Category 2: Industry Excellence in Consulting, Research or Education

A Study of Fatigue Damage of Foamed Bitumen Stabilised (FBS) Materials for Pavement Design

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SPARC HUB Smart Pavements Australia Research Collaboration

2021 AustStab Awards of Excellence

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Research Aims

The main aim of this research is, ultimately, to develop a more rational and advanced pavement design approach to maximize the performance of Foamed Bitumen Stabilised pavement materials

Specific Aims

- To understand:
  - Fundamental properties relevant to the mix design and flexural fatigue characteristics;
  - The influence of flexural strength and modulus on fatigue performance;
  - The relationship between IDT testing and flexural beam testing; and
  - The effects of temperature, density and age of curing on the dynamic flexural properties of FBS materials.
- To devise an appropriate test method for FBS materials to resolve the following key issues in relation to flexural beam testing:
  - Selection of the appropriate mode of loading for FBS materials (Strain-control or Stress control);
  - Selection of shape of stress/strain waveform mostly suitable for FBS materials; and
  - Selection of the best results analysing method.
- To maximise the flexural fatigue performance by optimizing the mix design of FBS materials:
  - Bitumen content;
  - Lime content; and
  - Density of FBS material.
- To develop a fatigue performance prediction model for FBS mixtures under variable test conditions
- To validate the experimental data using available actual pavement performance data (Accelerated Loading Facility – ALF).

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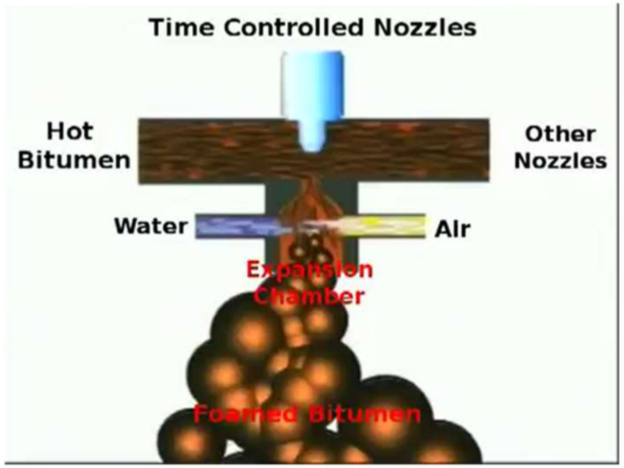
What is Foamed Bitumen Stabilisation?



+

Aggregate

+

Cement

Or

Lime

Field

Laboratory

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Distinct characteristics of FBS materials

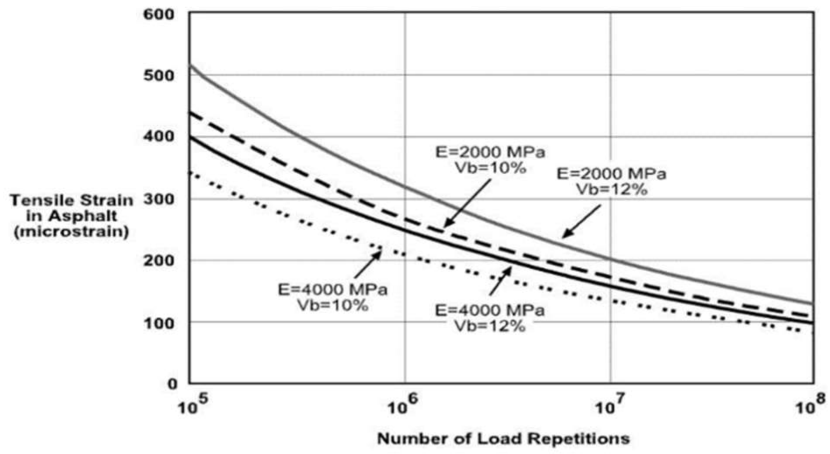
Asphalt

$$N = RF\left[\frac{6918(0.856V_b + 1.08)}{E^{0.36}{}_{flex}\,\mu\varepsilon}\right]^5$$

