TU 1404 COST ACTION

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Presentations eBook

according to 1st WORKSHOP

with Focus on experimental testing of cement-based materials

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Outline

INTRODUCTION

About COST ACTION TU1404

Cement-based materials (CBM) are the foremost construction materials worldwide. Therefore, there are widely accepted standards for their structural applications. However, for service life designs, current approaches largely depend on CBM strength class and restrictions on CBM constituents.

Consequently, the service life behaviour of CBM structures is still analyzed with insufficiently rigorous approaches that are based on outdated scientific knowledge, particularly regarding the cumulative behaviour since early ages. This results in partial client satisfaction at the completion stage, increased maintenance/repair costs from early ages, and reduced service life of structures, with consequential economic/sustainability impacts.

Despite significant research advances that have been achieved in the last decade in testing and simulation of CBM and thereby predicting their service life performance, there have been no generalized European-funded Actions to assure their incorporation in standards available to designers/contractors.

The main purpose of COST TU1404 Action is to bring together relevant stakeholders (experimental and numerical researchers, standardization offices, manufacturers, designers, contractors, owners and authorities) in order to accelerate knowledge transfer in the form of new guidelines/recommendations, introduce new products and technologies to the market, and promote international and inter-speciality exchange of new information, creating avenues for new developments.

About 1st Workshop of COST ACTION TU1404

The Workshop was focused on specific tasks related to an extended Round Robin Testing (RRT+) organized within Workgroup 1 of COST ACTION TU1404. The following main objectives were:

- to make a scientific discussion on the proposed plan of RRT+ procedure and to allow the participants to provide their own comments/suggestions;
- to define of all the activities together with a detailed time schedule necessary to adequately start with the RRT+ procedure (i.e. to define transportation logistics, amount of basic materials that need to be transported to specific laboratory, etc.);
- to present the leaders of Group Priorities of WG1 and to allow them to express their ideas, demands, strategies, and expectations related to their GP in the form of short presentations;
- to allow other RRT+ participants to present some contributions relevant for a specific GP (e.g. their experiences related to previous RRT programs, etc.);
- to present expectations of WG2 and WG3 members related to the results of RRT+;
- to invite relevant speakers not included in COST ACTION TU1404;
- to allow the participants (i.e. members of RRT+) to present themselves, their organizations, their scientific work and contributions;
- to get acquainted with other RRT+ participants and WG members, etc.

About 1st Workshop of COST ACTION TU1404

SESSION for GP1.a – Fresh properties and setting
Chairman: Ivan Gabrijel

Ivan Gabrijel: Testing of fresh properties and setting of cement based materials – experimental plan for GP1a

Dalibor Sekulić: Determination of precision of fresh concrete test methods from inter-laboratory test results

Matija Gams: US testing of fresh cement based materials using frequency spectra of US P-waves

TU1404 COST ACTION

Testing of fresh properties and setting of cement based materials – experimental plan for GP1a

Ivan Gabrijel - University of Zagreb, Faculty of Civil Engineering

About the

- … institution

  University of Zagreb
  Faculty of Civil Engineering
  - 9 departments
  - undergraduate, graduate and doctoral studies

- … Department of materials

  Chairs:
  - materials research
  - technology of materials

  Laboratory for materials
  - Accreditation according to EN ISO/IEC 17025 (aggregate, fresh and hardened concrete

About the

- … author
  - Position
    - assistant professor, head of laboratory for materials
  - Activities related to this WP
    - coordination of proficiency test by inter-laboratory comparisons (HRN EN 12350-2:2009, HRN EN 12390-3:2009, HRN EN 933-1:2012)
    - Research in monitoring of hydration induced changes
      - ultrasonic measurements (UPV, acousto-ultrasonics)
      - complementary methods:
        - Heat of hydration, maturity method, setting time, strength development numerical simulation
    - Modelling of temperature changes in early-age concrete

EXPERIMENTAL PLAN FOR GP1A

Introduction

MAIN OBJECTIVE OF THE ACTION

guidelines/recommendations to predict/evaluate the service life of CBM's → **integrating** the most recent developments (advanced) in *experimental* and *numerical* approaches

Fresh concrete + advanced technique → **Rheology tests**

Setting + advanced technique → **Ultrasonic testing**

Input from/for WG2 + period of fresh state and setting → **Heat of hydration**

Testing of fresh properties and setting of cement based materials | Ivan Gabrijel

HEAT OF HYDRATION

Heat of hydration

- Monitoring heat output from CBM's is probably the most widespread method for characterization of hydration process.
- Standards
  – ASTM C1679 -14 Standard Practice for Measuring Hydration Kinetics of Hydraulic Cementitious Mixtures Using Isothermal Calorimetry
  – EN 196-9:2010 - Heat of hydration - Semi-adiabatic method
  – Adiabatic, semi-adiabatic calorimetry (RILEM 119-TCE, 1999)

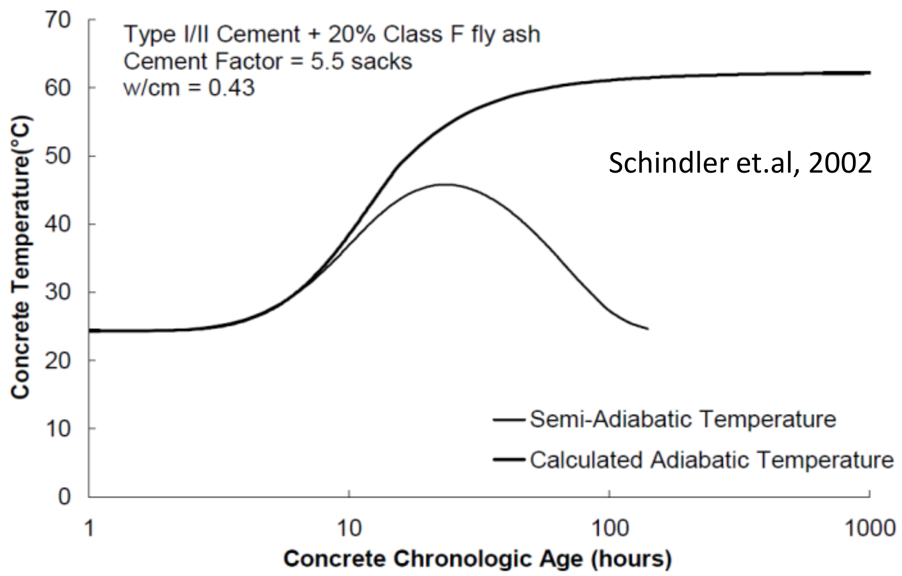
Properties	Testing techniques	Potential participants
Heat of hydration	Isothermal calorimetry – material: cement paste or mortar	Ghent University
		Ozyegin University
		Faculty of Civil Engineering, Porto University, Portugal
		Université Libre de Bruxelles
	Semi adiabatic, adiabatic or heat flow calorimetry Material: mortar or concrete	University of Zagreb, Faculty of Civil Engineering
		Technische Universität Braunschweig,
		MPA Braunschweig, IBMB TU Braunschweig
		BAM Federal Institute for Materials Research and Testing

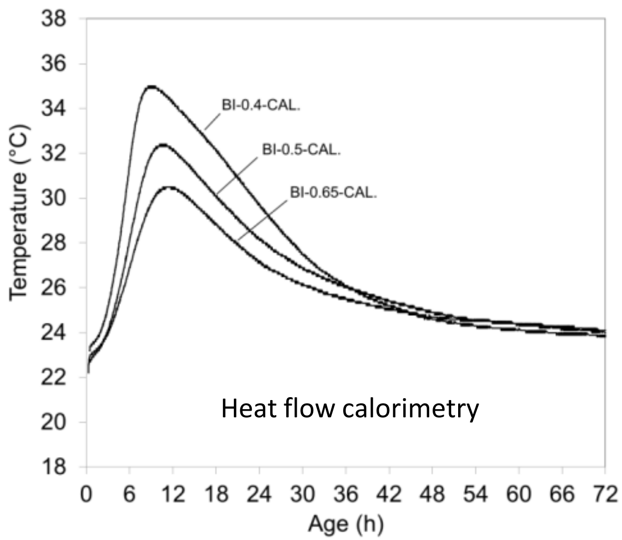
Heat of hydration

- Measured data will serve as an input for different models in WG2.
- RRT?
  - Information from participants about the method used:
    - Which material can be tested?
    - Is the measurement done according to standard?
      - If yes than the procedure of measurement is known
      - If no than the procedure of measurement must be described
  - Comparison of results
    - Isothermal calorimetry
      - Total heat released $\boldsymbol{Q}$ [J/g], rate of heat liberation $\boldsymbol{q}$ [J/(g·h)]
      - Which statistic to use for comparison?
        - » evaluating rate of heat evolution and heat released at different ages – calculating: average, standard deviation
        - » Other methods: nonparametric statistic – Wilcox test, linear regression

Heat of hydration

- Comparison of results
  - Semi-adiabatic, adiabatic, heat flow calorimetry
    - Aditional problem: **different temperature history**





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ULTRASONIC TESTING

Ultrasonic testing

- Benefits and applications
  - Real-time quasi-continuous monitoring of transition from plastic to solid state
  - Insight into structure formation mechanisms
    - Monitoring the rate of hydration (mostly through physical changes: porosity, connectivity of particles)
    - Evaluating influence of admixtures on the rate of structure formation
  - Prediction of (compressive) strength

- Standards
  - Recommendations of Rilem TC 218 SFC (2011) – Testing by ultrasound transmission

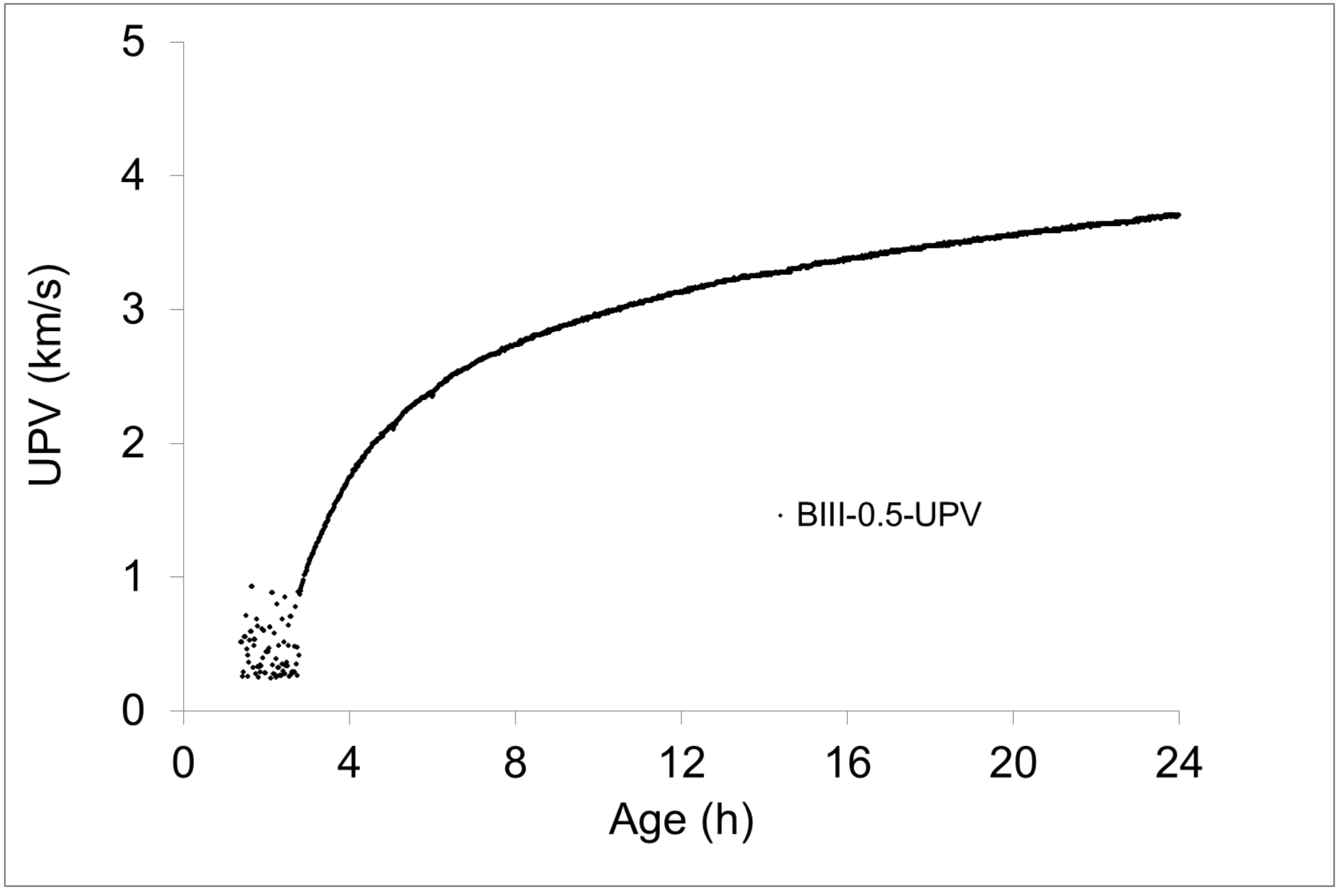
Ultrasonic testing

- Participants

Properties	Testing techniques	Potential participants
Physical changes caused by hydration	Ultrasonic transmission technique	University of Zagreb, Faculty of Civil Engineering
		Instituto de Tecnologías Físicas y de la Información Leonardo Torres Quevedo - ITEFI
		Ghent University
		Technische Universität Braunschweig
		Ecole centrale de Nantes
		Escuela Técnica Superior de Ingenieros de Telecomunicación. Universidad Politécnica de Madrid.
		Silesian University of Technology
		Igmat Building Materials Institute, SLO
		Vrije Universiteit Brussel
		Technische Universitaet Muenchen
		INSTITUTO TECNOLÓGICO DE LA CONSTRUCCION- AIDICO

Ultrasonic testing

- RRT
  - Most of the participating laboratories can measure ultrasonic pulse velocity (UPV) in through transmission
  - Comparison of obtained UPV curves
    - Compare UPV from different participants at certain age (for example every hour during the first 12 to 24 hours of hydration).
    - Compare the age at which characteristic points at the UPV curve are found (start of UPV increase, inflection point)


UPV (km/s)
5
4
3
2
1
0
0
4
8
12
16
20
24
Age (h)
BIII-0.5-UPV

Ultrasonic testing

- Sources of variability (other than mixture)

TRANSDUCERS

↙ broadband or resonant

↓ frequency: 50 – 500 kHz

↘ different sensitivity/dispersion

SAMPLE SIZE AND MOULD MATERIAL

↓

different temperature history

↓

maturity method

↓

activation energy ?

} **Temperature during test must be measured!**

Ultrasonic testing

- Sources of variability (other than mixture)

COMPACTION

↓

Mould material damps vibration

↙

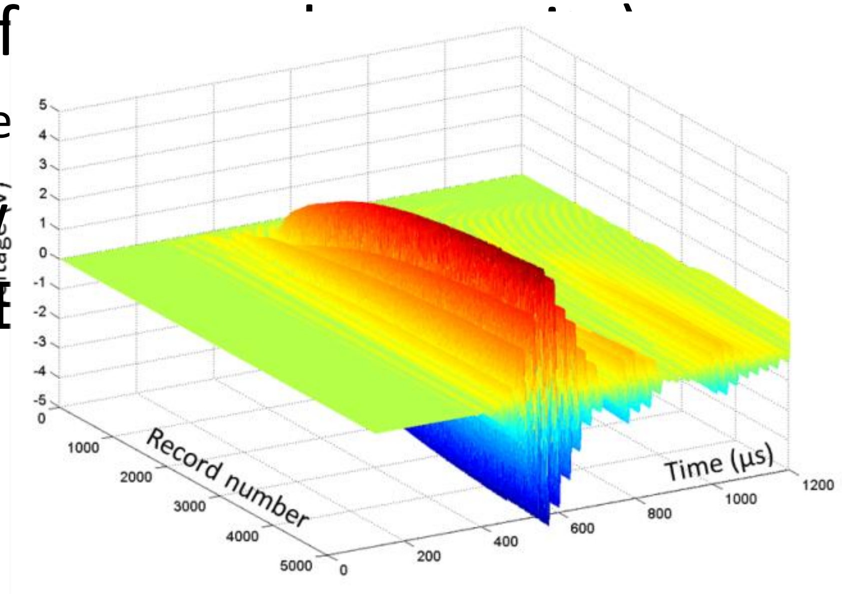
Homogenity check after test ? → Procedure described in ISO 13528:2012

↓

Method: compressive strength test, air void analysis,...?

Ultrasonic testing

- Comparison with other methods
  - initial and final setting (Vicat test and Proctor test).
  - microstructural characteristics of CBM's at different ages (f
- Several laboratories can e ...eristics.
  - These results w ...rent properties of CE



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RHEOLOGY TESTS

Flow properties tested by rheometers

- Participants

Properties	Testing techniques	Potential participants
Fresh state properties	Measurements made by rheometer Cement paste	Faculty of Civil Engineering, Porto University, Portugal
		Mehmet Akif Ersoy University
		Silesian University of Technology
		BAM Federal Institute for Materials Research and Testing
		Povazska cementaren a.s Ladce
	Mortar	Mehmet Akif Ersoy University
		Silesian University of Technology
		BAM Federal Institute for Materials Research and Testing
	Concrete	Universidad Politecnica Madrid
		Mehmet Akif Ersoy University
		Silesian University of Technology
		University of Malta
		OTH University of Applied Sciences Regensburg
		BAM Federal Institute for Materials Research and Testing

Flow properties tested by rheometers

- Based on the input from WG2 results of rheometer tests are not going to be used for modelling.
- 2 participants have the interest to compare results from self-developed concrete rheology measurements
- RRT of rheological parameters?
  - Rheometers for concrete with different geometries will give results that are not related (NIST report NISTIR 6819, 2001)
    - some of rheometers will measure directly *yield stress* and *plastic viscosity* and others will express results in terms of *torque/rotational speed*.
      - Description of instruments should be provided by the participants!
  - For RRT usually all participants take samples from the same batch

Flow properties tested by rheometers

- RRT of rheological parameters?
  - Evaluation of different mix compositions rheometer measurements can be made but it should be noted that:
    - rheometer measurements are an attempt to treat fresh concrete as a fluid [Ferraris C. et al, 2001].
    - properties of fresh concrete or more generally CBM's can be tested in numerous ways.
    - slump test is probably the most widespread way to test consistency and should be used here for comparison of fresh concrete consistency.

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REFERENCE VALUES, MIXTURES, CONDITIONS, …

Reference values

- It is expected that all laboratories involved are capable of making tests according to EN 12350 and/or EN 196 standards which will serve to evaluate properties of the mix.
- These tests will also be needed for all other group priorities.
  - First a consensus between all participants from all group priorities has to be made on the procedure how reference values of properties for the mixtures will be determined.
  - This procedure is described in ISO 13528:2012 and presents just one of the possible approaches.

Mix compositions

- OC mixture is already proposed.
- MC mixture
  - evaluating effect of w/c ratio
  - at 3 different w/c levels.
- Mortar mixture
  - equivalent mortar mixtures based on the concrete compositions
- Cement paste
  - w/c ratio of cement pastes should be chosen independently of the w/c ratios of mortar or concrete mixtures
    - cement paste with w/c ratio >0,5 is not really a paste but a suspension of particles in water and homogeneity of mix is lost after mixing process is finished.

Additional conditions

- Temperature measurement inside CBM's must be made during:
  - ultrasonic testing
  - determination of setting time of cement paste and setting time of mortar
- environment temperature during test should be recorded.
- each test should be repeated at least 2 times.

Conclusion

- 3 possible RRT
  - Heat of hydration
  - Ultrasonic testing
  - Rheology testing
- Mixtures with different mineral aditives should be organized by each participant according to their interests and available materials

Determination of fresh concrete test methods precision from the interlaboratory test results

Dalibor Sekulić - dalibor.sekulic@igh.hr

Introduction

- Round Robin for fresh concrete – difficult and challenging task

Why?

- Properties of fresh concrete are fast changing
  - problem with test repeating
- Hard to obtain mixtures with equal properties even all mixing parmeters is known

→ Simultanous testing using one mixture?

Introduction

- Simultanous testing using one mixture
- Pros:
  - Good repeatability conditions (as possible)
- Cons:
  - Expensive
    - Traveling costs
    - Equipment transport
  - Coordination is not easy
    - Many performers
    - Different Tests in short time properties (few minutes)

Introduction

Reasonable option?

- Testing of mixtures prepared in particular laboratories using same compounds
- Repeatibility conditions
  - Same mixing components
  - Same well defined procedure for components preparation and mixing
  - Same well defined test procedures
- Reproducibility conditions
  - Different Test operators
  - **Not same Mixture***
  - Equipment used
  - Environment conditions
  - **Time of testing***

***Significant influence is expected**

It is important to investigate influence of these factors

Influence of different mixtures (same mix composition)

- Hard to obtain several tests in repeatability conditions
- It is possible to make *n* simultanous determinations of one property with *t* performers
- **Example:** Slump test, *t*=5

t	Mix 1 x_{t1} (mm)	Mix 2 x_{t2} (mm)	$\bar{x}_t$ (mm)	w_t (mm)
1	92	102	97	10
2	84	98	91	14
3	78	92	85	14
4	95	103	99	8
5	94	96	95	2

s_x (mm)	s_w (mm)	s_s (mm)
5,5	7,5	1,7

CALCULATIONS

Sample averages:

$$\bar{x}_t = \sum (x_{t1} + x_{t2}) / 2$$

General average:

$$\bar{x}_{.,.} = \sum \bar{x}_{t,.} / g$$

Between mixture ranges:

$$w_t = |x_{t1} - x_{t2}|$$

Standard deviation of sample averages:

$$s_x = \sqrt{\sum \left(x_{t,.} - \bar{x}_{.,.}\right)^2 / (g-1)}$$

Within-samples standard deviation:

$$s_w = \sqrt{\sum (w_t)^2 / (2g)}$$

Between-samples standard deviation:

$$s_s = \sqrt{\sum s_x^{\ 2} - s_w^{\ 2} / 2}$$

Influence of different mixtures (same mix composition)

s_s = *1,7* mm = 1,8% $s_s \leq 0{,}3\hat{\sigma}$ $\hat{\sigma}$ The standard deviation for proficiency testing

How to obtain $\hat{\sigma}$?

Information on the repeatability and reproducibility is available (EN 12350-3):

Level	Repeability conditions				Reproducibility conditions			
	σ_r (n=1)		σ_r (n=2)		σ_R (n=1)		σ_R (n=2)	
mm	mm	%	mm	%	mm	%	mm	%
65	5,8	8,9	4,1	6,3	9,0	13,8	8,0	12,3

CALCULATIONS:

Between laboratory standard deviation:

$$\sigma_L = \sqrt{\sigma_R^2 - \sigma_r^2}$$

Standard deviation for proficiency testing:

$$\hat{\sigma} = \sqrt{\sigma_L^2 - \sigma_r^2 / n}$$

σ_r – Repeability standard deviation

σ_R – Reproducibility standard deviation

n – Number of replicate measurements for each lab.

$\sigma_L = 6{,}9$ mm $\hat{\sigma} = 9{,}0$ mm $= 13{,}8\%$

$s_s = 1{,}8\%$ $0{,}3\hat{\sigma} = 4{,}2\%$

$$s_s \leq 0{,}3\hat{\sigma}$$

Homogenity condition is satisfied!

Influence of testing time

- Two determinations of same property (slump) after 2 and 4 minutes

n	x (mm) t=2 min	y (mm) t=4 min
1	92	83
2	74	82
3	78	66
4	95	103
5	94	88
$\bar{x}, \bar{y}$	85,5	83,8
$\lvert\bar{x}-\bar{y}\rvert$	1,7 mm	

$$\lvert\bar{x}-\bar{y}\rvert \le 0{,}3\hat{\sigma} \qquad 0{,}3\hat{\sigma} = 3\text{mm}$$

1,7mm ≤ 3 mm

Satisfied!

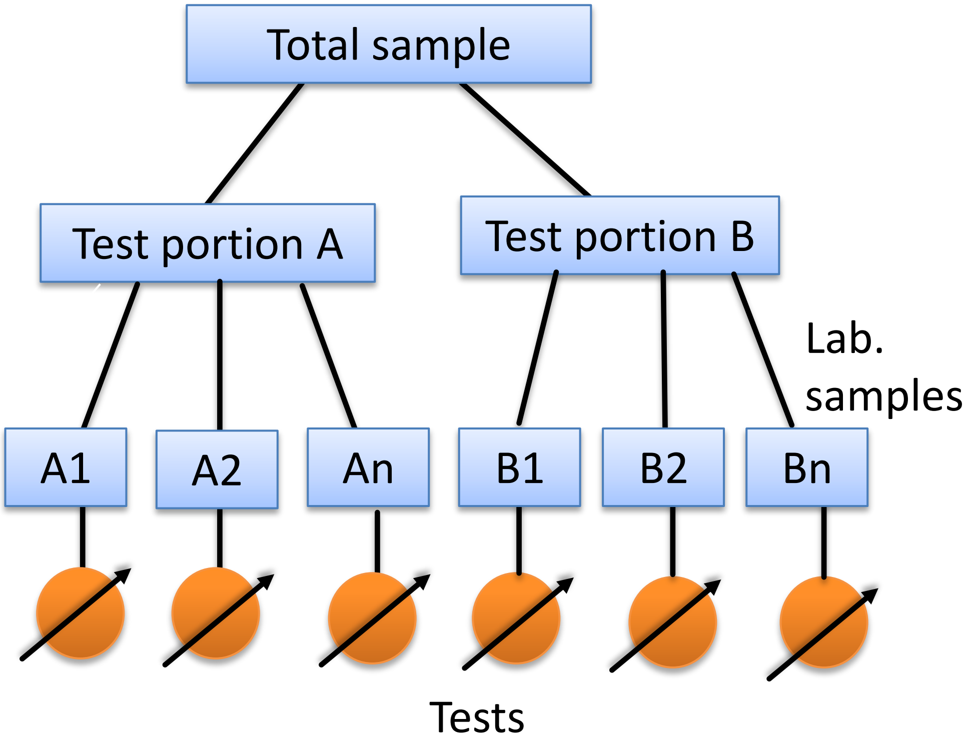
Proove for third determination of slump!

➢ Results reporting

- Rounding not less than $\sigma_r/2$ = 4,5%
- For s = 100 mm it is $\sigma_r/2$ = 4,5 mm, for S=50 mm $\sigma_r/2$ = 2,3 mm
- Slump test results should be rounded to **1 mm** (EN 12350-3 require rounding to 10 mm)

Measurement of aggregates homogenity

- Divide total sample into two test portions
  - Each test portion divide into *n* laboratory samples
  - Apply selected test method
    - For example passing through the 8 mm sieve



Measurement of aggregates homogenity

Sample No. $t=1,2,..n$	x_{t1} (%)	x_{t2} (%)	$\bar{x}_t$ (%)	w_t (%)
1	36,9	38,1	37,5	1,2
2	37,3	36,6	37,0	0,7
3	37,4	35,9	36,7	1,5
4	37,8	35,8	36,8	2,0
5	38,3	37,8	38,1	0,5
6	37,7	35,7	36,7	2,0
7	38,4	38,3	38,4	0,1
8	38,1	37,5	37,8	0,6
9	37,4	37,6	37,5	0,2
10	36,5	35,7	36,1	0,8
11	36,9	35,1	36,0	1,8

Calculate s_x, s_w and s_s standard deviations:

s_x (%)	s_w (%)	s_s (%)
0,77	0,87	**0,46**

From known repeability and reproducibility standard deviations

σ_R	2 %
σ_r	0,6 %

calculate

σ_L	1,9 %
$\hat{\sigma}$	**2,0 %**

Condition $s_s \leq 0,3\hat{\sigma}$

$$0,46 \leq 0,60$$

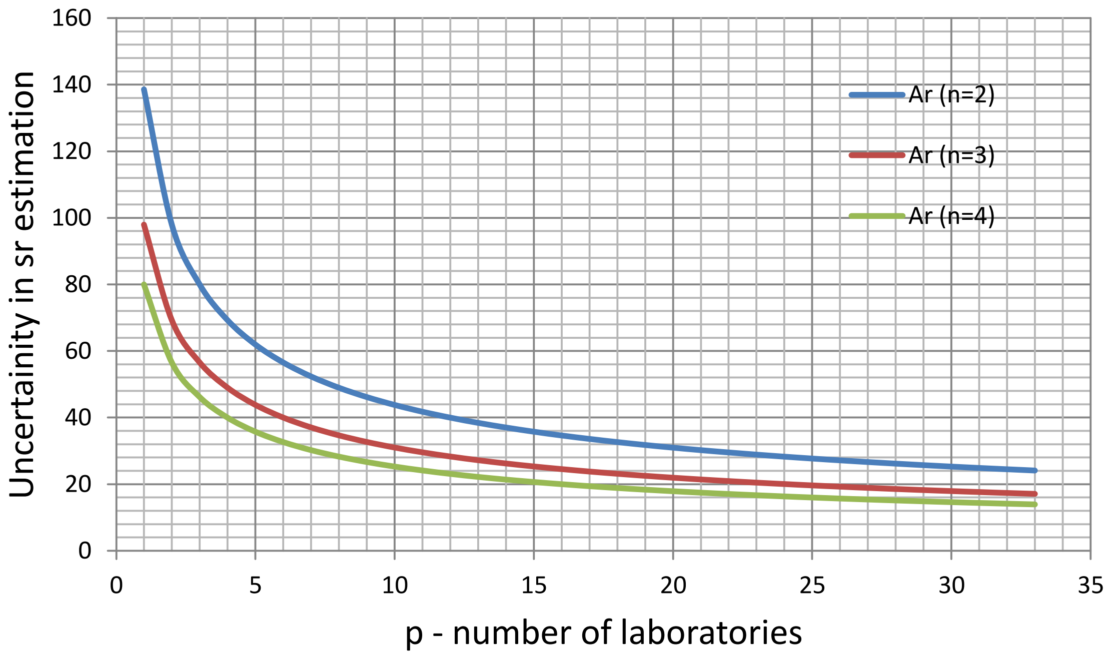
is satisfied – Homogenous aggregates

Number of participating laboratories

- Uncertainity of the repeability estimation (A_r)
  - dependins on the number of testing laboratories (p) and test results for each laboratory (n)

$$A_r = 1{,}96\sqrt{\frac{1}{2p(n-1)}}$$

p	A_r (%) (n=2)	A_r (%) (n=3)	A_r (%) (n=4)
5	62,0	43,8	**35,8**
11	**41,8**	29,5	24,1



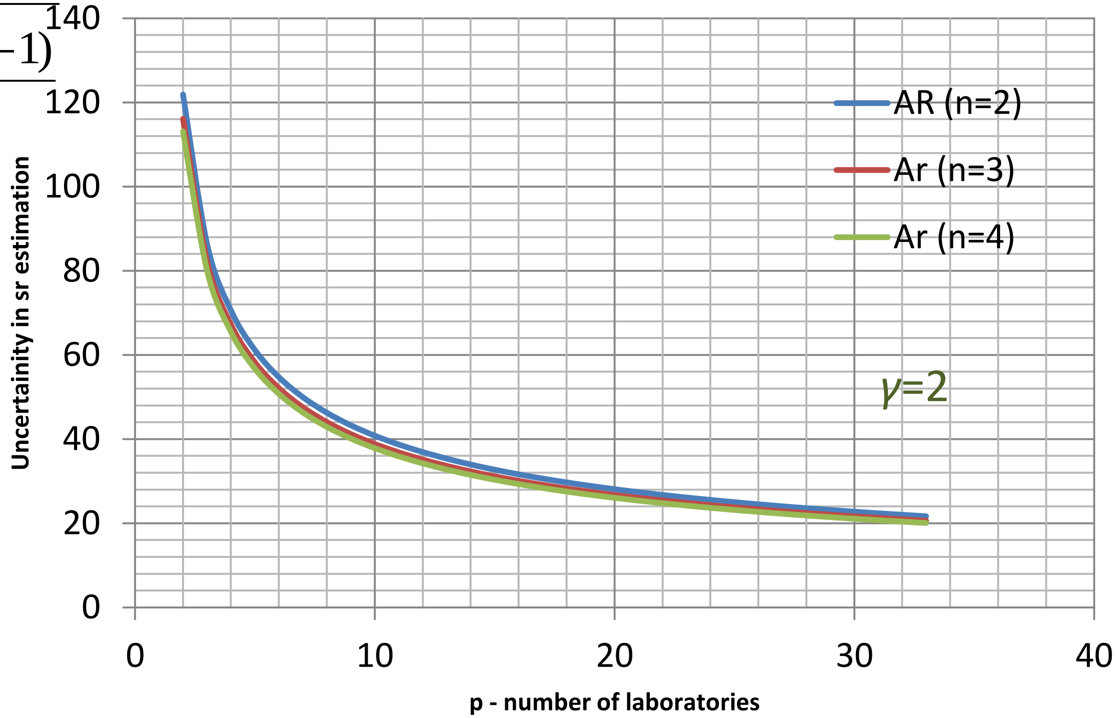
Number of participating laboratories

- Uncertainity of the reproducibility estimation (A_R)
  - dependins mainly on the number of testing laboratories (*p*) and factor *γ* (ratio between reproducibility and repeatibility)

$$A_R = 1{,}96\sqrt{\frac{p\left[1+n\left(\gamma^2-1\right)\right]^2+(n-1)(p-1)}{2\gamma^2 n^2 (p-1)\,p}}$$

$$\gamma = \sigma_R / \sigma_r$$

- γ depends on the used test method
  - Slump *γ*=1,6
  - Density *γ*=1,9
  - Air content *γ*=2,8



Example: Slump test – 11 laboratories

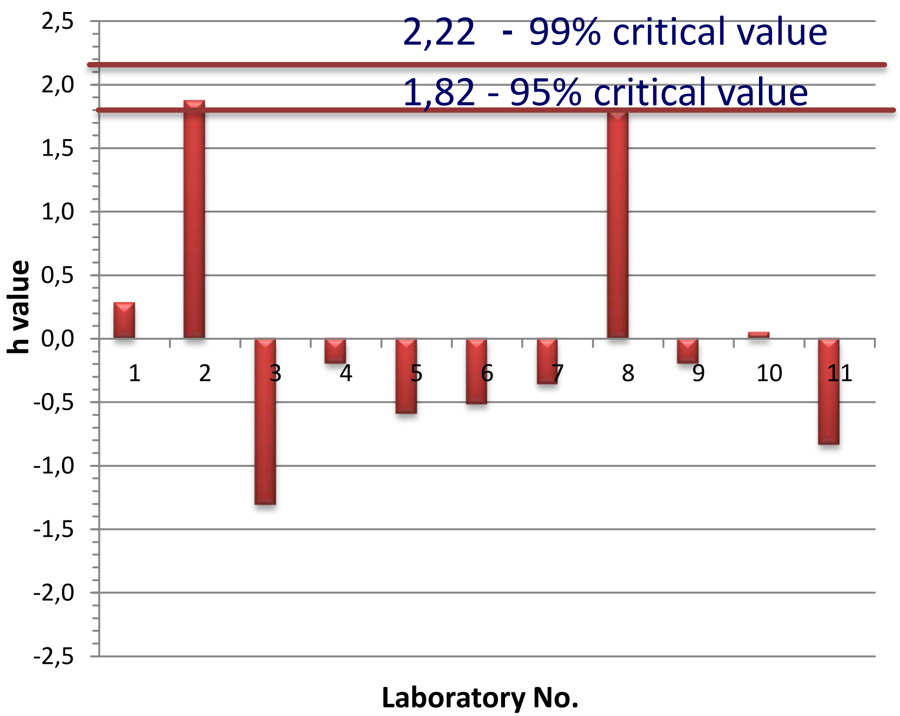
Laboratory No.	x_1 (mm)	x_2 (mm)	$\bar{x}$(mm)	σ (mm)
1	88	83	86	3,54
2	98	93	**96***	3,54
3	79	72	76	4,95
4	87	78	83	6,36
5	78	82	80	2,83
6	86	75	81	7,78
7	83	80	82	2,12
8	89	101	**95***	8,49
9	87	78	83	6,36
10	80	88	84	5,66
11	82	75	79	4,95
Mean value:	**85,2**	**82,3**	**83,7**	

* Questionable results (stagglers)

Consistency of results assesment - Mandel h and k statistics

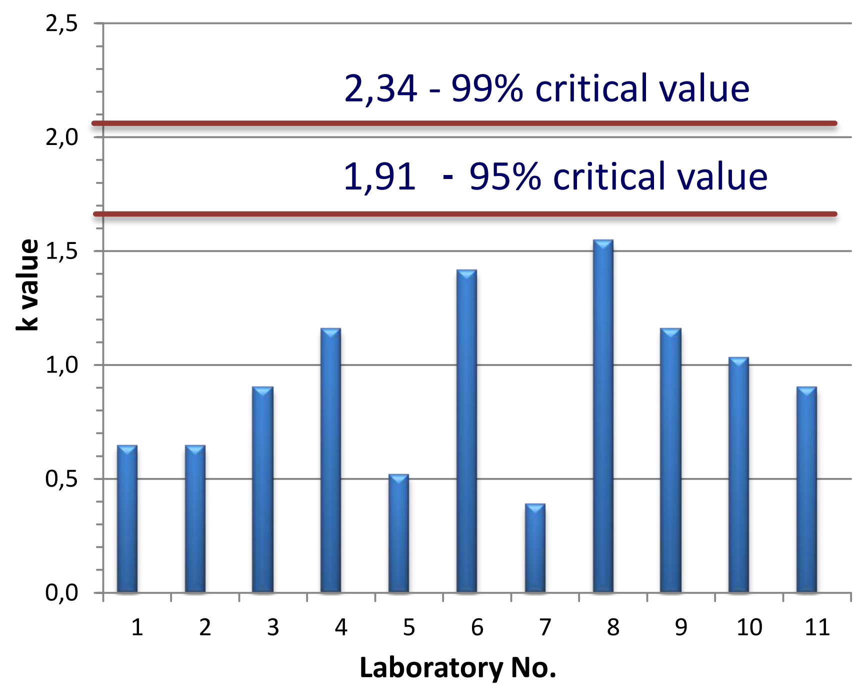
- *h - between laboratory statistics*

$$h_{i,j} = \frac{\bar{y}_{ij} - \bar{\bar{y}}_j}{\sqrt{\frac{1}{(p_j - 1)} \sum_{i=1}^{p_j} (\bar{y}_{ij} - \bar{\bar{y}}_j)^2}}$$

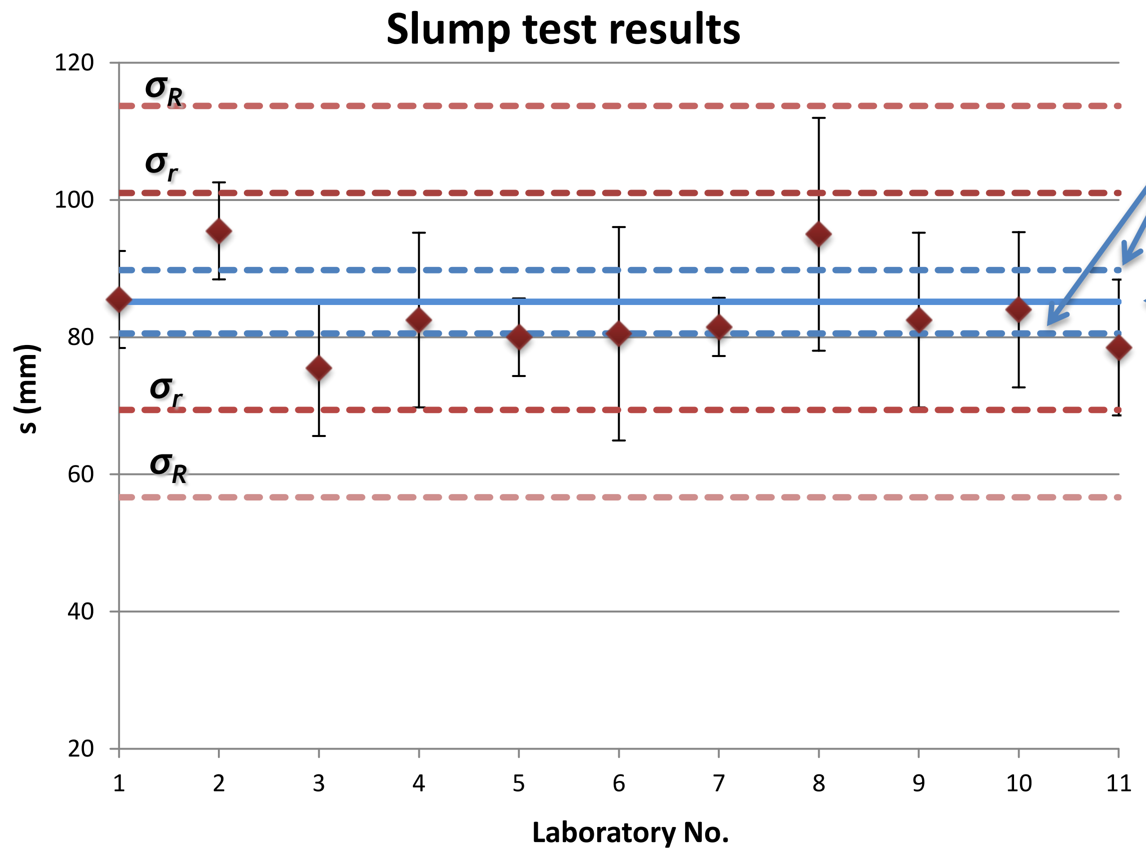


- *k - inside laboratory statistics*

$$k_{i,j} = \frac{s_{i,j}}{s_p} \qquad s_p = \sqrt{\frac{\sum_i s_{ij}^2}{p_j}}$$



Example: Slump test – 11 laboratories



u_x=4,62 mm – standard uncertainity of the assigned value

85,2 mm – assigned value

Condition for the assigned value uncertainity is satisfied

$$u_x \leq 0{,}3\hat{\sigma} \qquad \hat{\sigma} = 13{,}8\%$$

Repeability stand. deviation σ_r	**5,6 mm**	**6,6 %**
Reproducibility stand. deviation σ_R	**8,5 mm**	**10,1 %**

Example: Slump test – 11 laboratories

➢ How assigned value is calculated (ISO 13528)

- Calculate initial values for x^* and s^*:

- Calculate $\delta = 1,5 s^*$
- For each x_i ($i = 1, 2, \ldots, p$), calculate
  $x_i^* = x^* - \delta$ if $x_i < x^* - \delta$
  $x_i^* = x^* + \delta$ if $x_i < x^* + \delta$
  $x_i^* = x_i$ otherwise
- Calculate the new x* and s* values from:

$$x^* = \sum x_i^* / p \qquad s^* = 1{,}134\sqrt{\sum (x_i^* - x^*)^2 / (p-1)}$$

- Update the old values of x^* and s^* until x^* and s* converge
- Calculate uncertainity of assigned value

$$u_x = 1{,}25 s^* / \sqrt{p}$$

Example: Slump test – 11 laboratories

➢ How repeability and reproducibility is calculated (ISO 5725-2)

- Repeability variance

$$\sigma_r^{\;2} = \frac{\sum_{i=1}^{p}(n_i - 1)s_i^{\;2}}{\sum_{i=1}^{p}(n_i - 1)}$$

- Interlaboratory variance

$$\sigma_L^{\;2} = \frac{\sigma_d^{\;2} - \sigma_r^{\;2}}{\bar{\bar{n}}} \qquad \sigma_d = \frac{1}{p-1}\sum_{i=1}^{p} n_i\left(\bar{x}_i - \bar{\bar{x}}\right)$$

$$\bar{\bar{n}} = \frac{1}{p-1}\left[\sum_{i=1}^{p} n_i - \frac{\sum_{i=1}^{p} n_i^{\;2}}{\sum_{i=1}^{p} n_i}\right]$$

- Reproducibility variance

$$\sigma_{\mathrm{R}}^{\;2} = \sigma_{\mathrm{r}}^{\;2} + \sigma_{\mathrm{L}}^{\;2}.$$

Interlaboratory results assesment

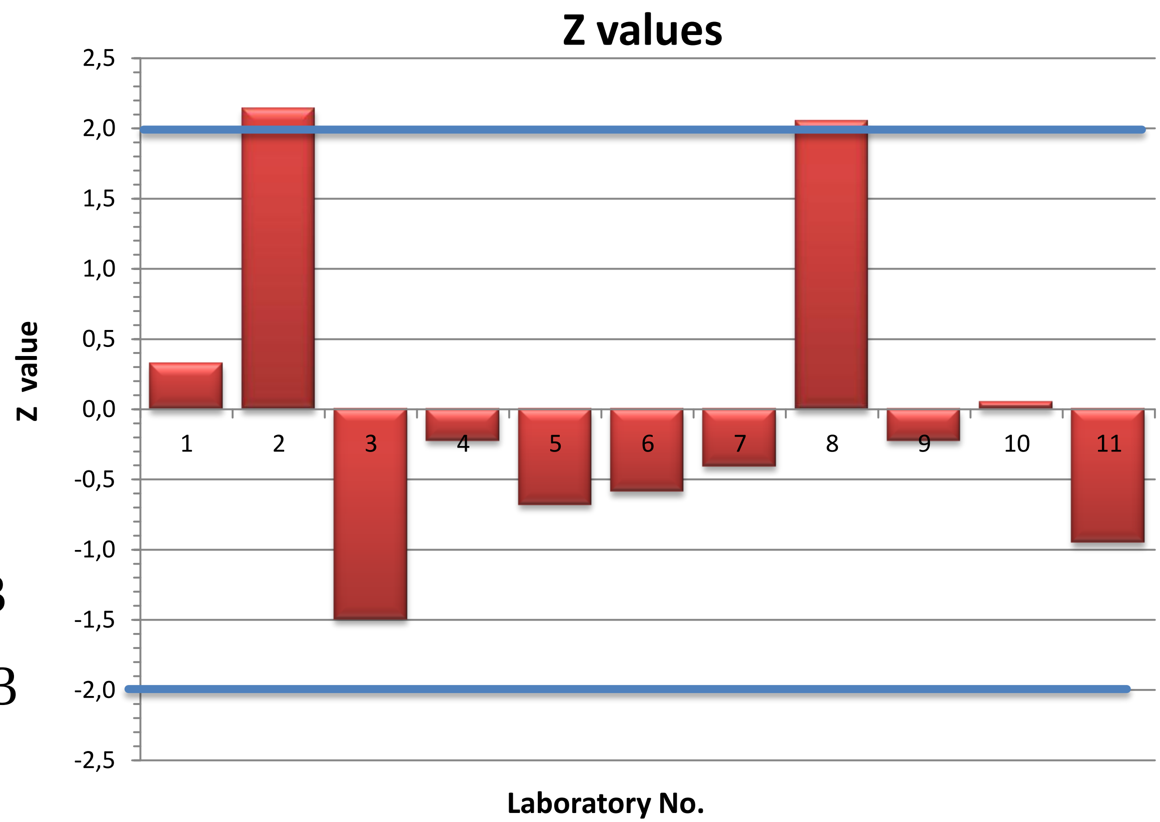
- *z* - score

$$z_i = \frac{x - X}{\hat{\sigma}}$$

Satisfactory $|Z| \leq 2$

Questionable $2 < |Z| < 3$

Nonsatisfactory $|Z| \geq 3$



- *z´* - score

$$z' = (x - X) / \sqrt{\hat{\sigma}^2 - u_X^2}$$

- *ζ*- sc<ore

$$\zeta = (x - X) / \sqrt{u_x{}^2 - u_X^2}$$

ANOVA Method

➢ How to obtain more informations from interlaboratory tests - Intermediate precision

- ANOVA METHOD (ISO 5725-3)
  - Difference between laboratories
  - Between mixtures
  - Between used equipment
  - Between test performers

Various approaches to experiment design

ANOVA Method - Experiment design schemes

➢ Three factor fully nested experiment

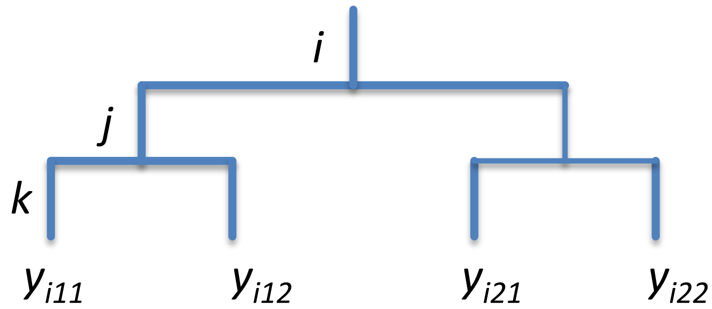
FACTOR

0 – LABORATORY

1

2 – RESIDUAL

y_{ijk}



➢ Four factor fully nested experiment

FACTOR

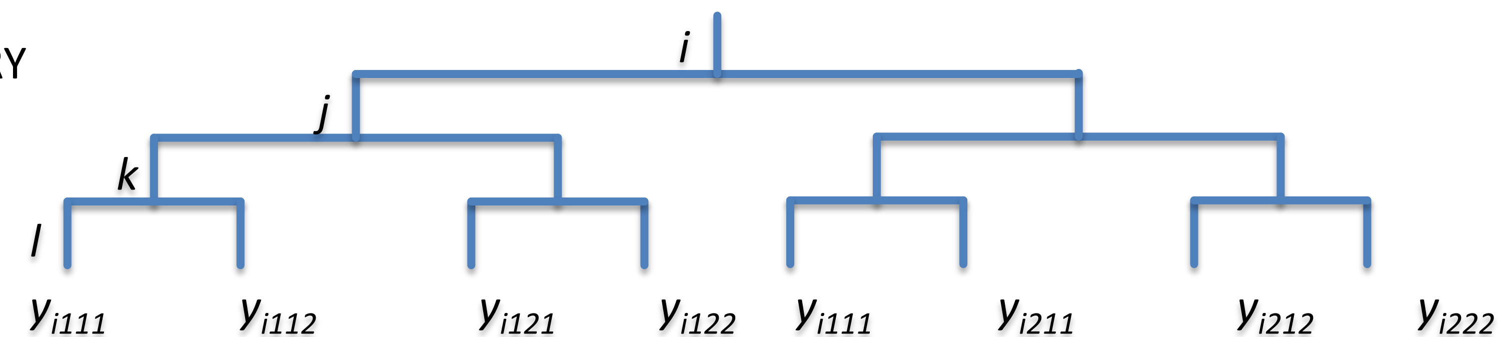
0 – LABORATORY

1

2

3 – RESIDUAL

y_{ijkl}



ANOVA Method - Example: Slump test

- Four factor staggered nested experiment
- Slump test EN 12350-3

FACTOR

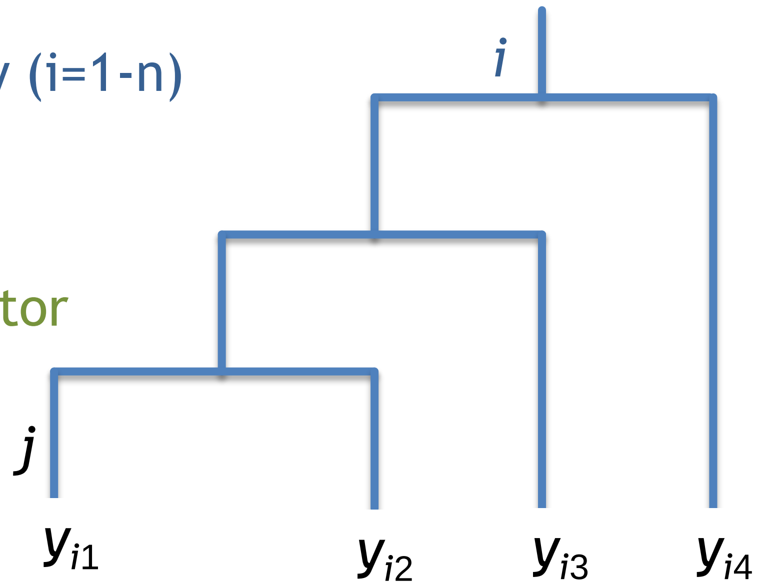
0 - Laboratory (i=1-n)

1 - Mixture

2 - Test operator

3 - Residual

y_{ij}



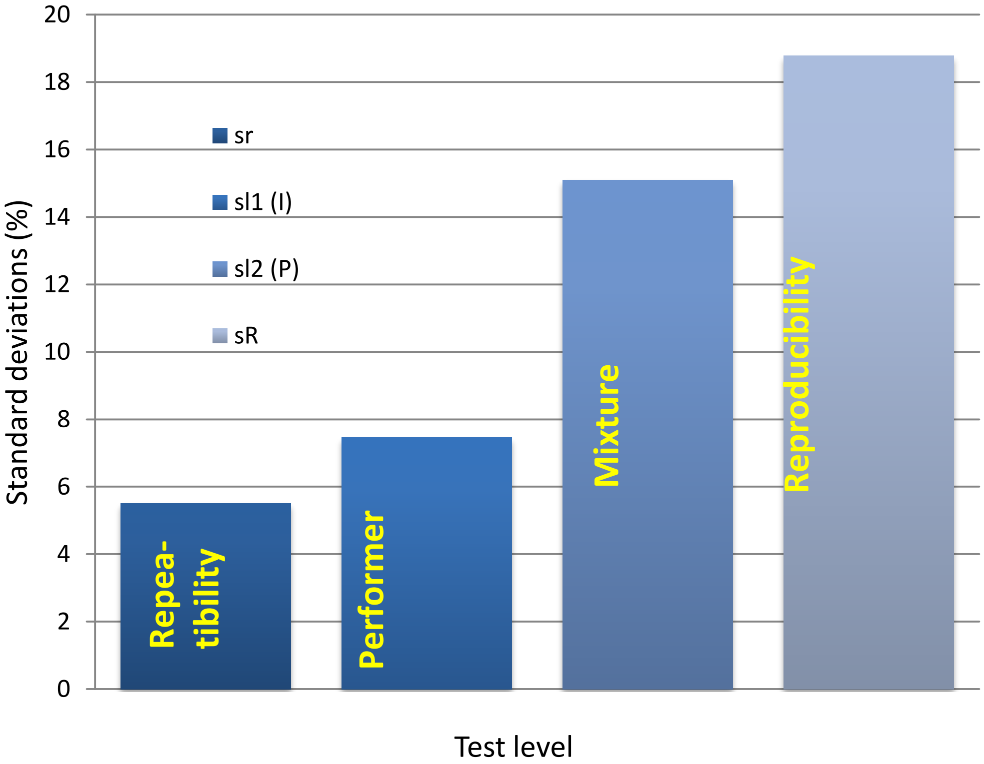
- Mixtures from same compounds
- Each laboratory make 2 mixtures

Mixture 1 –
2x first operator
+ 1x second operator
Mixture 2 –
1x first operator

ANOVA Method - Example: Slump test

- Beside repeability and reproducibility influences of operator and mixtures preparation is investigated

Lab. No.	Slump [mm]			
	Mix 1			Mix 2
	Operator 1	Operator 1	Operator 2	Operator 1
	Y_{i1}	Y_{i2}	Y_{i3}	Y_{i4}
1	88	83	72	86
2	105	98	92	83
3	79	72	78	94
4	87	78	72	96
5	78	82	73	107



ANOVA Method - Example: Slump test

➢ How it is calculated (ISO 5725-3)

Mean values:

$$\bar{y}_{i(1)} = \frac{1}{2}\left(y_{i1} + y_{i2}\right) \quad \bar{y}_{i(2)} = \frac{1}{3}\left(y_{i1} + y_{i2} + y_{i3}\right) \quad \bar{y}_{i(3)} = \frac{1}{3}\left(y_{i1} + y_{i2} + y_{i3} + y_{i4}\right)$$

i - number of participants in the round robin scheme

y_{i1} *i* y_{i2} - test results of specimens 1 and 2;

y_{i3} - test results of specimen 3

General mean for i^{th} laboratory: $\bar{\bar{y}} = \frac{1}{p}\sum_{i} \bar{y}_{i(3)}$ p – number of participating laboratories

Ranges:

$$w_{i(1)} = \left|y_{i1} - y_{i2}\right| \quad w_{i(2)} = \left|\bar{y}_{i(1)} - y_{i3}\right| \quad w_{i(3)} = \left|\bar{y}_{i(2)} - y_{i4}\right|$$

ANOVA Method - Example: Slump test

➤ How it is calculated (ISO 5725-3)

Sums of squares (SST): $SST = \sum_i \sum_j \left(y_{ij} - \bar{\bar{y}}\right)^2 = SS0 + SS1 + SS2 + SSe$

$SS0 = 4\sum_i \left(\bar{y}_{i(2)}\right)^2 - 4p\left(\bar{\bar{y}}\right)^2$ $SS1 = \frac{3}{4}\sum_i w_{i\,(3)}^2$ $SS2 = \frac{2}{3}\sum_i w_{i\,(2)}^2$ $SSe = \frac{1}{2}\sum_i w_{i\,(1)}^2$

$MS0=SS0/(p-1)$ $MS1=SS1/p$ $MS2=SS2/p$ $MSe=SSe/p$

Repeability: $s_r = \sqrt{MSe}$

Mix influence: $s_{l\,(1)} = \sqrt{s_r^2 + s_{(1)}^2}$ Performer influence: $s_{l\,(2)} = \sqrt{s_r^2 + s_{(2)}^2}$

Reproducibility: $s_R = \sqrt{s_r^2 + s_{(1)}^2 + s_{(2)}^2 + s_{(0)}^2}$

Conclusion

- Round robin of fresh concrete properties
  - Difficult and challenging task
    - Fresh concrete properties is fast changing
    - Nonhomogenous material
    - Hard to obtain same mixtures
    - Hard to obtain repeatability conditions
- Reasonable option – Testing of mixtures prepared in particular laboratories using same compounds

Conclusion

- Analysis prior interlaboratory tests
  - Homogenity of different mixtures
  - Influence of time in which tests must be completed
  - Aggregates homogenity
  - Influence of number of laboratories and repeated tests to uncertainity of obtained results
- Selection of appropriate interlaboratory scheme
  - Depends on the results of previous analysis
  - Depends on number of intermadiate precision data wanted to obtain (operators, equipment etc.)
  - Avoid too complicated schemes which is hard to perform

TU 1404 COST ACTION

US TESTING OF FRESH CEMENT BASED MATERIALS USING FREQUENCY SPECTRA OF US P-WAVES

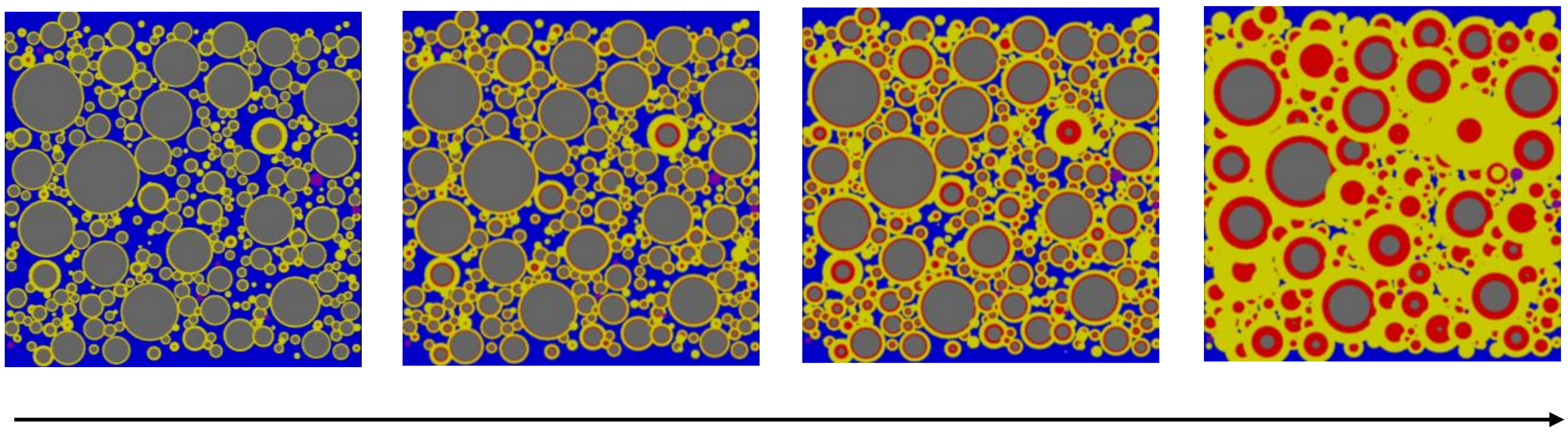
Matija Gams

Gregor Trtnik

ZAG
ZAVOD ZA GRADBENIŠTVO SLOVENIJE
SLOVENIAN NATIONAL BUILDING AND CIVIL ENGINEERING INSTITUTE

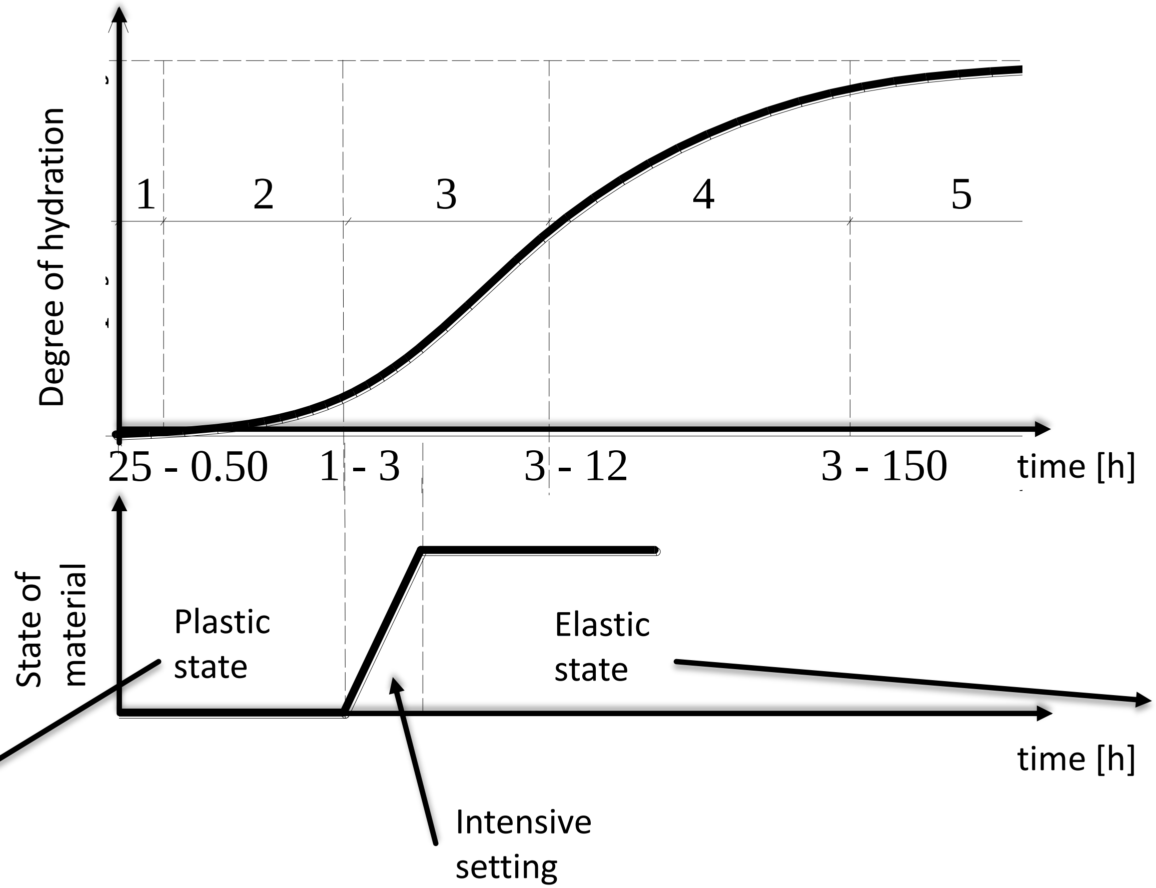
igmat d.d.
Building materials institute

INTRODUCTION: HYDRATION AND FORMATION OF STRUCTURE OF CEMENT BASED MATERIALS



Development of the hydration products (connected solid phase)

INTRODUCTION: SETTING OF CEMENT BASED MATERIALS



US TECHNIQUES FOR DETERMINATION OF SETTING

MOST FREQUENTLY USED METHODS:

- US wave transmission method (USWT) – velocity of US waves – vP
- US wave reflection method (USWR) – shear reflection coefficient – dr

Important increase in the development of US techniques to determine various properties of cement based materials has been achieved recently.

ADVANTAGES OF US TECHNIQUES

- Physically clear and relatively straightforward interpretation,
- The methods are usually fully automated,
- Possibility of detecting various phenomena in the evolution of microstructure of cement based materials
- Accuracy
- Low price

US TECHNIQUES FOR DETERMINATION OF SETTING

DISADVANTAGES OF US TECHNIQUES

- Velocity of US P-waves and shear wave reflection coefficient strongly depend on the presence of aggregate (amount of total solid phase in the microstructure of the materials),
- Relatively unclear and difficult determination of initial and final setting time – threshold values are usually used to define initial and final which depends strongly on the type of the material,

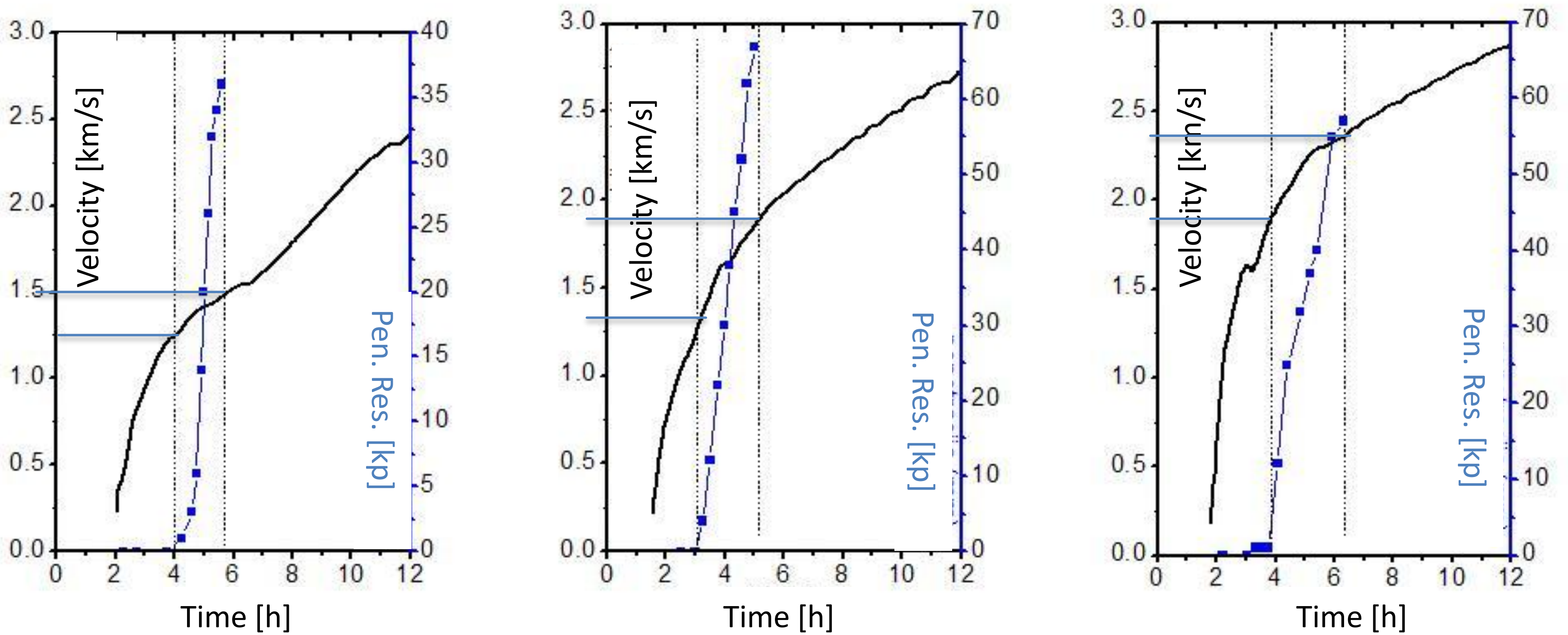
CBM	v_P [m/s]
portland cement based mortars	800-980
fly ash mortars	920-1070
concretes	1000-1500
concretes	2300-2700
cement paste	1450

beginning of setting

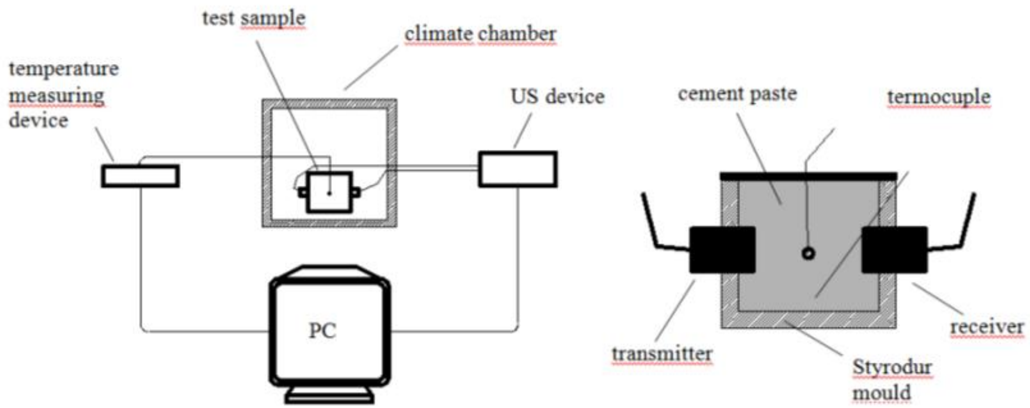
CBM	v_P [m/s]
concretes	1500
cement paste	1650
mortars	1200-1400
concretes	2000-3000
concretes	2790-3180

end of setting

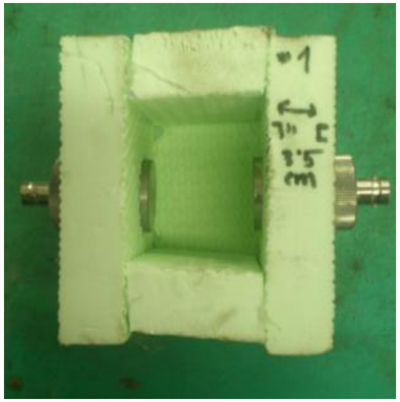
US TECHNIQUES FOR DETERMINATION OF SETTING



