Monitoring of the creep and the relaxation behaviour of concrete since setting time, part 1: compression.

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Context

- Numeric computations and experimental data are needed for early age prediction of the structures behaviour.
- At early age, thermal and autogenous strains, if they are restrained, induce traversing cracks which lead to service life or safety reduction, and/or aesthetic problems.
- Not only the evolution of the autogenous shrinkage, the thermal deformations, the CTE, the tensile strength and the E-modulus are involved in the cracking process but:

A realistic estimation of the stress field takes into account the evolution of creep and relaxation of the material.

Summary

Cooperation ULB / IFSTTAR: Two newly developed and designed testing equipments for creep and relaxation tests at early age:

TSTM[1] (ULB) & BTJASPE[2] (IFSTTAR)

- Concrete and its characterization at early age.
- New testing device for creep and relaxation in compression
- Results and models.
- Conclusions

1. ***Darquennes, A., Staquet, S., Delplancke, M.-P., Espion B.,*** *Effect of autogenous deformation on the cracking risk of slag cement concretes. Cement and Concrete Composites.available online 17 December 2010.*
2. ***Boulay C., Merliot E., Staquet S., Marzouk O.***, *Monitoring of the concrete setting with an automatic method, 13th International Conference Structural Faults & Repair - 2010, Edinburgh, 15-17/6/2010. Proceedings CD ROM (M. FORDE, editor), Engineering Technics Press, Edinburgh, U.K., 11 pp., ISBN 0-947644-67-9. (Book of Abstracts: ISBN 0-947644-66-0; p.98).*

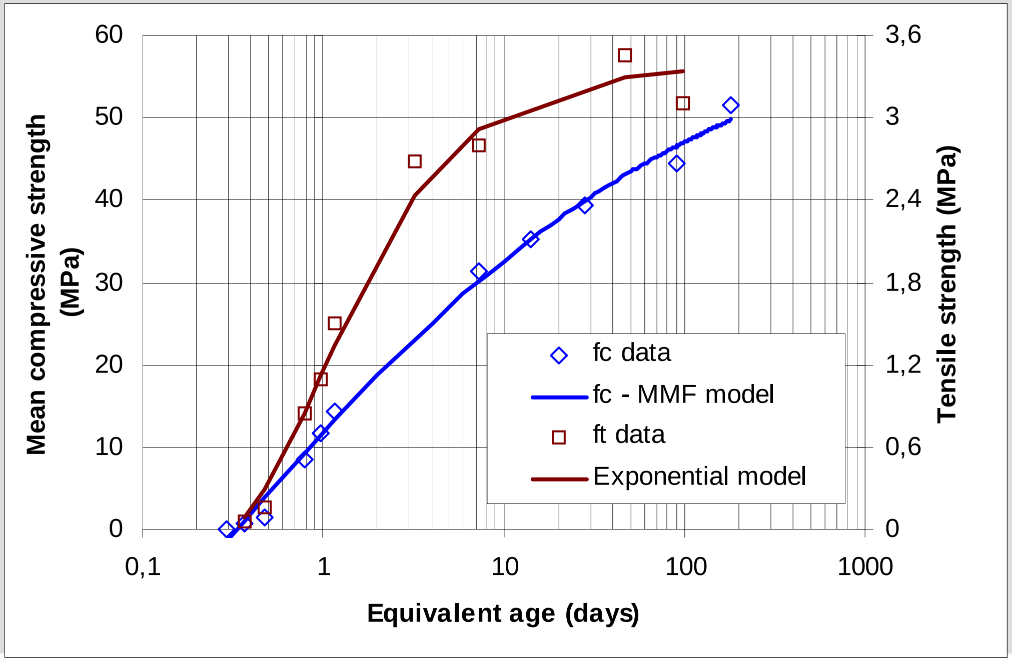
Concrete: compressive and tensile strentgh

Components	Mass (kg /m^3)
CEMI 52.5 N PMES CP2	340
Sand (Bernières 0/4)	739
Gravel (Bernières 8/22)	1072
Total water	184

Mix proportions

w/c = 0.54

Low autogenous shrinkage



Strength development

$$f_{cm}(t) = \frac{a\,b + c\,t_{eq}^{\,d}}{b + t_{eq}^{\,d}}$$

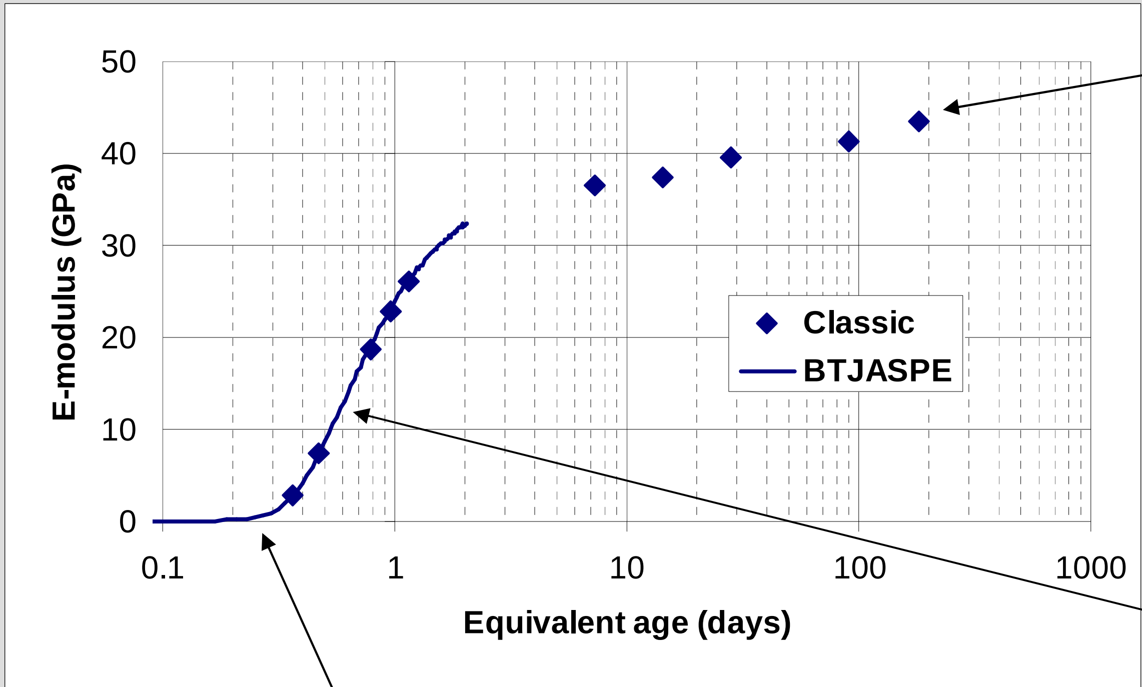
$$f_{ct,\,sp} = a\,e^{-\frac{1}{t_{eq}}} - b$$

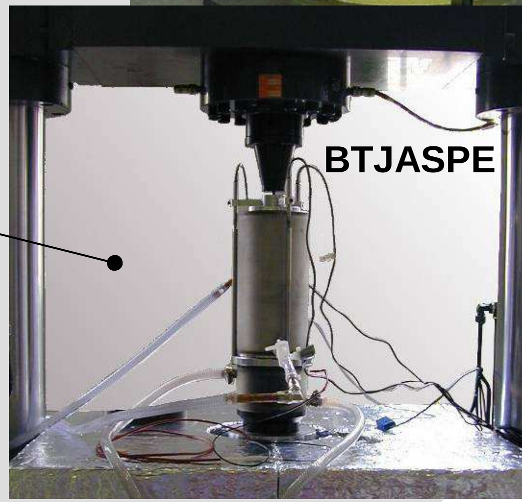
Application:

creep and relaxation loadings.