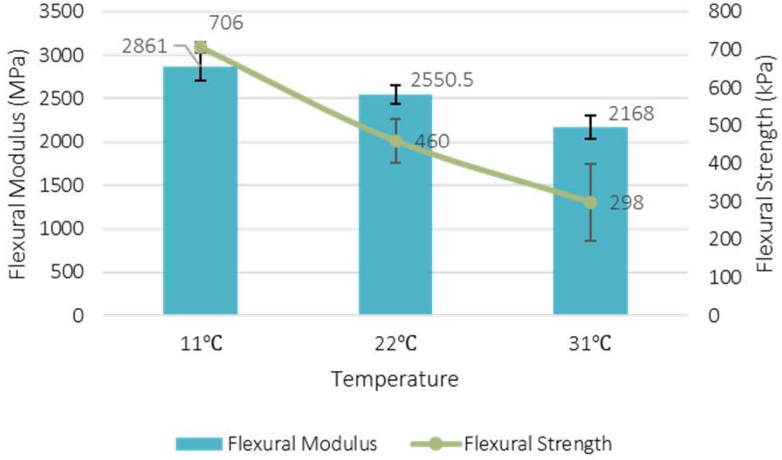
V_b=bitumen percentage by volume;
E=asphalt resilient modulus

με = load-induced tensile strain at base of the asphalt (microstrain)

