Effect of temperature on fatigue-based rational pavement design

S. Manjarrés[1], S. Mangiafico[1], C. Sauzéat[1], J. Van Rompu[2], V. Le Menec[3]

[1]ENTPE, Ecole Centrale de Lyon, CNRS, LTDS, UMR5513, 69518 Vaulx-en-Velin, France
[2]Eiffage Route, 69964 Corbas, France
[3]Eiffage Route, 02220 Ciry-Salsogne, France

Laboratoire de **Tribologie** et **Dynamique** des **Systèmes**

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Contact

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Introduction & Objectives

The French pavement design method conventionally uses a reference temperature of **15°C.** However, temperature influences the **fatigue behavior** of bituminous materials and the calculation of strain/stress field inside the pavement. Nowadays, increasing service temperatures raise questions about the validity of this assumption.

Objectives

Evaluate the effect of temperature on :

- Fatigue behavior of bituminous and bio-based asphalt mixture
- Design and service life of pavements

Materials and methods

2 Mixtures

Same gradation curve: GB3 0/14 + 40% RAP

Two binders 70/100 & Bio-binder

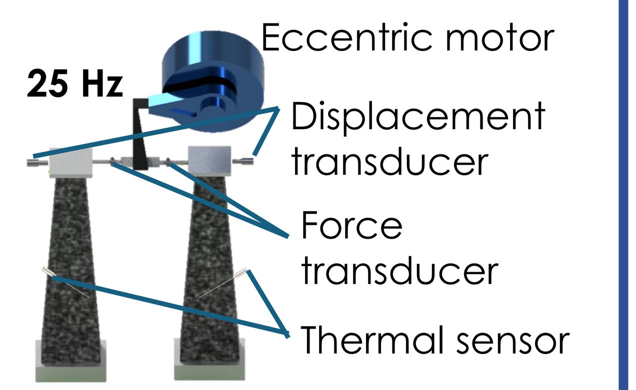
- **GB3 70/100 (T_{mix} = 163°C)**
- **GB3 Bio-binder (T_{mix} = 131°C)**

Conventional fatigue

- Cyclic sinusoidal loading
- Frequency: 25 Hz
- 3 Strain amplitudes: 70 - 170 µm/m
- 3 Temperatures: 10°C, 15°C, 20°C

Complex modulus

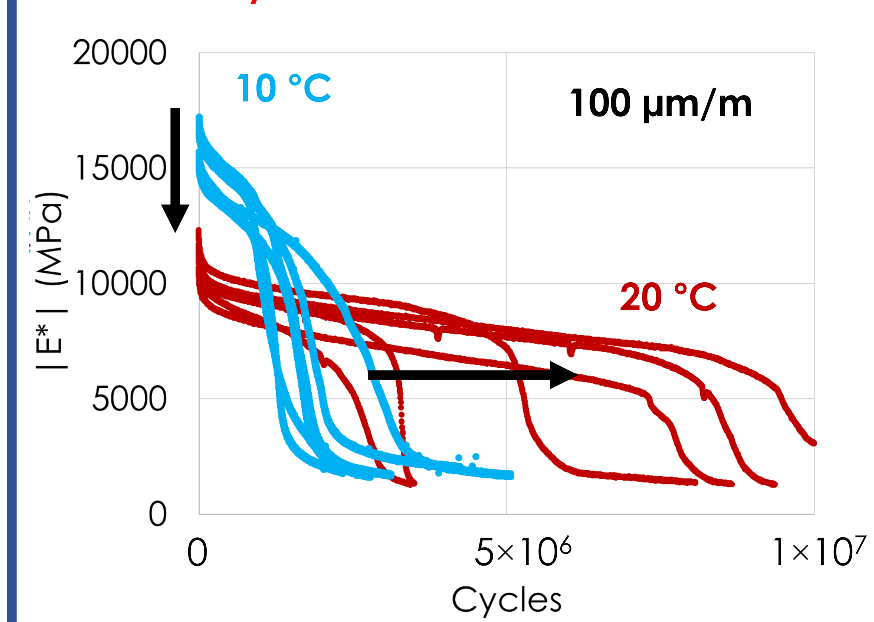
- Cyclic sinusoidal loading
- 4 Frequencies: 3 - 30 Hz
- Strain amplitude 30 µm/m
- 9 Temperatures: 0 - 40°C