Concrete: Young's modulus monitoring

E_0 = f(age) determination for modeling



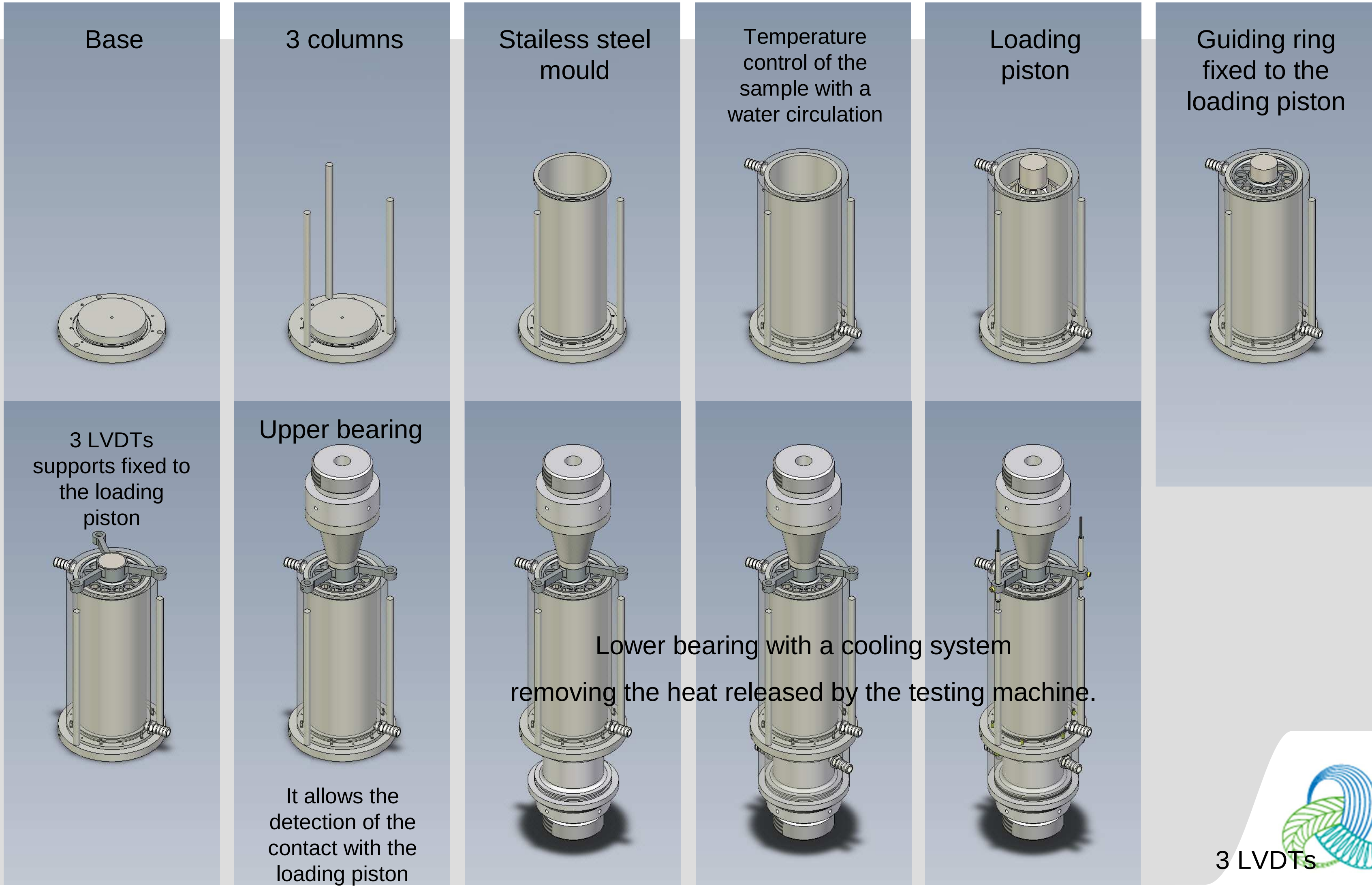


t_0 detection (7 hours).

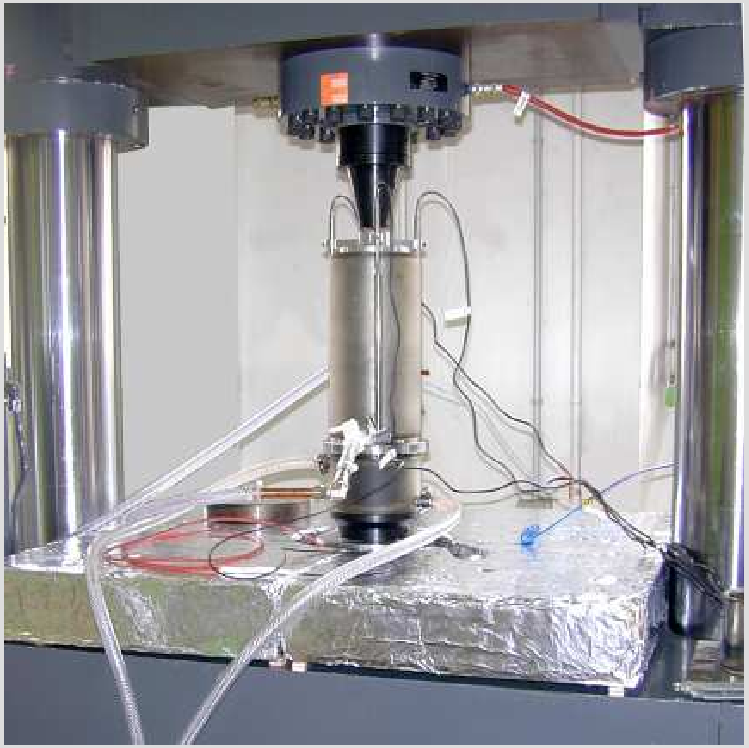
The sample behaves like a solid.

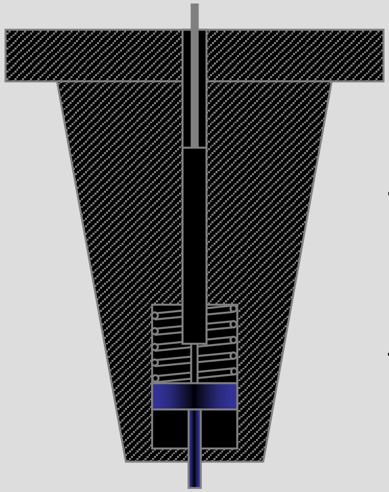
The creep begins to exist.

BTJASPE: E-modulus monitoring but also adapted for creep and relaxation at early age.



BTJASPE, test setup and upper bearing

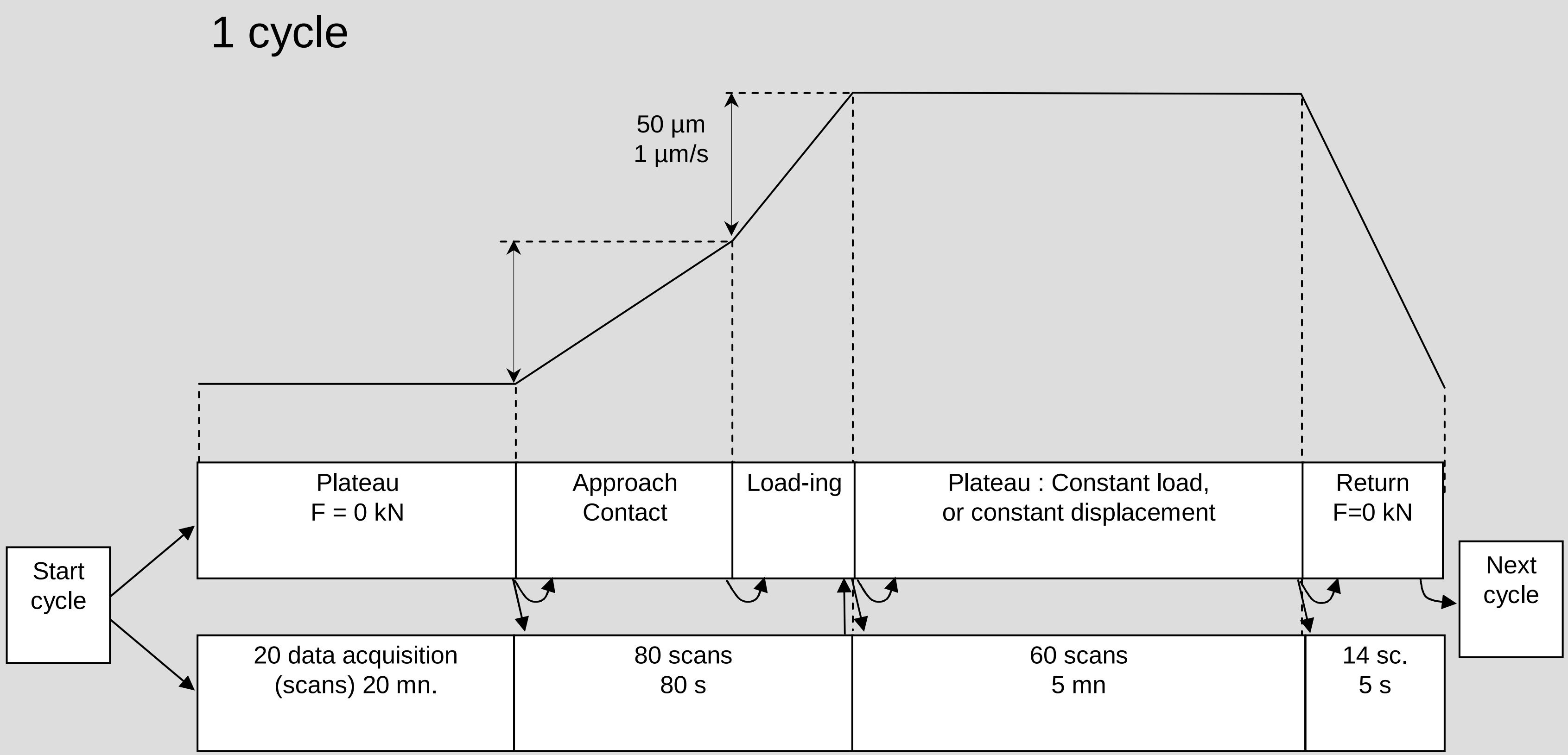




The upper bearing is equiped with a probe detecting the contact with the loading piston.