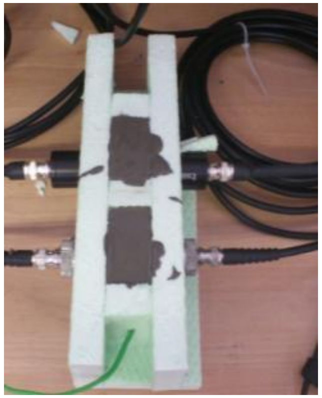
TEST SET-UP



Pulse

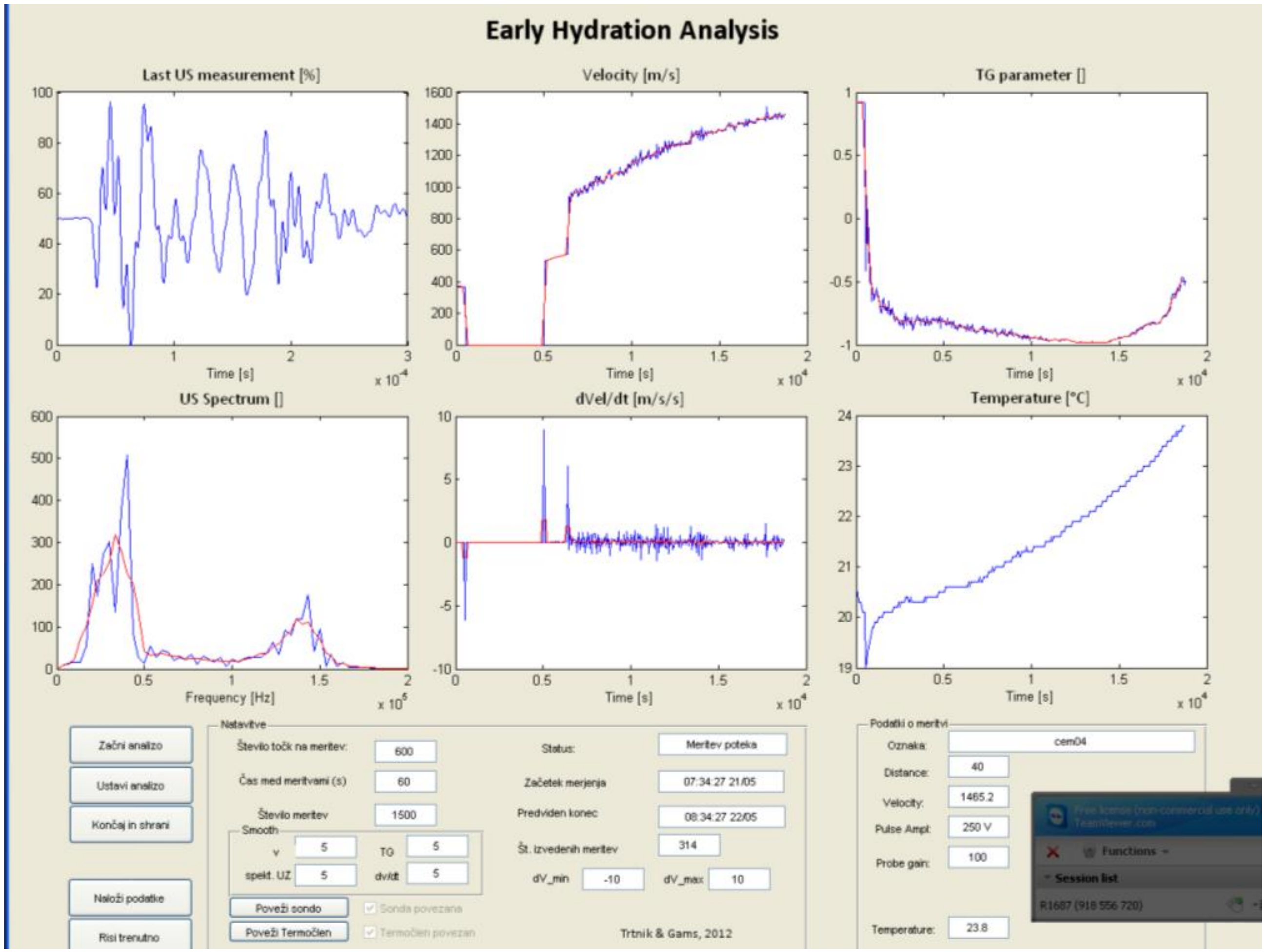


Mould

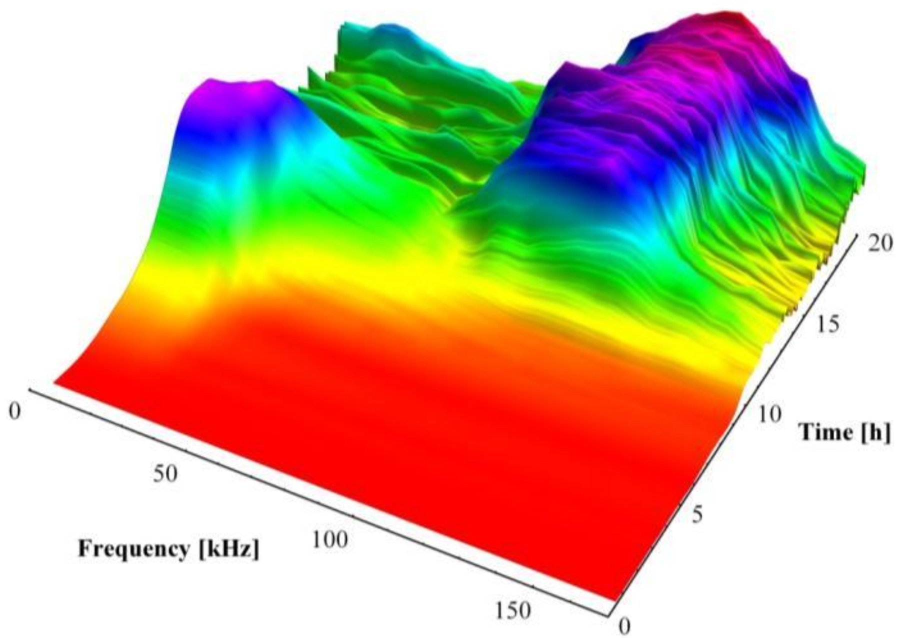


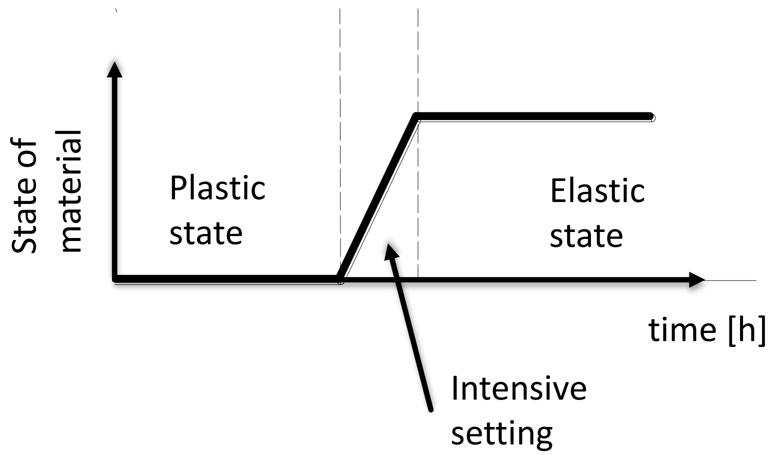
Samples

Measurements are observed in real time

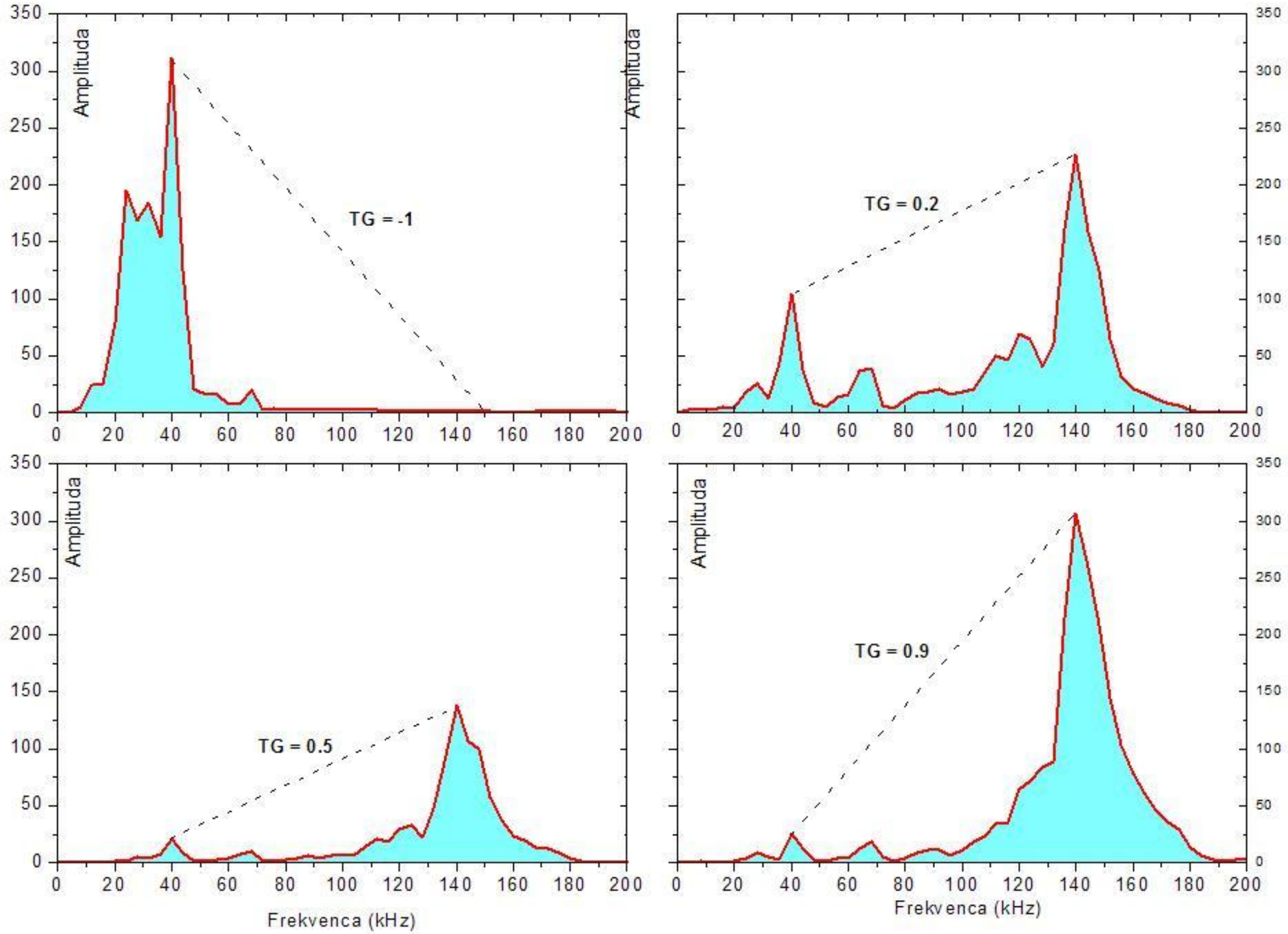


CHANGES IN SPECTRUM WITH TIME





TG PARAMETER

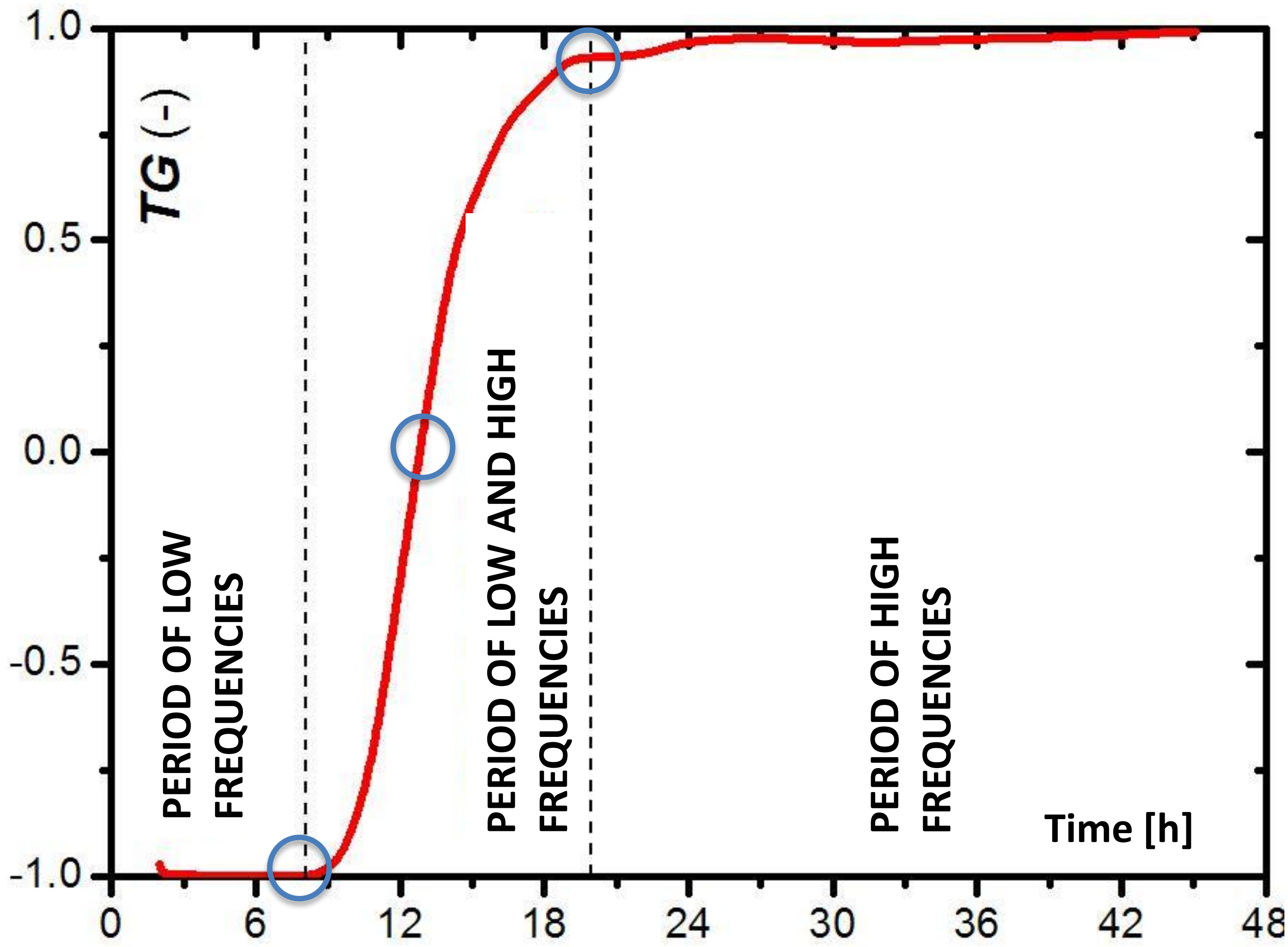


$$TG = \frac{a2 - a1}{a2 + a1}$$

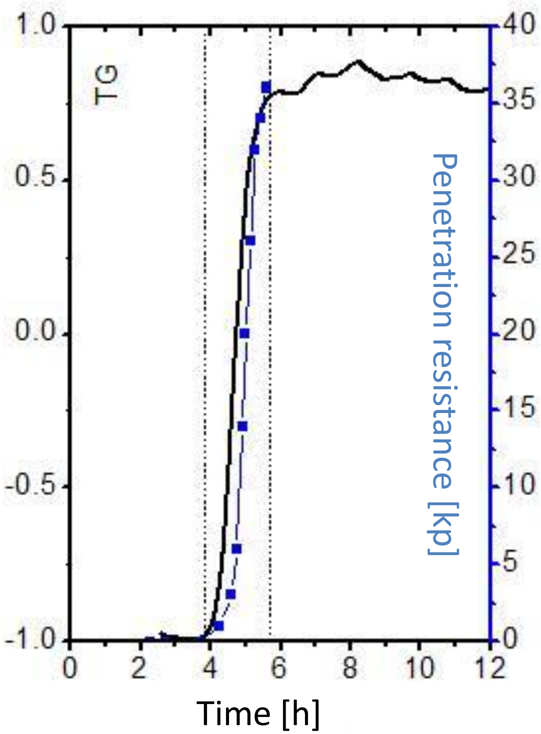
$$a2 = 0 \rightarrow TG = -1$$

$$a1 = 0 \rightarrow TG = 1$$

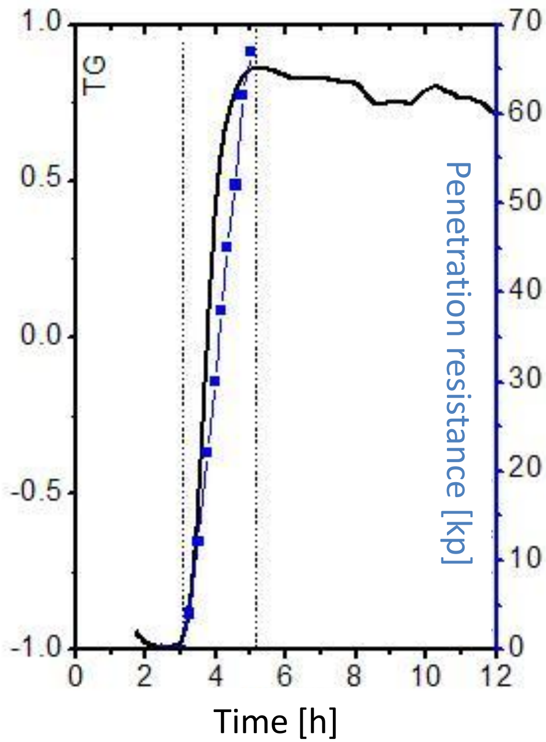
TG PARAMETER



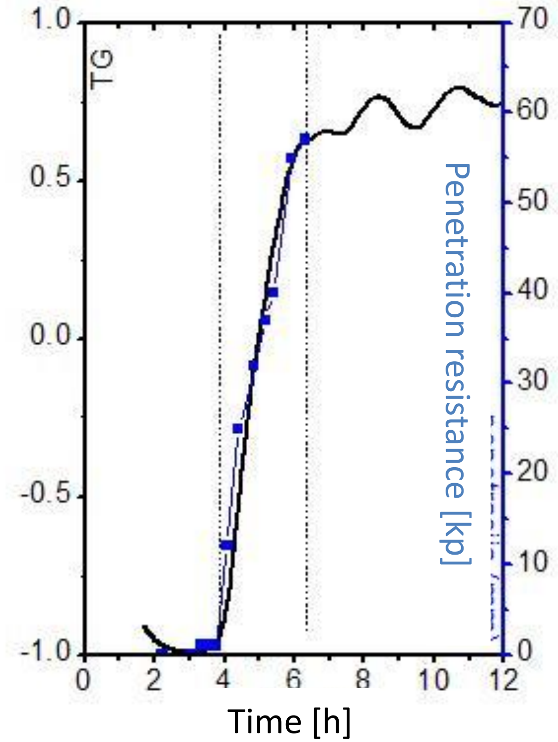
COMPARISON BETWEEN TG PARAMETER AND PENETRATION RESISTANCE



cement paste

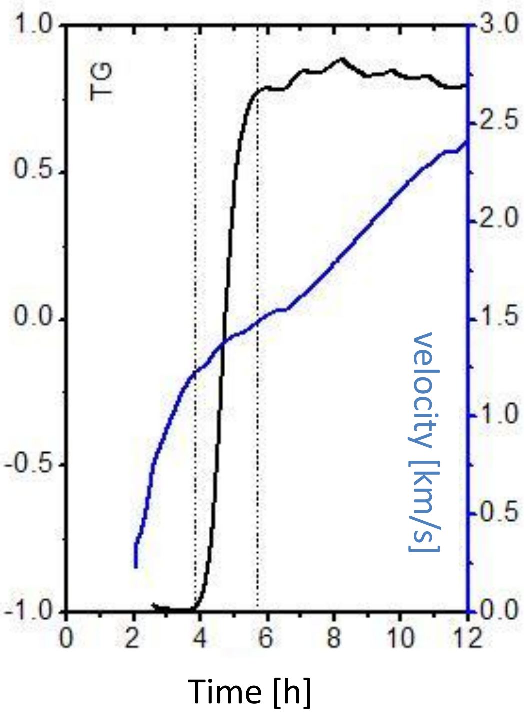


mortar

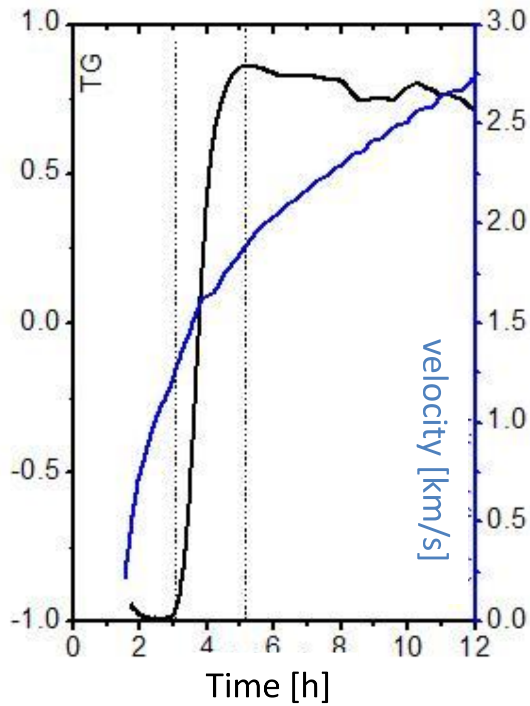


concrete

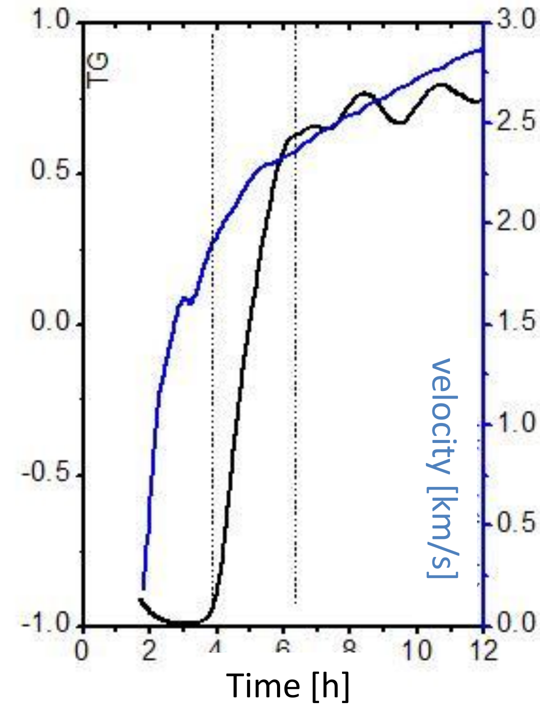
COMPARISON BETWEEN TG PARAMETER AND PULSE VELOCITY



cement paste

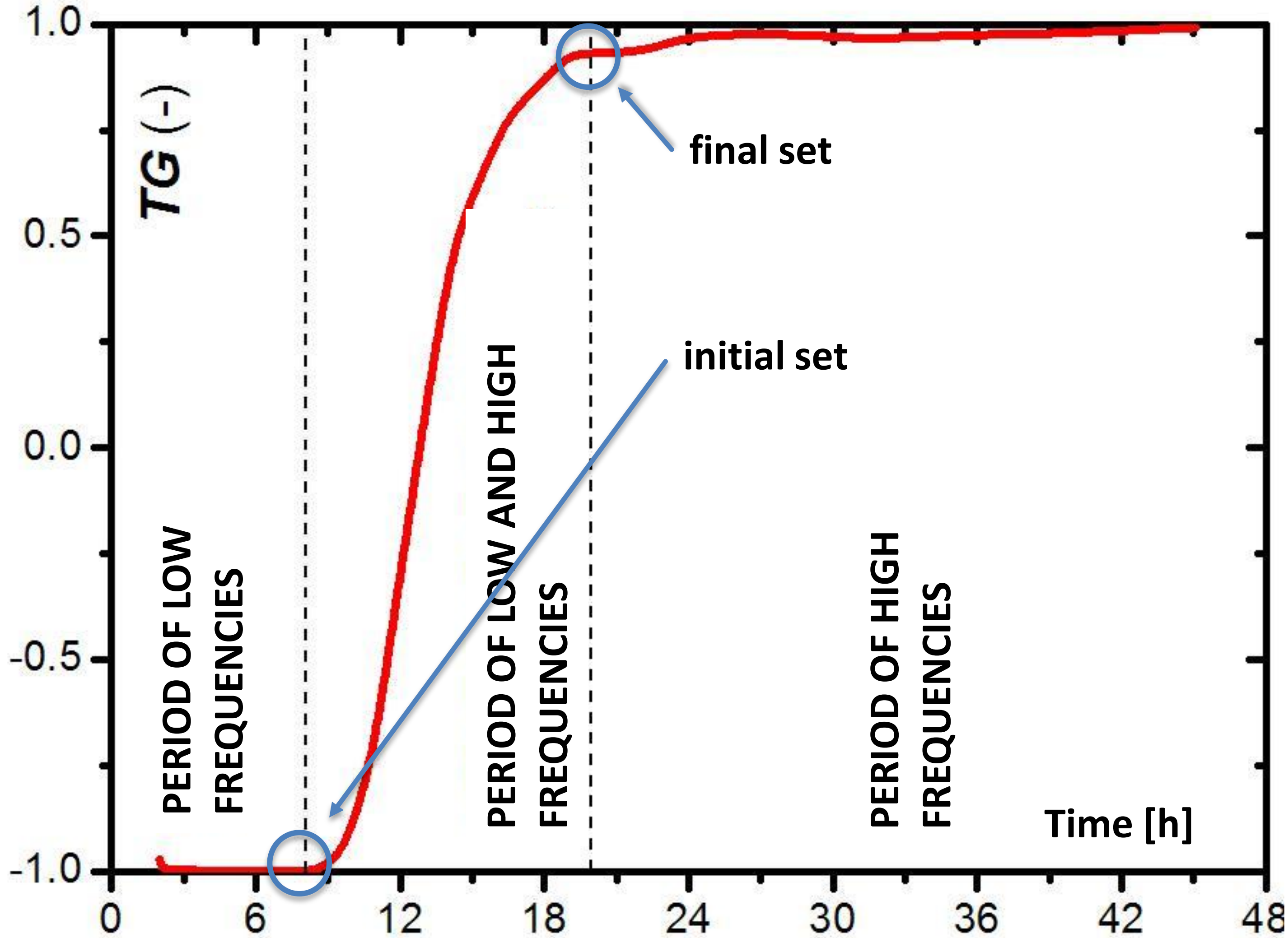


mortar

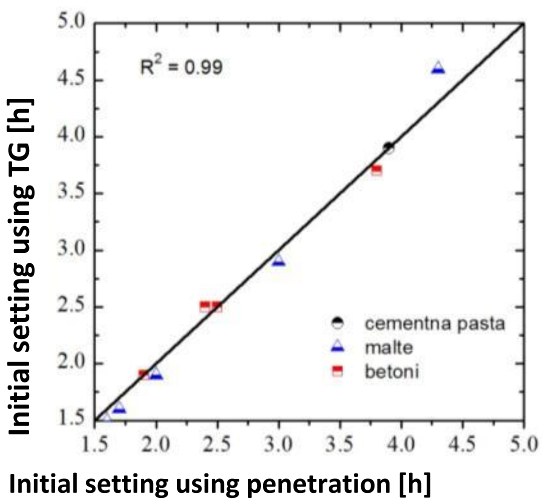


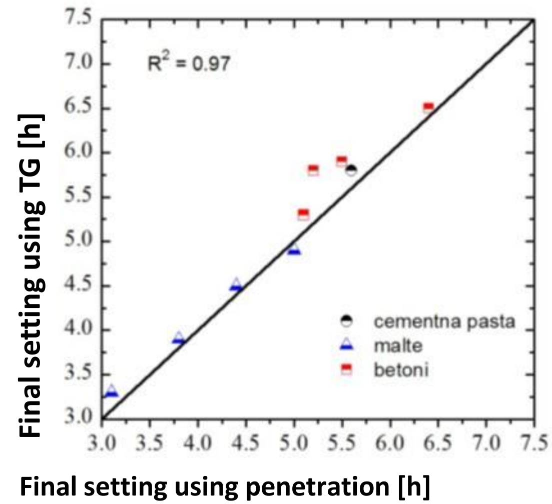
concrete

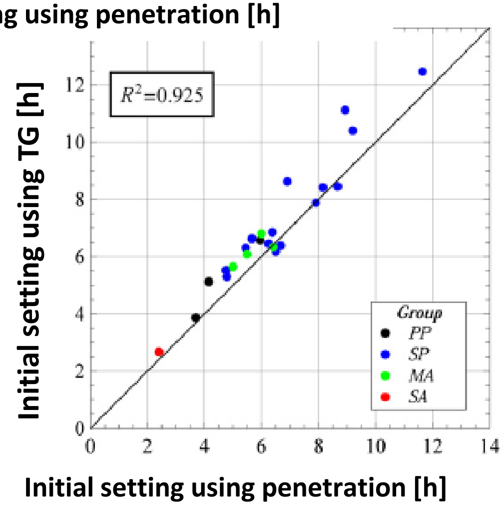
DETERMINATION OF SETTING USING TG

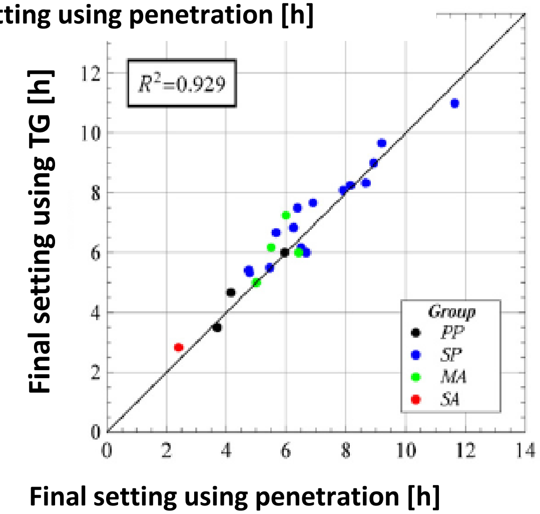


INFLUENCE OF MATERIAL’S COMPOSITION ON THE ACCURACY OF THE METHOD









CONCLUSIONS

- A new US method based on the analysis of frequency spectrum of US P-waves in transmission was presented;
- Analysing also the frequency spectrum improves the accuracy of determining setting;
- The new method has the ability to clearly and undoubtedly indicate intensive setting period of the material, i.e. transformation of the material from liquid to solid state;
- The results were validated by comparison to results of penetration resistance;
- It works regardless of the presence of aggregates in the material's composition.

SESSION for GP1.b – Chemical and microstructural characterization

Chairman: Özlem Cizer

Özlem Cizer:	Chemical and microstructural characterization - experimental plan for GP1b
Ruben Snellings:	XRD as an indispensable technique for cement hydrate assemblage characterisation in view of service life/durability predictions
Guang Ye:	What do we need for validation of the microstructure of cement-based materials simulated by computer models?

TU 1404 COST ACTION

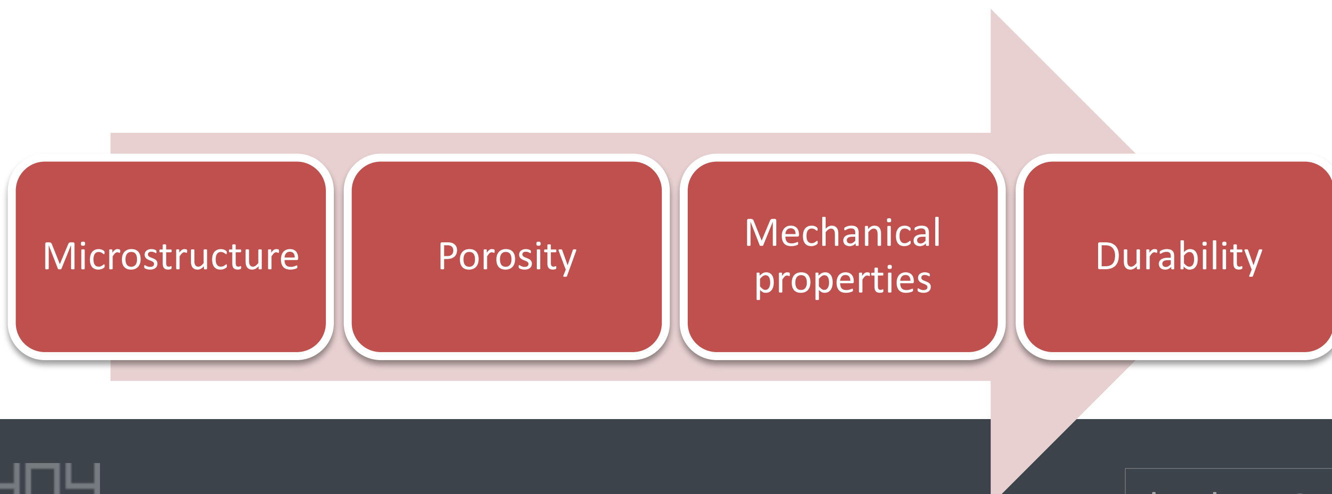
Chemical and microstructural characterization – Experimental plan for GP1b

Özlem Cizer - University of Leuven (KU Leuven), Belgium

www.tu1404.eu

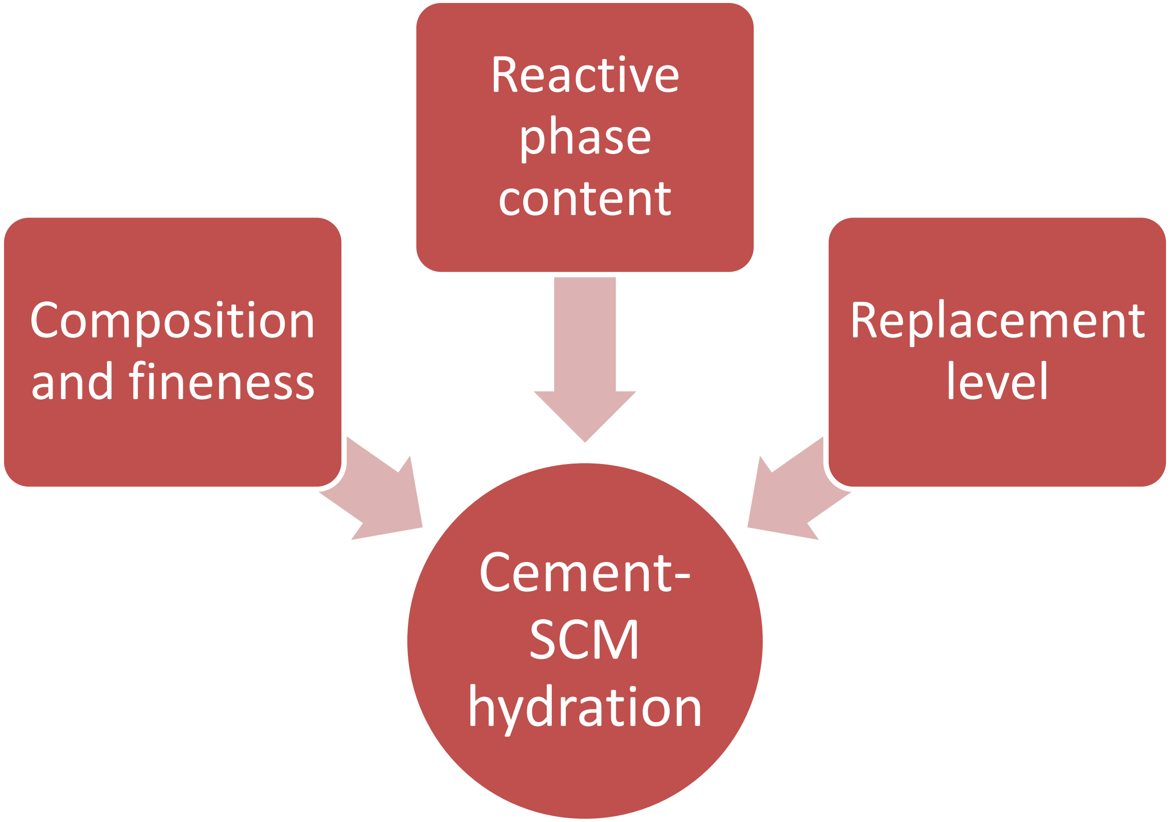
Motivation

- Cement hydration is a complex chemical process that involves dissolution of cement grains and nucleation of solid phases of hydration products.
- The presence of supplementary cementitious materials (SCMs) complicates this chemical process by:
  - affecting the rate and degree of hydration due to filler effect leading to extra space and enhanced nucleation for hydration products,
  - affecting the structure of C-S-H phase due to chemical effect,
  - producing additional amount and type of hydration products.



Motivation

- A database of material properties is needed in particular when SCMs (by-products and waste residues) are incorporated in concrete.



Objectives

To characterize hydration degree and microstructure of CBM, in particular for high-performance concrete and eco-concrete where SCMs are incorporated

To mutually validate non-standardized and advanced experimental techniques in European laboratories

To build up reliable database as input data for simulation models in WG2

Experimental program (tentative)

Characterization of cement and SCMs

- Particle size distribution
- Specific surface area
- Chemical composition
- Mineral composition

Hydration degree of cement and SCMs

- Thermal analysis
- Selective dissolution
- QXRD analysis
- SEM image analysis

Characterization of microstructure

- Mercury intrusion porosimetry (MIP)
- SEM image analysis
- X-ray computed microtomography (X-CT)

Experimental program (tentative)

- **Characterization of cement and SCMs (all GP1b participants)**
  - Particle size distribution
    - Laser diffraction method
    - Dispersion medium, solids concentration, dispersion procedure, and type and duration of ultrasonic treatment
    - At least five measurements
  - Specific surface area
    - Blaine surface area (EN 196-6)
    - BET surface area
    - At least five measurements
  - Chemical composition
    - X-ray fluorescence analysis
  - Mineral composition
    - Powder X-ray diffraction analysis (quantitative phase analysis)

Experimental program (tentative)

- **Hydration degree of cement and SCMs**
  - Thermal analysis *(Scrivener et al. 2015)*
    - To assess the total degree of hydration attributed to the chemically bound water of CH, C-S-H and other hydrates
    - To quantify the amount of calcium hydroxide (CH) formed by cement hydration and consumed by SCMs
    - Cannot distinguish the hydration of SCM from the hydration of cement
    - Reference state of material (removal of free water) is crucial
    - Associated with a number of errors such as filler effect of SCMs, CH consumption vs. degree of SCM reaction, and formation of other phases such as hemicarbonate and stratlingite

Experimental program (tentative)

- **Hydration degree of cement and SCMs**
  - Selective dissolution *(Scrivener et al. 2015)*
    - To measure the reactions of SCMs in blended cements
    - Preferential chemical dissolution of the hydration products and unhydrated cement leaving the unreacted SCMs as a residue
    - Choice of selective dissolution method (EDTA with NaOH or DEA for slag and salicylic acid for fly ash) plays a critical role
    - Application of this method for other types of SCMs needs to be considered carefully

Experimental program (tentative)

- **Hydration degree of cement and SCMs**
  - QXRD analysis
    - To quantify crystalline phases (e.g. CH) and the total amount of X-ray amorphous materials in cement and SCMs
    - Limited to the quantification of the degree of hydration and identification of the hydration products due to their amorphous nature
    - Simultaneous presence of amorphous C-S-H and SCM
    - New approaches using PONCKS approach applying phase constant
  - SEM image analysis
    - To measure the degree of cement hydration through identification of different phases (C-S-H, CH, SCMs and unhydrated cement)
    - Corresponds well with the other measures of degree of hydration, for example QXRD with Rietveld analysis
    - Obtaining the lowest reasonable standard error is the main challenge

Experimental program (tentative)

- **Characterization of microstructure**
  - Mercury intrusion porosity (MIP)
    - Pore diameters varying from 0.001 μm to 1000 μm can be measured
    - Total porosity, effective porosity, threshold pore diameter and pore size distribution
    - Limitations include ink-bottle effect, high intrusion pressure causing internal damage, and assumption of pores being cylindrical and accessible from the outer surface
  - SEM image analysis
    - Useful means for the characterization of large capillary pores
    - Contrary to MIP method, SEM image analysis proves that the pore shape is not cylindrical
  - X-ray computed microtomography (X-CT)
    - To quantify the microstructural features and pore structure of CBM
    - To provide information on real size and spatial distribution of the pores, which cannot be obtained by classical techniques such as MIP

Output image for WG2

Reliable and mutually validated experimental data as input parameter for the simulation models in WG2

- Materials properties
- Degree of cement hydration
- Degree of the reaction of SCMs
- Microstructure features
- Pore structure features

- Which experimental data are needed for which simulation models?
- What is the hydration model?
- What is the microstructure model?

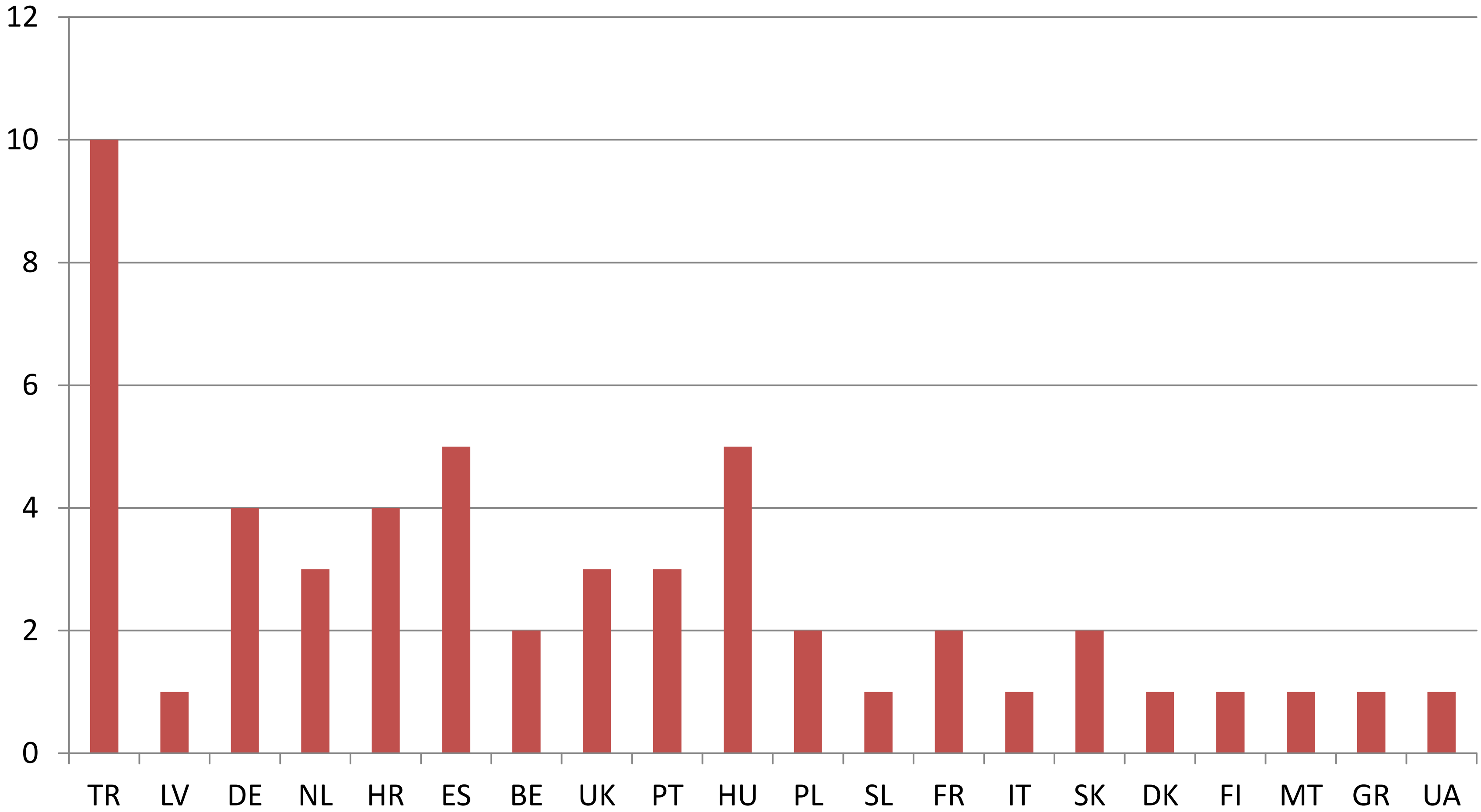
Mix compositions and curing

- Cement paste
  - cement, SCMs (to be selected) and distilled water
  - w/c = 0.62 selected for concrete (relatively high)
- Curing in small polyethylene flasks (e.g. 60 ml volume), sealed and stored at 20 °C
- Characterization of the hydration degree at 1, 3, 7, 14, 28, 60 and 90 days?
- Characterization of microstructure at 1, 3, 7, 28, and 90 days?

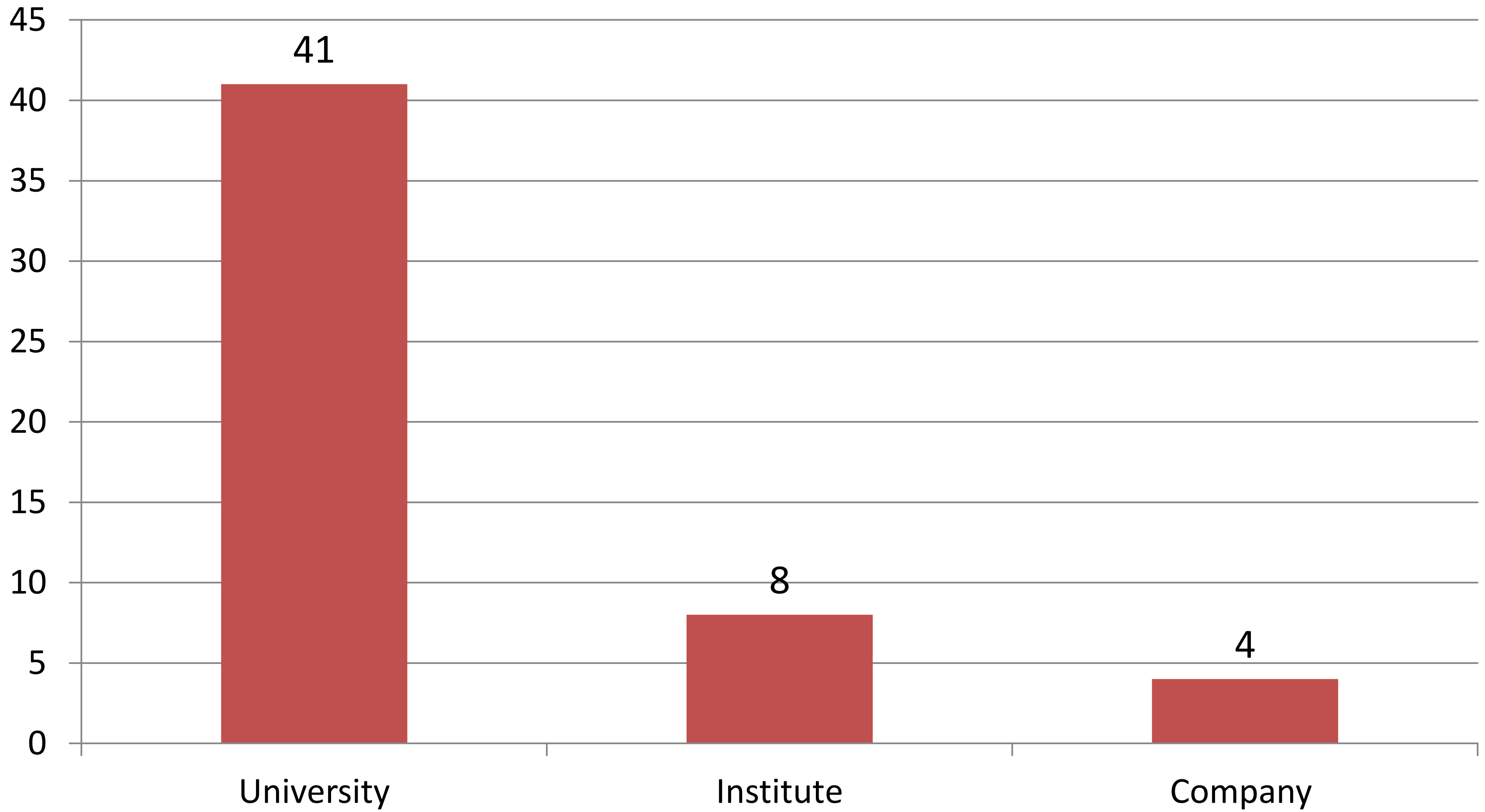
Specific conditions

- Stopping the ongoing hydration reactions particularly for TGA and XRD analysis
  - Freeze drying
  - Vacuum drying
- Drying hardened samples for microstructure characterization
  - Freeze drying
  - Vacuum drying
- More participants are needed for selective dissolution (if included)
- Application of nitrogen gas adsorption for microstructure characterization
  - Pore diameter range that can be determined is from 0.3 to 300 nm, which is not completely covered by MIP
  - Is there an added value for WG2?
- Others?

Partners = 53



Partners = 53



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XRD analysis of cementitious materials:

binder components and their deterioration

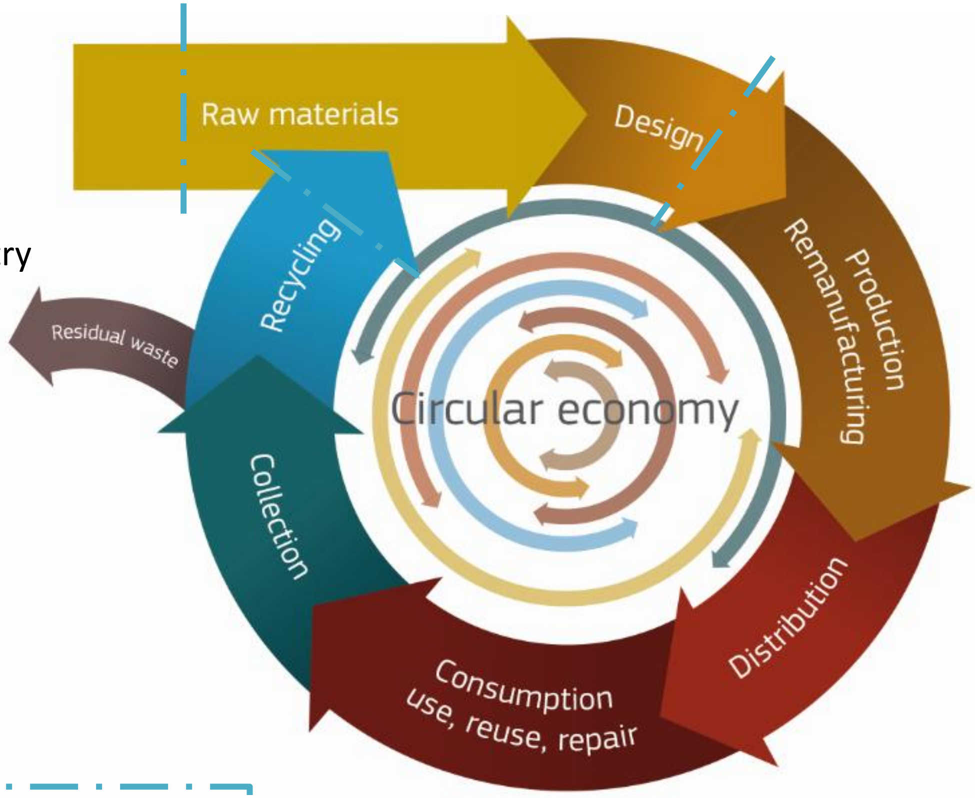
Ruben Snellings – ruben.snellings@vito.be

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

"Zero waste" and cement-based binders

"The future of cement is blended"

- EU 2015: majority of produced cements is blended
- Waste processing is big business for cement industry
  - **Alternative fuels**
  - **Alternative raw materials**
  - **SCMs**
- Coping with waste streams/alternative SCMs:
  - **Diversifying range**
  - **Compositional variability**
  - **Environmental quality**
  - **Impact on durability/service life?**



[EC, 2014]

Gateway role for characterisation studies (XRD)

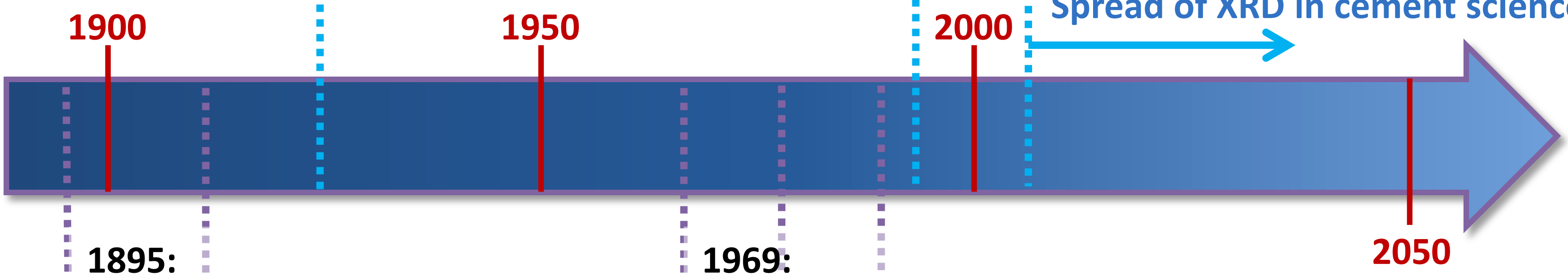
XRD as a characterisation tool for cementitious materials

X-ray diffraction & cement - a historical perspective

1993:
1st Rietveld QPA on cement (Taylor & Aldridge)

1928:
1st XRD studies on cement (Hansen, Brownmiller)

2000s:
Spread of XRD in cement science



1895:
Discovery of X-rays (Röntgen)

1912:
XRD on crystals (von Laue)

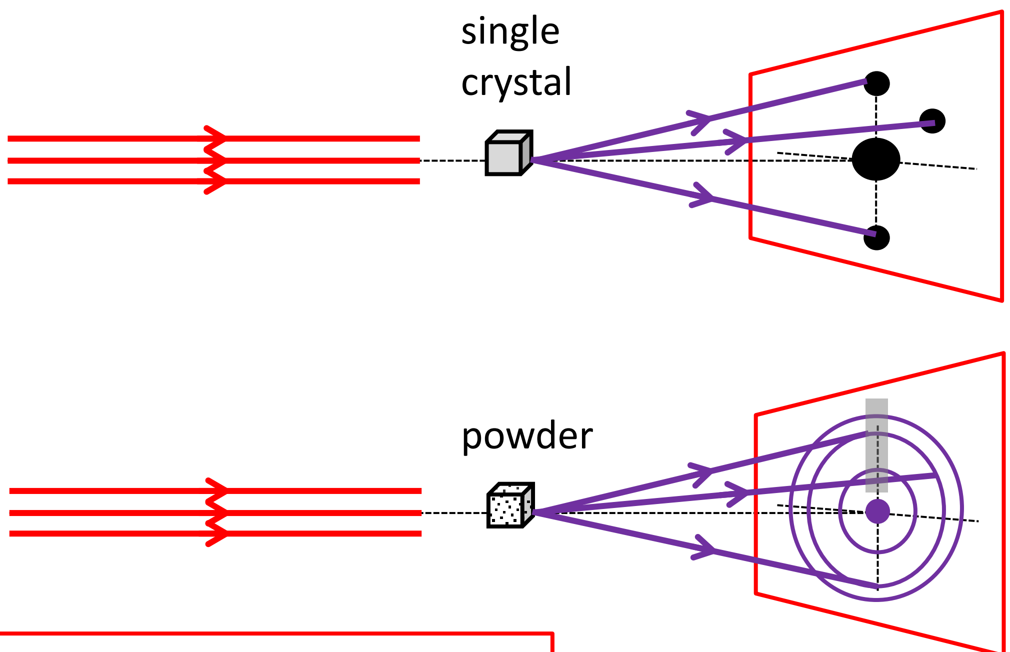
1969:
Rietveld method for neutron diffraction (Rietveld)

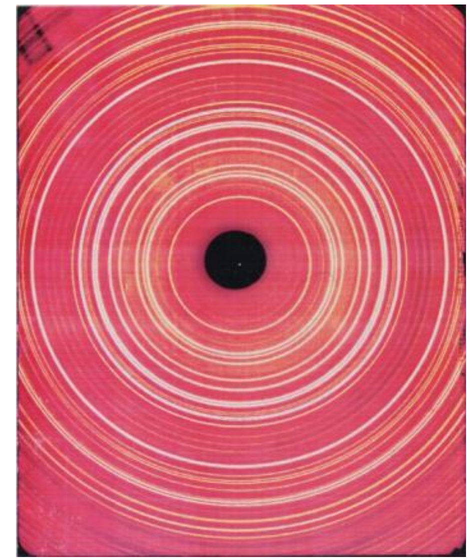
1977:
Rietveld method for XRD (Cox, Young, Thomas)

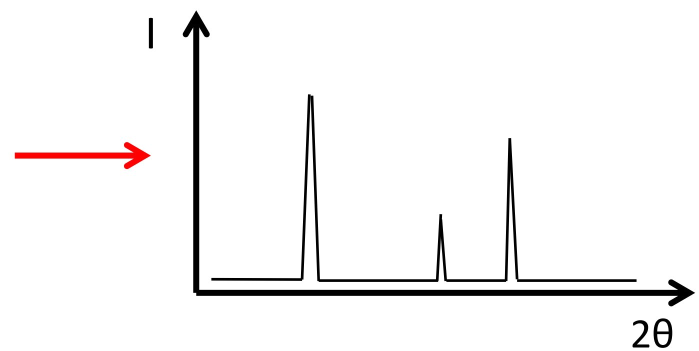
1987:
Rietveld method for quantitative analysis (Hill & Howard)

X- ray diffraction: principles

- Single crystal vs powder diffraction







Data compressed into one dimension

Bragg's law $n\lambda = 2d \sin\theta$

XRD – latest developments and applications

- Latest developments:
  1. Spread of Rietveld quantitative phase analysis (software developments – spread of expertise)
  2. New, performant detector systems enable in situ studies, acquisition of large, systematic sets of data

- Applications/examples:
  1. Quantitative phase analysis
     a. Anhydrous cements
     b. Hydrated cements
     c. Blended cements/novel cements
  2. Durability studies – tracking of deterioration processes

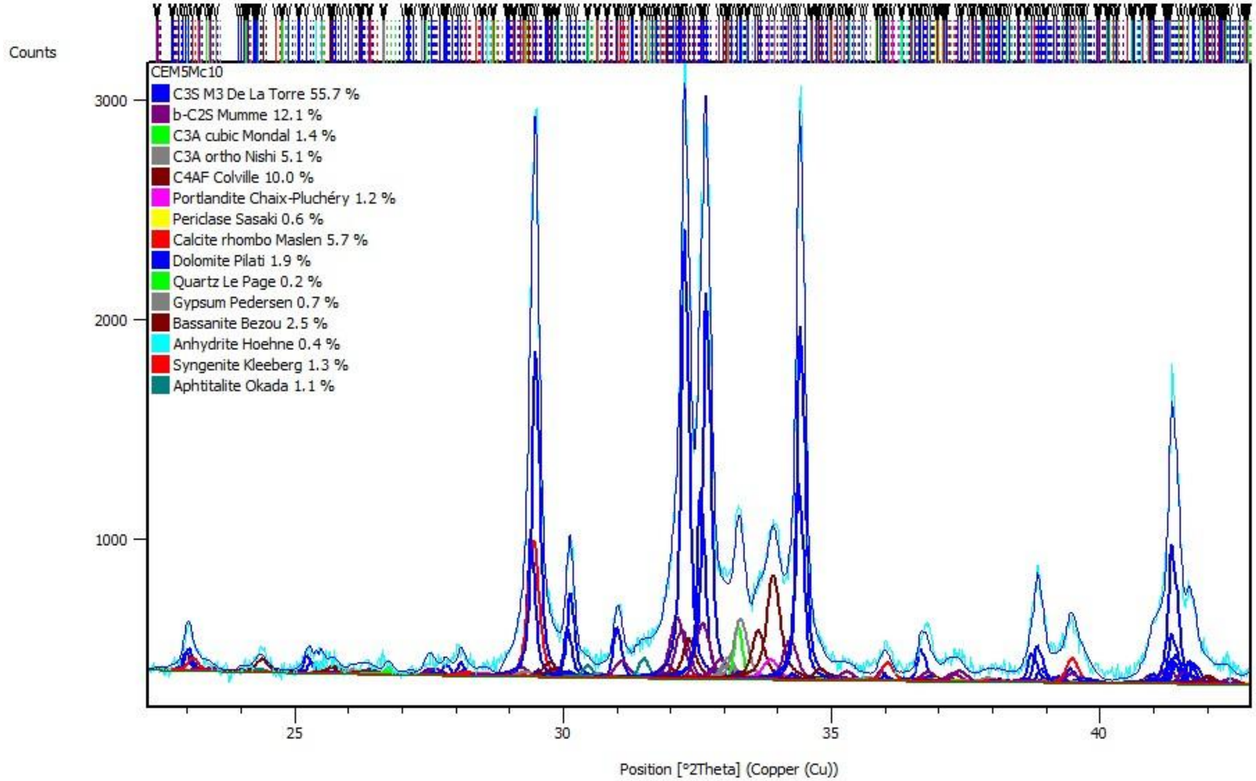
Example 1a-c – Quantitative phase analysis

Quantifying the phase composition of cements

"Tell me what you're made of, and I'll tell you how long you'll last"

Example 1a: quantitative phase analysis of Portland cement

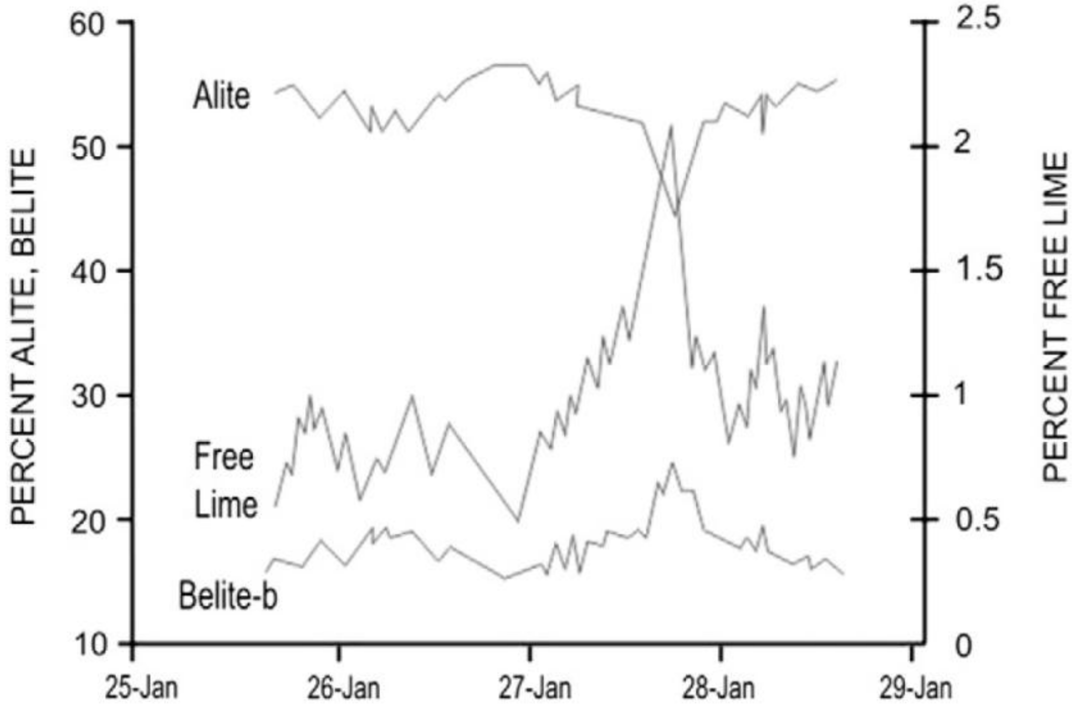
Portland cement is a complex mix of phases, whole patten fitting methods (e.g. Rietveld) can deal with peak overlap in the XRD scans



Differences in strength development and durability can be correlated with the phase composition

Example 1a: quantitative phase analysis of Portland cement

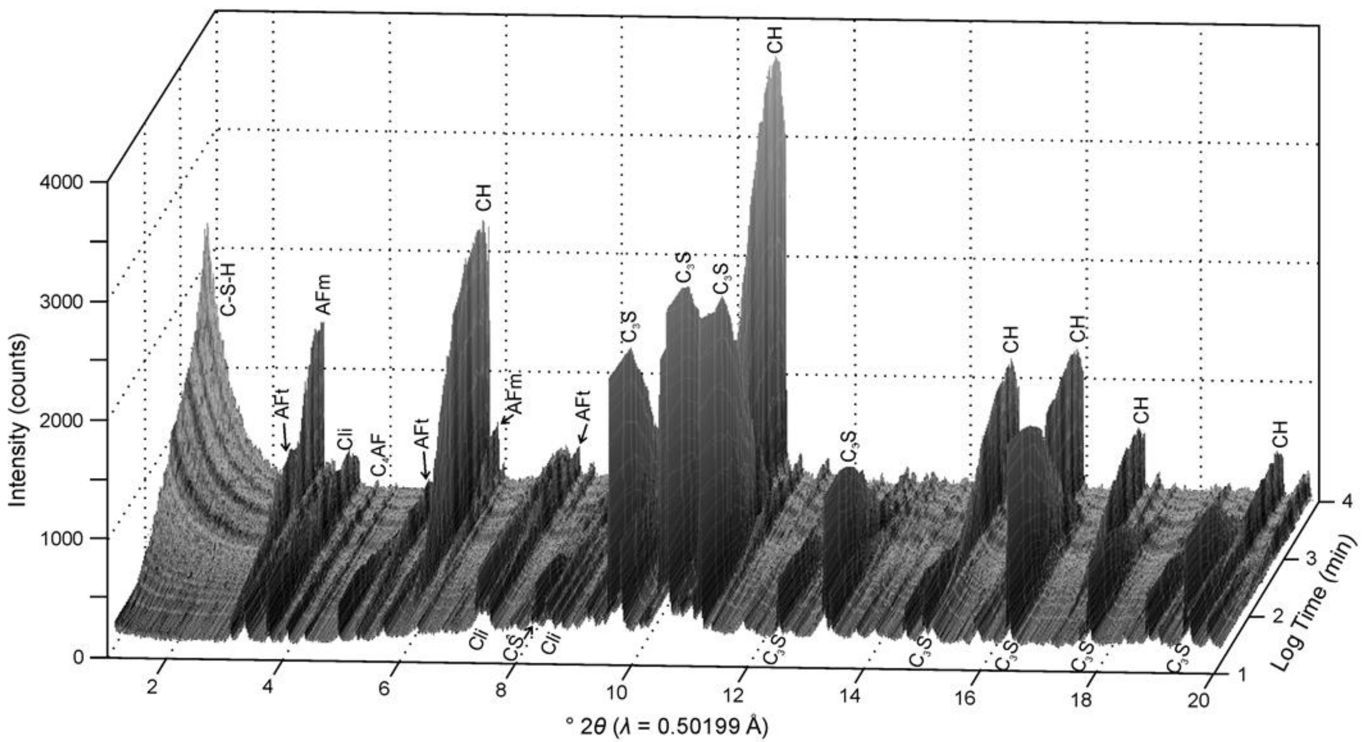
- Rietveld QPA in production process and quality control in cement plants:



Rapson and Storer (2006)

Example 1b: Hydration kinetics of blended cement

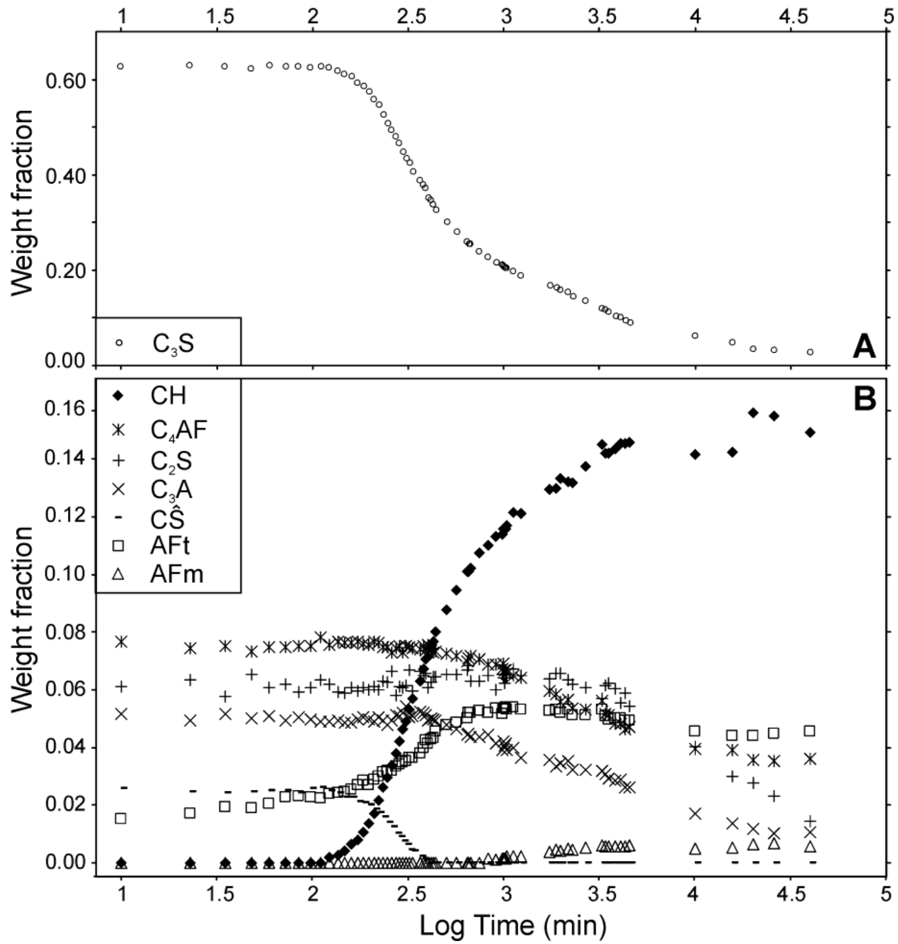
- In-situ XRD of a hydrating zeolite blended cement



Snellings et al. (2010)

Example 1b: Hydration kinetics of cement

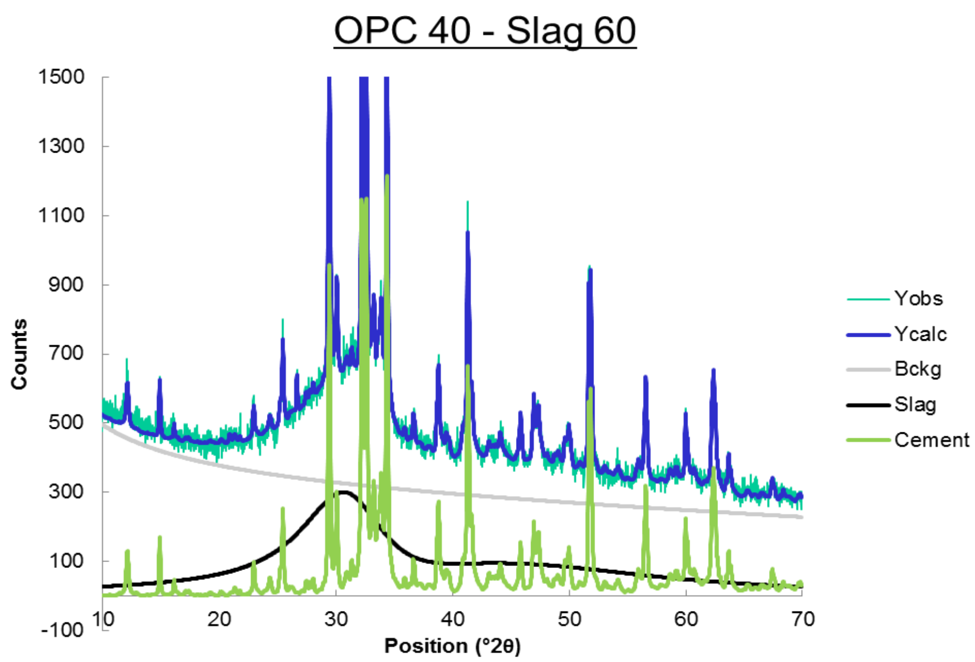
- In-situ synchrotron XRD of a hydrating cement paste



Snellings et al. (2010)

Example 1c: PONCKS – quantification of amorphous phases

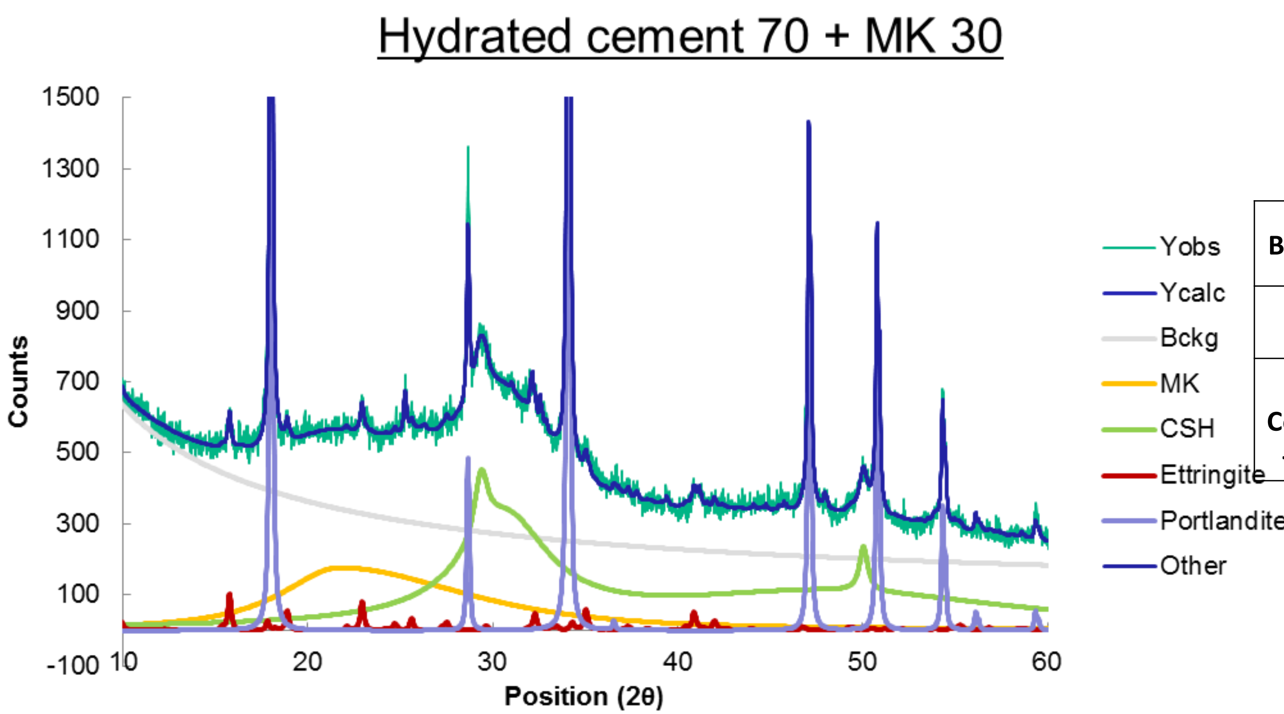
- Partial Or No Known Crystal Structure (PONCKS) method (Scarlett & Madsen, 2006)
  - Application to cements (Snellings et al., 2014)
    - E.g. Anhydrous blended cement



% Measured	Slag	39.8
σ	Slag	0.3
% Weighed	Slag	39.5
Absolute deviation	Slag	0.3

Example 1c: PONCKS – quantification of amorphous phases

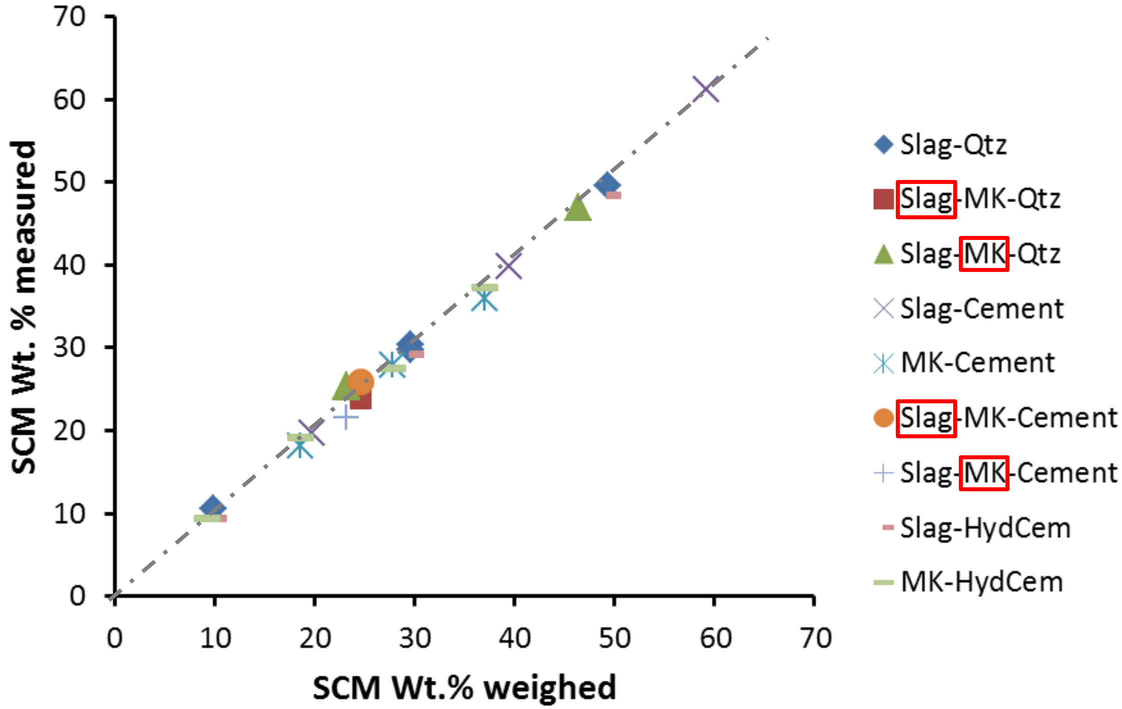
- Partial Or No Known Crystal Structure (PONCKS) method (Scarlett & Madsen, 2006)
  - Application to cements – model mixes (Snellings et al., 2014)
    - E.g. hydrated blended cement – distinction MK/C-S-H



Binary mix	Average	σ	Weighed	Absolute deviation
Sample	Wt% MK	Wt% MK	Wt% MK	Wt% MK
White Cement 70 – MK 30	**27.5**	0.5	**27.8**	0.3

Example 1c: PONCKS – quantification of amorphous phases

- Partial Or No Known Crystal Structure (PONCKS) method (Scarlett & Madsen, 2006)
  - Application to cements – model mixes (Snellings et al., 2014)



Example 2 – Durability testing

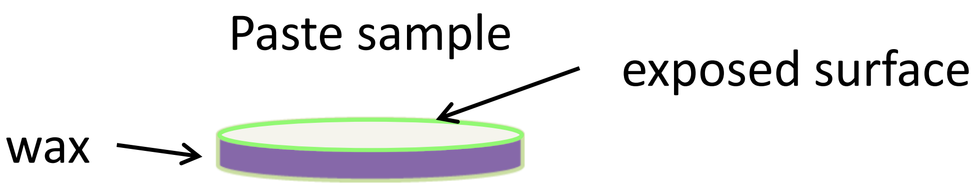
Quick ponding tests as a proxy for chloride and sulfate resistance

Delivers:

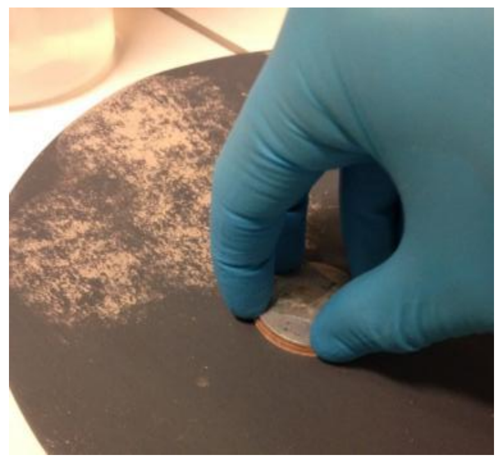
Calibration of transport/thermodynamic models for concrete service life predictions

Most of the material from H. Kamyab, P. Henocq, M. Antoni (EPFL)

Method : Quick Ponding tests on paste



15, 20, 38 h
1,2 weeks
NaCl 0.5 M
Na_2SO_4 0.05 M



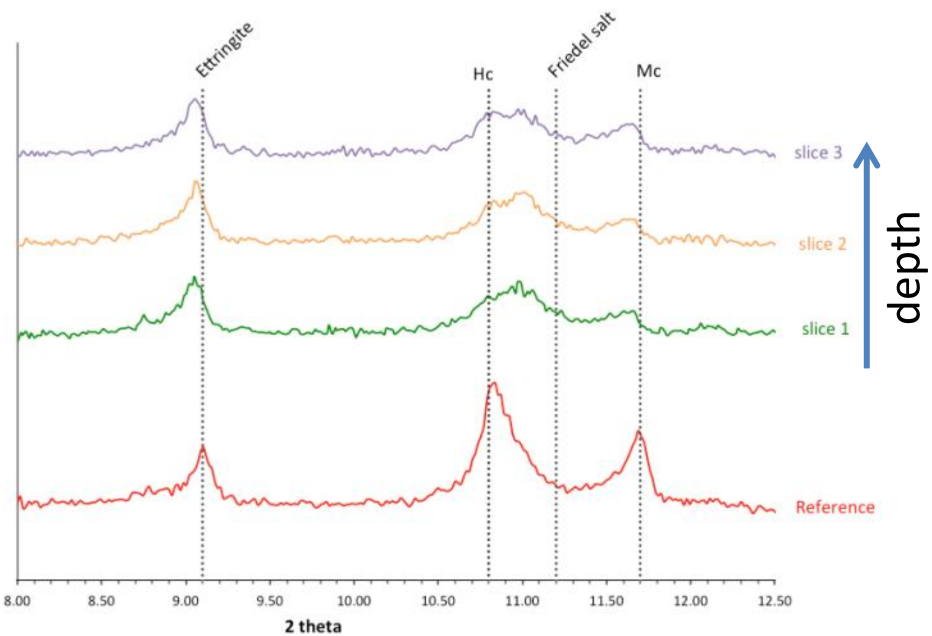
Removal of 200 µm layers by polishing

15 min measurement time to avoid surface carbonation

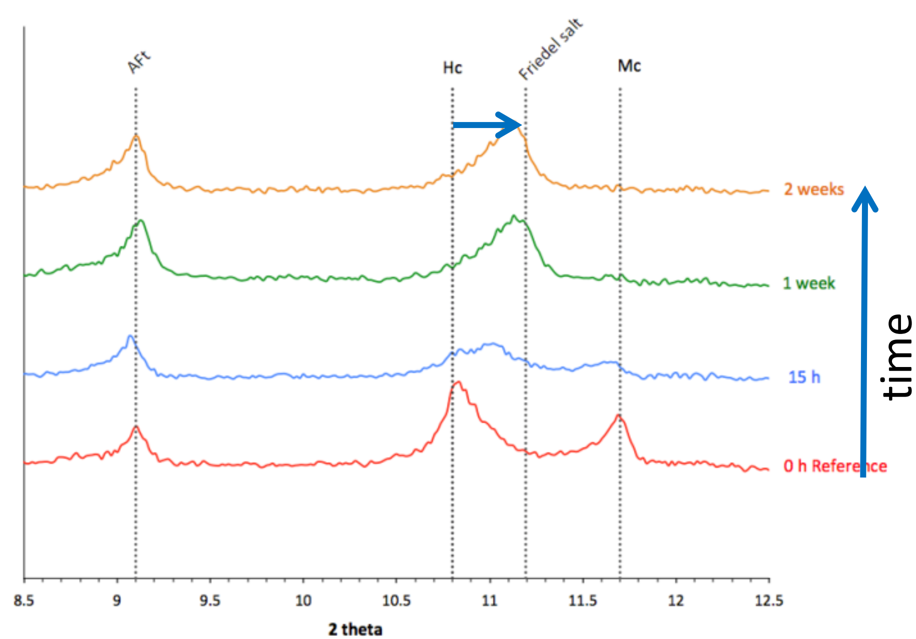
Method: Quick ponding – Cl/sulfate

- Identify **Friedel's salt/gypsum** at different depths
- Time-depth profiles of chloride/sulfate binding in the matrix
- Needed for modelling: mass balance of deterioration reactions

