Fatigue of Asphalt Mixtures, Endurance Limit, Polymer Modifications, Healing

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Fatigue of asphalt mixtures

4 p bending

2 p bending

indirect tension

direct tension

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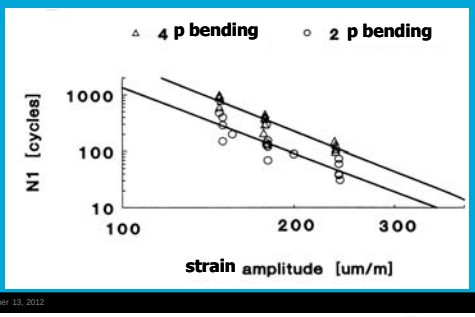
Fatigue resistance is a specimen, not a material property



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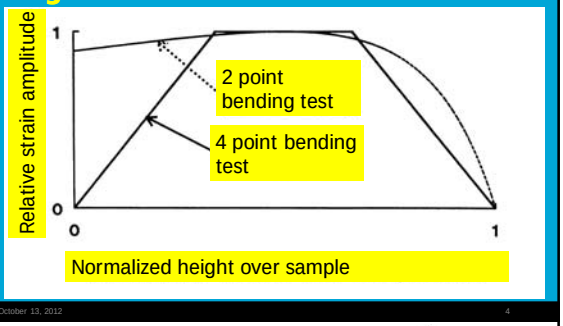
Area in 2 and 4 p test subjected to fatigue



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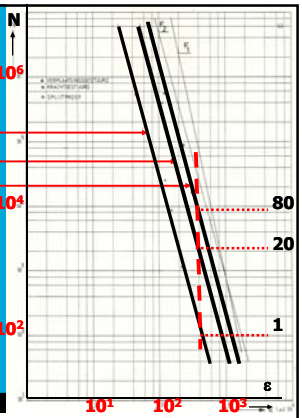
Fatigue resistance is a specimen, not a material property

indirect tension load contr.
4 p bending load contr.
4 p bending displ contr.



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Interpretation of fatigue tests

Input: half sine or haversine displacement signal

Output: residual stress develops; after some time peak load is 50% of initial peak load and load signal becomes sinusoidal

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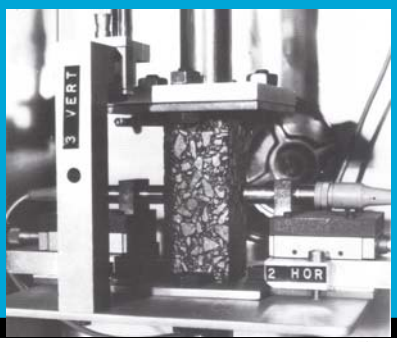
Test set-up



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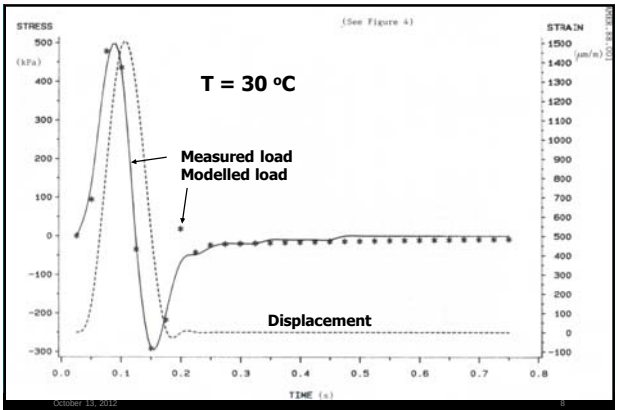

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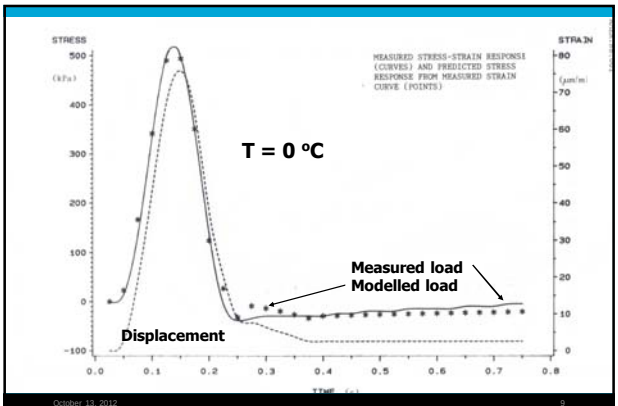