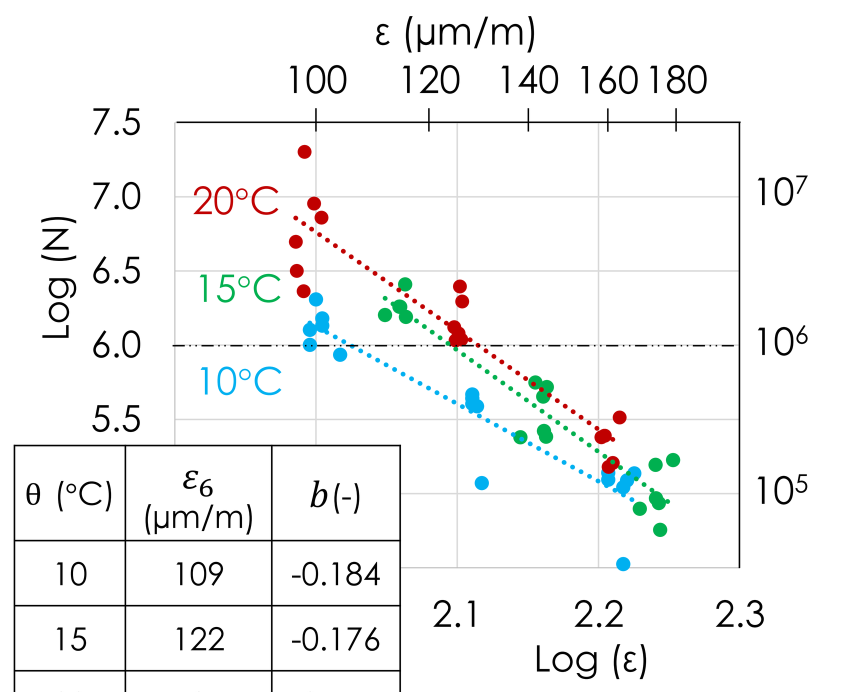


Two-point bending test

Experimental results

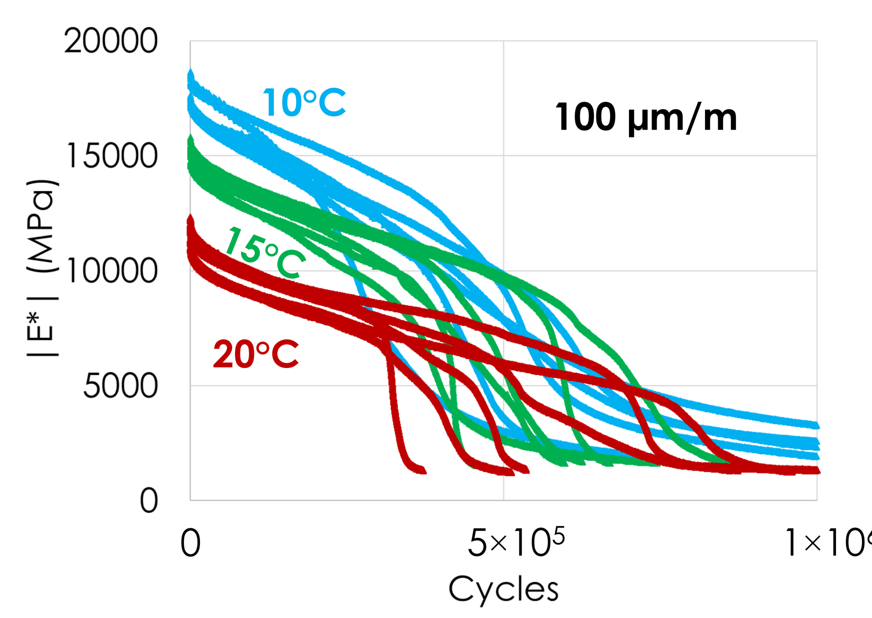
GB3 70/100

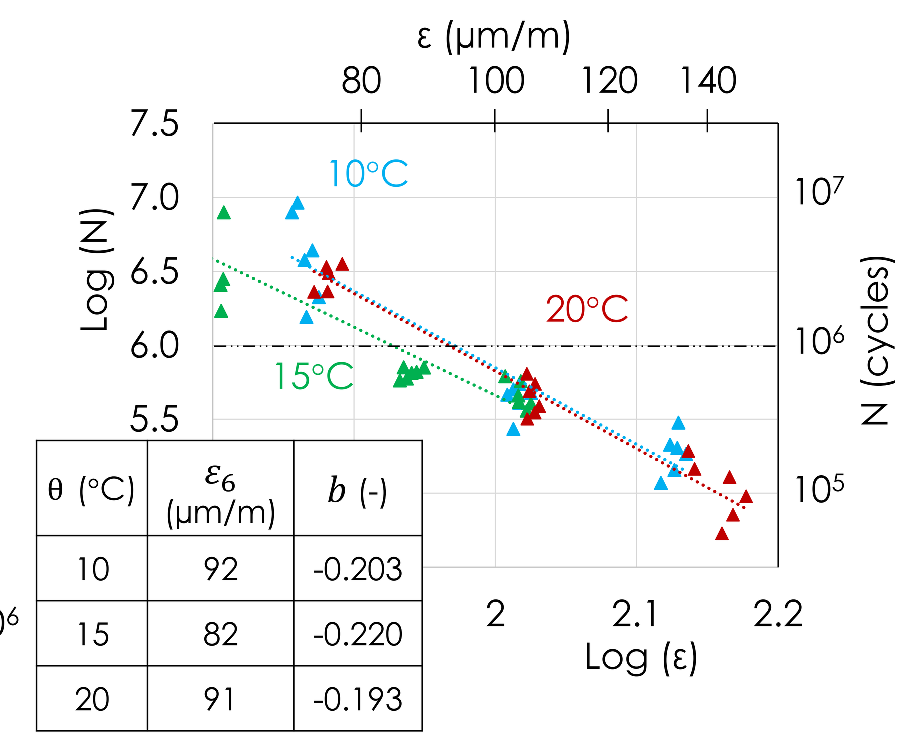




θ (°C)	ε_6 (µm/m)	b (-)
10	109	-0.184
15	122	-0.176
20	127	-0.156

GB3 Bio-binder

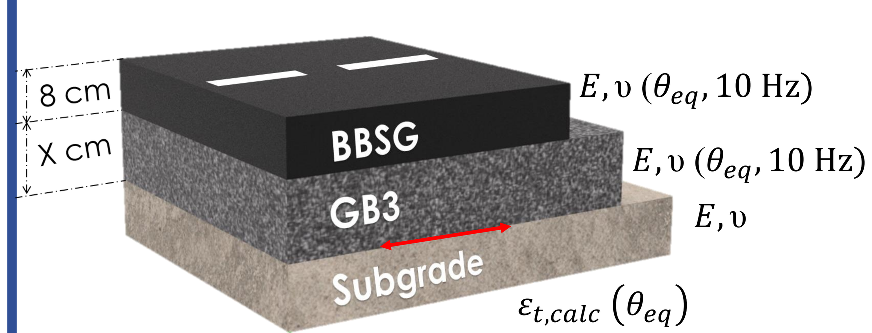




θ (°C)	ε_6 (µm/m)	b (-)
10	92	-0.203
15	82	-0.220
20	91	-0.193

Impact on pavement design

Calculated horizontal strain $\varepsilon_{t,calc}$



Following Burmister model (e.g., Alizé)