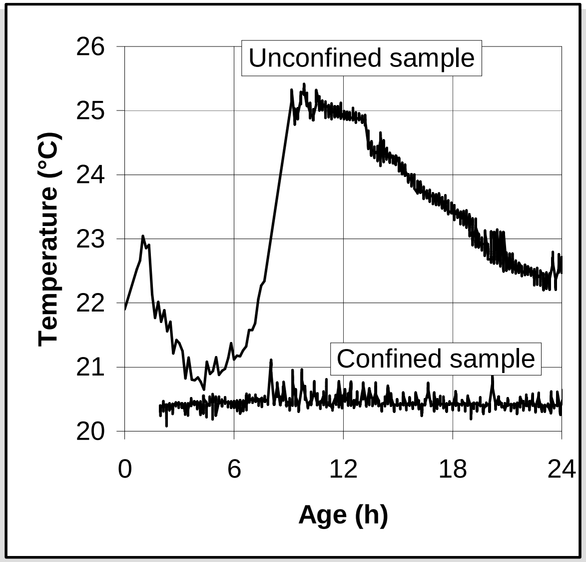
The circulation of water around the sample allows a perfect control of the temperature. Maturity is then well determined.

BTJASPE, loading protocol



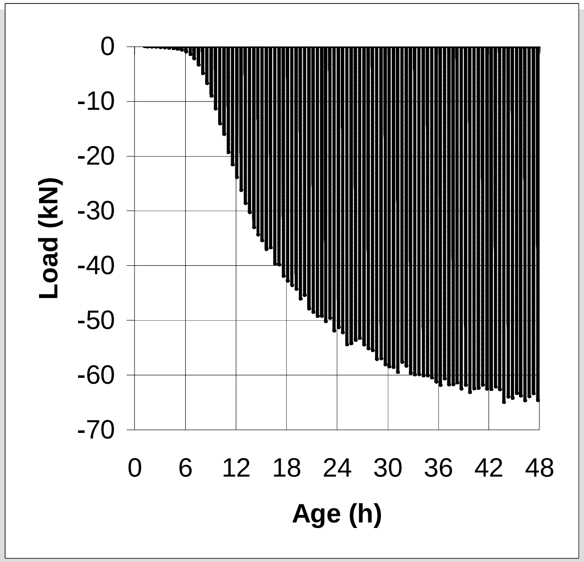
- 1 cycle / 30 mn – 48 h recordings: 96 cycles
- Two tests performed : one creep test and one relaxation test.