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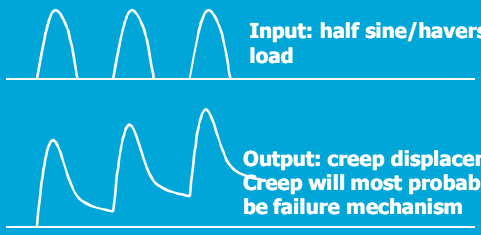
Interpretation of fatigue tests



Input: half sine/haversine load

Output: creep displacement; Creep will most probably be failure mechanism

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Conclusion

- Reported nr of load repetitions to failure is depending on type of test.
- Reported nr of load repetitions to failure is depending on whether test is load or displacement controlled
- Reported applied strains are depending on how test is performed (full sine vs half sine)
- Reported endurance limits are in fact specimen properties

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What is reality?

LINTRACK
Linear tracking device
35 – 100 kN wheel load
20 km/h
Uni and bi directional
Temperature controlled
Built at end/beginning 1980's/1990's

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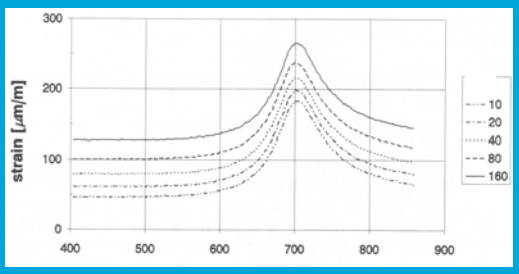
Transversal strain vs nr of load repetitions; residual strains are not taken into account in common design procedures



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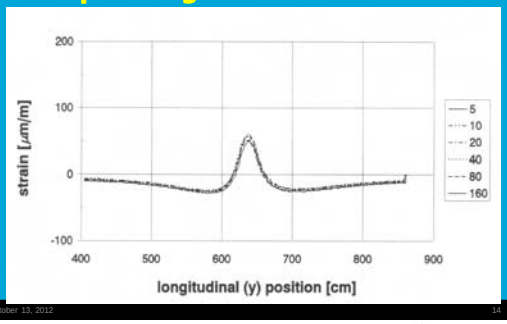
Residual strains do not seem to develop in longitudinal direction



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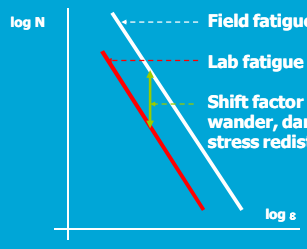
Substantial corrections needed to match lab result with practice



Field fatigue

Lab fatigue

Shift factor (healing, lateral wander, damage propagation, stress redistribution etc. 2.5 - 40)

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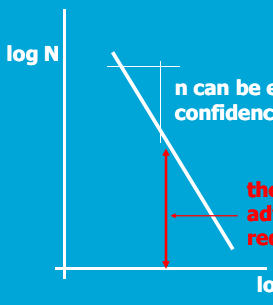
From lab to in situ fatigue relations



n can be estimated with confidence

the big unknown, advanced theories required

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Theory on crack growth in visco-elastic media is of help

- Crack growth law: $dc/dN = AK^n$
- $A = f(S_{mix}, m, \sigma_t, \Gamma)$
- $n = f(2/m$ and void content$)$
- Fatigue law: $N = k_1 (\varepsilon)^{-n}$ =
- $k_1 = f(A, m,$ specimen geometry$)$ it is a specimen dependent parameter !
- m is slope of master curve for stiffness!

