Investigation into the Size effect on Four Point Bending Fatigue Tests

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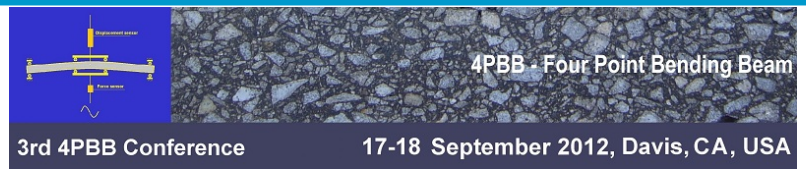
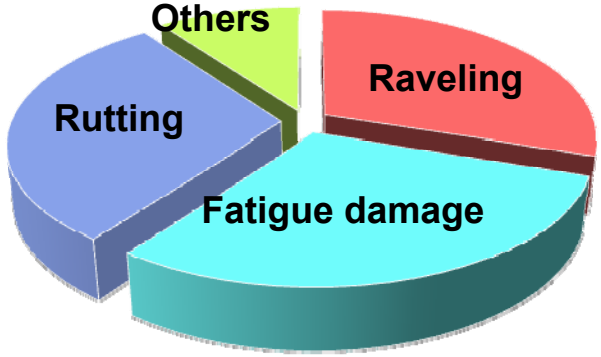


Outline

- Introduction
- Partial healing model
- Experimental work
- Test results and discussion
- Conclusions