Admissible horizontal strain $\varepsilon_{t,ad}$

❖ Corrected from standard lab test at 10°C ($\varepsilon^{Corr}_{t,ad}(\theta_{eq})$)

$$\varepsilon^{Corr}_{t,ad}(\theta_{eq}) = \varepsilon_6(10°\mathrm{C}, 25\ \mathrm{Hz}) \sqrt{\frac{|E^*|(10°C, 10\ \mathrm{Hz})}{|E^*|(\theta_{eq}, 10\ \mathrm{Hz})}} \left(\frac{NE}{10^6}\right)^{b(10°\mathrm{C}, 25\ \mathrm{Hz})} k_c\, k_s\, k_r$$

❖ Measured From lab test at θ_{eq} ($\varepsilon^{Lab}_{t,ad}(\theta_{eq})$)

$$\varepsilon^{Lab}_{t,ad}(\theta_{eq}) = \varepsilon_6(\theta_{eq}, 25\ \mathrm{Hz}) \left(\frac{NE}{10^6}\right)^{b(\theta_{eq}, 25\ \mathrm{Hz})} k_c\, k_s\, k_r$$

$$NE = CAM \times 365 \times 700\ \frac{(1+7\%)^{20}-1}{7\%}$$

Fixed variables

- BBSG Thickness = 8 cm
- BBSG laboratory results from Freire, 2020.
- 700 HV/day
- Annual growth rate of traffic (7%)
- Design period (20 years)

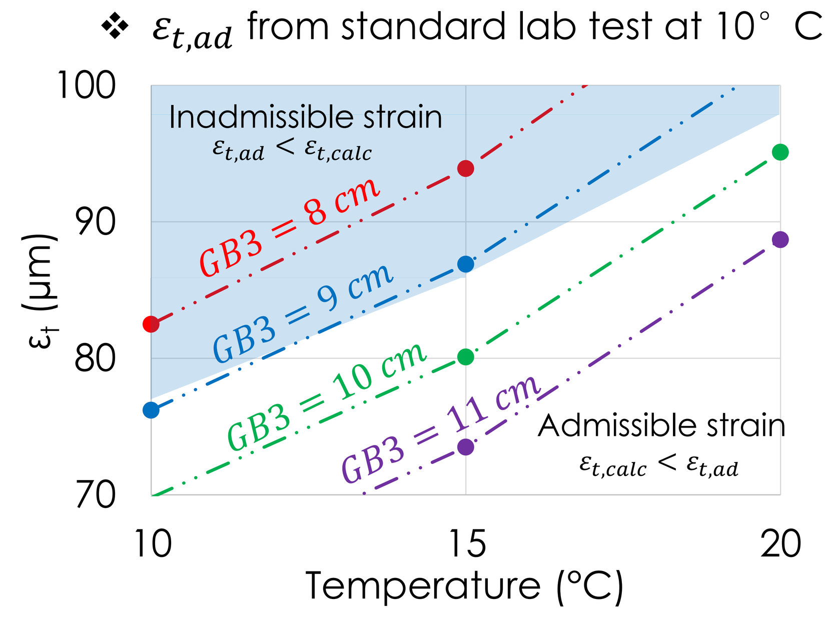
θ (°C)	GB3 70/100 |E*| (MPa)	GB3 70/100 |υ*| (-)	GB3 Bio-binder |E*| (MPa)	GB3 Bio-binder |υ*| (-)	CAM	k_c	k_s	GB3 70/100 k_r(θ)	GB3 Bio-binder k_r(θ)
10	15964	0.25*	17267	0.25	0.8	1.3	1	0.809	0.780
15	12920	0.28*	13654	0.28				0.811	0.779
20	9666	0.30*	10237	0.30				0.782	0.809