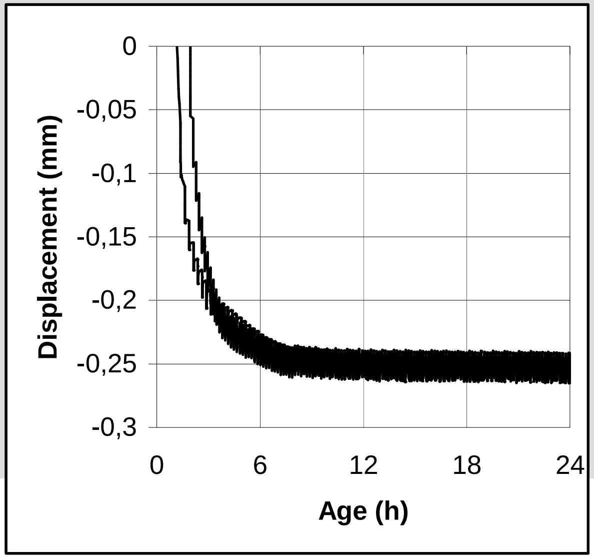
Results: concrete characterization



Temperatures

Load increasing





Residual strain &
autogenous shrinkage

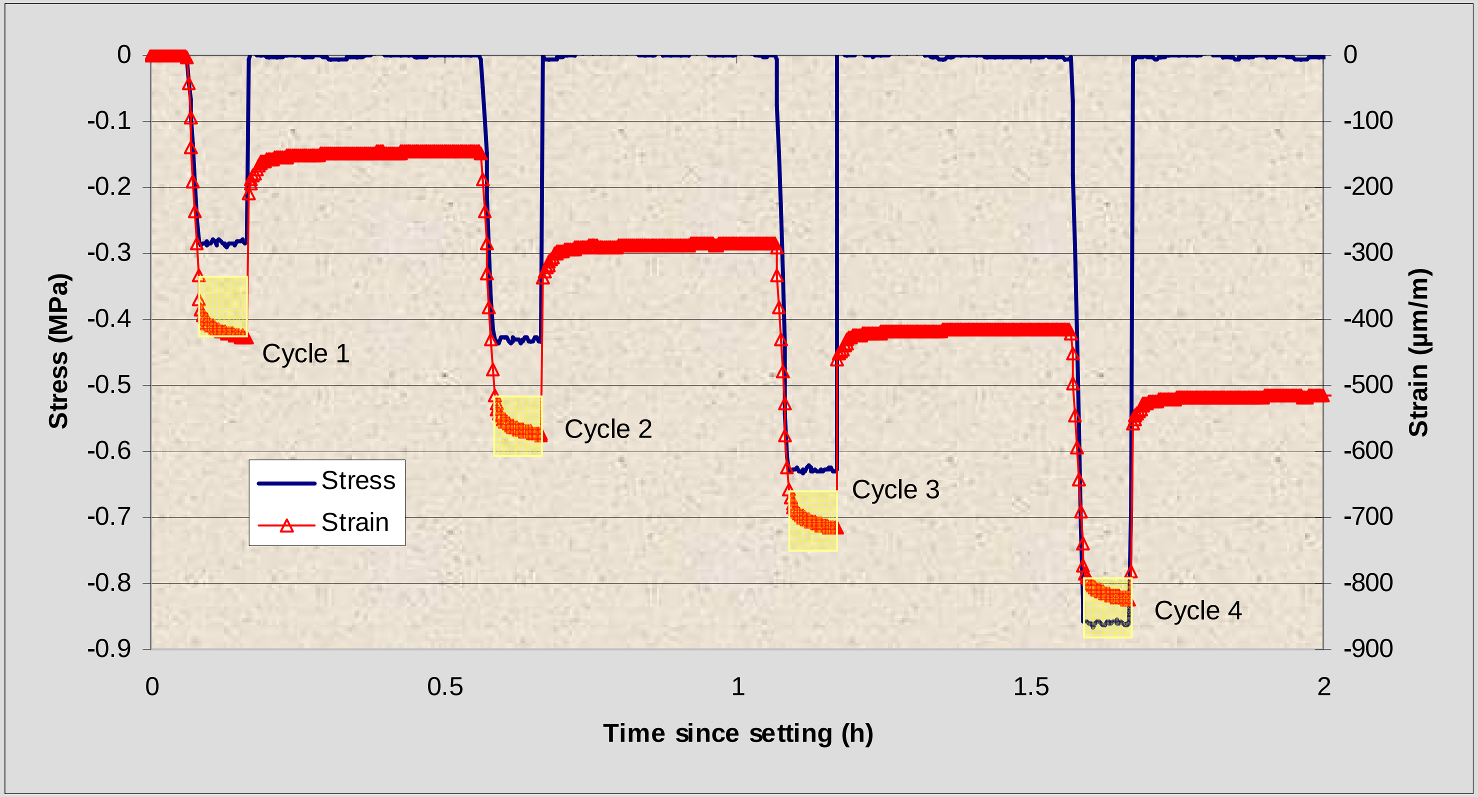
E-modulus monitoring

Results: several typical creep records

Setting time: 7 h

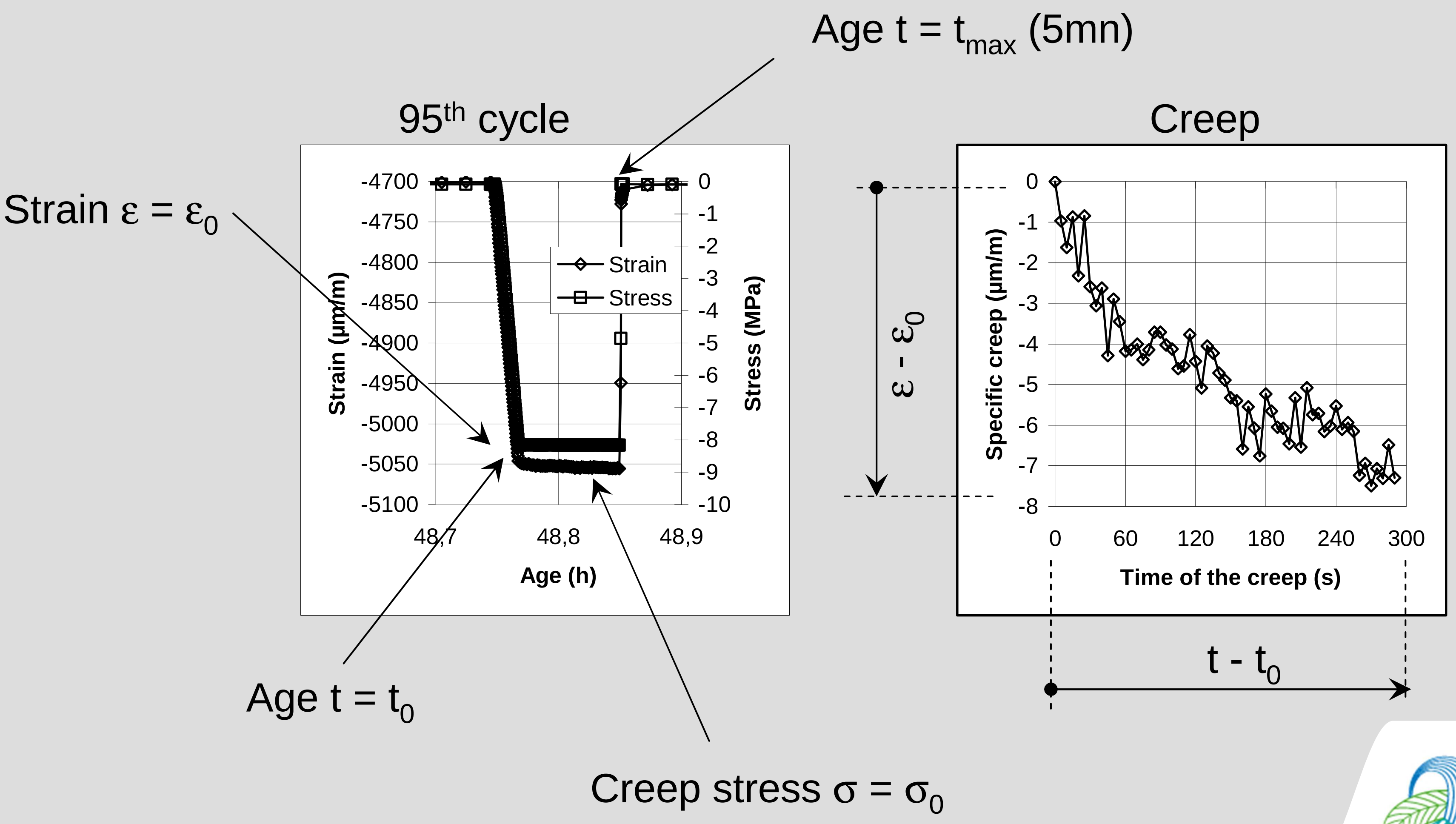
$\varepsilon_0(t)$ = 350 µm/m

$\sigma_0(t)$ increases



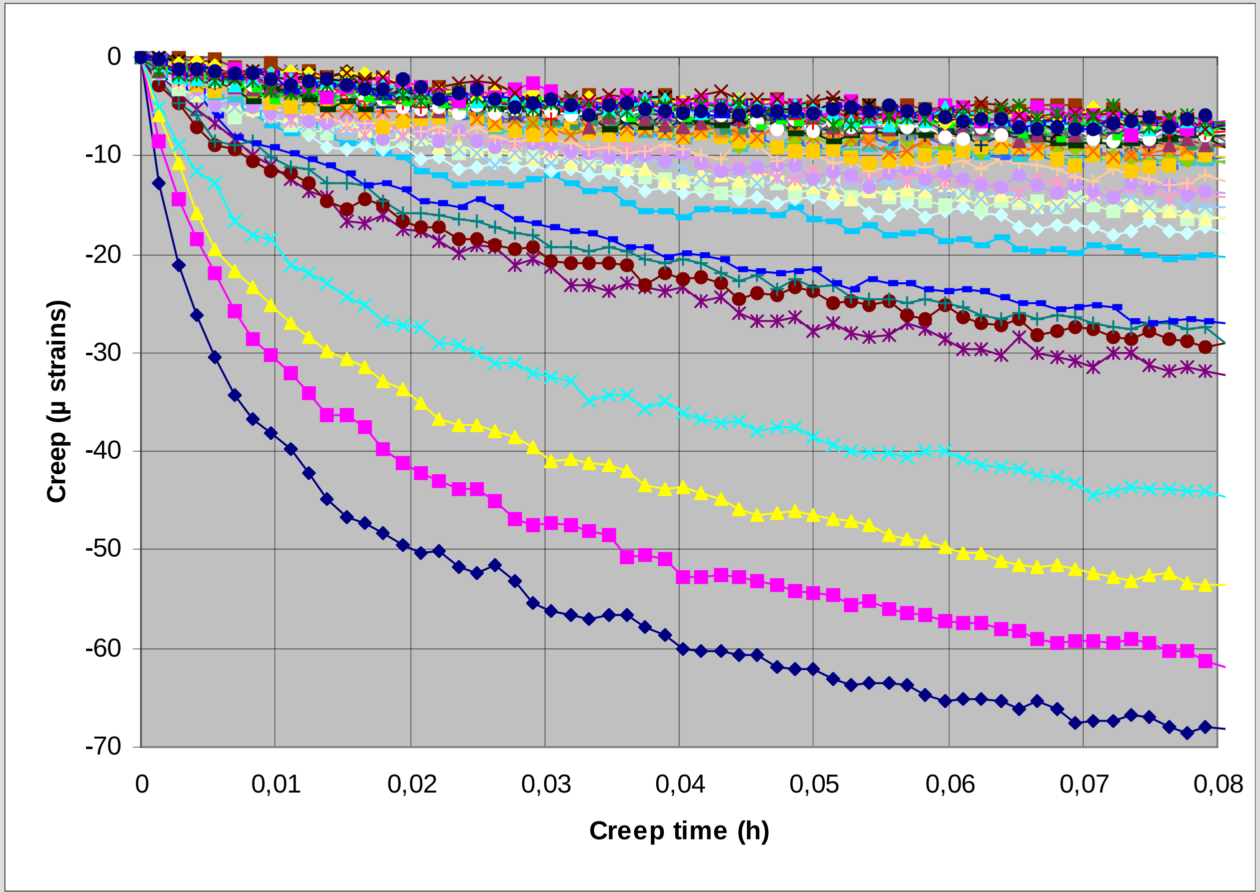
Presented creep observations: yellow windows

