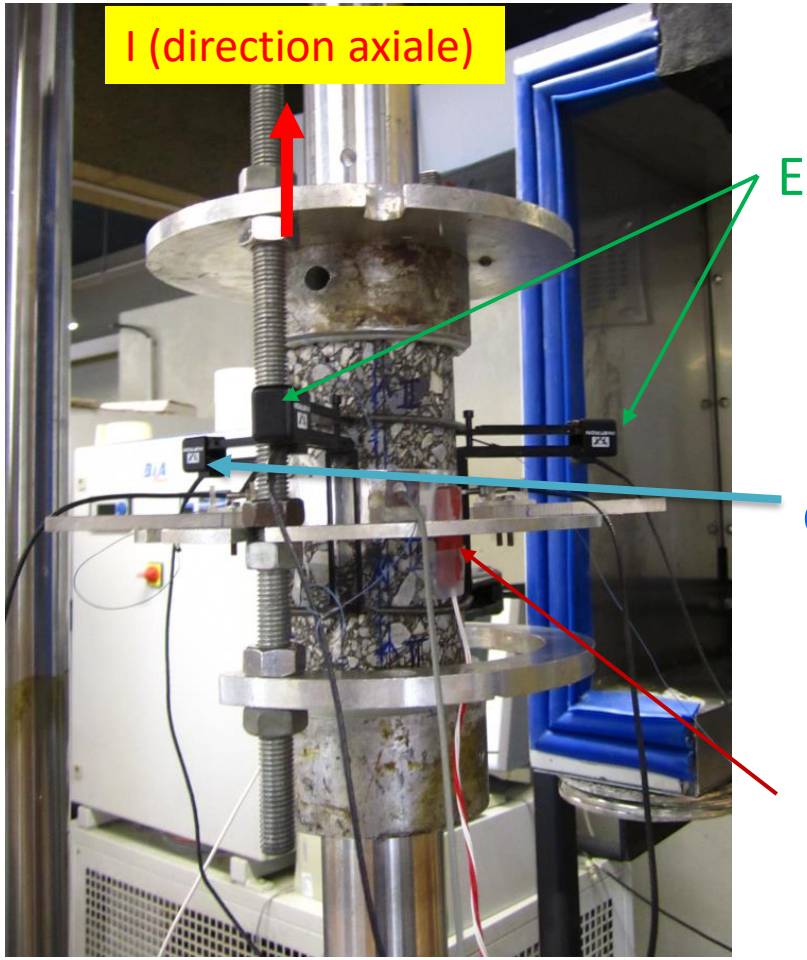
Amplitude : cycles **FT** from -15°C to 10°C
cycles **HF** from -15°C to 50°C
cycles **HC** from 10°C to 50°C