CC-blended cement
0.5 M NaCl - 15 h



CC-blended cement
0.5 M NaCl – 400 µm depth



Method: Quick ponding – Cl/sulfate

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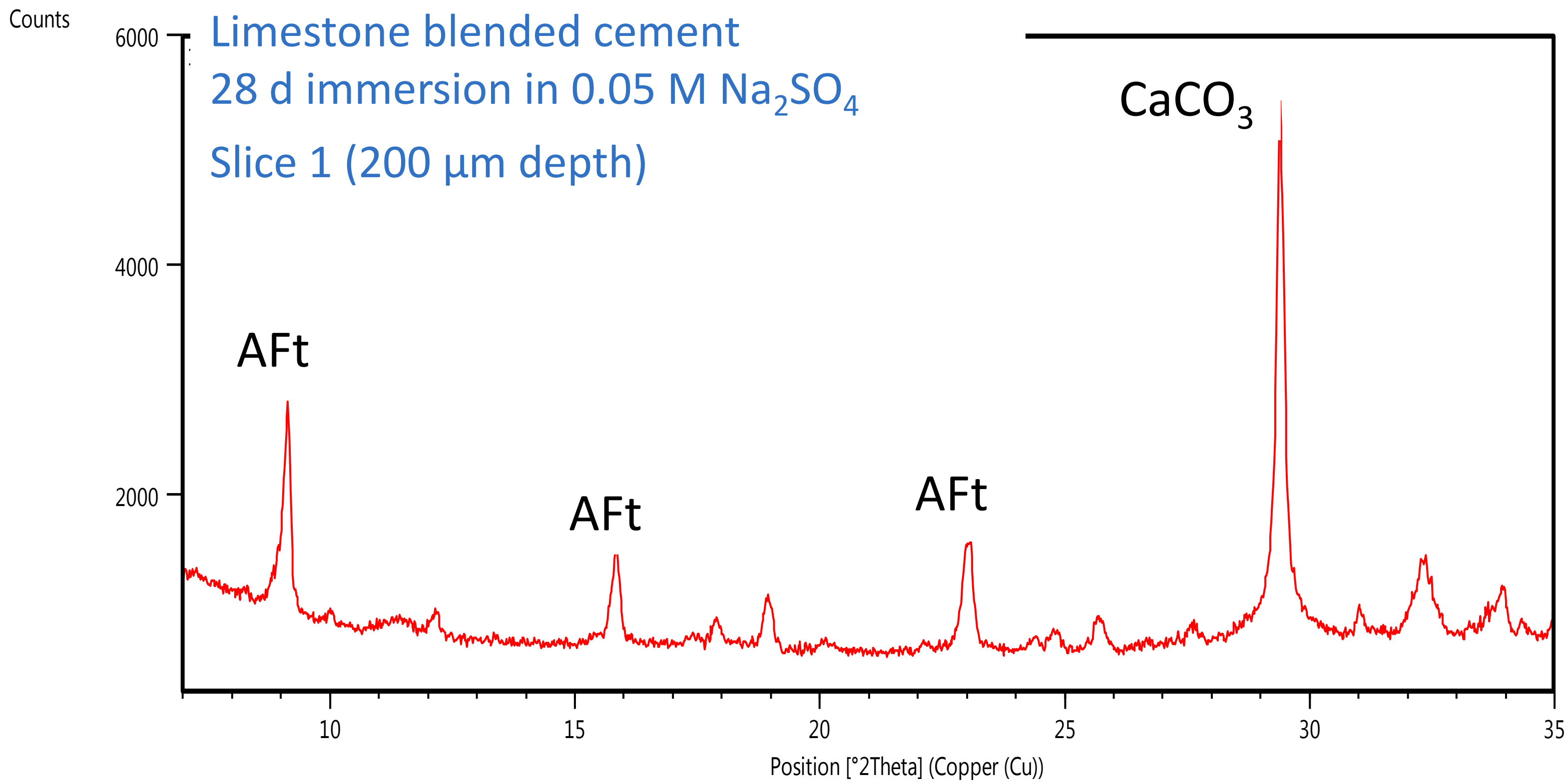

Method: Quick ponding – Cl/sulfate

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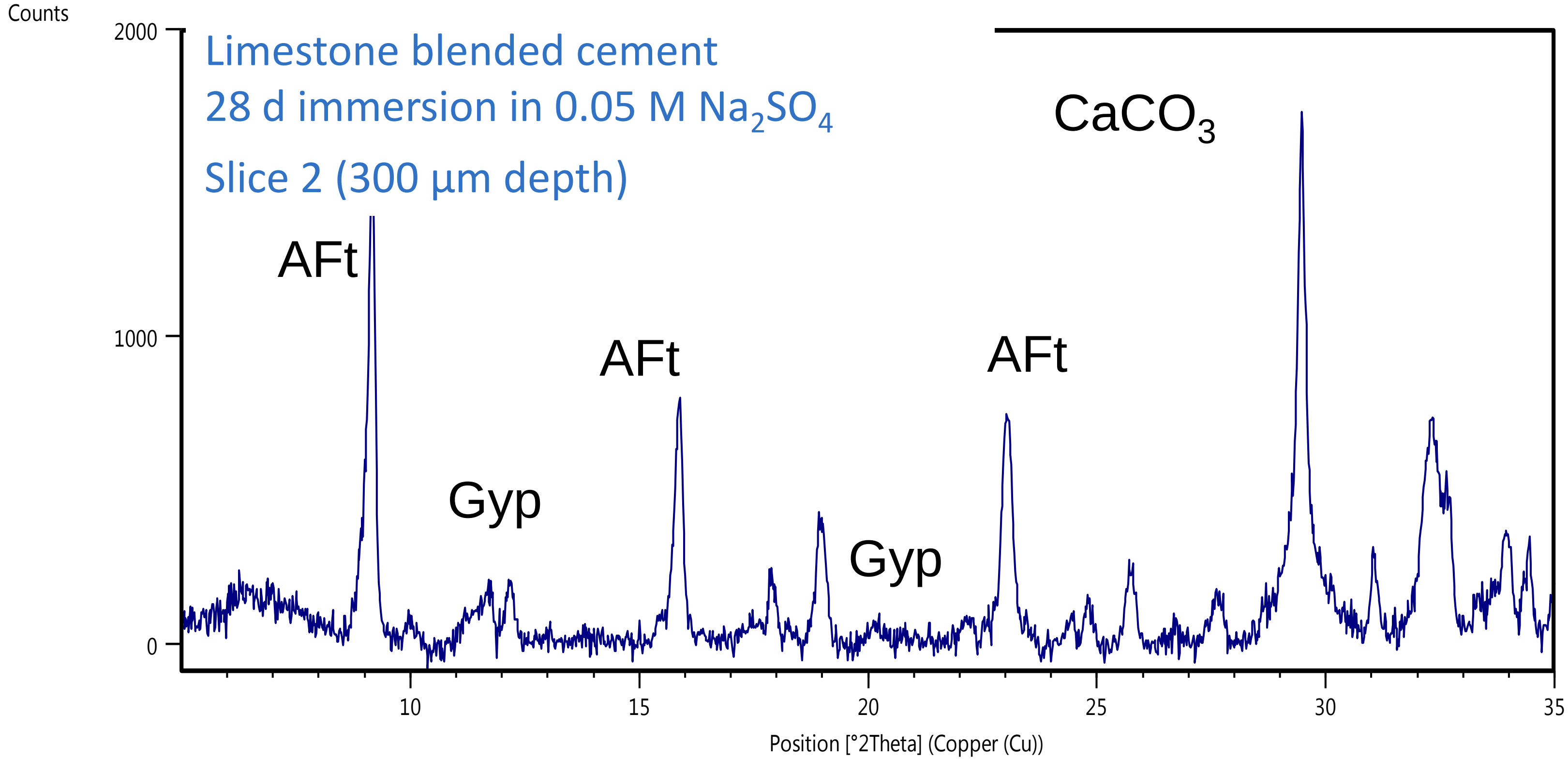

Method: Quick ponding – Cl/sulfate

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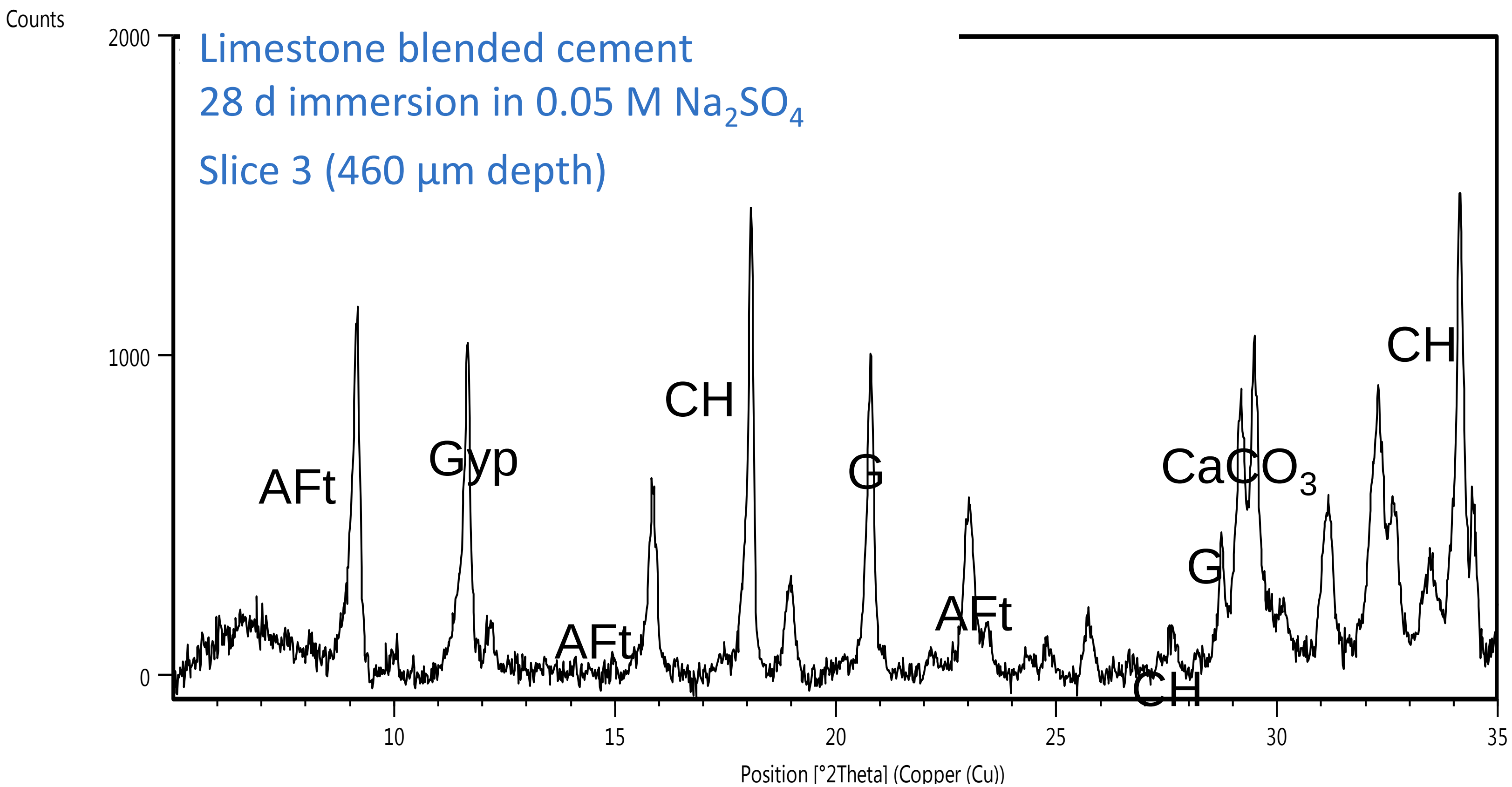
– Time-depth profiles of chloride/sulfate binding in the matrix



Method: Quick ponding – Cl/sulfate

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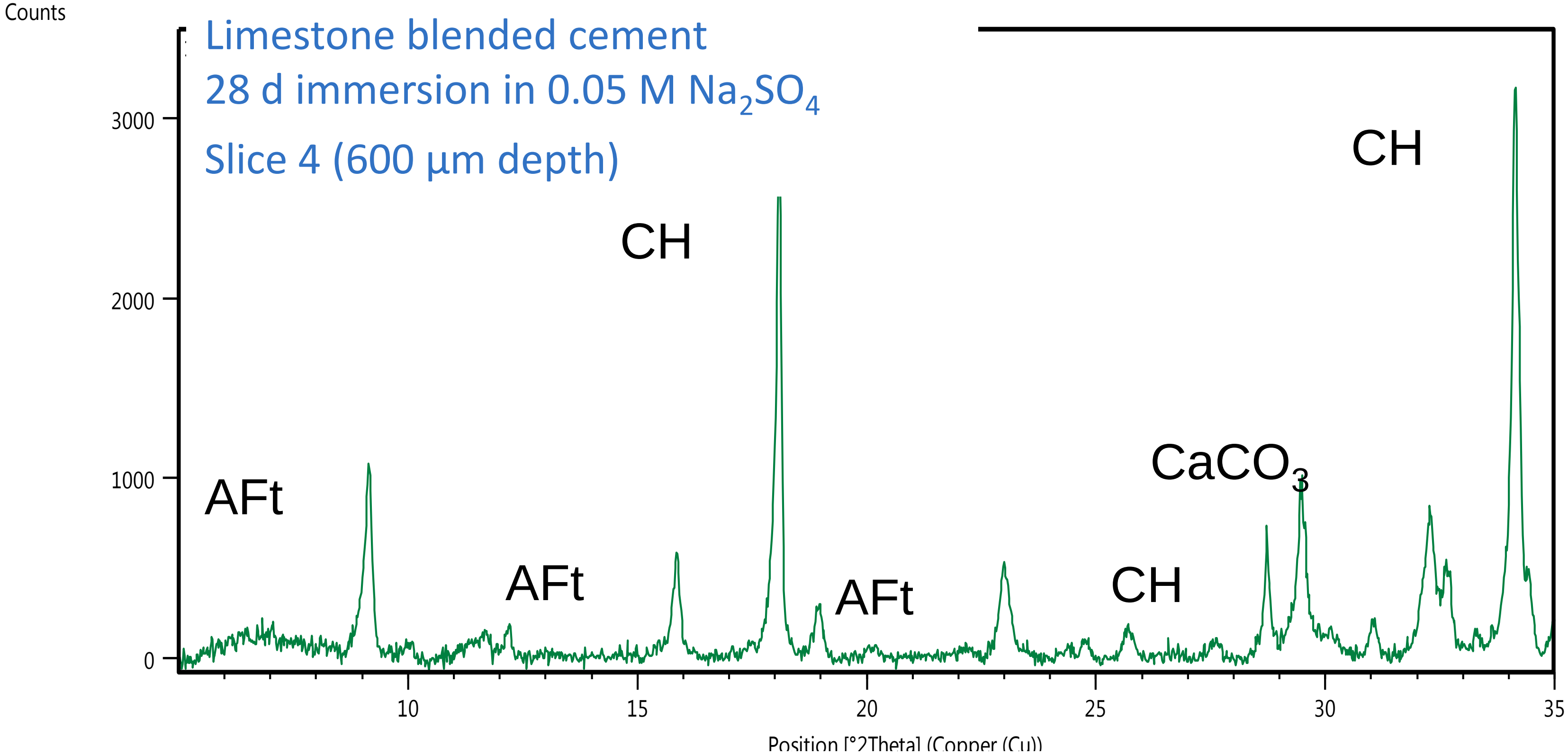


Method: Quick ponding – Cl/sulfate

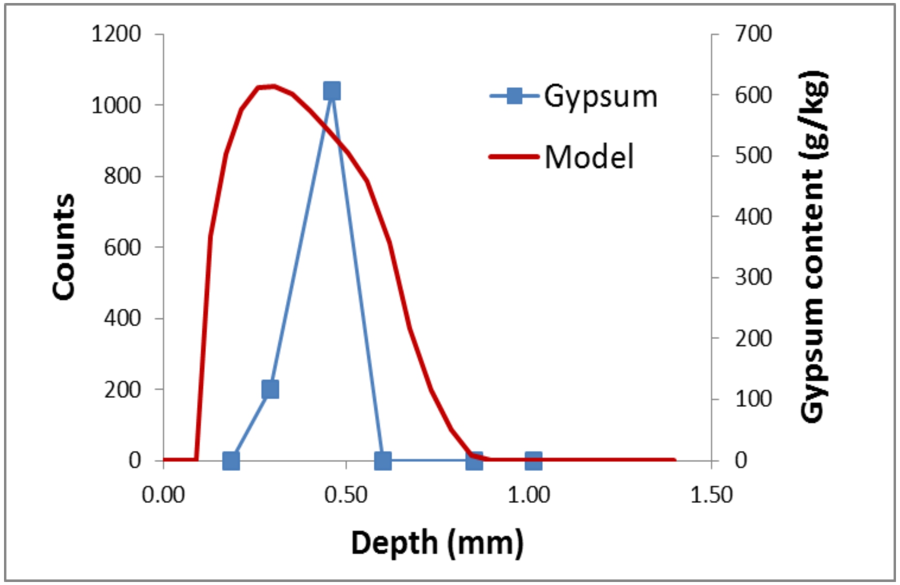
– Example of sulfate ingress modelling (Stadium®) – by P. Henocq

– D_{OH}=17 10^{-11} m^2/s (close to D_{OH} determined by migration test)

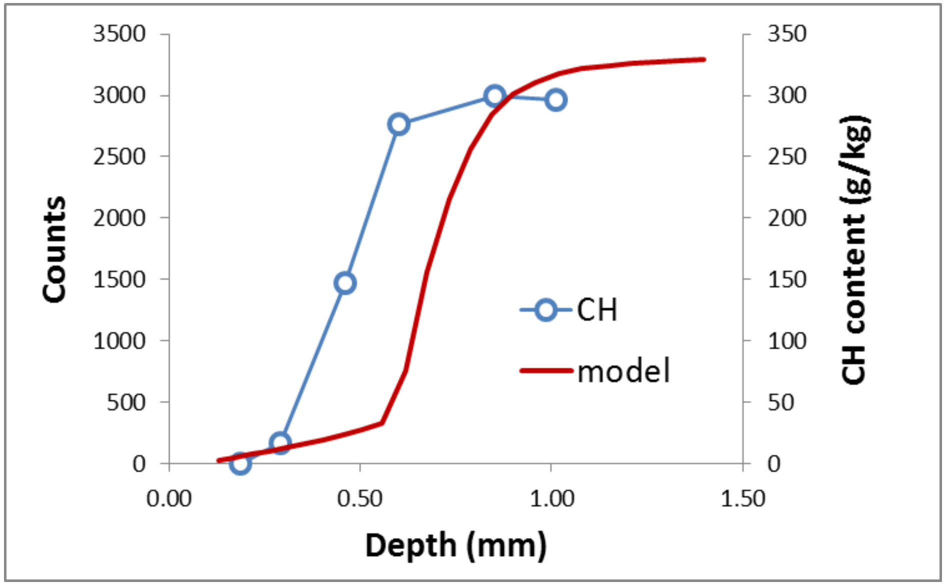
– XRD can be used to verify/calibrate modelled dissolution/precipitation mechanisms

– Presence of $Ca(OH)_2$ induces the peak of gypsum

Gypsum



Portlandite



XRD – a tool for routine analysis

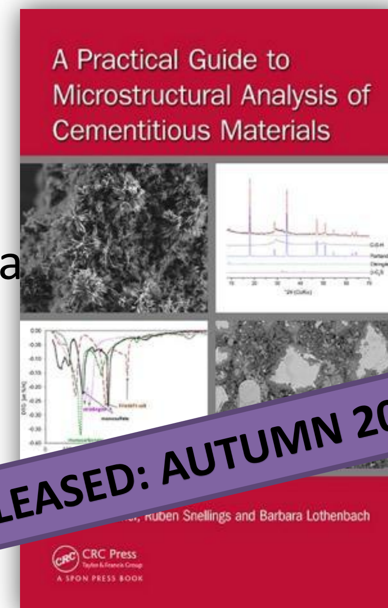
XRD has become a quantitative characterisation tool in cementitious materials

+ Assets
  + Phase assemblage characterisation: quantification of individual phases
  + Straightforward sample preparation
  + Short measurement times
  + Accessible in most material science labs
  + Automated analysis possible (e.g. cement production)

– Limitations
  – Accuracy: 2-3 wt.% for major phases, 1-2 wt.% for minor phases (can be better)
  – Expert knowledge needed for non-routine analyses

But there's more…

- **XRD should be used together with other techniques to verify and complete the characterisation of the microstructure**
- See **poster** for examples of electron microscopy
- **Book** on microstructural charactisation of cementitious ma



TO BE RELEASED: AUTUMN 2015

- Edited by K. Scrivener, R. Snellings, B. Lothenbach
- Chapters on Sample preparation, Calorimetry, Chemical shrinkage, XRD, TGA, Solid NMR, H NMR, Electron microscopy, MIP, Gas sorption,…

COST Action TU1404 1st Workshop Ljubljana, Slovenia, April 16-17, 2015

What do we need for validation of the microstructure of cement-based materials simulated by computer models?

Dr. Ye Guang, associate professor

Microlab, Delft University of Technology, The Netherlands

Content

- **Introduction**
- **Current hydration and microstructural models**
- **Modelling example: HYMOSTRUC 3D**
- **Experimental validation**

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Introduction

To build up cement hydration and microstructural model, we need to know

– What are the chemical composition of cement and what are the cement hydration kinetics?

– What kind of phases and how much of each phase are present?

– What is the shape and length scale of each phase?

– What are the phase - to - phase interfaces look like?

– What is the topology of each phase, i.e. how does this phase connect to itself and other phases?

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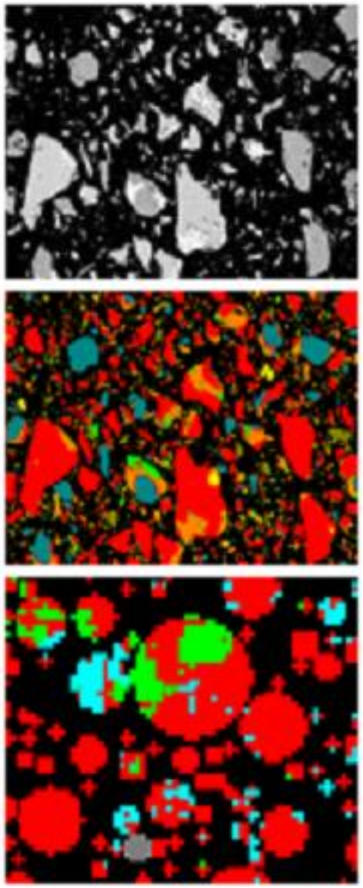
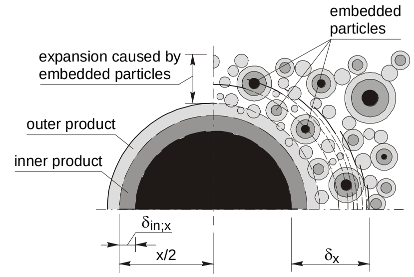
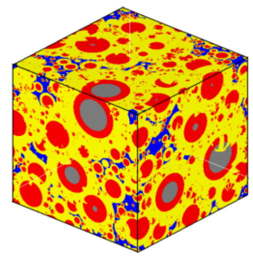
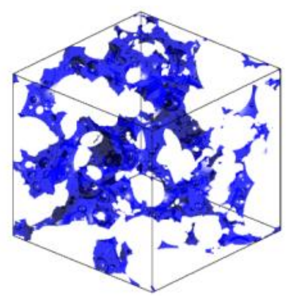
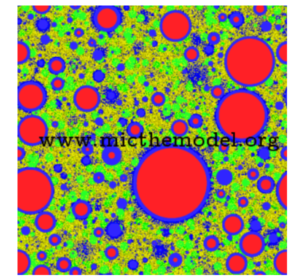
Current models

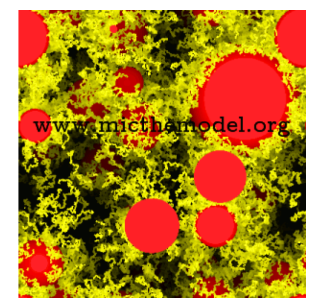












CEMHYD3D / VCCTL

Bentz, 2005/Bullard, 2014

HYMOSTRUC3D

van Breugel, 1991, Koenders, 1997, Ye 2003

μic

Bishnoi, 2008

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Microstructure Simulated by HYMOSTRUC3D

- Input parameters

  - ✓ **Particle size distribution of cement particles**
  - ✓ Water/cement ratio
  - ✓ **Clinker composition of the cement**
  - ✓ Reaction temperature
  - ✓ Size of calculation body

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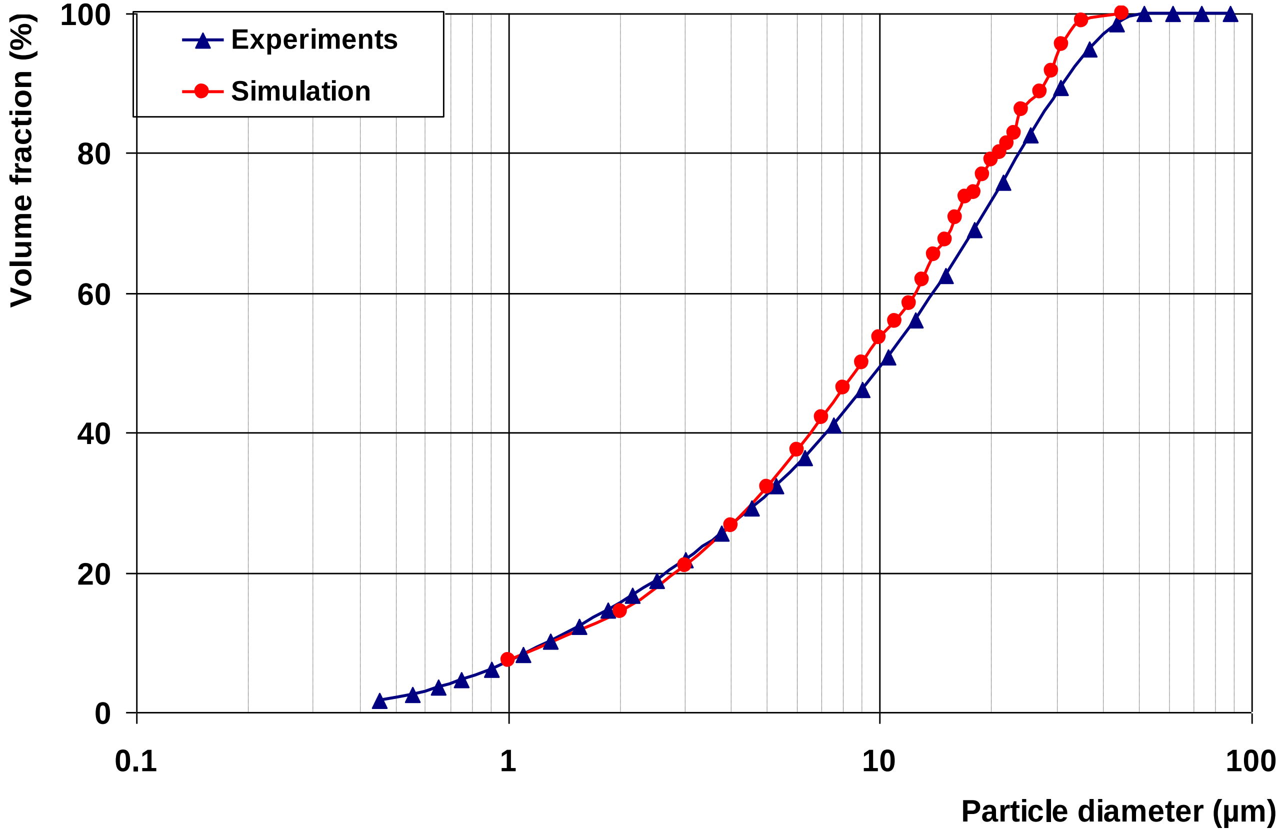
Particle size distribution: Laser diffraction



Particle size distribution of cement CEMI 42.5

Z.H. Sun, G. Ye, S.P. Shah, Microstructure and Early Age Properties of Portland Cement Pastes — Effects of the Connectivity of the Solid Phases, ACI Materials Journal, vol. 102 No. 2 2005 pp 122-129

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Microstructure Simulated by HYMOSTRUC3D

- Output parameters

  - ✓ degree of hydration
  - ✓ microstructures, pore structure
  - ✓ phase composition
  - ✓ porosity, pore size distribution, connectivity of pores
  - ✓ elastic modulus, cracking pattern
  - ✓ diffusivity, water permeability

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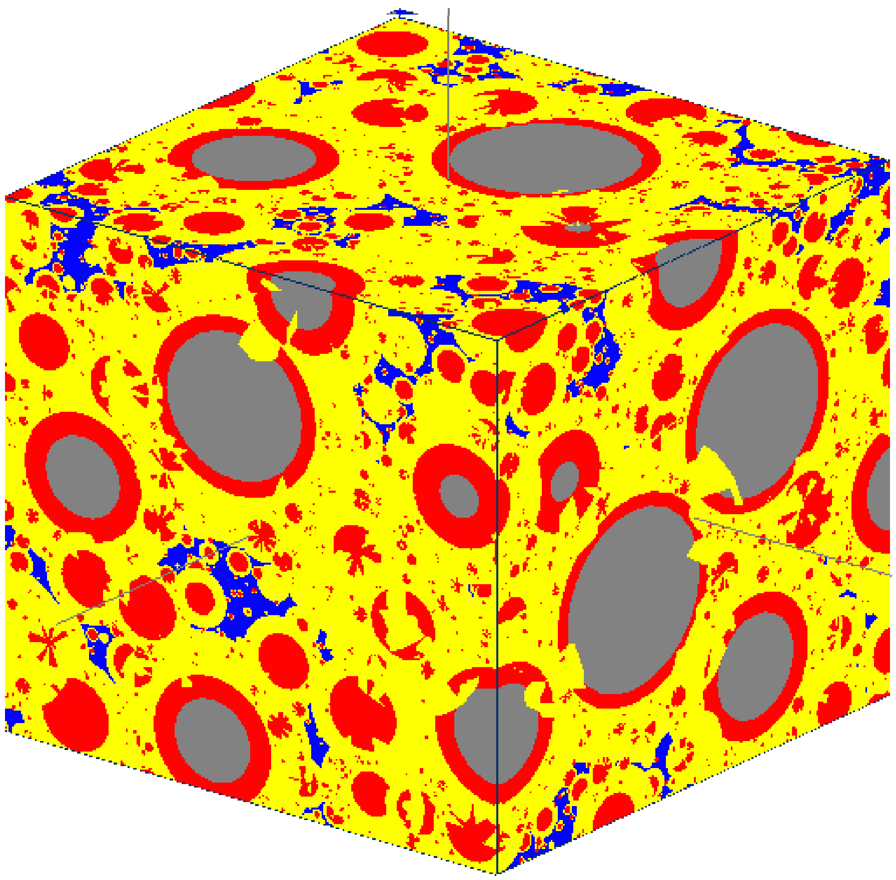
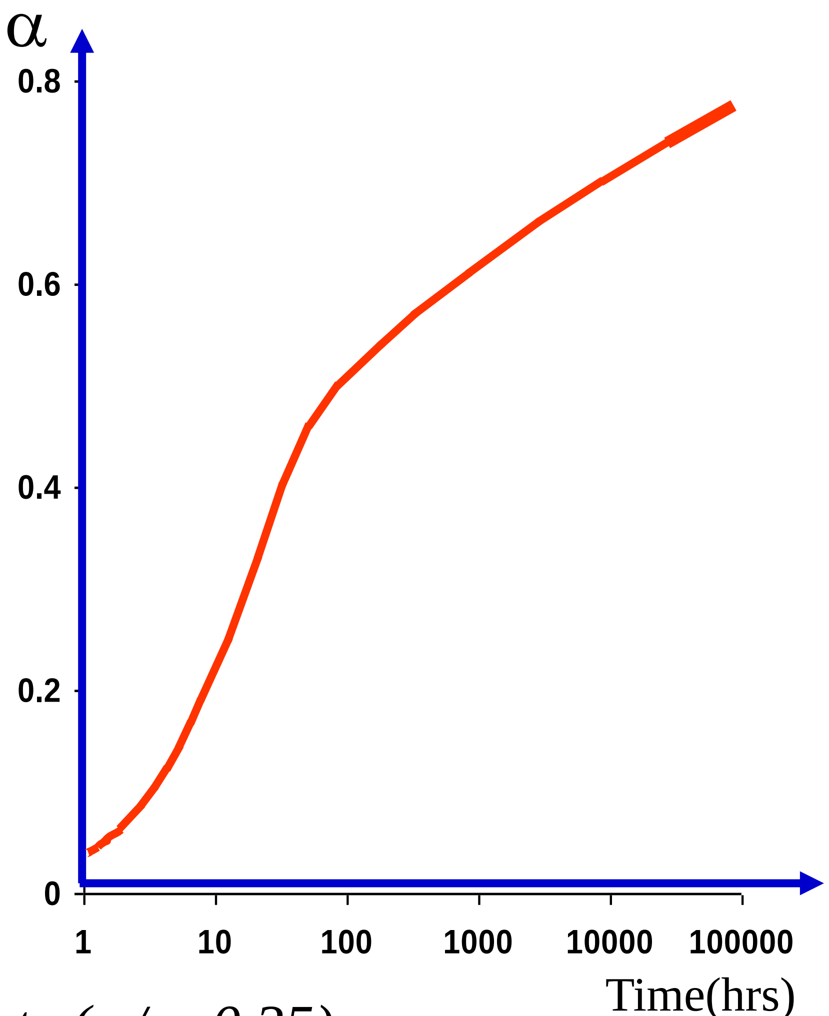
Microstructure Simulated by HYMOSTRUC3D





3D simulated cement paste (w/c=0.35)

G. Ye, K. van Breugel, "Three-dimensional microstructure simulation model of cement based materials', HERON, vol 48 No. 4 2003 pp 251－275.

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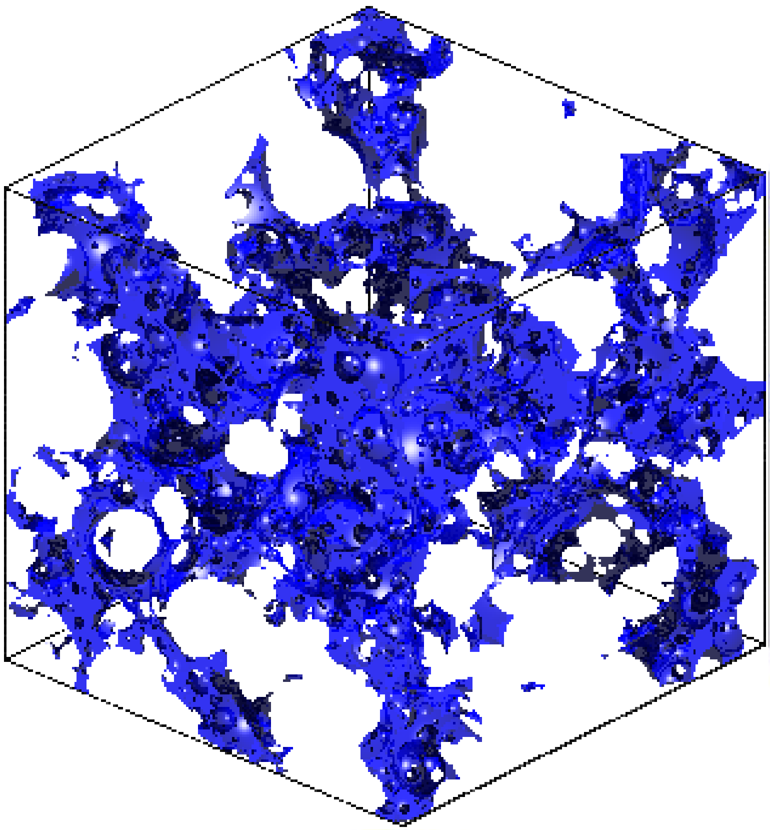
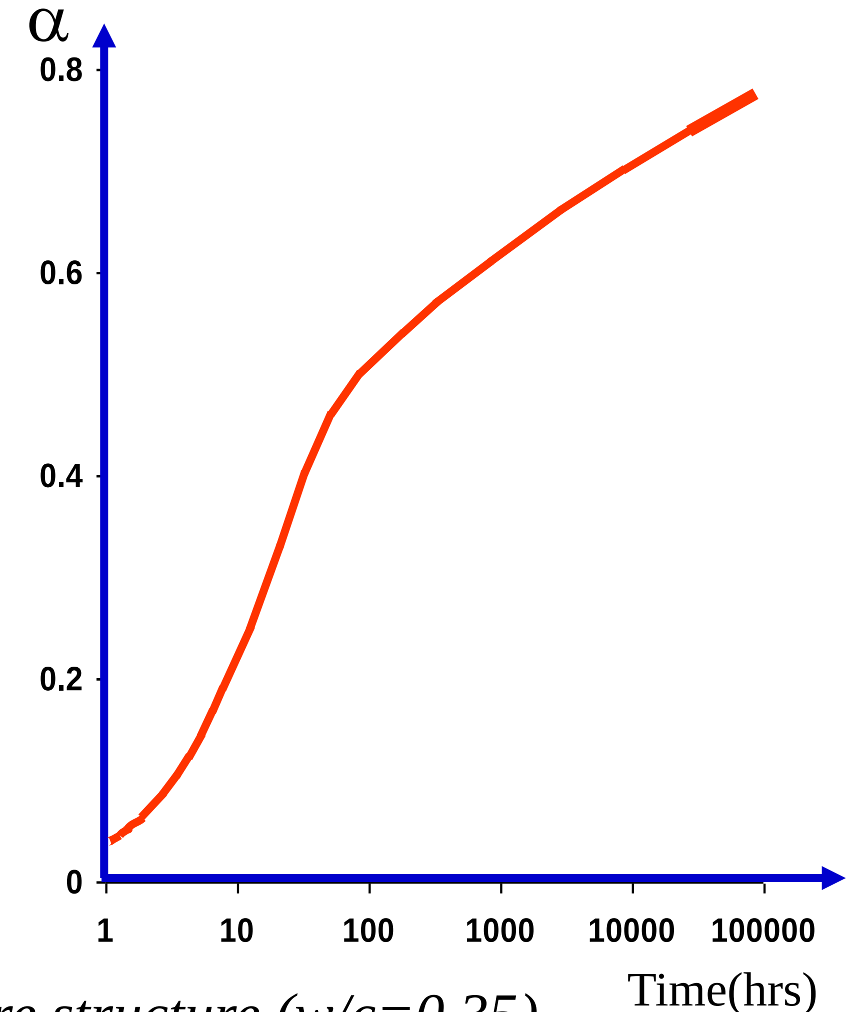
Microstructure Simulated by HYMOSTRUC3D





3D simulated cement paste, Pore structure (w/c=0.35)

G. Ye, K. van Breugel, "Three-dimensional microstructure simulation model of cement based materials', HERON, vol 48 No. 4 2003 pp 251—275.

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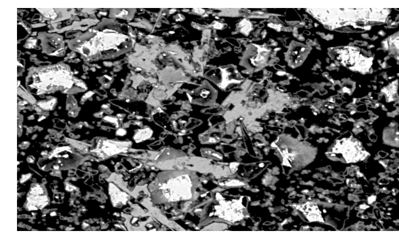
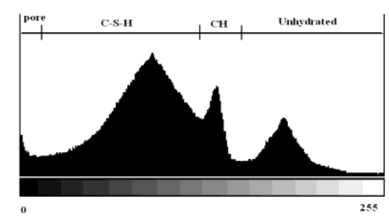
Degree of hydration

- Chemical shrinkage
- Non-evaporable water content
- Isothermal heat evolution
- Backscattering image analysis





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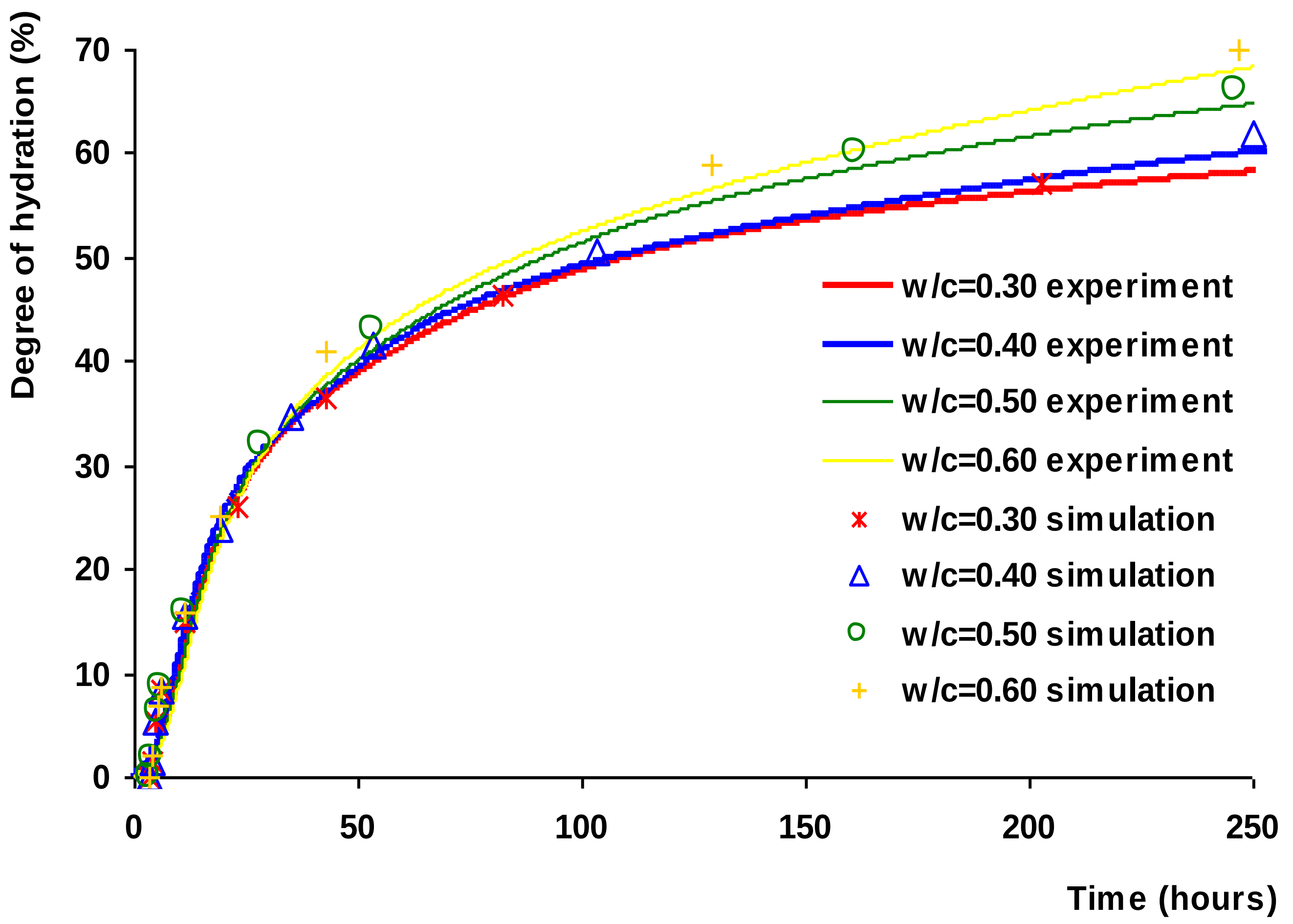
Degree of hydration: isothermal heat evolution



Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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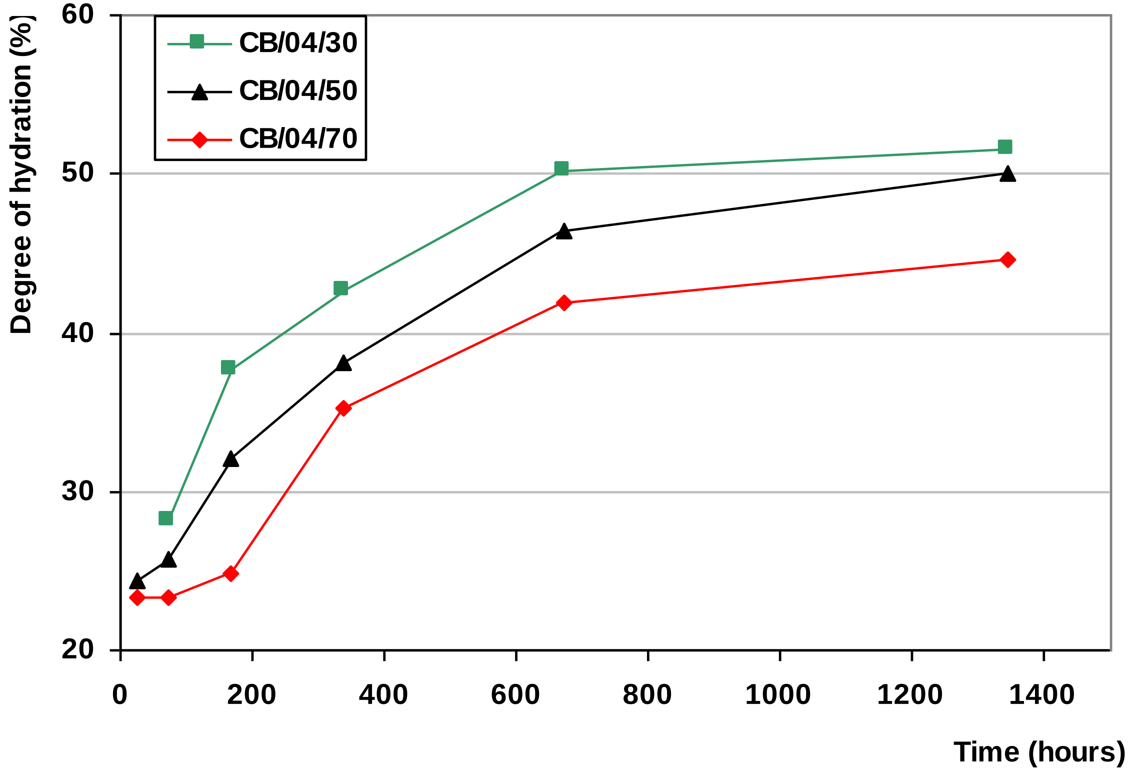
Degree of hydration: non- evaporable water content



Blast furnace slag cement

Ye, G., Zhou, J, Breugel, K van, & Schutter, G (2006). Characterization of the hydration of portland cement blended with blast furnace slag based on SEM image analysis. In K Kovler (Ed.), Concrete durability and service life planning (concrete life '06) (pp. 444-453). Israel, Ein-Bokek: RILEM publication S.A.R.L.

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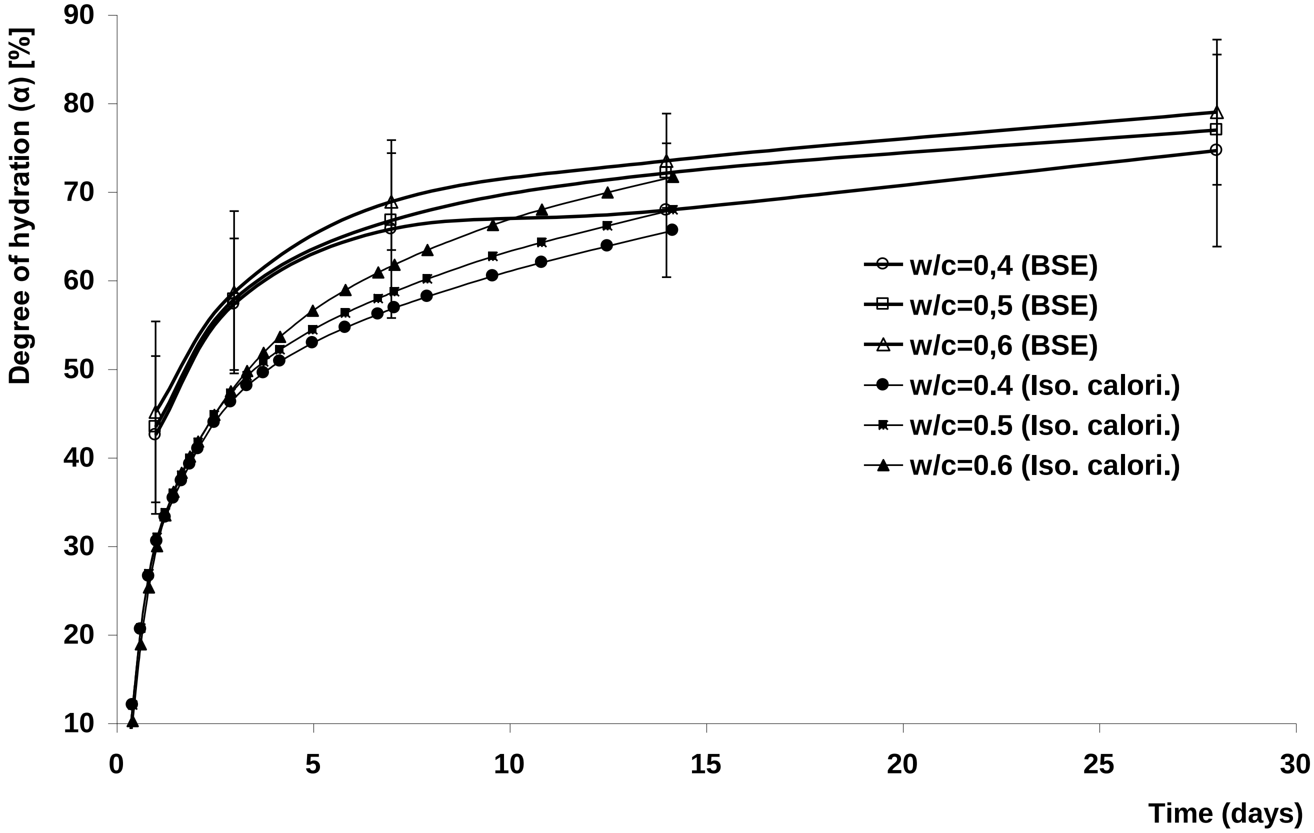
Degree of hydration: BSE imaging analysis



Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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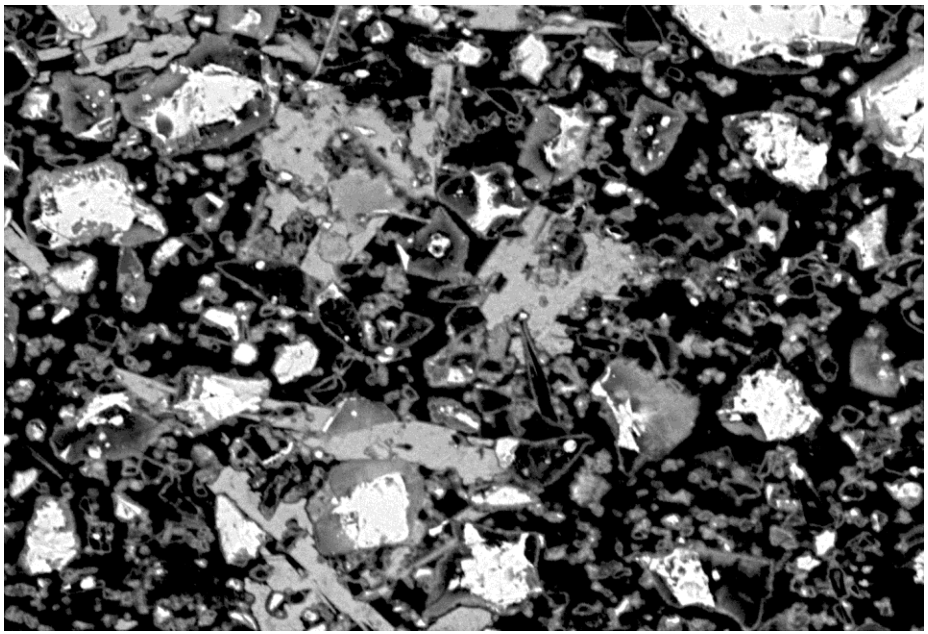
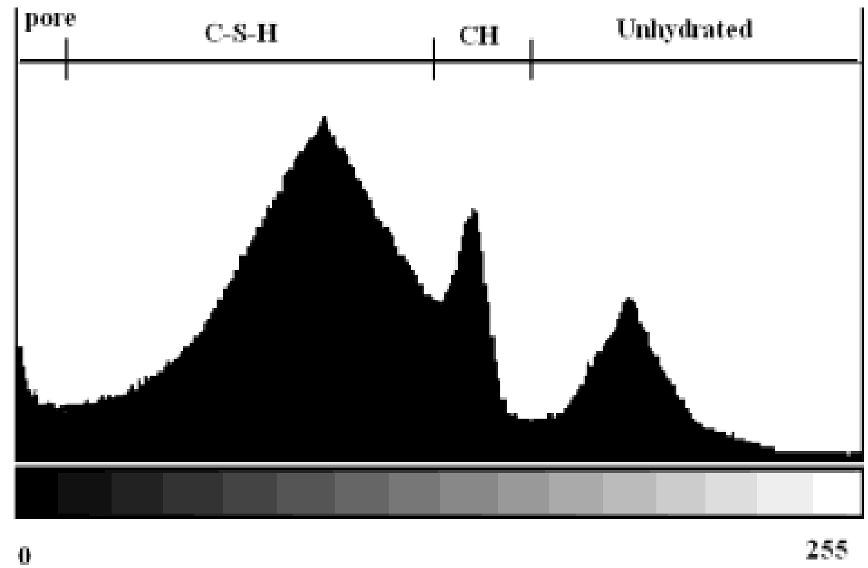
BSE imaging analysis





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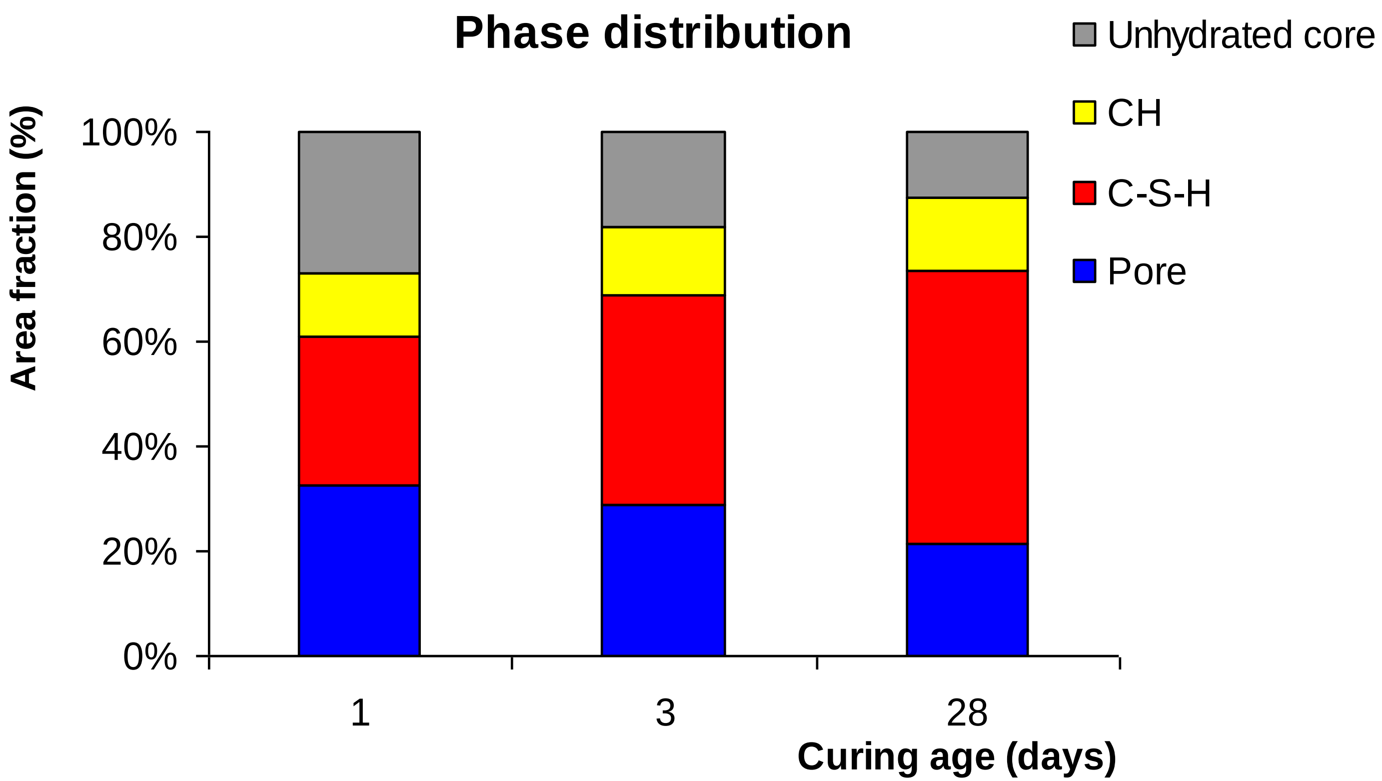
Phases distribution: BSE imaging analysis



Ye, G. (2003), The Microstructure and permeability of Cementitious Materials,
PhD thesis, Delft University of Technology.

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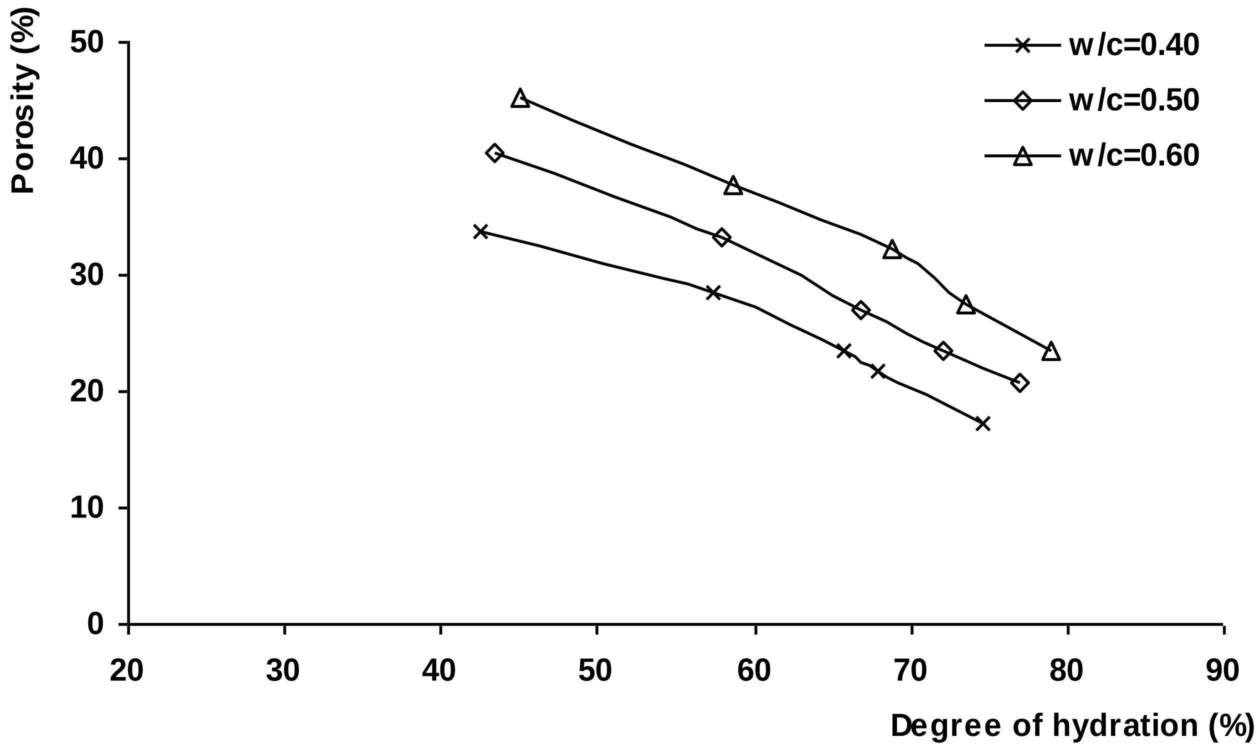
Porosity: BSE imaging analysis



Development of porosity as a function of hydration time

Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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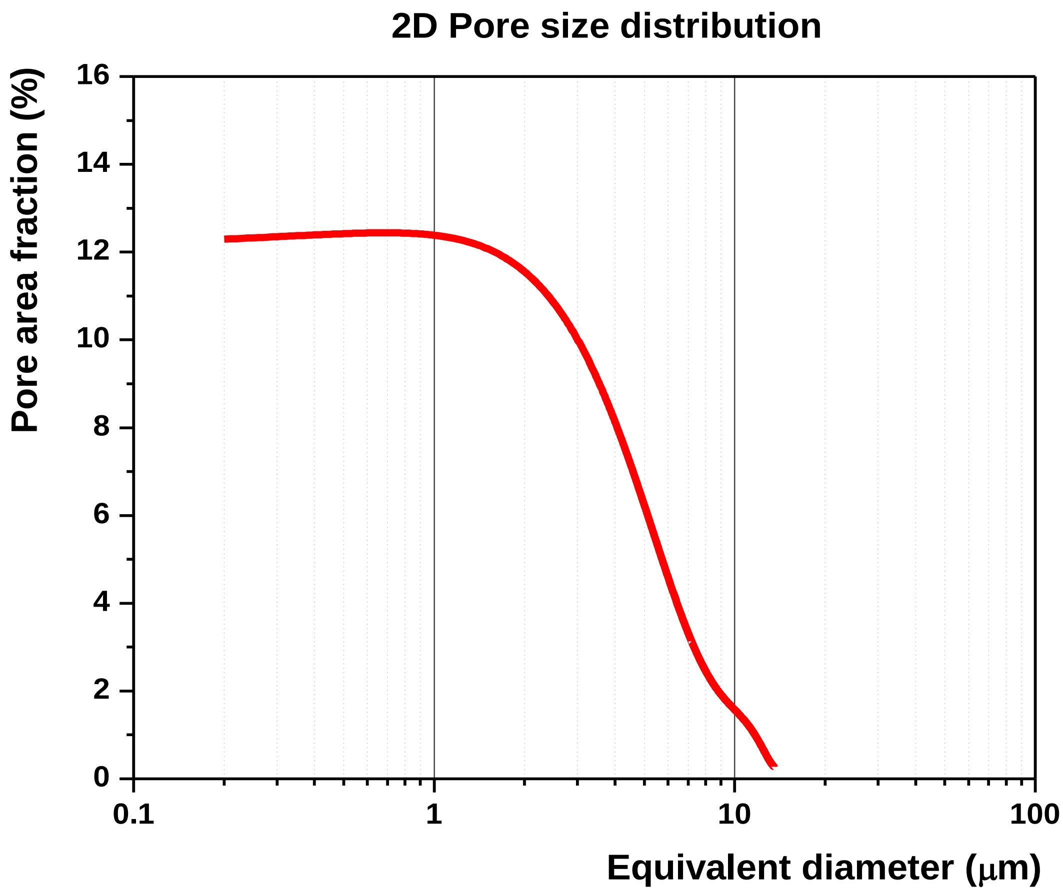
Pore size distribution: BSE imaging analysis



Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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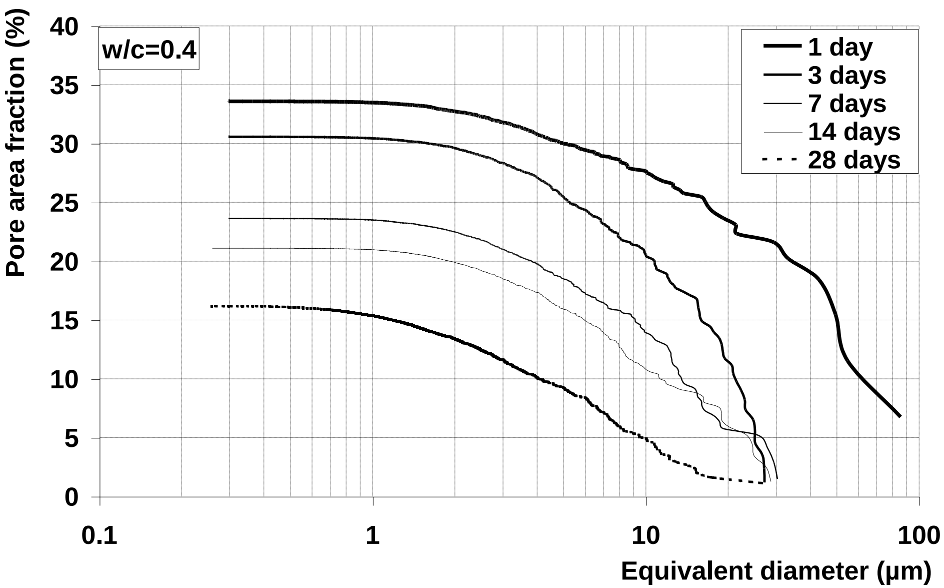
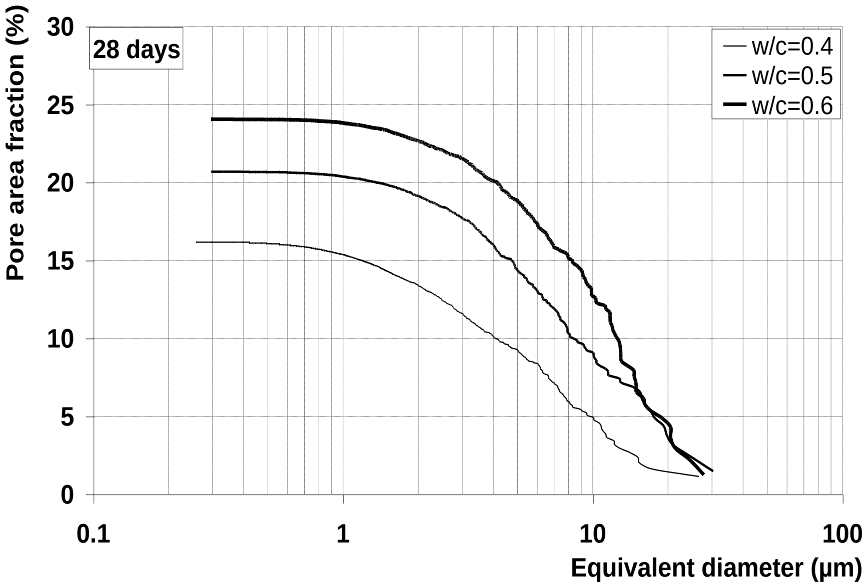
Pore size distribution: BSE imaging analysis



Pore size distribution for samples with w/c ratio 0.40 at different curing ages



Pore size distribution for samples with different w/c ratio at 28 days

Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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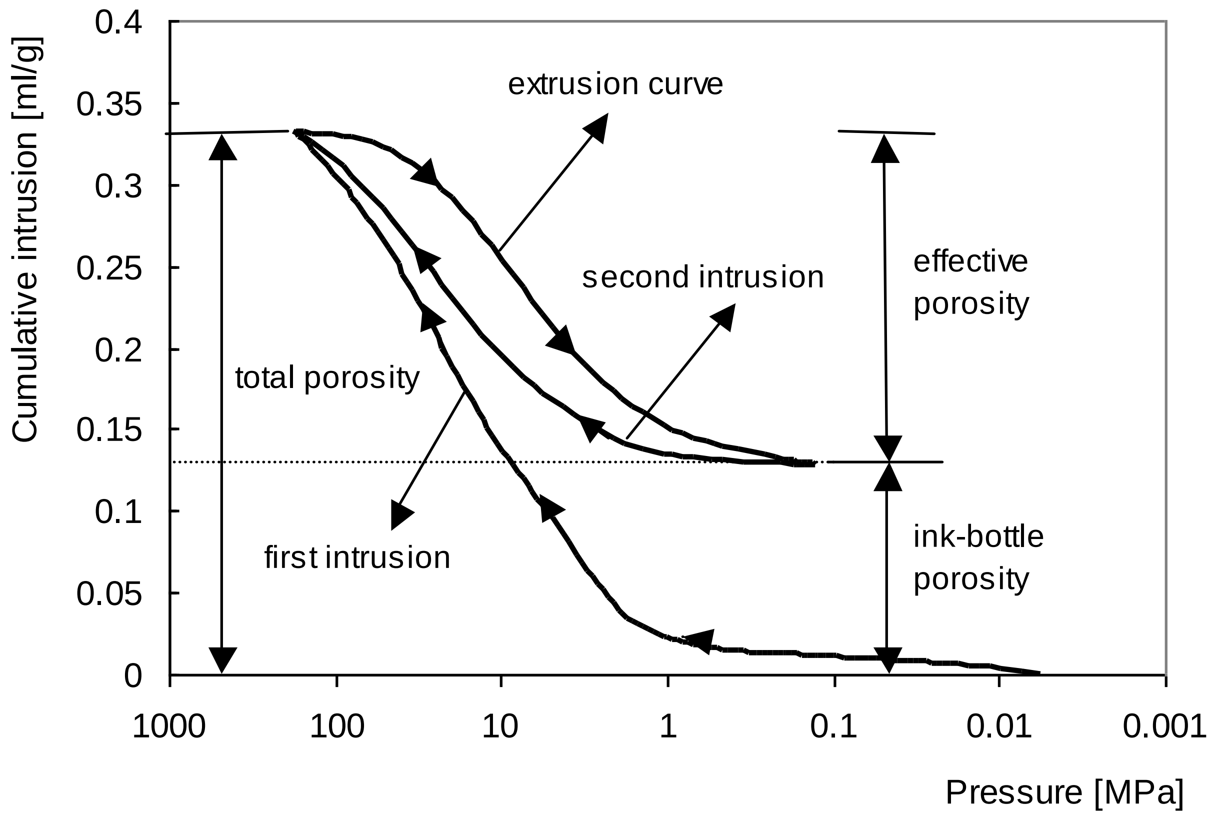
Porosity, and pore size distribution (PSD): Mercury Intrusion Porosimetry (MIP)



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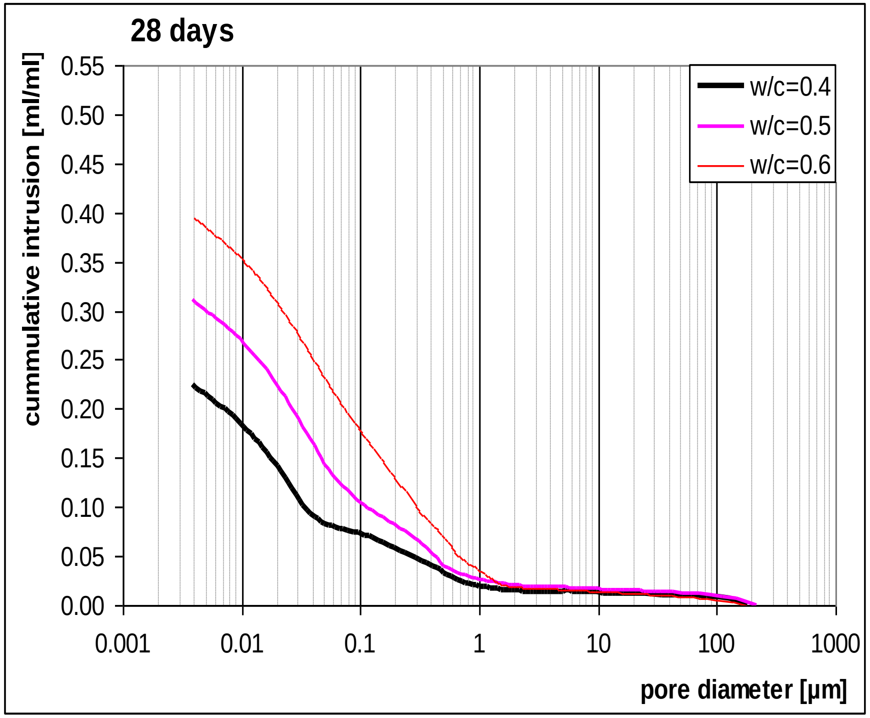
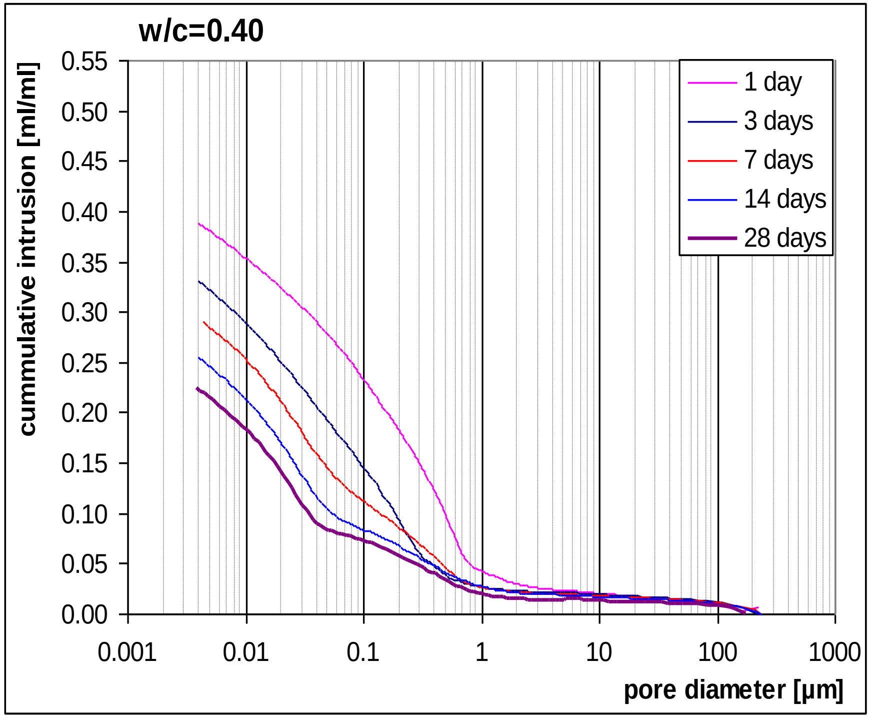
Porosity, and pore size distribution: MIP





(left) Effect of w/c ratio on MIP measurements for the samples cured for 28 days, (right) the effect of curing age on the samples with w/c 0.40

Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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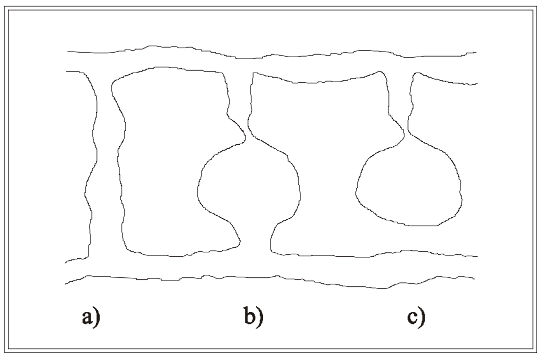
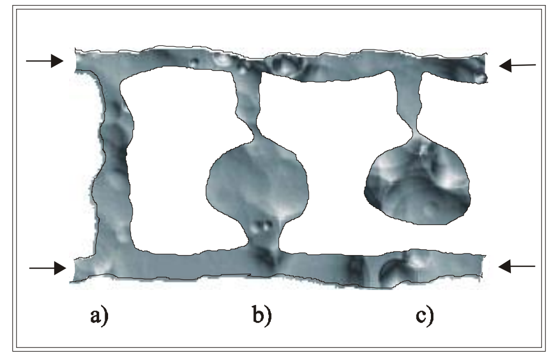
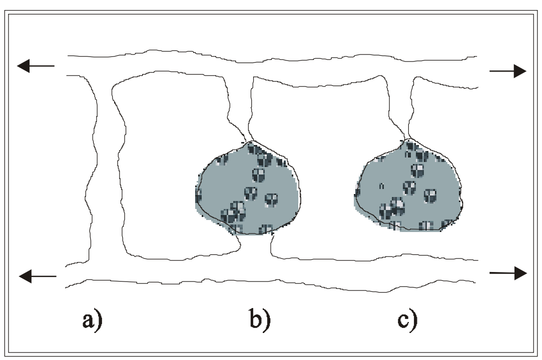
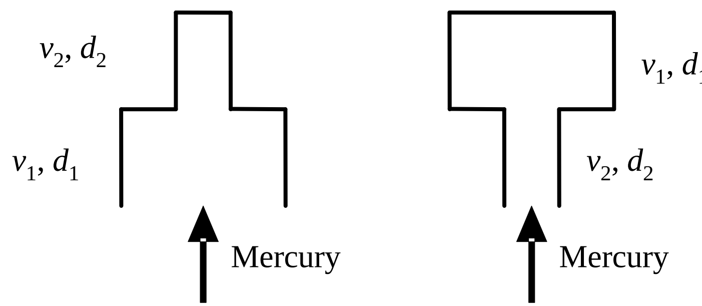
Limitation of the MIP