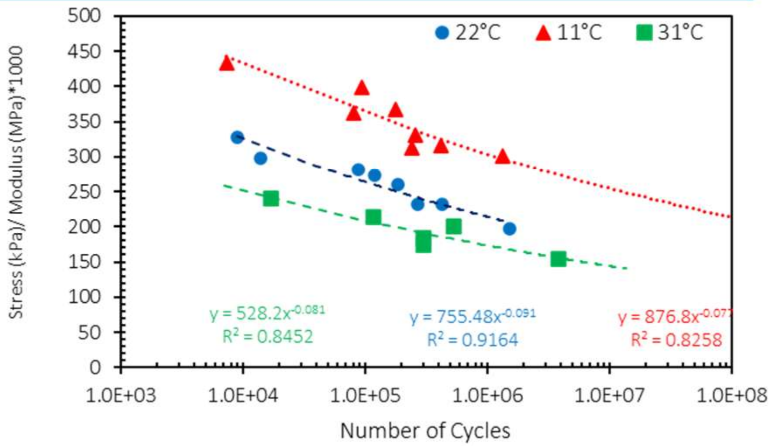
E ↑ N ↓



FBS



E ↑ N ↑



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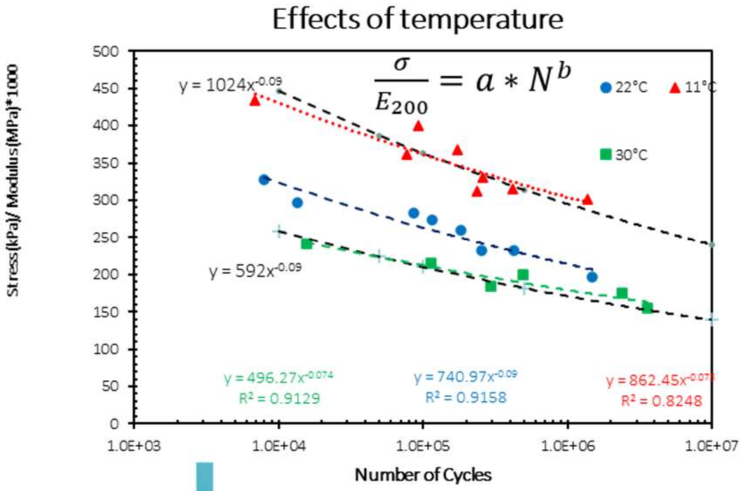
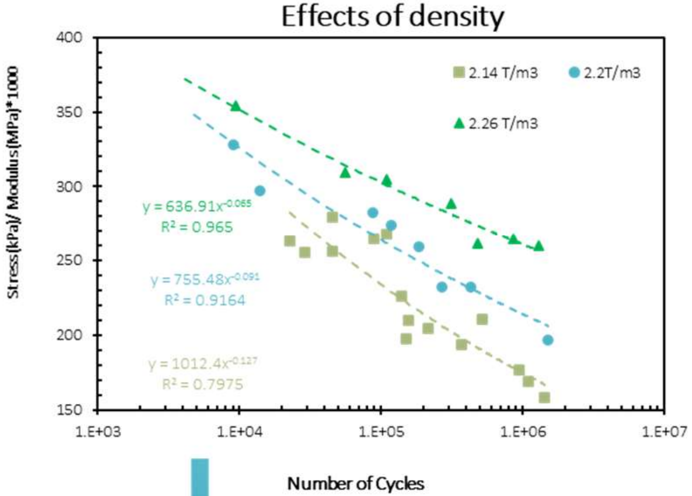
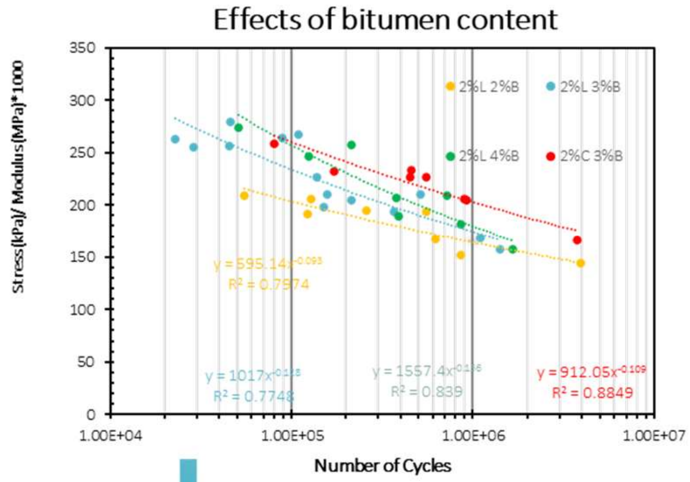
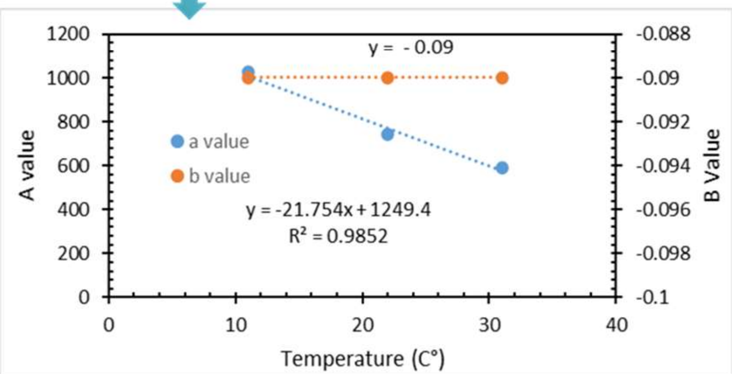
Development of fatigue life prediction model under stress-controlled mode