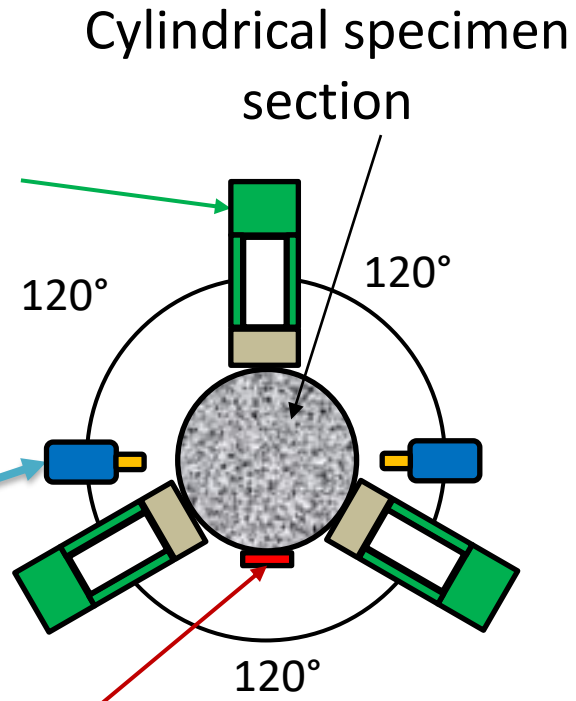


Drying, vacuum drying or no drying



Complex modulus test: testing devices





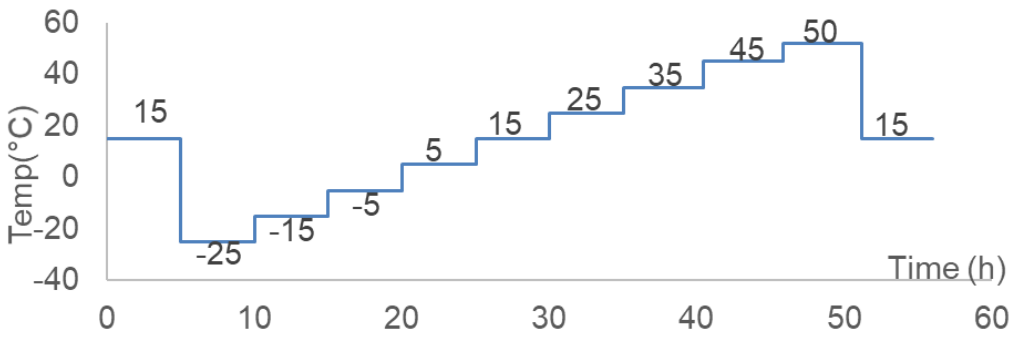
Specimens size:
D ~ 75mm; H ~140mm

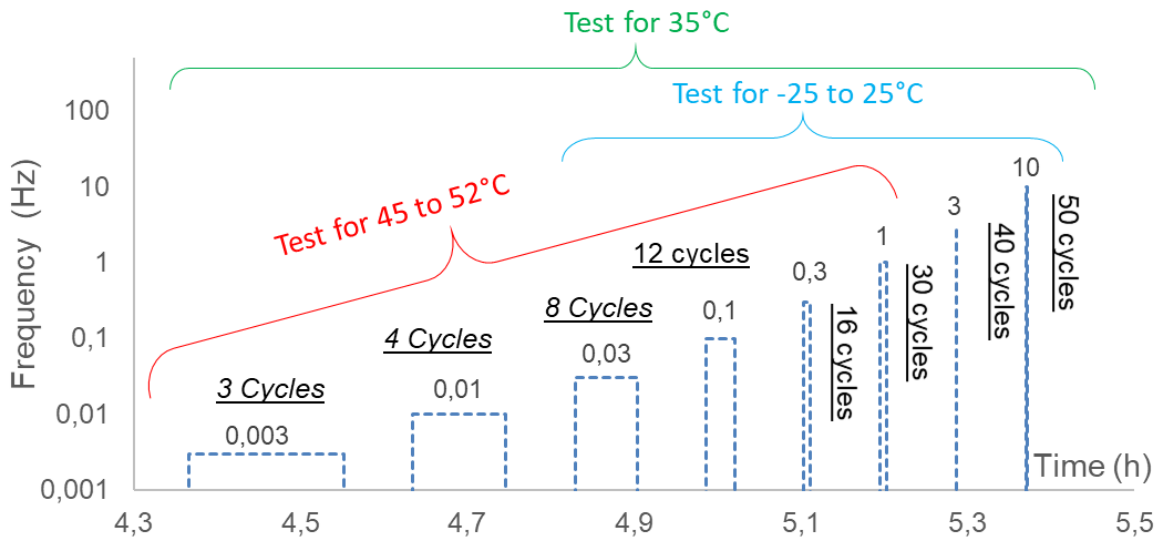


Complex modulus test: sollicitations

Strain controlled cycles:
amplitude $\varepsilon_0 \sim 50.10^{-6}$

Temperature sweep →



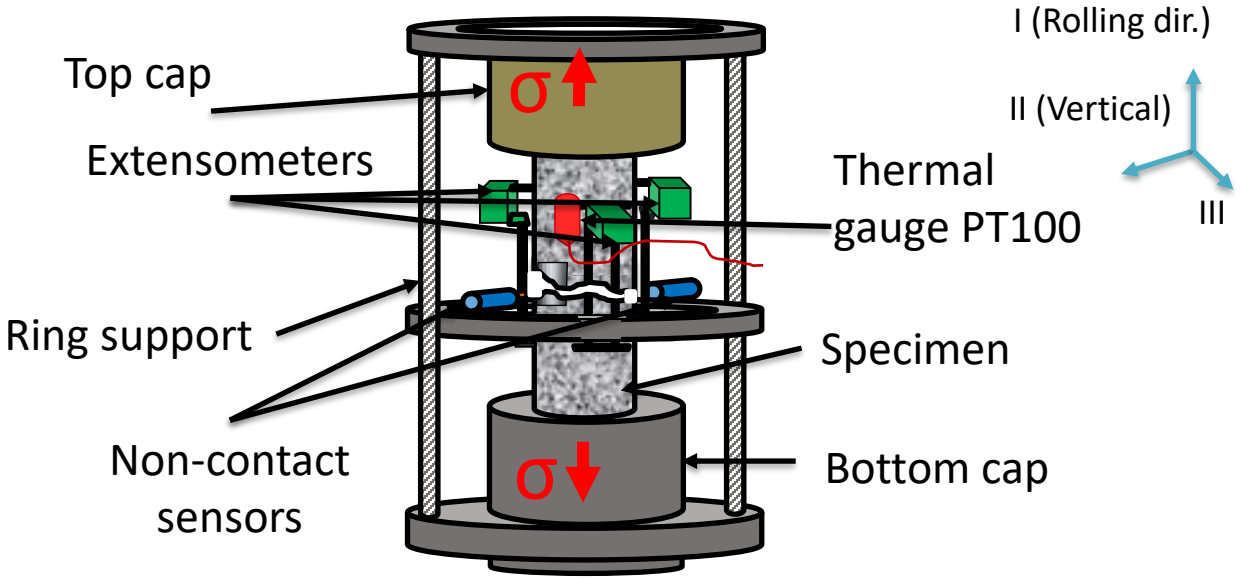


← Frequency sweep (depending on T°C)



Thermal Stress Restrained Specimen Test(TSRST)