- **Ink-bottle effect:** overestimation of the volume of the fine pores and an underestimation of the pore volume of the wide ones









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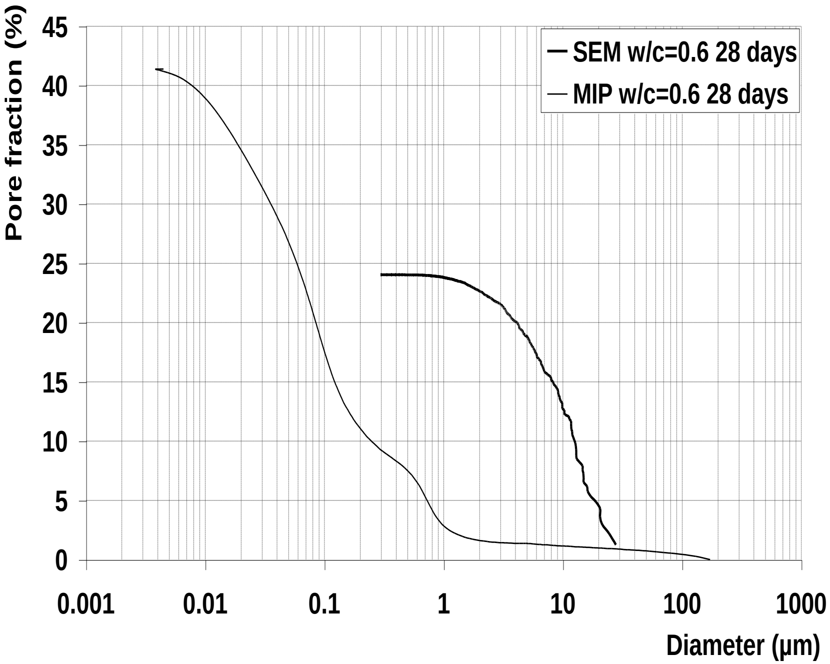
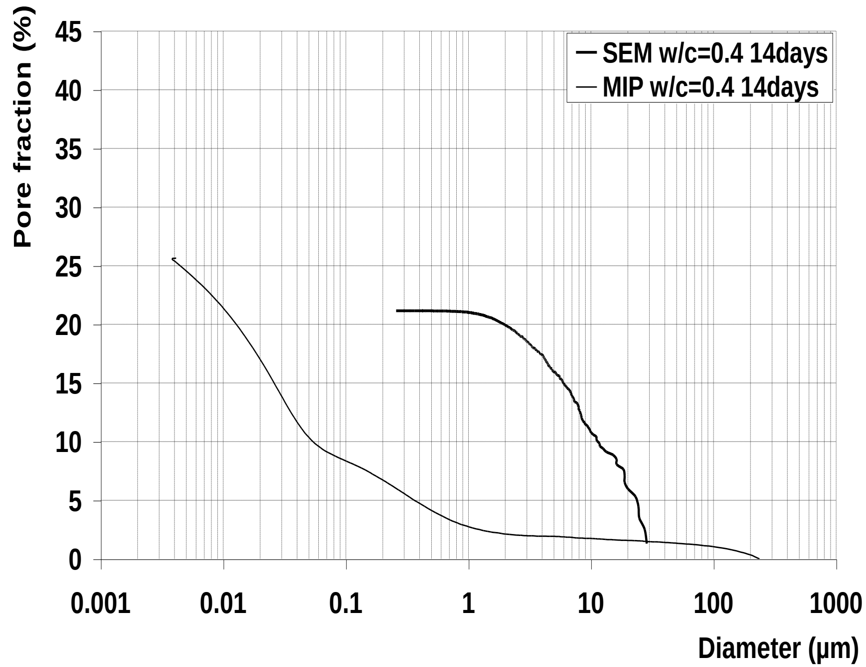
Pore size distribution: MIP vs. image analysis





Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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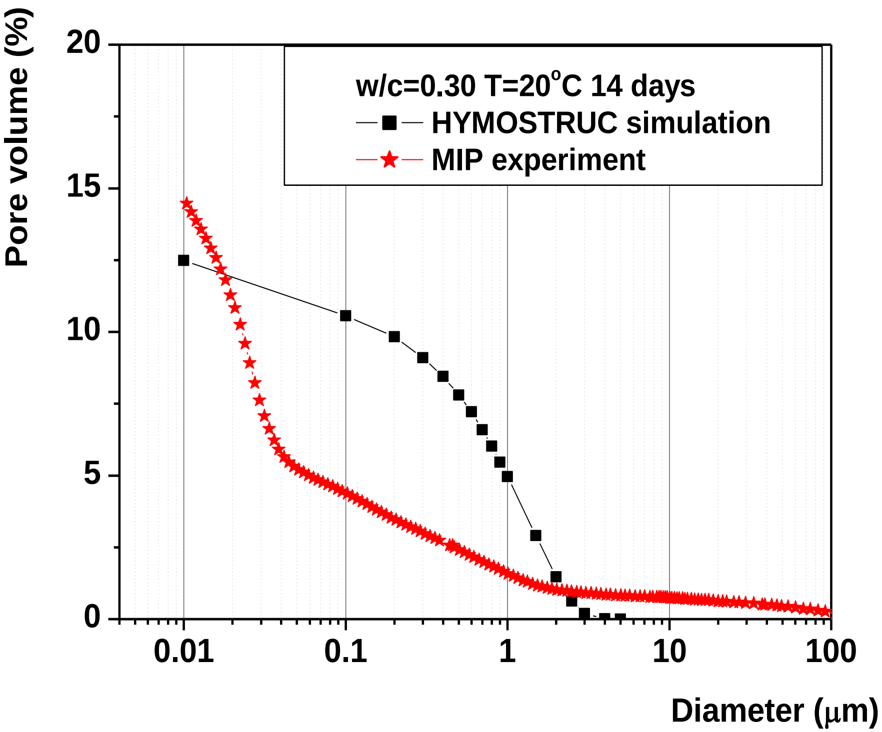
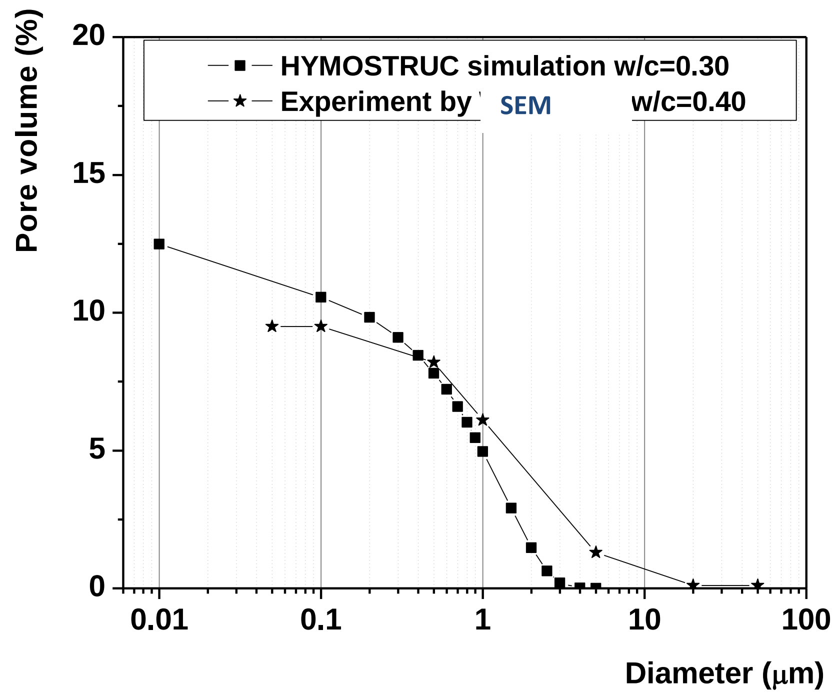
PSD: MIP vs. image analysis vs. simulation



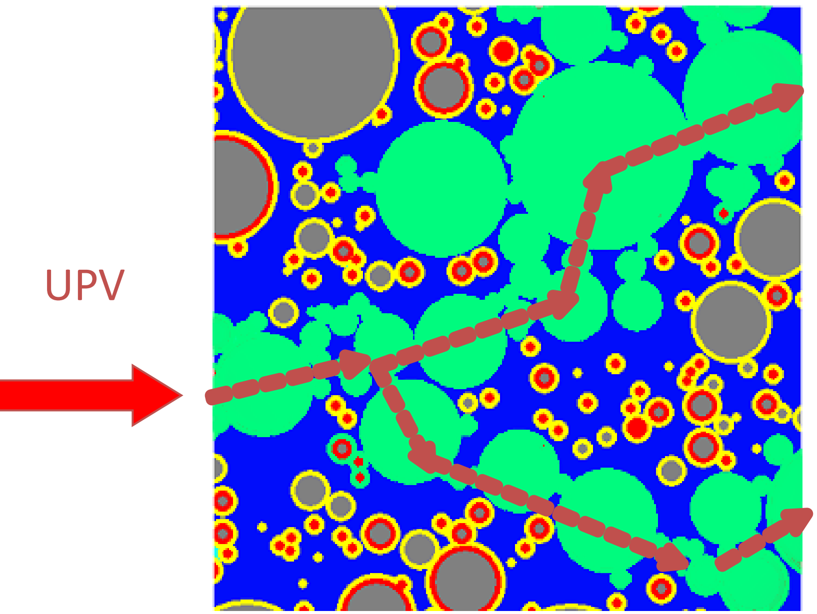


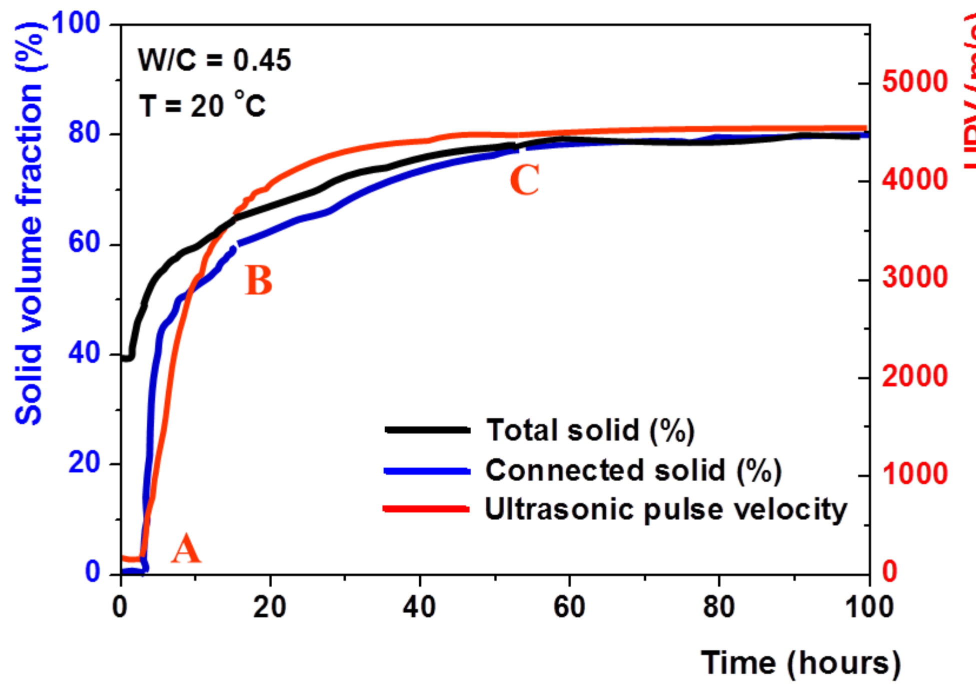
Simulated pore size distribution is close to BSE image analysis

Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

back to GP1.b overview

Connectivity of solid phase: UPV





Ye, G. (2003), The Microstructure and permeability of Cementitious Materials, PhD thesis, Delft University of Technology.

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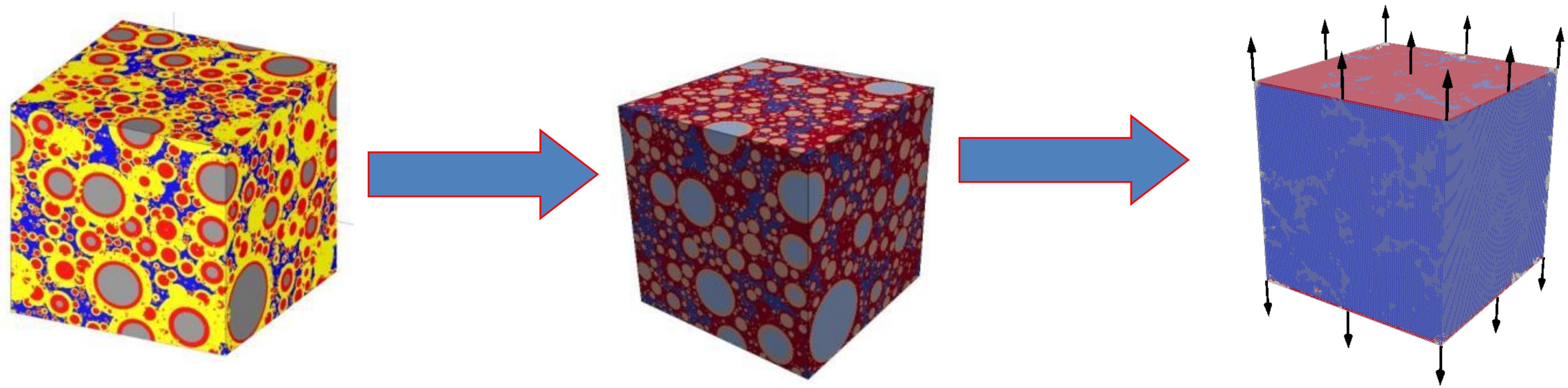
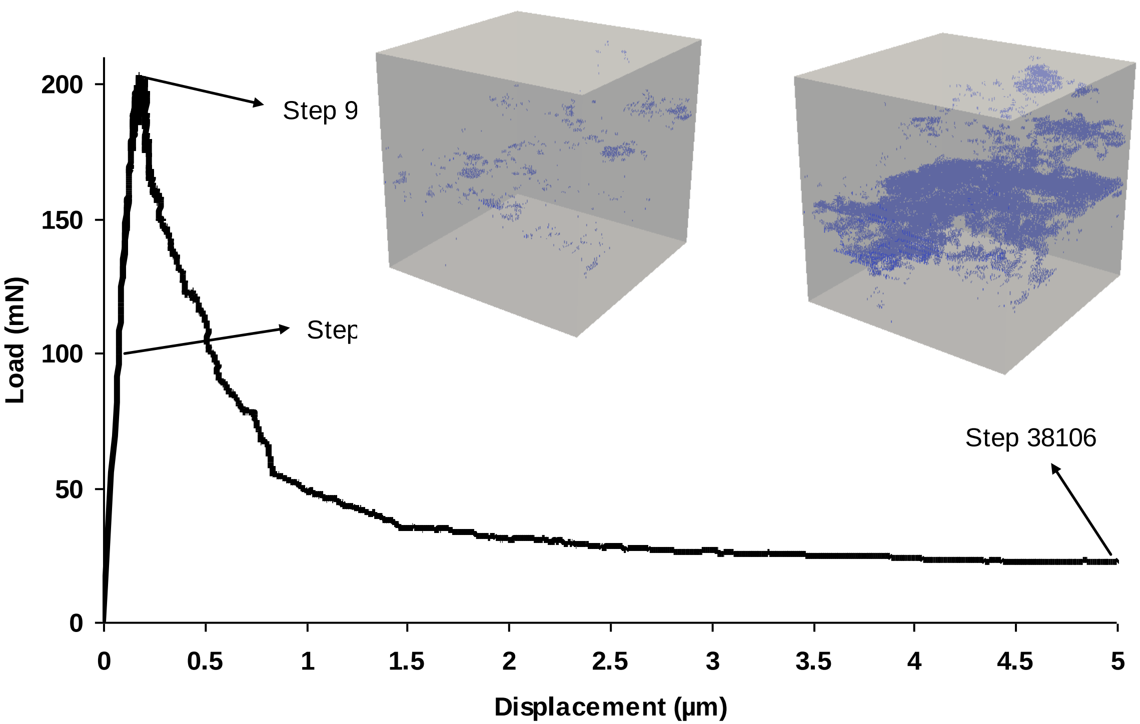
Mechanical Performance Evaluation





E=13 GPa
ft=20 MPa
Fracture Energy=22 J/m^2

Qian, Z., Schlangen, E; Ye, G, et al (2010), Prediction of mechanical properties of cement at microscale, MATERIALES DE CONSTRUCCION., 60 297 P7-18

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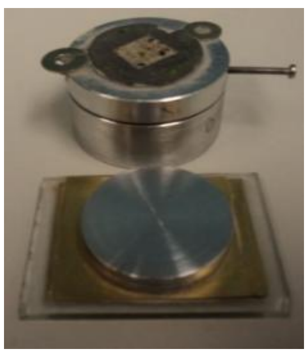
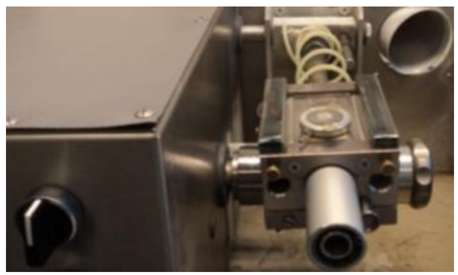
Validation fracture properties at microscale in 3D



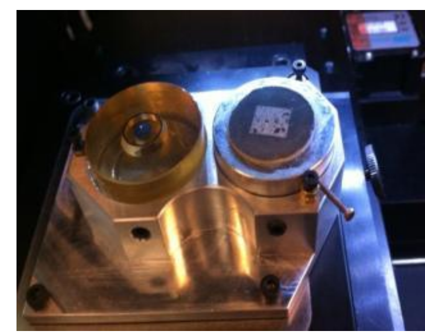
Sample holder



Thin section machine

Checking thickness

ESEM 2D imaging



Nanoindentation testing

M. Lukovic; E. Schlangen, G. Ye, (2015) Combined experimental and numerical study of fracture behaviour of cement paste at the microlevel, Cement and Concrete Research, 73, 123–135.

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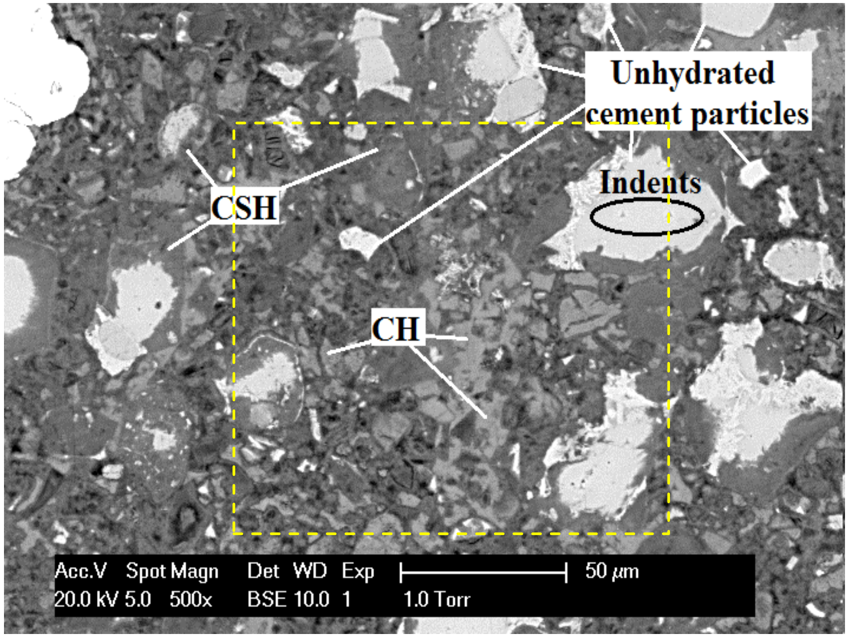
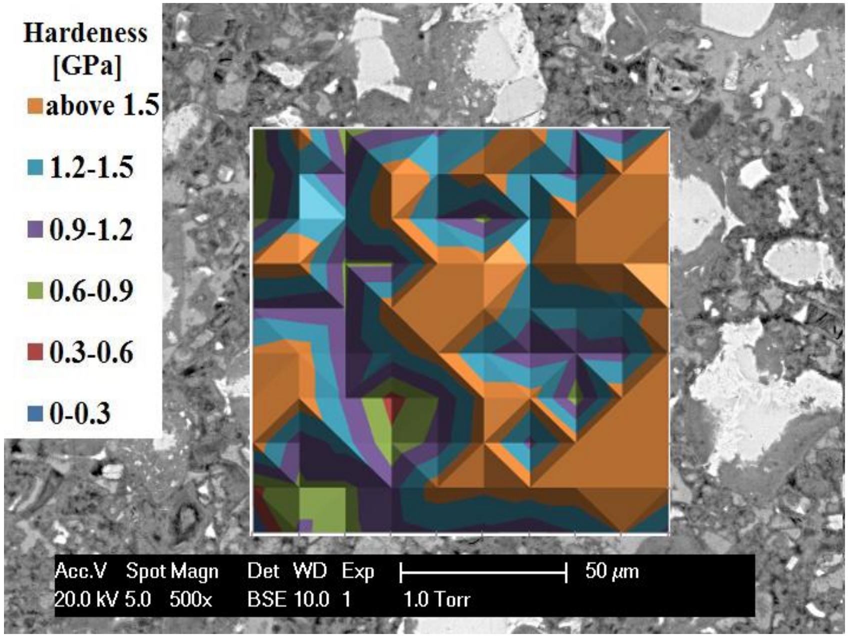
Validation fracture properties at microscale in 3D

Fracture at microscale in three dimension





Photomicrographs of Step 1 with corresponding hardness values

M. Lukovic; E. Schlangen, G. Ye, (2015) Combined experimental and numerical study of fracture behaviour of cement paste at the microlevel, Cement and Concrete Research, 73, 123–135.

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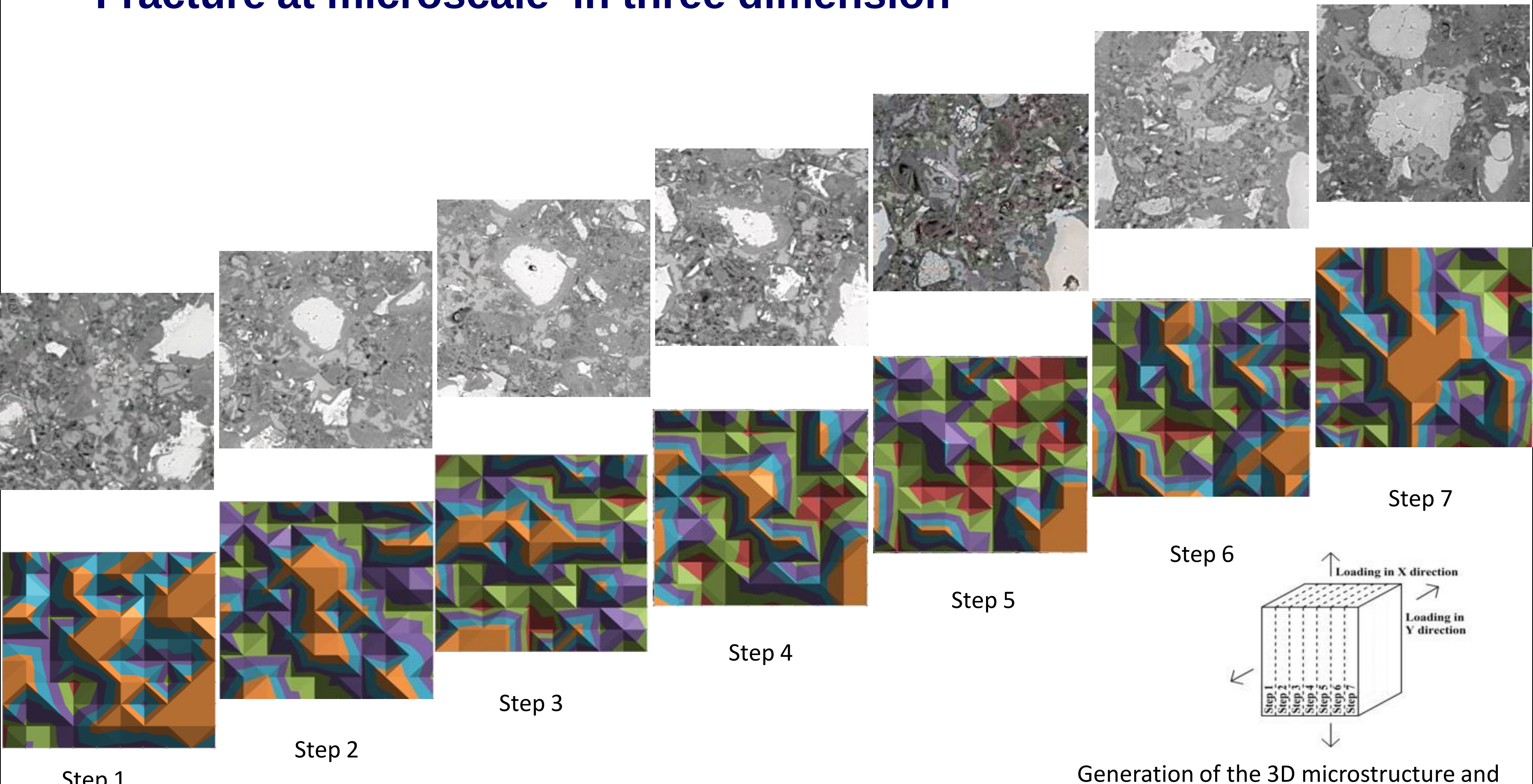
Validation fracture properties at microscale in 3D

Fracture at microscale in three dimension



Generation of the 3D microstructure and loading conditions

M. Lukovic; E. Schlangen, G. Ye, (2015) Combined experimental and numerical study of fracture behaviour of cement paste at the microlevel, Cement and Concrete Research, 73, 123–135.

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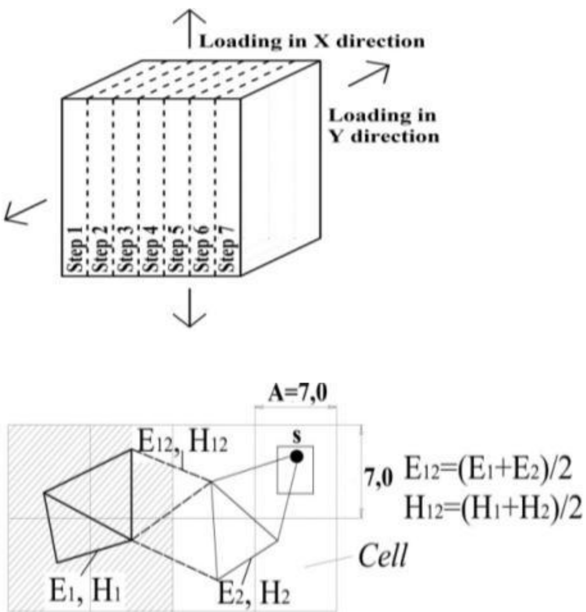
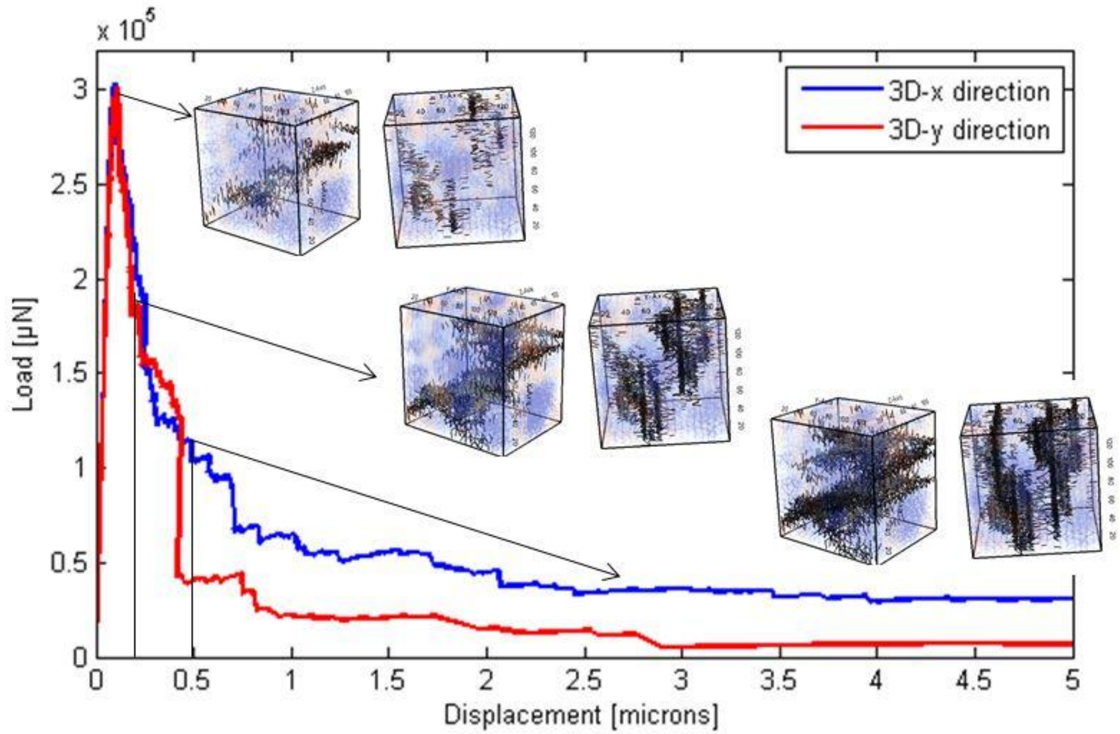
Validation fracture properties at microscale in 3D

Fracture at microscale in three dimension





Load displacement diagrams with corresponding damage evolution in x and y direction

M. Lukovic; E. Schlangen, G. Ye, (2015) Combined experimental and numerical study of fracture behaviour of cement paste at the microlevel, Cement and Concrete Research, 73, 123–135.

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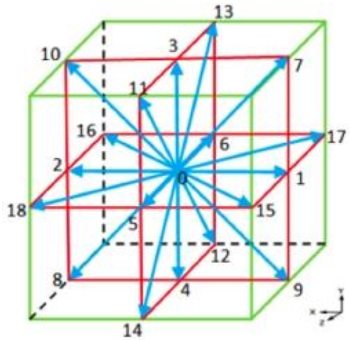
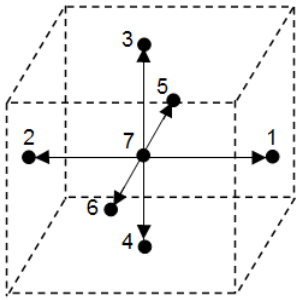
Micro-scale Solver: Lattice Boltzmann Method





Micro-scale solver

- **PermLBS module**: Multiple-relaxation-time lattice Boltzmann model → Permeability of cement-based materials at micro level
- **SCMPLBS module**: Multi-phase lattice Boltzmann model → Moisture distribution in cement-based materials at micro level
- **DiffLBS module**: Lattice Boltzmann model for diffusion → Ionic/gas diffusivity in cement-based materials at micro level

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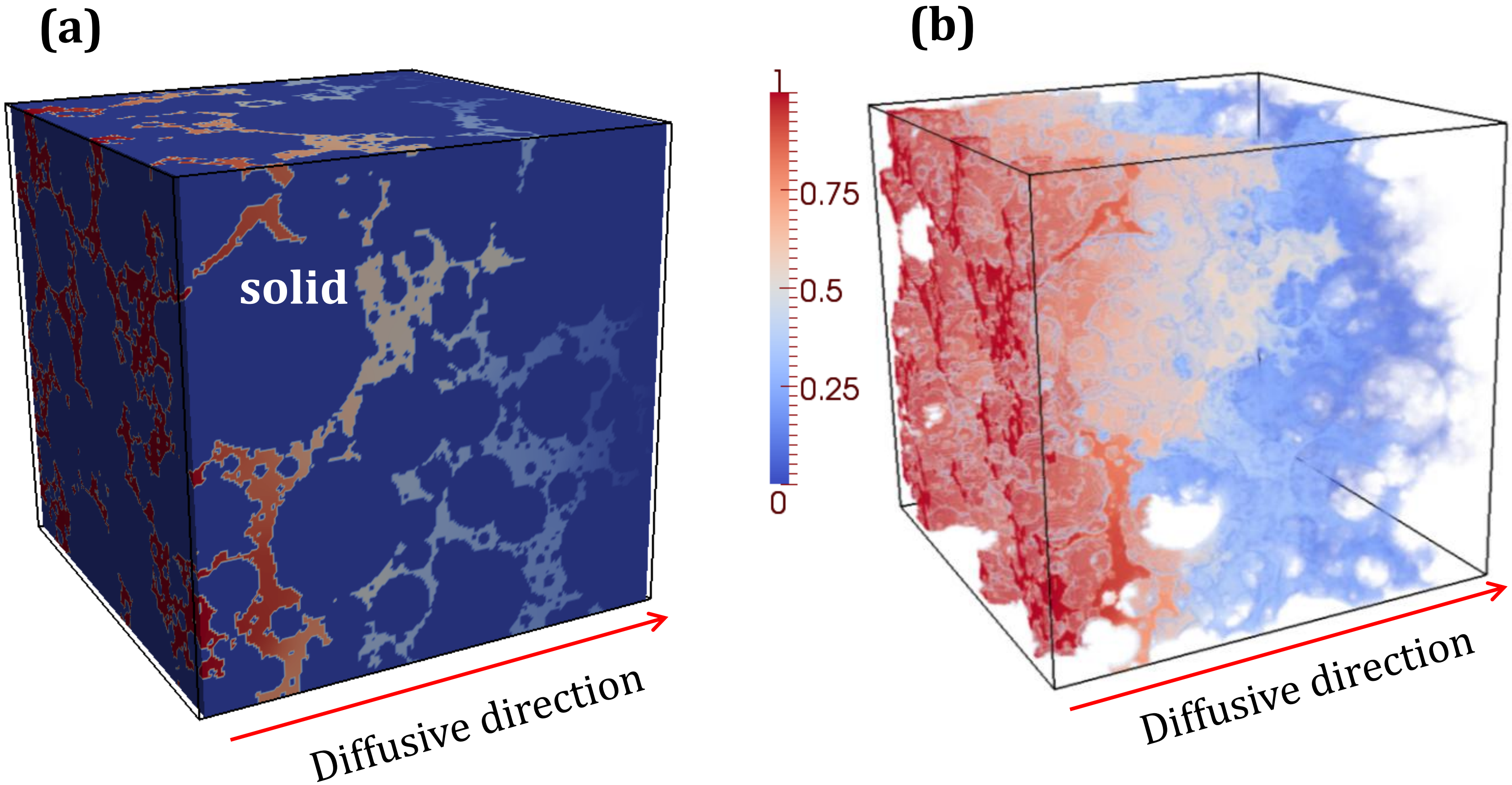
Diffusion in cement paste: DiffLBS Module



Concentration distribution of chloride ions in the connective pore structure of cement paste

M Zhang, G Ye, K van Breugel (2014), Multiscale lattice Boltzmann-finite element modelling of chloride diffusivity in cementitious materials. Part II: Simulation results and validation, *Mechanics Research Communications* 58, 64-72 1

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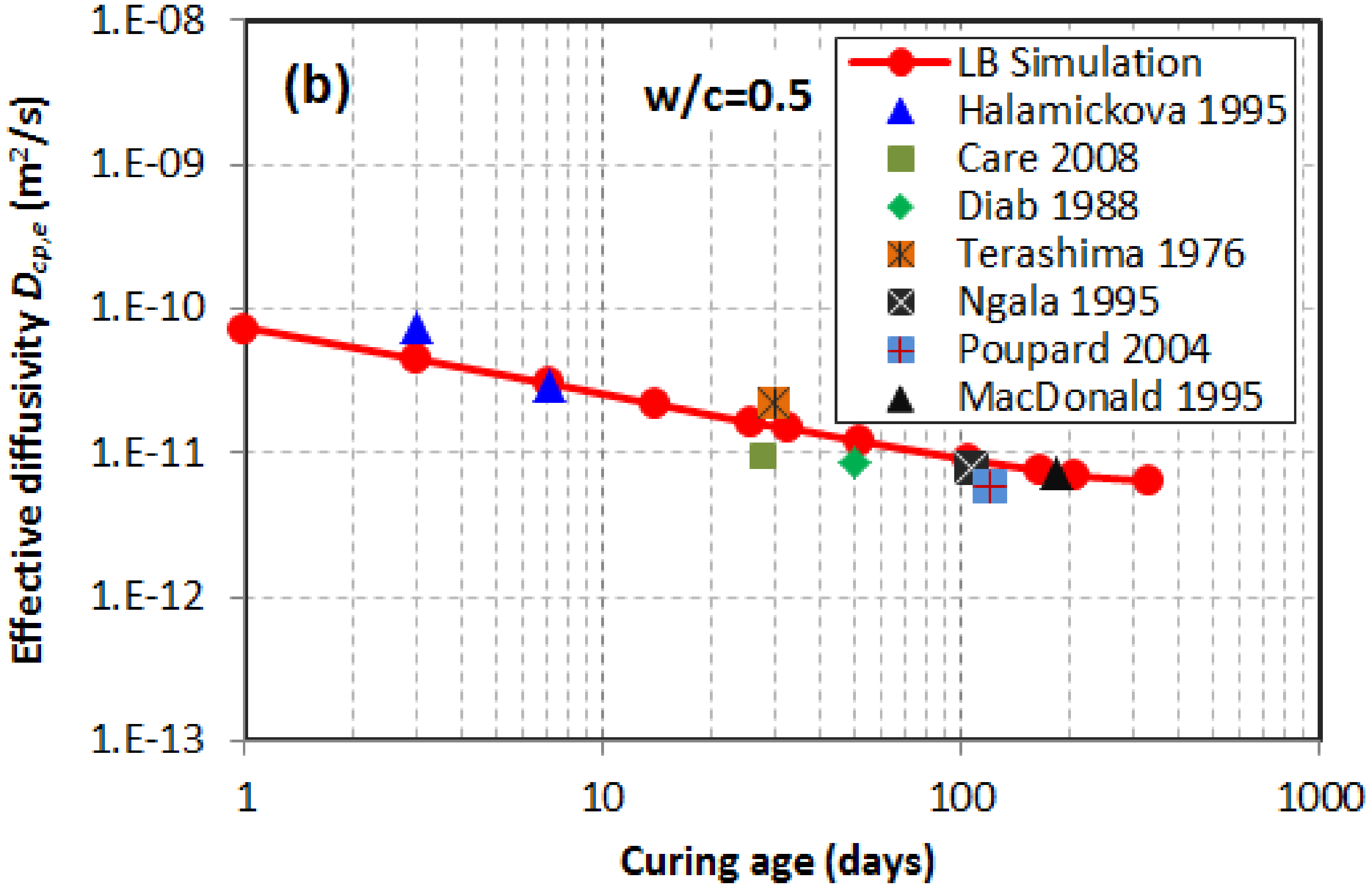
Diffusion in cement paste: DiffLBS Module



M Zhang, G Ye, K van Breugel (2014), Multiscale lattice Boltzmann-finite element modelling of chloride diffusivity in cementitious materials. Part II: Simulation results and validation, *Mechanics Research Communications* 58, 64-72 1

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Conclusion

Raw materials: particle size, particle shape chemical composition

Hydration: degree of hydration of each phase

Microstructures: Phases distribution, total porosity and pore size distribution

Pore size distribution determined by BSE image analysis is much close to numerical simulation

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SESSION for GP1.c – Transport properties and boundary effects
Chairman: Muhammed Basheer

Sree Nanukuttan: Transport properties and boundary effects - experimental plan for GP1c

Filipe Pedrosa: Tests to determine transport properties - Indirect and Field based tests

Tang Luping: Testing and Modelling for mass transport focus on test results and the effect of boundary conditions on modelling

Muhammed Basheer: *Non-destructive tests for determining transport properties and facilitate the discussions towards RRT (not authorized for publication)*

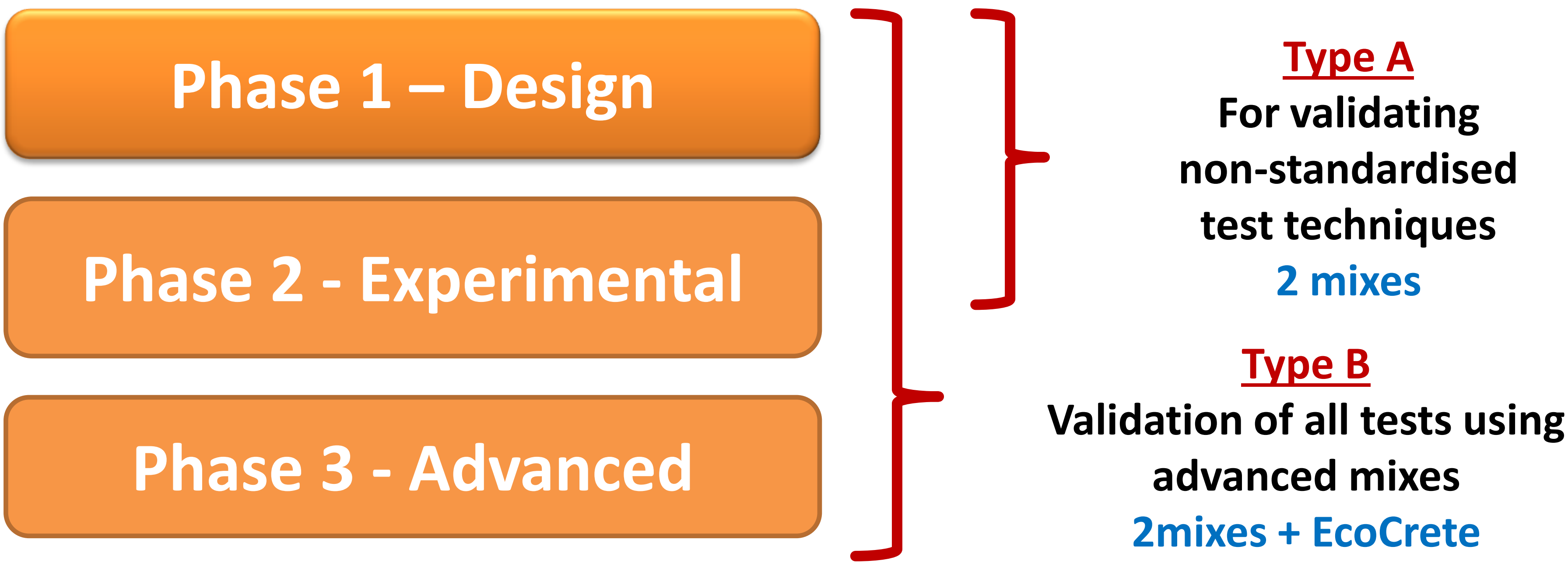
GP1c: Transport Properties and Boundary Effects – Experimental Plan for GP1c

Prof. P.A. Muhammed Basheer

on behalf of Dr. Sreejith Nanukuttan

Objectives of the RRT

To provide a platform to validate advanced and non-standardised test techniques for characterising transport and to benchmark capabilities of innovative concrete mixes.



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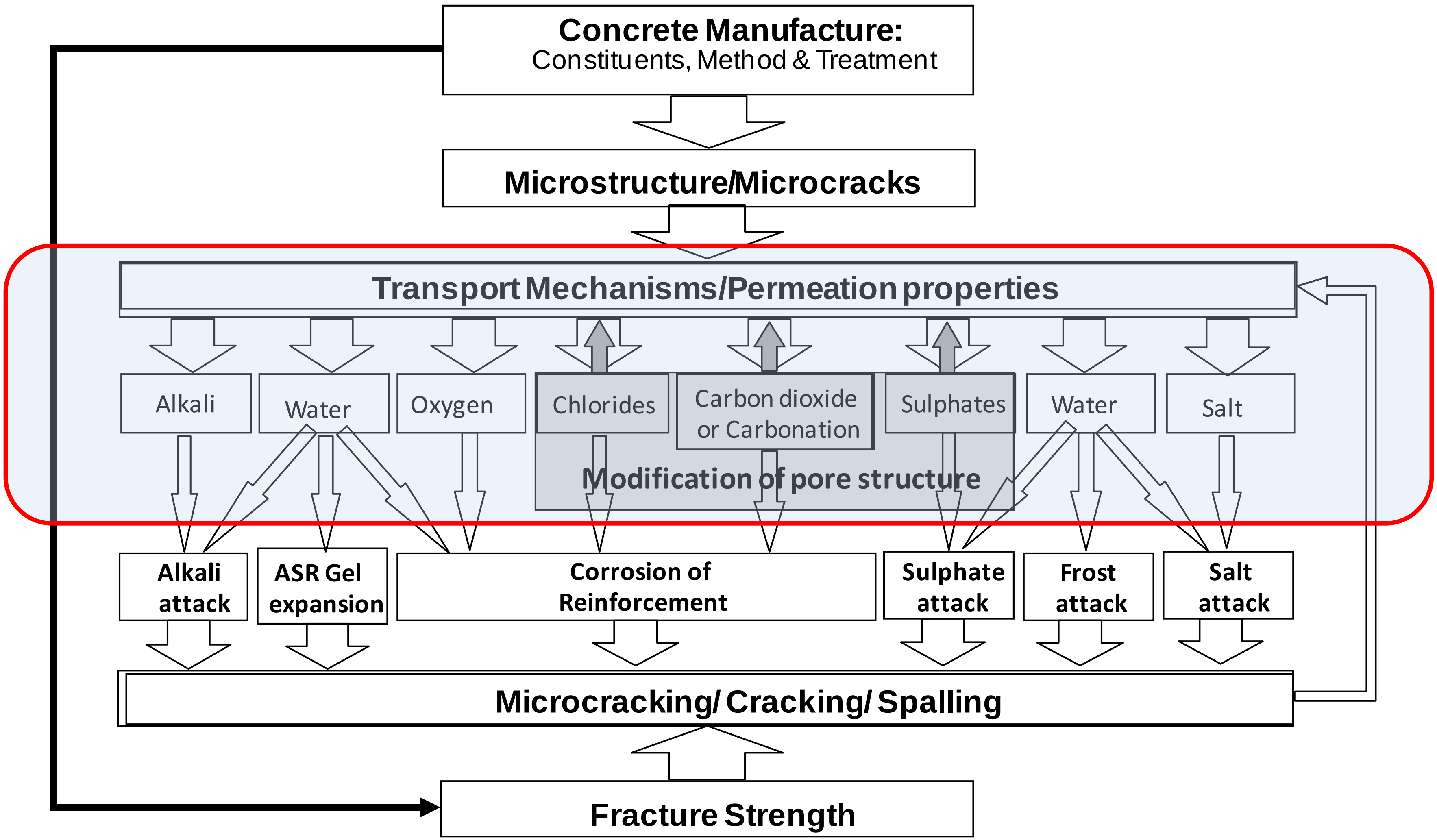
Transport Properties - Scope



The key is in collecting data that would help towards modelling the transport behaviour and predicting the service life of structures in different service environments.

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Phase 1 – Design (to be agreed between partners)

- Material preparation, water content, mixing procedure, curing, storing, etc. (applicable to all RRTs).
- Two mixes (OC and MOC) as given in the RRT document (see next slide) will be used.
- Template for recording and sharing data.
- Test for compressive strength, setting time, temperature measurement + non-invasive tests, such as electrical resistivity.
- Comparison of results to identify outliers – progress to Phase 2 – experimental phase.

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Phase 1 – Design

Composition of ordinary concrete OC and MOC mix used in the RRT programme

Basic Material	Type of the material	Mix 1 - OC [kg/m³]	Mix 2 -MOC [kg/m³]
Cement	CEM I 52,5 N CE CP2 NF Gaurain	320	To be agreed
Dry sand	0-4 mm, REC GSM LGP1 (13 % of CaO and 72 % of SiO2)	830	To be agreed
Dry gravel	4-11mm, R GSM LGP1 (rounded, containing silicate and limestone)	445	To be agreed
	8-16 mm, R Balloy (rounded, containing silicate and limestone)	550	To be agreed
Admixtures	Plasticizer SIKAPLAST Techno 80	2.75	To be agreed
Total water	Absorbed + efficient water (free water)	197.6	Low w/b

Mix 2 to be the Same as other GP's

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Phase 2 – Experimental

- Two mixes (OC and MOC) as given in the RRT document for all in Type A
- All tests as agreed to be carried out and results reported in correct template. Details of tests in Excel File.
- Analysis of results & make recommendations

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Phase 3 – Advanced

- Two mixes (OC and MOC) as given in the RRT document for all in Type A + EcoCrete – Type B
- All tests as agreed to be carried out and results reported in correct template. Details of tests in Excel File
- Analysis of results & drafting recommendations

EcoCrete to be decided by a participating institution or a cluster of institutions, based on locally available materials and technology.

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Discussion points:

1. Phase 1 – Rapid test to be included. If any suggestions other than resistivity exist, discuss the merits and select one as appropriate. This is in addition to compressive strength, setting time & temperature profile.
2. Grouping of Transport Mechanisms – identification of a group leader.
3. Decisions at the end of Phase 1 and its impact on further work. For example if a laboratory has been identified outlier, what happens, then.
4. Deadline for presenting Phase 1 results and identification of outliers.
5. Phase 3 - EcoCrete – Who all are interested. Is there an interest to form clusters with one laboratory producing concrete.

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Action Plan for all participants

1. Identifying details of tests to be included in Phase 2 – All participants to ensure the GP1c Excel file is completed. – 24th April
2. Material requirement to be filled in and sent to the coordinator without adding the wastage. - tbc
3. Develop templates for test that does not currently have one. Use the NT Build 492 and Bulk Resistivity as examples. – 1st May
4. Transport Mechanism leader to send an outline on their test and finalise the template. – 8th May

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Checklist of Deliverables

Item	Completed/Pending
Rapid test to include in Phase 1 on behalf of transport properties	Agreed/Pending
Leaders for each transport mechanism	Agreed/Pending
All participants made aware of their tasks:	
- Excel file of tests in Dropbox	Yes/No – 24th April
- Sample size and material requirements	Yes/No - tbc
- Template for each tests	Yes – 1st May
- Documents concerning different tests + outline send by leader	Yes – 7th May
Deadlines for all remaining activities discussed:	
- Phase 1 results & identification of outliers	Enter date
- Phase 2 programme	Enter date

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Questions/Comments

Contact

- Sree Nanukuttan
- s.nanukuttan@qub.ac.uk
- skype id: snanukuttan

Dropbox Link for folder - **GP1c Transport Properties**

https://www.dropbox.com/sh/nkm5m4k697uu2fe/AACoexOIWhe50MclVKkhaxbha?dl=0

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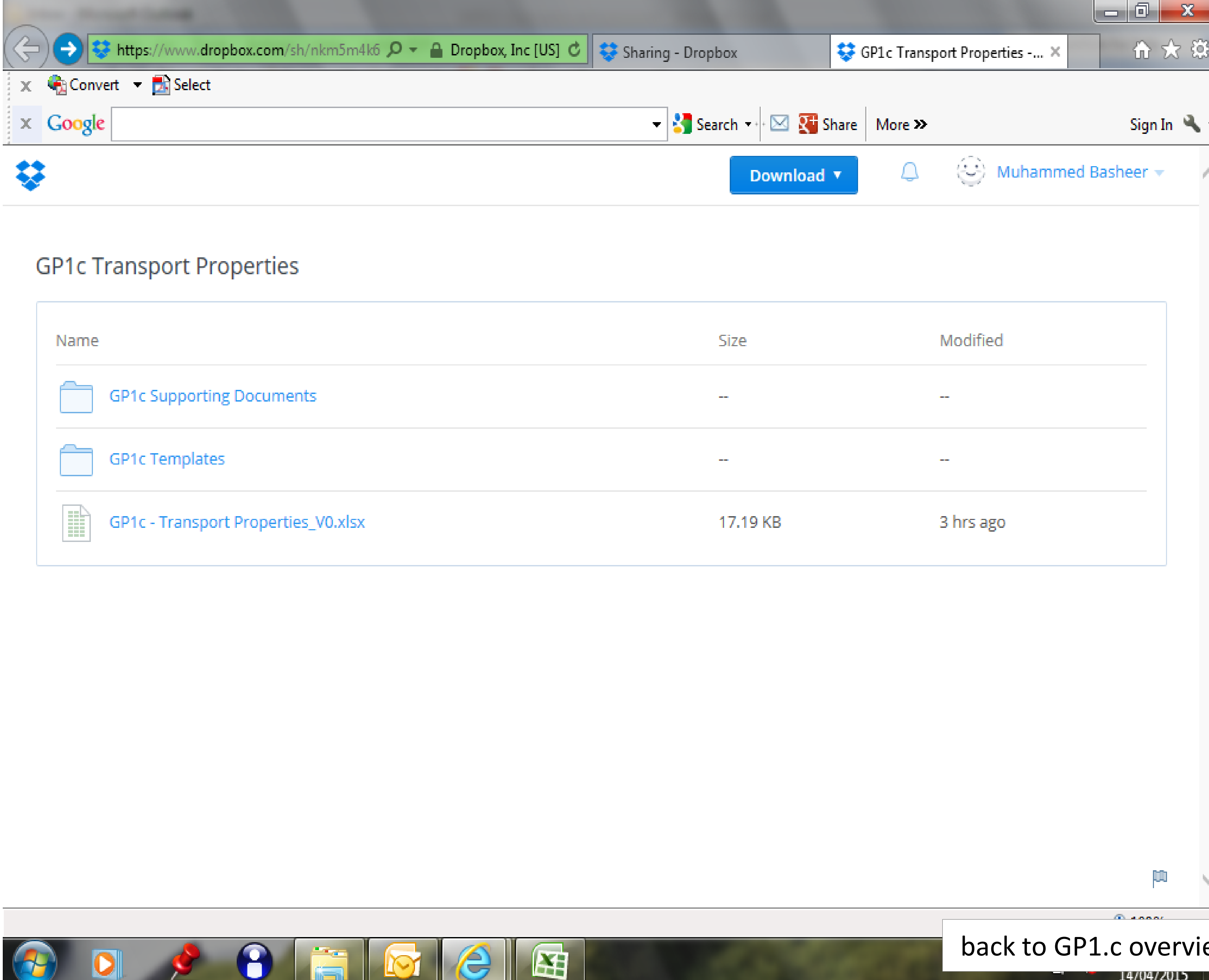

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GP1c Supporting Documents

Name	Size	Modified
Permit Test Protocol.docx	11.06 KB	3 hrs ago
Permit_Service Life Design.docx	520.49 KB	3 hrs ago

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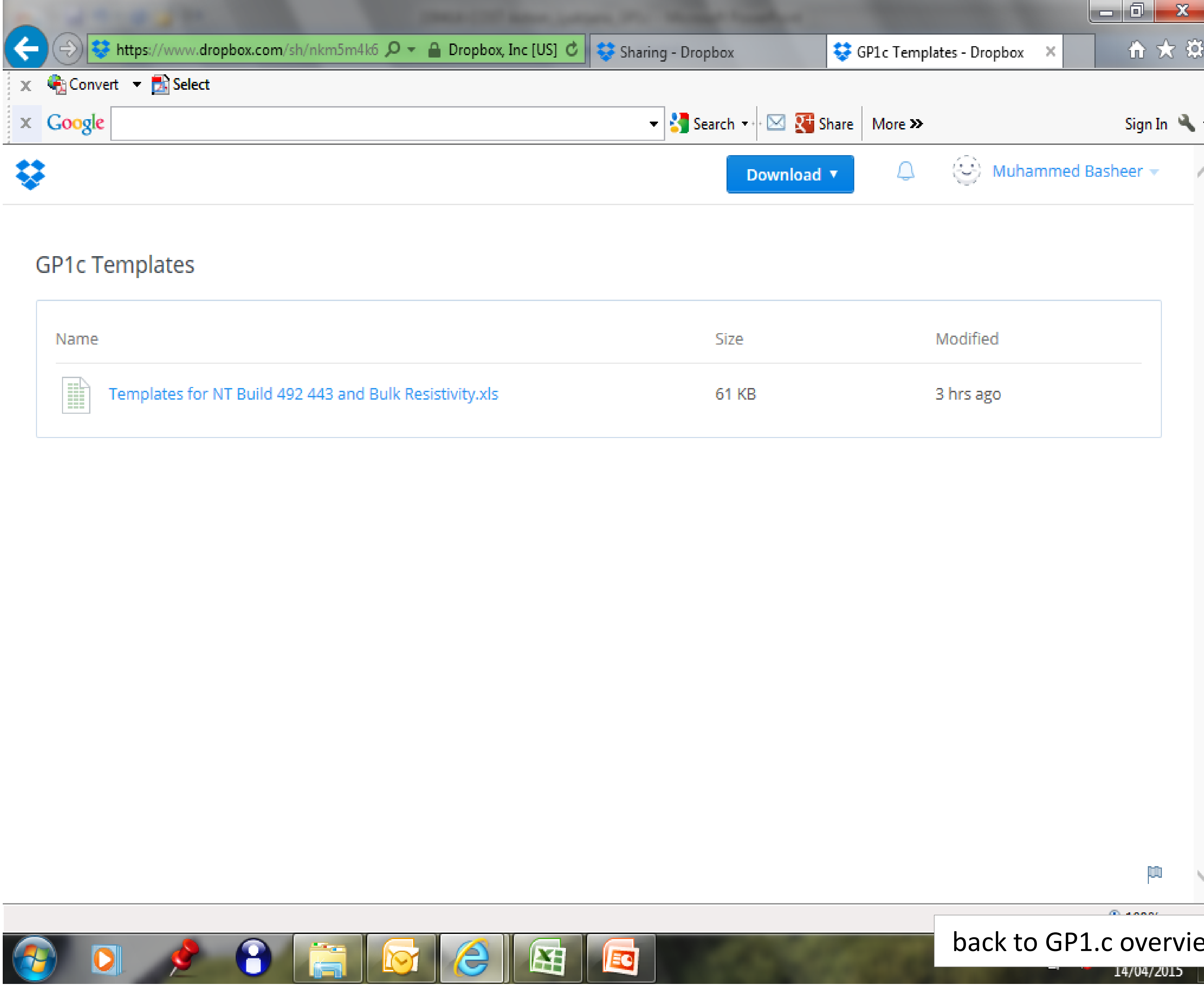

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TU 1404
COST ACTION

Tests to determine transport properties
Indirect and Field based tests

Filipe Pedrosa
Carmen Andrade Eduardo Torroja Institute for Construction Science, Spain
Nuria Rebolledo

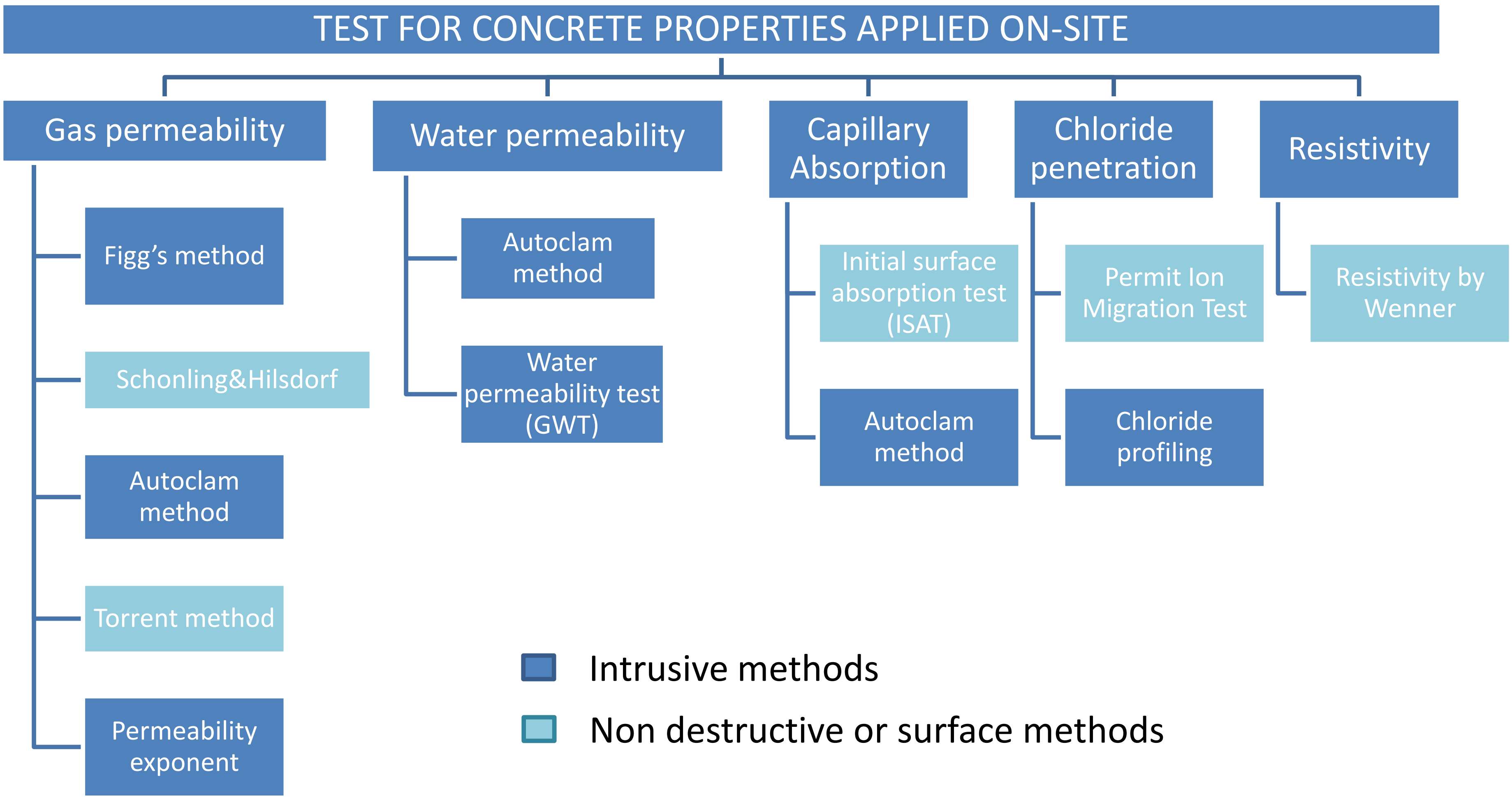
INSTITUTO EDUARDO TORROJA

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Outline

- Gas Permeability
- Water Permeability
- Water Absorption
- Chloride Penetration
- Resistivity and Resistivity SL Model



RILEM TC PSC Performance-based specification and control of concrete durability
CHAPTER 4. STATE OF THE ART REPORT

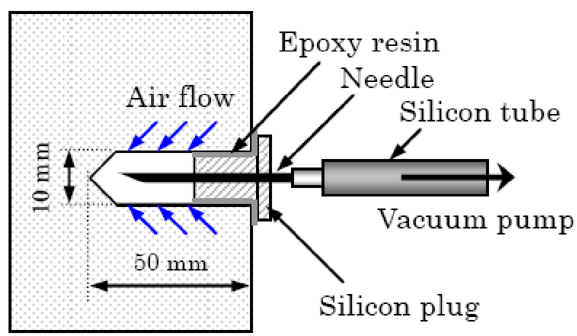
Gas Permeability

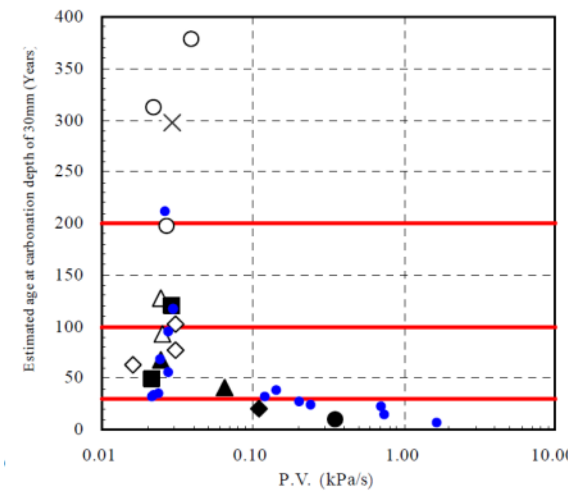
FIGG´S METHOD:

Create a negative relative pressure inside a small hole (-55 kPa).

Time for the pressure to rise by 5 kPa - air permeability index.

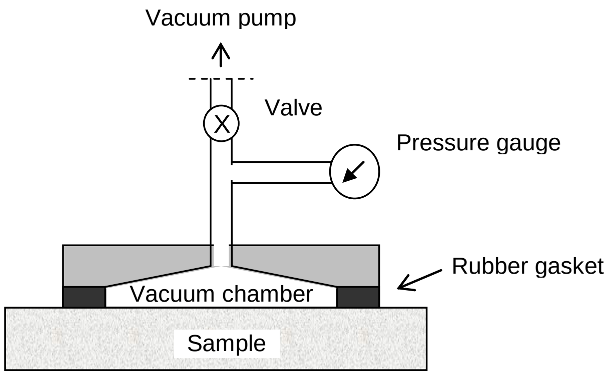
Permeability velocity (PV) related to carbonation progress.





Shematic of Figg's permeability test and Relationships between carbonation progress and air permeability (Imamoto, K., 2009)

Gas Permeability



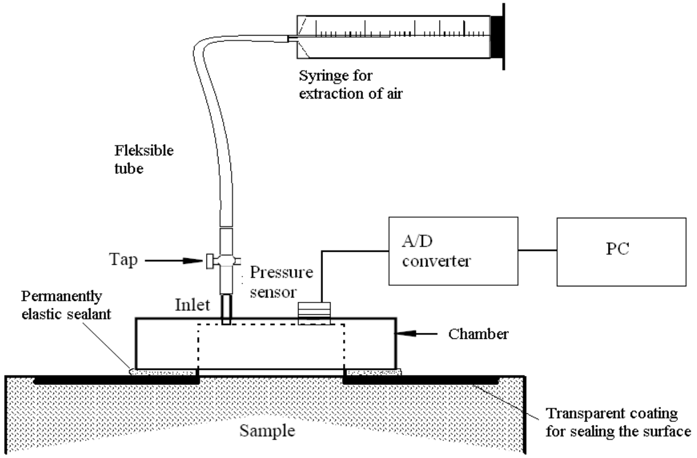
SCHÖNLIN & HILSDORF:

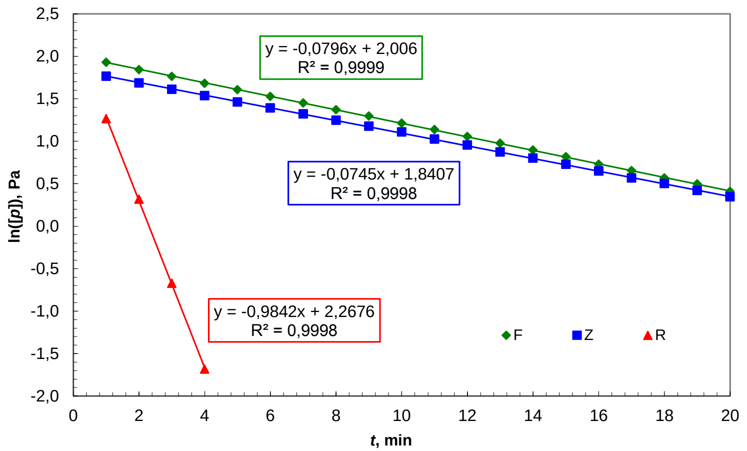
Non intrusive alternative to Figg's method

From <-99KPa to a predefined level (e.g. -70 kPa)

Simplified version using a syringe.

ln(pressure) vs. time curve presents the air permeability index





Schönlin & Hilsdorf method used on concrete prepared in regular formwork and ones prepared in CPF (Bjegovic, D., 2012)

Gas Permeability

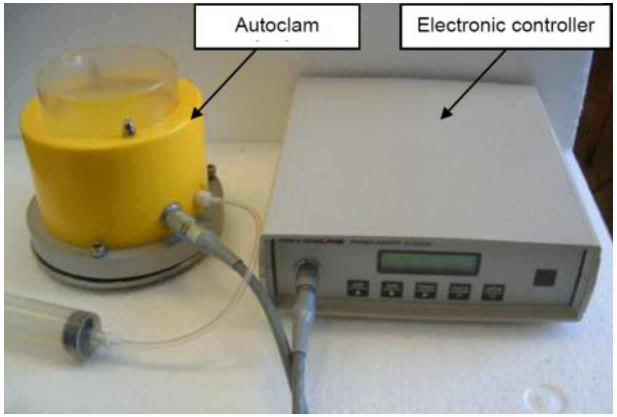
AUTOCLAM METHOD:

Area of 50 mm diameter isolated with a metal ring.

Test is carried out by increasing the air pressure on the test surface to 0.5 bar and noting the decay of pressure with time.

Ends after 15 minutes or until the pressure has diminished to zero

Air permeability index, in ln(pressure)/min.



Gas Permeability

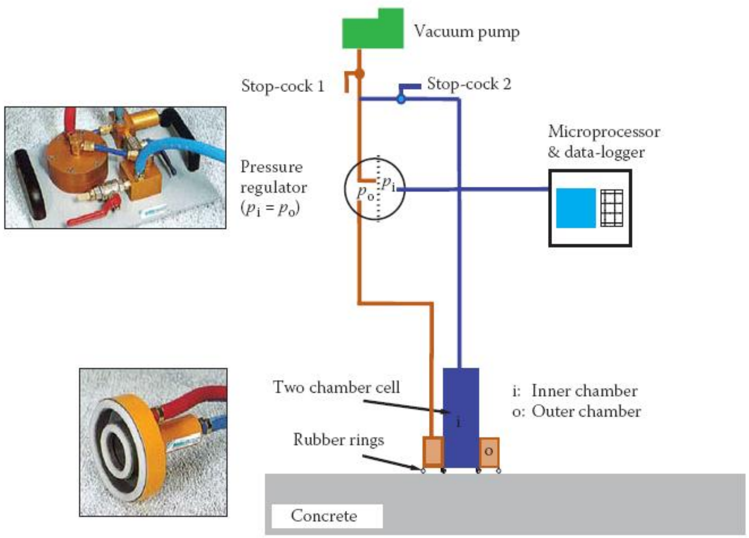
TORRENT METHOD:

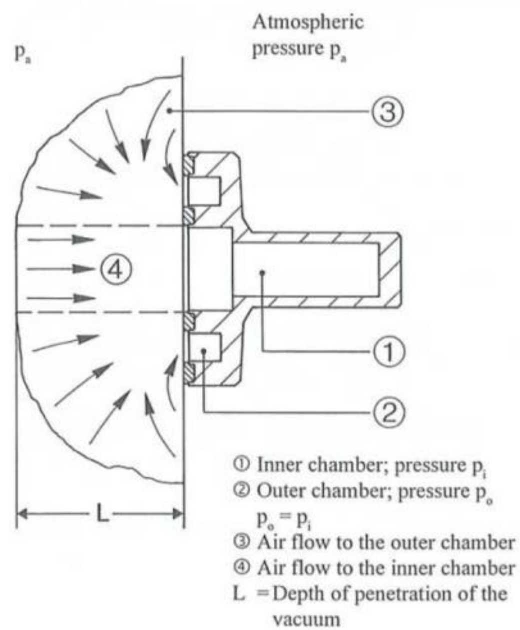
Double-chamber cell and a pressure regulator that balances the pressure in both chambers.

Controlled, unidirectional flow of air from the pores of the concrete into the inner chamber. Outer chamber acts as a guard-ring.

Calculates the coefficient of permeability to air, kT.

Swiss Standard SIA 262/1:2003





Water Permeability

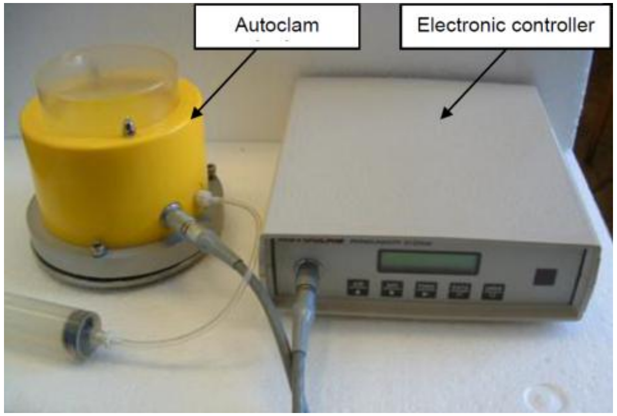
AUTOCLAM METHOD:

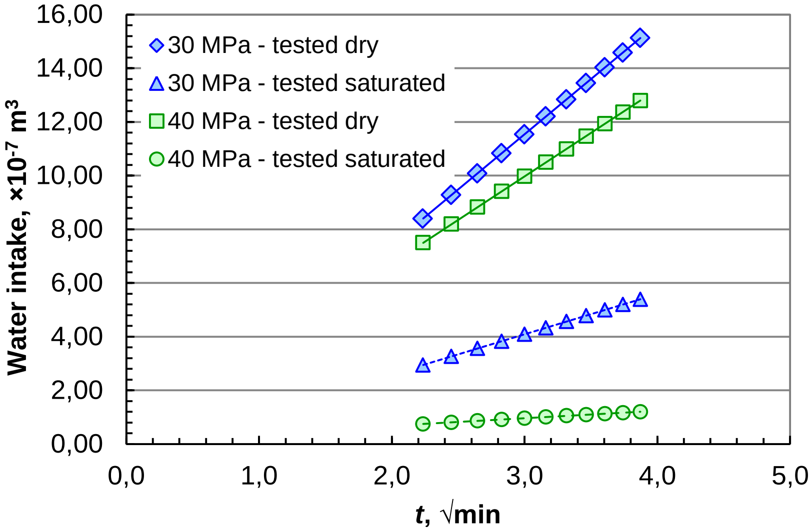
Area of 50 mm diameter isolated with a metal ring.

Test is carried out by increasing the water pressure on the test surface to 0.5 bar and noting the decay of pressure with time.

Cumulative water penetration into concrete is plotted against the square root of time.

Water permeability index, in $m^3 \cdot min^{-0.5}$.



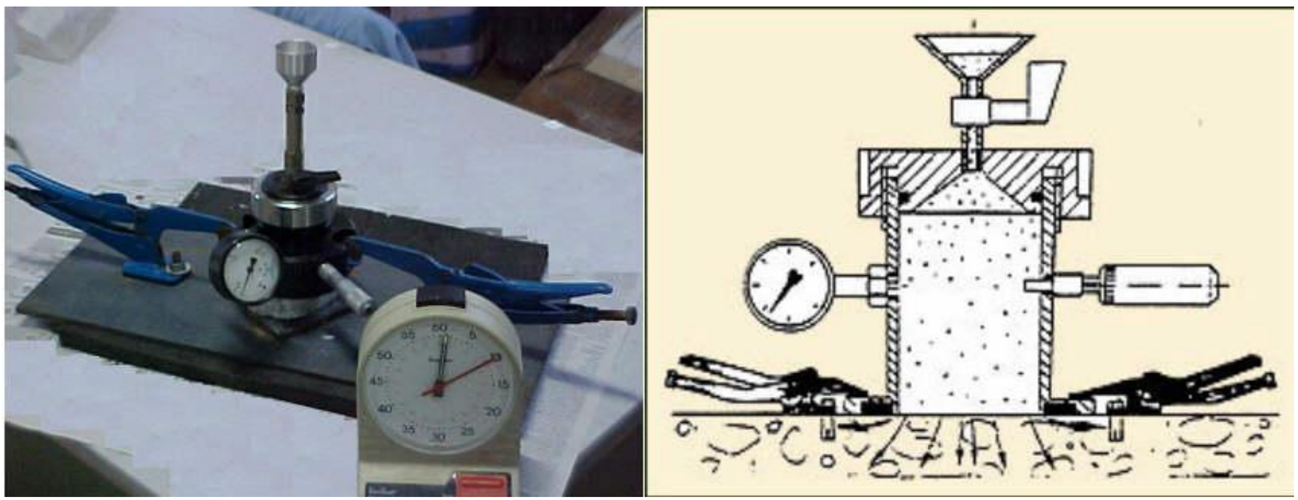


Application of Autoclam water permeability test (Gabrijel, I., 2008)

Water Permeability

Water permeability Test (GWT):

Sealed pressure chamber filled with water.



