Towards Improved Thickness Design Procedures for Foamed Bitumen Stabilised Layers: New Experimental Findings

Didier Bodin, Principal Technology Leader – NTRO

Damian Volker, A/Director (Pavement Rehabilitation), Pavements, TMR

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Outline

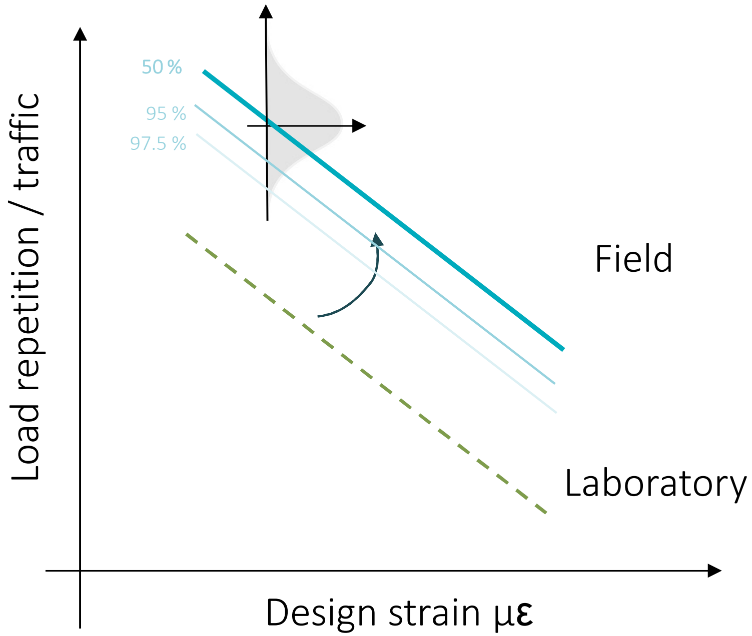
- Background
- Scope of the initiative
- Effect of temperature and loading speed on FBS modulus
- Fatigue characterisation and temperature susceptibility
- Innovative laboratory XL-WT testing under field-simulated conditions
- Conclusions

Background

- TMR structural design procedure was developed and used at large scale
- Current mix design practice 3. to 3.5 % bitumen & 1.5 to 2% hydrated lime/ fly ash
- Typical mixtures are rut resistant in early life and beyond (research showed validity up to 50% RAP)
- Thickness design based on an empirical performance relationship:
  - Design modulus (derived from mix design) 3-day cured soaked IT modulus of laboratory prepared specimens adjusted for temperature/loading speed and capped to 2,500 MPa
  - Strains determined from design response to load model (i.e. Circly/AustPads)
  - Empirical performance relationship ⇨ allowable loading
  - Allowable loading ≤ design traffic?
- Method translated to AGPT05:2019 for pavement rehabilitation treatment design
- Reliability factors are not available for FBS pavements

Towards a performance-based characterisation and design procedure

- Aim at a probabilistic approach consistent with the Austroads Mechanistic-Empirical design procedure for bound materials (AGPT02)
- Laboratory-derived performance relationship
- Shift factor (calibrate mean lab performance on mean field performance)
- Reliability factors for given design reliability (97.5%, 95% survival probability)



Flexural modulus and fatigue performance

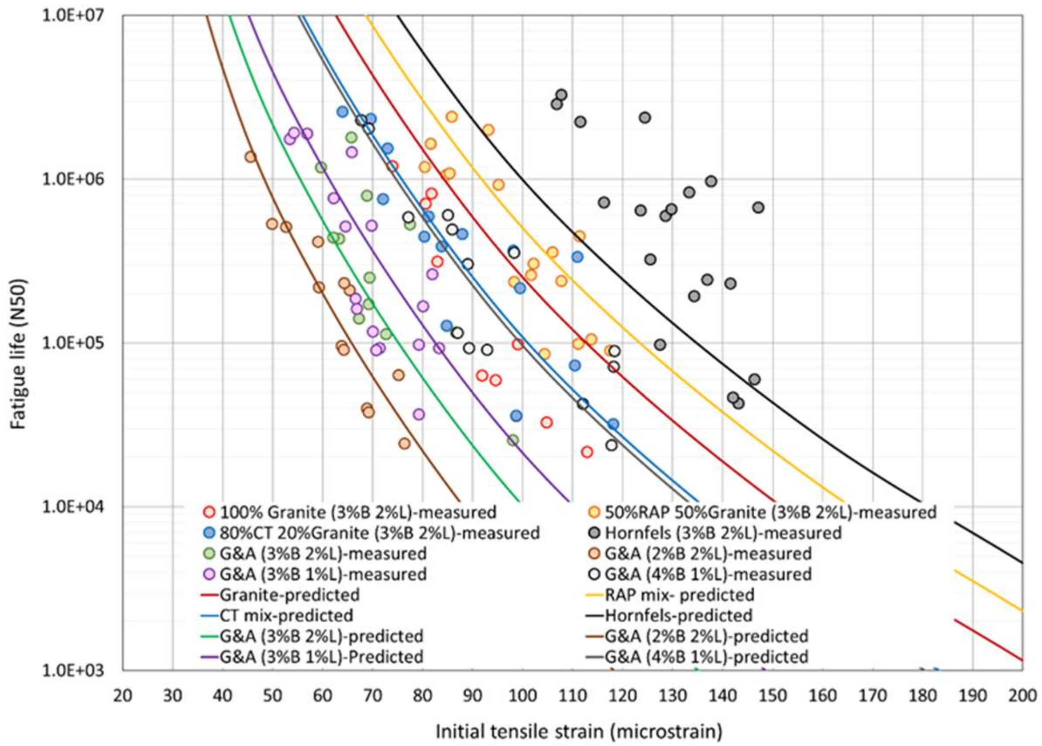
New laboratory characterisation procedures

- 90-days cured laboratory-prepared beams (100 x 100 x 400 mm)
- 4pt bending testing conditions
- Flexural modulus (T, f, ε ≤ 50 με)
- Flexural fatigue (TºC, f = 10Hz, varying stress)

Source: Zhalehjoo, N, 2022, Laboratory fatigue characterisation of foamed bitumen stabilised materials, Research report, AP-R666-22, Austroads, Sydney, NSW.