- Same device as E* tests
- Conditions:
  - *Specimen* : D ~ 60mm; H ~ 225mm
  - *Starting temperature*: 20°C
  - *Cooling rate*: -10°C/h





2 experimental campaigns

Campaign with Freeze-Thaw cycles

Effect of stauration and freeze-thaw cycles on thermomechanical properties

→ *Specimens evolution (air voids content, saturation, volumetric strain) during the different conditioning phases : saturation/drying and freeze-thaw cycles*

Campaign with Freeze-Cool-Hot cycles (FT – HC)

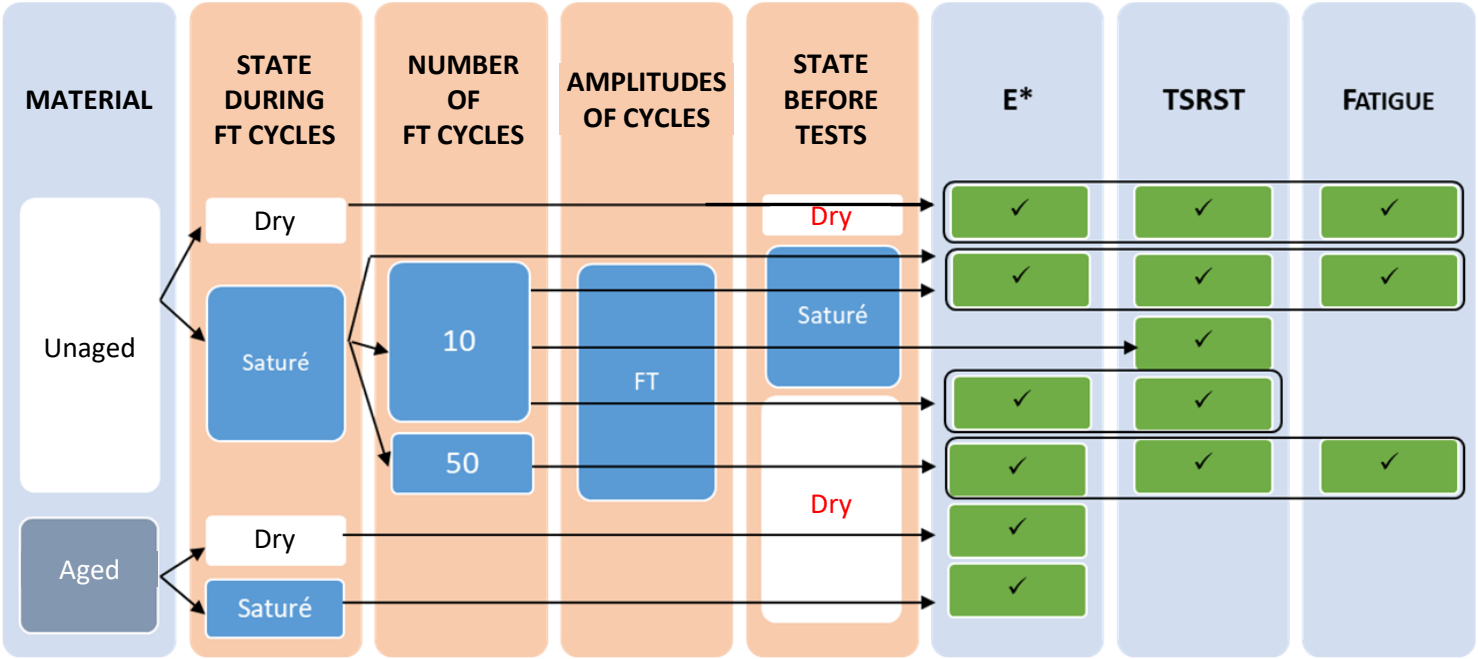
Effects of damage at high temperature compared with effects of damage during freeze-thaw cycles