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Geometry dependency of lab fatigue relationship

$$N = h^{(1-n/2)} F_c \varepsilon^{-n} / A\, Smix^n$$

$F_c = \int_{c0/h}^{cf/h} d(c/h) / [1.99(c/h)^{0.5} - 2.47(c/h)^{1.5} - 12.97(c/h)^{2.5} - 23.17(c/h)^{3.5} - 24.8(c/h)^{4.5}]^n$

The thicker the beam the lower the fatigue life at same strain level

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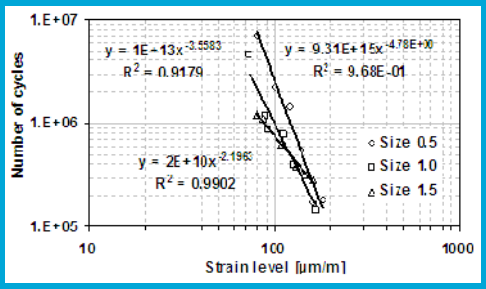
Size effect on 4p beam bending tests



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Endurance limits

Size 0.5	Size 1	Size 1.5
58 µm/m	44 µm/m	37 µm/m

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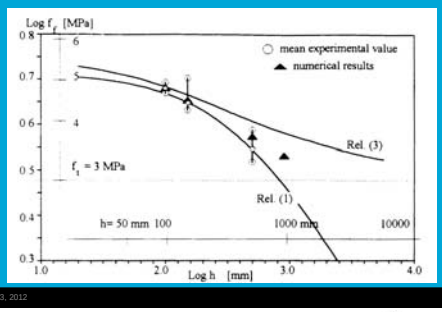
Effect of beam thickness on flexural strength



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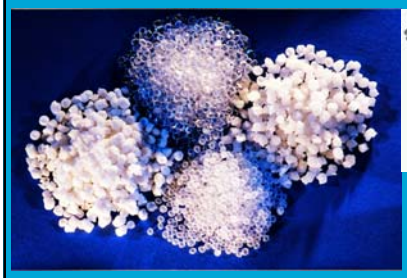
SBS



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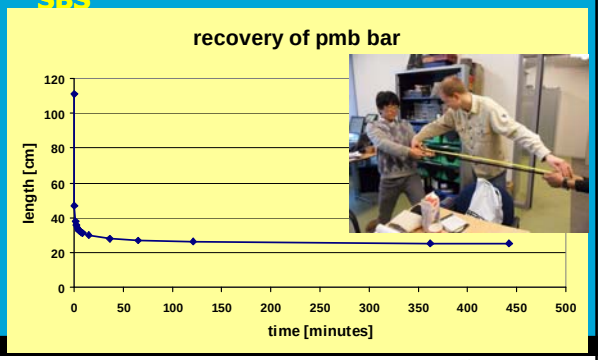
Simple tests to determine effect of SBS



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Simple experiment to show strength of SBS modified asphalt mixtures

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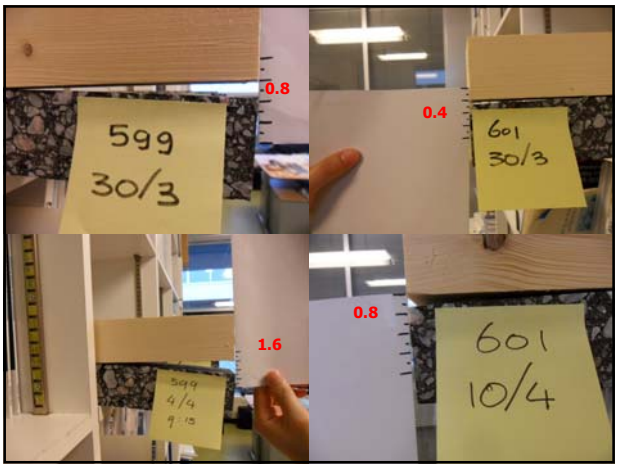
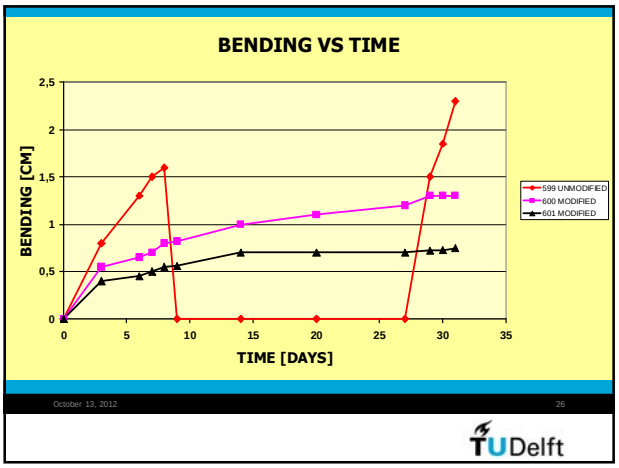
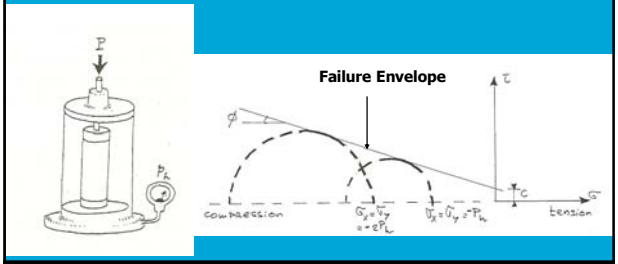