Laboratory flexural fatigue relationships

- Austroads report (AP-R666-22)
- 8 different mixes tested to investigate fundamental parameters affecting fatigue performance
  - Effect of modulus
  - Effect of the bitumen content
  - Effect of strength
- Testing at 20ºC
- On going NACOE/Austroads research to consolidate the findings



Source: Zhalehjoo (2022)

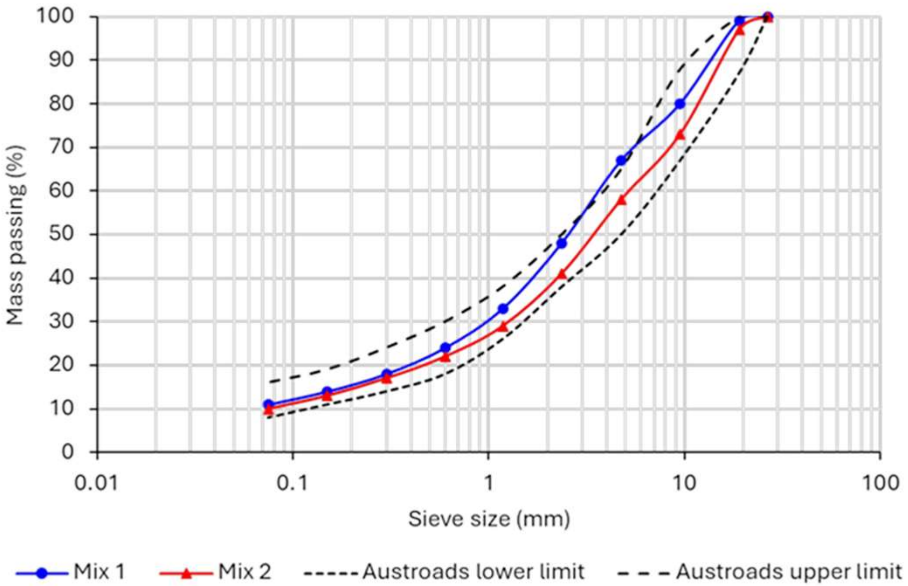
Scope of the research

- Undertake fatigue testing on two typical FBS mixes representative of TMR practice
- Assess effect of temperature and loading speed on flexural modulus
- Perform fatigue testing and assess sensitivity to temperature
- Better understanding lab to field shift factor based on XL-WT test

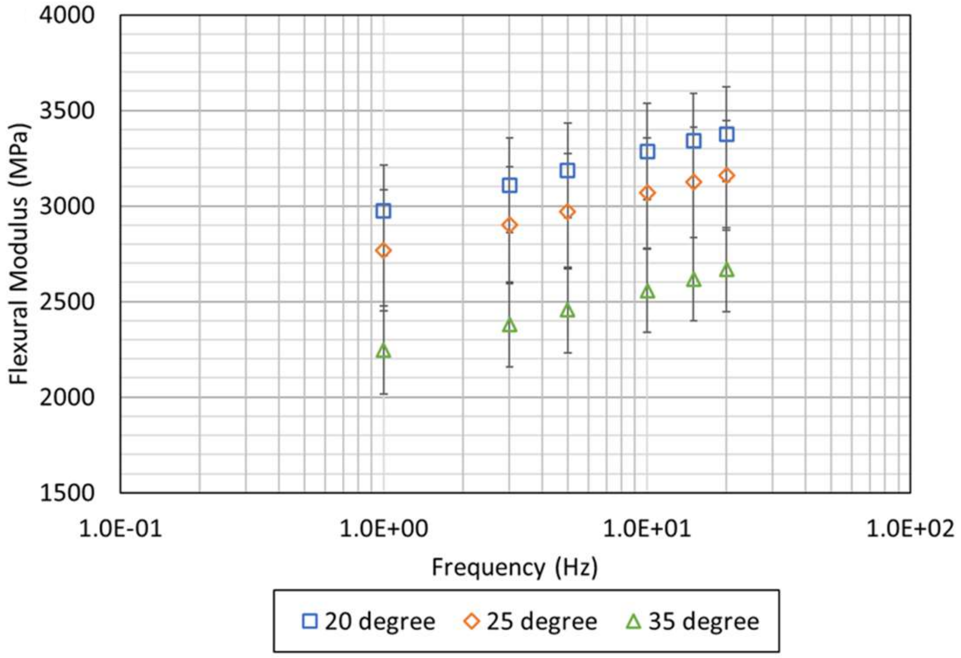
Effect of loading speed/temperature on FBS materials modulus

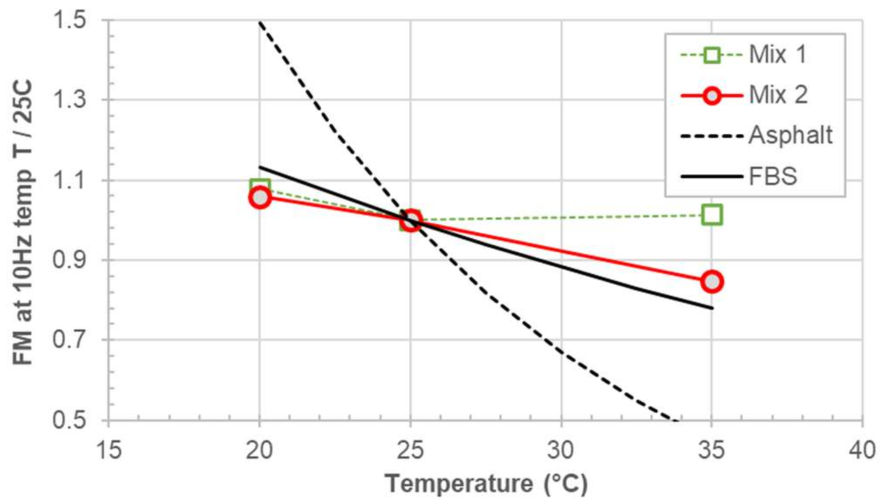
- Similarly to asphalt and all bituminous materials, FBS mixes are sensitive to temperature and loading speed (viscoelastic material) ⇨ New lab study