*From 3D complex modulus tests on cylindrical shaped specimens

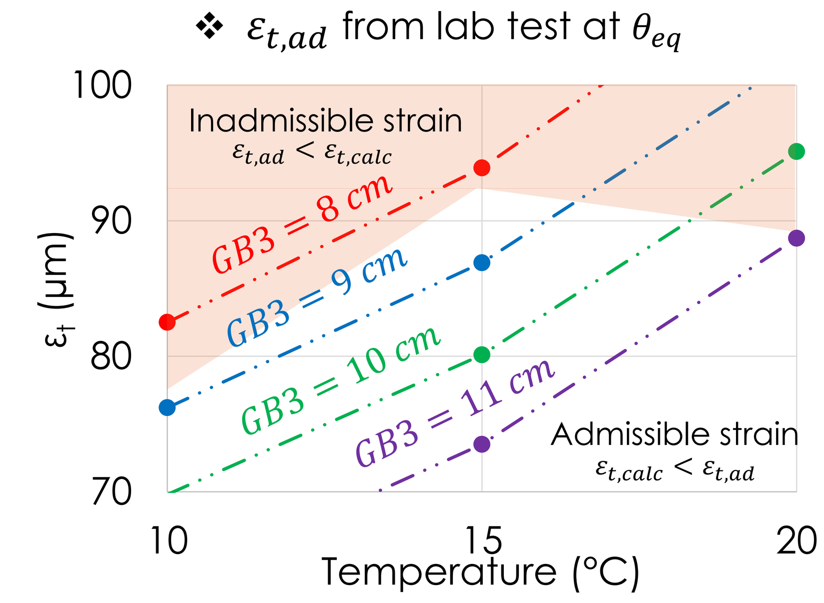
GB3 70/100

Thickness variation

❖ $\varepsilon_{t,ad}$ from standard lab test at 10° C



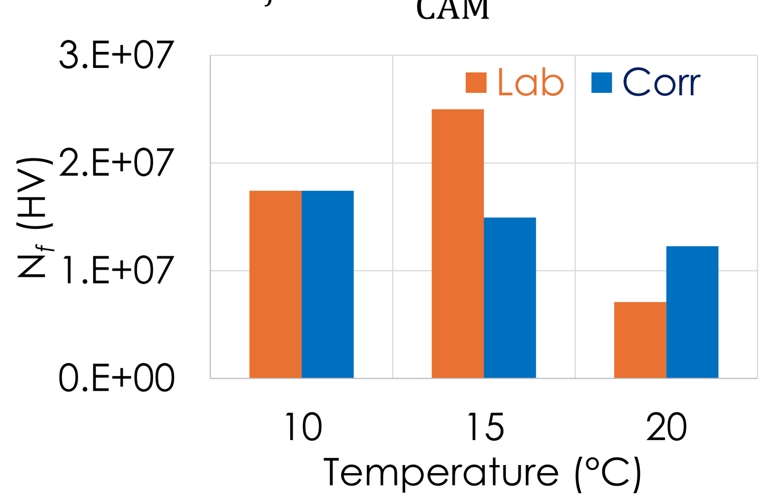
❖ $\varepsilon_{t,ad}$ from lab test at θ_{eq}



Damage for a 10 cm of GB3 70/100 structure

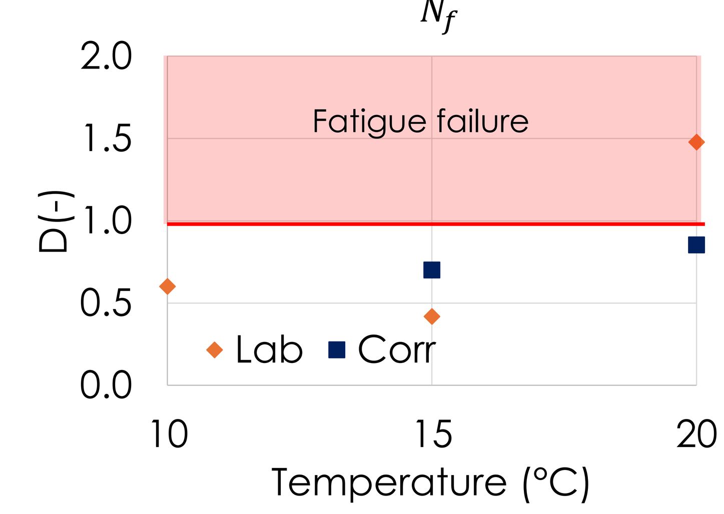
Estimated number of vehicles to failure - N_f