Results: one typical creep record



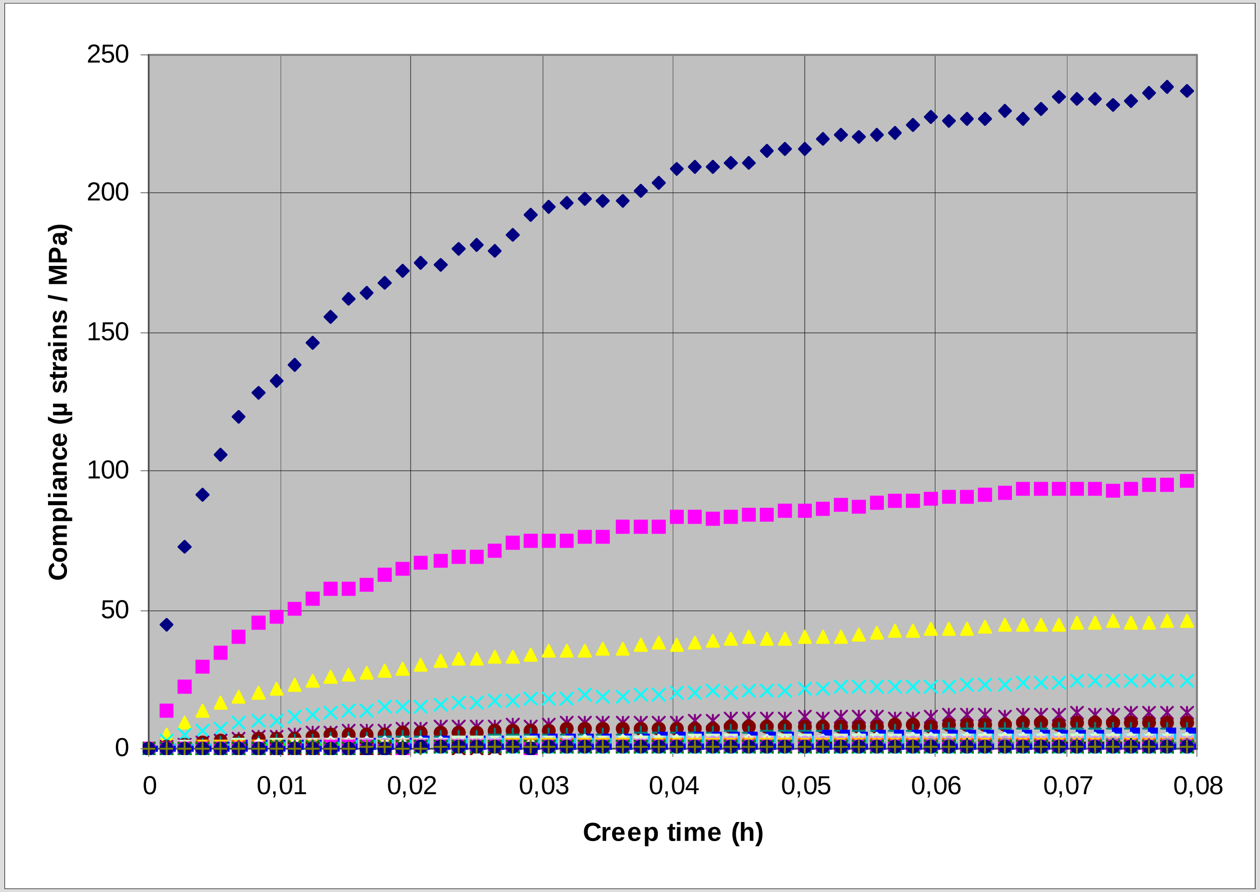
Results: creep data (1/5)

Specific creeps $J_c(t-t_0)$, $J_e(t)=1/E_0(t)$ removed.



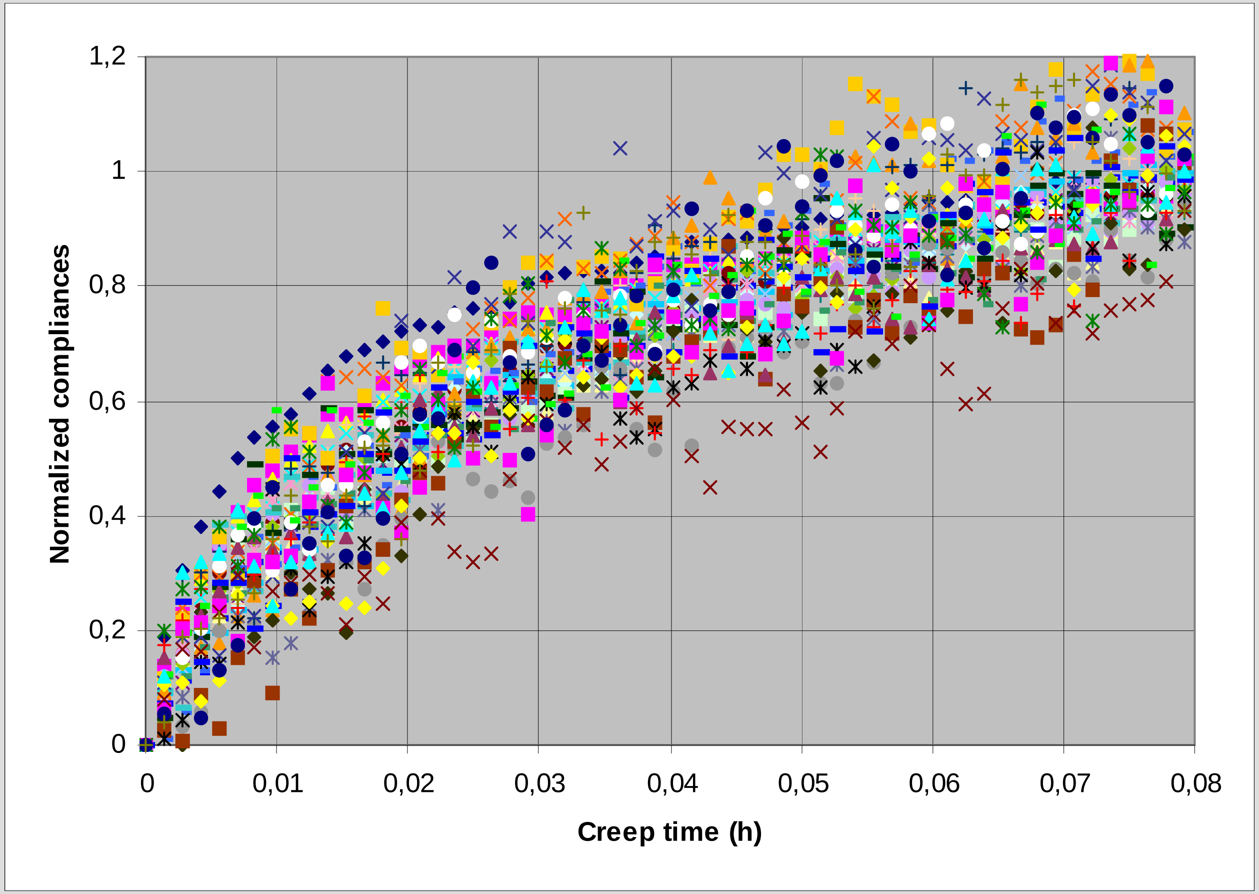
Results: creep data (2/5)