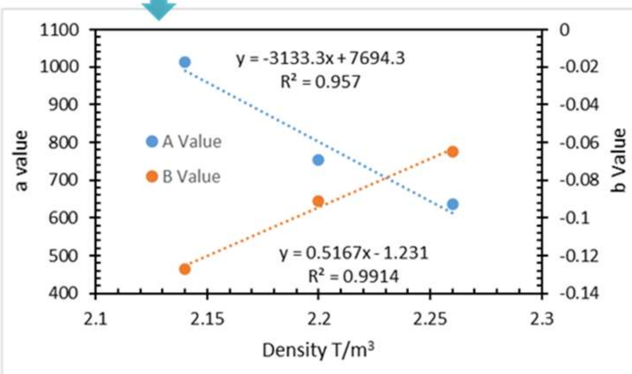
Effects of different parameters

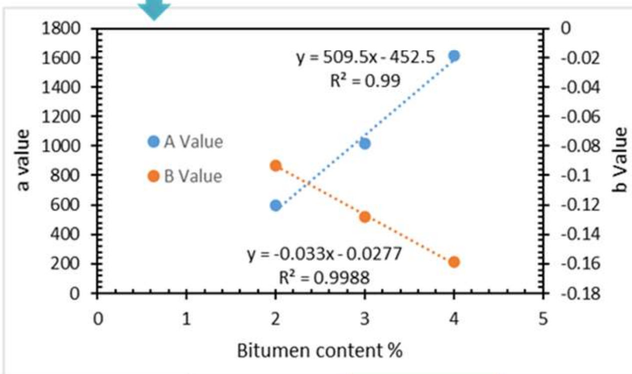












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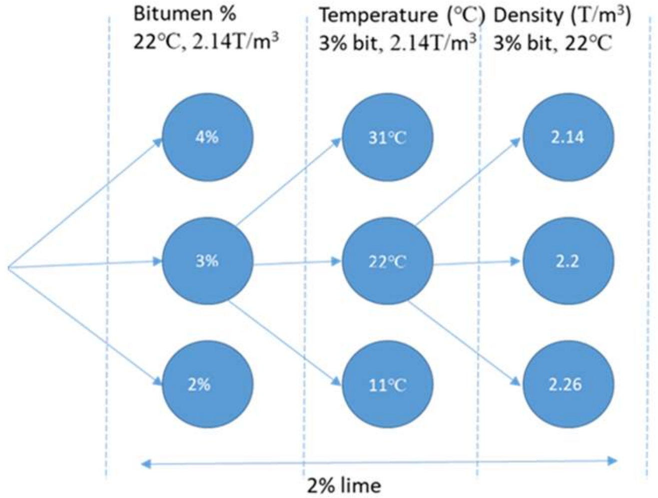
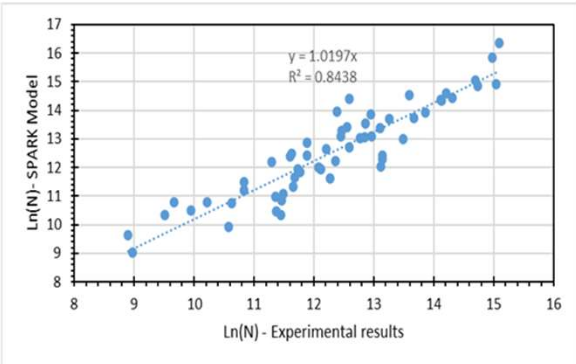
Fatigue life prediction under stress-controlled mode – SPARK Model 2

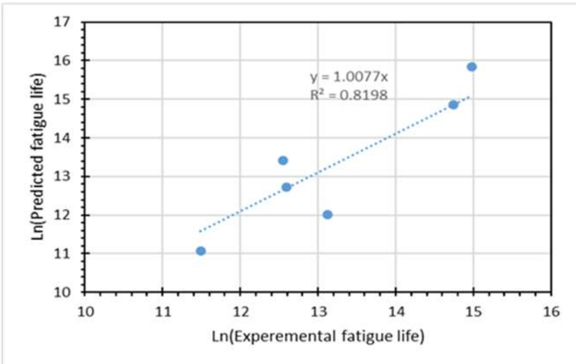


- **Step 1.** Calculate the "a" and "b" values using Equation 3 and Equation 4, respectively
- **Step 2.** Back calculate the corresponding temperature values by substituting previously found "a" value to Equation 1.
- **Step 3.** Find the reduced temperature for "a" value.
- **Step 4.** Calculate the "a" value again by substituting Rt_a value to Equation 1
- **Step 5.** Back calculate the corresponding bitumen content values by substituting previously found "a" and "b" values to Equation 5 and Equation 6, respectively.
- **Step 6.** Find the reduced bitumen content for "a" and "b" values separately.
- Reduced bitumen content (Rbi_a) = bi_a (2.33%)– [base bitumen content (3%) – required
- **Step 7.** Calculate again the "a" and "b" values by substituting Rbi_a and Rbi_b values to Equation 3 and Equation 4, respectively.