→ *From procedures of « water sensibility » tests (AASHTO T283, NF EN 12697-12)*

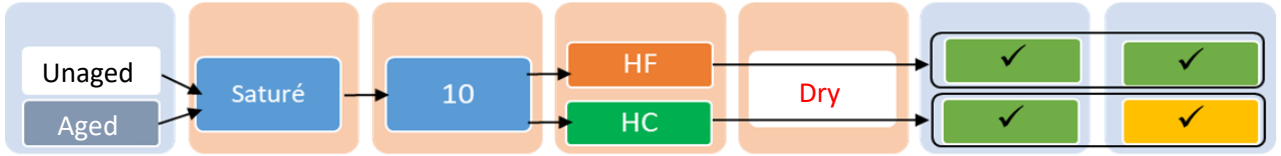


2 experimental campaigns

Campaign with Freeze-Thaw cycles



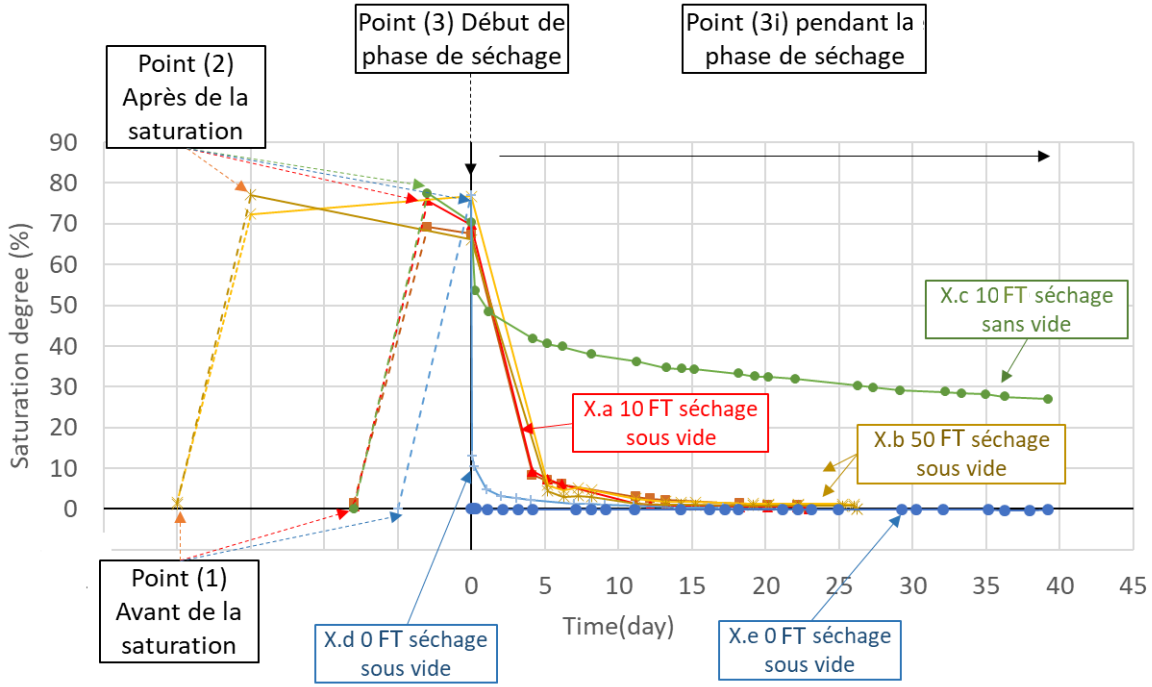
Campaign with Freeze-Cool-Hot cycles



Freeze – Thaw (FT): -15°C↔10°C
Heating - Freeze (HF): -15°C↔ 50°C
Heating - Cooling (HC): 10°C↔50°C



Specimen evolution during conditioning phases: saturation



- Saturation degree under vacuum : approx.70%
- Specimen completely dry after 6 months storage (in office ambient)
- Drying: under vacuum → After 7 days, DS < 5%
  → desaturation faster without freeze-thaw cycles (0FT)
  without vacuum → desaturation slower than under vacuum



Specimen evolution during conditioning phases

Conclusions:

- Degree of saturation reached: approx. 70%
- Drying under vacuum efficient: DS < 5% after 1 week
- Observed specimens evolution due to applied conditioning:

  Volume increase, %voids increase

  → greatly explained by the effect of freeze-thaw cycles
  → partly explained by the effect of vacuum during drying

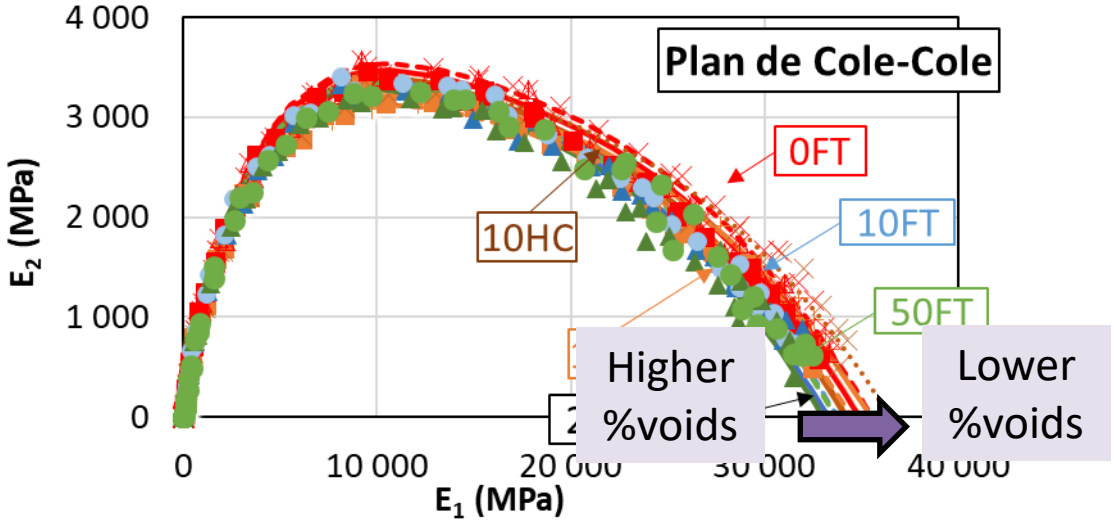
  ⇒ Important to correct the value of %voids, TEV_0 , measured just after coring (approx. 2% increase)