Introduction

Fatigue cracking



Failure modes on pavement

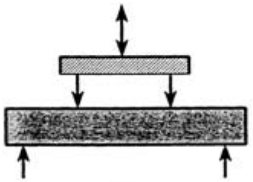
Fatigue cracking

Introduction

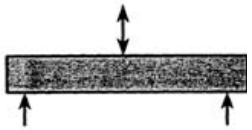
Fatigue tests in the lab

Simple Flexure：

2-point bending



4-point bending



3-point bending

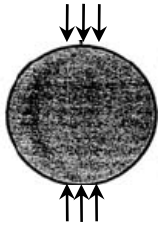
Rotating cantilever

Direct Axial Loading：

Uniaxial tension and compression with Cylindrical specimen

Necked-cylindrical specimen

Diametral Loading：



Indirect tensile test

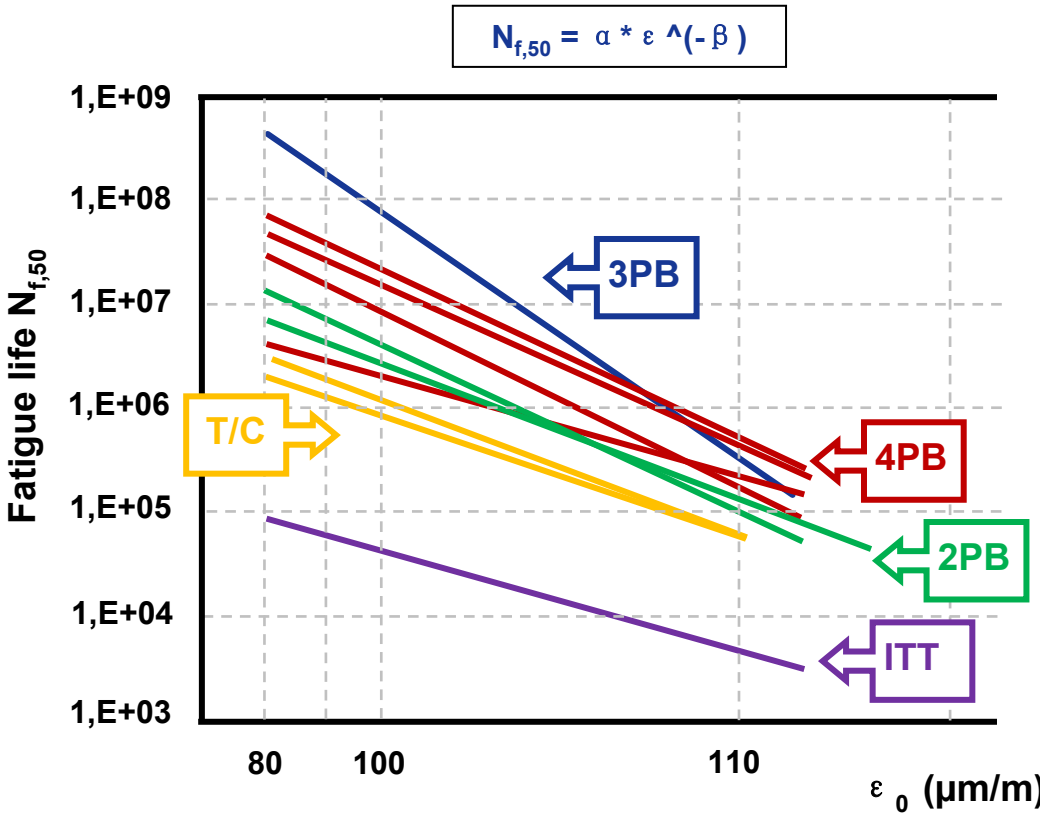
Introduction

4PB test equipments

Introduction

4PB test equipments

RILEM committee TC 182 PEB



T/C: France, Sweden

2PB: France, Belgium

3PB: the Netherlands

4PB: the Nethlands, UK, Poland, Portugal

ITT: Sweden

$N_{3PB} > N_{4PB} > N_{2PB} > N_{T/C} > N_{ITT}$

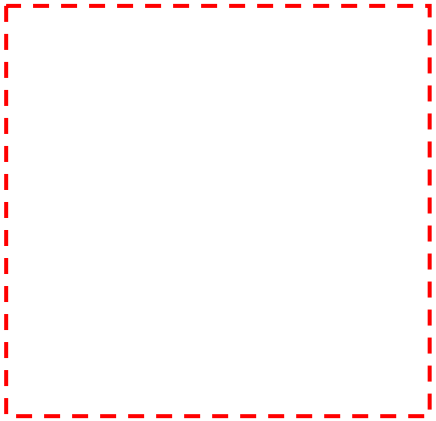
Introduction

Stress-strain distribution

Inhomogeneous test

Specimen property

Homogenous test



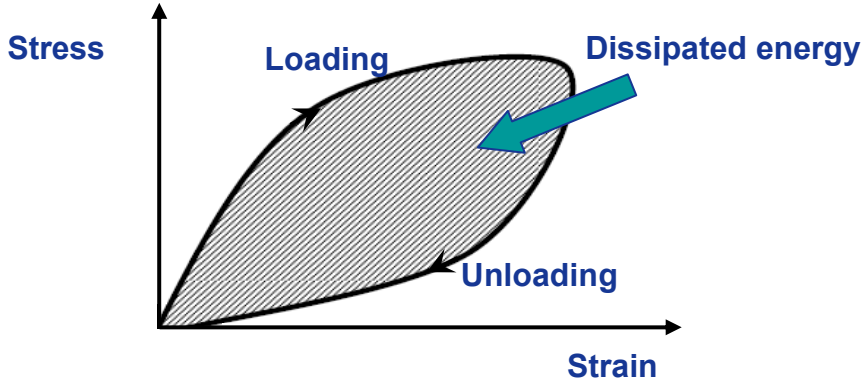
Material property

Introduction

Influence factors for stress-strain field

Partial Healing model

Theory **[A.C. Pronk 2001]**



Total dissipated energy W_{tot}

- **System loss** W_{syst} — can be ignored for good equipment
- **+**
- **Fatigue consumption** W_{fat} — decrease the stiffness and increase the phase angle — $W_{fat} = \delta \cdot W_{dis}$
- **+**
- **Visco-elastic loss** W_{dis} — transformed into heat — $W_{dis} = \pi \cdot \varepsilon \cdot \sigma \cdot \sin\phi$

Partial Healing model

Functions in strain controlled mode

Stiffness damage part Q ⟶ $W_{fat} = \delta \cdot W_{dis} = \delta \cdot \pi \cdot \varepsilon \cdot \sigma \cdot \sin\phi = \delta \cdot \pi \cdot \varepsilon_0^2 \cdot S \cdot \sin\phi$

$$\frac{d}{dt}Q = \frac{d}{dt}\delta \cdot W_{dis} \approx \delta \frac{\Delta W_{dis}}{\Delta t} = \delta \cdot f \cdot \pi \cdot \varepsilon_0^2 \cdot S \cdot \sin\phi$$

Describe the evolution of the loss and storage stiffness modulus during the fatigue test for a unit volume

Loss modulus $$F\{t\} = S \cdot \sin\phi = F_0 - \int_0^t \frac{dQ\{\tau\}}{d\tau}\left[\alpha_1 e^{-\beta(t-\tau)} + \gamma_1\right] \cdot d\tau$$

Storage modulus $$G\{t\} = S \cdot \cos\phi = G_0 - \int_0^t \frac{dQ\{\tau\}}{d\tau}\left[\alpha_2 e^{-\beta(t-\tau)} + \gamma_2\right] \cdot d\tau$$