- FBS mixtures
  - Type 2.1 crushed rock (x2)
  - Bitumen content 3.5%
  - Secondary binder 1.5% (50/50 Hydrated lime/Fly ash)
- 90-day cured lab-manufactured beams
- ‘Master curve’ testing:
  - Temperatures = 20, 25 and 35ºC
  - Frequency sweep f = 1, 3, 5, 10, 15, 20 Hz



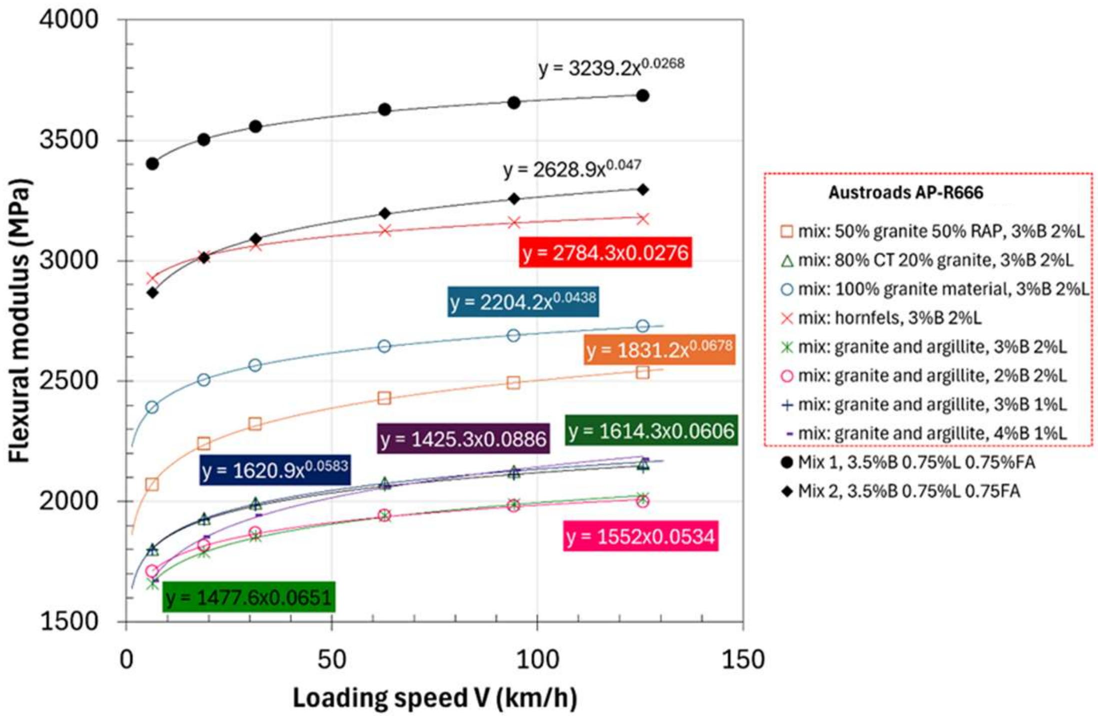
Effect of temperature on the flexural modulus