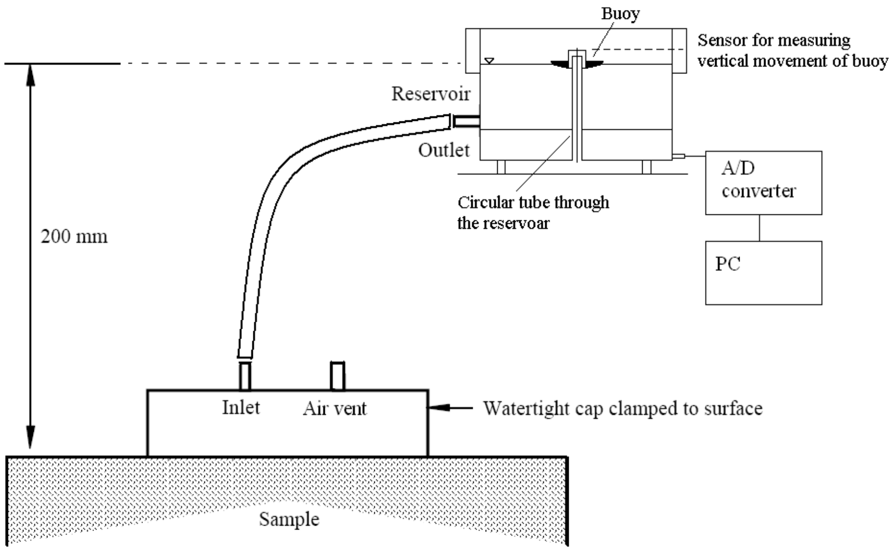
Water Absorption

INITIAL SURFACE ABSORPTION TEST (ISAT):

Reservoir filled with water connected to the concrete through a cap.

Level of water in the reservoir is 200±5 mm above the concrete.

Outflow from the reservoir is equal to the water inflow into the concrete. The initial surface absorption value is then calculated and expressed in the units ml/(m^2 s).



Water Absorption

AUTOCLAM METHOD:

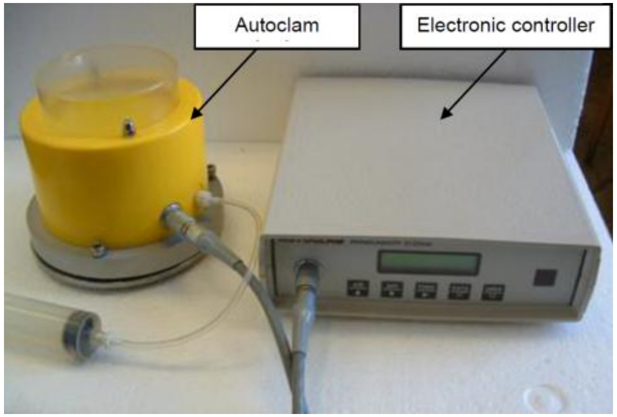
Area of 50 mm diameter isolated with a metal ring.

Applied pressure of 0.02 bars.

Cumulative water penetration into concrete is plotted against the square root of time.

Sorptivity index.

Internal relative humidity of concrete at 10 mm depth should be less than 80%.



Chloride Penetration

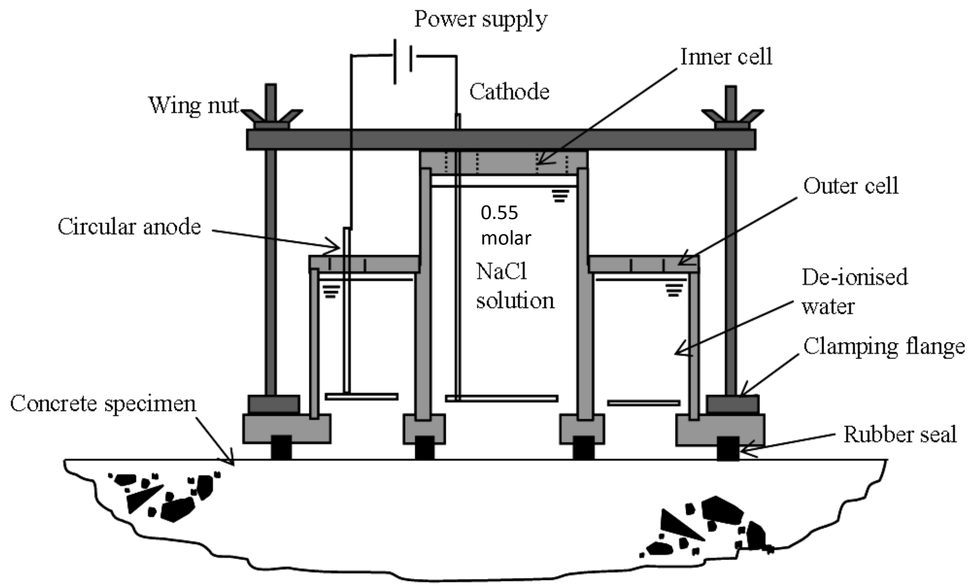
Permit Ion Migration Test (PERMIT):

Determine the chloride migration coefficient of cover concrete.

Introduces chloride ions into the test surface.

Migration coefficient determined based on the rate of flow of Cl^-.

Good correlation with lab tests.



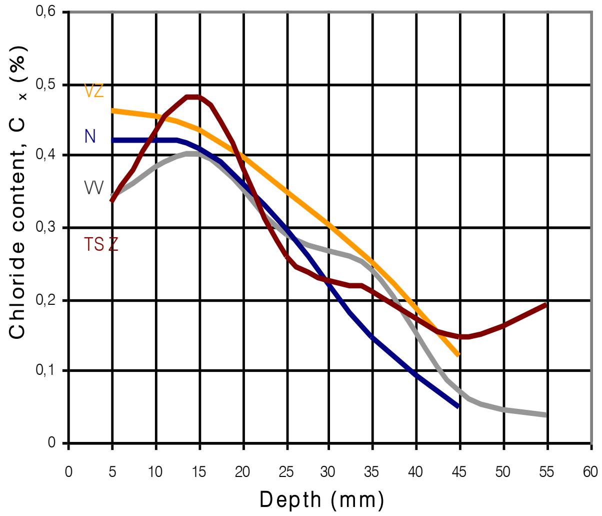
Chloride Penetration

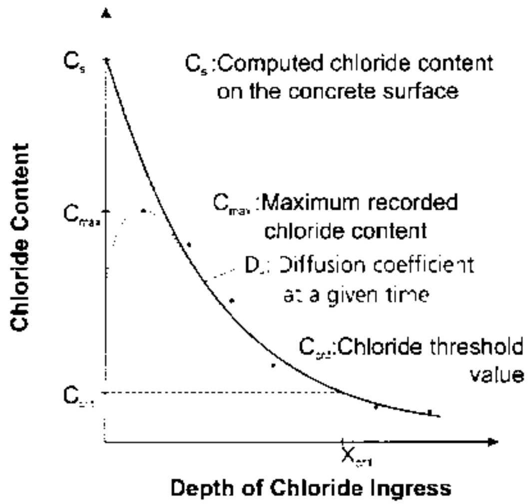
Chloride profiling method:

Slices from drilled cores or from concrete drilling dust.

Dust specimens are tested in the laboratory, usually by a potentiometric titration method, to determine chloride content

After that the *erfc*-solution to Fick's 2nd law can be fitted to measured chloride profiles





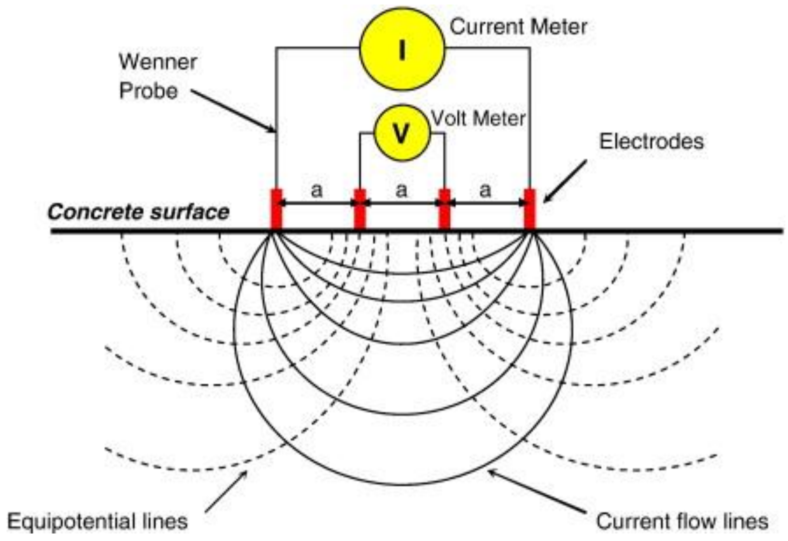
Concrete Resistivity

4 point Wenner probe:

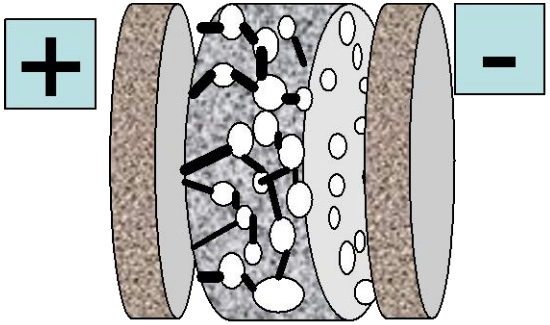
NDT which can be used in lab and in situ. Fast measurement.

Facilitates routine quality control

ρ is related to porosity, degree of saturation and transport processes through concrete.



Resistivity



$$R = \frac{V}{I} = \rho \frac{l}{A}$$

In-situ

Specimens

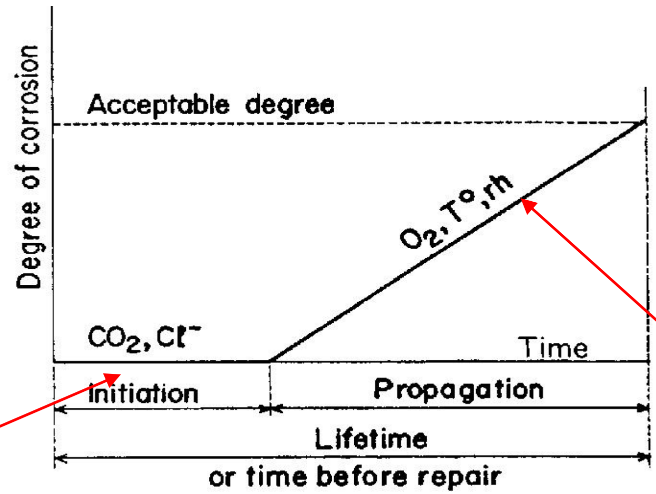
$$\rho_{semi-infinite} = Re \cdot 2 \cdot \pi \cdot a$$

$$\rho_{specimens} = Re \cdot 2 \cdot \pi \cdot a \cdot F_{shape}$$

Geometric factor

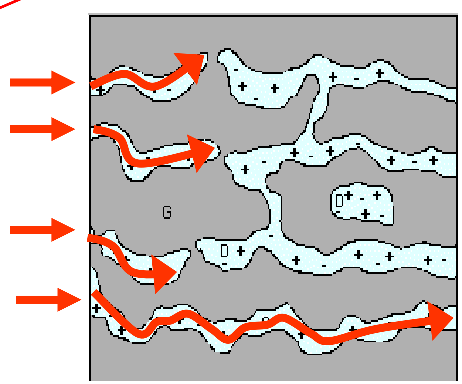
A. Sagües, F. Morris. C&CR.

Resistivity SL Model



Relationship with the diffusion coefficient

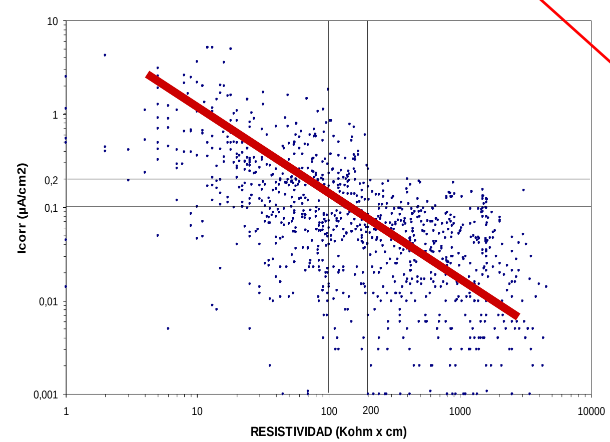
$$D_{Cl} = \frac{K}{\rho}$$



C. Andrade- C&CR 23 (1993) 724

Relationship with the corrosion

$$I_{corr} = \frac{K}{\rho}$$



C. Alonso, C. Andrade, J.A Gonzalez- C&CR 18 (1988) 687.

Resistivity SL Model

$$t_{LIFE} = t_i + t_p$$

$$x = V \cdot \sqrt{t}$$

+

$$t_p = \frac{P_{lim}}{V_{corr}}$$

$$V = \sqrt{D} = \sqrt{\frac{K}{\rho}}$$

$$t_{LIFE} = \frac{x^2 \cdot \rho_{ef} \cdot \left(\frac{t}{t_0}\right)^q}{k_{Cl,CO_2}} \cdot r_{Cl,CO_2} + \frac{P_x \cdot \rho_{ef} \cdot \left(\frac{t}{t_0}\right)^q \cdot W_s}{K_{corr}}$$

Resistivity SL Model

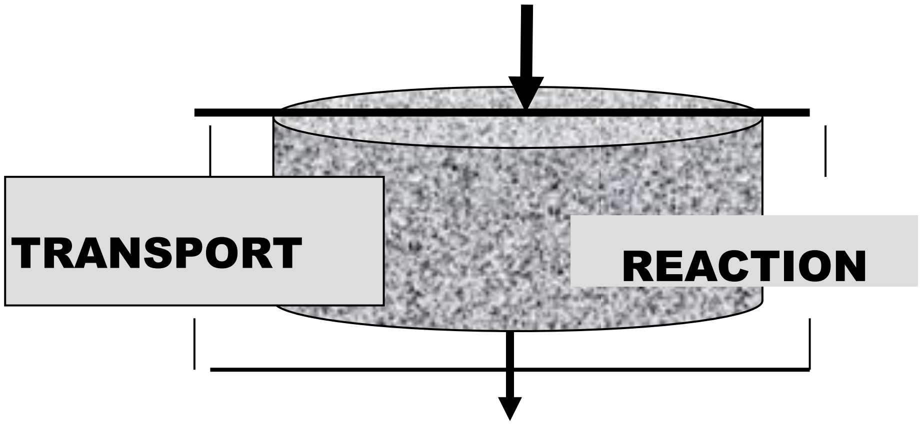
$$t_i = \frac{x^2 \cdot \rho_{ef} \cdot \left(\frac{t}{t_0}\right)^q}{k_{Cl,CO_2}} \cdot r_{Cl,CO_2}$$

t_i, initial time or depassivation time, years;
x, depth, cm;
ρ_{ef}, electrical resistivity measured by direct method or 4 points method, Ω·cm;
q, ageing factor;
$r_{Cl, CO2}$, reaction factor (depends on the type of cement);
$k_{Cl,CO2}$, environmental factor, Ω·cm³/year;

Resistivity SL Model

$$t_i = \frac{x^2 \cdot \rho_{ef} \cdot \left(\frac{t}{t_0}\right)^q}{k_{Cl,CO_2}} \cdot r_{Cl,CO_2}$$

→ **Reaction factor**



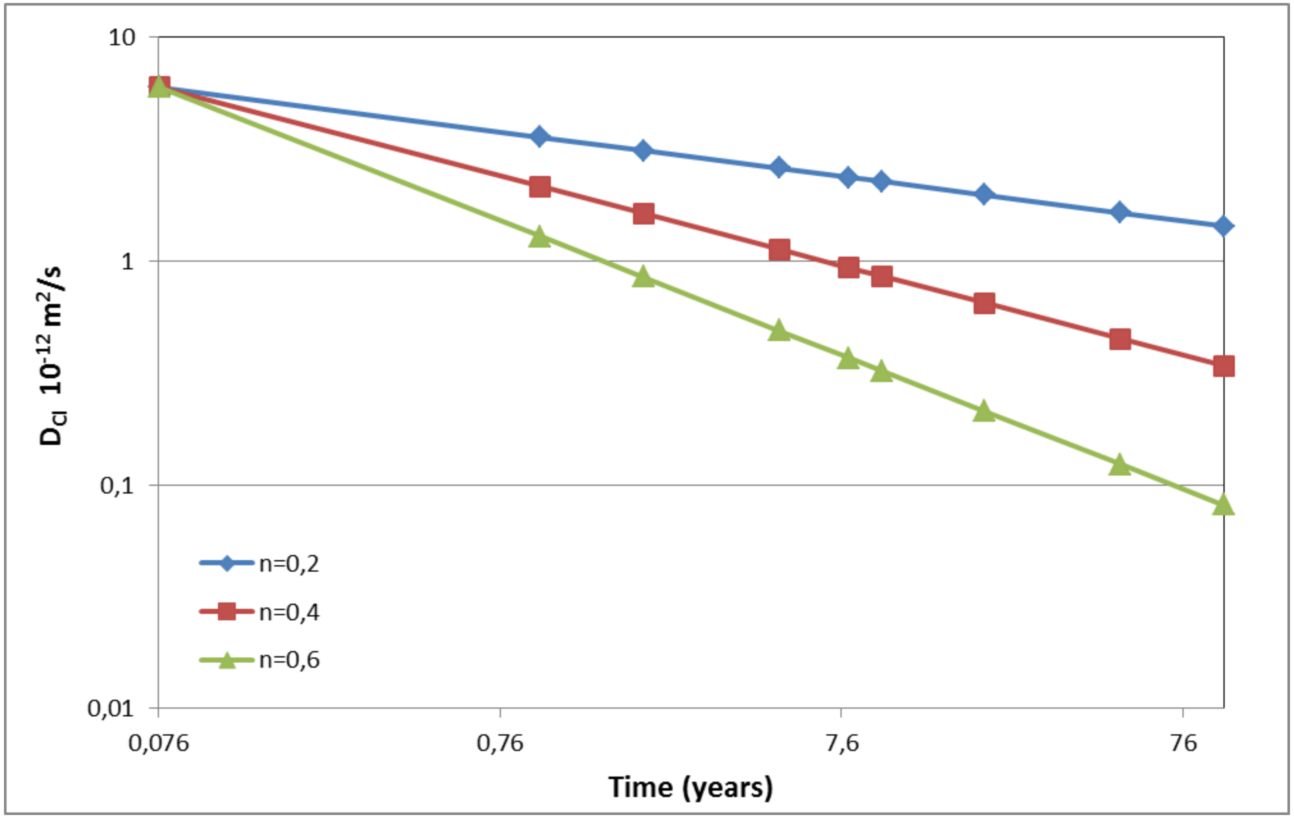
Cement	r_{Cl}
I	1.5 - 2*
I + Silica Fume	1,5
Tipo II/A	3

To account for Transport and Binding with cement phases, in the resistivity model it was defined the Apparent resistivity ρap= ρef · $r_{Cl,CO2}$, by analogy with the steady and non-steady diffusion coefficients.

Resistivity SL Model

→ **Ageing factor**

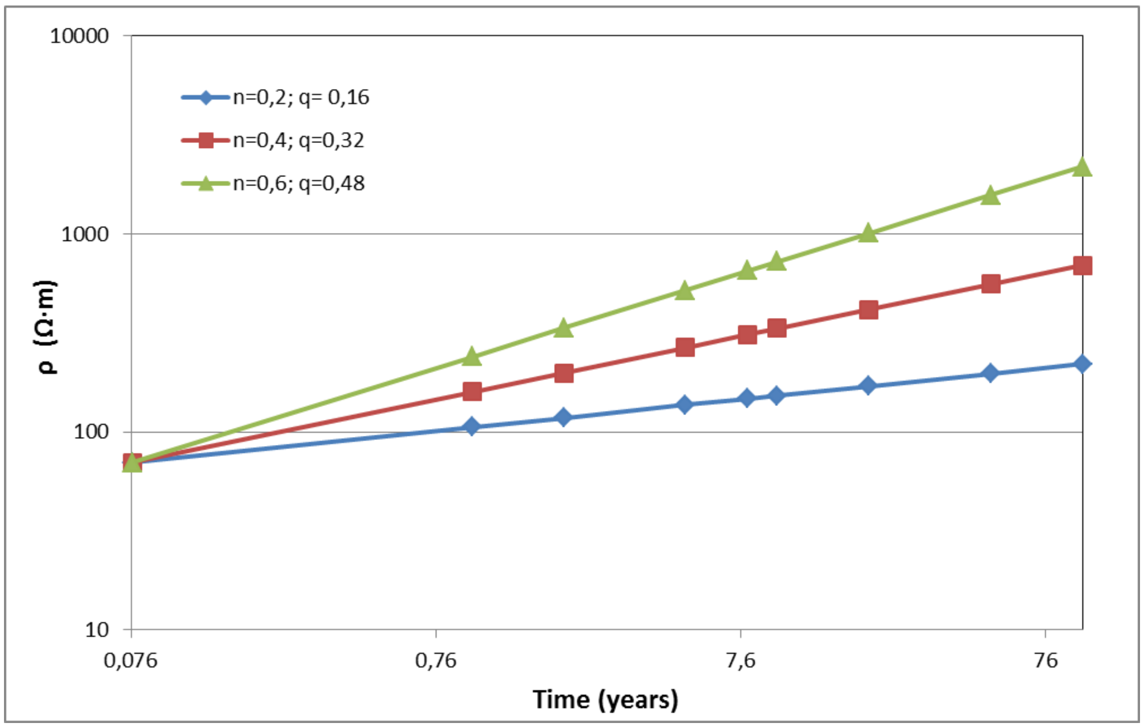
$$D_{Cl,t} = D_{Cl,to} \cdot \left(\frac{t_0}{t}\right)^n$$



Resistivity SL Model

→ **Ageing factor**

	CEM I	CEM II/A-P	CEM II /A-V CEM II/B-V	CEM III
q	0,22	0,37	0,47	0,5



$$\rho_t = \rho_0 \left(\frac{t}{t_0}\right)^q$$

Relationship between n and q

$$q = 0{,}8 \cdot n$$

TU 1404 COST ACTION

Testing and Modelling Mass Transport

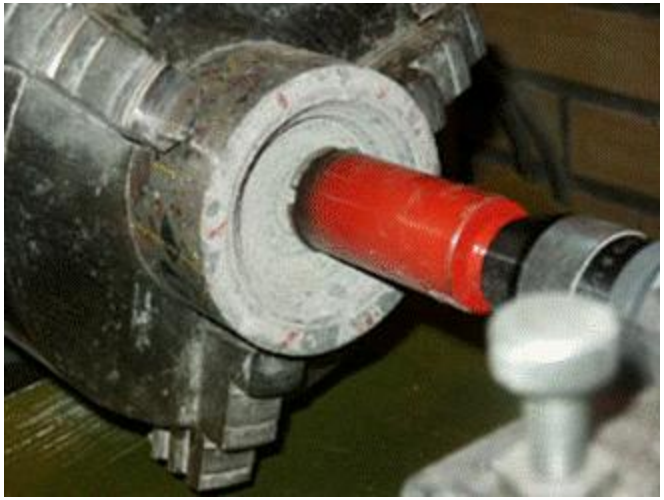
Tang Luping – Chalmers University of Technology, Sweden

Standard methods for chloride transport

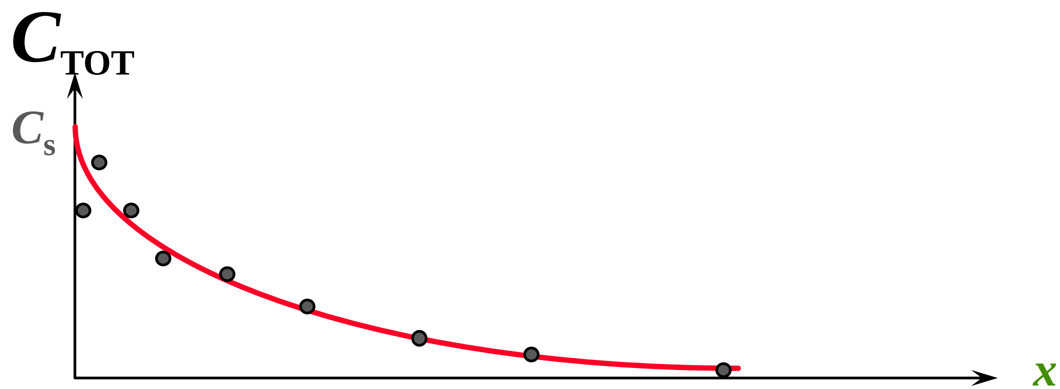
Immersion/Ponding Test

Method	Conditions	Duration	Outcome (property)
NT BUILD 443 (1995)	165 g NaCl per litre, at (23 ± 2)°C	35 days	Curve-fitted apparent D_a and C_s
ASTM C 1543 (2010)	3% (by mass) NaCl with the depth of (15 ± 5) mm, stored at (23 ± 2)°C and (50 ± 5) % RH	3 months, and subsequently after 6 and 12 months of ponding and at 12-month intervals thereafter	Chloride content as a function of penetration depth and ponding duration
ASTM C 1556 (2004)	Similar to NT BUILD 443, but pre-conditioning acc to ASTM C1202	35 days	Curve-fitted apparent D_a and C_s
prEN/TS 12390-11 (2014)	3% (by mass) NaCl as reference, at (20 ± 2)°C	90 days as reference	Curve-fitted apparent D_a and C_s

Chloride profiling and curve-fitting



Curve-fitting Two parameters: C_s and D_a



$$C(x,t) = C_s - (C_s - C_i)\,\mathrm{erf}\left(\frac{x}{2\sqrt{D_a\, t}}\right)$$

C_s = chloride content at surface

C_i = initial chloride content at surface

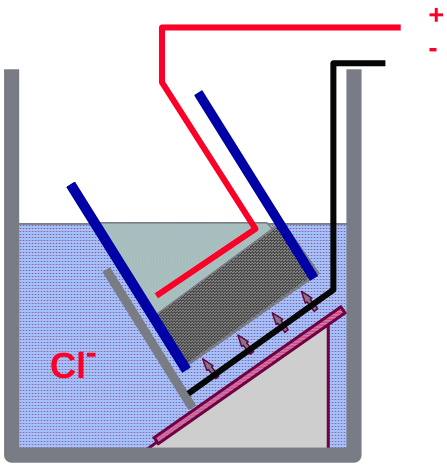
D_a = apparent chloride diffusion coefficient

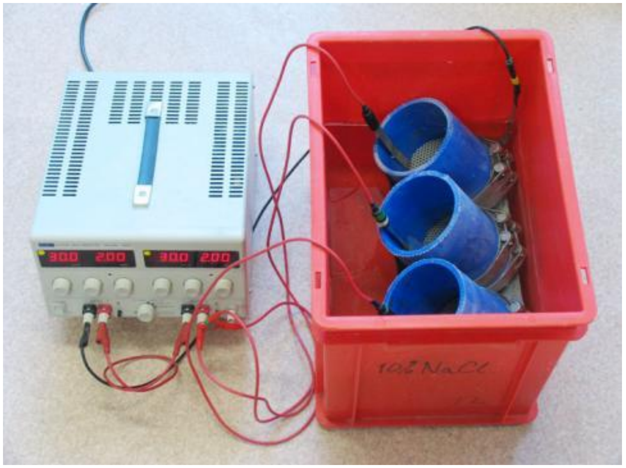
Standard methods for chloride transport

Migration Tests

Method	Conditions	Duration	Outcome (property)
NT BUILD 355 (1997)	5% NaCl as catholyte and 0.3 mol/L NaOH solution as anolyte	Months until steady state flow	D_{ssm} calculated from the steady state chloride flow rate
NT BUILD 492 (1999)	10% NaCl as catholyte and 0.3 mol/L NaOH solution as anolyte	24 h but can vary from 4 h to 96 h depending on the initial current under 30 V.	D_{nsm} calculated from penetration depth
SIA 262/1 (2003)	3% NaCl in 0.2 mol/L KOH solution as catholyte and 0.2 mol/l KOH as anolyte	24 h or 16 h depending on the applied potential (20 or 30 V)	D_{nsm} calculated from penetration depth
AASHTO TP64 (2003)	Similar to NT BUILD 492	18 h	Penetration depth mm/(V·h)
BAW guideline (2004)	10% NaCl in 0.2 mol/L KOH solution as catholyte and 0.2 mol/L KOH as anolyte	4-168 h under 30 V to reach a penetration depth 10-30 mm	D_{nsm} calculated from penetration depth
GB/T 50082 (2009)	Similar to NT BUILD 492	Similar to NT BUILD 492	D_{nsm} calculated from penetration depth

Rapid Chloride Migration Test



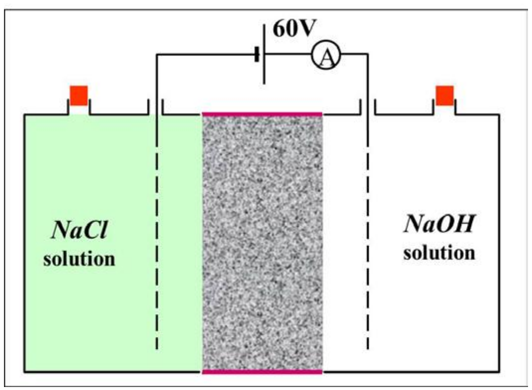


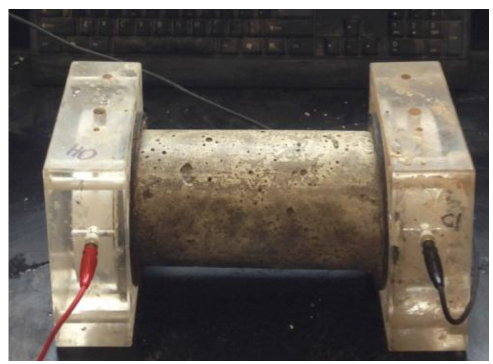
$$D = \frac{R\,T\,L}{z\,F\,\Delta E} \cdot \frac{x_d - \alpha\sqrt{x_d}}{t}$$

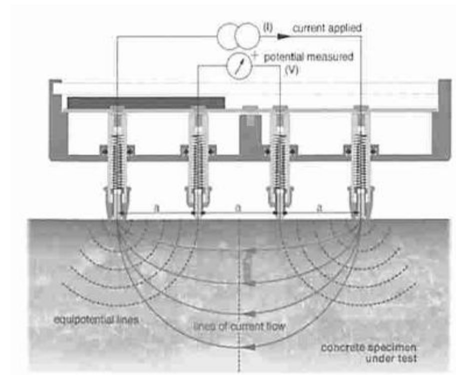
$$\alpha = 2\sqrt{\frac{R\,T\,L}{z\,F\,U}} \cdot \mathrm{erf}^{-1}\left(1 - \frac{2c_d}{c_0}\right)$$

Standard methods for conductivity or resistivity

Method	Conditions	Duration	Outcome (property)
ASTM C 1202 (since 1991)	3% NaCl as catholyte and 0.3 mol/L NaOH solution as analyte	6 h under 60 V	Charge passed
AASHTO TP 95 (2011)	Standard laboratory curing (moist room at 23 °C & >95%RH)	A few minutes	Resistivity
ASTM C 1760 (2012)	Similar to ASTM C 1202	A few minutes	Conductivity at 1 min DC



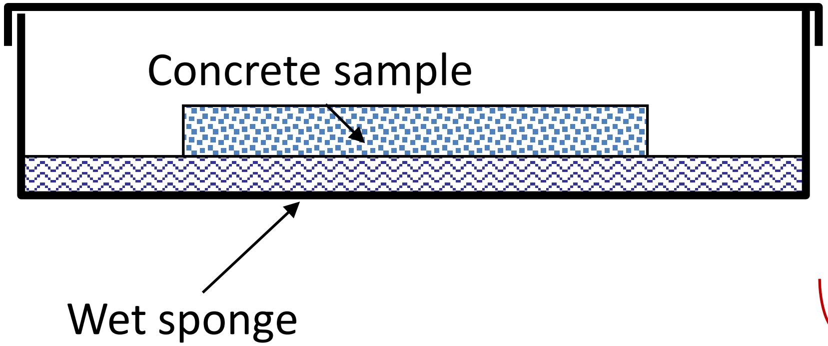


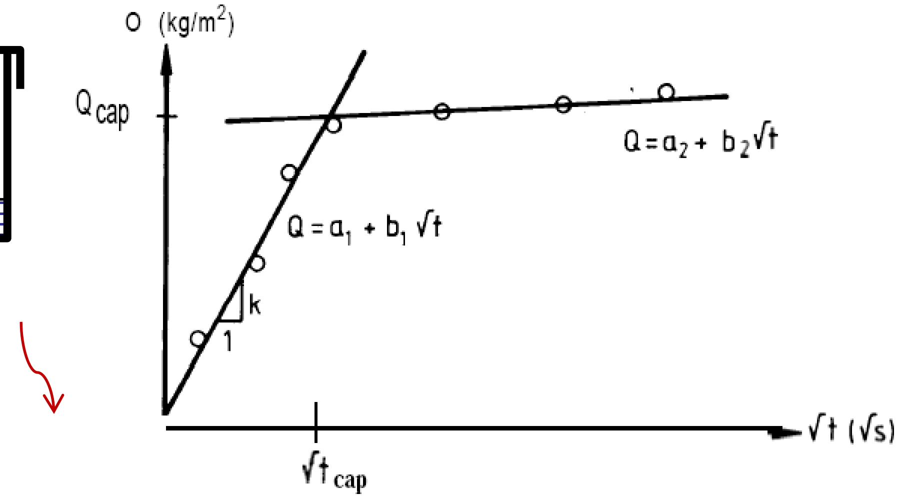


Calibration is needed to relate the conductivity/resistivity to transport properties

Standard methods for water absorption

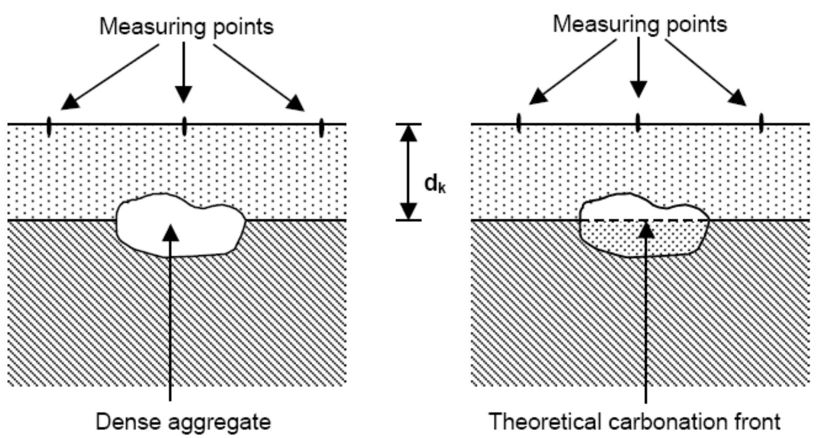
Method	Conditions	Duration	Outcome (property)
NT BUILD 368 (1991)	Drying at 40 °C until constant moisture	4 days absorption	Absorption rates
ASTM C 1585 (2004)	Drying at 50 °C & 80%RH for 3 days, followed by storage in a sealed container at 23 °C for at least 15 days	7-9 days absorption	Absorption rates

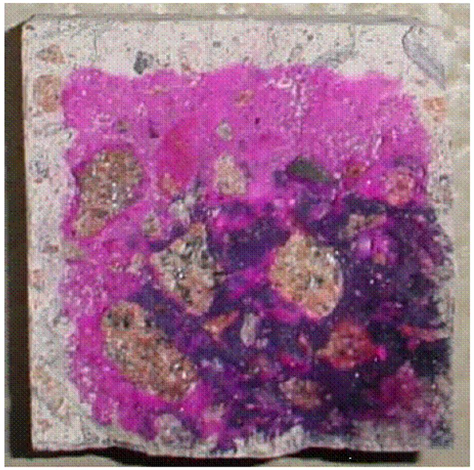




Standard methods for carbonation rate

Method	Conditions	Duration	Outcome (property)
NT BUILD 357 (1989)	3% CO_2 at 20 °C & 60%RH	Carbonation for months	Carbonation rate
EN 13295 (2004)	1% CO_2 at 21 °C & 60%RH	Carbonation for 56 days	Carbonation rate
EN/TS 12390-12 (2011)	4% CO_2 at 23 °C & 60%RH	Carbonation for 140 days	Carbonation rate
ISO 1920-12.2 (2014)			





Inter-laboratory tests (Round-Robin tests)

Nordic RRT

Method	Lab No.	Concrete types	r CoV	R CoV
NT BUILD 355	2-3	CEM I, w/c 0.5, f_{cc} 63 MPa at 28d CEM II/A-D, 8% silica fume, w/b 0.4, f_{cc} 83 MPa at 28d CEM III/B (70% ggbs, w/b 0.5, f_{cc} 45 MPa at 28d	9.4%	56.1%
NT BUILD 443	2-3		11.6%	18.9%
NT BUILD 492	6		7.5%	16.2%

Inter-laboratory tests (Round-Robin tests)

EU ChlorTest RRT

Method	Lab No	Concrete types	r CoV	RCoV
NT BUILD 443	6-8	CEM I, w/c 0.35; 0.42 and 0.5 CEM II/A-D, 5% silica fume, w/b 0.42 CEM II/A-V, 18% fly ash, w/b 0.42, CEM III/B (70% ggbs, w/b 0.42	29.1%	42.2%
NT BUILD 492	7-8		17.3%	23%
IETcc steady state migration (in principle similar to NT BUILD 355)	6-7		20.8%	79.9%
Resistivity (similar to ASTM C 1760)	6-7		9.3%	23.3%

Inter-laboratory tests (Round-Robin tests)

American RRT for standard surface resistivity test
AASHTO TP95

Lab No.	Concrete types	Test age	r CoV	R CoV
12-14	12 mixes with various CRMs, w/b 0.3 to 0.41	28 days	4.3%	8.5%
		56 days	4.1%	11.5%
		91 days	4.3%	11%

Uncertainty of an indirect test method

$$u = \sqrt{u_{direct}^2 + u_{direct}^2} > u_{direct}$$

When correlating an indirect test to the direct test the measurement uncertainty will always be larger than the direct test!

Modelling chloride transport

Model	Principles	Boundary conditions	Input parameters
Simple ERFC (1972)	ERFC to Fick's 2nd law	C_s: constant D_a: constant	– Both C_s and D_a from short term exposure to the real environment
DuraCrete (2000)	ERFC to Fick's 2nd law with age factor and other correction factors	C_s: constant D_a: decreasing with time	– C_s and age factor n from short term exposure or Guidelines – D_0 from NT BUILD 492 – Other correction factors from Guidelines
fib Code (2006)	Similar to DuraCrete	Similar to DuraCrete	– C_s and age factor n from short term exposure or Code – D_0 from NT BUILD 492 or NT BUILD 443 – Other correction factors from Code
Mejlbro-Poulsen	Analytic solution to Fick's 2nd law with time-dependent C_s and D_a	C_s: increasing with time D_a: decreasing with time	– D_{aex} from short term exposure in the lab and corrected to the real environment – Age factors for both C_s and D_a as well as other factors from experience or comparison with the infield data

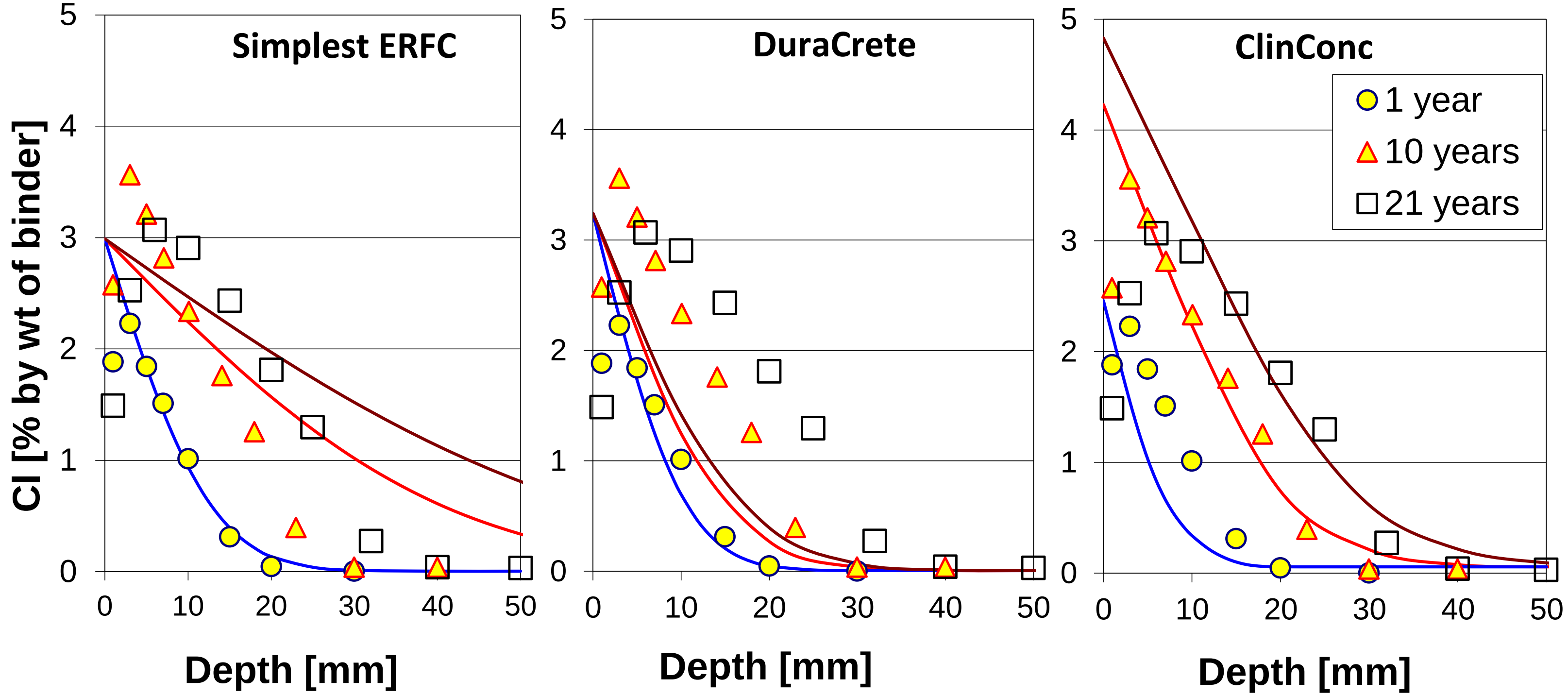
Modelling chloride transport

Model	Principles	Boundary conditions	Input parameters
Life 365 (software needed)	Numerical solution to Fick's 2nd law with time-dependent D_a.	C_s: constant dependent on binder type D_a: decreasing with time but constant after 30 years	– C_s from in-built database or short term exposure to the real environment – D_{ref} from short term exposure to the real environment under the reference time – Temperature from in-built database or local climate
STADIUM (software needed)	Numerical solution to multi-species diffusion functions with binding	c_i: constant ionic concentration in the exposure solution D_i: constant initial ionic diffusion coefficients	– Mix proportions and exposure conditions including concentrations of various ions and temperature – Ionic binding isotherms
ClinConc	Fick's 1st law of diffusion with non-linear chloride binding and temperature effect	c_s: constant chloride concentration in the exposure solution D_{nsm}: constant measured at 6 months	– Mix proportions and exposure conditions including concentrations of chloride ions and temperature – Chloride binding isotherms – Other constants as given in (Tang, 2006)

Modelling carbonation

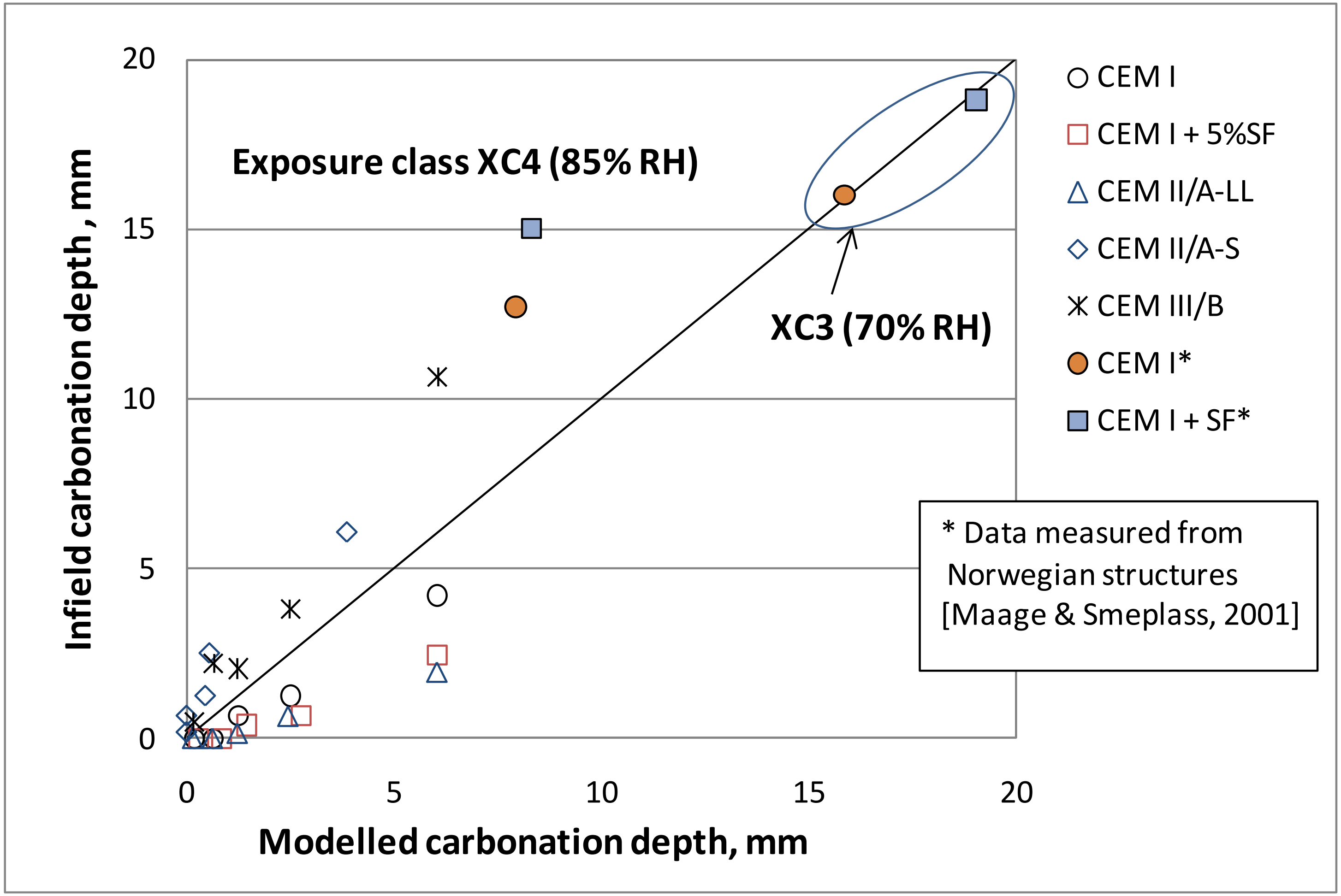
Model	Principles	Boundary conditions	Input parameters
Papadakis et al. (1991)	Square root time function with empiric equations for effective CO_2 diffusivity	C_{CO2}: constant $D_{e,CO2}$: constant depending on RH	– Mix proportions – C_{CO2} – Exposure RH
DuraCrete (2000)	Square root time function with age factor and other correction factors	C_{CO2}: constant $D_{e,CO2}$: decreasing with time	– C_{CO2} and age factor n from Guidelines – $D_{ca,0}$ from an accelerated test (not specified) – Other correction factors from Guidelines
Thiery et al. (2007) (software needed)	Analytically solve the CO_2 mass balance	C_{CO2}: constant $D_{e,CO2}$: as a function of porosity and degree of water saturation	– Mix proportions – C_{CO2} – Water absorption/desorption isotherms (by computing)

Validation of models for chloride ingress



More than 20 years infield data are available for validation of various models

Validation of carbonation models



SESSION for GP1.d – Mechanical properties
Chairman: Violeta Bokan Bosiljkov

Violeta Bokan Bosiljkov: Mechanical properties and creep - experimental plan for GP1d

Miguel Azenha, José Granja, Cyrille Dunant: EMM-ARM retrospective and current developments

Brice Delsaute: Inter-laboratory comparison on the measurement of concrete E-modulus at very early ages through several techniques

Bernhard Pichler: Early-age macroscopic elasticity, creep, and strength testing of cementitious materials

TU 1404 COST ACTION

Mechanical properties and creep - experimental plan for GP1d

Violeta Bokan Bosiljkov – University of Ljubljana, Slovenia

University of Ljubljana

GP1d co-leaders

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Bernhard Pichler

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- The aim of GP1d of WG1 is to characterize mechanical properties of cementitious materials in order to support the development and the validation of material models in WG2.
- GP1d is open for all testing activities regarding mechanical properties of cementitious materials.
- For round robin testing (RRT), emphasis will be put on the practically most important GP1d properties:
  - strength,
  - elastic stiffness,
  - creep.

- To support multiscale models GP1d aims to provide test data referring to different length scales:
  - individual microscopic constituents, including hydration products,
  - cementitious binder (cement paste),
  - intermediate level of mortar, and
  - concrete.

- Thus, GP1d aims to include microscopic test methods (such as nano-indentation and micro-indentation) as well as classical and innovative macroscopic test methods.

- To support thermo-hydro-chemo-mechanical modelling of (porous) concrete, GP1d aims to carry out tests on specimens:
  - with known temperature histories and
  - with well-controlled and uniformly distributed moisture contents.

- Therefore drying protection of specimens will be very important task - specimens will be either sealed against the ambient environment or they will be stored under water.

- GP1d aims to coordinate well-structured testing activities, being aware that mechanical properties of cementitious materials depend on many factors, including: raw materials, composition, curing conditions, maturity (degree of hydration), temperature, moisture content, loading rate, poromechanical boundary conditions (drained or undrained).

Overview of properties

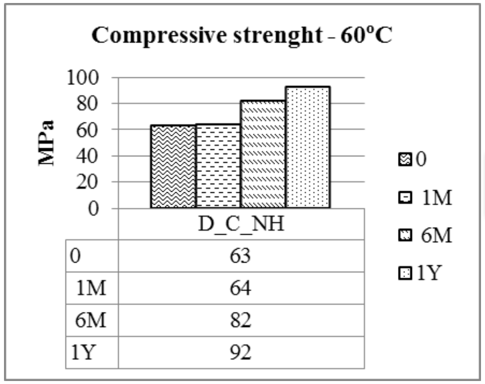
- STRENGTH PROPERTIES quantify the load carrying capacity of a material. The strength of cementitious materials particularly depends on the type of loading which can be uniaxial, biaxial, or triaxial, and tensile and/or compressive.
- Uniaxial compressive strength is the most commonly determined strength property.
  - standardized cube compression tests suffer from uncontrollable shear stresses resulting from friction in the interfaces between load platens and specimen - shear stresses increase the strength of the tested cubes.
  - the „correct“ uniaxial compressive strength of cementitious materials is accessible by testing cylindrical specimens with a diameter-to-length ratio equal to 2 - however, producing specimens with perfectly co-planar loading surfaces is much more challenging for cylinders compared to cubes.
- Tensile strength testing is challenging. Uniaxial tensile strength - typically carried out on dog-bone shaped specimens and the load application has to be controlled with very high precision. Therefore, more simple indirect test methods are frequently used: three-point-bending tests and Brazilian splitting tests.
- Biaxial strength testing requires special experimental devices.
- Triaxial testing typically combines a test machine for uniaxial loading with a triaxial loading cell.

Overview of properties

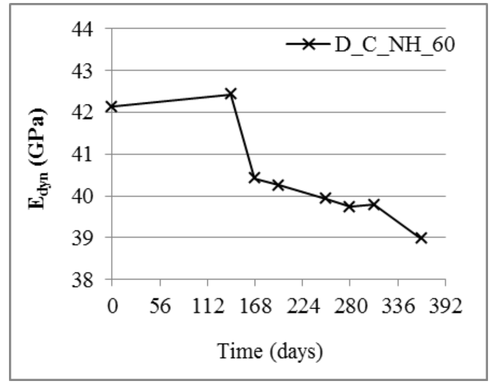
- ELASTIC PROPERTIES govern the relationship between mechanical loading and *spontaneous* deformation. Undamaged cementitious materials are typically considered to be macroscopically *isotropic* media, i.e. identification of *two* independent elastic constants is sufficient to fully characterize their elastic behavior.
- The available test methods are typically subdivided into two groups:
  - quasi-static mechanical test methods and
  - dynamic test methods, including ultrasonics and resonance frequency method.

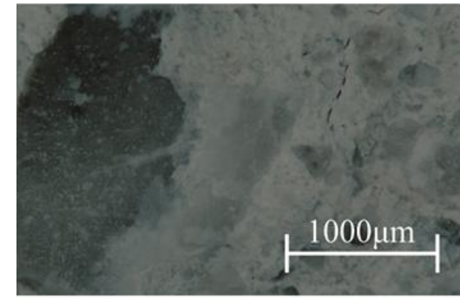
- Uniaxial loading experiments allow to determine Young's modulus and Poisson's ratio.

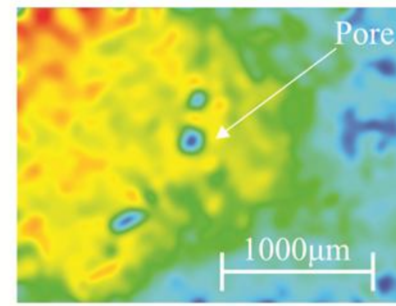
- Dynamic test methods such as ultrasonics are based on the theory of wave propagation in elastic media.

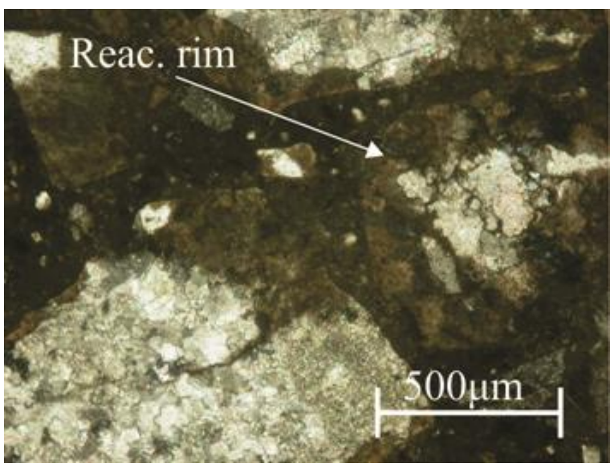


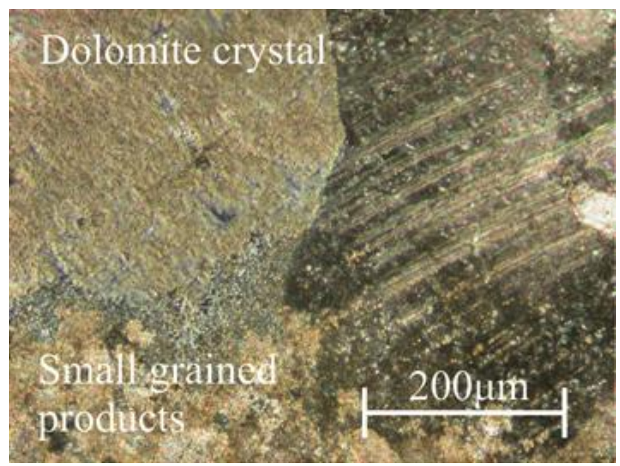
	D_C_NH
0	63
1M	64
6M	82
1Y	92

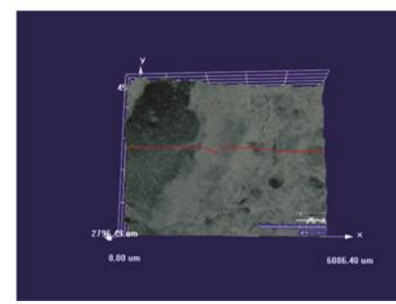












Overview of properties

- CREEP is the process resulting in increasing deformation under sustained loading.
- Creep properties of cementitious materials govern the *time-dependent* relationship between loading and deformation of cementitious materials. They are the basis for long-term serviceability design of structures.
- Creep is very important for the serviceability of:
  - bridges made of reinforced concrete, where deflections increase progressively under the action of the dead load,
  - prestressed structures, because creep results in a progressive loss of prestress,
  - tunnels driven according to the New Austrian Tunneling Method, where relaxation of sprayed concrete allows for effectively reducing the stresses inside tunnel shells.
- While several existing standards still consider creep to be an asymptotically decaying phenomenon, there is clear experimental evidence that creep is a process that *does not come to an end*. Therefore creep testing is very important challenge for scientists concerned with mechanical properties of cementitious materials.

Participating laboratories

- 69 laboratories expressed intention to collaborate in testing in framework of the **GP1d**
- Please give information about advanced test methods for the mechanical properties, available in your laboratory

TU1404 COST ACTION

EMM-ARM
Retrospective and current developments

Miguel Azenha - University of Minho, Portugal
José Granja - University of Minho, Portugal
Cyrille Dunant – EPFL, Switzerland

Universidade do Minho
Escola de Engenharia

isise Institute for Sustainability and Innovation in Structural Engineering

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

WHAT IS EMM-ARM?

EMM-ARM -> Elasticity Modulus Monitoring through Ambient Response Method

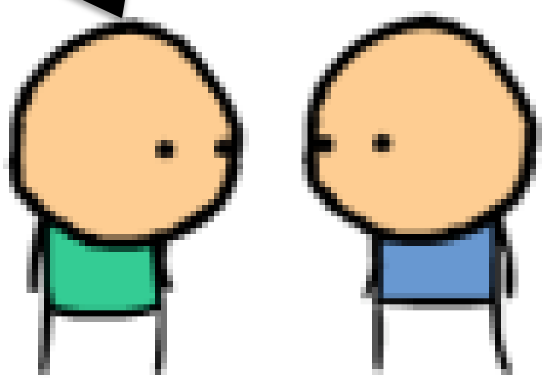
- **Continuous and automatic** monitoring of the E-modulus of concrete since casting.
- Variant to classical resonant frequency testing.
- Under development since 2008.
- Applied to concrete, cement paste, stabilized soil, hydraulic lime, epoxy,…

THE BIRTH OF THE IDEA…

Sparkled by a conversation overheard in the corridor

The permanent dynamic monitoring system of the Infante Bridge is 1 year now. Did you know that we are actually capturing the stiffening of concrete in the identified resonant frequencies?

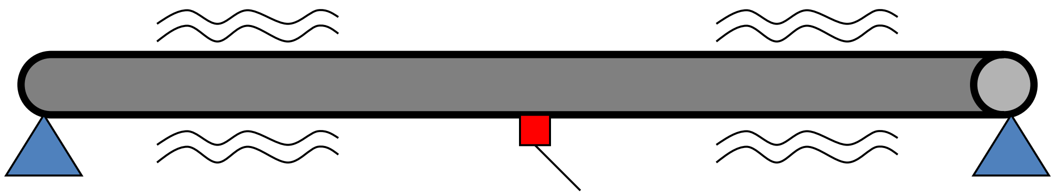
Infante Bridge - Porto



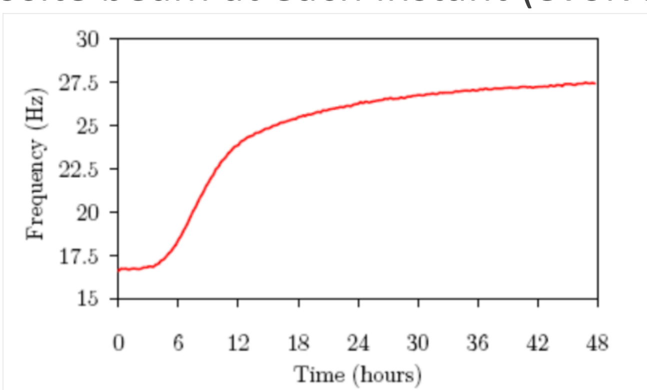
GENERAL PRINCIPLE

Cast a concrete specimen inside a cylindric acrilic tube (mold)

Immediately after casting, place the composite beam simply supported and monitor accelerations due to ambient vibration at mid-span



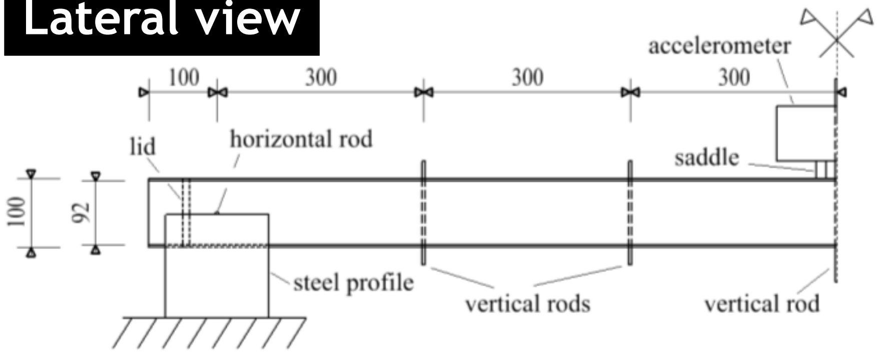
The measured accelerations allow the identification of the 1st resonant frequency of the composite beam at each instant (evolves with hardening)



Possibility of applying the equations of motion for the composite beam and obtain a curve of concrete E-modulus *versus* time

FIRST TEST SETUP - CONCRETE

Lateral view



Top view

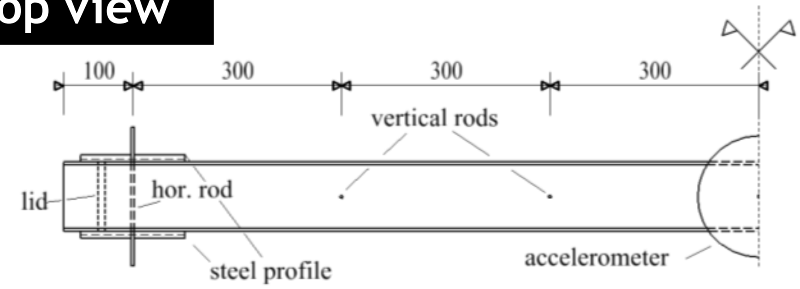
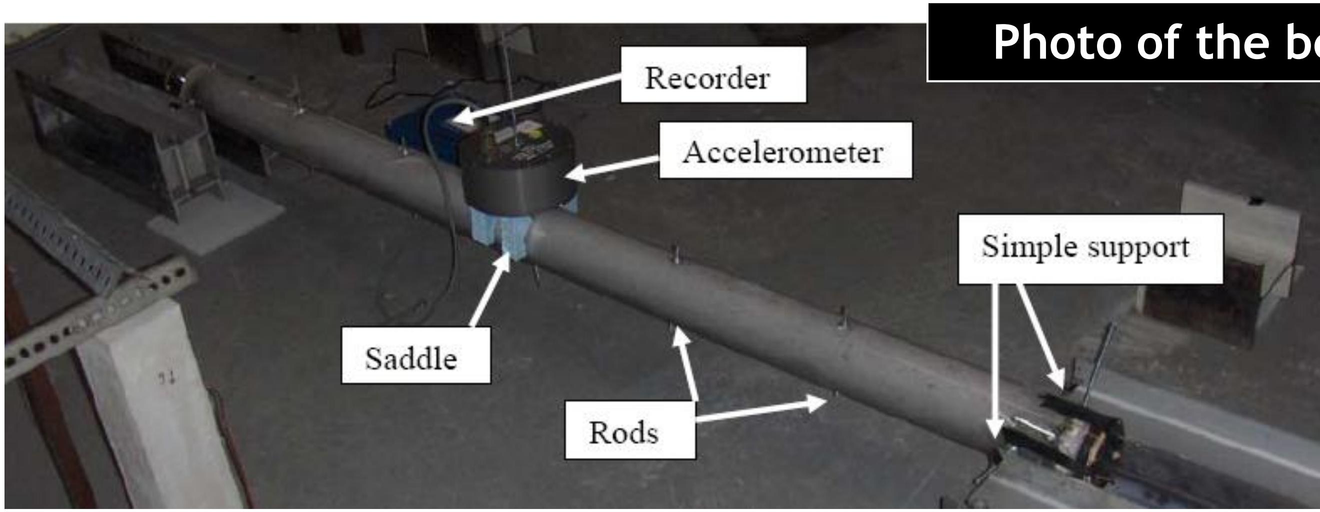
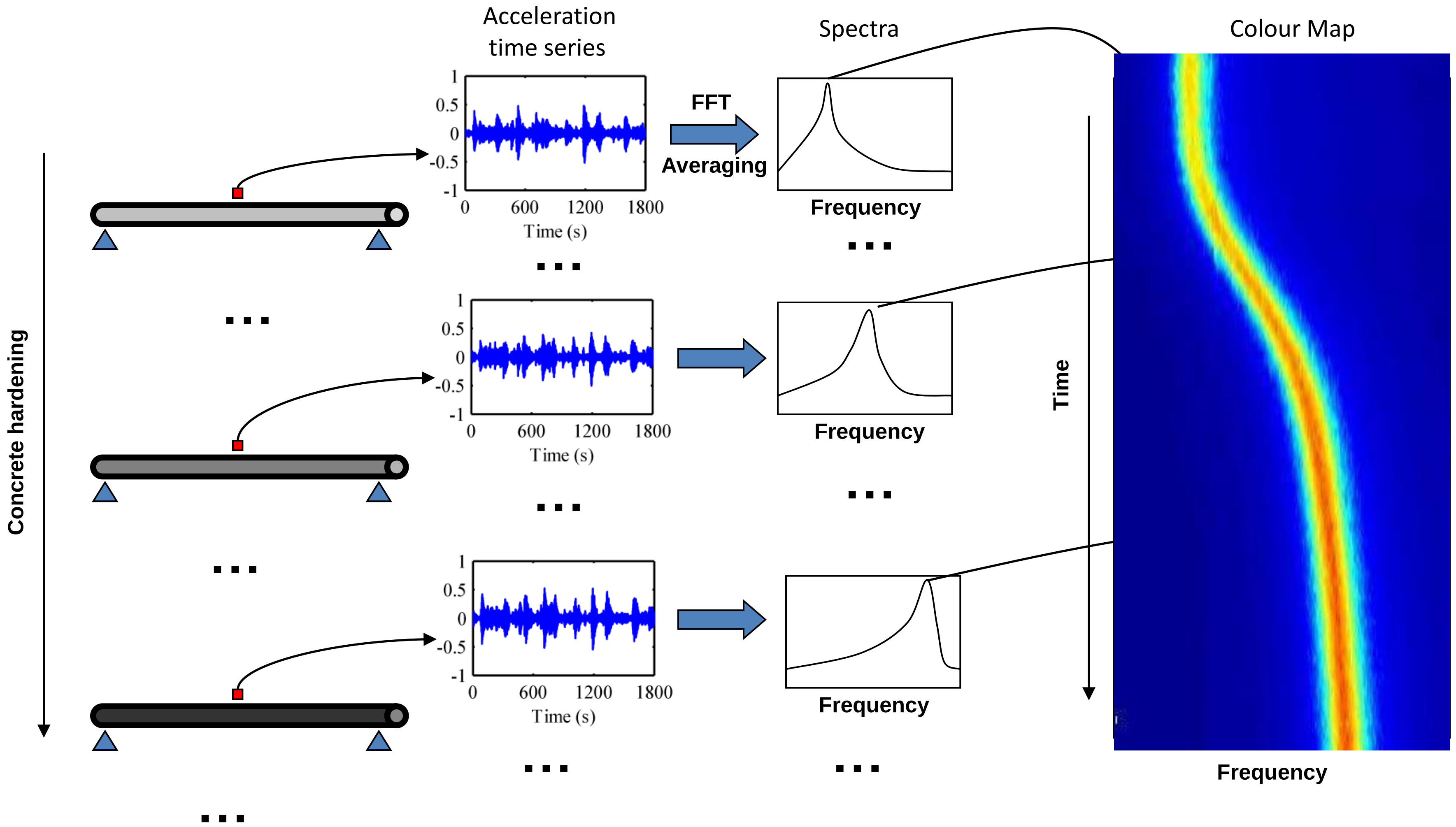


Photo of the beam

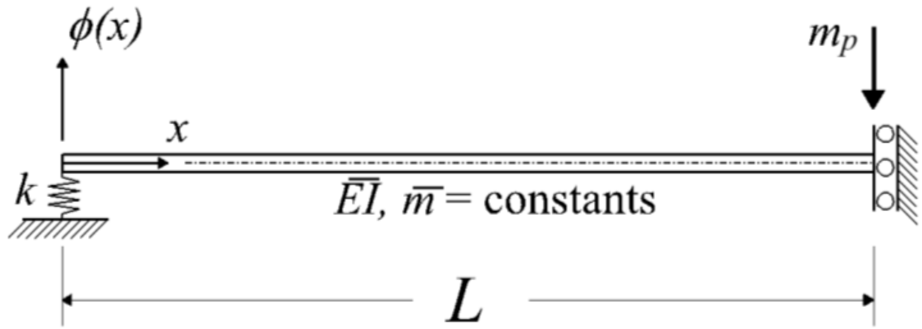


MODAL IDENTIFICATION



EVALUATION OF CONCRETE E-MODULUS

Based on the equations of free motion of a simply supported beam with a concentrated load at mid-span



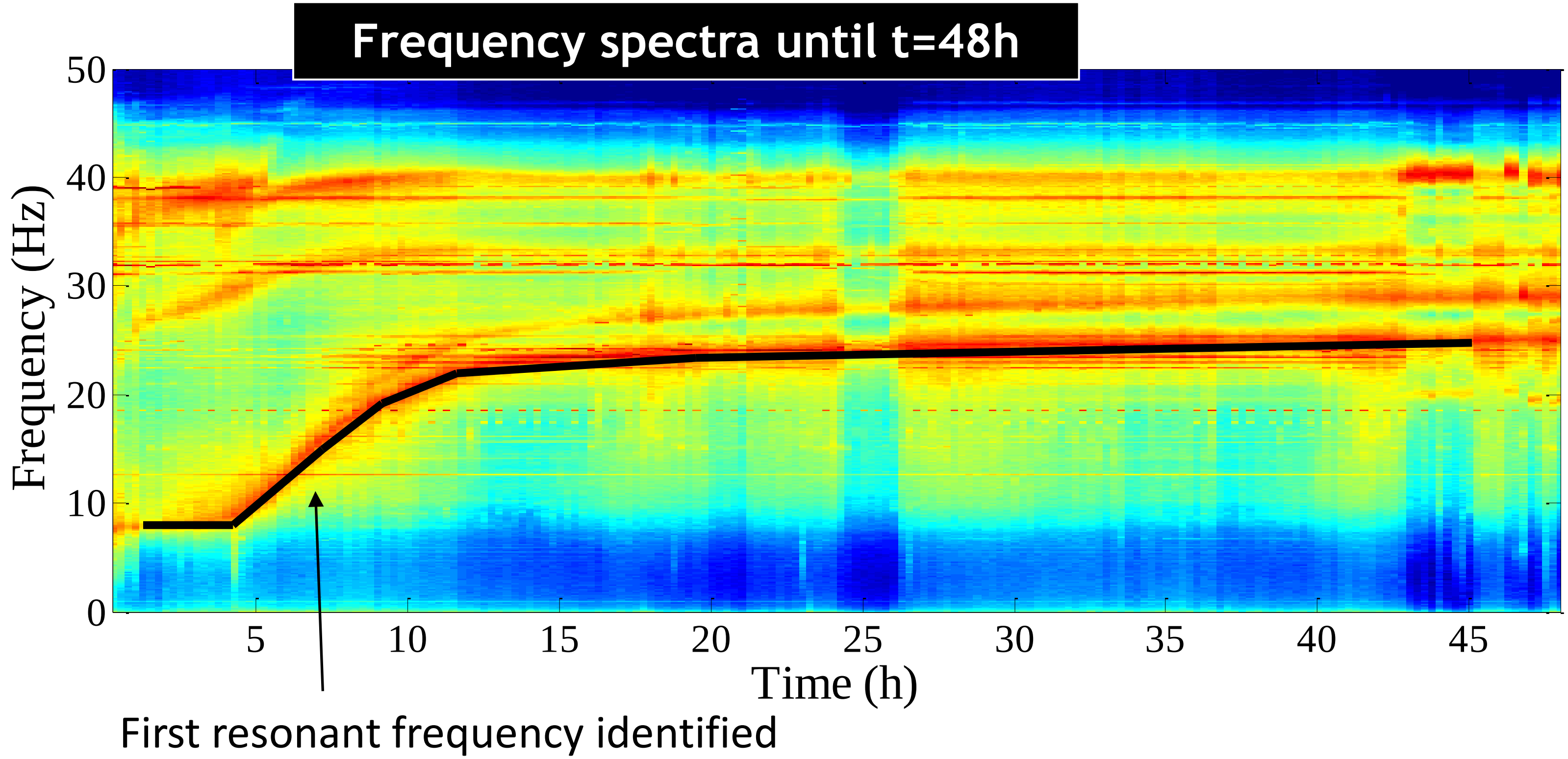
it is possible to relate the 1st resonant frequency of the composite beam *w* with its stiffness $\overline{EI}$ (which is the only unknown in the following equation):

$$-1/(2k)\Big[\overline{EI}\,a^3\sin(aL)^2 w^2 m_p + 2\cosh(aL)k\,w^2 m_p\sin(aL) + \cosh(aL)^2 w^2 m_p\,\overline{EI}\,a^3$$
$$+2(\overline{EI})^2 a^6\sin(aL)\cosh(aL) - \overline{EI}\,a^3\sinh(aL)^2 w^2 m_p, + 2\cos(aL)(\overline{EI})^2 a^6\sinh(aL) -$$
$$4\cos(aL)k\,\overline{EI}\,a^3\cosh(aL) + \cos(aL)^2 w^2 m_p\,\overline{EI}\,a^3 + 2\cos(aL)w^2 m_p\,\overline{EI}\,a^3\cosh(aL) -$$
$$2\cos(aL)k\,w^2 m_p\sinh(aL)\Big] = 0 \quad with \quad a = \sqrt[4]{\frac{w^2\overline{m}}{\overline{EI}}}$$

$$\overline{EI} = E_a I_a + E_c I_c$$

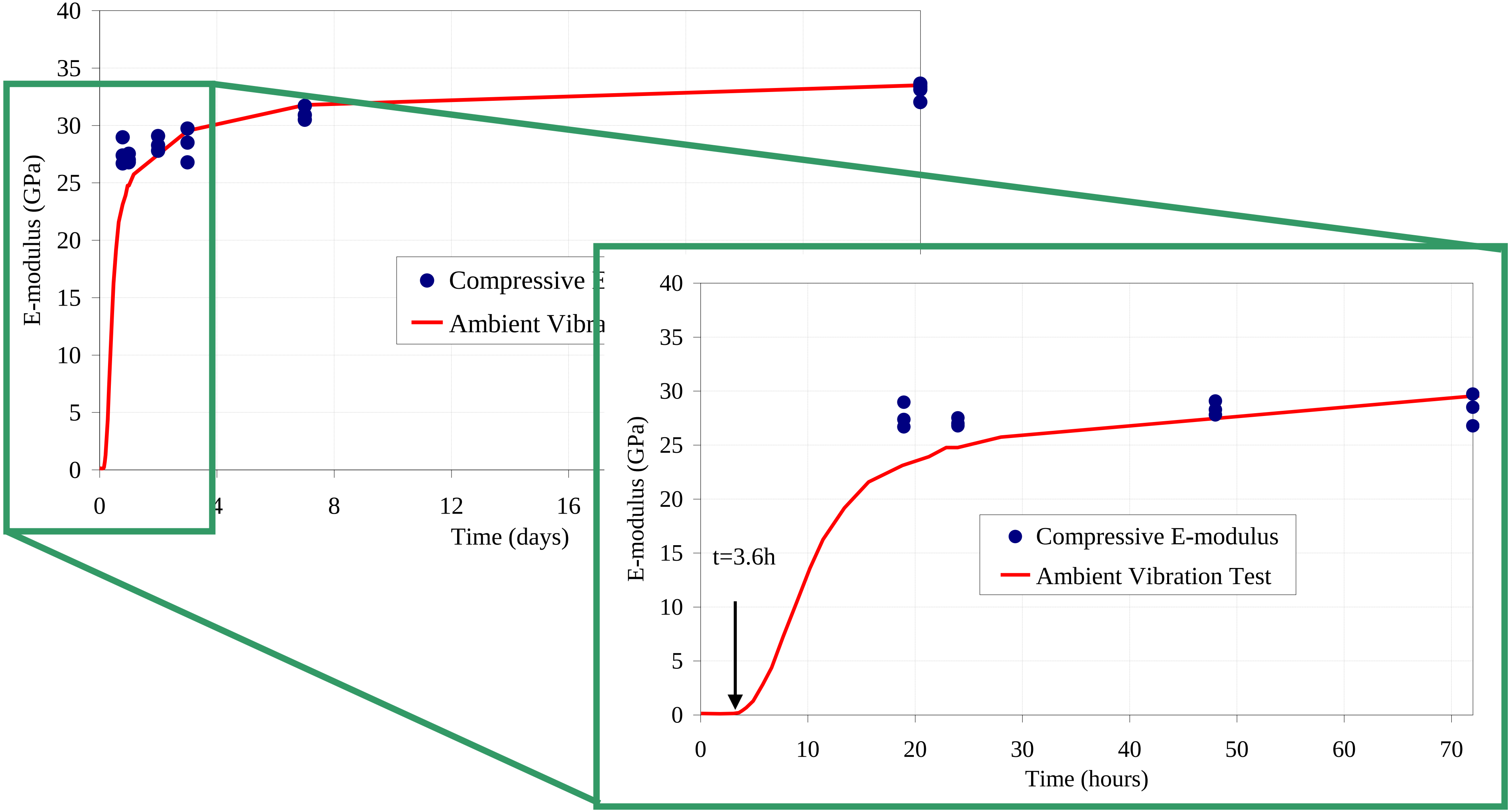
Concrete E-modulus is obtained.