recoverable damage **unrecoverable damage**

Partial Healing model

Solutions for UT/C fatigue test

Loss modulus

$$F\{t\} = S \cdot \sin\phi = F_0 e^{-Bt}\left[Cosh\{Ct\} + DSinh\{Ct\}\right]$$

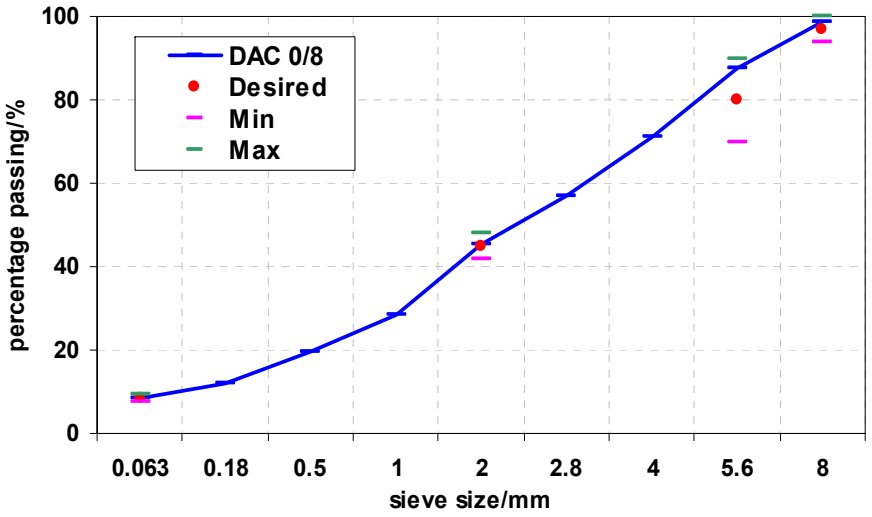
Storage modulus

$$G\{t\} = G_0 - F_0\left[\begin{array}{l}\frac{\alpha_2}{C} e^{-Bt} \cdot Sinh\{Ct\} + \\ \frac{\gamma_2}{\gamma_1}\left(1 - e^{-Bt} \cdot \left[Cosh\{Ct\} + ESinh\{Ct\}\right]\right)\end{array}\right]$$

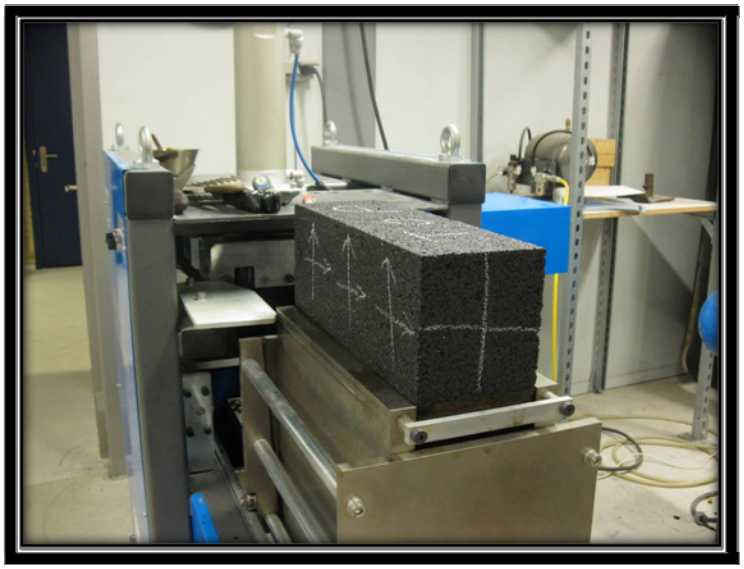
Model parameters: F_0, G_0, α_1, α_2, β^*, γ_1, γ_2

Experimental work

Materials



Gradation of Dense asphalt concrete (DAC 0/8)



PReSBOX compactor

Composition of DAC 0/8

	Crushed stone			Crushed sand	Filler	Binder	Total
Sieve (mm)	8-5.6	5.6-4	6-2	2-0.18	0.18-0.063		
Wt. %	11.2	19.6	21.5	33.2	7.9	6.5	100

Experimental work

Specimen

Size 1.5

Size 0.5 Size 1.0

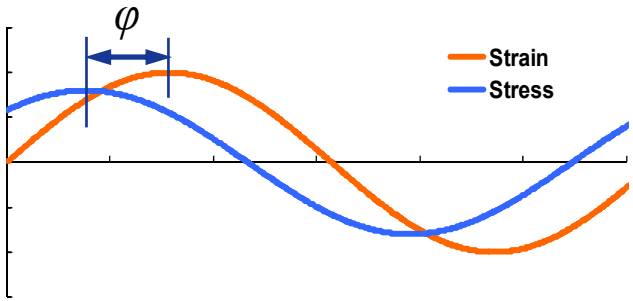
Dimensions of specimen

Specimen size	Length [mm]	Width [mm]	Height [mm]	H/L ratio
0.5	450	50	25	0.056
1.0	450	50	50	0.111
1.5	450	50	75	0.167