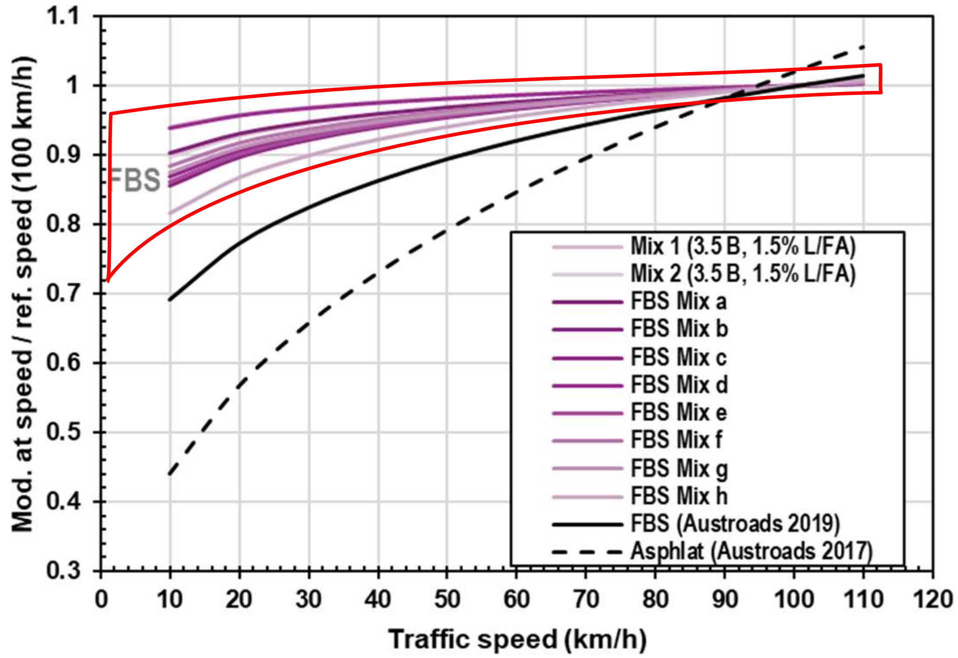




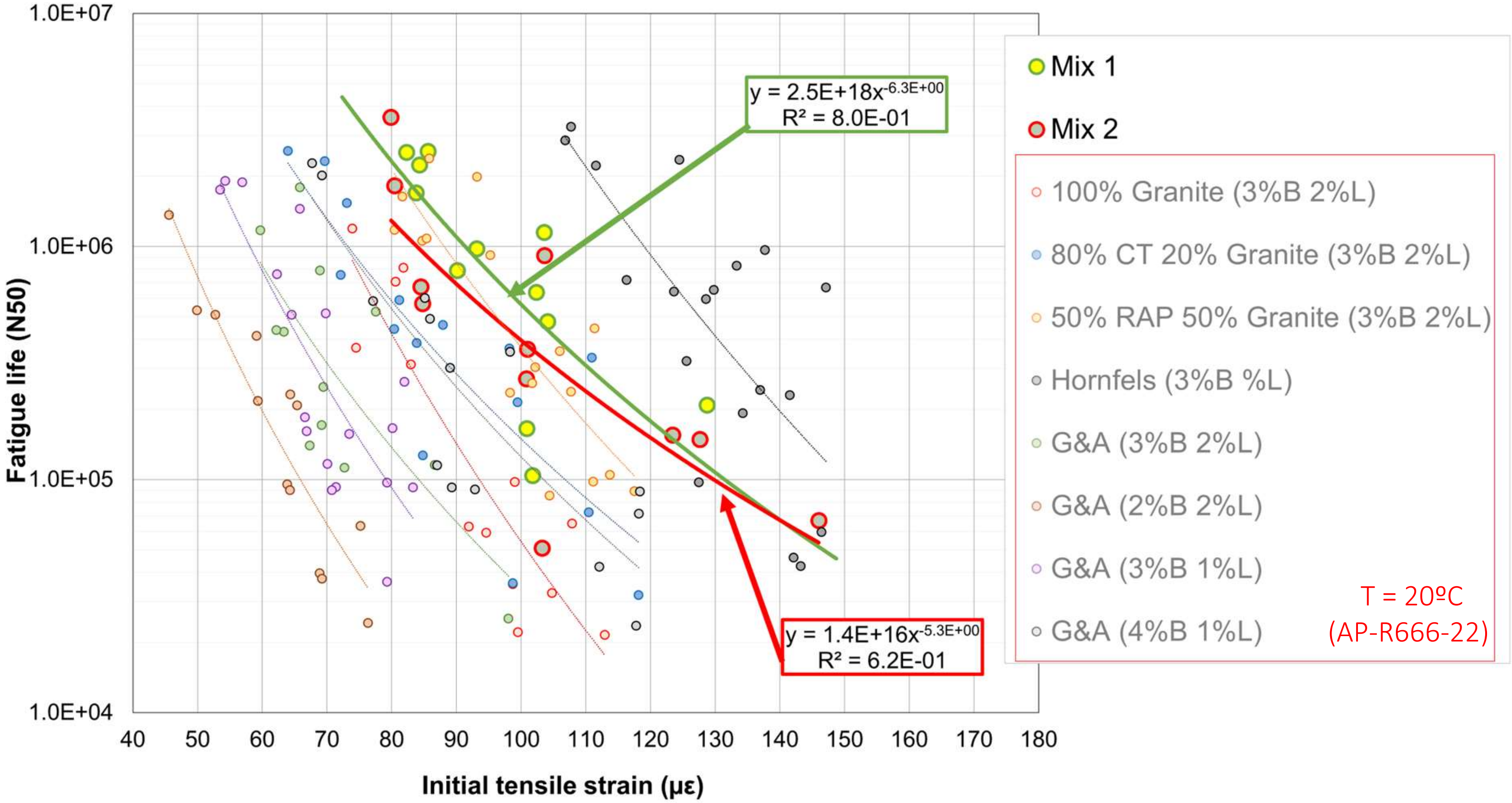
Effect of loading frequency of modulus

- Experiment 2 Mixtures + Austroads (2022) data



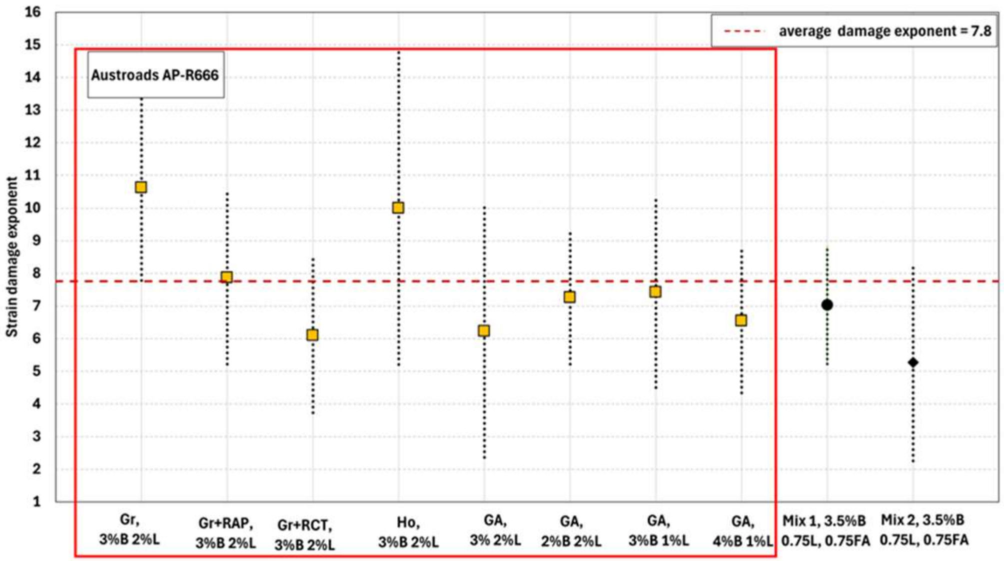


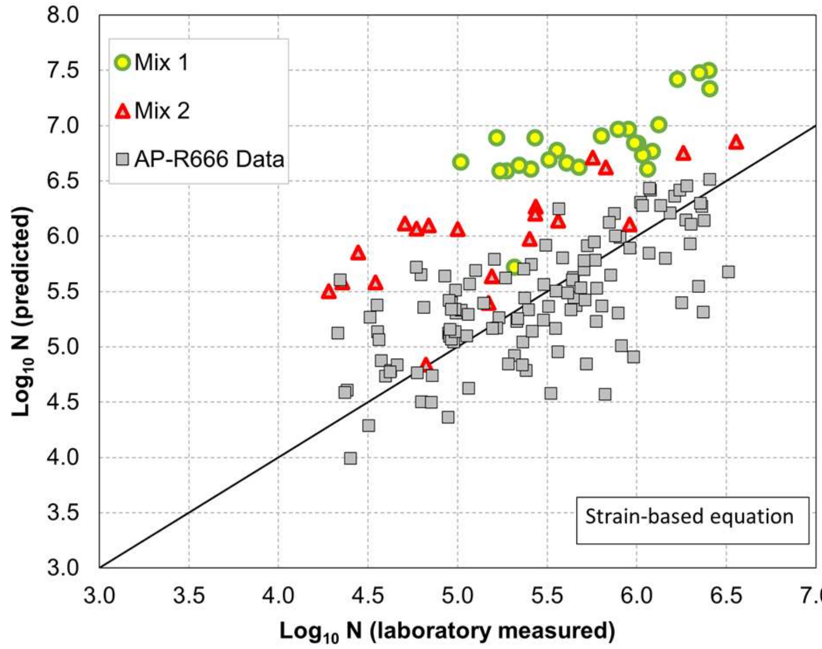
Fatigue Testing at 25°C



Fatigue relationship SDE / Model

- Strain damage exponent (SDE)

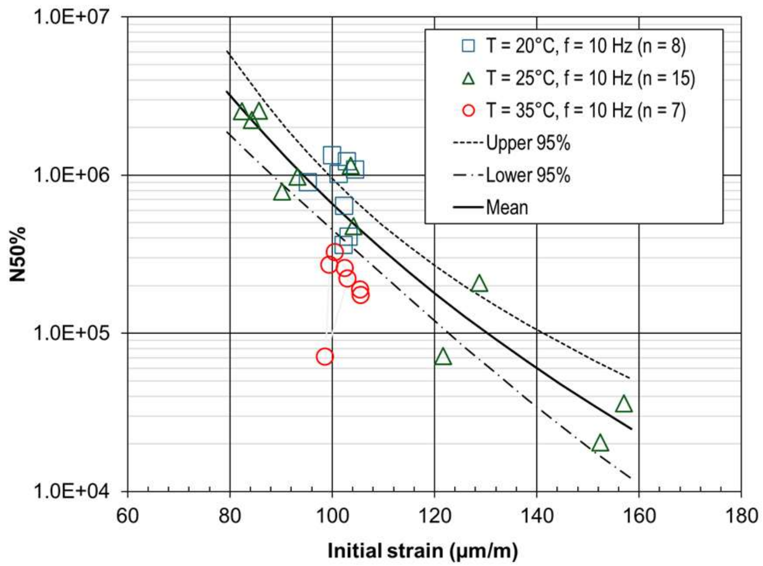