TYPICAL RESULTS – FIRST APPLICATION (I)



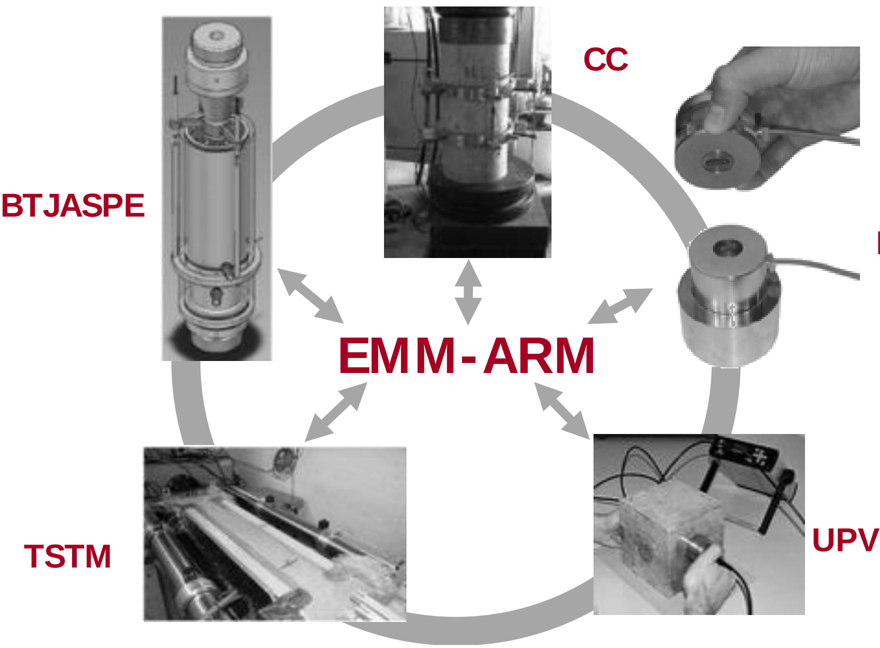
M. Azenha, F. Magalhães, R. Faria, A.Cunha (2010) "Measurement of concrete E-modulus evolution since casting: A novel method based on ambient vibration". Cement & Concrete Research 40:1096-1105

TYPICAL RESULTS – FIRST APPLICATION (II)

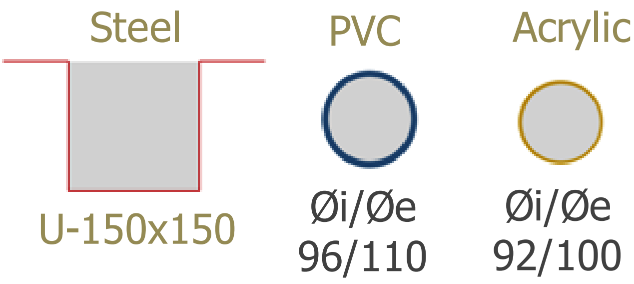


ADDITIONAL ASPECTS

Validation

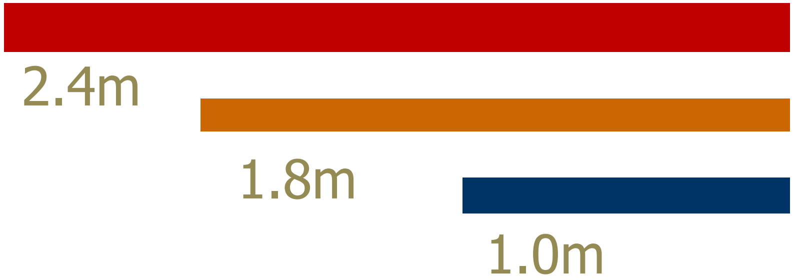


Alternative mould geometry/material



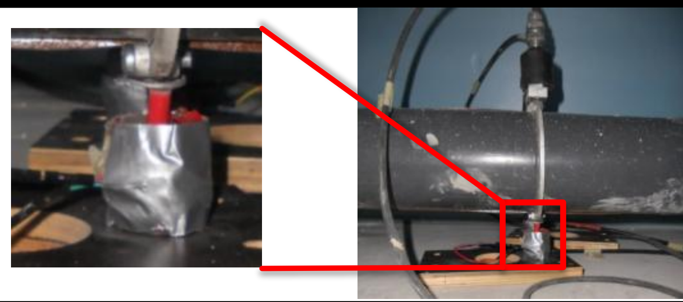
Changing support conditions

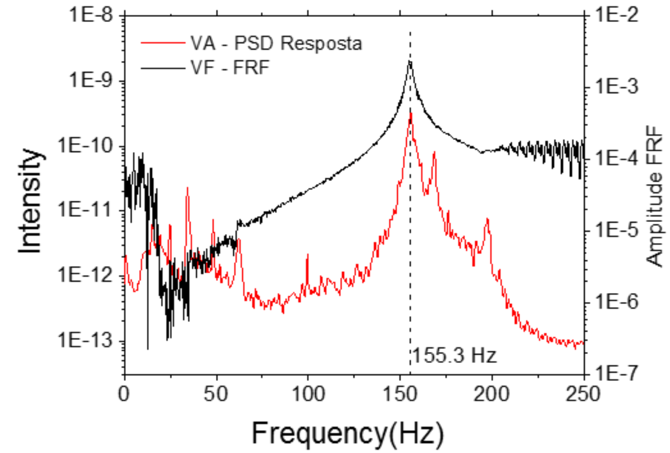
Evaluating alternative spans



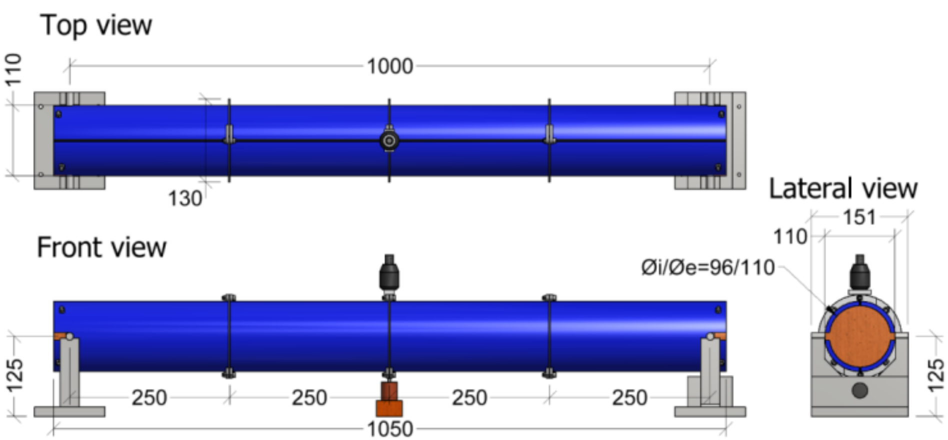
ADDITIONAL ASPECTS

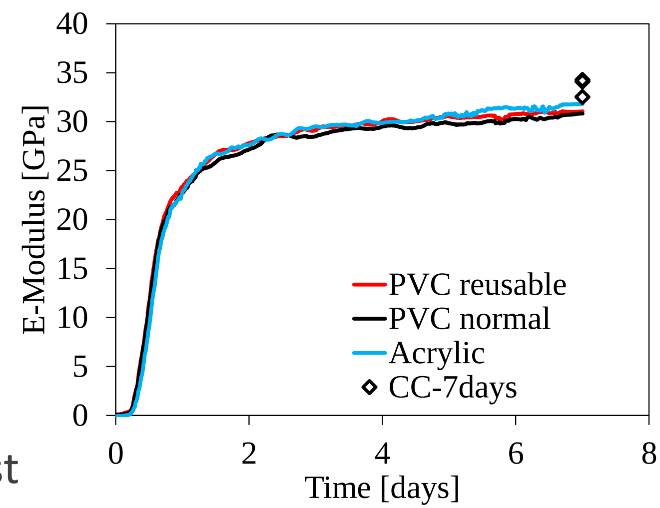
Introducing a magnetic coil for improved modal id.





The reusable mould -> accumulated set of improvements

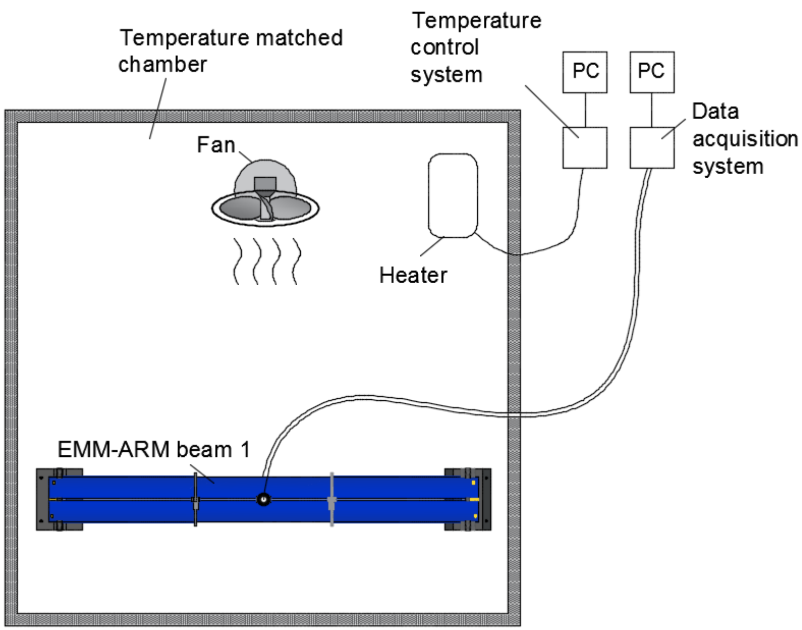




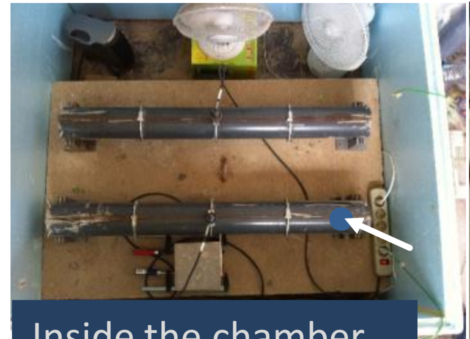
Smaller, easier, faster, cheaper, more sustainable, more robust (modal id and less prone to support problems)

IN-SITU APPLICATION

Segmental Prestressed RC Bridge

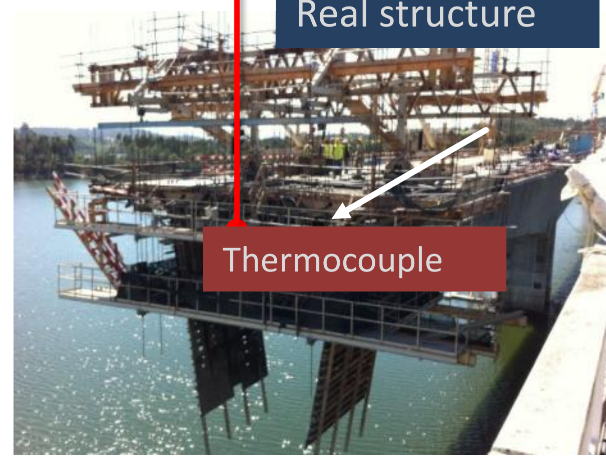


Temperature matched curing system



Inside the chamber

Chamber

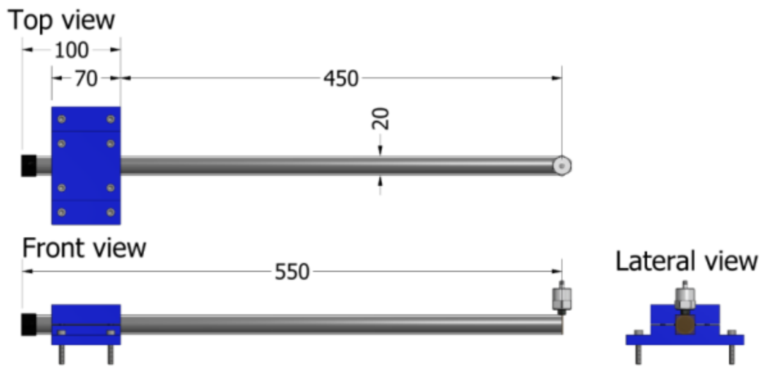


Real structure

Thermocouple

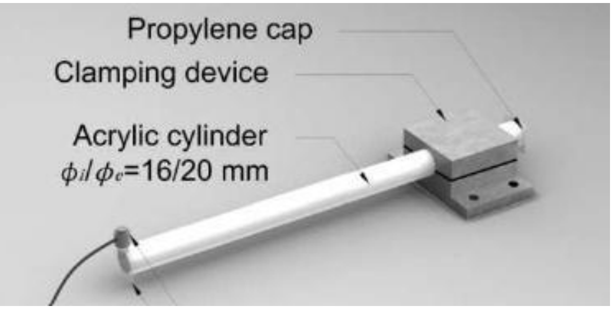
EMM-ARM ON OTHER MATERIALS

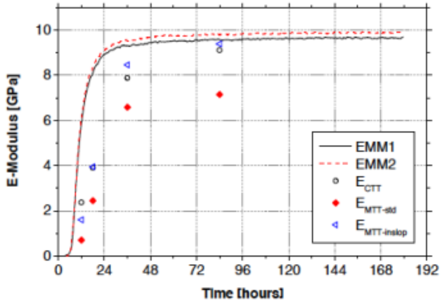
Cement paste



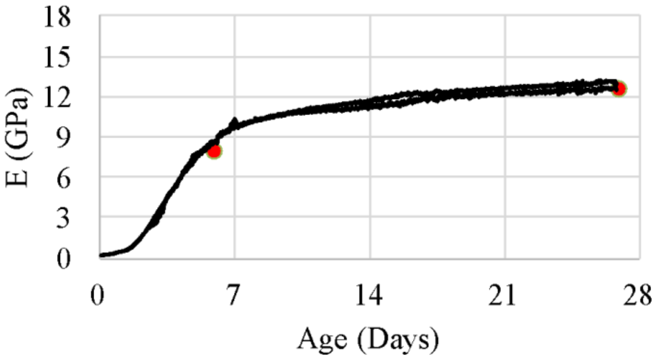
Stabilized soils

Epoxy resins





Hydraulic limes



STSM -> Collaboration UMinho / EPFL

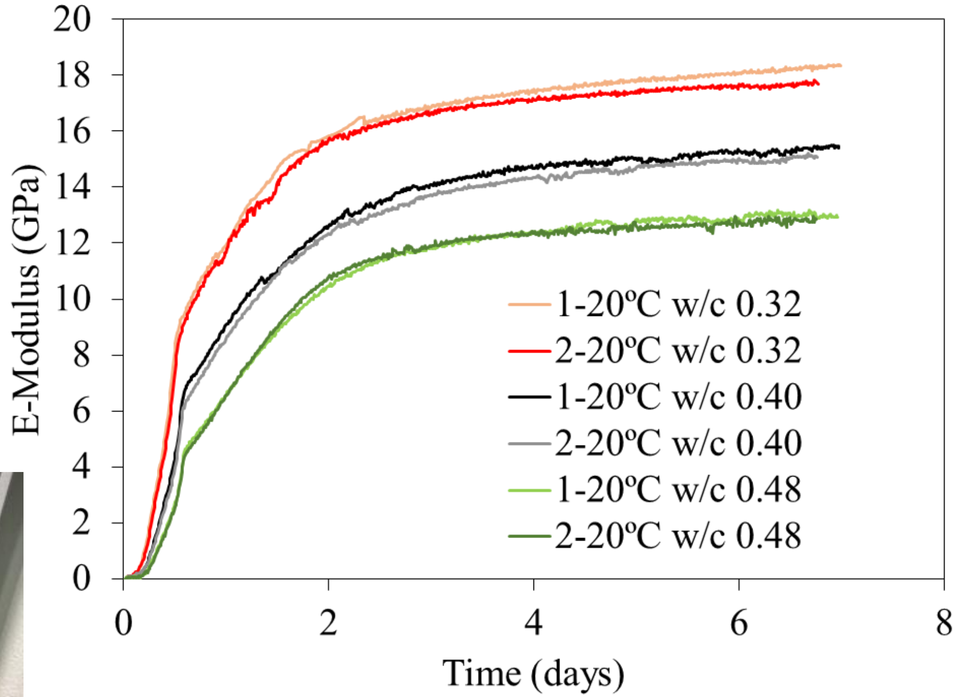
- February 2015 – April 2015
- STSM Candidate: José Granja
- Hosted by: EPFL – Cyrille Dunant
- Title: “Characterization of cement-based materials: experimental analysis and micro-mechanics modeling”

- Main objectives:
  - Implementation of EMM-ARM at LMC
  - Testing several cement pastes with EMM-ARM
  - Compare the EMM-ARM results with the results from other methods/characteristics
  - Simulate the stiffness of a cement paste with µic/AMIE and compare the results with EMM-ARM

STSM -> Collaboration UMinho / EPFL

Cement paste with white cement:

- w/c 0.32
- w/c 0.40
- w/c 0.48

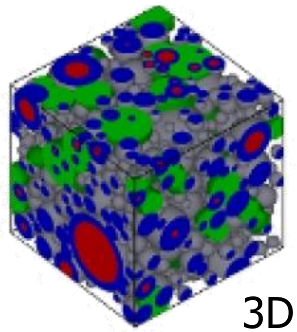


Simulation of cement pastes stiffness

μic

Cement Paste:

- Chemical composition
- w/c ratio
- PSD of the particles
- Reactions



3D Model

EMM-ARM

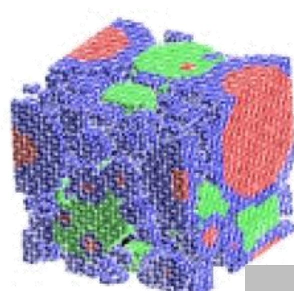
AMIE

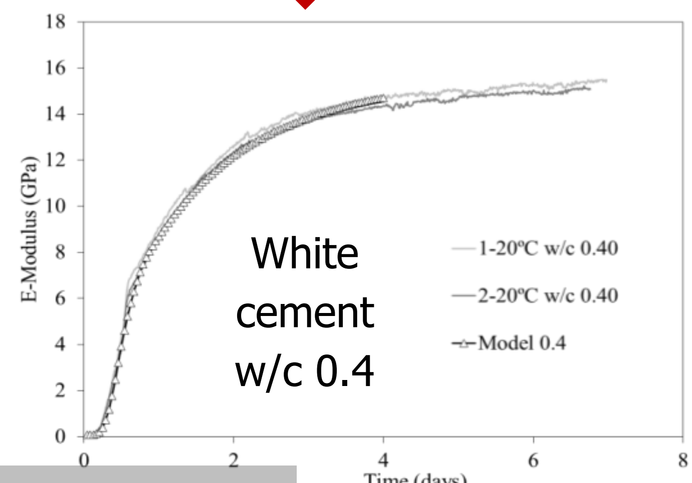
Meshing

Hydrated and unhydrated phases:

- Mechanical properties

C-S-H??





Back analysis to get the bulk properties of the C-S-H + pores

ACNOWLEDGEMENTS

- FCT PhD grant SFRH/BD/80682/2011.
- FCT research project VisCoDyn EXPL/ECM-EST/1323/2013.
- COST Action TU1404 (STSM)

POPH
QUALIFICAR É CRESCER.

QREN
QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
PORTUGAL 2007.2013

GOVERNO DA REPÚBLICA PORTUGUESA

UNIÃO EUROPEIA
Fundo Social Europeu

EMM-ARM / UMinho are open for collaborations and STSM's!

TU 1404 COST ACTION

Inter-laboratory comparison on the measurement of concrete E-modulus at very early ages through several techniques

Brice Delsaute*, **Jérôme Carette, Cédric Dumoulin, Grigoris Karaiskos, Arnaud Deraemaeker ,Stéphanie Staquet** – Université Libre de Bruxelles, Belgium

Claude Boulay – IFSTTAR, France

Miguel Azenha, José Granja – University of Minho, Portugal

ULB UNIVERSITÉ LIBRE DE BRUXELLES

BATir

IFSTTAR Materials & Structures Department

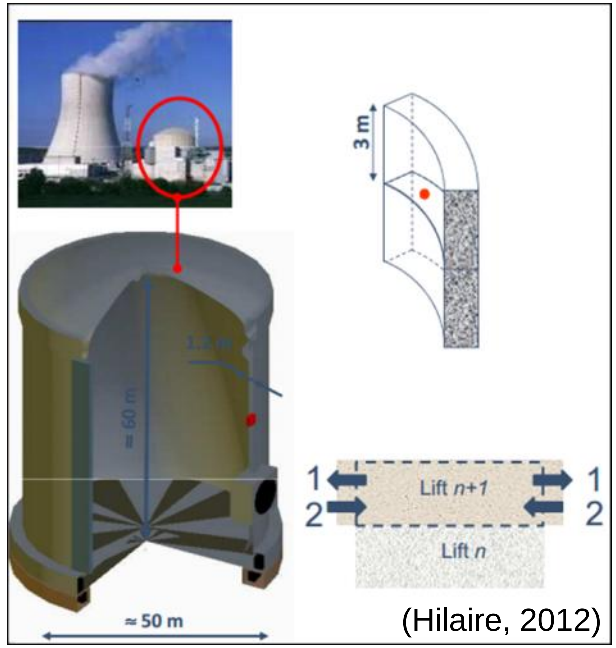
isise Institute for Sustainability and Innovation in Structural Engineering

Universidade do Minho

Restrained shrinkage

(Darquennes, 2012)

Water treatment plan



(Hilaire, 2012)

Nuclear powerplant

Pier of a bridge

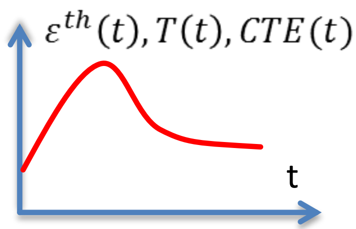
But also:
dam, prestressed structure, gas container…

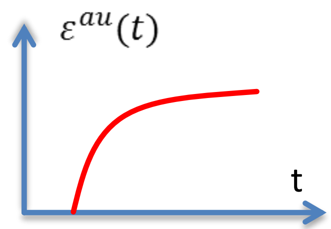
The performance of structures **built in several phases**, **massive** or **prestressed** depends on early age concrete behavior.

➡ **Restrained deformation** ➡ **Risk of cracking**

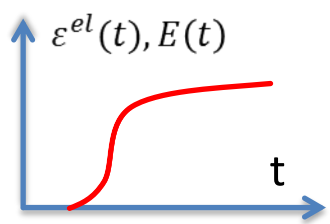
Restrained shrinkage

Free deformation

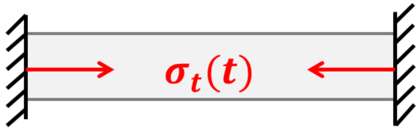


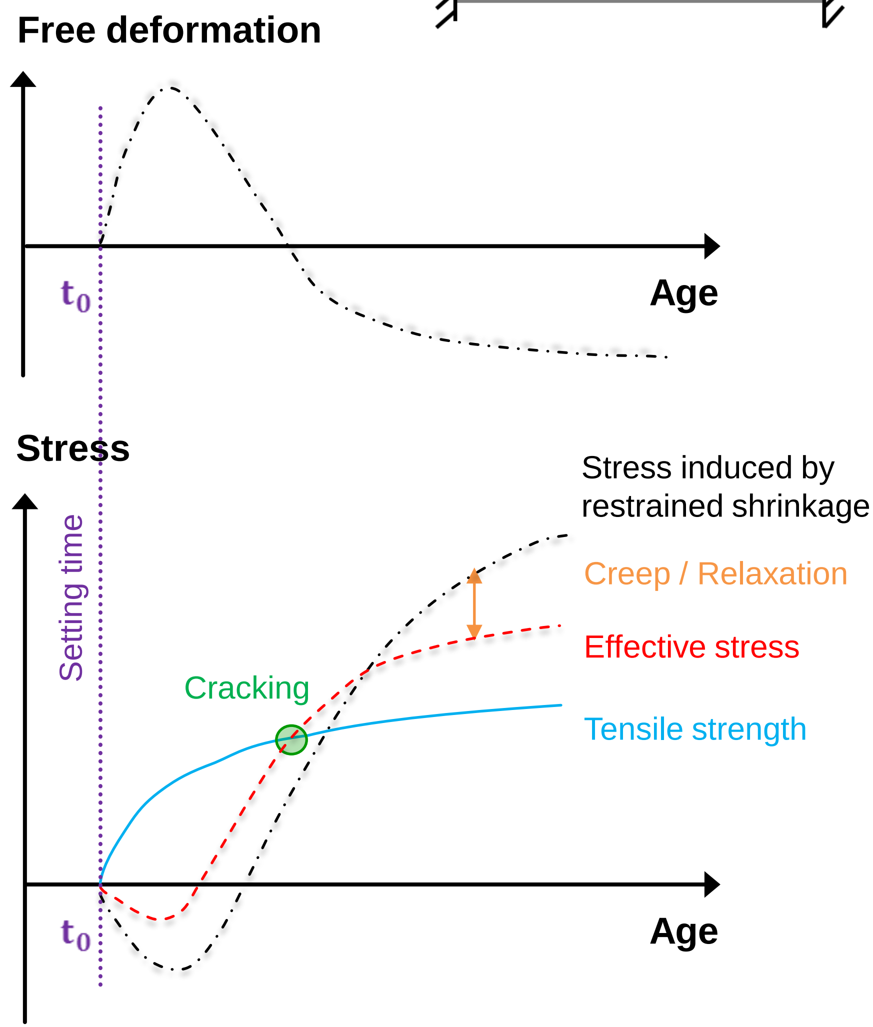


Visco-elastic behavior



Creep / Relaxation





What is the evolution at early age?

AND HOW TO OBTAIN IT?

PLAN

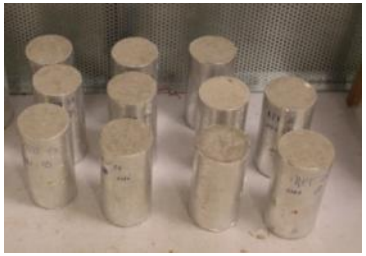
- Concrete composition
- Experimental setup
- Results & comments
- Conclusion

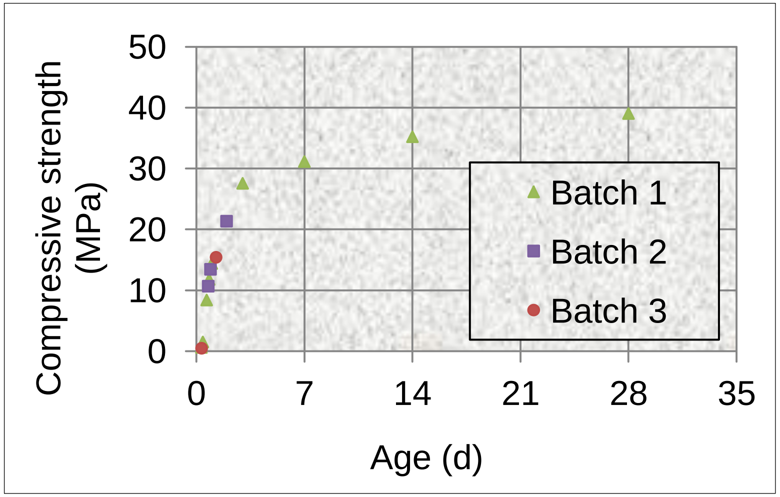
Concrete composition

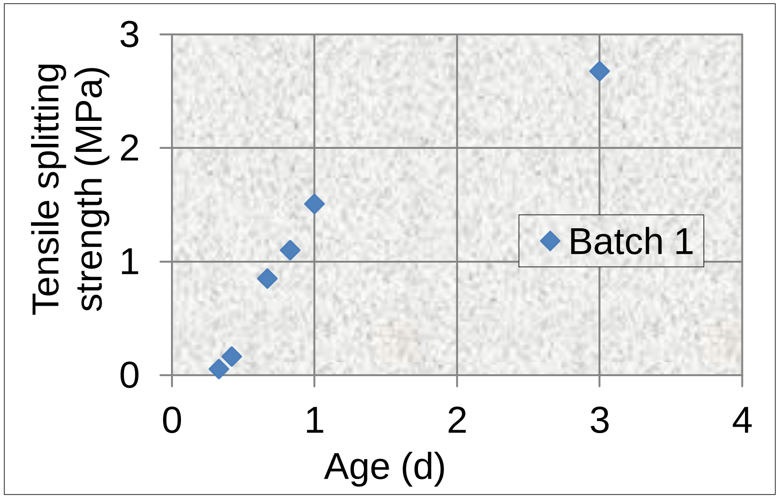
Components	Mass (kg /m³)
CEM I 52.5 N PMES CP2	340
Sand (Bernières 0/4)	739
Gravel (Bernières 8/22)	1072
Total water	184

W/C = 0.54

Ordinary concrete used at IFSTTAR (France)



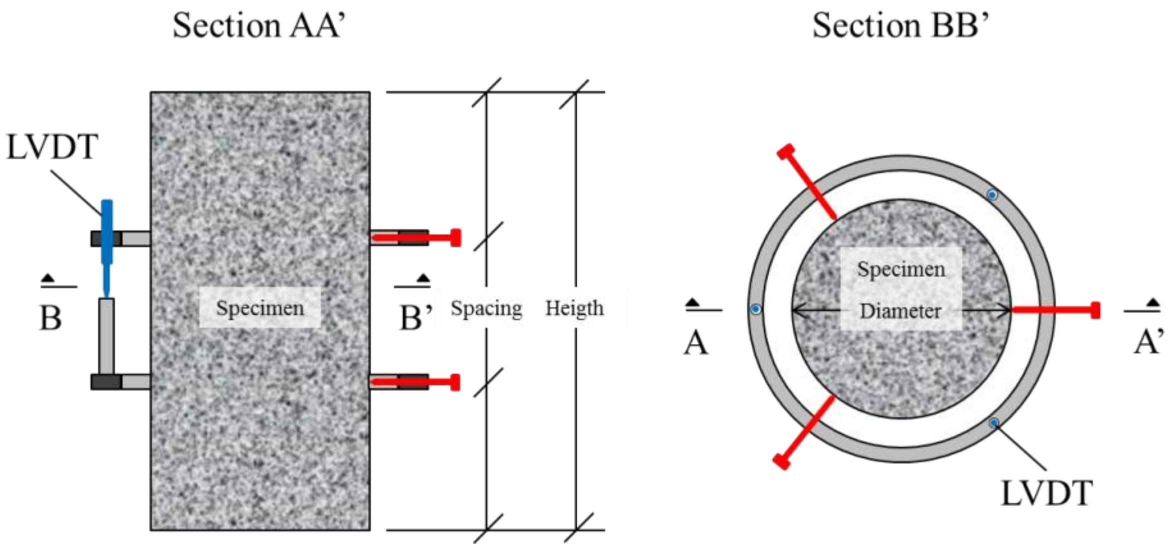




Boulay, et al.:"How to monitor the modulus of elasticity of concrete, automatically since the earliest age", Materials and Structure, January 2014, Vol 47, pp141-155.

Experimental setup

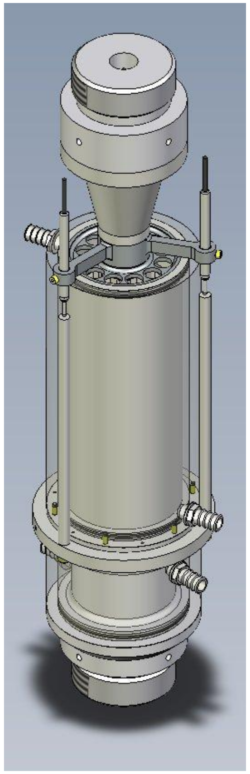
References tests



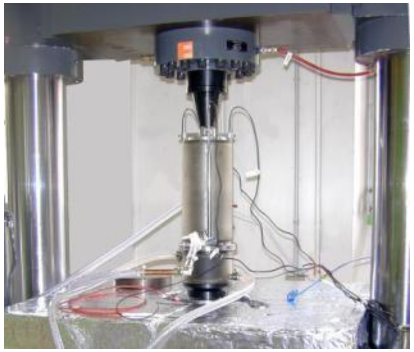
	Extensometer	Sample		Protocol of loading	
	Spacing (cm)	Heigth (cm)	Diameter (cm)	Loading (MPa)	Stress rate (MPa/s)
IFSTTAR	12	22	11	5% to 30% of fc	0.5
ULB	12	22	11	20 % of fc	0.2 to 0.55
U Minho	10	30	15	0.8 to 33% of fc	0.3

Experimental setup

BTJASPE



- Cylinder (Ø 10 cm x 20 cm)
- Left in the stainless steel form
- Temperature imposed
- Cyclic loading (every 15 to 60 min, 5 µstrain/s, 250 µstrain)
- Start : after casting
- 3 external LVDT + thermocouple



Boulay, et al.:"How to monitor the modulus of elasticity of concrete, automatically since the earliest age", Materials and Structure, January 2014, Vol 47, pp141-155.

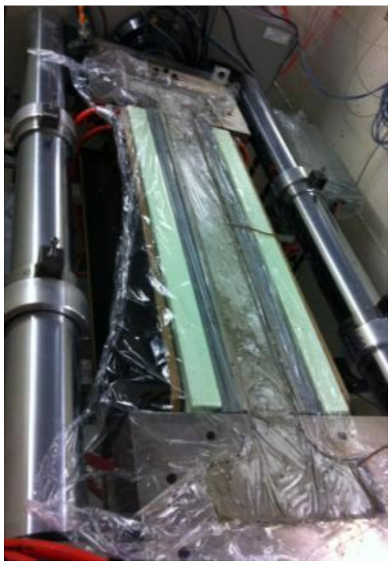
VALIDATION TESTS

- Cylinder (Ø 11 cm x 22 cm)
- Remove from the form after setting
- Capping: sulphur mortar
- Cyclic loading (every 15 to 60 min, 5 µstrain/s, 250 µstrain)
- Start : 2h after setting
- 3 external LVDT + thermocouple

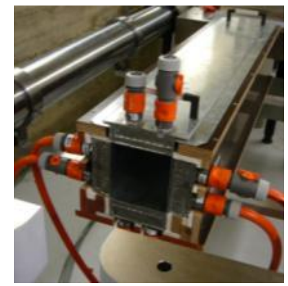
Experimental setup

TSTM (Temperature Stress Testing Machine)

Moving head

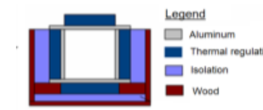


Fixed head



Measurement of displacement

Temperature control and thermal insulation



- Dog-bone shape (10 cm x 10 cm in the span)
- Left in the form
- Temperature imposed
- Cyclic loading (every 30 min, 10 sec, 20 % of f_c)
- Start : after setting
- 2 without contact sensors + thermocouples

S. Staquet, B. Delsaute, A. Darquennes, B. Espion, Design of a revisited TSTM system for testing concrete since setting time under free and restraint conditions, Concrack3, 15-16 March 2012, Paris, France, pp.99-110.

Experimental setup

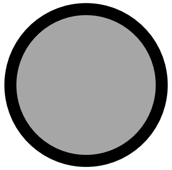
EMM-ARM (Elasticity Modulus Measurement through Ambient response Method)

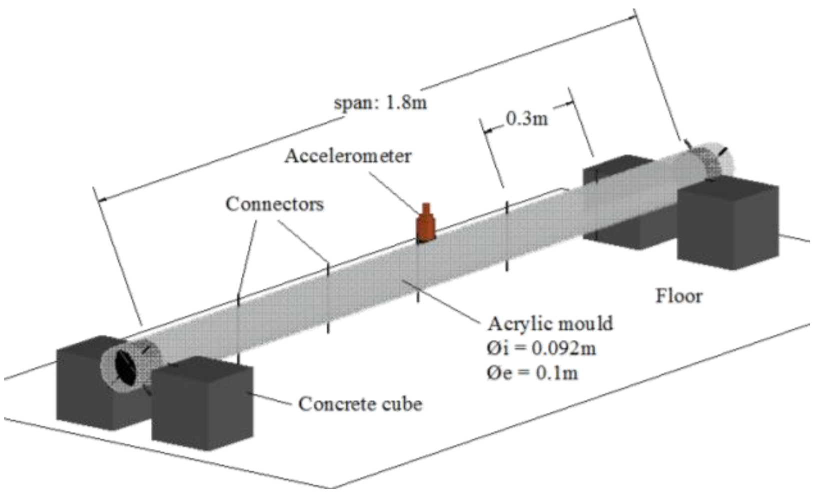
- Cylinder (Ø 9.2 cm x 180 cm)
- Start : after casting
- Based on the frequency of the beam it is possible to estimate the stiffness of the composite cross-section
- Mould and sample stiffness are separated
- E-modulus of concrete depends on frequency evolution.

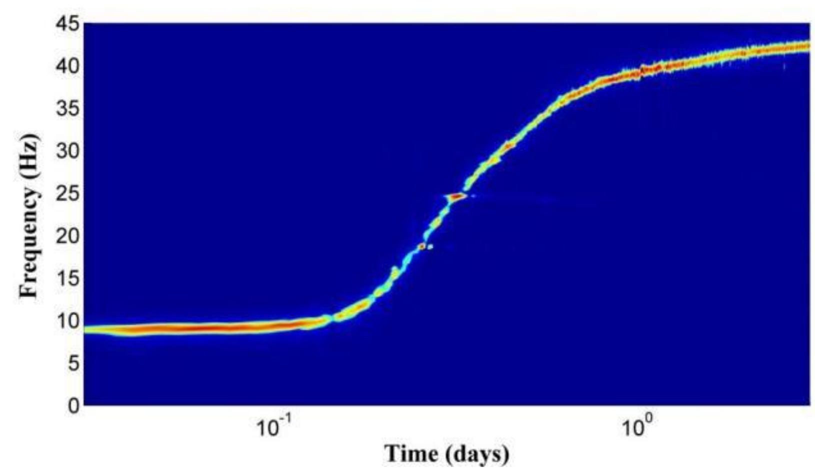
Cross-section

Ea=3.3GPa

Ec=?







Azenha M, Magalhães F, Faria R, Cunha Á., Measurement of concrete E-modulus evolution since casting: A novel method based on ambient vibration, Cement and Concrete Research. 2010; 40(7):1096-105.

Experimental setup

Ultrasonic measurements : external transducers

$$E_{dyn} = V_p^2 \rho \frac{(1+\upsilon_{dyn})(1-2\upsilon_{dyn})}{1-\upsilon_{dyn}}$$

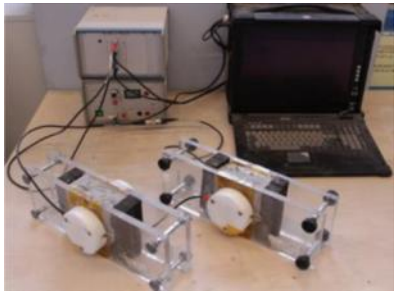
BTPULS at IFSTTAR (only p-waves)

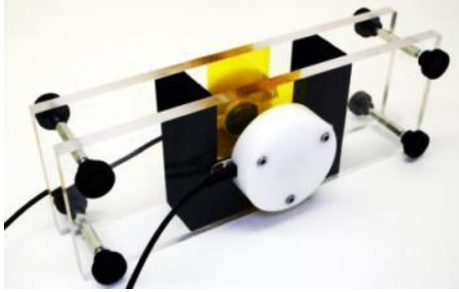
$$\nu_{dyn} = 0.3$$

Cannard G., Orcel G., Prost J., Le suivi de la prise des ciments par ultrasons, Bulletin de liaison des laboratoires des Ponts et Chaussées, n° 168, juillet août 1990, pp 89–95.

Freshcon at ULB (p- and s-waves)

$$\nu_{dyn} = \frac{1-2\left(\frac{V_s^2}{V_p^2}\right)}{2-2\left(\frac{V_s^2}{V_p^2}\right)}$$





Boulay, C., Crespini, M., Carette, J., Staquet, S., Elastic properties of concrete at early age: monitoring of the E-modulus and the Poisson's ratio with cyclic loadings and ultrasonic measurements, Structural Faults & Repair, Edinburgh, 2012.

Experimental setup

Ultrasonic measurements : internal transducers

$$E_{dyn} = V_p^2 \rho \frac{(1+\upsilon_{dyn})(1-2\upsilon_{dyn})}{1-\upsilon_{dyn}}$$

Smart Aggregates (SMAG)

$$\nu_{dyn} = 0.3$$

a) Piezoelectric patch

b) With waterproof coating

c) With conductive paint

d) Smart Aggregate

Piezoelectric ceramics are embedded in a resin coating and a mortar.

A pair of SMAG has been embedded in a prismatic sample (42x12x10 cm) at a distance of 5.6 cm from each other.

C. Dumoulin, G. Karaiskos, J. Carette, S. Staquet and A. Deraemaeker, Monitoring of the ultrasonic P-wave velocity in early-age concrete with embedded piezoelectric transducers, Smart Materials and Structures., 2012, Tanabe et al. (eds), Sept. 30th – Oct. 2nd, Ise-Shima, Japan, pp 321-327.

Experimental setup

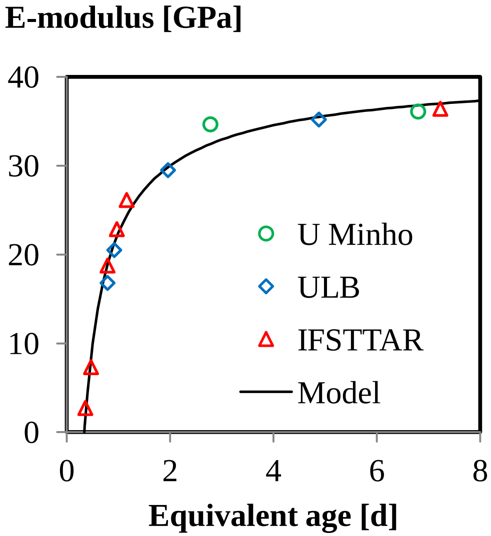
Synthesis of all devices

Device	Loading control (corresponding strain or stress rate)	
Classical tests	0.2 - 0.55 MPa/s	Low frequency
BTJASPE	5.10^{-6} /s (0.001 to 0.2 MPa/s)	
TSTM	10 s from 0 to 0.2 fcm (0.002 to 0.5 MPa/s)	
EMM-ARM	9-45 Hz (0.1 to 1 10^{-6}/s*)	
BTPULS	10-100 kHz	High frequency
FreshCon	10-100 kHz	
Smart aggregates	10-100 kHz	

Results & Comments

Low frequency testing

References Tests

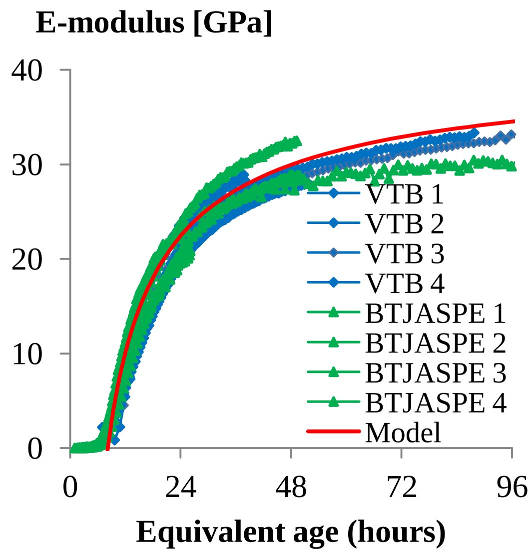


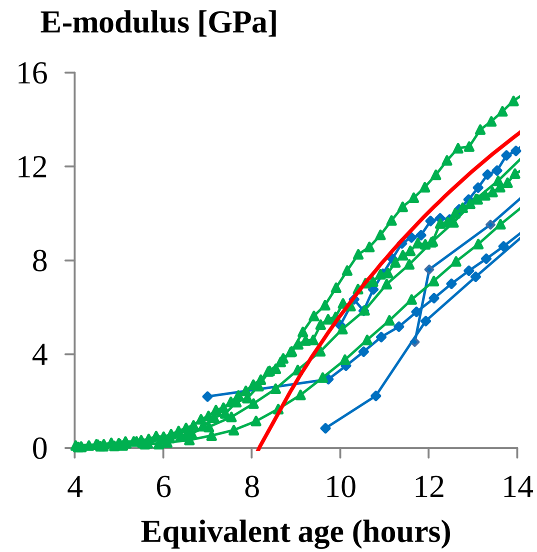
Model

$$E(t) = \frac{a}{t^b} + E_\infty$$

$a = -19.13$
$b = 0.72$
$E_\infty = 41.57$

BTJASPE and Validation Tests



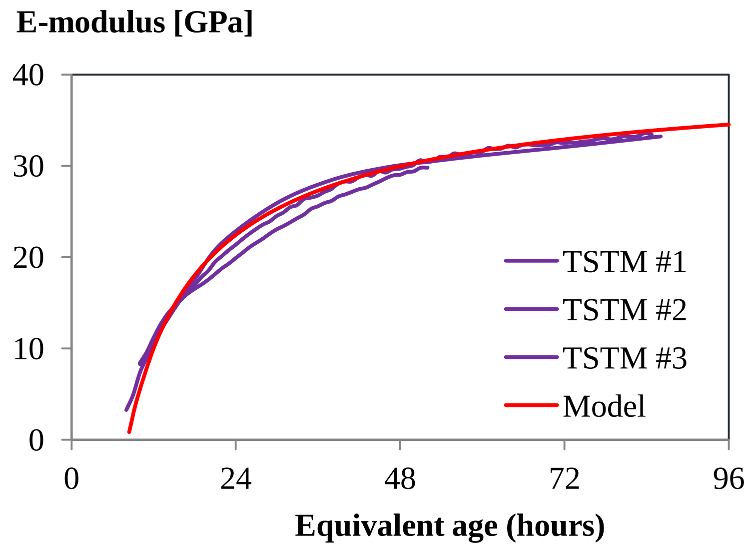


- Results of BTJASPE and Validation Tests are very close
- However scattering occurs during the first hours after setting

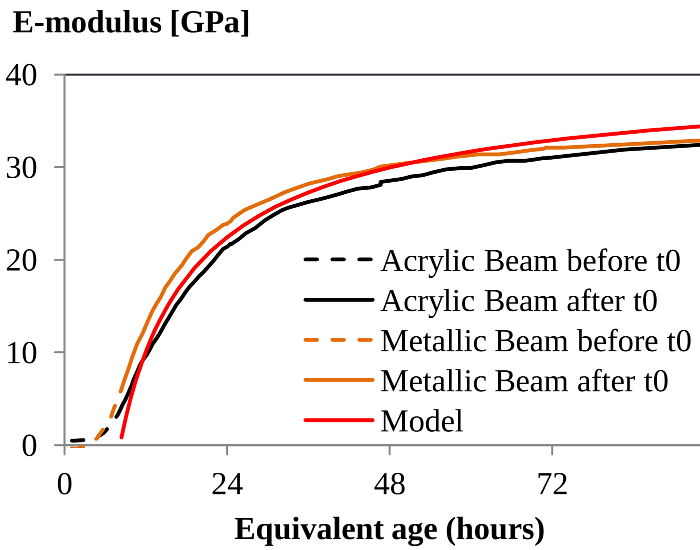
Results & Comments

Low frequency testing

TSTM

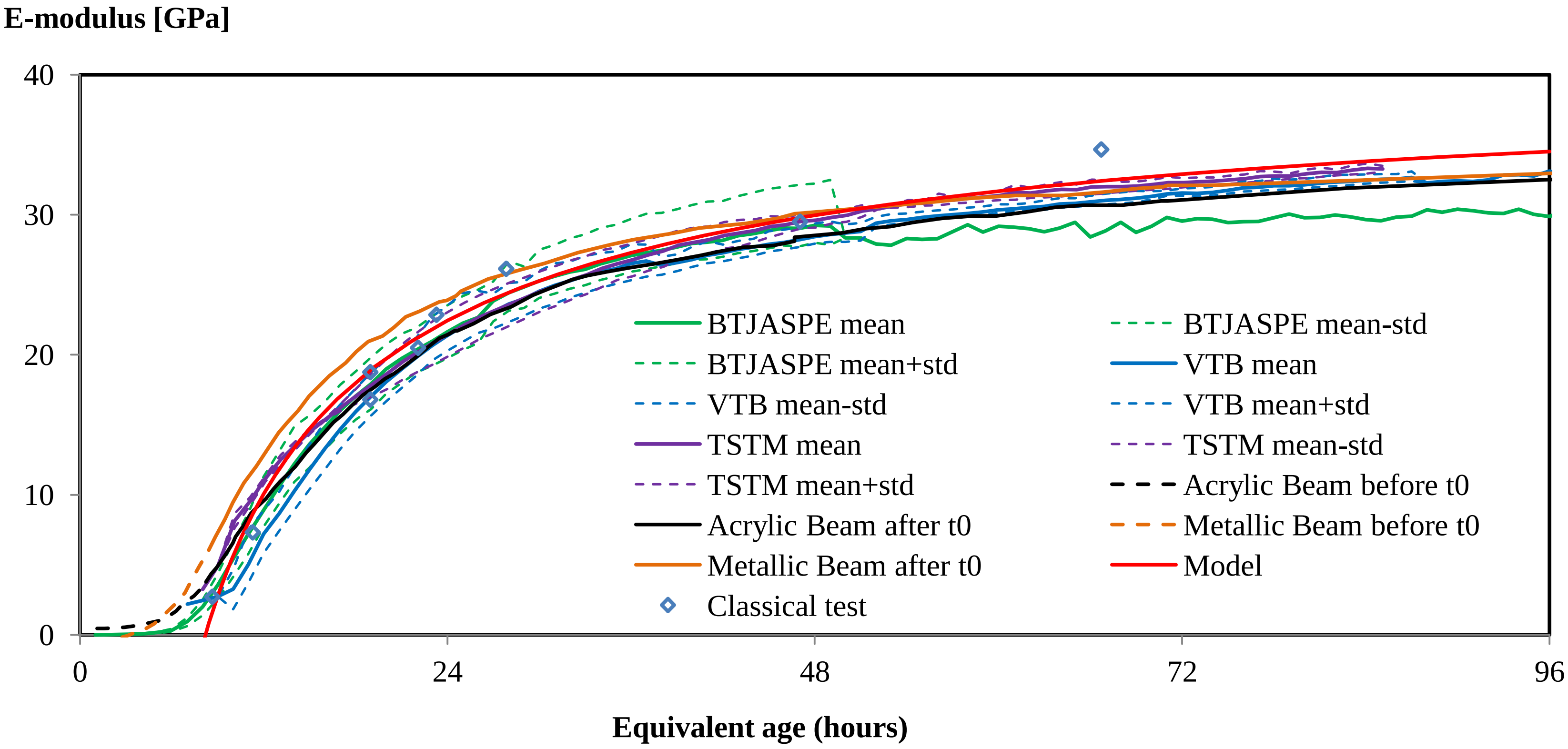


EMM-ARM



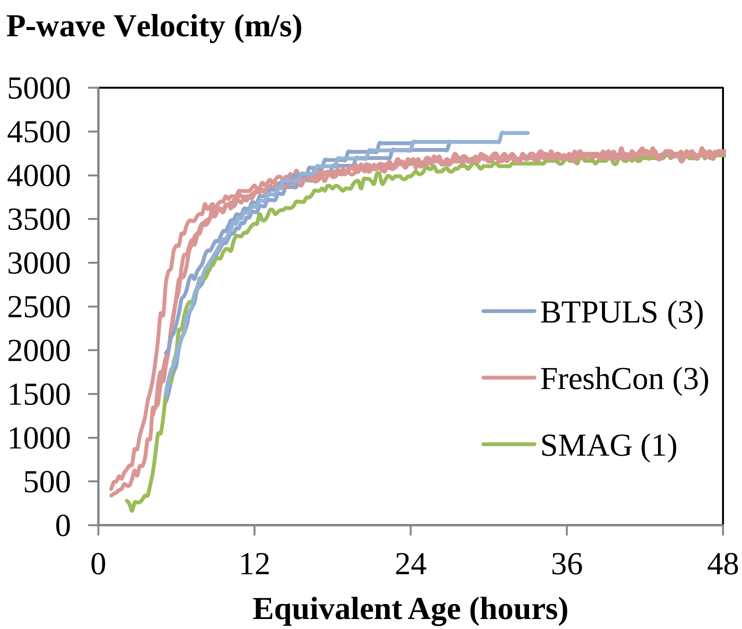
Results & Comments

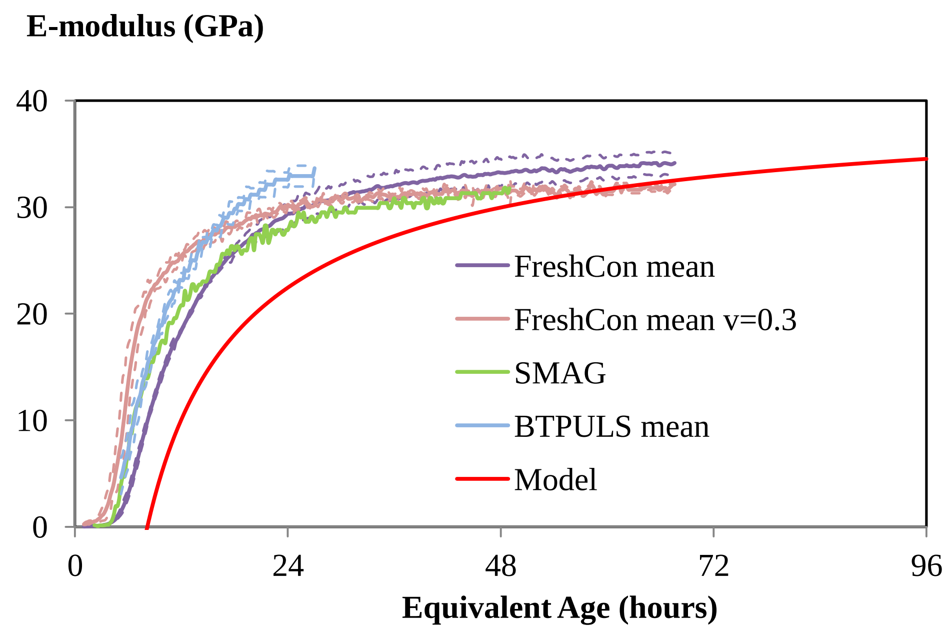
Low frequency testing



Results & Comments

High frequency testing





- High increase of the p-wave velocity during the setting
- Fast stabilisation of the p-wave velocity

- Considering s-wave
  - Decrease the E-modulus during first hours after setting
  - Increase the E-modulus for higher ages.

CONCLUSION

- Inter-laboratories comparison of the stiffness monitoring of a concrete at very early age . The same concrete mix has been used with 7 different devices.
- Two set of methods appear: low frequency testing and high frequency testing
- BTJASPE, TSTM and EMM-ARM methods are quite coherent with each others and coherent with a more classical testing approach
- This relative coherence is reached despite:
  - different mixing procedures on this ordinary concrete, knowing that mixing procedures have a clear influence on mechanical properties [Dills et al., 2012].
  - different loading protocols which do not show clearly an effect of the loading rate on E-modulus over the range covered by these tests (static to 45 Hz) neither an effect of the loading amplitude.
- Nevertheless, improvements are still needed concerning, mainly, the loading protocols to compare low frequency testing and high frequency testing

Elasticity, creep, and strength testing of cementitious materials supporting the development/validation of existing/future, macro/multi-scale models in WG2

Experiments and modeling go hand in hand. They are mutually inspiring!

Bernhard Pichler, Christian Hellmich, Josef Eberhardsteiner

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Institute for Mechanics of Materials and Structures

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

nanocem
THE INDUSTRIAL-ACADEMIC NANOSCIENCE RESEARCH NETWORK FOR SUSTAINABLE CEMENT AND CONCRETE

TU 1404 COST ACTION
TOWARDS THE NEXT GENERATION OF STANDARDS FOR SERVICE LIFE OF CEMENT-BASED MATERIALS AND STRUCTURES

Motivation: New Austrian Tunneling Method

- Sequential excavation followed by shotcreting
- Shotcrete is loaded at very early ages
- Daily monitoring of tunnel shell displacements

Shotcrete modeling status:

1985: time-dependent

1995: macroscopic thermo-chemo-mechanical

2005: multiscale thermo-chemo-mechanical

Shotcrete properties:

→ elasticity, creep, and strength evolutions at early ages

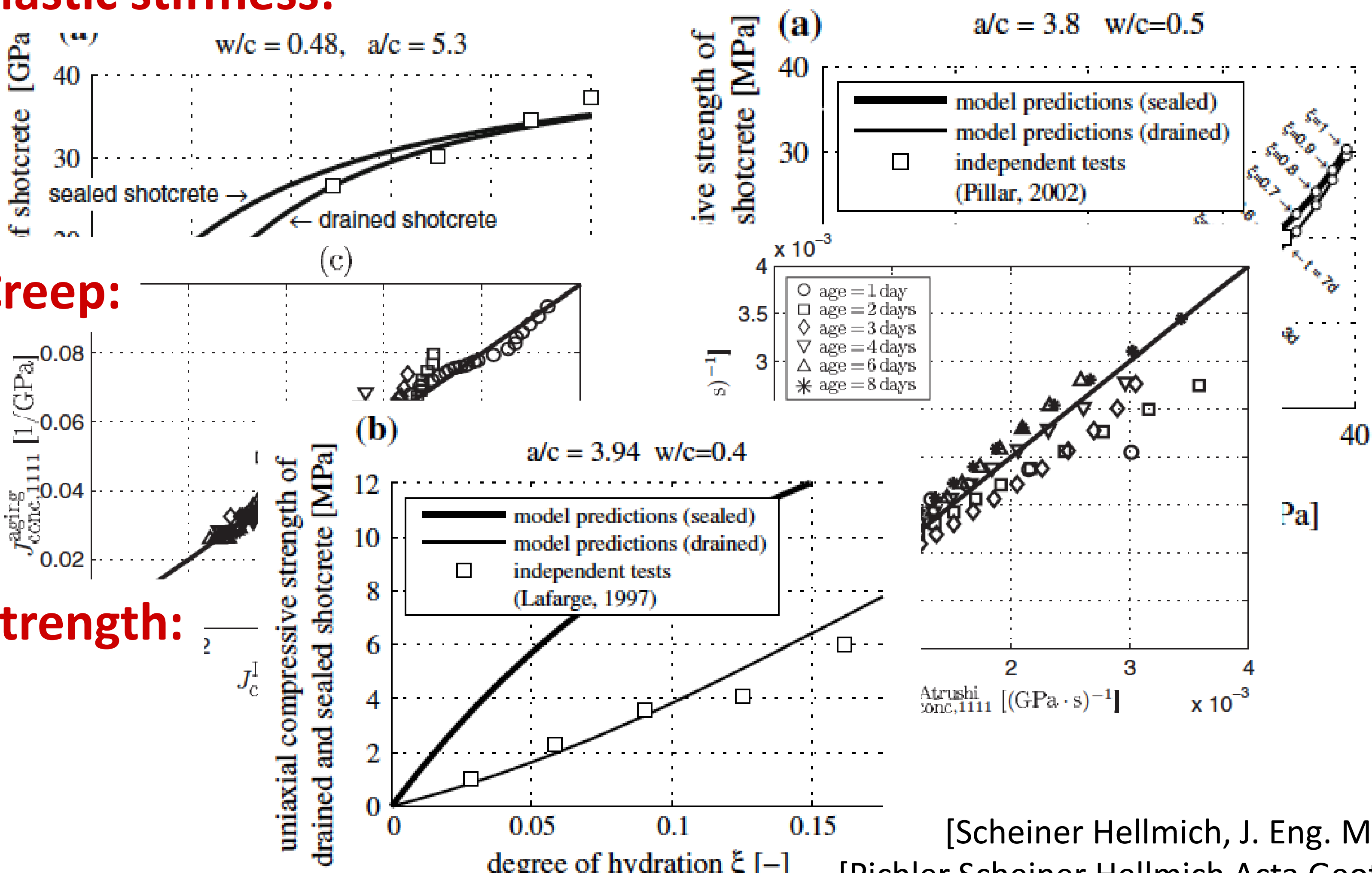
[for literature see the last two slides]

Shotcrete model validation for different compositions:

Elastic stiffness:

Creep:

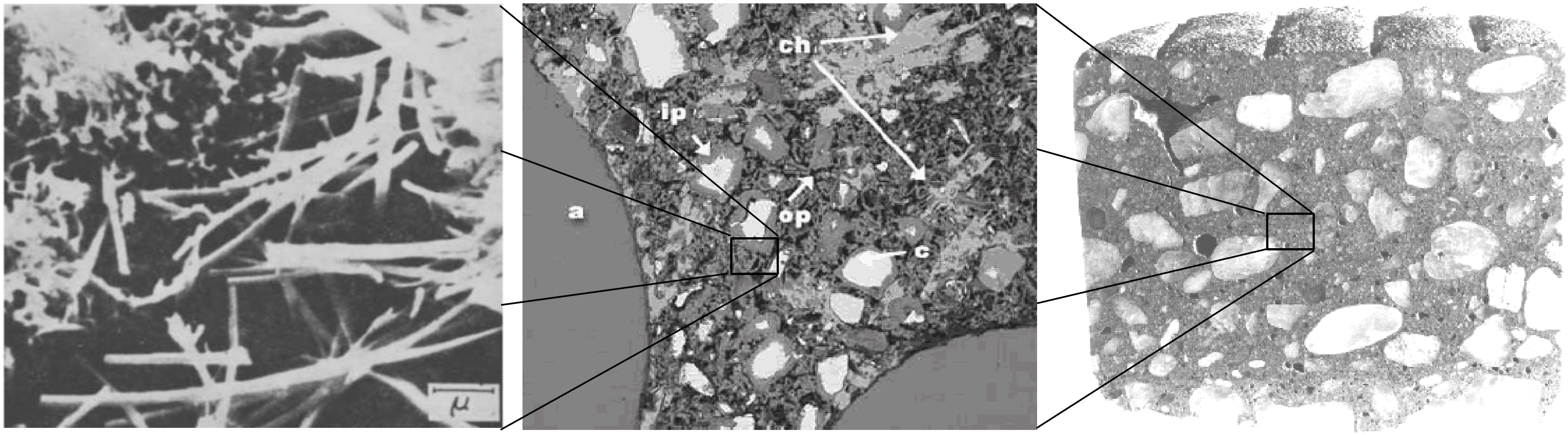
Strength:



[Scheiner Hellmich, J. Eng. Mech., 2009]
[Pichler Scheiner Hellmich Acta Geotech, 2008]

Multiscale strength modeling:

Multiscale organization of cement paste and (sprayed) concrete



Chatterji and Jeffrey, Nature, 209, 1966

http://www.fhwa.dot.gov

http://www.fhwa.dot.gov

Macroscopic loading → stress concentration into hydrate needles

Once max. hydrate stress = hydrate strength → macroscopic failure

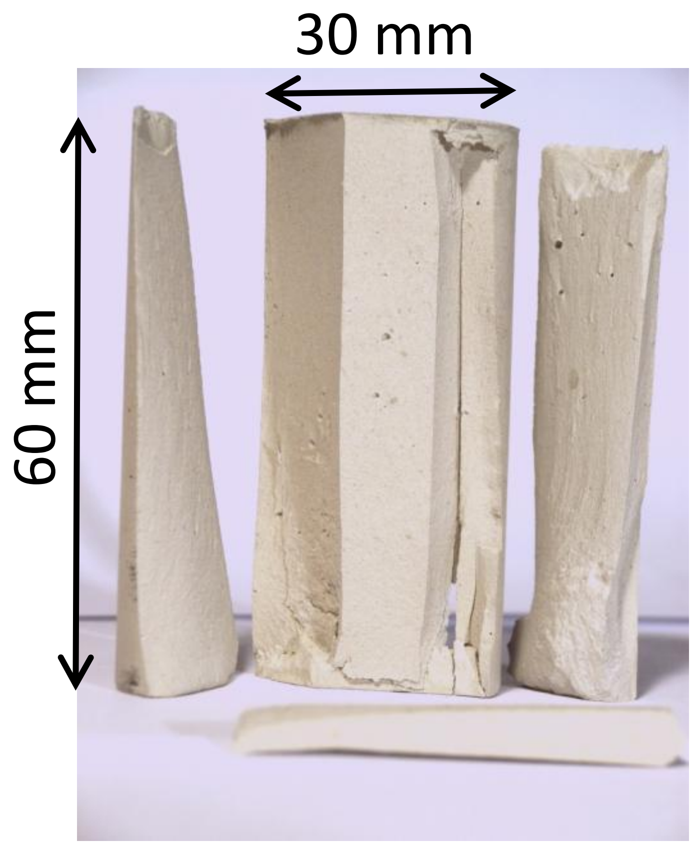
Hydrate strength → identified from nanoindentation

[Pichler, Hellmich, Cem.Con.Res, 2011]

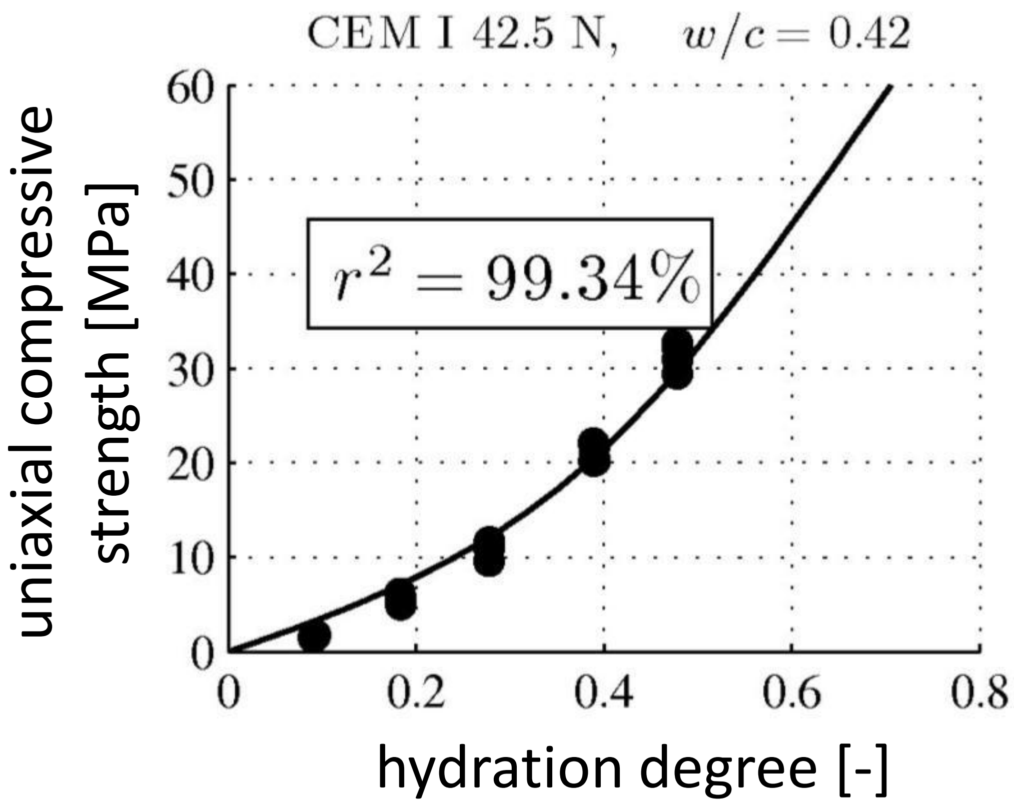
Cement paste: compressive strength = f (hydration degree)

Experiments:

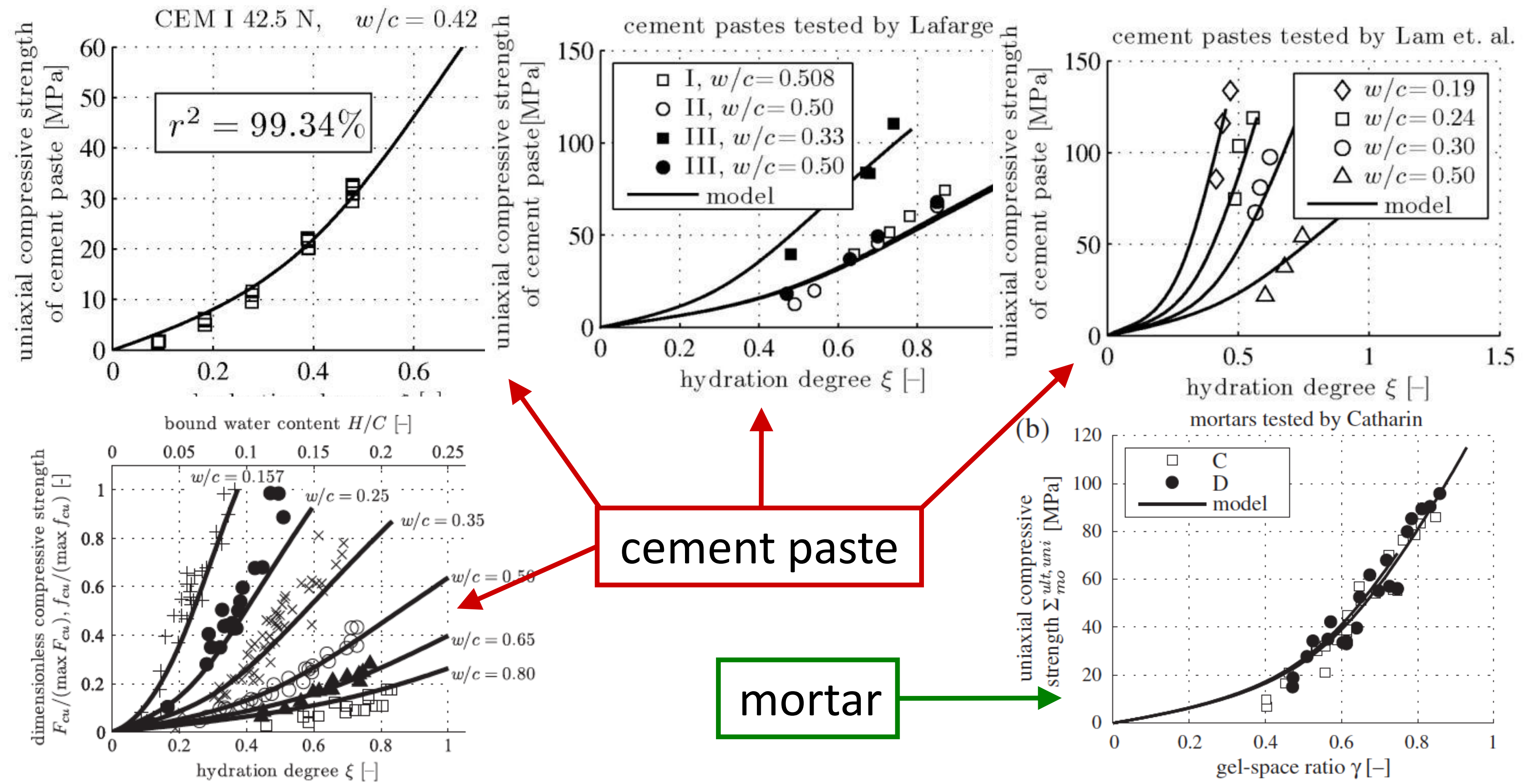
- Quasi-static testing at very early ages
- Friction reduction + central load application



axial splitting



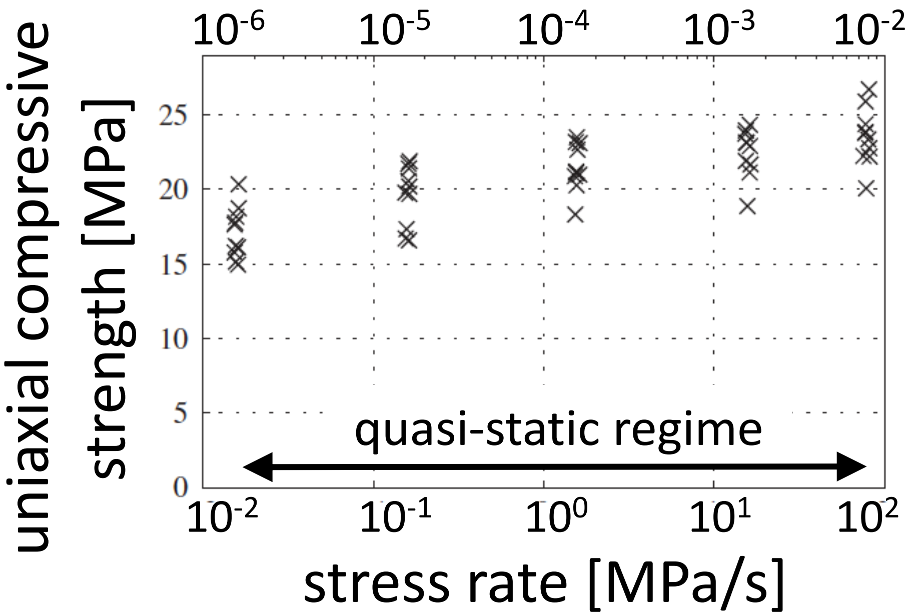
Validation of multiscale model without fitting parameters:



[Pichler, Hellmich, Eberhardsteiner, Wasserbauer, Termkhajornkit, Barbarulo, Chanvillard, Cem.Con.Res, 2013]

Cement paste: compressive strength = f (loading rate)

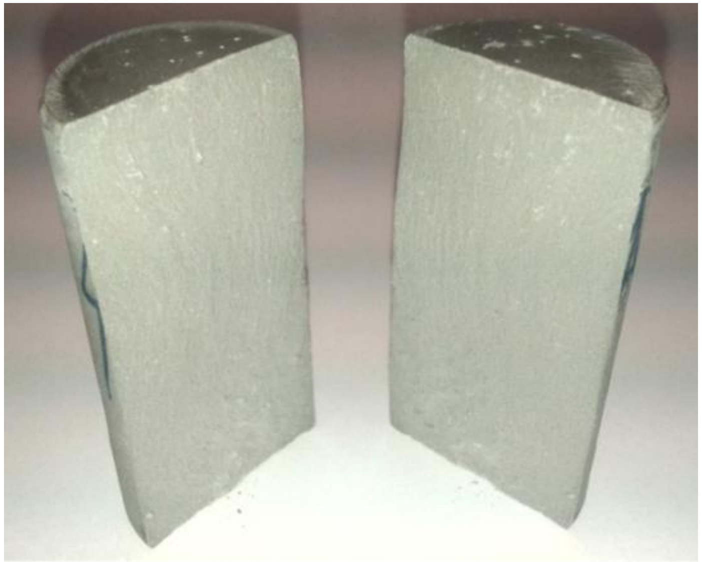
Campaign 1: w/c = 0.43, age = 2 days



[Fischer, Pichler, Lach, Terner, Barraud, Britz, Cem.Con.Res., 2014]

Experiments:

axial splitting

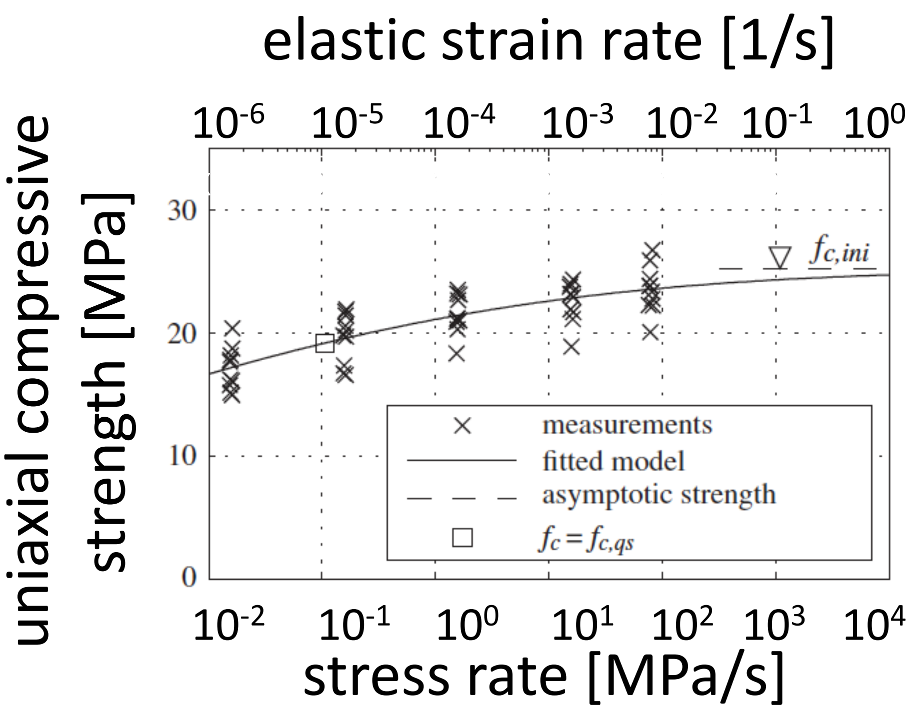


d = 30 mm h = 60 mm

T = 20°C E = 10.8 GPa

Cement paste: compressive strength = f (loading rate)

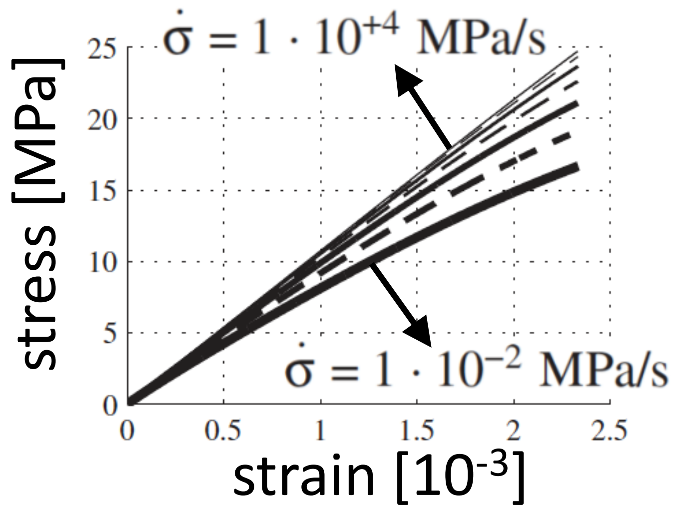
Campaign 1: w/c = 0.43, age = 2 days



[Fischer, Pichler, Lach, Terner, Barraud, Britz, Cem.Con.Res., 2014]

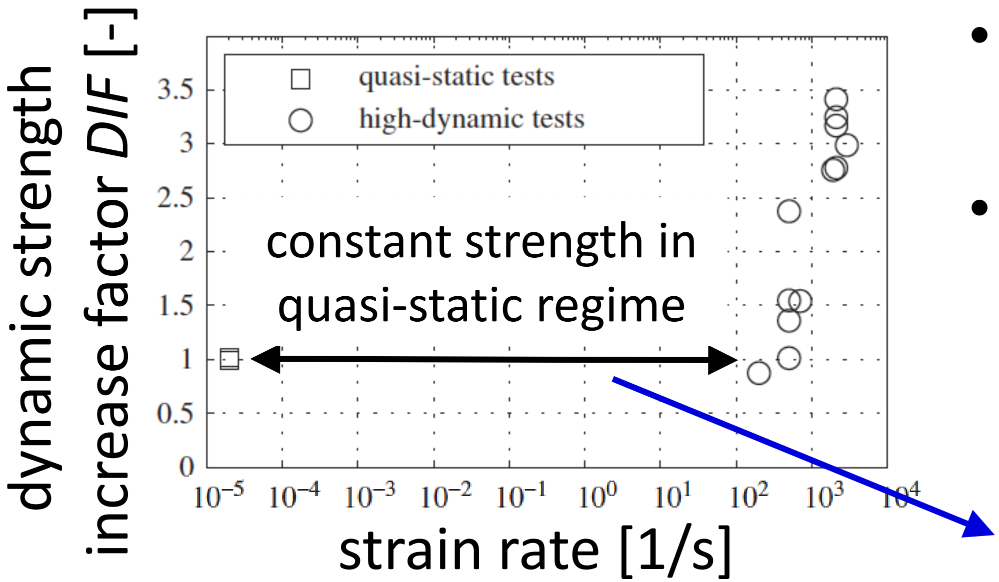
Modeling:

- Creep results in pre-peak non-linearities
- Nonlinear creep model
- Ultimate strain criterion



Cement paste: compressive strength = f (loading rate)

Campaign 2: w/c = 0.60, age = 6 months, oven drying before testing



[Fischer, Pichler, Lach, Terner, Barraud, Britz, Cem.Con.Res., 2014]

Experiments:

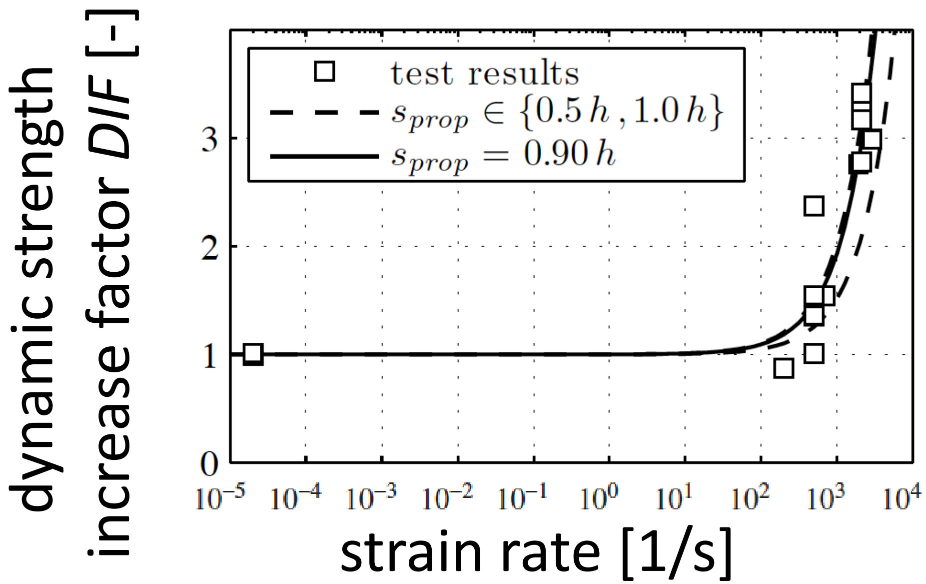
- Quasi-static tests
  d = 30 mm h = 66 mm $f_{c,qs}$ = 48 MPa
- High-dynamic tests:
  Split Hopkinson Pressure Bar
  d = 10 mm h = 6.6 mm

Dry cementitious materials:

- very small creep activity
- no creep-associated damage

Cement paste: compressive strength = f (loading rate)

Campaign 2: w/c = 0.60, age = 6 months, oven drying before testing



$$DIF = 1 + [0.5\ ,\ 1.0] \times \frac{h\,\dot{\varepsilon}\,E}{f_{c,qs}}\sqrt{\frac{\rho}{\mu}}$$

[Fischer, Pichler, Lach, Terner, Barraud, Britz, Cem.Con.Res., 2014]

Modeling:

- High-dynamic strengthening = structural effect under purely elastic behavior
- Time to failure
  = time until 1st crack nucleates
  + time required for this crack to split the sample in loading direction

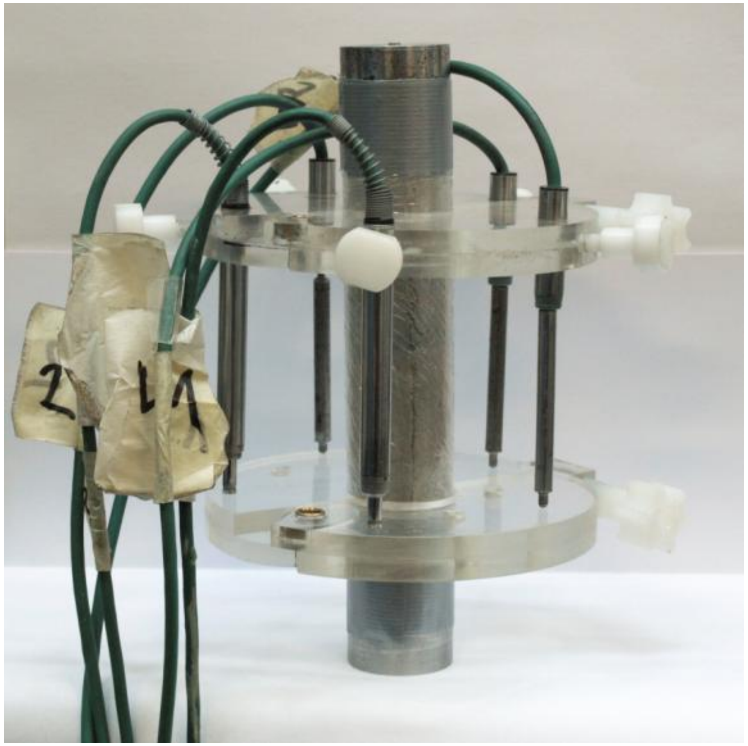
No fitting parameter

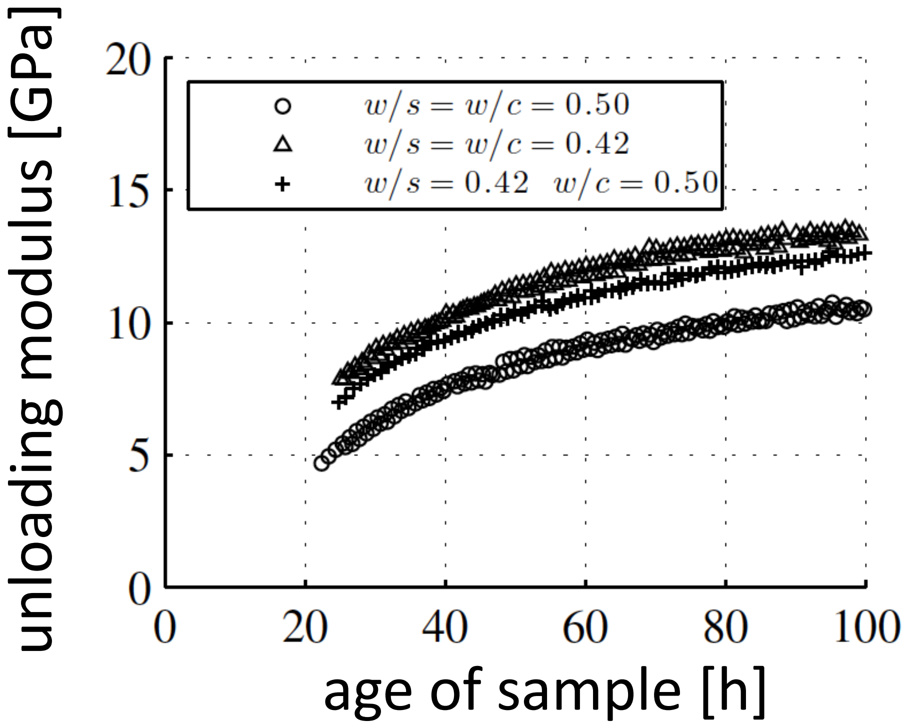
How about (visco-)elasticity?