- Assumption of dry specimens after storage: true

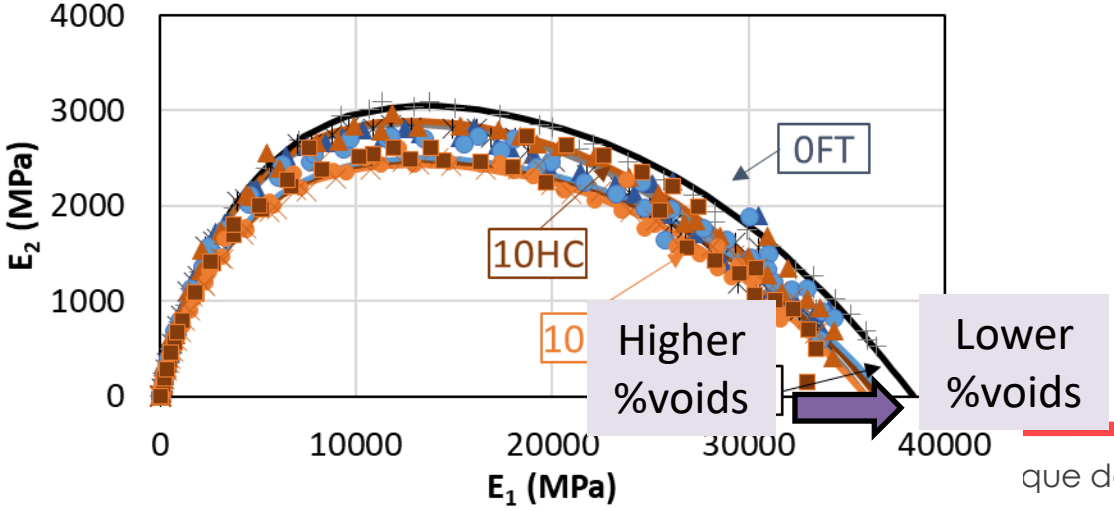


Complex modulus E*

Unaged

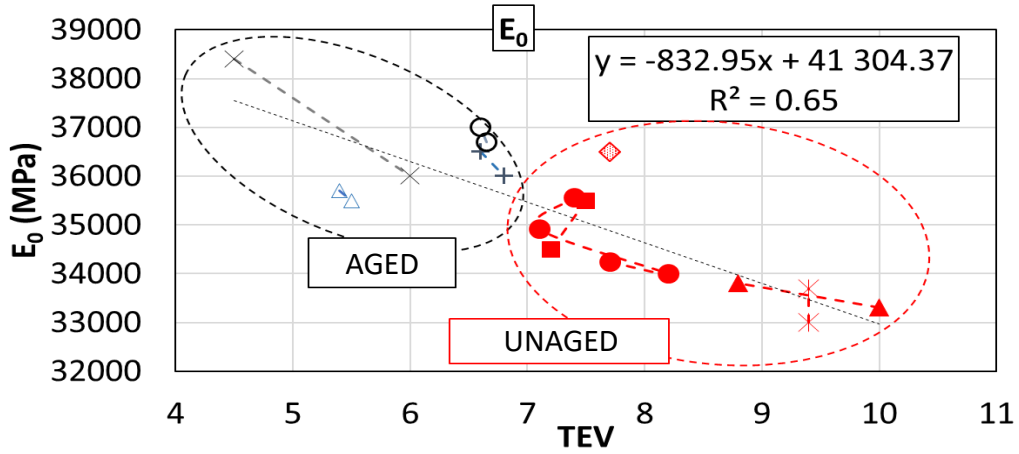


Aged



- Not significant effect of cycles Freeze-Thaw (FT) cycles on unaged material
- Not significant effect of Hot-Freeze (HC) or Hot-Cold (HC)cycles on aged material
- 2S2P1D model describes correctly experimental data
- E_0 decreases as %voids increases