Experimental work

Test setup

Size 0.5 Size 1.0 Size 1.5

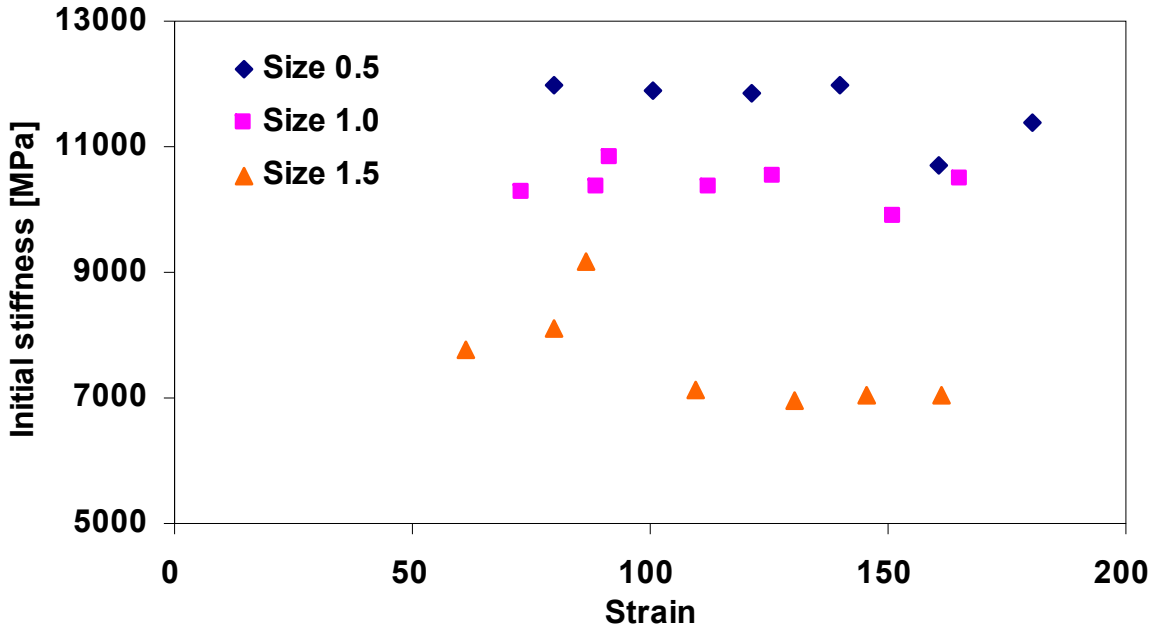


Test conditions

Loading mode	Strain-controlled
Temperature	20 ºC
Frequency	10 Hz
Waveform	sinusoidal
Strain level	50~200 μ m/m