Shifted creep curves : t_0, ε_0=0

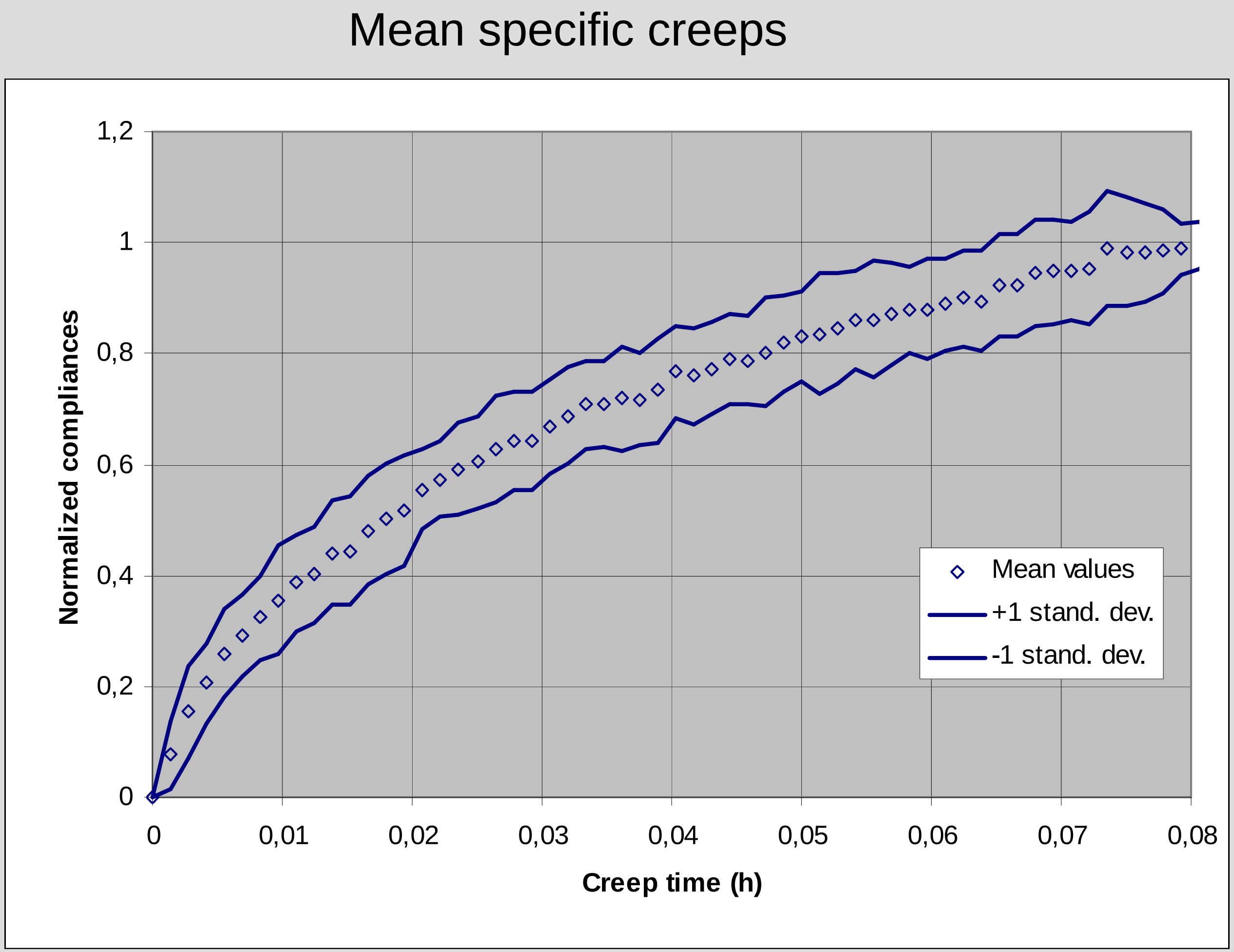


Results: creep data (3/5)

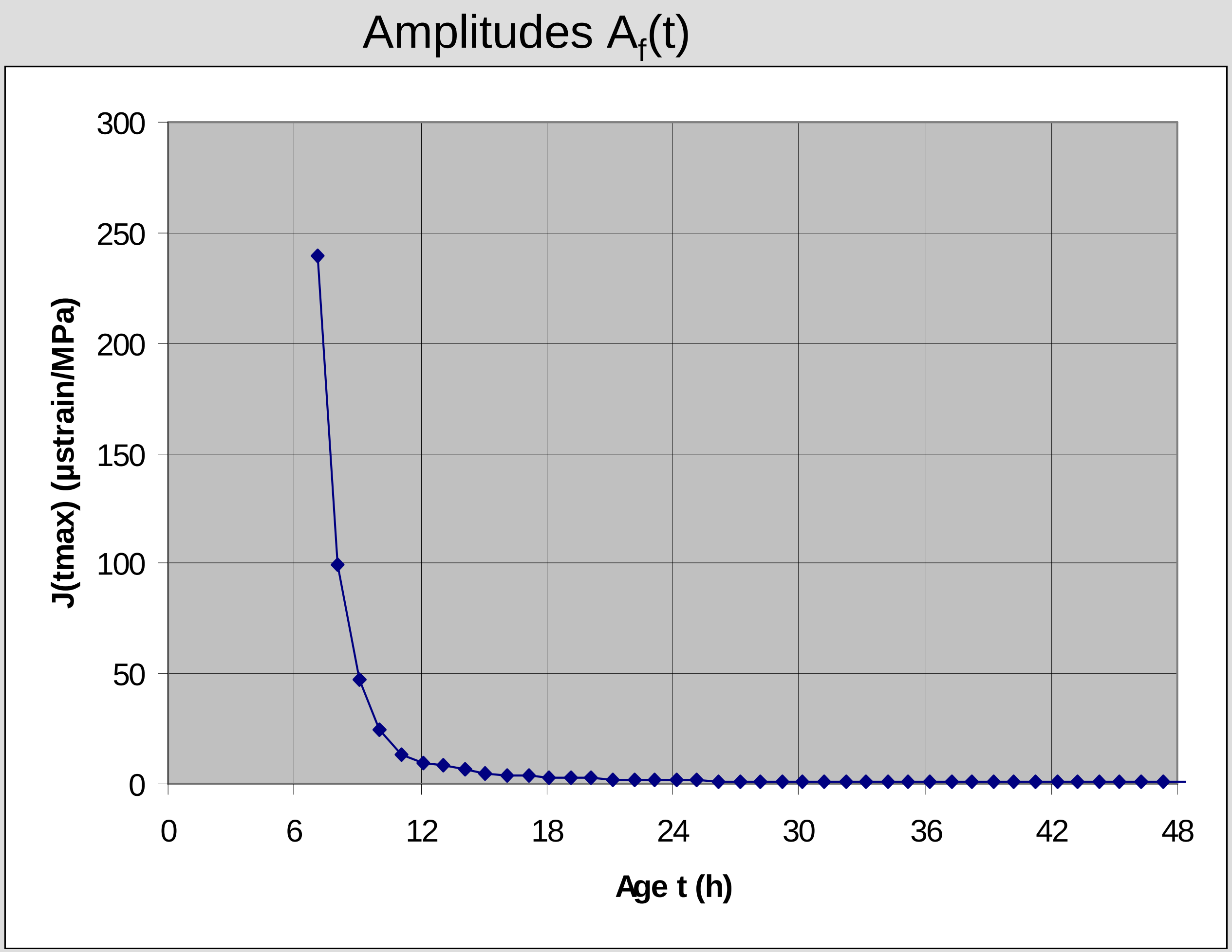
$\Omega(t-t_0) = J_c(t-t_0) / J_c(t=5mn)$



Results: creep data (4/5)

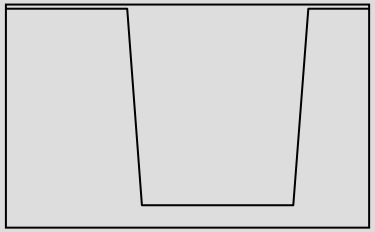


Results: creep data (5/5)

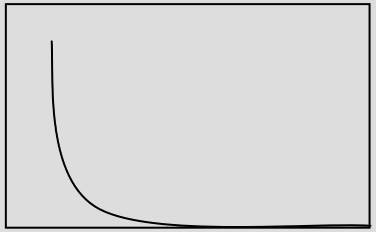


Results: creep modeling

$\Delta\varepsilon(t) =$



X



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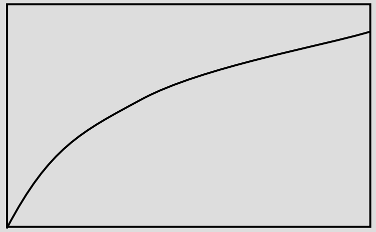