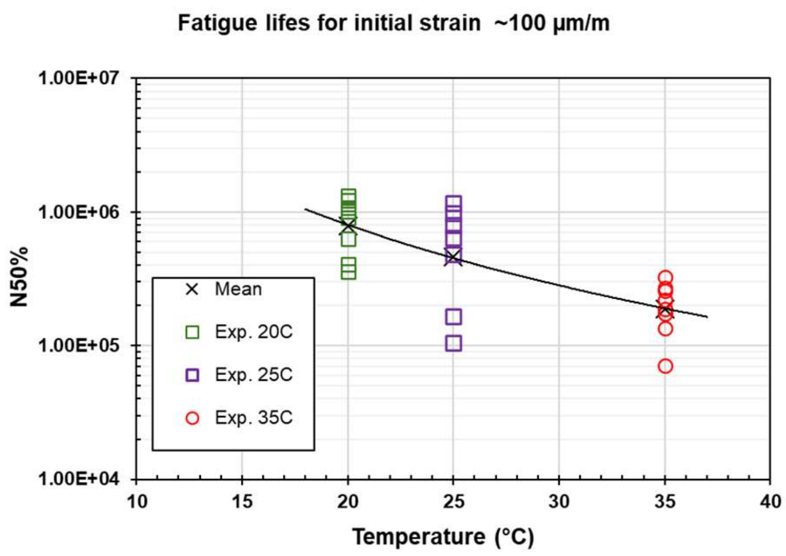


- Laboratory model predicts higher lives than measured

Effect of temperature on fatigue

- Use similar testing protocol at varying temperature (20, 25 and 35ºC)





- Drop in fatigue about 4 to 5 times between 20 to 35 °C lower than previous findings showed lives more than 10 times greater for a 10ºC increase