Test results and discussion

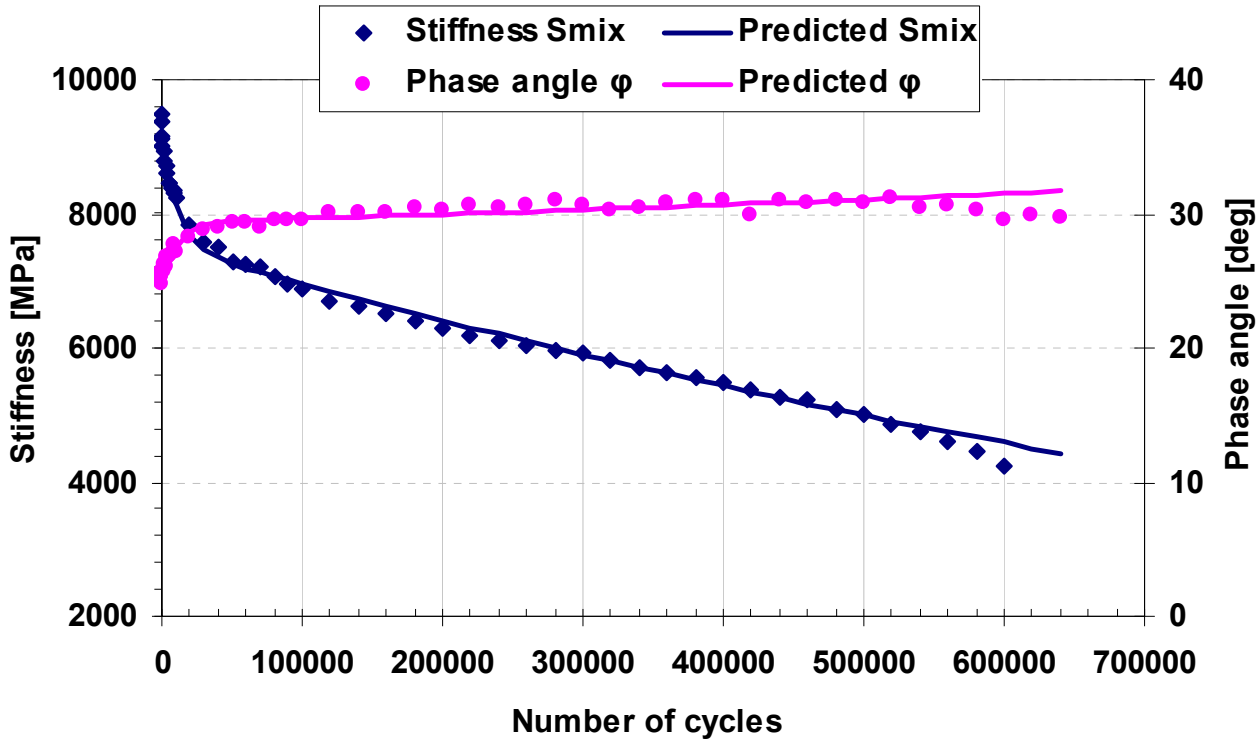
Initial stiffness



$$F_0 = S_0 \times \sin\varphi_0 ; G_0 = S_0 \times \cos\varphi_0$$

Test results and discussion

Evolution of stiffness and phase angle

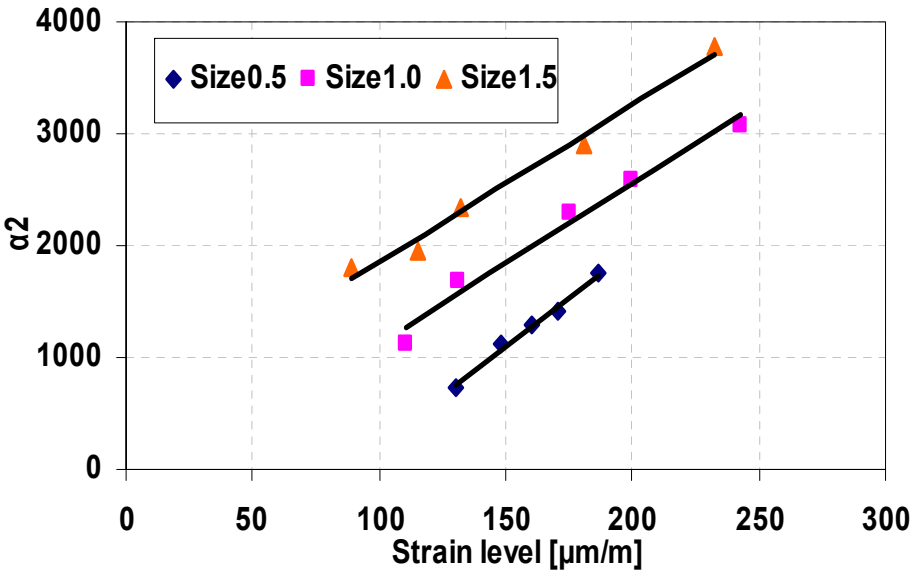


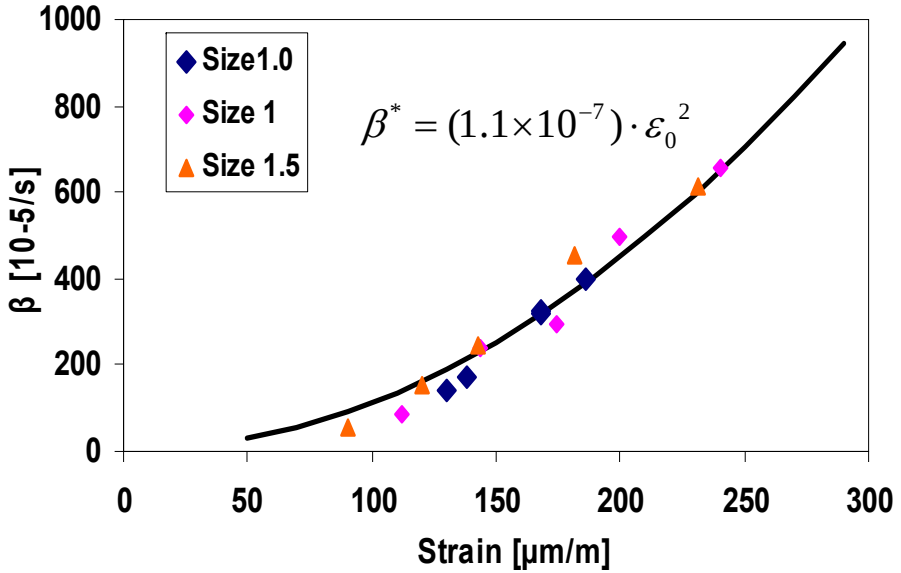
Size 1.0, C-10-9, ε_0 = 100 μm/m

α_1=0; α_2=937; β=68345; γ_1=21; γ_2=47

Test results and discussion

Parameter α_1, α_2 & β^*



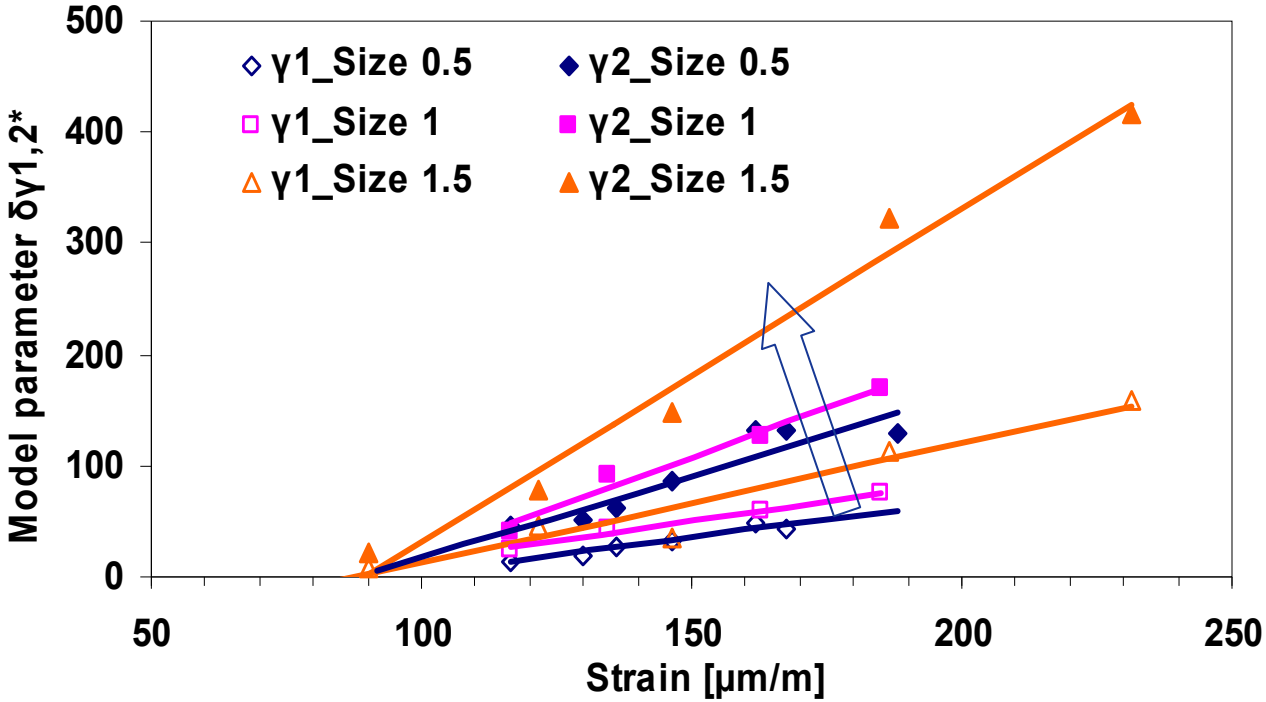