Cement paste: unloading modulus = f (age of the material)

- Hourly-repeated loading/unloading tests
- Quantification of unloading modulus

Experiments:





Test method: [Karte, Hlobil, Reihsner, Dörner, Lahayne, Eberhardsteiner, Pichler, Strain, 2015]

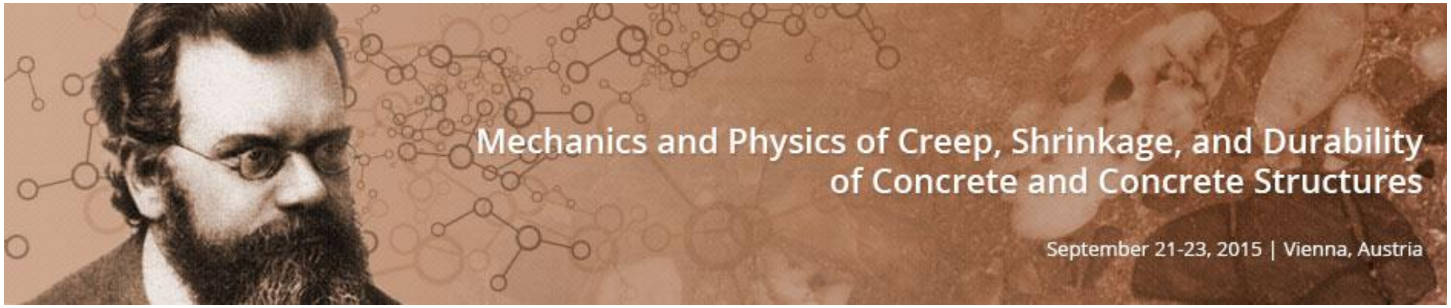
Cement paste: viscoelastic properties = f (hydration degree)

- Hourly-repeated 3-minutes creep tests for quantification of
  - Young's modulus and power-law creep properties

$$\varepsilon^{mod}_{creep}(t) = \sum_{i=1}^{n} \frac{\Delta\sigma_i}{E_c} \left(\frac{t - t_i}{t_{ref}} \right)^{\beta}$$

- 3-minutes too short for significant hydration progress
- 1 hour is enough for measurable hydration progress

Experimental results will be shown at CONCREEP-10:



[Irfan-ul-Hassan, Pichler, Reihsner, Hellmich, in preparation]

Group Priority 1d: Mechanical Properties

- **RRT: same test on same materials at different labs (focused)**
  - TU 1404 is time-limited: impossible to test for 120 years
  - Long-term durability requires durability at early ages
  - RRT will focus, in GP1d, on elasticity, creep, strength
- **Experimental input (= database) for modeling is never complete**
  - *Every additional test method is very warmly welcome*!
  - Let us test properties at *all possible* length and time scales!
  - **Which testing activity/data do you want to contribute?**
  - E-mail us: Violeta.Bokan-Bosiljkov@fgg.uni-lj.si
    Bernhard.Pichler@tuwien.ac.at
- **COST: initiate scientific discussions and promote collaboration**
  - chemists, physicists, material scientists, engineers, …

Literature

Multiscale modeling of shotcrete and corresponding safety analyses in tunneling:

- Hellmich, Mang (2005) Shotcrete elasticity revisited in the framework of continuum micromechanics: from submicron to meter level. Journal for Materials in Civil Engineerig (ASCE) 17(3):246–256.
- Pichler, Scheiner, Hellmich (2008) From micron-sized needle-shaped hydrates to meter-sized shotcrete tunnel shells: Micromechanical upscaling of stiffness and strength of hydrating shotcrete. Acta Geotechnica, 3(4), 273-294.
- Scheiner, Hellmich, C. (2009) Continuum microviscoelasticity model for aging basic creep of early-age concrete. Journal of Engineering Mechanics (ASCE), 135(4), 307–323.
- Ullah, Pichler, Scheiner, Hellmich (2010) Shell-specific interpolation of measured 3D displacements, for micromechanics-based rapid safety assessment of shotcrete tunnels. Computer Modeling in Engineering and Sciences, 57(3), 279-314.
- Ullah, Pichler, Scheiner, Hellmich (2012), Influence of shotcrete composition on load level estimation in NATM tunnel shells: micromechanics-based sensitivity analyses. International Journal for Numerical and Analytical Methods in Geomechanics, 36(9), 1151-1180.
- Ullah, Pichler, Hellmich (2013) Modeling ground-shell contact forces in NATM tunneling based on three-dimensional displacement measurements. Journal of Geotechnical and Geoenvironmental Engineering, 139(3), 444-457.

Multiscale modeling of strength of cementitious materials

- Pichler, Hellmich, Eberhardsteiner (2009) Spherical and acicular representation of hydrates in a micromechanical model for cement paste - Prediction of early-age elasticity and strength. Acta Mechanica, 203(3-4), 137-162.
- B. Pichler, Hellmich (2011) Upscaling quasi-brittle strength of cement paste and mortar: a continuum micromechanics approach. Cement and Concrete Research, 41(5), 467-476.

Additional references follow on the next slide …

Multiscale modeling of strength of cementitious materials (cont'd)

- Pichler, Hellmich, Eberhardsteiner, Wasserbauer, Termkhajornkit, Barbarulo, Chanvillard (2013) Effect of gel-space ratio and microstructure on strength of hydrating cementitious materials: an engineering micromechanics approach. Cement and Concrete Research, 45, 55-68.
- Pichler, Hellmich, Eberhardsteiner, Wasserbauer, Termkhajornkit, Barbarulo, Chanvillard (2013) The Counteracting Effects of Capillary Porosity and of Unhydrated Clinker Grains on the Macroscopic Strength of Hydrating Cement Paste: A Multiscale Model. Proceedings of the Ninth International Conference on Creep, Shrinkage, and Durability Mechanics of Concrete and Concrete Structures (CONCREEP-9), American Society of Civil Engineers (ASCE), Reston, VA, USA, 2013, ISBN: 978-0-7844-1311-1.

Loading-rate sensitivity of uniaxial compressive strength of cementitious materials:

- Fischer, Pichler, Lach, Terner, Barraud, Britz (2014) Compressive strength of cement paste as a function of loading rate: Experiments and engineering mechanics analysis. Cement and Concrete Research, 58, 186-200.
- Pichler, Fischer, Lach, Terner, Barraud, Britz (2014) The influence of loading rate on the compressive strength of cementitious materials: experiments and "separation of time scales"-based analysis. Proceedings of the conference "Computational Modeling of Concrete and Concrete Structures", (EURO-C).

Quasi continuous characterization of visco-elastic properties of cementitious materials

- Karte, Hlobil, Reihsner, Dörner, Lahayne, Eberhardsteiner, Pichler (2015) Unloading-based stiffness characterization of cement pastes during the second, third, and fourth day after production. Strain, 51(2), 156-169.
- Irfan-ul-Hassan, Pichler, Reihsner, Hellmich (2015) Hourly repeated minutes-long creep tests on young cement pastes provide access to power-law creep properties at early ages. In preparation.
- Irfan-ul-Hassan, Pichler, Reihsner, Hellmich (2015) Minutes-long creep tests on young cement pastes provide access to creep properties relevant for ageing creep with a duration of 2 days. Proceedings of the Tenth International Conference on Creep, Shrinkage, and Durability of Concrete and Concrete Structures (CONCREEP-10). In preparation.

SESSION for GP1.e – Volume stability

Chairman: Emmanuel Roziere

Emmanuel Roziere: Tentative experimental programme for RRT on volume stability

Florent Baby: BTJADE : measurement of concrete autogenous shrinkage

Ahmed Loukili: Experimental decoupling of autogenous shrinkage and thermal deformation of cement-based materials at early age

Stéphanie Staquet: Experimental assessment of autogenous shrinkage

Benoit Parmentier: Test methods for the assessment of restrained shrinkage effects on cracking: some feedback from the ring test and the dog-bone test

TU 1404 COST ACTION

TOWARDS THE NEXT GENERATION OF STANDARDS FOR SERVICE LIFE OF CEMENT-BASED MATERIALS AND STRUCTURES

Round Robin Test

on different properties of cement based materials

GP1E: VOLUME STABILITY

Emmanuel.Roziere@ec-nantes.fr

Ljubljana, 17 April 2015

ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Tentative experimental programme for RRT

The author

- Associate professor at GeM Laboratory, Ecole Centrale de Nantes, France
- Leader of COST GP1e – Volume stability

Ecole Centrale de Nantes

- 2000 students: Engineering school, Masters, PhD Dtudents
- 4 Laboratories : GeM, LHEEA (Hydrodyamics), IRCCYN (Cybernetics), CERMA (Architecture)

GeM – Civil engineering and Mechanics Research Institute

Civil engineering	Computational mechanics	Materials science

Mechanics and durability of soils, rocks, and **concrete**

Profs. P.-Y. Hicher, P. Kotronis, **A. Loukili**

7 researchers

22 PhD students

back to GP1.e overview

Tentative experimental programme for RRT

The author

- Associate professor at GeM Laboratory, Ecole Centrale de Nantes, France
- Leader of COST GP1e – Volume stability

Activity related to this WP

- 10-year experience on experimental investigations on cement-based materials
- Participation to inter-laboratory tests:

  Autogenous shrinkage of High-Strength and Normal-Strength Concrete

  Long-term drying shrinkage of concrete made of natural and recycled aggregates
- **Shrinkage-induced cracking of cementitious materials**

  Early-age behavior: plastic and autogenous shrinkage, direct tensile testing

  Long-term: free and restrained shrinkage (ring test)
- **Performance-based approach of durability of concrete**

  Concept of Equivalent performance

  Development of representative ageing tests: carbonation, leaching, sulfate resistance

  National Project PERFDUB (Round Robin Tests)

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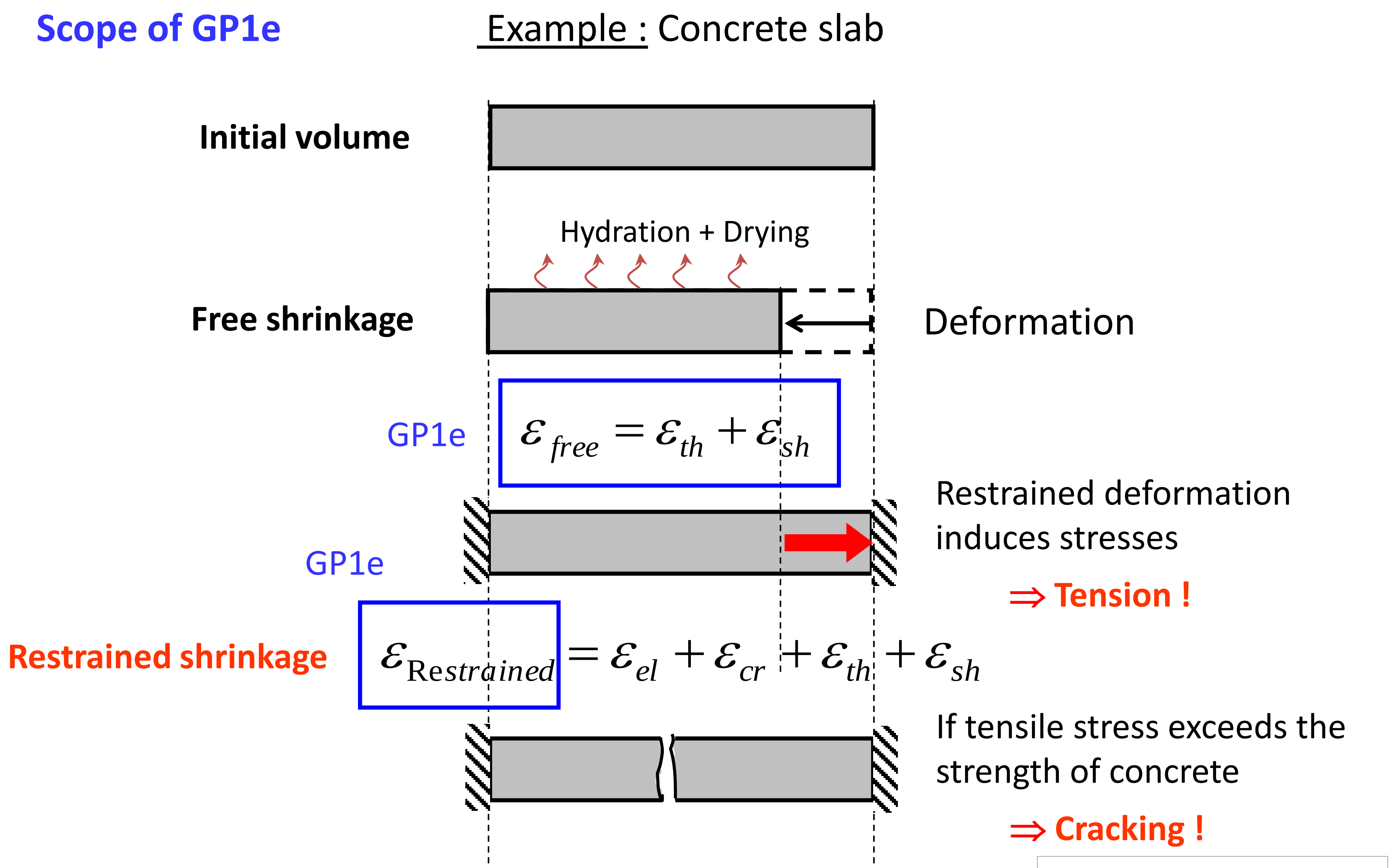
Causes and consequences of volume changes



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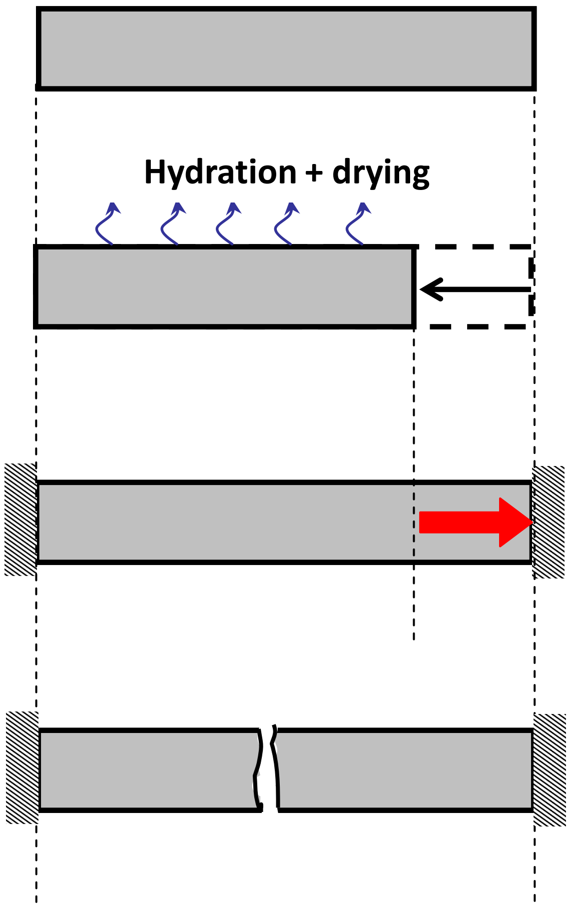
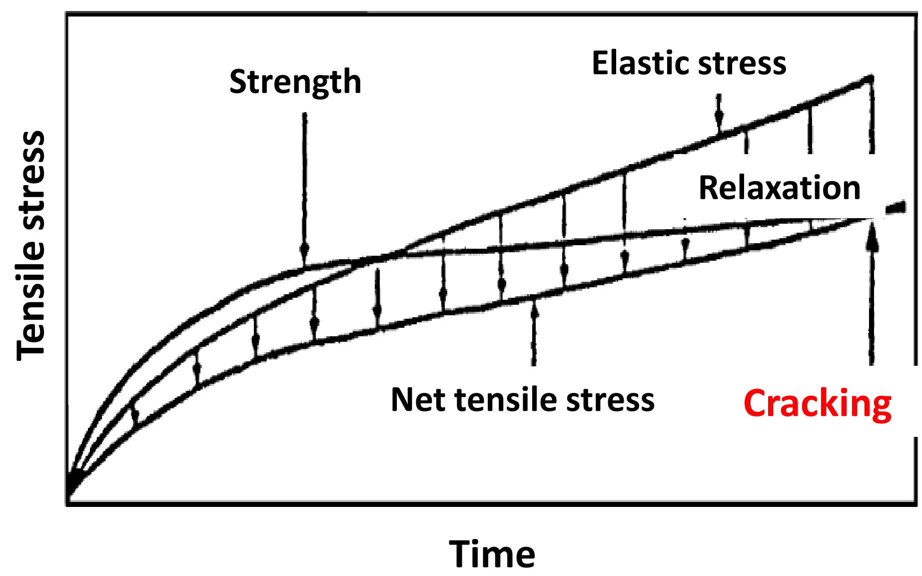
Causes and consequences of volume changes

Cracking due to
Restrained shrinkage



Influence of creep/relaxation/damage
on the development of tensile stresses
:

Cf. GP1d, GP1f



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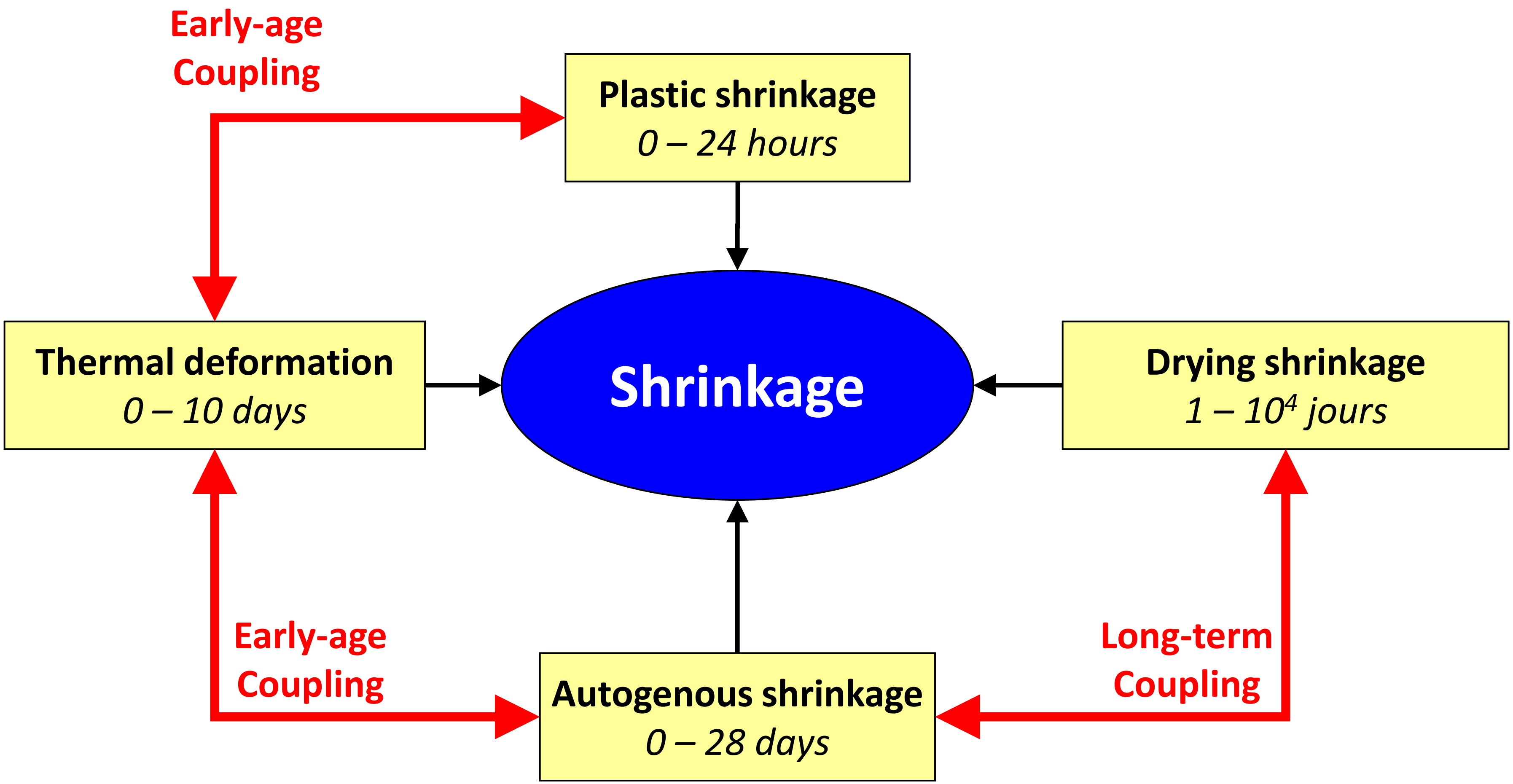
Causes and consequences of volume changes

Shrinkage-inducing phenomena



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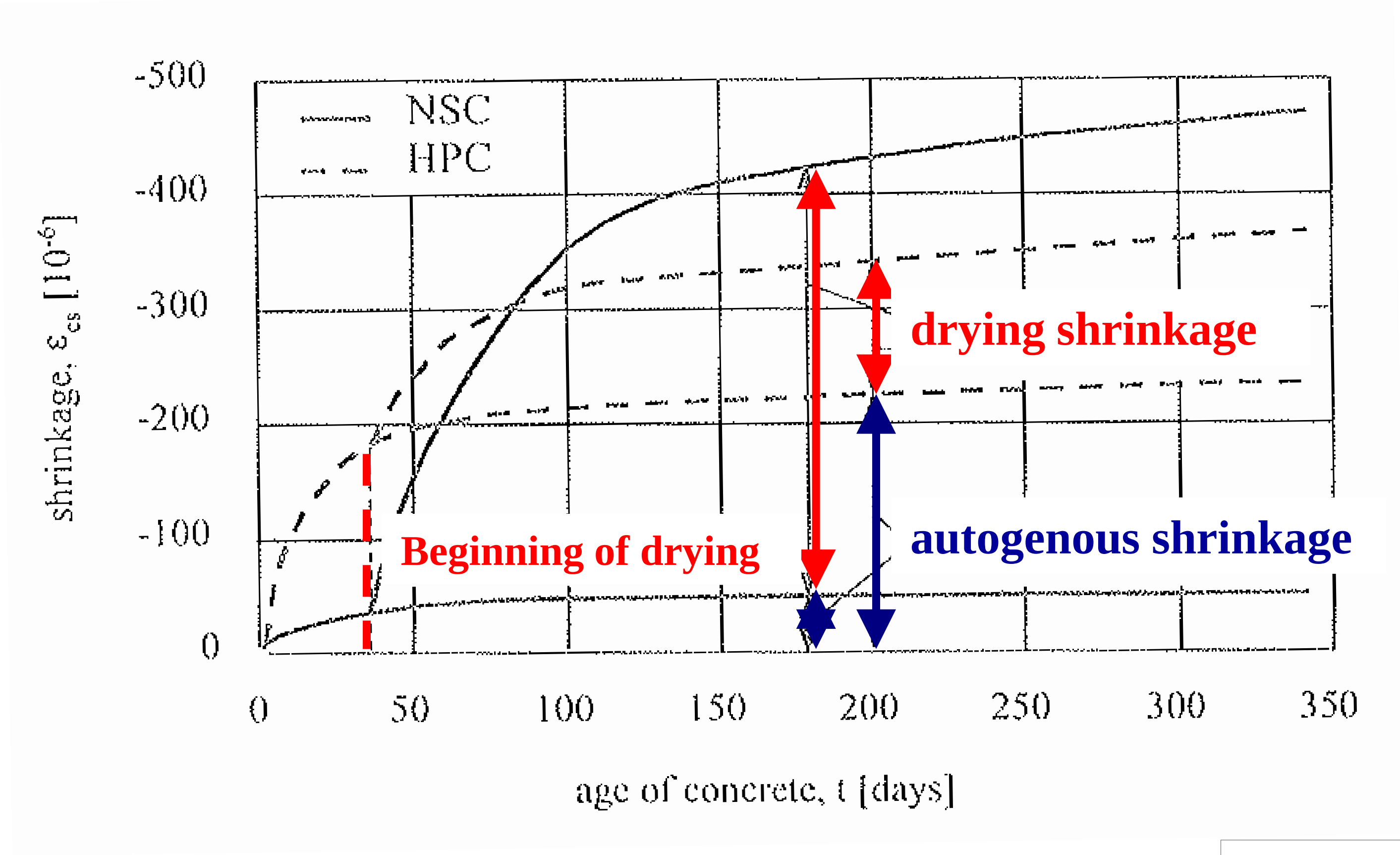
Causes and consequences of volume changes

Influence of mix-design parameters

Autogenous and drying shrinkage in **normal strength concrete (NSC)** and **high-performance concrete (HPC)** [*Müller et al., RFGC, 1999*]



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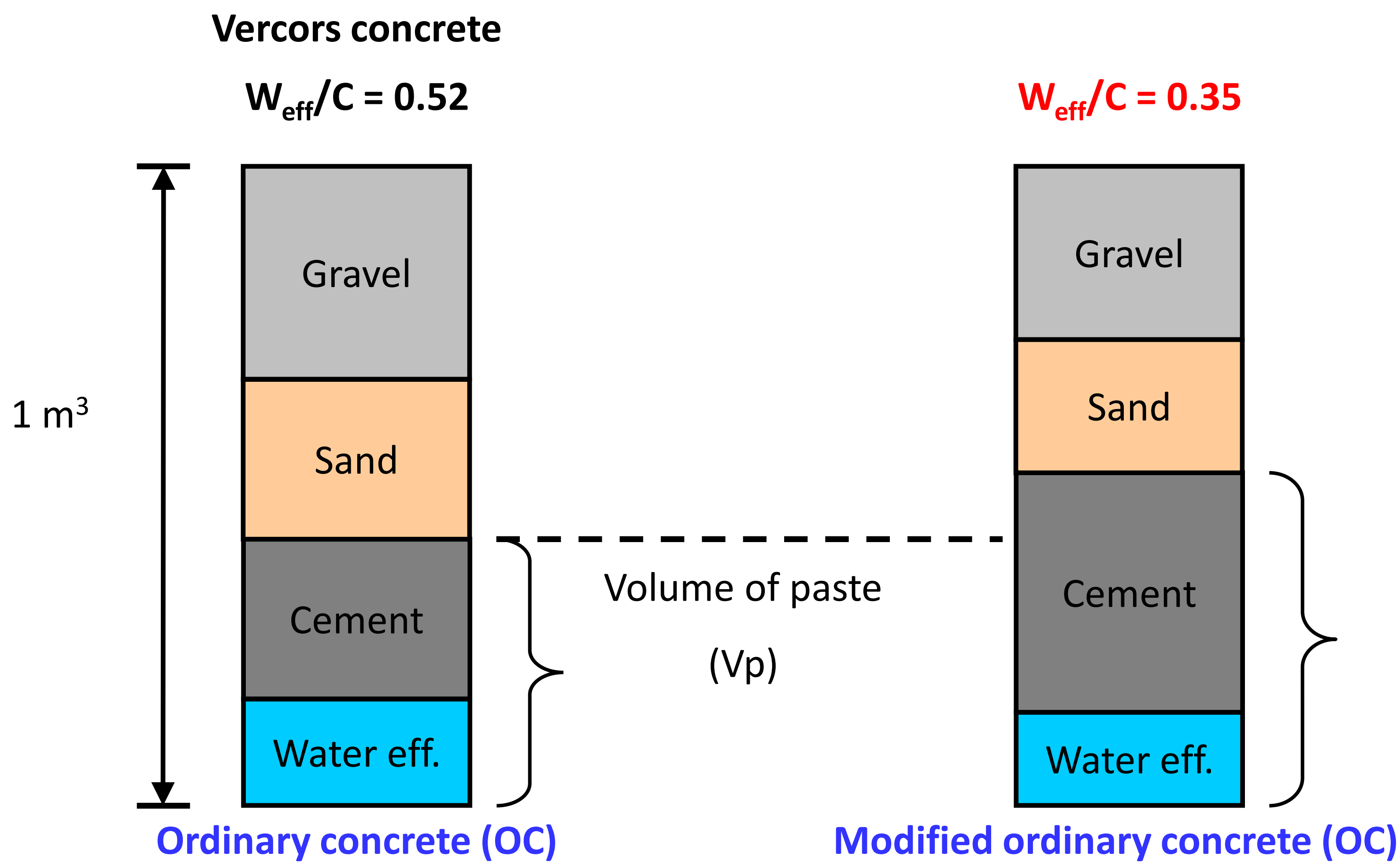
Causes and consequences of volume changes

Influence of mix-design parameters



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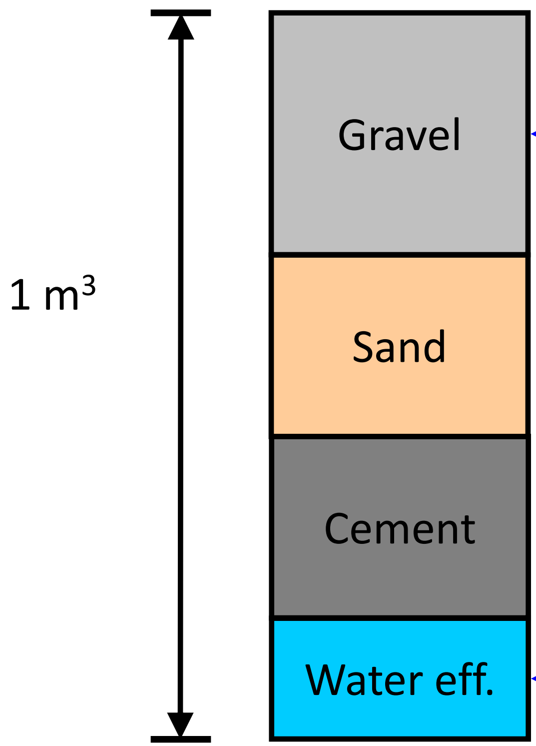
Causes and consequences of volume changes

Influence of mix-design parameters

Vercors concrete

$W_{eff}/C = 0.52$



Ordinary concrete (OC)

Effective water

$$W_{eff} = W_{added/\,dry\,aggregates} - W_{absorbed}$$

	Absorption coefficient (% of dry mass)
Gravel 2	**2.25**
Gravel 1	**2.61**
Sand	0.77

back to GP1.e overview

Causes and consequences of volume changes

Influence of mix-design parameters

Dry aggregates

	Constant eff. water	Constant add. water
Added water	Variable	-----
Effective water	-----	Variable
Total water	Constant	Variable
References	*[AL HOZAIMY, 09], [PEREIRA et al., 09],* ***[NF EN 206-1]***	*[TOMA, 99], [KHOON Ng & CHI Ng, 11]*

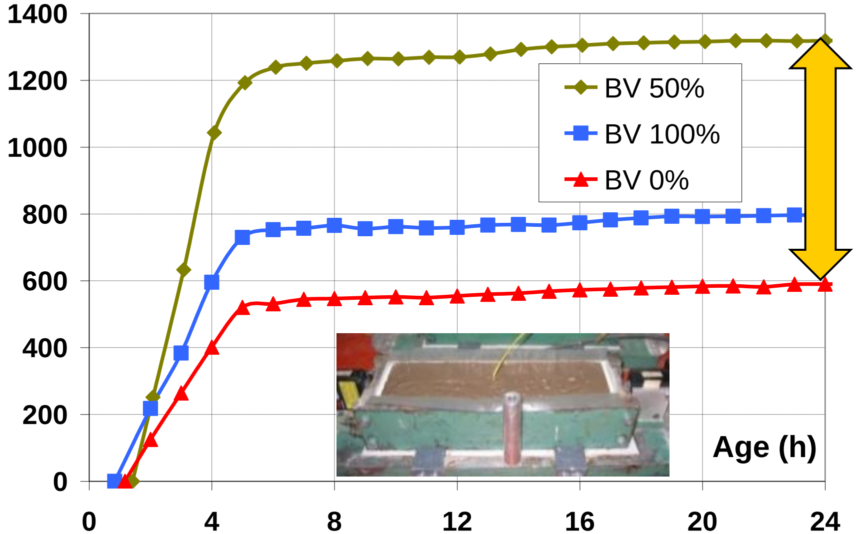
$$W_{Eff} = W_{Added/Dry\,aggregates} - W_{Absorbed}$$

back to GP1.e overview

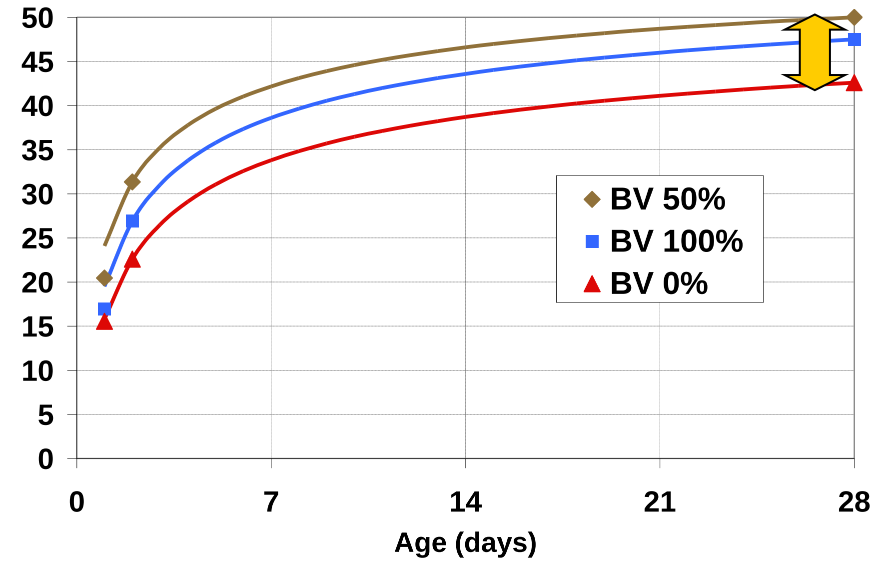
Causes and consequences of volume changes

Influence of mix-design parameters: initial water saturation

Plastic shrinkage



Compressive strength



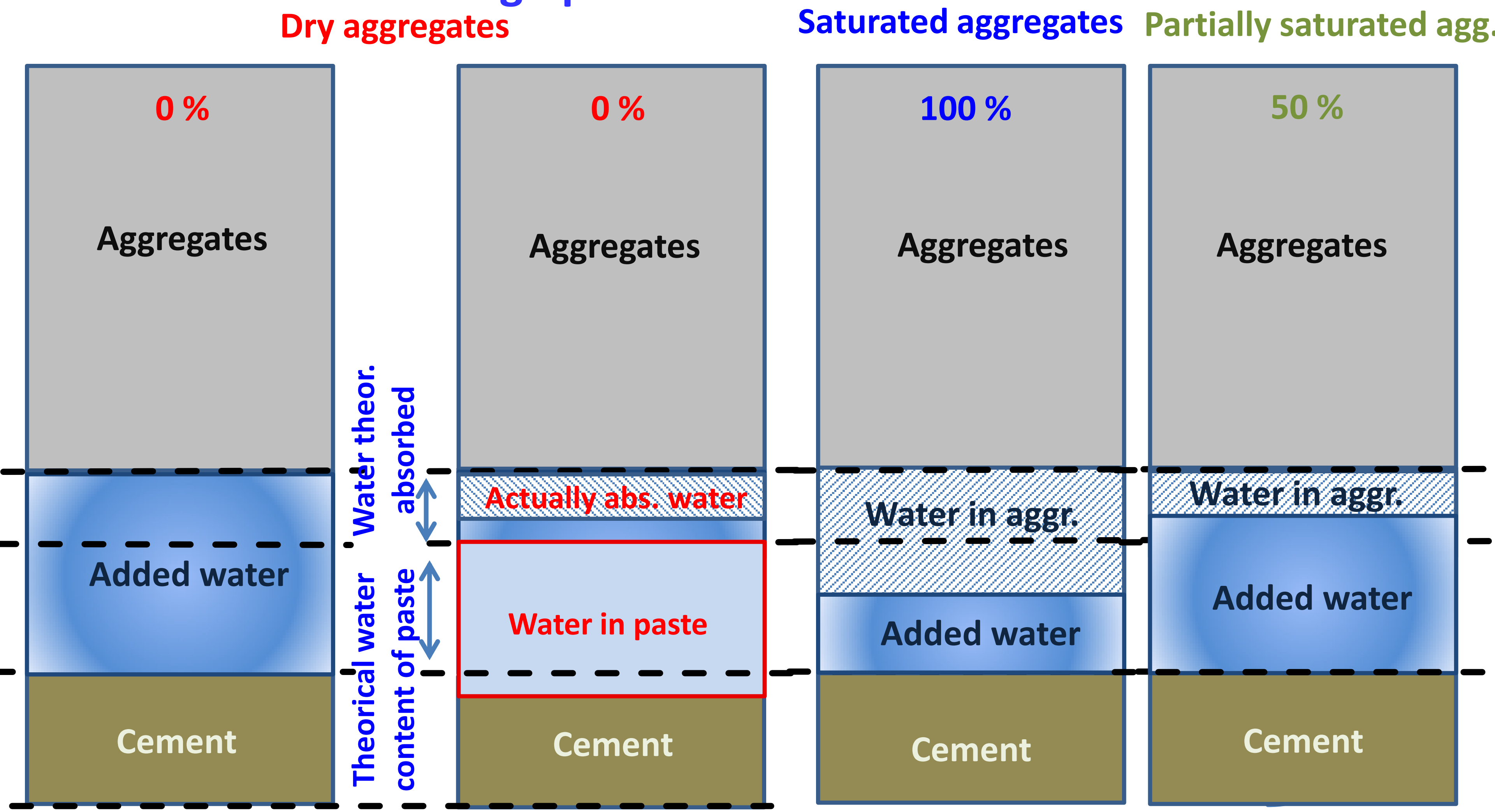
⇒ **Significant Influence of initial water saturation on shrinkage and mechanical properties of concrete [*Cortas et al., CCC, 2014*]**

⇒ **If dry aggregates are used, water actually absorbed < water theoretically absorbed, thus higher (unknown) Water eff./Cement ratio**

back to GP1.e overview

Causes and consequences of volume changes

Influence of mix-design parameters: initial water saturation



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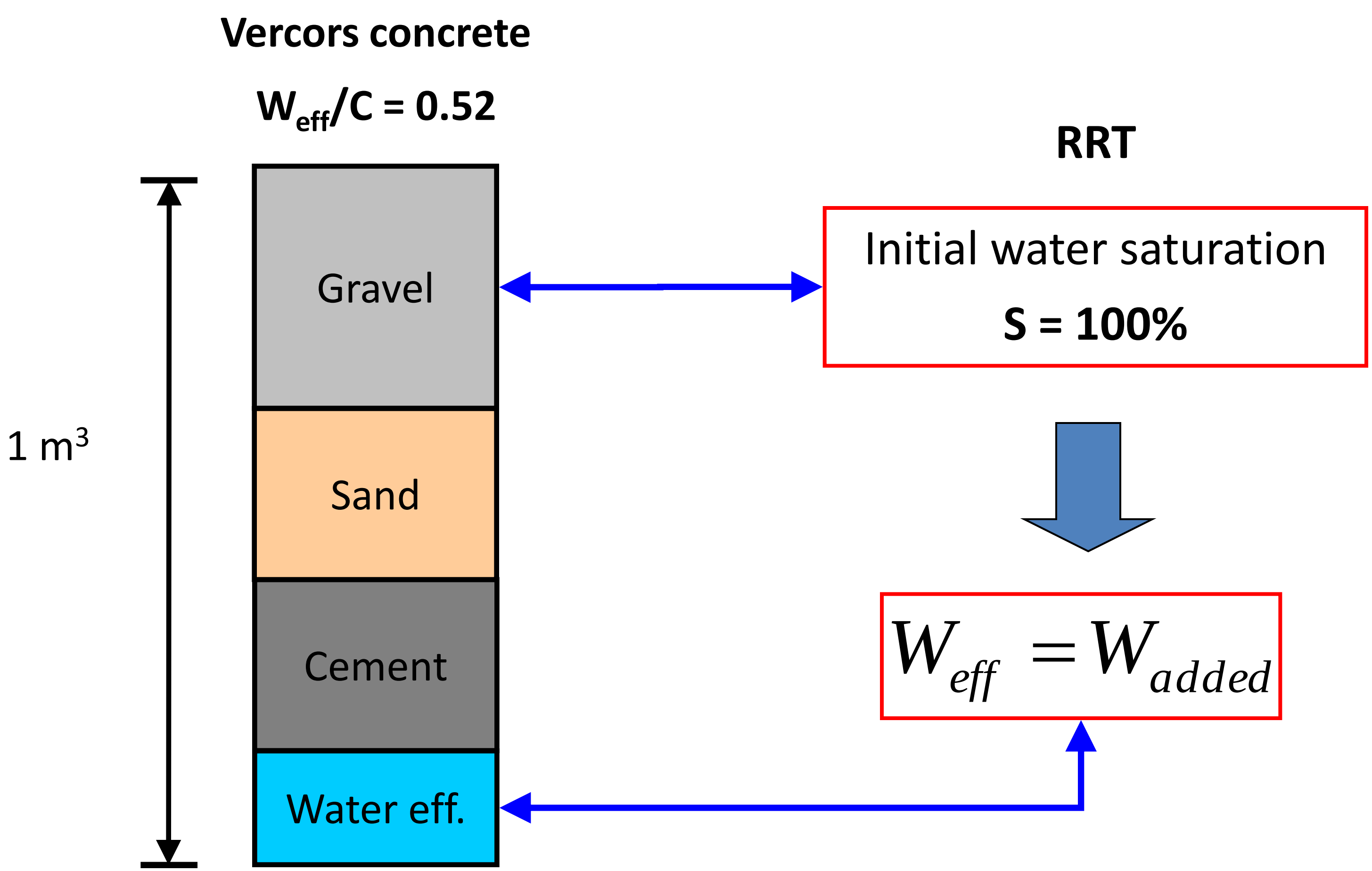
Round Robin Test (RRT) programme

Influence of mix-design parameters: initial water saturation



Ordinary concrete (OC)

back to GP1.e overview

Round Robin Test (RRT) programme

RRT main programme

Properties	Early age *0 – 24 hours or more*	Long term *1 – 28 days or more*
Shrinkage	Chemical: OCP Autogenous: MOC, OC Plastic: OC	Autogenous: MOC, OC Total/drying: OC

OC : Ordinary concrete (W/C = 0.52)
MOC : Modified ordinary concrete (W/C = 0.35)

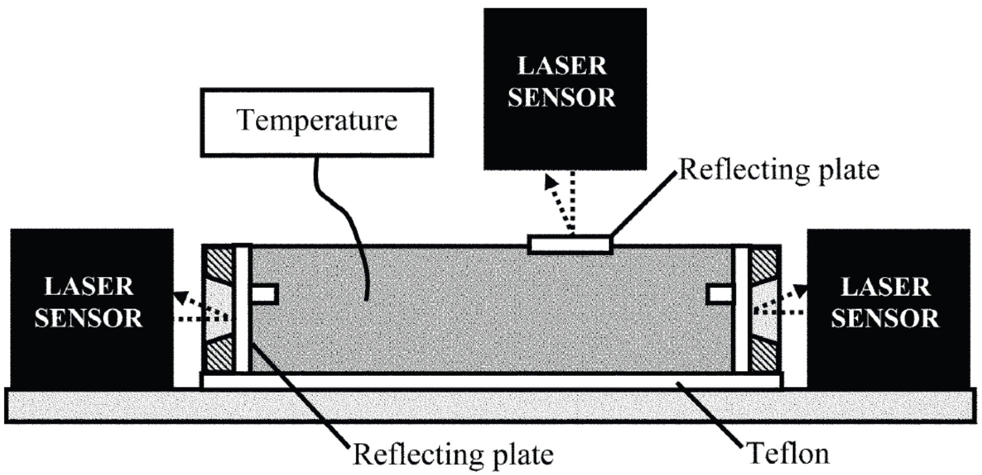
OCP: Ordinary cement paste

back to GP1.e overview

Round Robin Test (RRT) programme

Autogenous and plastic shrinkage

Thermal deformation (CTE)



Schematic section view of plastic shrinkage measurement [Turcry and Loukili, 2006]

Monitoring

Displacements (µm)

Internal temperature (T, °C)

Weight loss (g)

External temperature (T, °C)

External relative humidity (RH, %)

Speed of air near the concrete specimen (m/s)

Time of casting (h:min)

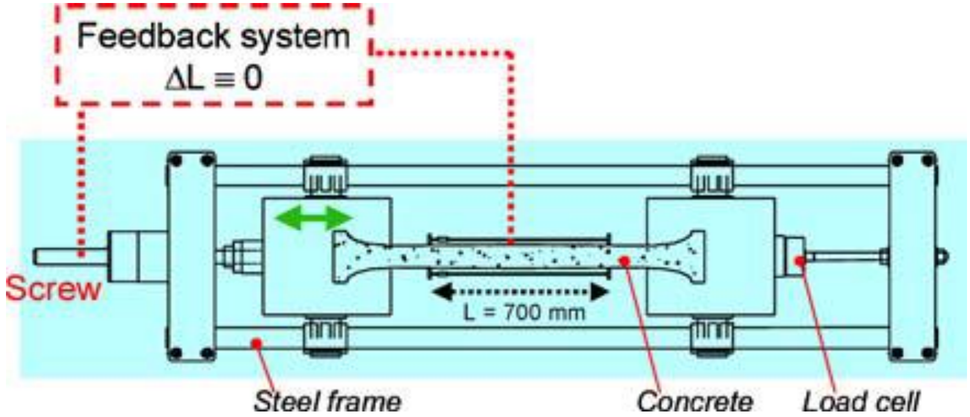
Time of first measure (h:min)

back to GP1.e overview

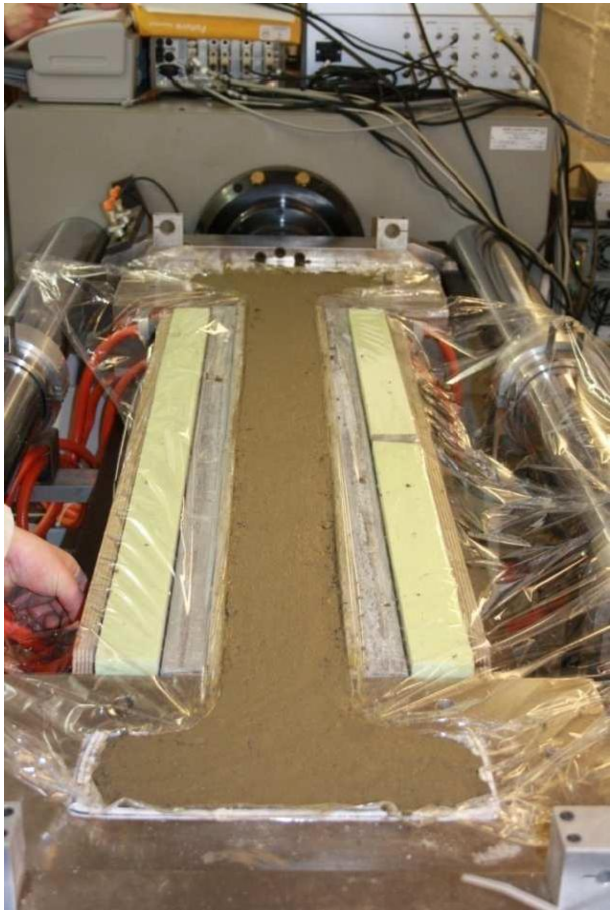
Round Robin Test (RRT) programme

Restrained shrinkage – Early-age

TSTM (*Temperature Stress Testing Machine*) :



Rig for testing of self generated stress
[Hammer et al., 2007]



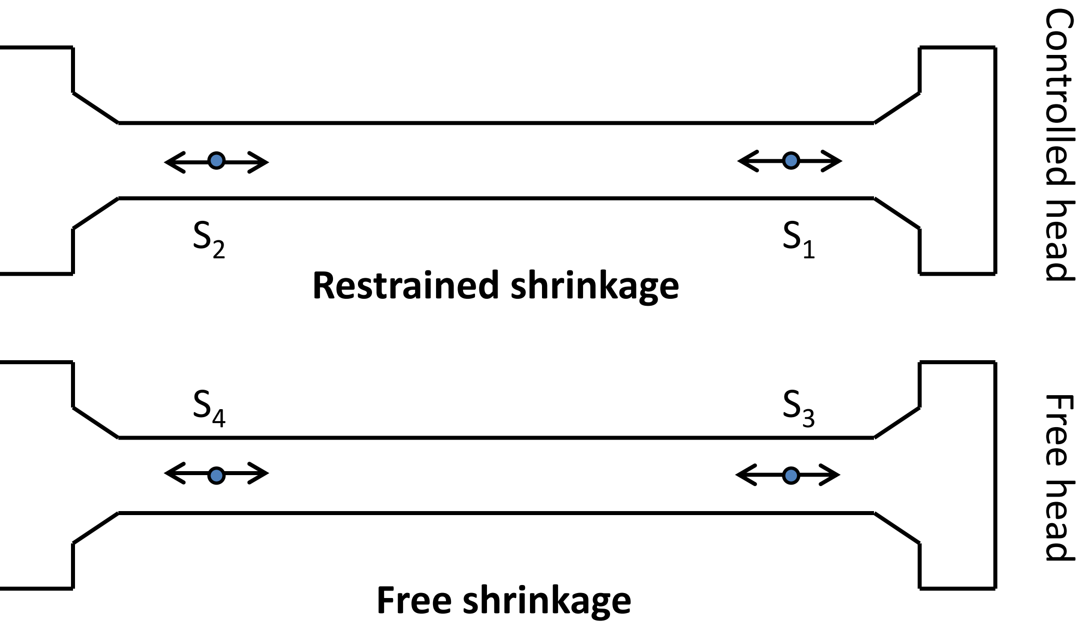
Dog-Bone specimen at ULB
[Staquet et al., 2012]

back to GP1.e overview

Round Robin Test (RRT) programme

Restrained shrinkage – Early-age

TSTM (*Temperature Stress Testing Machine*) :



Monitoring

Displacements (µm)

Load (kN)

Internal temperature (T, °C)

Displacements (µm)

Internal temperature (T, °C)

External temperature (T, °C)

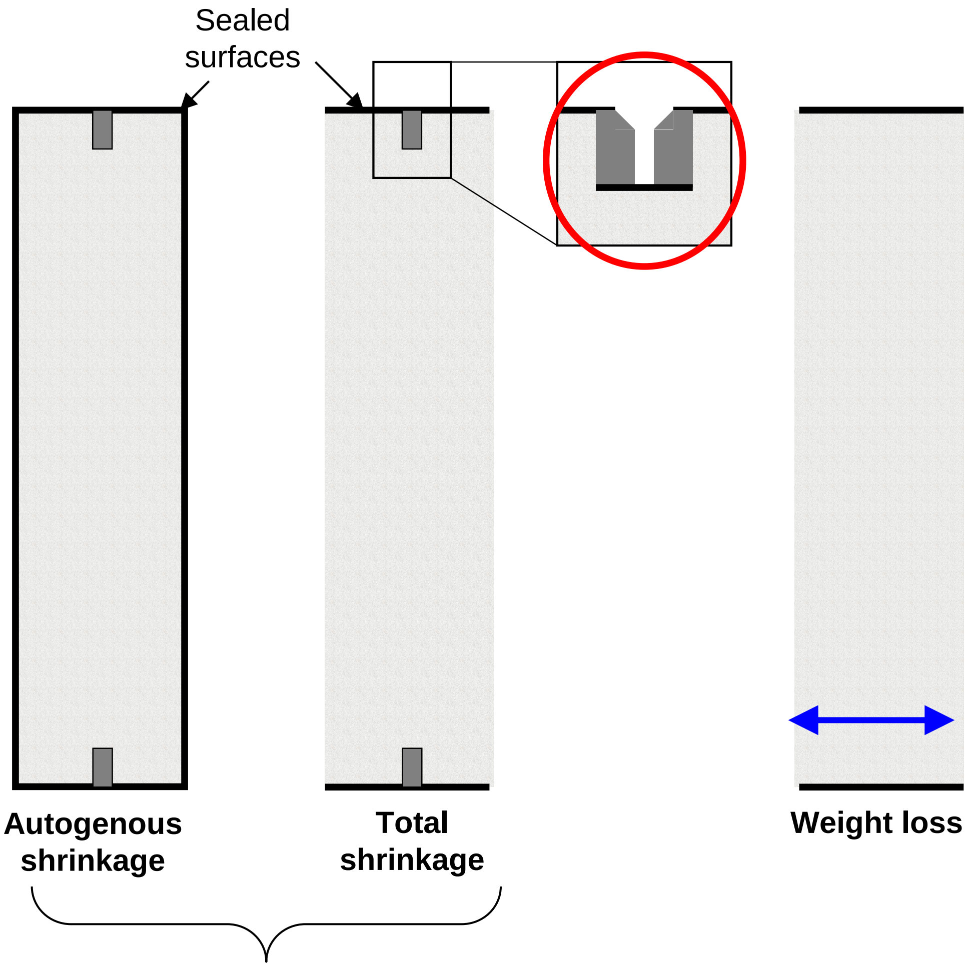
Time of casting (h:min)

Time of first measure (h:min)

back to GP1.e overview

Round Robin Test (RRT) programme

Drying shrinkage



Drying sh. = Total sh. – Autogenous sh.

Monitoring

Displacements: autogenous, drying (µm)

Weight loss (g)

External temperature (T, °C)

External relative humidity (RH, %)

Time of formwork removal (h:min)

Time of first measure (h:min)

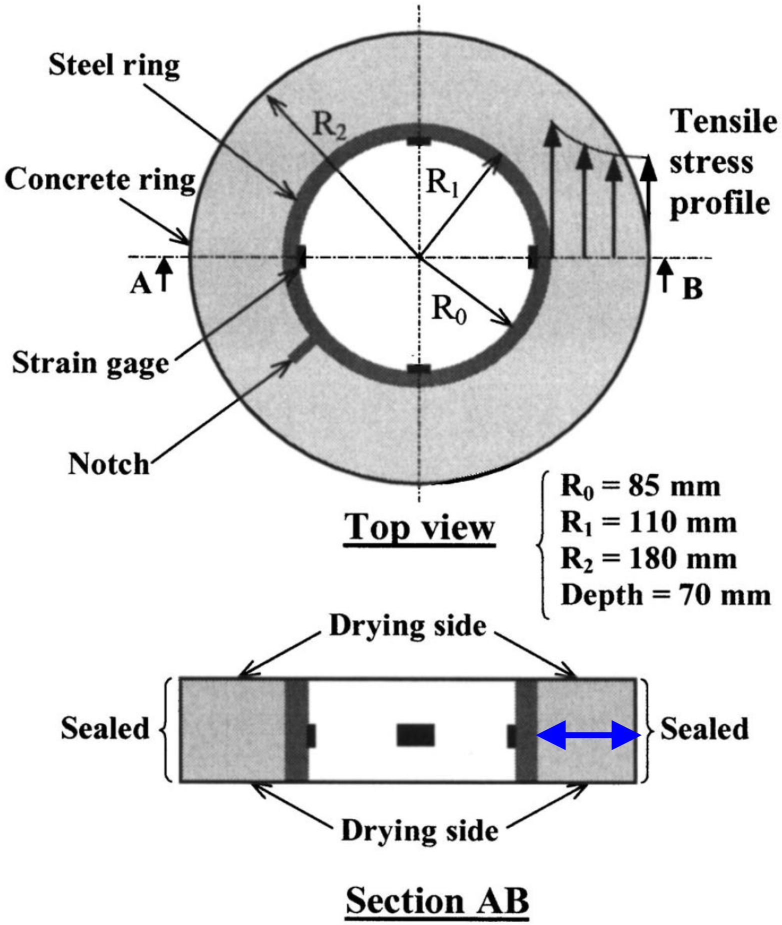
Minimum diameter/width : 5 x Maximum aggregate size

The shape, dimensions, and materials of moulds shall be given with data

back to GP1.e overview

Round Robin Test (RRT) programme

Restrained shrinkage – Long-term



Schematic of ring specimen
[Turcry et al., ASCE, 2006]

Monitoring:

Deformation at inner radius of steel ring from the time of casting (µm/m),

Age of cracking (days)

External temperature (T, °C)

External relative humidity (RH, %)

Time of formwork removal (h:min)

Time of first measure (h:min)

Minimum diameter/width : 5 x Maximum aggregate size

The shape, dimensions, and materials of moulds shall be given with data

back to GP1.e overview

Round Robin Test (RRT) programme

RRT main programme

Properties	Early age *0 – 24 hours or more*	Long term *1 – 28 days or more*

Characterization of fresh and hardened concrete:

- Properties of fresh concrete: density, entrapped air content, slump, initial concrete temperature

- Setting (initial and final setting times)

- Strength at 2 ages (e.g. 1 and 28 days)

- Degree of hydration

- Capillary pressure

back to GP1.e overview

Round Robin Test (RRT) programme

RRT main programme

Properties	Early age *0 – 24 hours or more*	Long term *1 – 28 days or more*

Plastic/Drying shrinkage:

- Ordinary concrete (OC),
- 20°C, 50% RH.

Autogenous shrinkage on Vercors (OC) and Modified ordinary concrete (MOC):

- under isothermal conditions, at 10, 20, and 40°C,
- under realistic temperature conditions, given by Vercors project.

OC : Ordinary concrete (W/C = 0.52)
MOC : Modified ordinary concrete (W/C = 0.35)

OCP: Ordinary cement paste

back to GP1.e overview

Round Robin Test (RRT) programme

Challenges: Influence of temperature on autogenous shrinkage

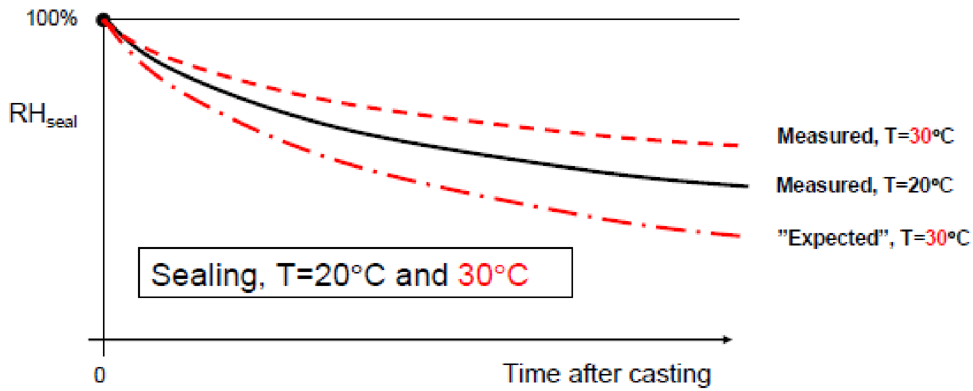


Figure 4: Drying for sealed conditions at 30°C compared with 20°C

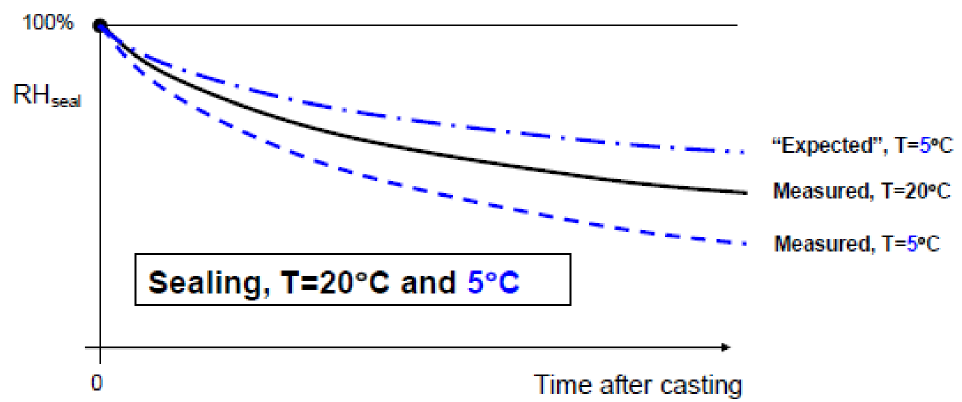


Figure 5: Drying for sealed conditions at 5°C compared with 20°C

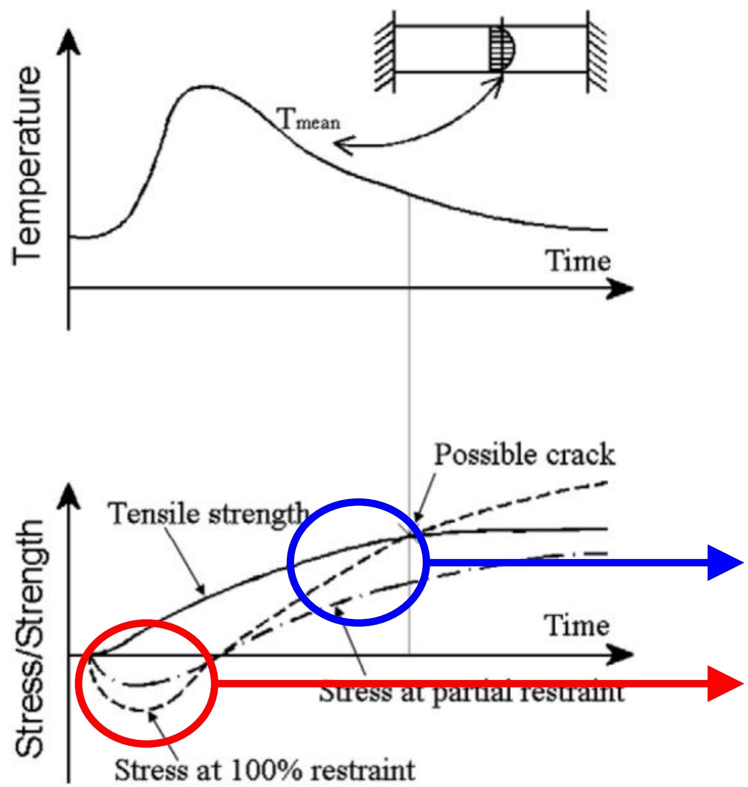
EFFECTS OF VARIABLE TEMPERATURE ON PROPERTIES OF EARLY AGE CONCRETE
J.-E. Jonasson and P. Fjellström
Microdurability, 2012

Influence of supplementary cementitious materials?

back to GP1.e overview

Round Robin Test (RRT) programme

Challenges: Creep at early-age during restrained shrinkage



- Effect of variable temperature?
- Tensile vs. compressive?

Tensile creep

Compressive creep

Fig. 3. Example of the mean temperature and stress and the strength development in a hardening concrete element restrained both partially and totally (degree of 100%) [9].