$\sigma_0(t) = \varepsilon_0 \, E_0(t)$ | $A_{c5}(t)$ | $\Omega(t-t_0)$

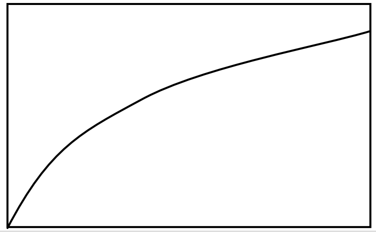
Stress term

Specific Creep Amplitude term

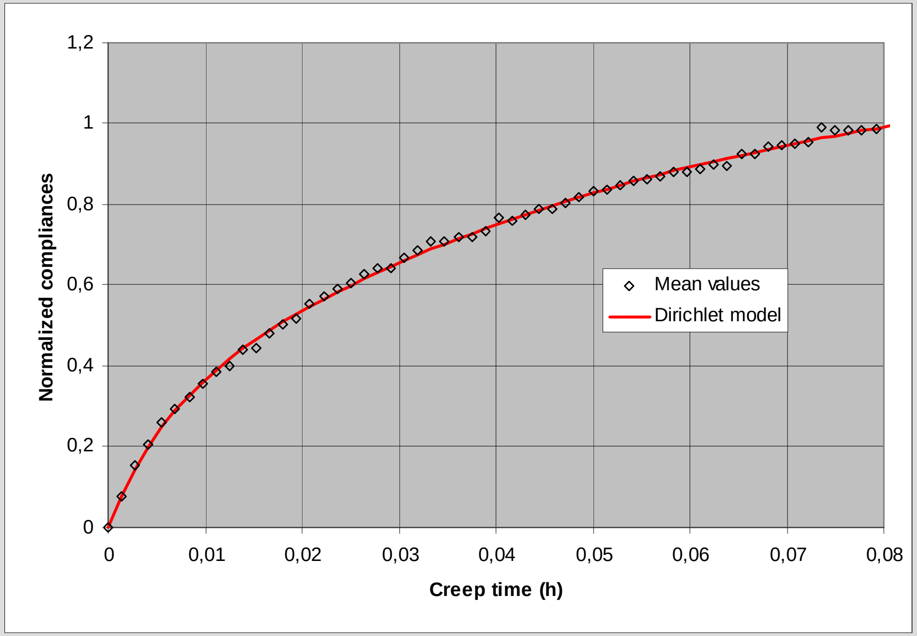
Dimensionless term

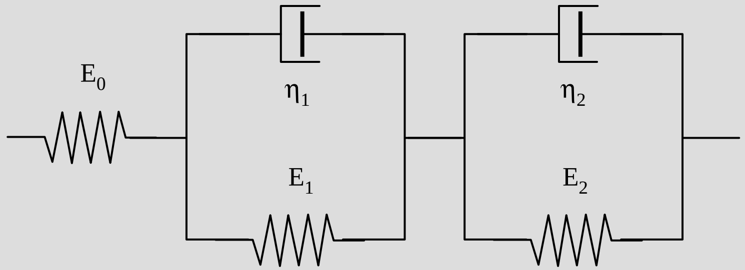
Fitted experimental data

Results: creep kinetic (dimensionless term)



$\Omega(t-t_0)$



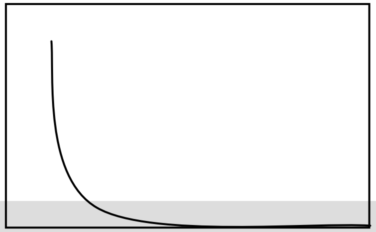


E_1 (MPa)	1,04
E_2 (MPa)	4,20
τ_1 (h)	0,0528
τ_2 (h)	0,00548

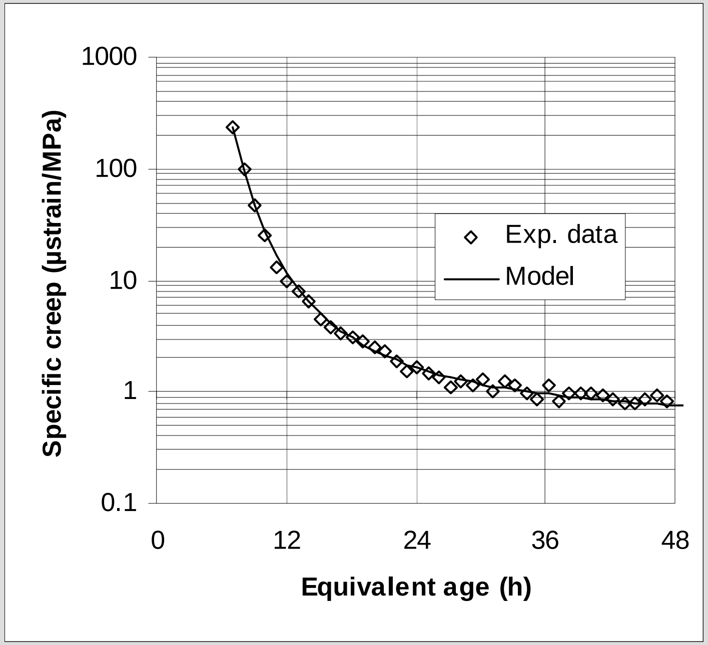
$$J(t-t_0)-\frac{1}{E_0}=\frac{1}{E_1}\left[1-\exp\left(-\frac{t-t_0}{\tau_1}\right)\right]+\frac{1}{E_2}\left[1-\exp\left(-\frac{t-t_0}{\tau_2}\right)\right]$$

$\tau_1 = \eta_1 / E_1$ et $\tau_2 = \eta_2 / E_2$

Results: creep amplitude



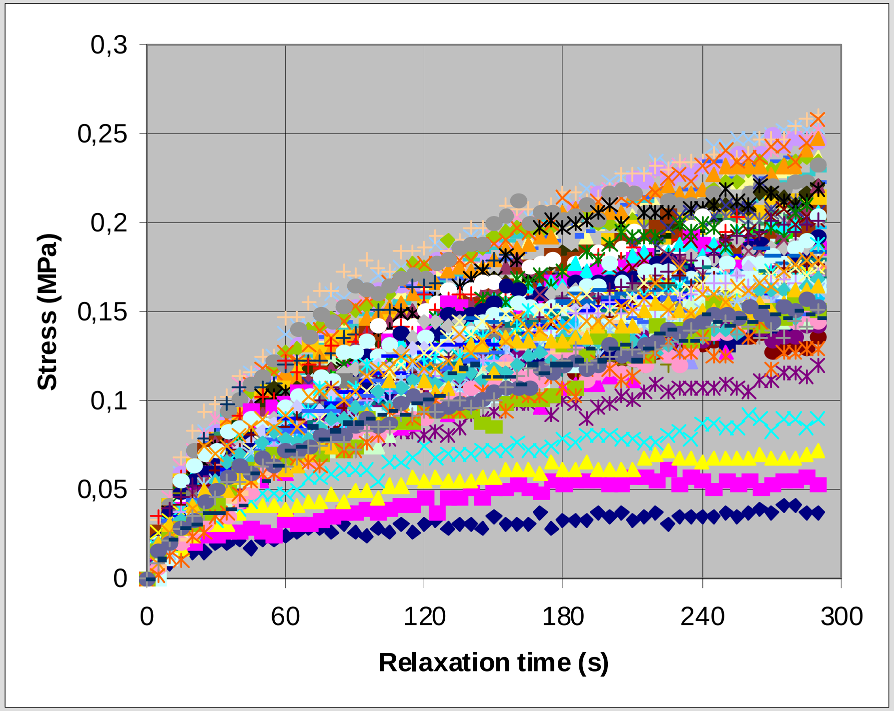
$A_{c5}(t)$



Great accuracy required just after setting and later.

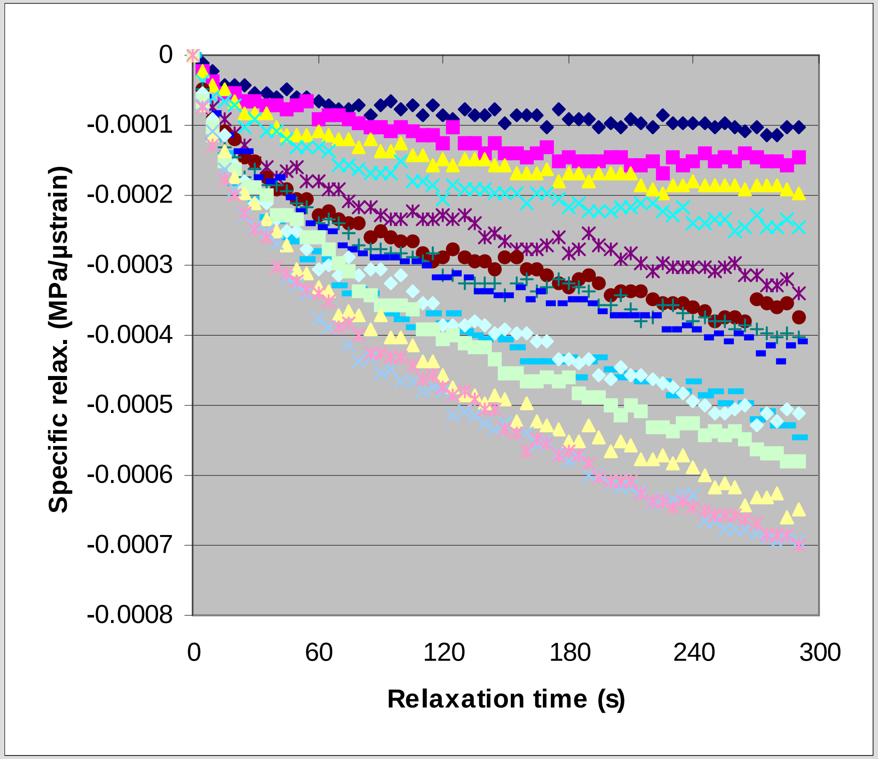
$A_{C5}(t_{0i}) = 0.155 \exp(51.98 / t_{0i}) + 0.3$

Results: relaxation data (1/5)