$$\alpha_1 = 0; \alpha_2 = a\cdot\varepsilon + b; \beta^* = \beta\cdot\varepsilon_0^{\,2}$$

Test results and discussion

PH model parameters γ_1 & γ_2

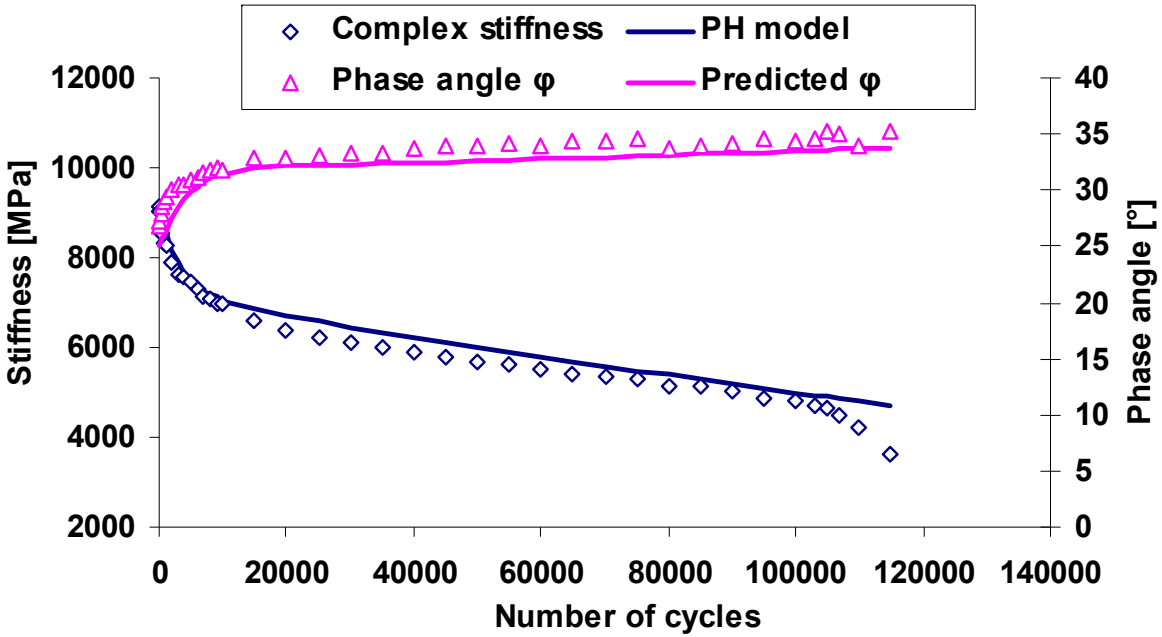
$$\gamma_1 = \gamma_1^* \cdot (\varepsilon_0 - \varepsilon_{\lim it1}); \gamma_2 = \gamma_2^* \cdot (\varepsilon_0 - \varepsilon_{\lim it2})$$



Specimen size	0.5	1.0	1.5
Predicted endurance limit [μm/m]	85~96	91~98	88~94

Test results and discussion

Verification



Size1.0@155 μm/m

$$Relative\ error = \frac{\sum_{1}^{n}\left|\frac{D_m - D_p}{D_m}\right| \times 100\%}{n}$$