Triaxial Test, Cohesion "C" and Angle of Internal Friction "ϕ"



General Case

- Failure envelope can also be generated by means of tension and compression tests.
- In generalized case, σ is replaced by bulk stress I_1 and τ is replaced by deviator stress parameter J_2

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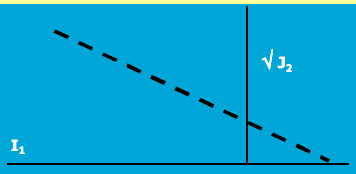
Parameters used in the Failure Envelope Graphs

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3$$

$$J_2 = \frac{1}{2}(s_1^2 + s_2^2 + s_3^2) = \frac{1}{6}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\right]$$



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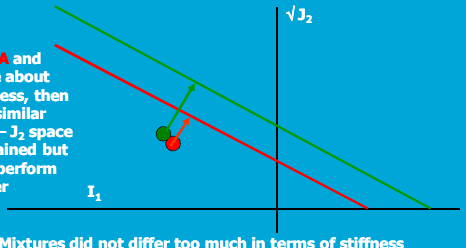
Importance of Failure Envelope

When mat A and mat B have about same stiffness, then an almost similar point in $I_1 - J_2$ space will be obtained but mat B will perform much better



Mixtures did not differ too much in terms of stiffness

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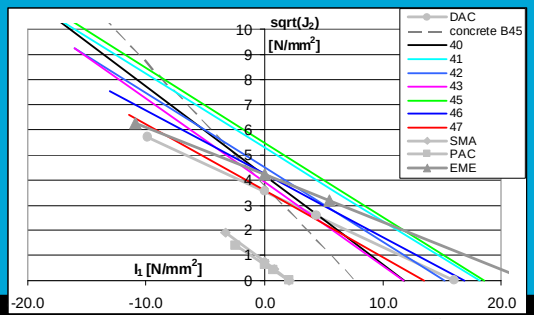
Failure Envelopes at 5 °C and Strain Rate of 0.01 %/s



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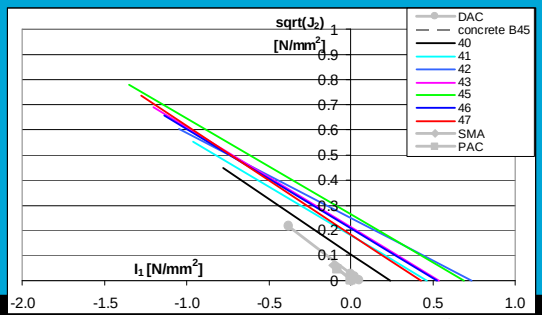
Failure Envelopes at 40 °C and Strain Rate 0.01 %/s



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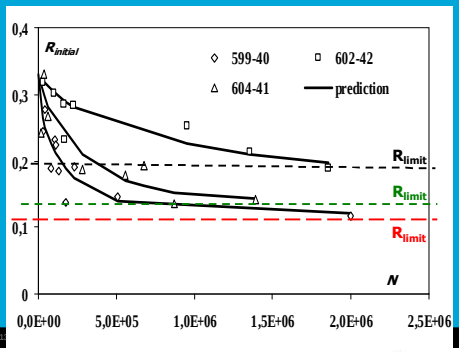
Fatigue Life in terms Stress Ratio