$$N_f = \frac{\mathrm{NE}(\theta_{eq}, \varepsilon_{t,calc})}{\mathrm{CAM}}$$



Cumulated damage in 20 years

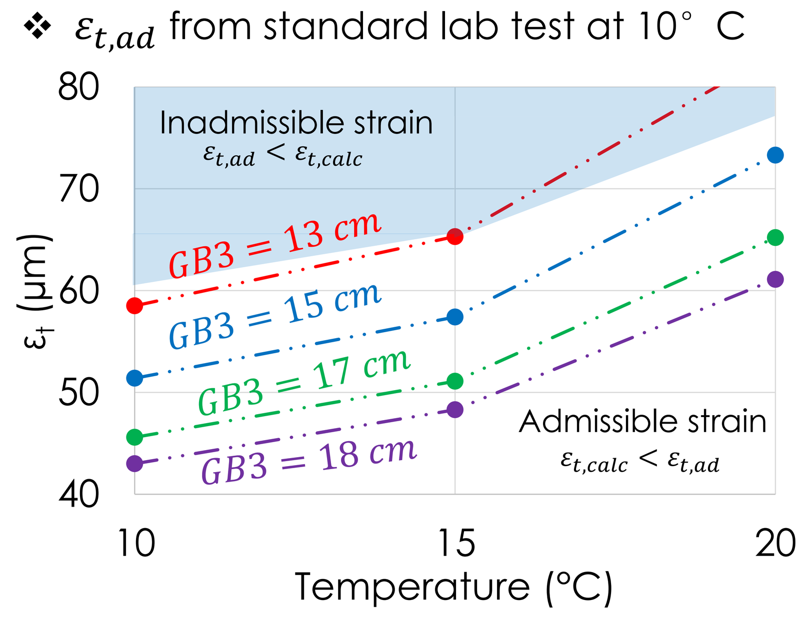
$$\mathrm{D} = \frac{365 \times 700\ \frac{(1+7\%)^{20}-1}{7\%}}{N_f}$$