D_m: measured data

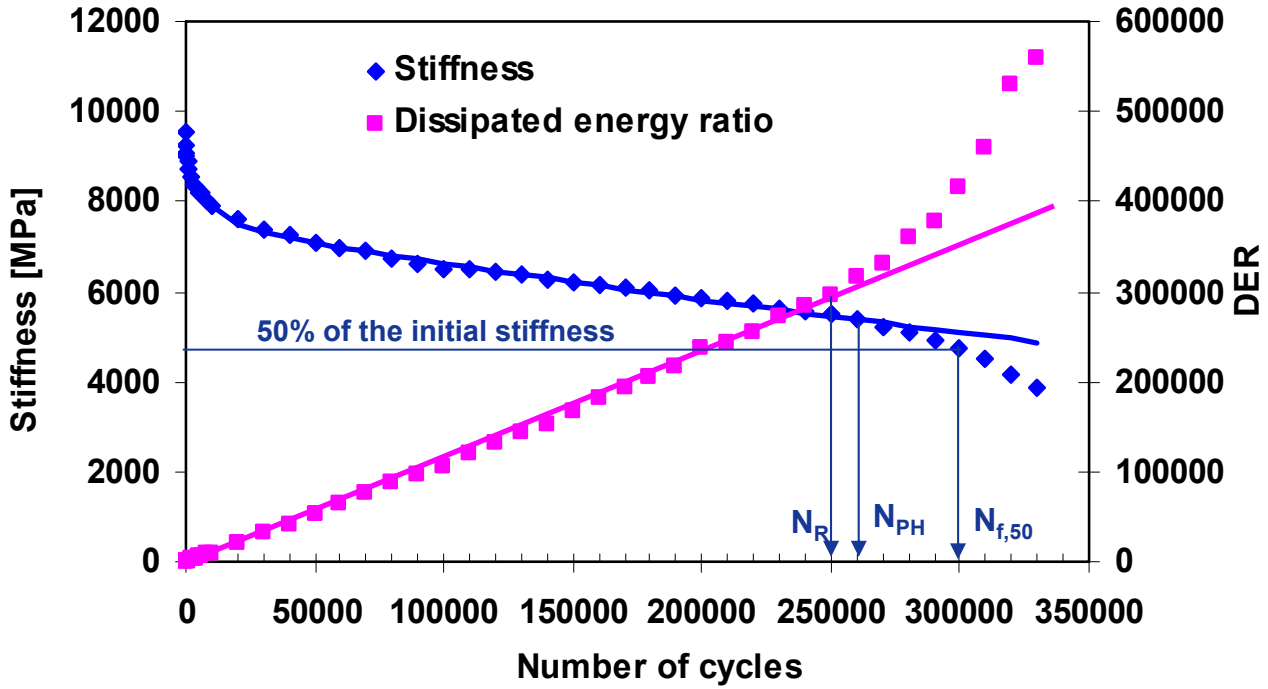
D_p: predicted data

n: total number of data

Model parameters	F_0	G_0	α_1	α_2	β^*	γ_1	γ_2	Relative error of S	Relative error of Φ
ε_0=155 μm/m	3798	8152	0	1941	276	42	101	5.74%	5.28%

Test results and discussion

Fatigue life definition



$N_{f,50}$: traditional fatigue life

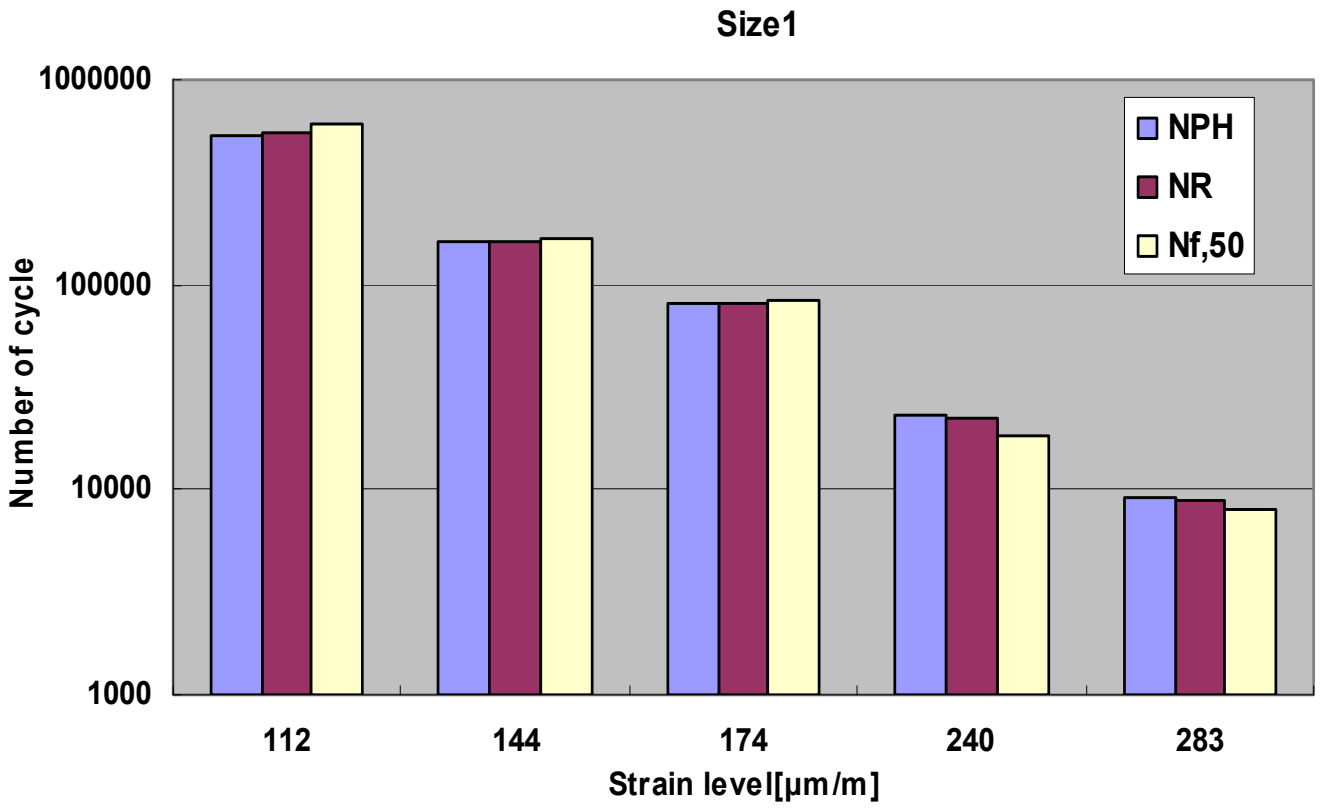
N_R: determined by dissipated energy ratio