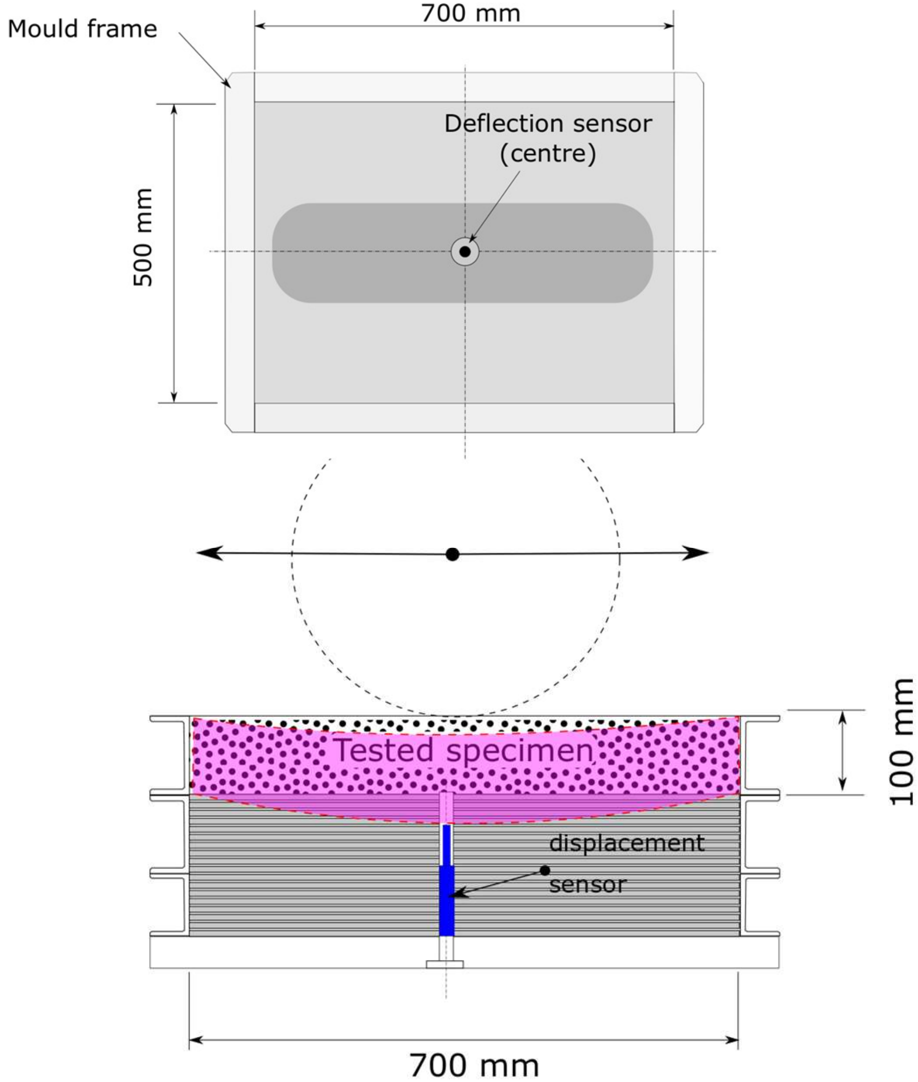
WT testing to better simulate field conditions

- Flexural fatigue
  - Uniaxial loading (i.e. bending)
  - Unconfined specimen
- Field
  - Rolling wheel load & 3D stress/strain state
  - Material confined in the layer by surrounding material
- Extra-large wheel tracker selected tobetter simulate field conditions
  - 20kN rolling wheel load
  - Confinement (i.e slab specimen confined in a steel mould)

Source: NTRO (2023)

Extra-Large Wheel-tracker for simulating pavement material fatigue

- XL-WT - originally developed for unbound granular materials
- Used to characterise cracking types of lightly bound stabilised materials (AP-R640-20)
- Allows in-flight response to load monitoring
- High load capacity with slab testing under 20 kN rolling wheel-load



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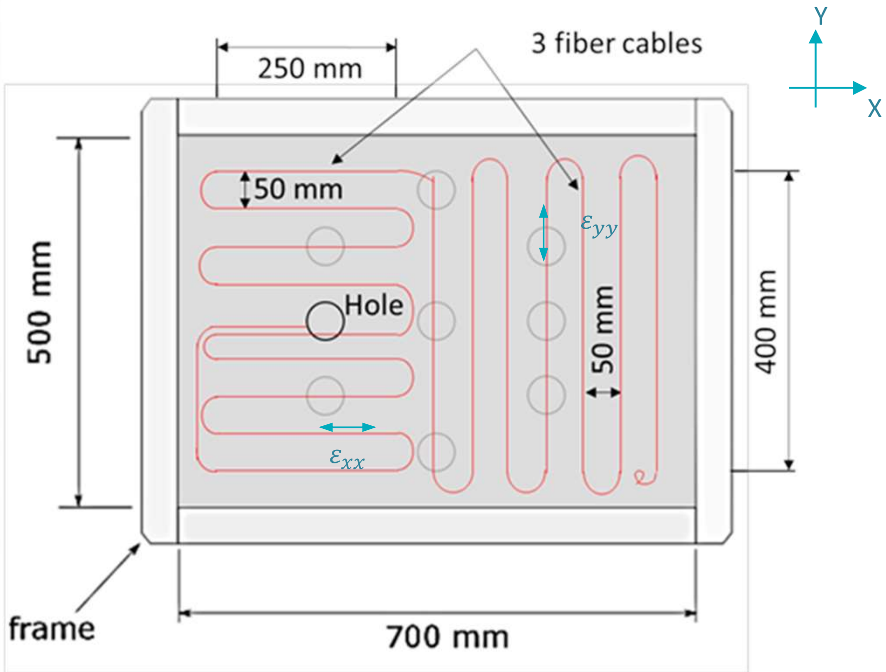
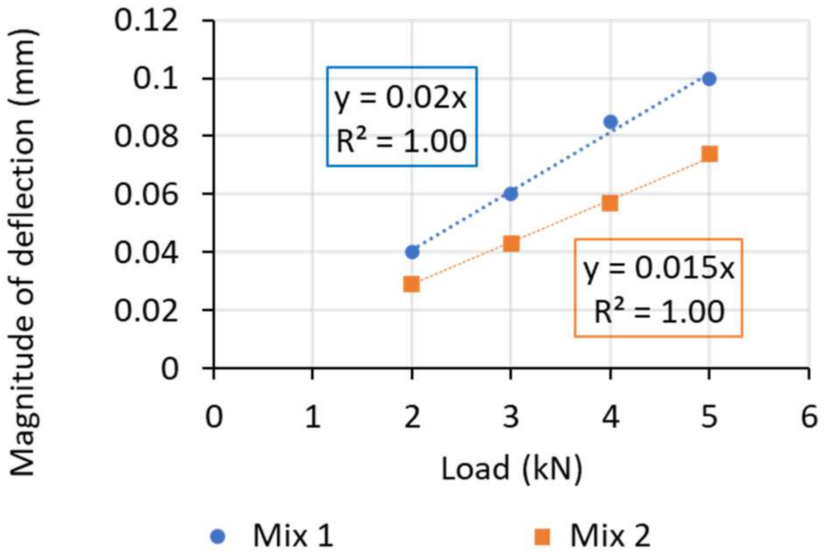
Optic fiber sensors implementation