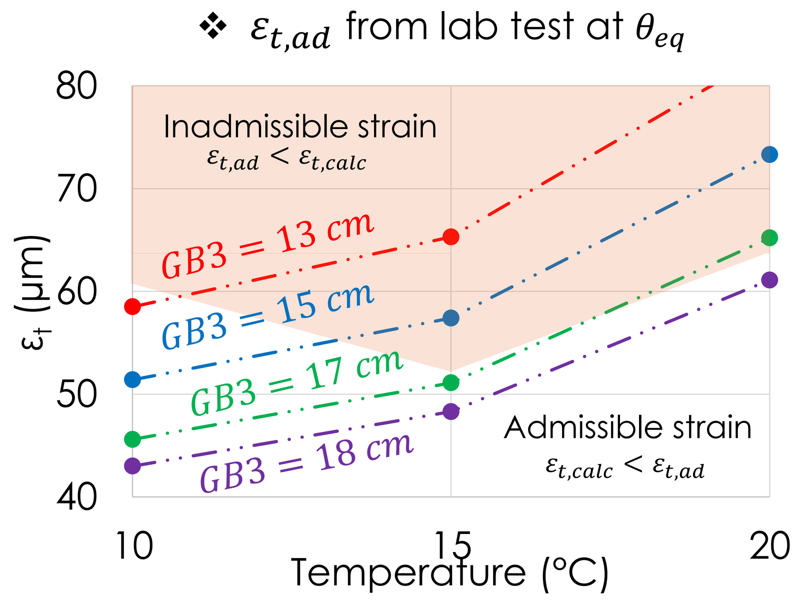
GB3 Bio-binder

Thickness variation

❖ $\varepsilon_{t,ad}$ from standard lab test at 10° C



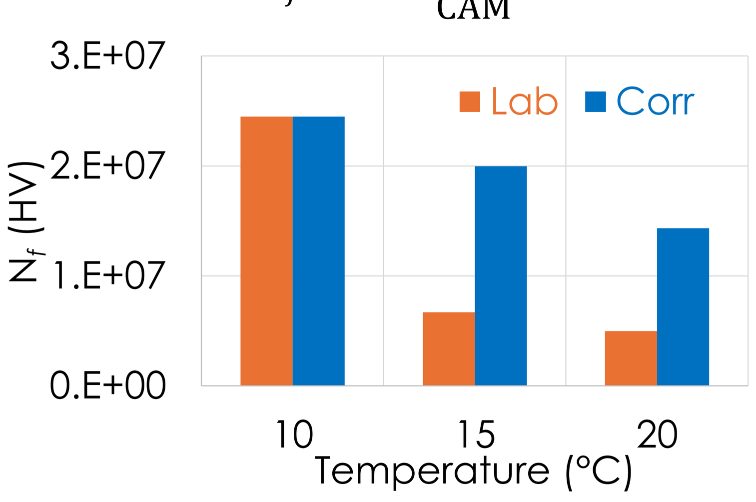
❖ $\varepsilon_{t,ad}$ from lab test at θ_{eq}



Damage for a 15 cm of GB3 Bio-binder structure

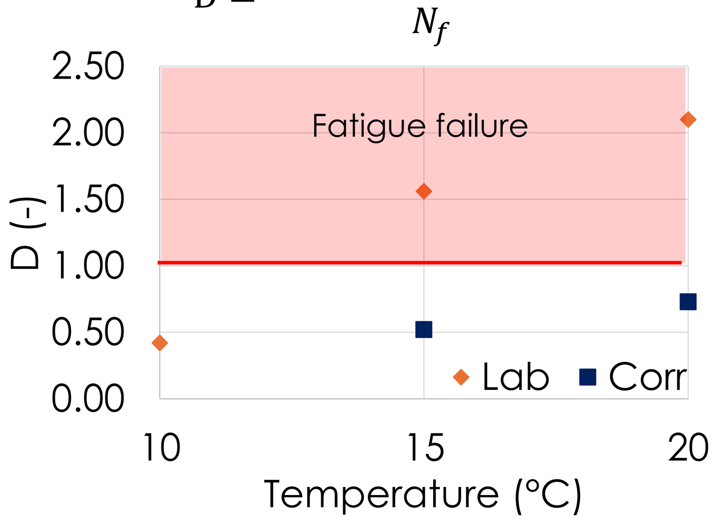
Estimated number of vehicles to failure - N_f

$$N_f = \frac{\mathrm{NE}(\theta_{eq}, \varepsilon_{t,calc})}{\mathrm{CAM}}$$



Cumulated damage in 20 years

$$\mathrm{D} = \frac{365 \times 700\ \frac{(1+7\%)^{20}-1}{7\%}}{N_f}$$



Conclusions

- Fatigue behavior and damage accumulation are highly temperature-dependent.
- Design temperatures higher than 15° C result in thicker pavement structures.
- Higher temperatures increase fatigue damage in current pavement designs, highlighting their sensitivity to climate change.
- Bio-based mixture did not exhibit the same temperature-related improvement in fatigue resistance as the 70/100 binder.

Perspectives

- Influence of temperature on other types of structure.
- Determine the influence of the seasonal temperature variation.
- Compare results with in situ measurements

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