N_{PH}: determined by PH model

$$DER = \frac{\sum_{i=1}^{i=N} w_i}{w_N}$$

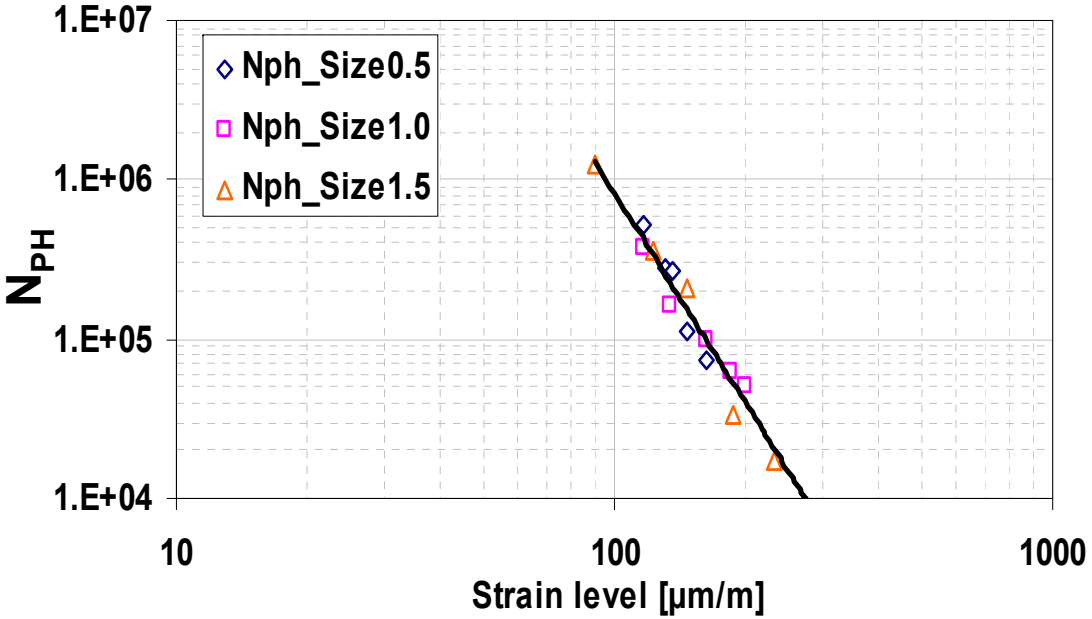
Test results and discussion

Comparison of fatigue life



Test results and discussion

Size effect on fatigue life



$$N_{PH} = k \cdot \varepsilon_0^{\ b}$$

Specimen size	Material coefficient		R^2
	k	b	
0.5	5.73E+14	-4.43	0.86
1.0	2.50E+14	-4.24	1.00
1.5	2.67E+14	-4.74	0.98
0.5+1+1.5	6.21E+14	-4.44	0.98

Conclusions

- PH model provides a good prediction for the evolution of complex stiffness modulus and phase angle in the uniaxial tension and compression test (UT/C test).

- The model parameter γ_1 and γ_2 can be used to determine the range of endurance limit, and and this range does not change significantly with the increase of the specimen size. But more tests are needed to validate this.

- N_{PH} and N_R are close to each other compared to the traditional fatigue life $N_{f,50}$

- The fatigue life obtained from the UT/C fatigue test is independent of the specimen size.

Study in the future

- ✓ Validate of the endurance limit ε_{limit} predicted by the PH model
- ✓ Based on the UT/C test results, apply the PH model to the inhomogeneous fatigue tests, e.g. 4-point bending, 2-point bending fatigue tests, etc.
- ✓ Investigate the influence of temperature, loading mode.


Thanks for your attention !