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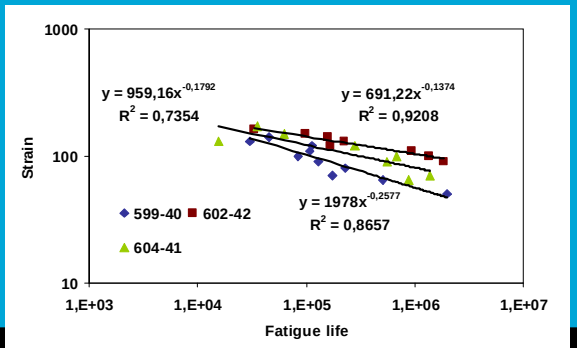
Fatigue Test Results at 20 °C and 8 Hz



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Endurance Limits at 8 Hz and 20 °C

Mixture	$S_{m,initial}$ (GPa)	ε_{limit} (10^{-6} m/m)
599-40	8.9	50
602-42	10.8	80
604-41	10.1	75

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Analyzed Pavement Structures

F = 50 kN; r = 150 mm

Variable thickness; Stiffness of mixtures 40, 41 and 42; μ = 0.35

E = 300 MPa; h = 300 mm; μ = 0.35

E = 100 MPa; μ = 0.35

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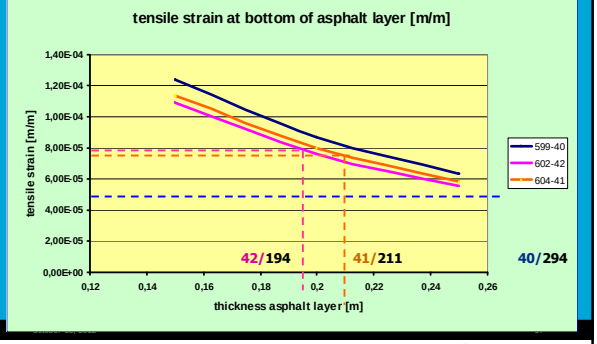
Required Asphalt Thickness



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Conclusion

- Modifying asphalt mixtures with specially designed polymers can result in a significant reduction of the asphalt layer thickness or a significant increase in pavement life when thickness is kept the same

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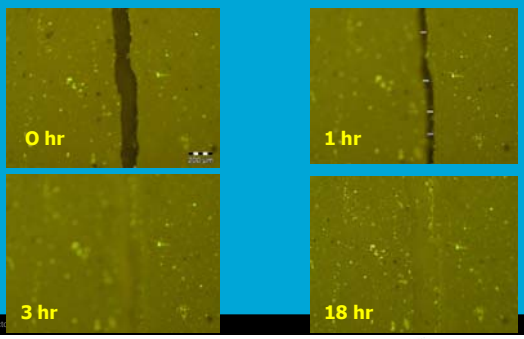
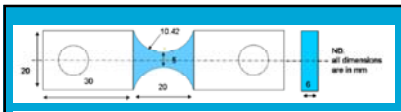
Healing of bituminous mastic

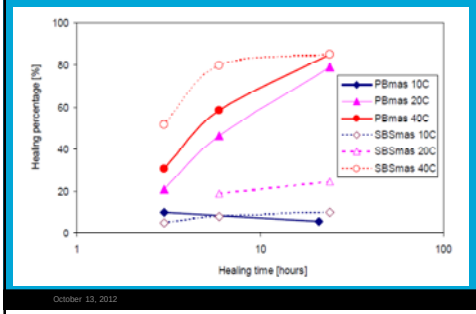
(bitumen + fine aggregate < 63 μm)



TUDelft Source: PhD Qiu

Healing of mastics





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Fatigue and healing

Mixture	Rest period	S_{retest} / $S_{1st\ test}$	N_{retest} / $N_{1st\ test}$
pen 40/60 void content 20 °C / 10 Hz end of test: S_n/S_i = 0.3	3.5 months at 15 °C	0.83	0.03
pen 40/60 void content 5 °C / 8 Hz end of test: S_n / S_N = 0.5	18 months at 15 °C	1	0.6 – 0.9

TUDelft Source: PhD Pramesti and Li

Conclusions

- Healing is recovery of strength and should not be confused with recovery of stiffness
- Most probably, stiffness recovery is due to thixotropy
- Healing of asphalt mixtures is mainly a flow driven process
- Long rest periods are beneficial but only at elevated temperatures
- Temperature is more important than time
- Healing (strength recovery) of asphalt mixtures is limited

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Thank you for your attention
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