Complex modulus E*

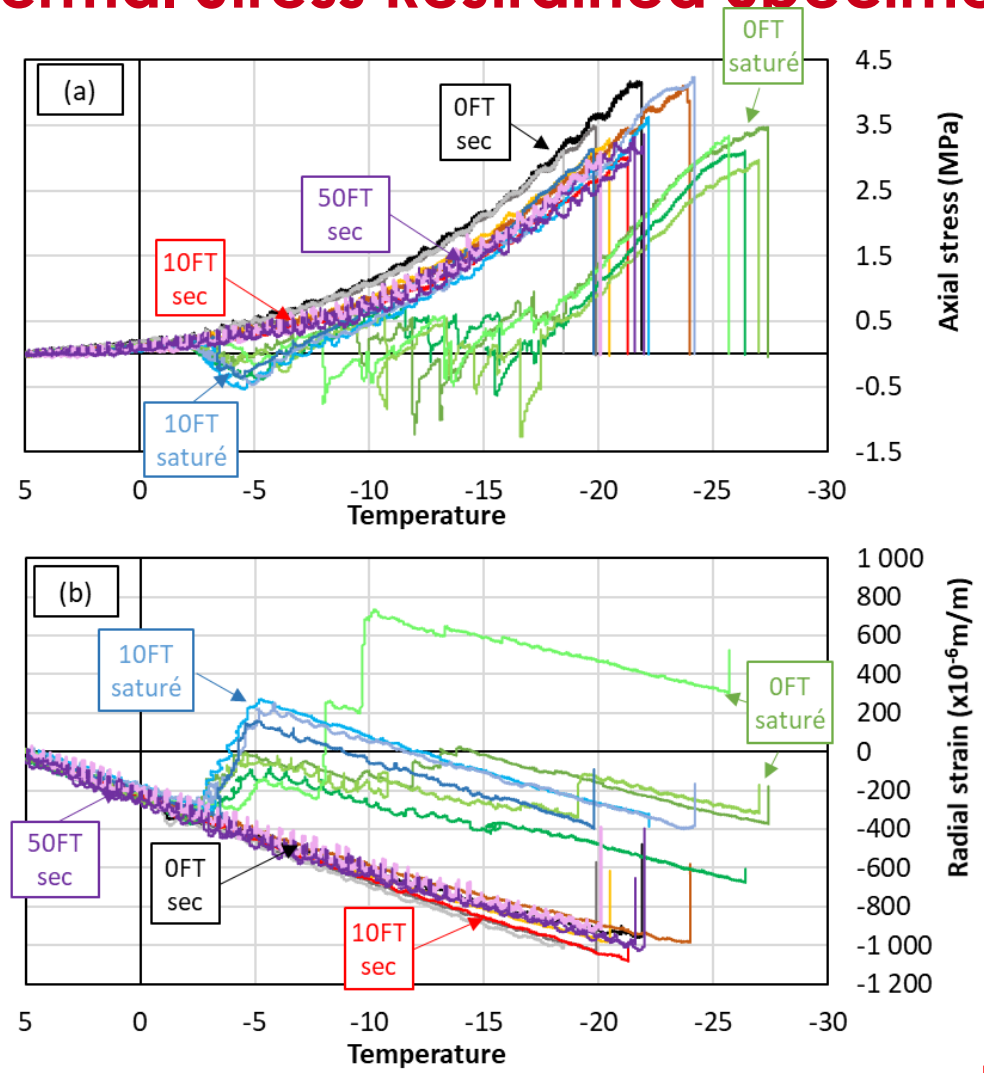


- E_0 decreases approx. 800MPa as %voids increases of 1%

- Not significant effect of cycles Freeze-Thaw (FT) cycles on unaged material
- Not significant effect of Hot-Freeze (HC) or Hot-Cold (HC)cycles on aged material
- 2S2P1D model describes correctly experimental data
- E_0 decreases as %voids increases



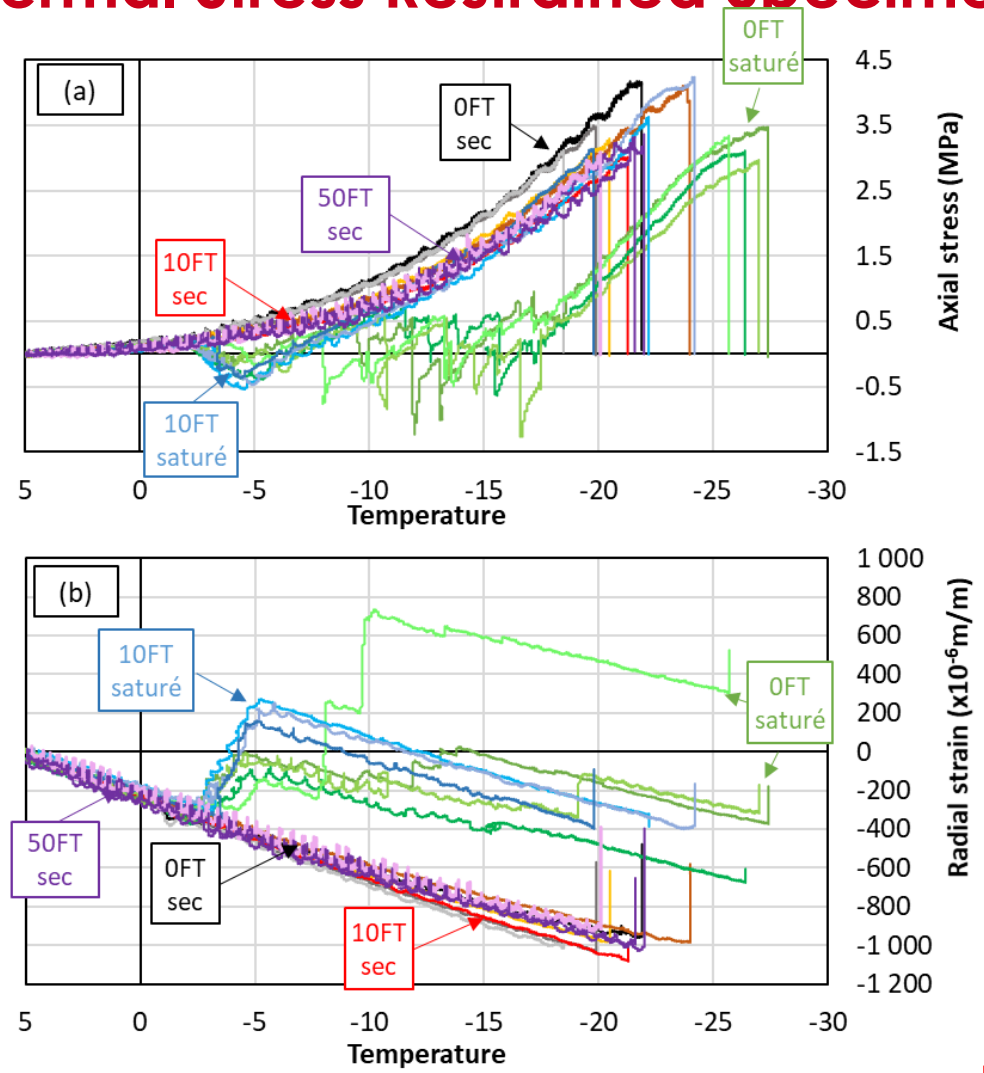
Thermal Stress Restrained Specimen Test (TSRST)