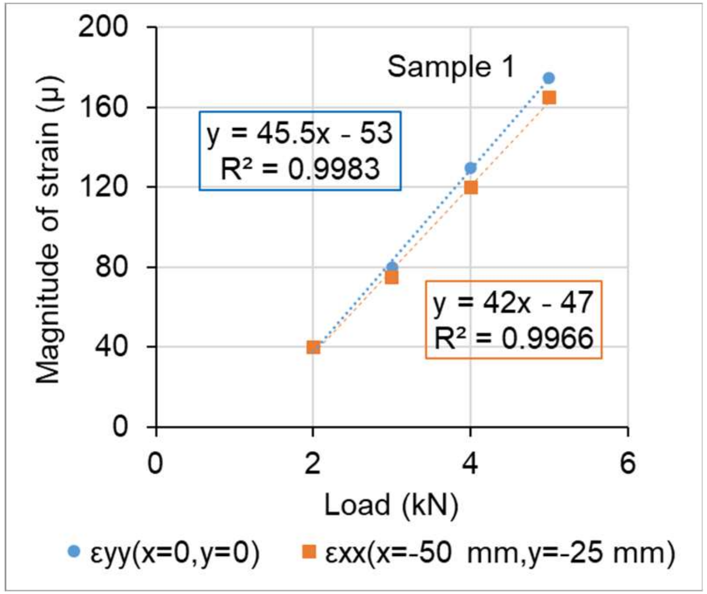
- Understanding tensile strain at the bottom of the slab
  - Longitudinal
  - Transverse
- Installation at the bottom & top of the slab
- Evaluate the technology robustness



Small strain response to load testing

- Determine load vs strain relationship (testing for 100 cycles)

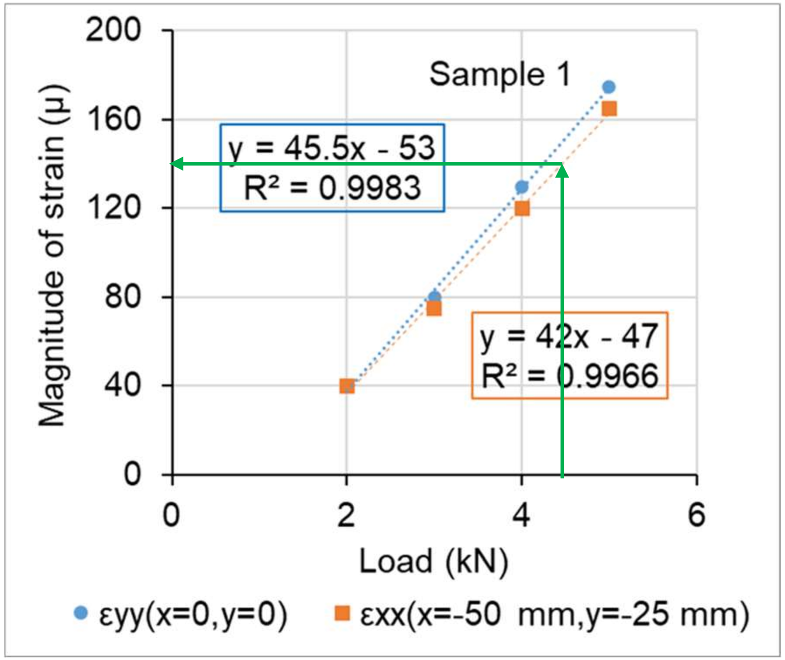


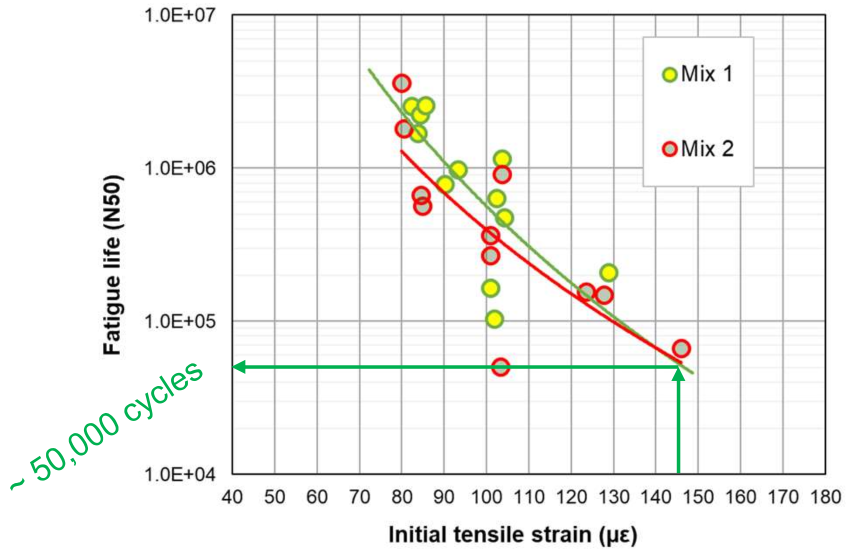


- Linear strain / displacement response with load
- Tensile strain ε_{xx} ε_{yy} consistent ⇨ bi-directional tensile strain