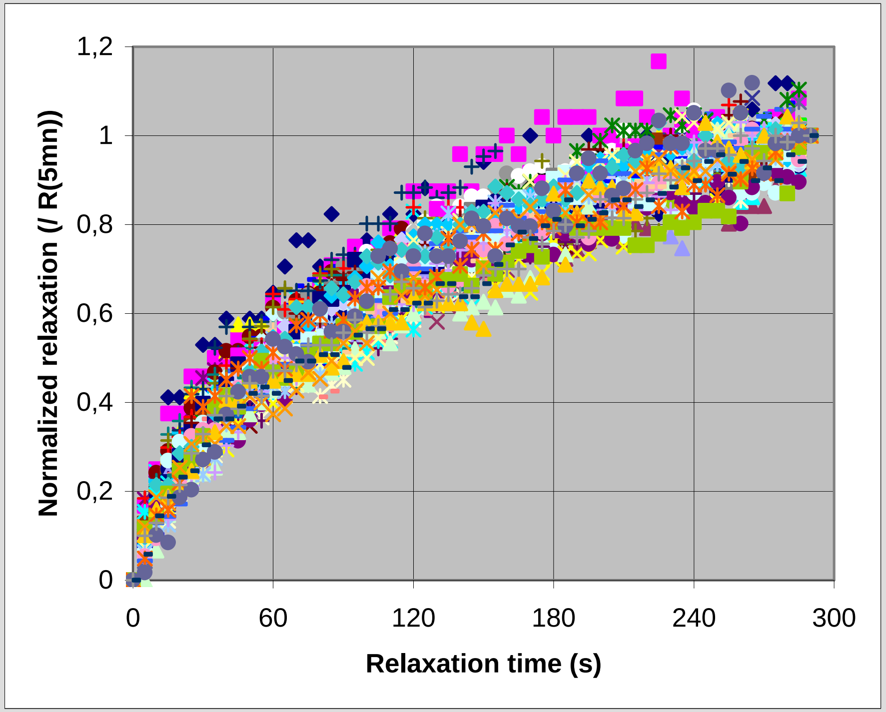
Relaxation

Results: relaxation data (2/5)



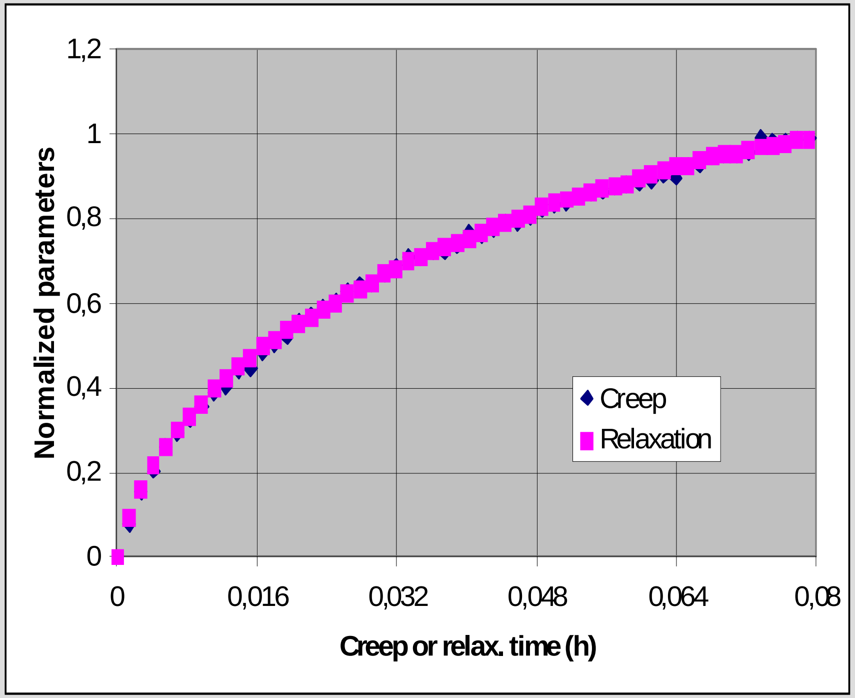
Specific relaxation

Results: relaxation data (3/5)



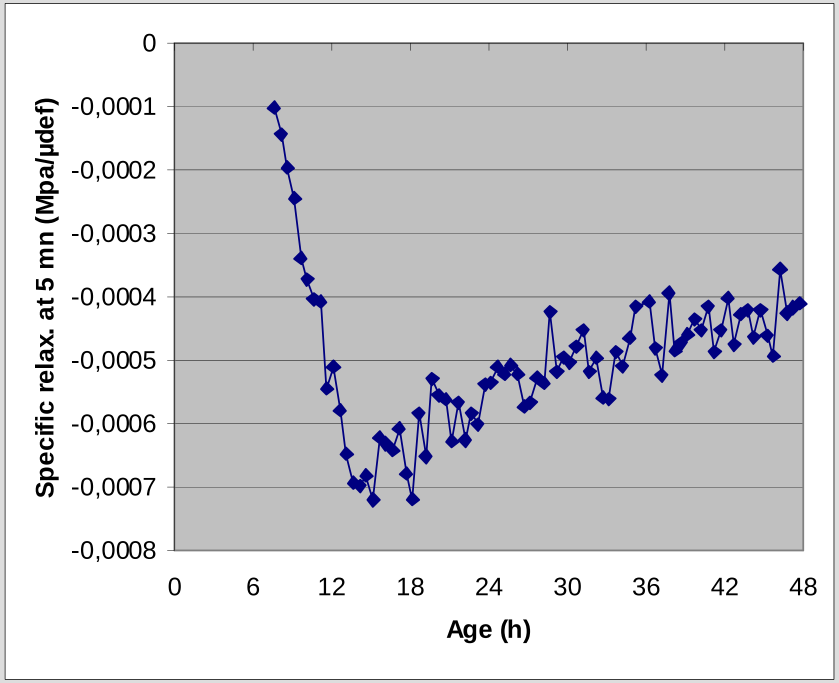
Normalized relaxation

Results: relaxation data (4/5)



Mean Normalized relaxations

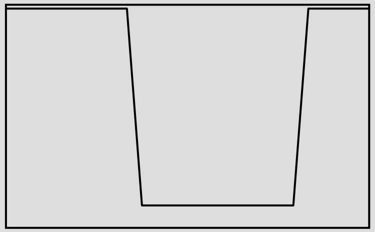
Results: relaxation data (5/5)



Amplitude

Results: relaxation modeling

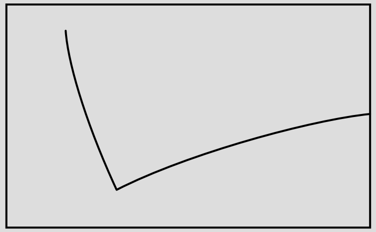
$\Delta\sigma(t) =$



$\varepsilon_0(t)$ = imposed value

Strain term

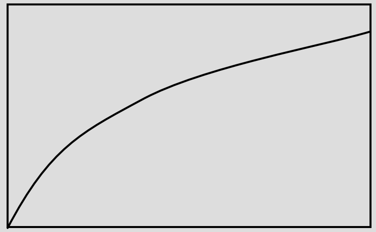
X



$A_{R5}(t)$

Specific Relax. Amplitude term

X



$\Omega(t-t_0)$

Dimensionless term equal to the term used for the creep

Fitted experimental data

Conclusion and perspectives (1)

- A new test rig and a new protocol gives the evolution of:
  - the E-modulus of concrete at early age
  - the creep and relaxation capacity

- Creep or relaxation observations are modeled as the product of 3 terms:
  - Either a stress or a strain term
  - An amplitude giving the creep or the relaxation at the end of a short period
  - the same kinetic term for the creep and the relaxation as well

- It is underlined that these observations start as soon as the setting occurs when elastic properties start sharply to increase.

Conclusion and perspectives (2)

- Transition from creep to relaxation has not yet been investigated. Repeatability tests are in progress on the same material. Other concretes should be tested.
- Tests on the influence of the temperature on the E-modulus, the creep and the relaxation are also in progress
- The influence of the initial strain rate on the E-modulus is also investigated.
- The models have to be completed to account for the creep recovery, eventual residual strains, the temperature and the maturity.
- In the frame of the cooperation with our partner from ULB, the mechanical properties of concrete at early age have been observed, both in compression and in tension, thanks to the TSTM. The next presentation will highlight this part of the study.
- The cooperation is now extended with Pr M. Azenha, University of Minho, Portugal.

Thank you for your kind attention