$a_{2.2,T,3} = -21.74(T)+1249.4$	Equation 1
$b_{2.2,T,3} = -0.09$	Equation 2
$a_{\rho,22°C,3\%} = -3133.3(\rho)+7694.3$	Equation 3
$b_{\rho,22°C,3\%} = 0.5167(\rho)-1.231$	Equation 4
$a_{2.2,22°C,bi} = -509.5(bi)-452.5$	Equation 5
$b_{2.2,22°C,bi} = -0.033(bi)-0.0277$	Equation 6



Validation of fatigue prediction using existing data set



Validation of fatigue prediction using a new data set

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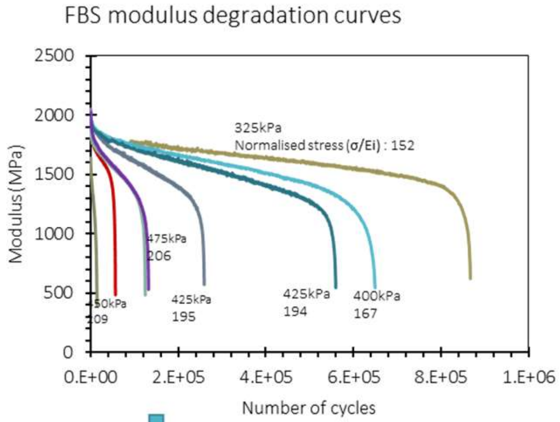
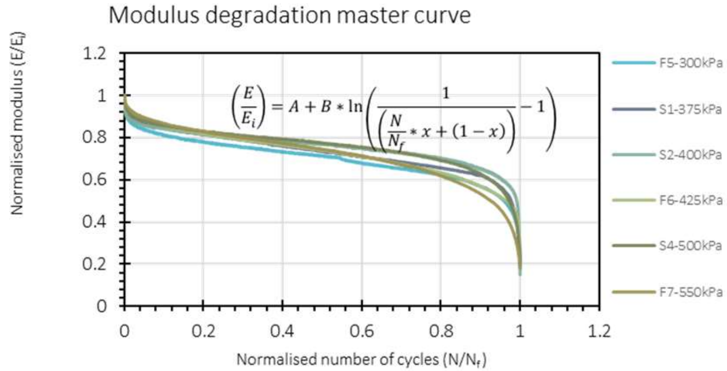
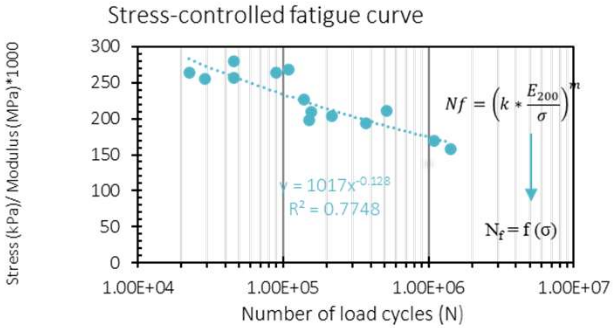
Fatigue life prediction – SPARK Model 3a

Strain-controlled fatigue life prediction based on stress-controlled fatigue results