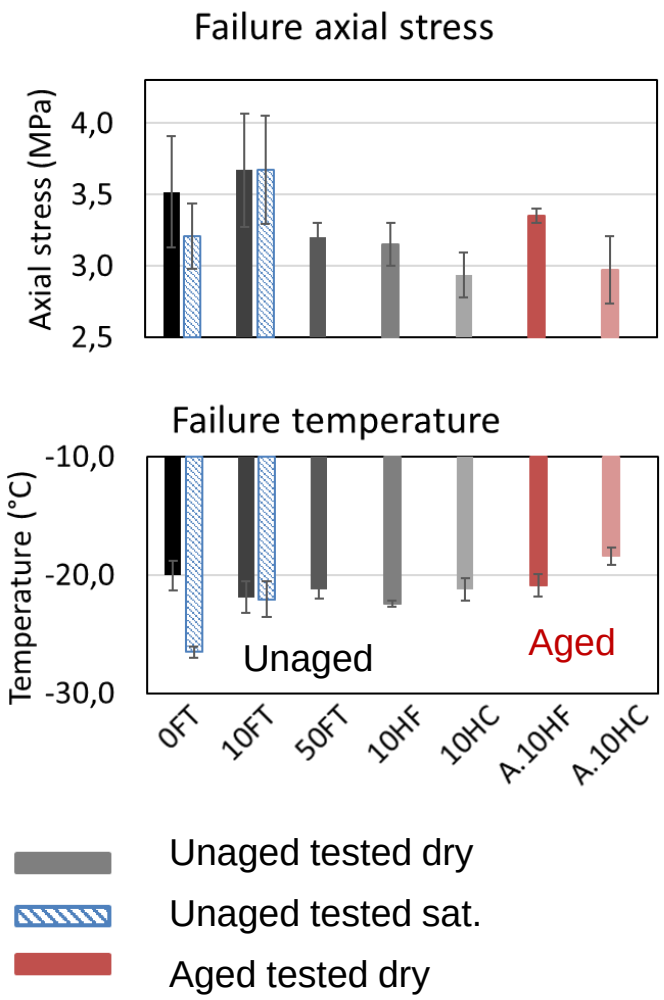
- Similar curve for specimen tested in dry state after freeze-thaw (FT) cycles
- For speciment tested in wet conditions (saturated), remarkable freezing effect, distinct
  - For specimens already subjected to cycles
  - For specimen never subjected to cycles (delay in tensile stress)



Thermal Stress Restrained Specimen Test (TSRST)