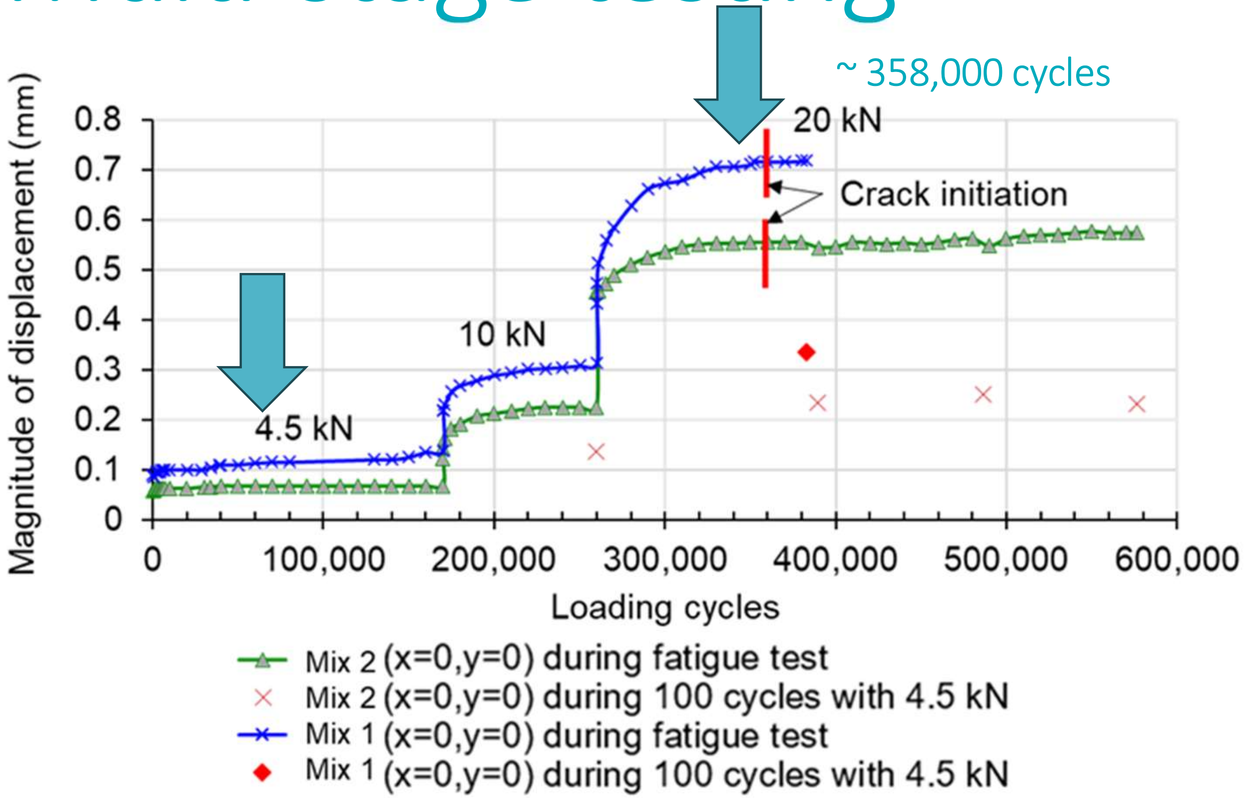
Life expectancy from flexural fatigue

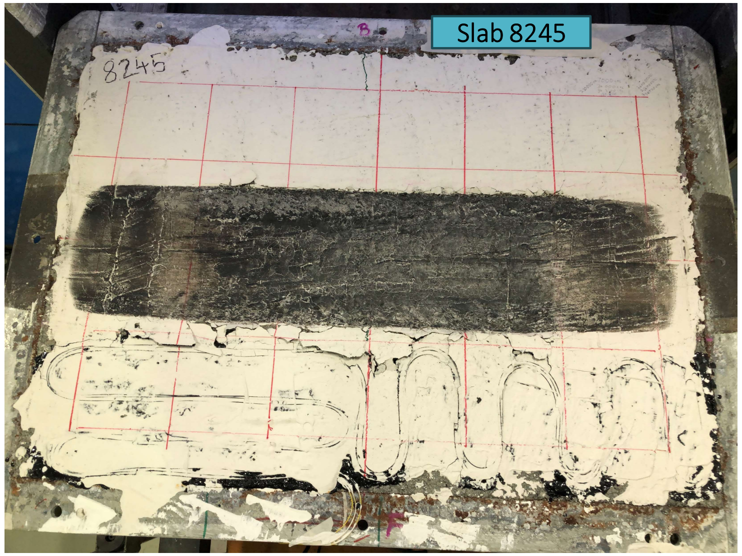
- Load magnitude 4.5 kN
- Life predicted based on flexural fatigue results





Multi-stage testing





- Number of load repetition far exceeded prediction from flexural testing

Conclusion

- Effect of temperature on modulus and loading speed found lower than currently assumed
- Improved assessment of fatigue performance temperature susceptibility
- Use of fibre optic cables gives an interesting insight into the flexural response under rolling wheel-load
- XL-WT testing provided a confined and 3D stress representing the field
- Shift factor between flexural testing and WT is far greater than 7

Continuing research

- Assessment of field performance to evaluate the lab-to-field shift factor
- Further ongoing validation of the effect of temperature/loading speed sensitivity and model refinements
- Reliability (i.e. surviving rate) of the fibre optic sensors should be improved

Thank you

Didier Bodin

PhD

Principal Technology Leader, Safer Smarter Infrastructure

Portfolio Leader - Pavement Research Leadership

NTRO

80a Turner St, Port Melbourne, VIC, Australia 3207

Didier.Bodin@ntro.org.au | arrb.com.au