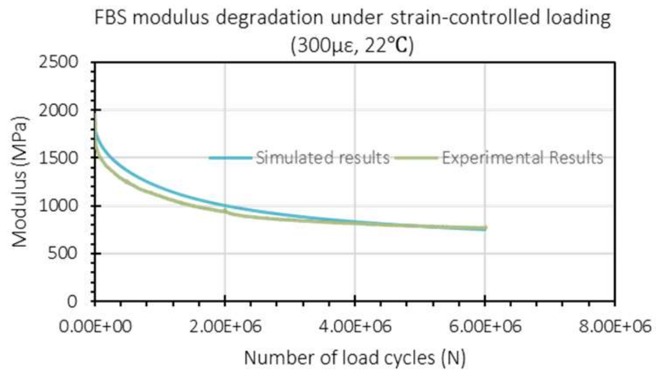






Key functions of the model

1) $N_f = f(\sigma)$
2) $\sigma = f(E)$
3) $(E/E_i) = f(N/N_f)$



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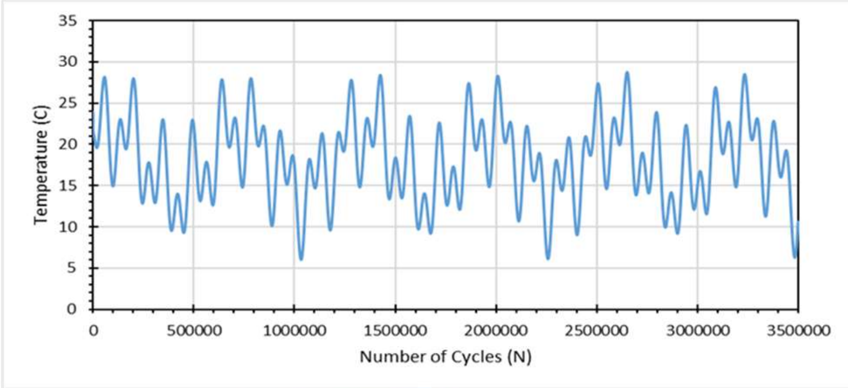
Fatigue life prediction – SPARK Model 3b

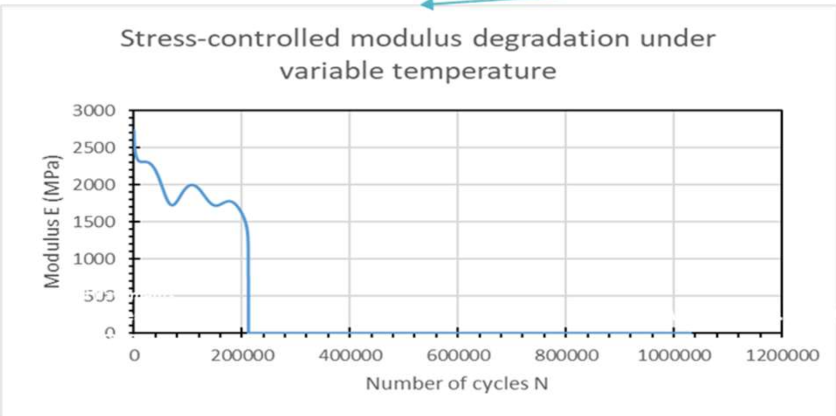
Strain-controlled fatigue life prediction in variable conditions

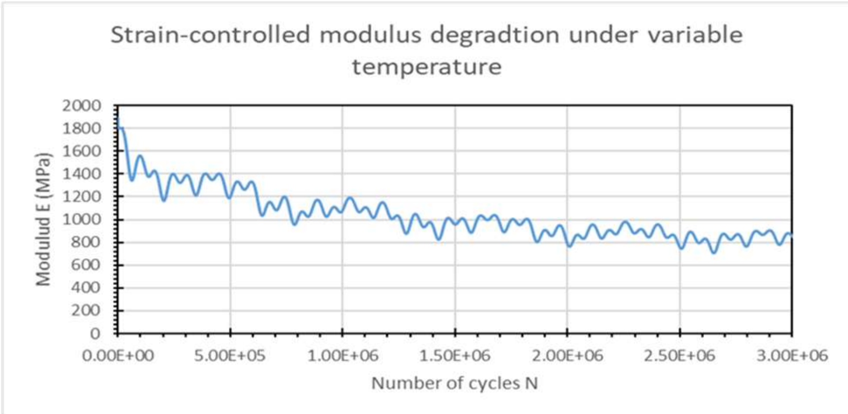
Key functions of the model

1) $N_f = f(\sigma, a, b)$
2) $a,b = f(T)$ (for a particular FBS mixture)
3) $E = f(T)$
4) $(E/E_i) = f(N/N_f)$

Where, N_f is the number of load cycles, T is temperature, a and b are functions of temperature, E is current modulus and E_i is the initial modulus.