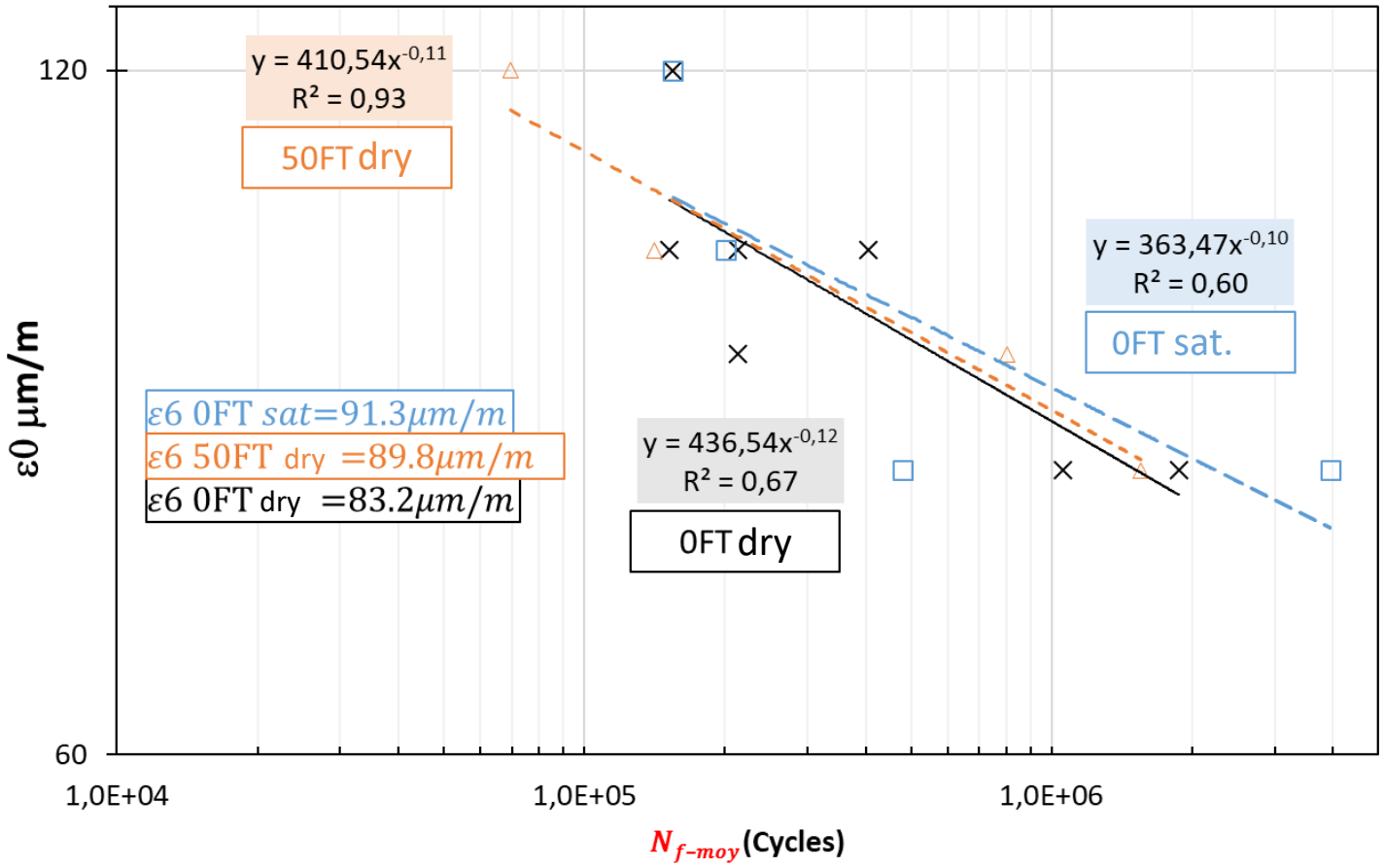
➢ Performances





Fatigue

Wöhler curve



➢ Negligible effects of saturation and 50 Freeze-Thaw cycles



▶ Complex modulus E*

- Saturated mixture without freeze-thaw cycles:
  - Only effect on $|E^*|$ and shift factor a_{TE} for T < 0°C → effect from fozen water
  - No effect on phase angle φ_{E^*} et $a_{T\varphi}$ → no effect on « viscous » properties from binder
- Dry mixture:
  - No significant effect of freeze-thaw cycles (up to N < 50)
  - Significant effects of Hot-Freeze and Hot-Cool cycles → high T effect (ageing)

▶ Thermal Stress Restrained Specimen Test

- Saturated mixture: effect on evolution of σ-T, on $T_{rupture}$ and on $\sigma_{rupture}$
- Dry mixture: no significant effect of freeze-thaw cycles, neither hot cycles

▶ Fatigue test

- Dry mixture:
  - No significant effect of freeze-thaw cycles (up to N < 50)
  - No significant effect of saturation



REFERENCES

- DVDC reports:
  - TRAN, D. T., DI BENEDETTO, H. & SAUZÉAT, C., 2018. Étude bibliographique sur l'endommagement des enrobés bitumineux à l'eau et au gel. DVDC Rapport LC/17/DVDC/09.
  - TRAN D.T., SAUZÉAT C., DI BENEDETTO H., « Endommagement des enrobés bitumineux à l'eau et au gel : Présentation de la campagne expérimentale et premiers résultats », DVDC rapport LC/18/DVDC/45, 2019
  - TRAN D.T., SAUZÉAT C., DI BENEDETTO H., « Endommagement des enrobés bitumineux à l'eau et au gel : Présentation de la campagne expérimentale et premiers résultats », DVDC rapport LC/19/DVDC/80, 2019
- PhD thesis:
  - TRAN D. T. 2020. Endommagement des enrobés bitumineux soumis à des cycles de gel/dégel. Thèse ENTPE. theses.hal.science/tel-03250064
- Articles
  - TRAN, D. T., DI BENEDETTO, H. & SAUZÉAT, C., 2019. Endommagement des enrobés bitumineux à l'eau et au gel: Étude bibliographique. Revue générale des routes et de l'aménagement - RGRA , Issue 963.
  - TRAN, D. T., DI BENEDETTO, H., SAUZÉAT, C., POUTEAU, B. 2020. Effects of water saturation and freeze-thaw cycles on fatigue behavior of bituminous mixtures. Int. conf. ISBM, Lyon , 2020. doi.org/10.1007/978-3-030-46455-4_85