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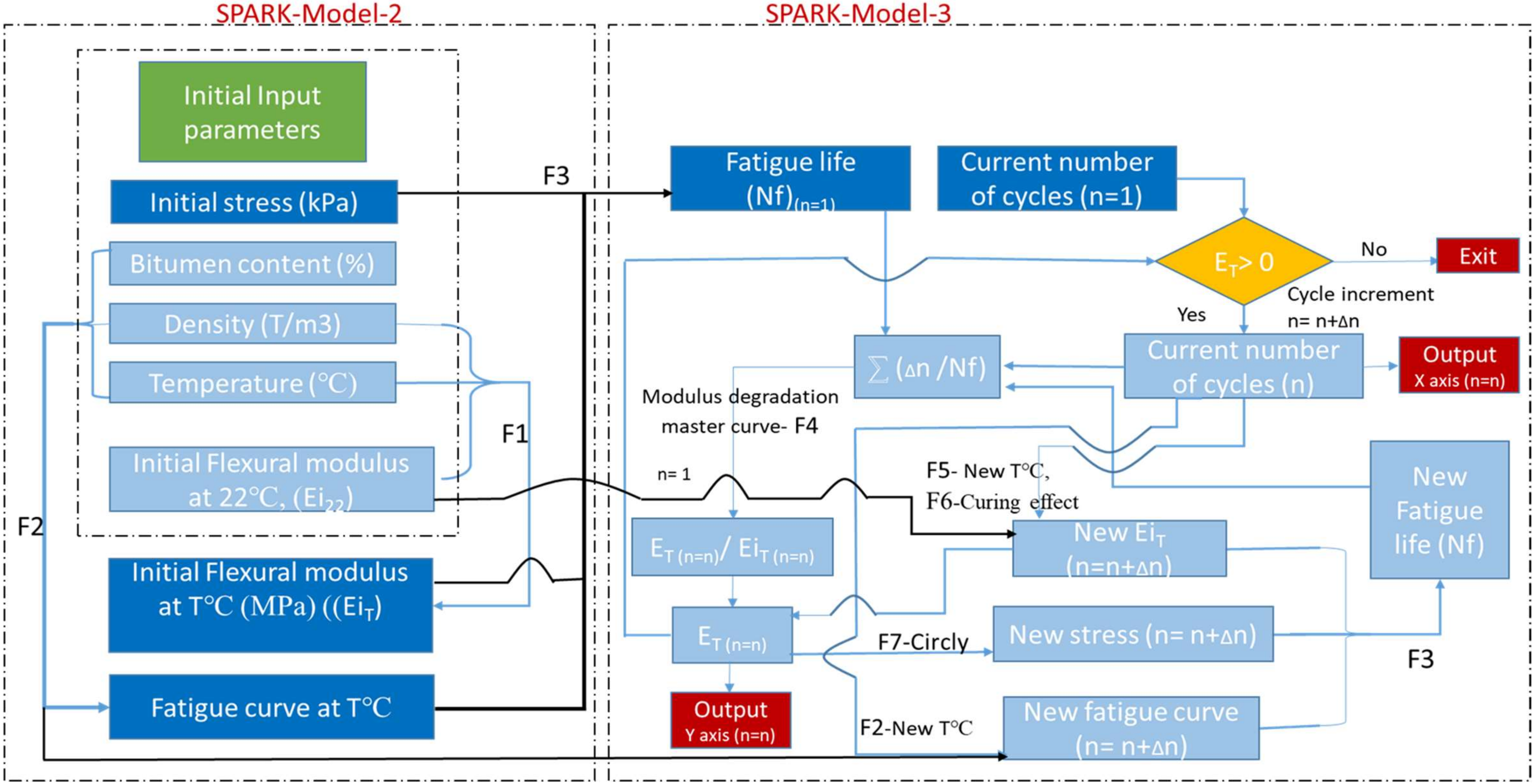
SPARK models for field fatigue life predictions



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Development of new pavement design approach

Field performance Data

Numerical analysis

Development of new fatigue model for field conditions

Validation Process

Material performance

Material classifications
ITS, E,v
Curing methods
Fatigue equations

Why research more?

Cost
Resources

Confidence
Sustainability
Serviceability

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Conclusions

- SPARK Model 2 can be used to predict laboratory fatigue life of FBS materials in stress-controlled mode at different test conditions
- It appears to have a normalised modulus degradation master curve irrespective of the stress level, temperature, and density
- The fatigue life in strain-controlled mode is approximately 20 times higher that in stress-controlled mode in the laboratory
- SPARK Model 3 is proposed to estimate the in-service fatigue life of FBS pavements and the model matches the fatigue test data obtained from ALF study