Nilsson, 2003

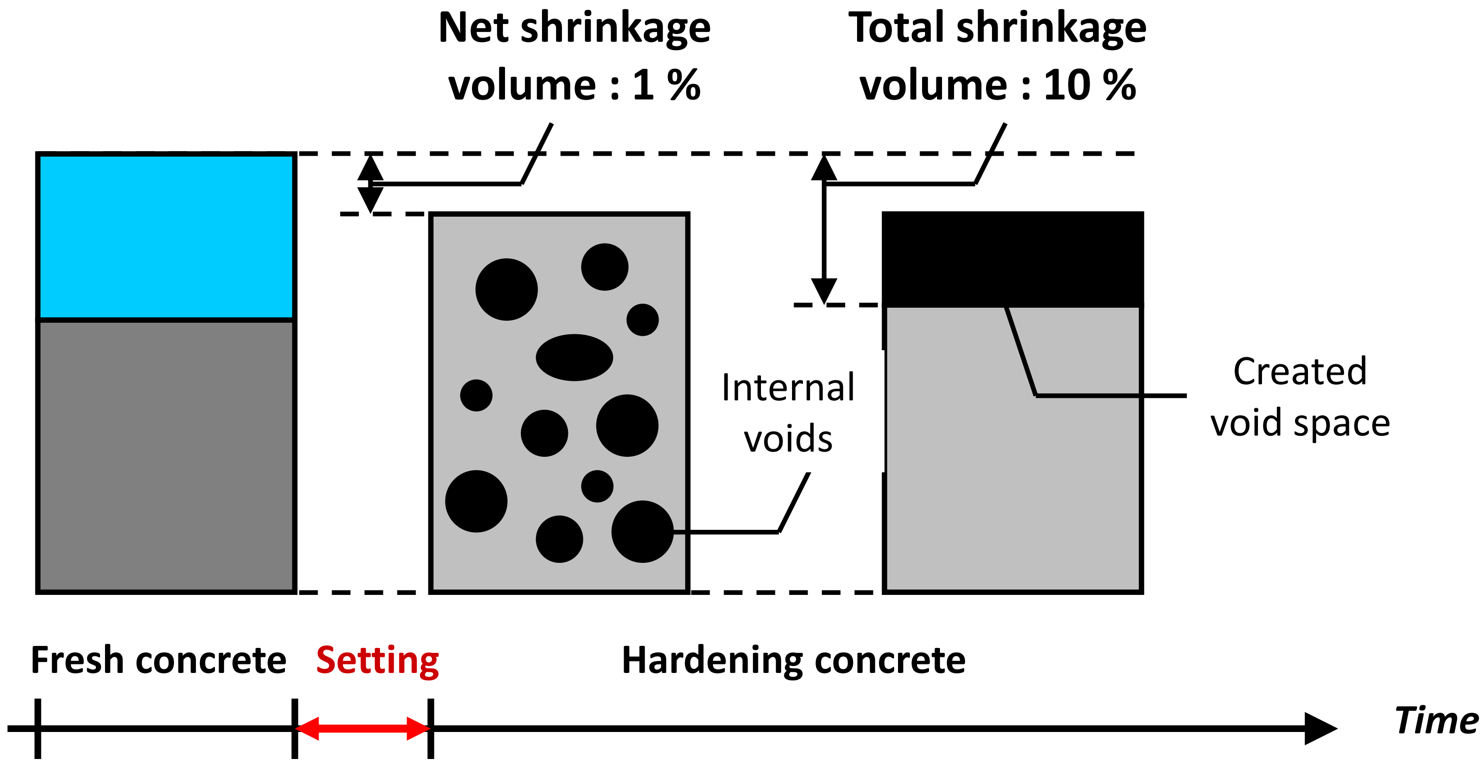
back to GP1.e overview

Causes and consequences of volume changes

Shrinkage-inducing phenomena

- **Chemical shrinkage and autogenous shrinkage**

Water + cement => hydration products



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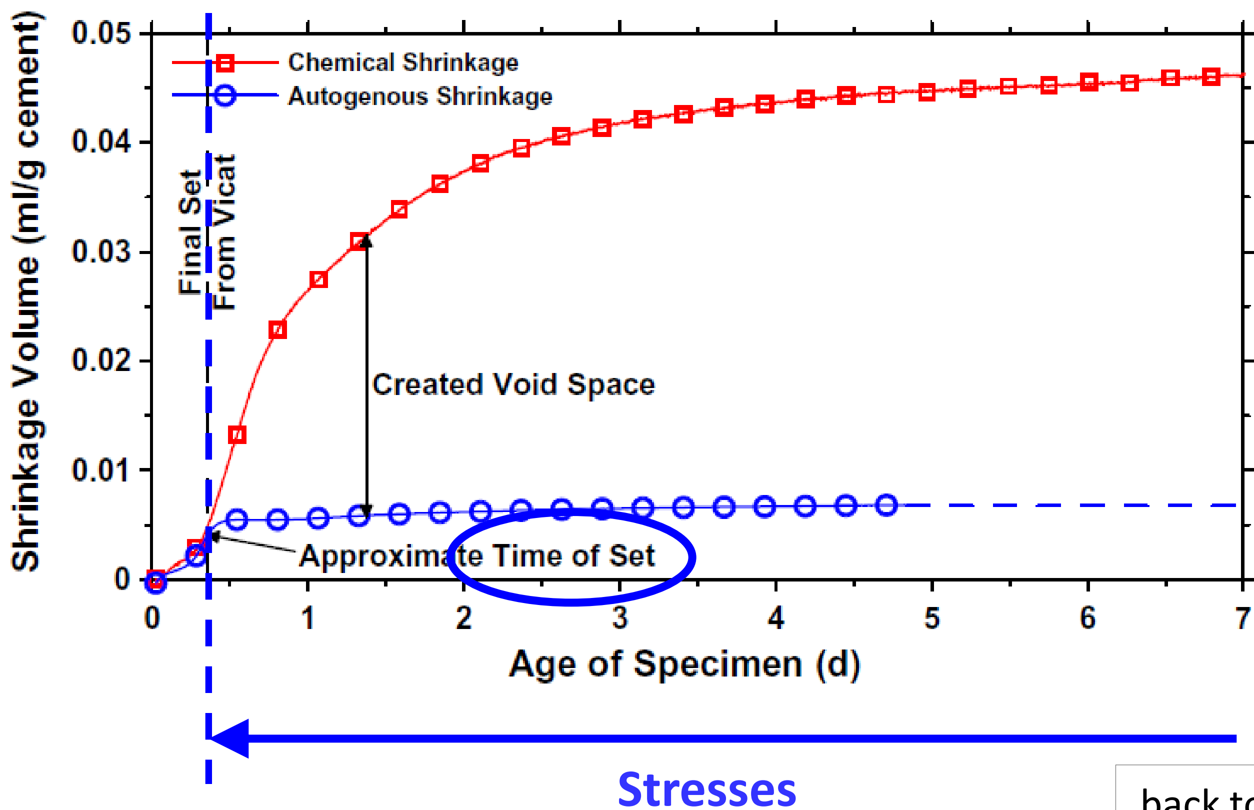
Causes and consequences of volume changes

Shrinkage-inducing phenomena

- **Chemical shrinkage and autogenous shrinkage**

Shrinkage volume of paste, W/C = 0.30 (Henkensiefken et al., 2008)



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Round Robin Test (RRT) programme

Autogenous and chemical shrinkage

	Cement paste	Mortar	Concrete
Linear measurements			
Horizontal testing			
Rigid moulds			
Flexible moulds			
Vertical testing			
Rigid moulds			
Flexible moulds			
Volumetric measurements			
Water level in a capillary tube			
Weight change of submerged sample			

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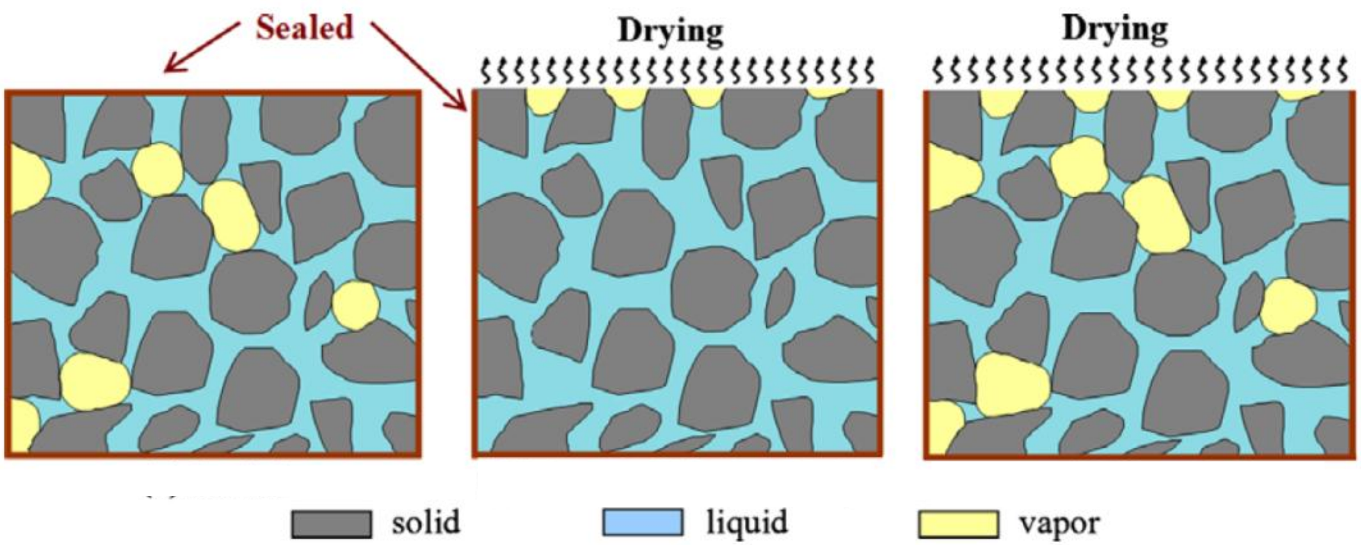
Causes and consequences of volume changes

Shrinkage-inducing phenomena

- **Plastic shrinkage**

Autogenous shrinkage: Internal drying + External drying = **Plastic shrinkage**



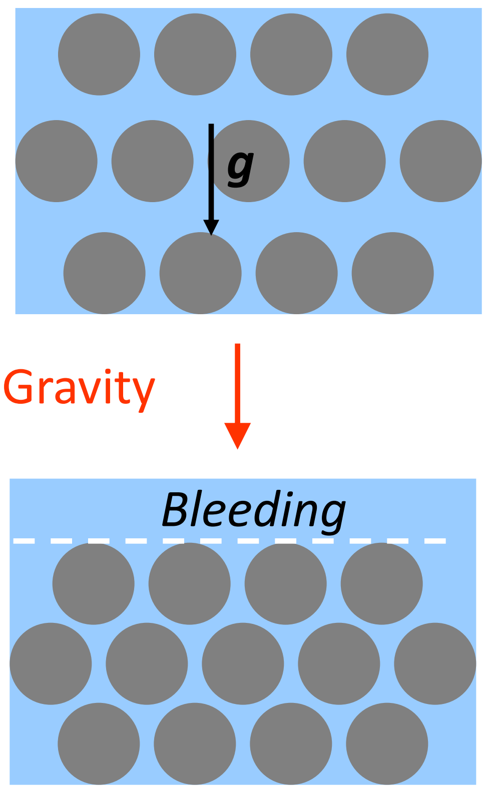
[Henkensiefken et al., 2009]

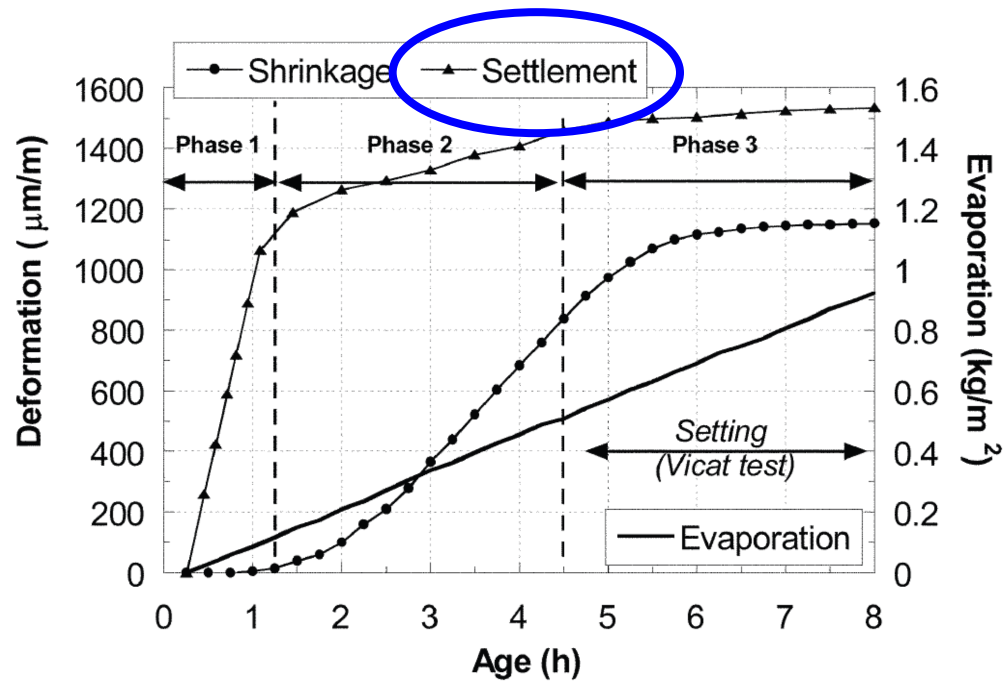
back to GP1.e overview

Causes and consequences of volume changes

Shrinkage-inducing phenomena

- **Plastic shrinkage** and settlement





Development of plastic shrinkage, settlement, and evaporation of SCC
[Turcry & Loukili, ACI, 2006]

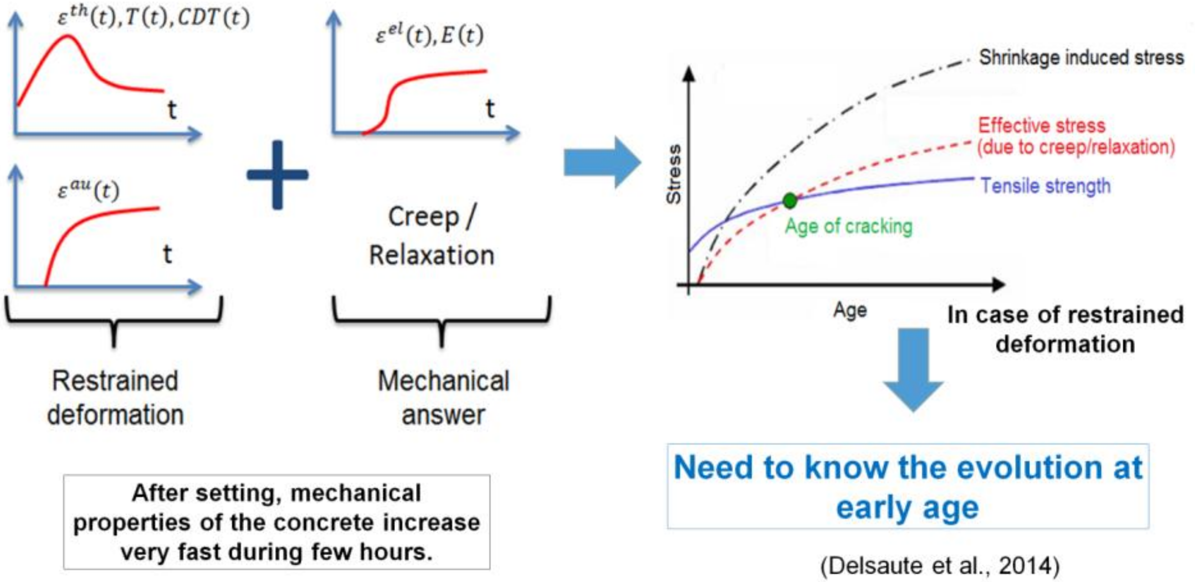
back to GP1.e overview

Early Age Measurement of the Autogeneous Shrinkage of a Concrete

C. Boulay, S. Ramanich, F. Baby, F. Toutlemonde, J.M. Torrenti – IFSTTAR
French institute of science and technology for transport, spatial planning, development and networks

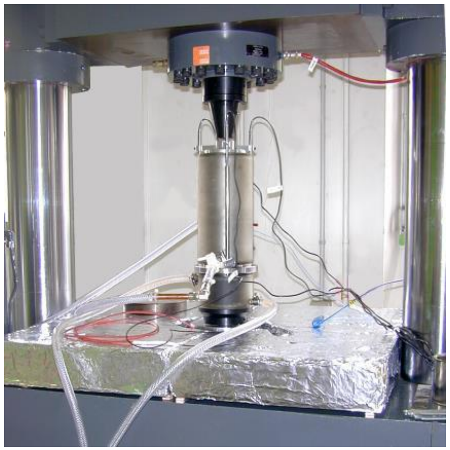
CONTEXT

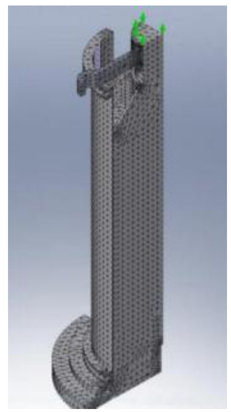
- Numeric computations and experimental data are needed for early age prediction of the structures behaviour.
- At early age, thermal and autogenous strains, if they are restrained, induce traversing cracks which lead to service life or safety reduction, and/or aesthetic problems.
- Numerous parameters are involved in the cracking process (thermal deformations, tensile strength, E-modulus, strength evolution, creep, relaxation…).



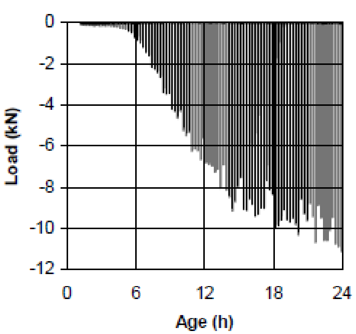
Early age mechanical behaviour of concrete : IFSTTAR equipments :

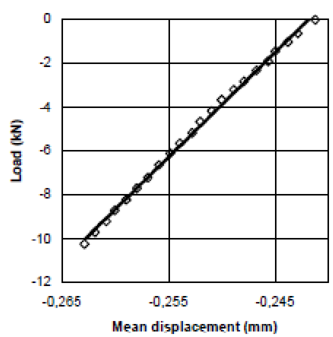
Elastic and viscous properties of concrete at early age

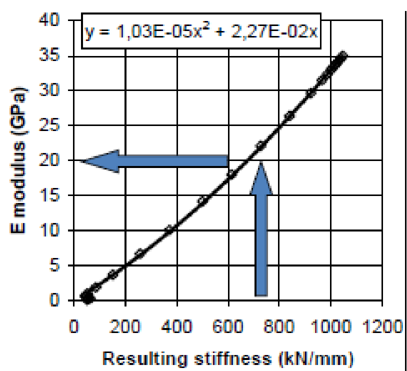




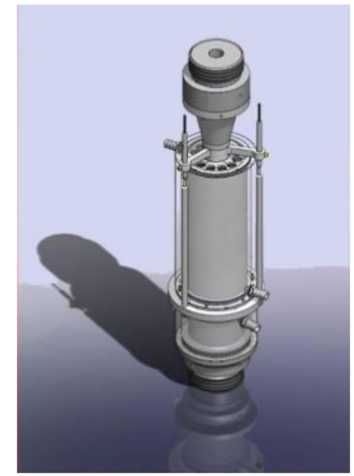
BTJASPE

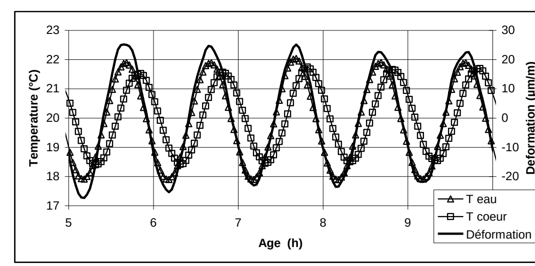






Coefficient of thermal expansion at early age





Early age mechanical behaviour of concrete : IFSTTAR equipments :

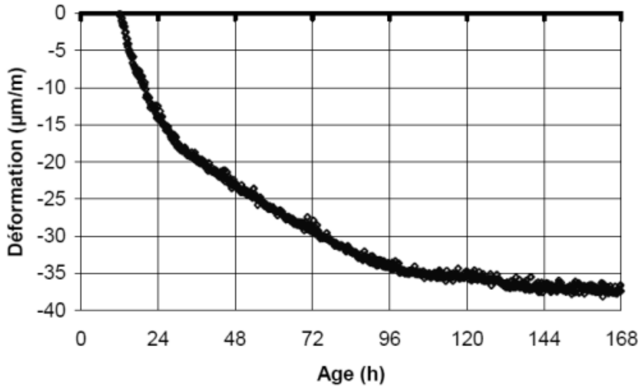
Autogeneous shrinkage

Autogeneous strains measurement of concrete

Setting time determination: Initiation BTJADE measurements

BTJADE

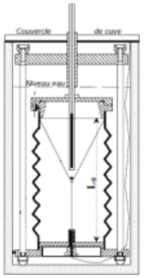
BTPULS

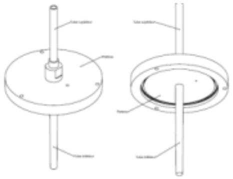


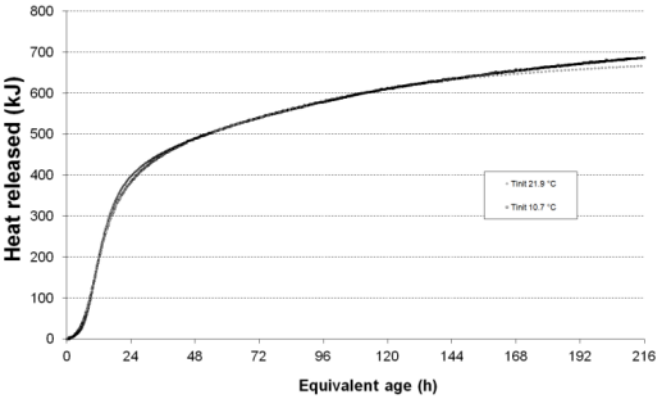
Calorimetry

Adiabatic and Quasi adiabatic calorimetry (heat released, Activation energy)

QACC

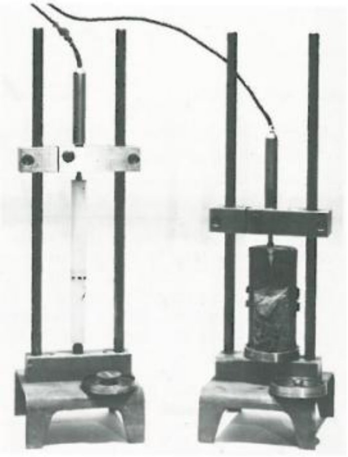


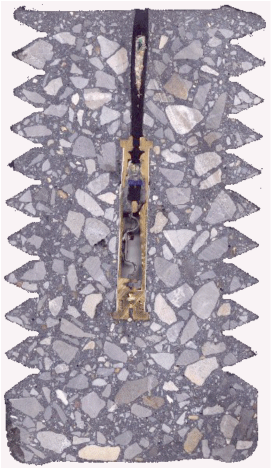




Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : History

- **Baron et al., 1977**: Friction in horizontal prisms
  Vertical frames, start after t_0.
- **Boulay et al., 1993**: Embedded gauges in corrugated moulds
- **First 2 prototypes design**: **Boulay (1997)**
  - First studies (2002, 2003) M. Moroni & F. Meloni, Cagliari University, Italy (+ congress RF2B, 2007)
  - Systematic testing (coop. ULB, S. Staquet).
- **Development of BTJADE (2006 - 2008)**

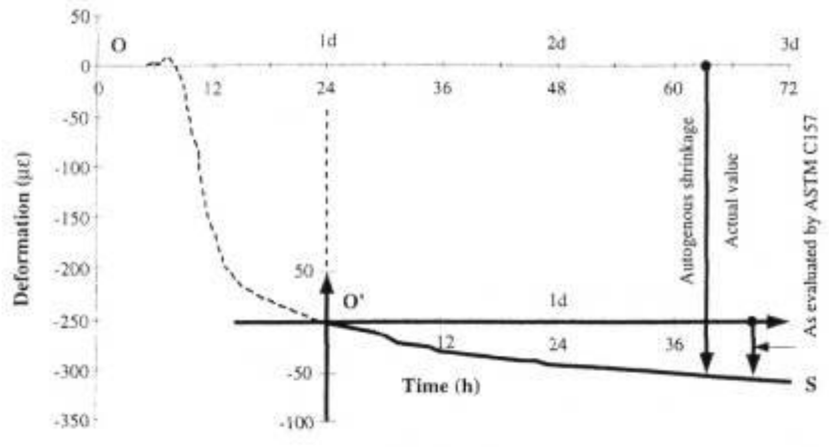


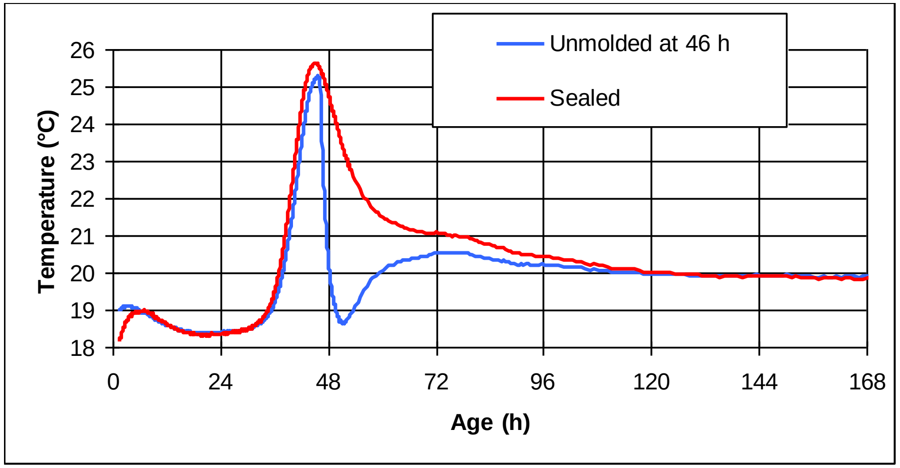


•Baron J., 1977
•Boulay C.et al., 1993
•Boulay C., 2007.
•S Staquet et al, 2008

Early Age Measurement of the Autogeneous Shrinkage of a Concrete : Standards methods

- Standards (P15 433, ASTM C157),
- Measurements start at 24 h. A great part of the shrinkage is forgotten[1].
- Shock of evaporative cooling during handlings[2].
- The temperature is not recorded. The degree of hydration is not well determined.

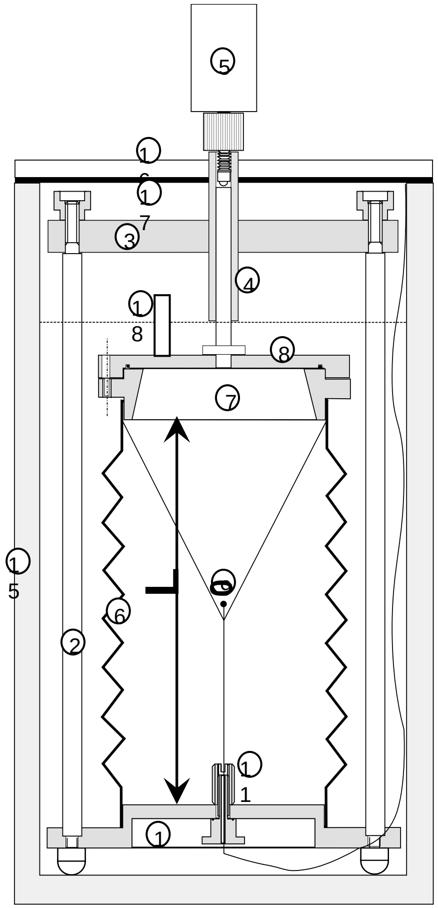




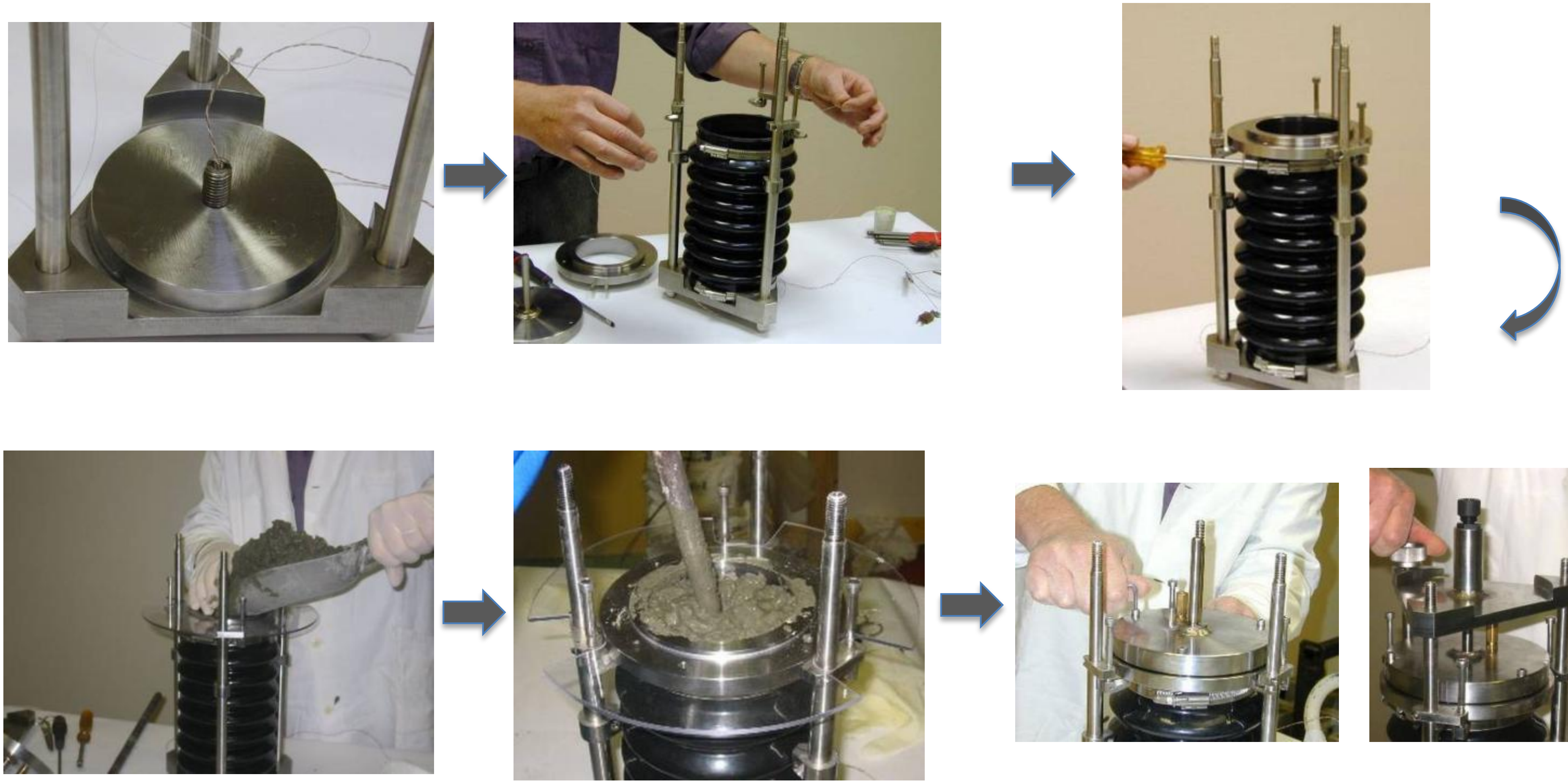
[1] *Aïtcin P. C., Autogenous shrinkage measurement, Autoshrink 98, Workshop on Autogenous Shrinkage of Concrete, E. Tazawa editor, Hiroshima, Japan, 1998, 245-256.*

[2] *Kovler, K. Shock of evaporative cooling of concrete in hot dry climates. Concrete International, 1995, V. 17, No. 10, pp. 65-69.*

Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : design



Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Protocol



Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Protocol

Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Analyzing

$\Delta\varepsilon_t$: Total strains

$\alpha_0\, \Delta\theta$: Thermal strains

$\Delta\varepsilon_e$: Cumulated shrinkage and swelling strains

α_0 : *CTE of sample (determined with steps at the end of the test)*

$\mathbf{L_0}$: **Base length**

$\mathbf{\Delta l_m}$: **Measured displacement**

$\Delta\theta_0$: ***Temperature variations of the sample***

$\mathbf{\Delta\theta_{ec}}$: **Temperature variations of the water inside the tank**

$\mathbf{\Delta\theta_{sc}}$: **Temperature of the air measured above the cover of the tank**

$C_{\theta ec}$: Thermal coefficient (temperature changes in the water of the tank)

$C_{\theta sc}$: Thermal coefficient (temperature changes above the cover of the tank)

TESTING CONDITIONS

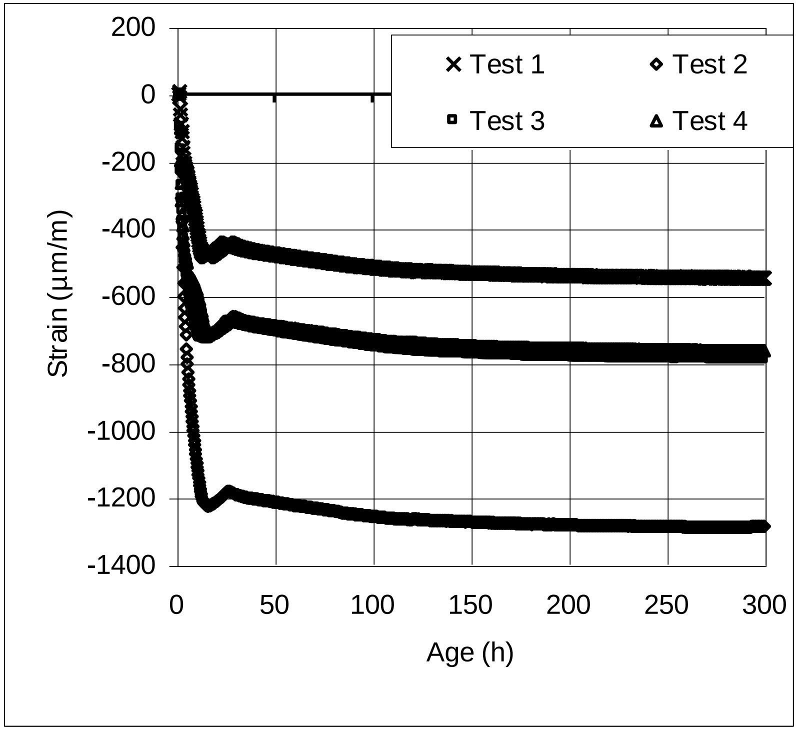
- θ_0 = 20 °C
- t_0 is known
- Δ: between t and t_0
- No stress
- No drying

$$\Delta\varepsilon_t = \Delta\varepsilon_e + \alpha_0\, \Delta\theta_0 \quad (1)$$

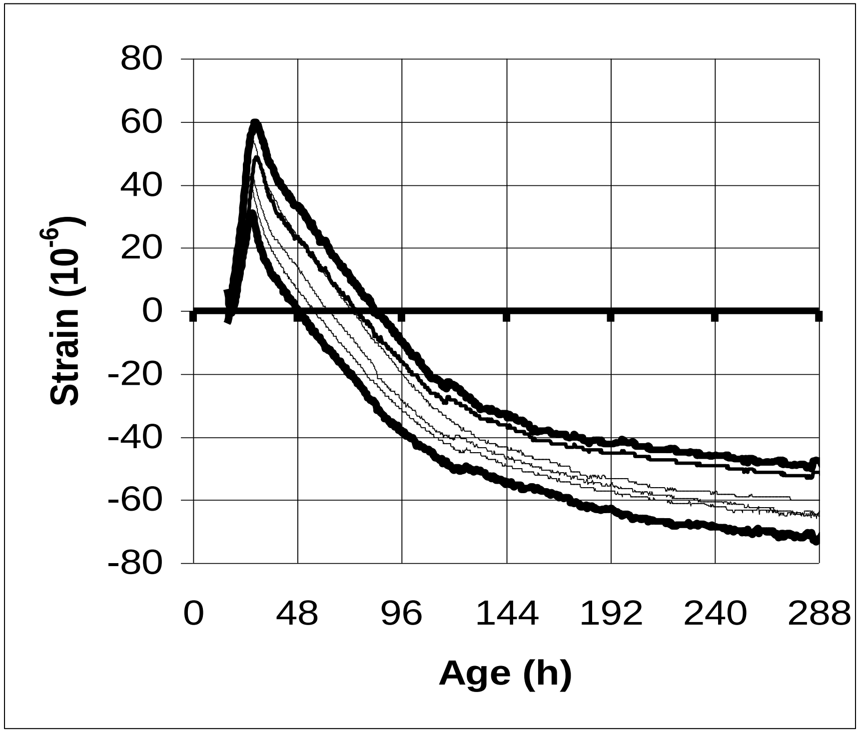
$$\Delta\varepsilon_e + \alpha_0\, \Delta\theta_0 = (C_{\theta ec}\ \Delta\theta_{ec} + C_{\theta sc}\, \Delta\theta_{sc} - \Delta l_m) / L_0 \quad (2)$$

$$\Delta\varepsilon_e = (C_{\theta ec}\ \Delta\theta_{ec} + C_{\theta sc}\, \Delta\theta_{sc} - \Delta l_m) / L_0 - \alpha_0\, \Delta\theta_0 \quad (3)$$

Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Raw data / Strain initialization



t_0 at the beginning of the measurements

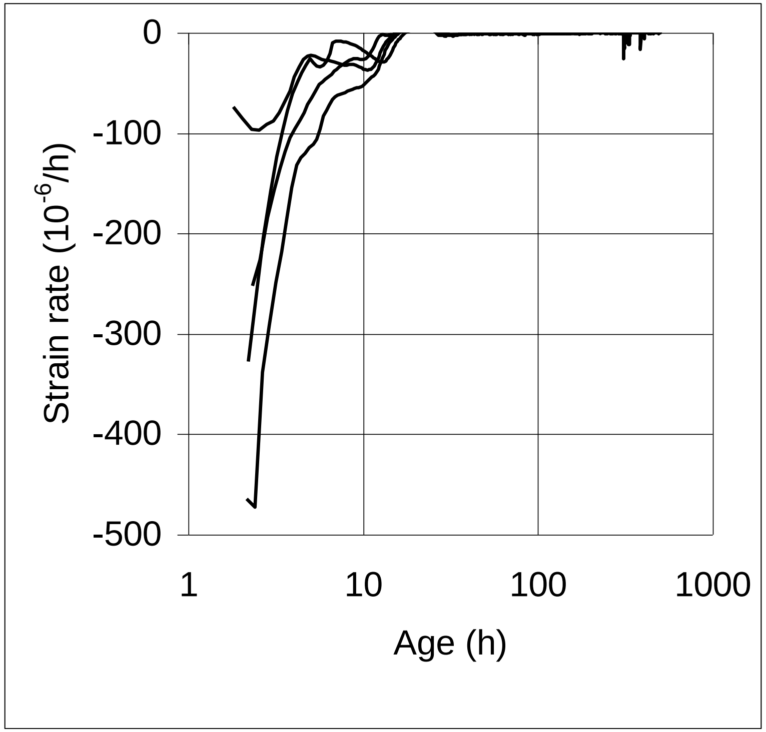


t_0 at the beginning of the swelling

4 successive batchs (concrete1) / 2 weeks recordings.

Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Raw data / Strain initialization

Strain rate :



- Swelling starts at 15.5, 15.8, 16 and 17.5 h

  (Swelling is when 0 < strain rate)
- Closer view : no special event.
- **Swellings are not observed in any case**
- **Strain rate is not reliable for concretes**

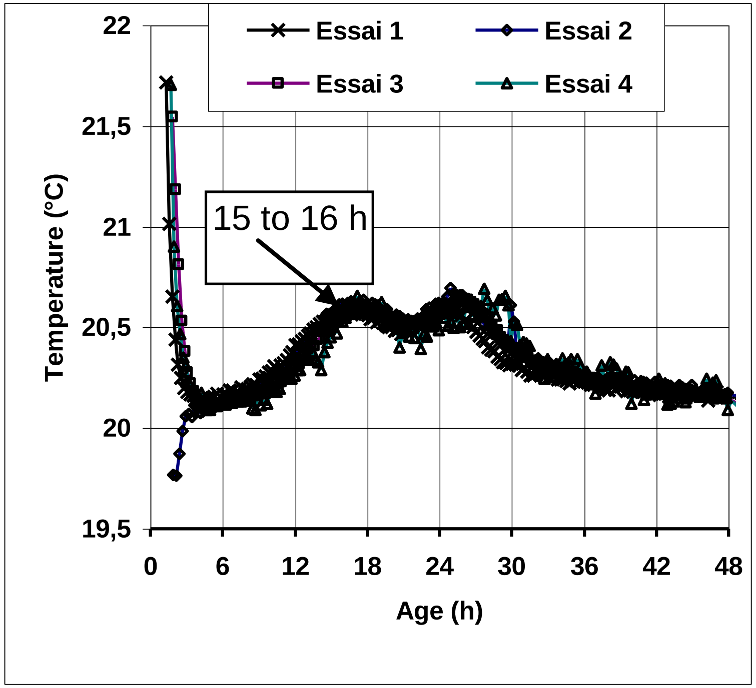
Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Raw data / Strain initialization

Temperature rate :

•Reproducible hydration process

•It is worth to underline that the temperature rate becomes null at the same age than the age of the swelling.

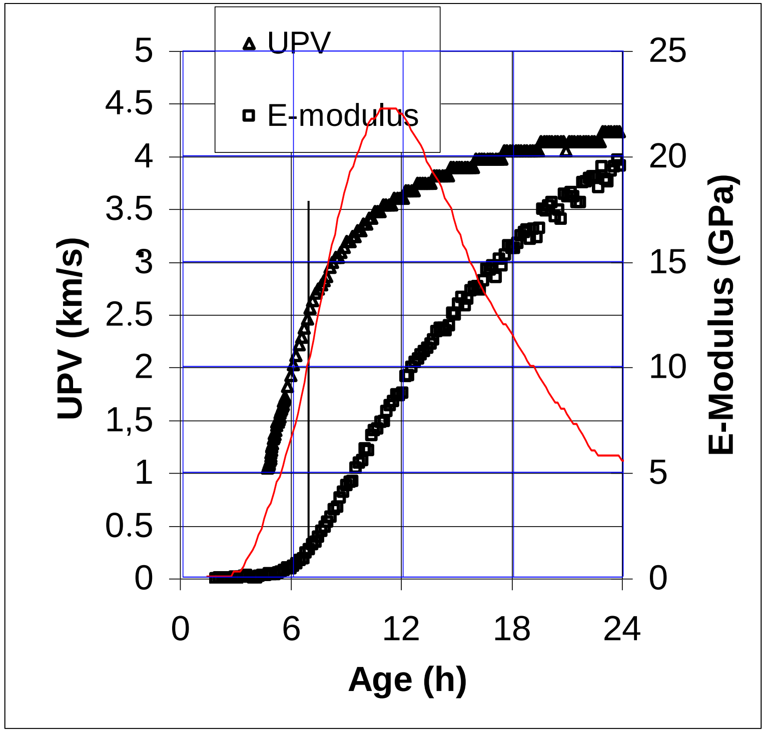
•**Temperature observations are more linked to chemical processes than to mechanical evolutions.**



Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Raw data / Strain initialization

Associated measurements :

- Ultrasonic Pulse Velocity : BTPULS
- E modulus monitoring[1] : BTJASPE
- Setting time: samples do not brake when handled :
  - Bottom end of the linear part of the E modulus curve.
  - UPV = 2500 m/s.
- Temperature monitoring: no particular event at this time.



Concrete 2

1 C.Boulay, E. Merliot, S. Staquet, O. Marzouk, *Monitoring of the concrete setting with an automatic method*

13th International Conference and Exhibition : Structural Faults and Repair, , Edinburgh, UK, 15th–17th June 2010

Early Age Measurement of the Autogeneous Shrinkage of a Concrete : BTJADE : Conclusions

- BTJADE : test rig for autogenous shrinkage measurements designed and developped by Claude Boulay. This equipment is used by IFSTTAR and ULB.
- Strain measurements take into account influential factors.
- The strain measurements are counted since the setting time of concrete
- Methods for setting time determinations have been examined :
    - Temperature monitoring, strain rate monitoring are not well adapted for this purpose on concretes.
    - Emodulus monitoring (BTJASPE) : the most reliable but not so easy to conduct
    - UPV measurements : promising but need additional studies (comparison between static and dynamic methods for different concretes)

Autogenous and thermal deformations of concrete at early age : sum or coupling ?

A. Loukili,Ph.Turcry, P. Mounanga

Institut de recherche en génie Civil et mécanique
UMR-CNRS 6183
Ecole Centrale de Nantes – France

1ST WORKSHOP OF TU1404 - LJUBLJANA - APRIL 16-17 2015

Introduction

- *Autoschrink'98 workshop, Hiroshima in Japan*

« AS is the macroscopic volume reduction of cementitious material after Initial Setting. AS does not include the volume change due to temperature variation….. »

- At early age, TD and AD occur simultaneously !
- In lab, AD Tests are performed at constant T (AD is merely corrected!)

back to GP1.e overview

Classical assumptions

$\varepsilon_{total} = \varepsilon_{el} + \varepsilon_{sh} + \varepsilon_{basic\ creep}$

1. $\varepsilon_{sh} = \varepsilon_{th} + \varepsilon_{au}$

$\varepsilon_{th} = f\ (T, TDC)$

2. **AD** depends only on the degree of hydration α

Scientific Approach

- ✓ Hydration – Temperature - autogenous shrinkage Relationship at early age
- ✓ Determination of Apparent Activation Energy Ea
- ✓ Maturity concept for predicting AD at different temperatures ?

back to GP1.e overview

Experimental Approach

- **Material :**
  - ✓ Mortar with Cement CEMI
  - ✓ W/C = 0.25, 0.3, 0.35, 0.4
- **Hydration monitoring :**
  - ✓ Thermogravimetric Analysis (0 - 24 h)
- **Shrinkage Measurement (**W/C = 0.25) **:**
  - ✓ Volumetric method based on Archimed principle
  - ✓ Isothermal Tests : 10 °C, 20 °C, 30 °C, 40 °C, 50 °C
  - ✓ Realistic Tests : 10 – 40 °C; 20 – 30 °C; 20 – 60 °C

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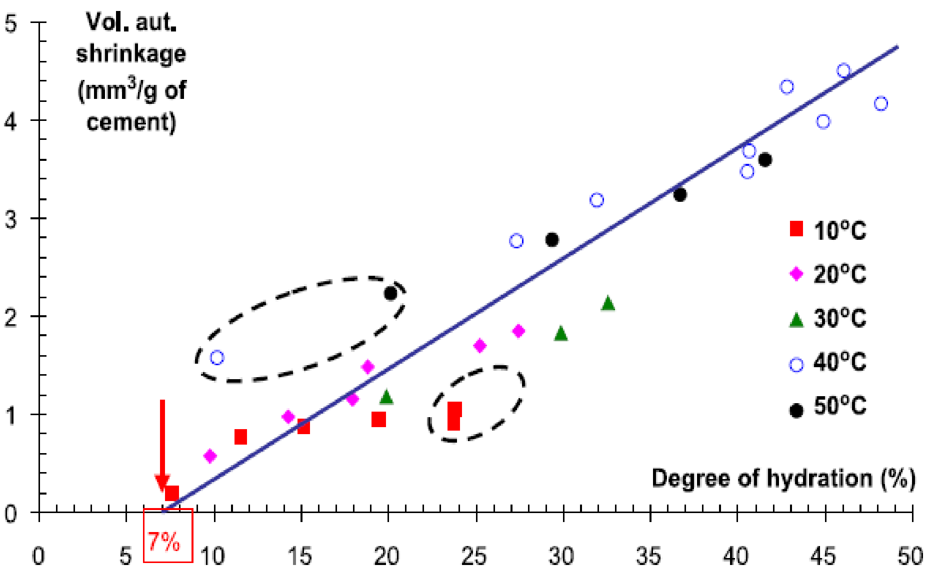
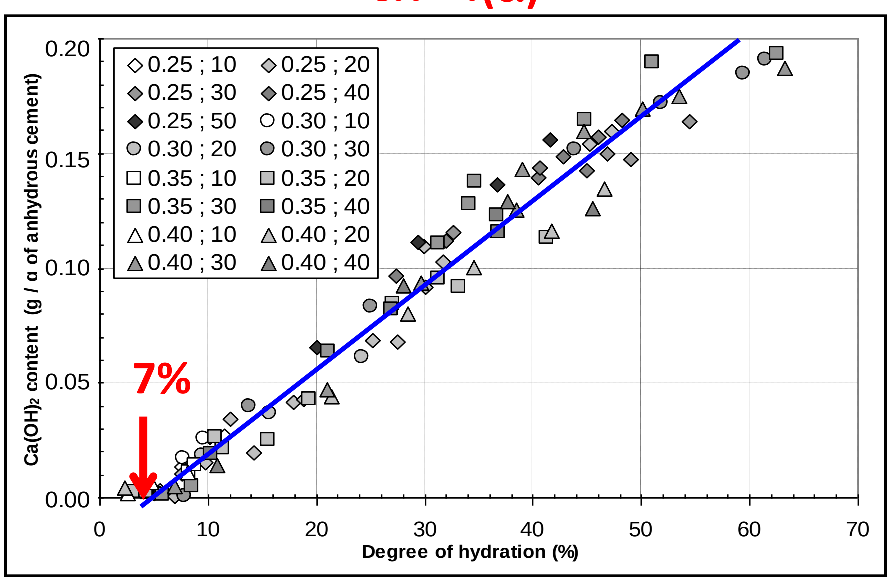
Microscopic Results

AD = f(α)



CH = f(α)



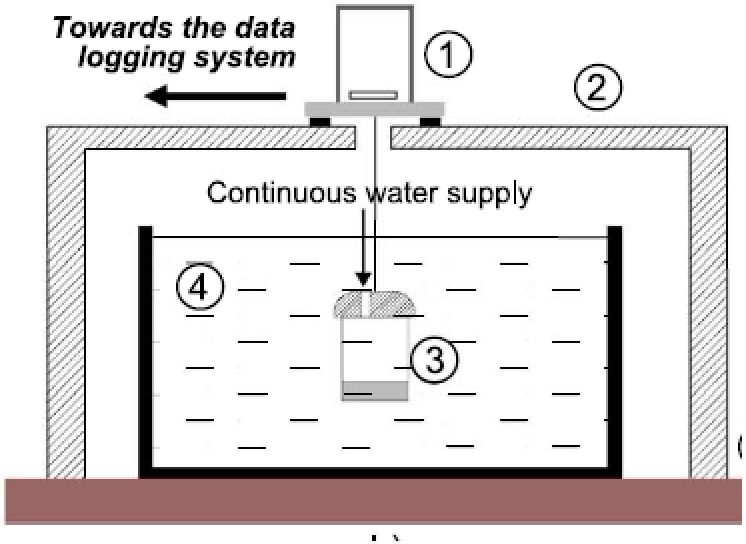
- **Quasi-linear relationship between AD and α Independent of T**
- **the second assumption seems to be verified**

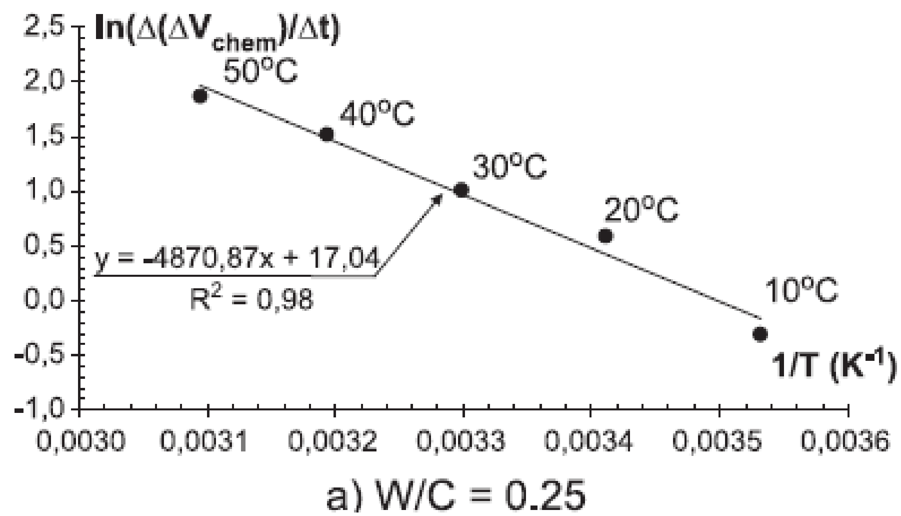
- **Unique and quasi-linear Relation Independent of T and W/C, fr**

- **α ~ 7 % : Precipitation threshold of portladite = initial setting !**

back to GP1.e overview

Determination of Activation Energy





Chemical shrinkage setup

- ***Before setting*** : E_a ***= 29 kJ/mol***
- ***During and after setting*** : E_a ***= 39 kJ/mol***

Arrhénius Law : $$t_{eq} = \int_0^t \exp\left(-\frac{E_a}{R}\left(\frac{1}{T(\tau)} - \frac{1}{T_{ref}}\right)\right) d\tau$$

L. D'Aloïa, G. Chanvillard, Determining the "apparent" activation energy of concrete Ea—numerical simulations of the heat of hydration of cement, Cem. Concr. Res. 32 (8) (2002) 1277–1289.

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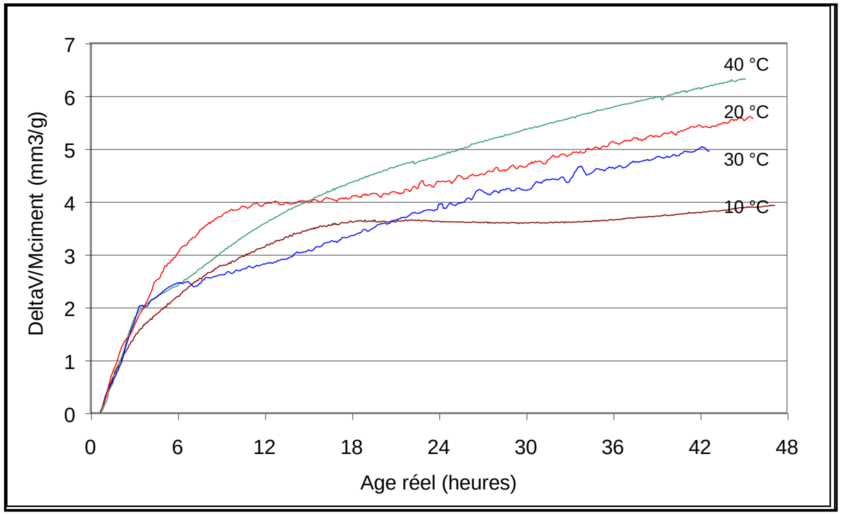
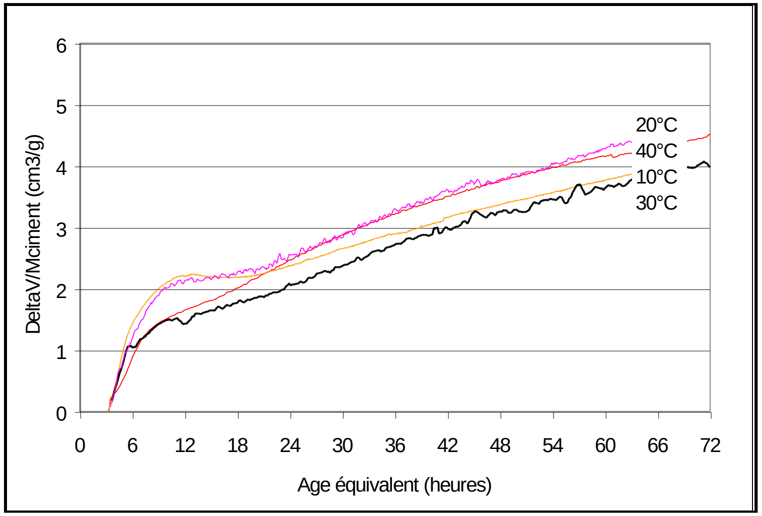
AD in Isothermal Tests





AD versus Real Age

AD versus Maturity

Unsystematic effect of Temperature on AD

Similar trends of curves at different temperatures

=>Under 40°C, The Maturity concept allows predicting AD in isothermal Conditions

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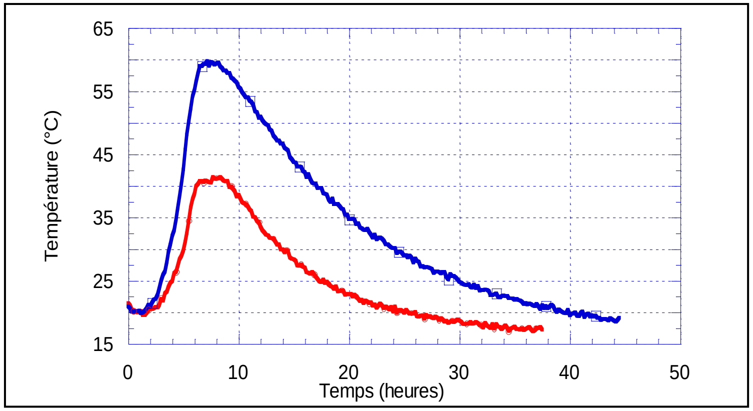
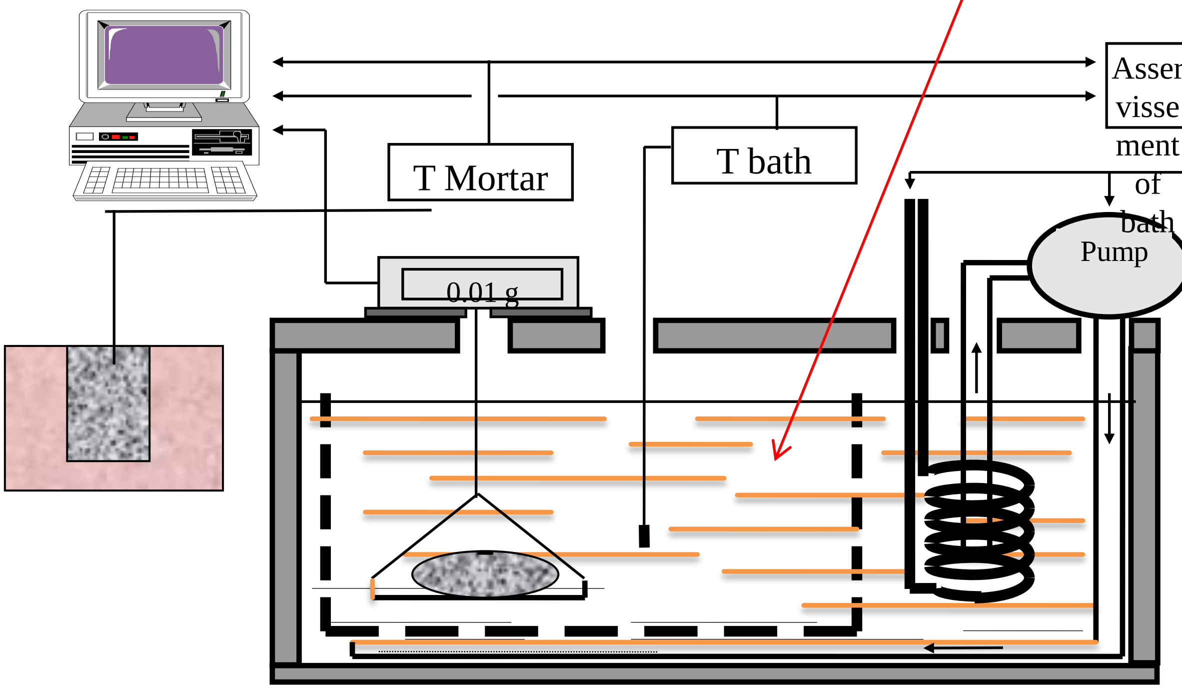
AD in Realistic Tests



✓ Three Temperature ranges : 10 – 40 °C; 20 – 30 °C; 20 – 60 °C

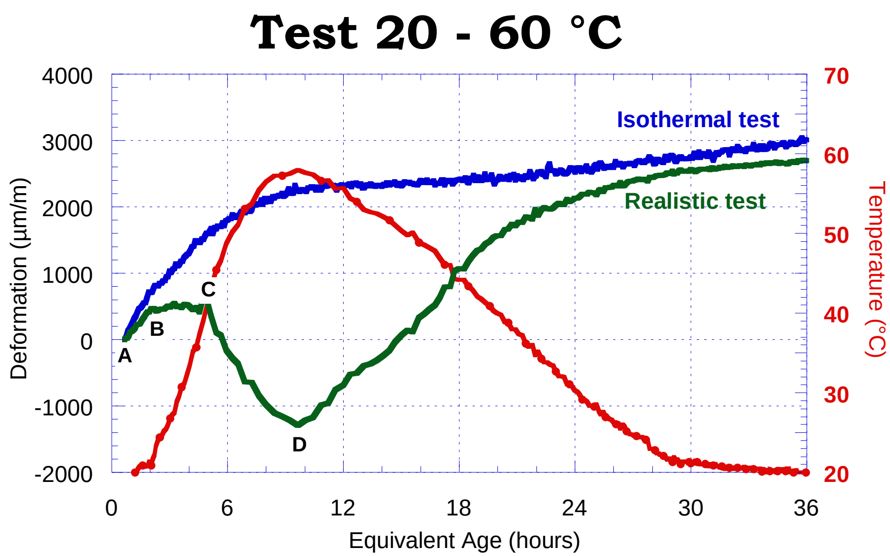
The bath Temperature is imposed by mortar sample placed in a quasi-adiabatic enclosure after casting.

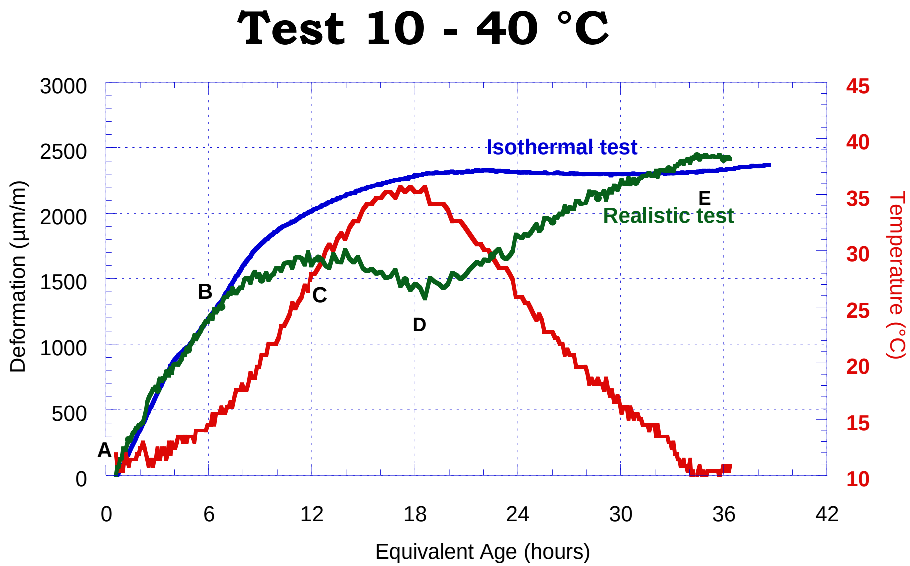


$$\frac{\Delta V}{M_c} = \left[\left(\frac{\rho_{iw}}{\rho_w(T)} - 1\right) - \frac{M_r}{V_i \rho_w(T)}\right]\frac{V_i}{M_c}$$

back to GP1.e overview

AD in Realistic Tests





Decoupling TD and AD

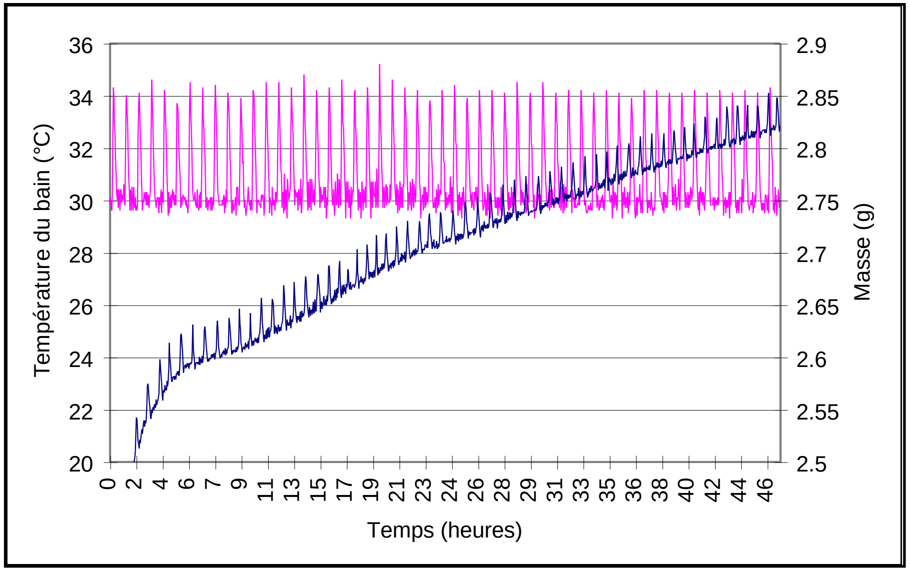
⇒ Need of Thermal Dilation Coefficient (TDC)

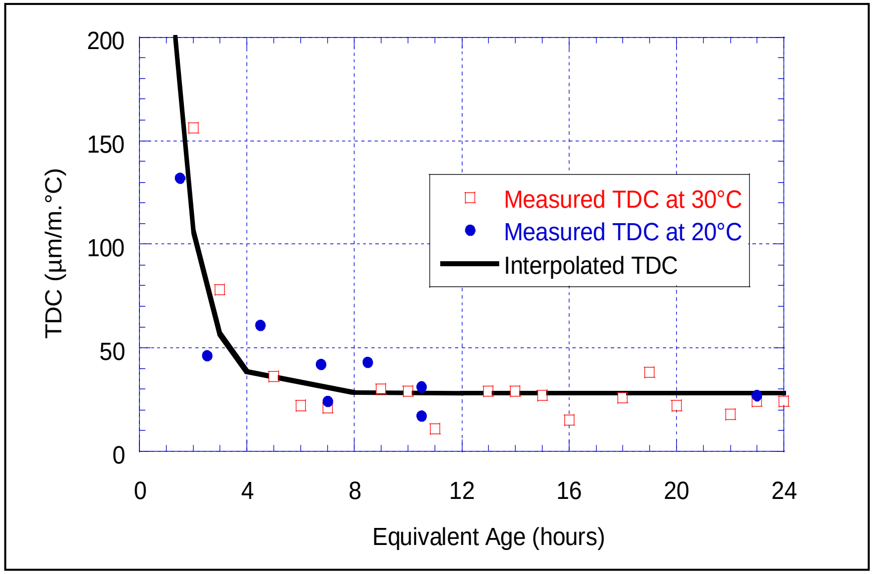
back to GP1.e overview

Monitoring of TDC during isothermal tests

Method : the Cememntitious material undergoes a Spontaneous heating-cooling and the volumetric variation is measured by hydrostatic Weighing

Two temperatures : 20 and 30 °C





$$TDC(t_{equ}) = 137 * \exp(1.44 - t_{equ}) + 28.$$

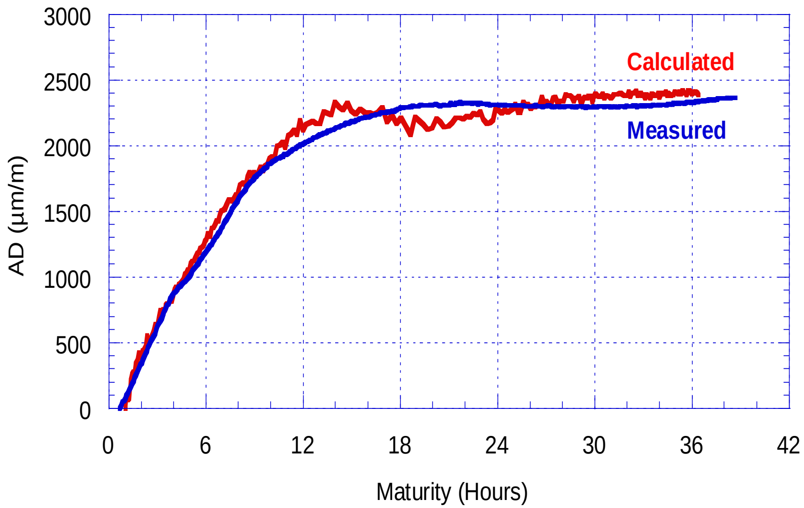
$$\varepsilon_{th} = TDC\,(t_{equ}) * \Delta T$$

[3] A. Loukili, D. Chopin, A. Khelidj, J.Y. Le Touzo, A new approach to determine autogenous shrinkage of mortar at early age considering temperature history, Cem. Concr. Res. 30 (6) (2000) 915–922.

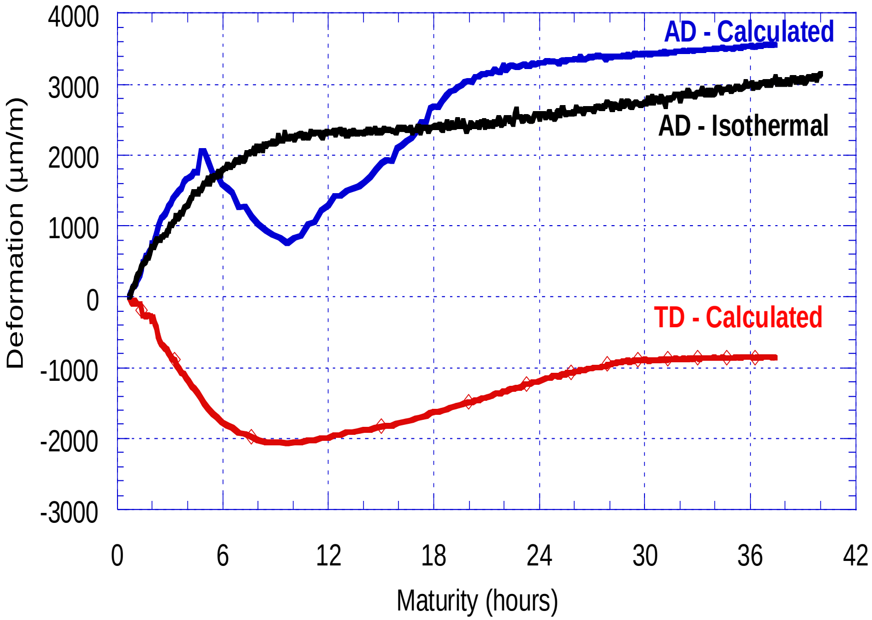
back to GP1.e overview

Decoupling Results

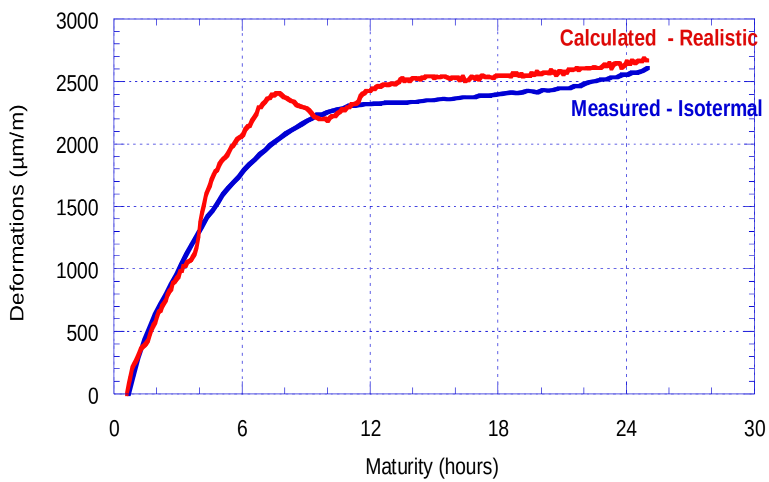
[10°C - 40°C]



[20°C - 60°C]



[20°C - 30°C]



back to GP1.e overview

Conclusions

- ✓ Quasi-linear relationship between AS, CH and α at different temperatures
- ✓ Chemical shrinkage is a simple and efficient tool to determine the Activation Energy of cementitious Materials.
- ✓ Maturity Concept allows the prevision of AD for temperatures under 40 °C.
- ✓ Beyond 40 °C, the AD amplitude seems to be strongly affected the temperature (strong Coupling !).
    - Complex phenomena related to the structuration of the material.
    - Determination of TDC under isothermal test is not sufficient !
- ✓ Necessity to include a research program on determination of TDC in realistic conditions in COST 1404.

back to GP1.e overview

TU 1404 COST ACTION

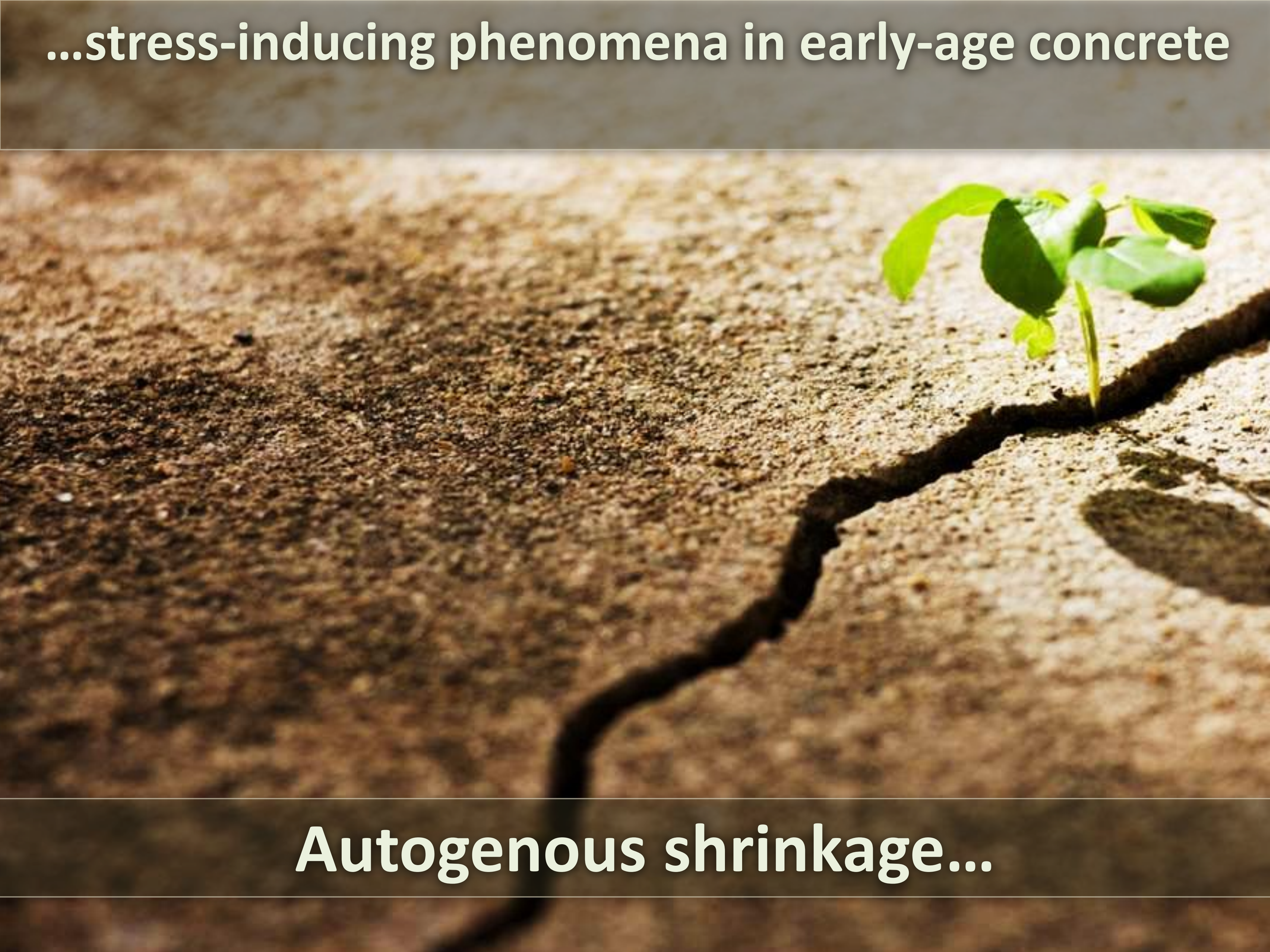
EXPERIMENTAL ASSESSMENT OF AUTOGENOUS SHRINKAGE

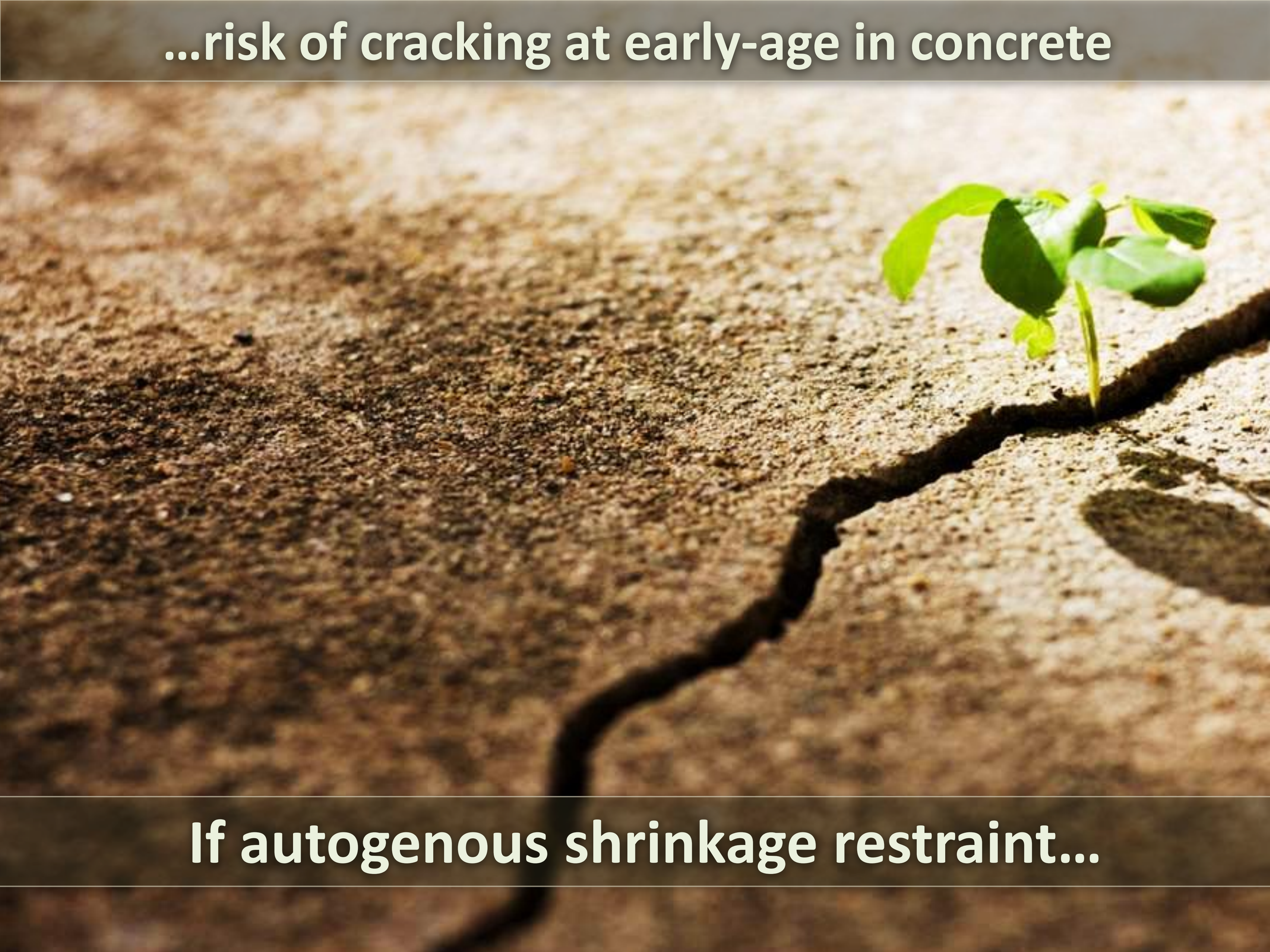
S. Staquet, B. Delsaute – LGC – Civil Engineering Lab – ULB – Brussels, Belgium

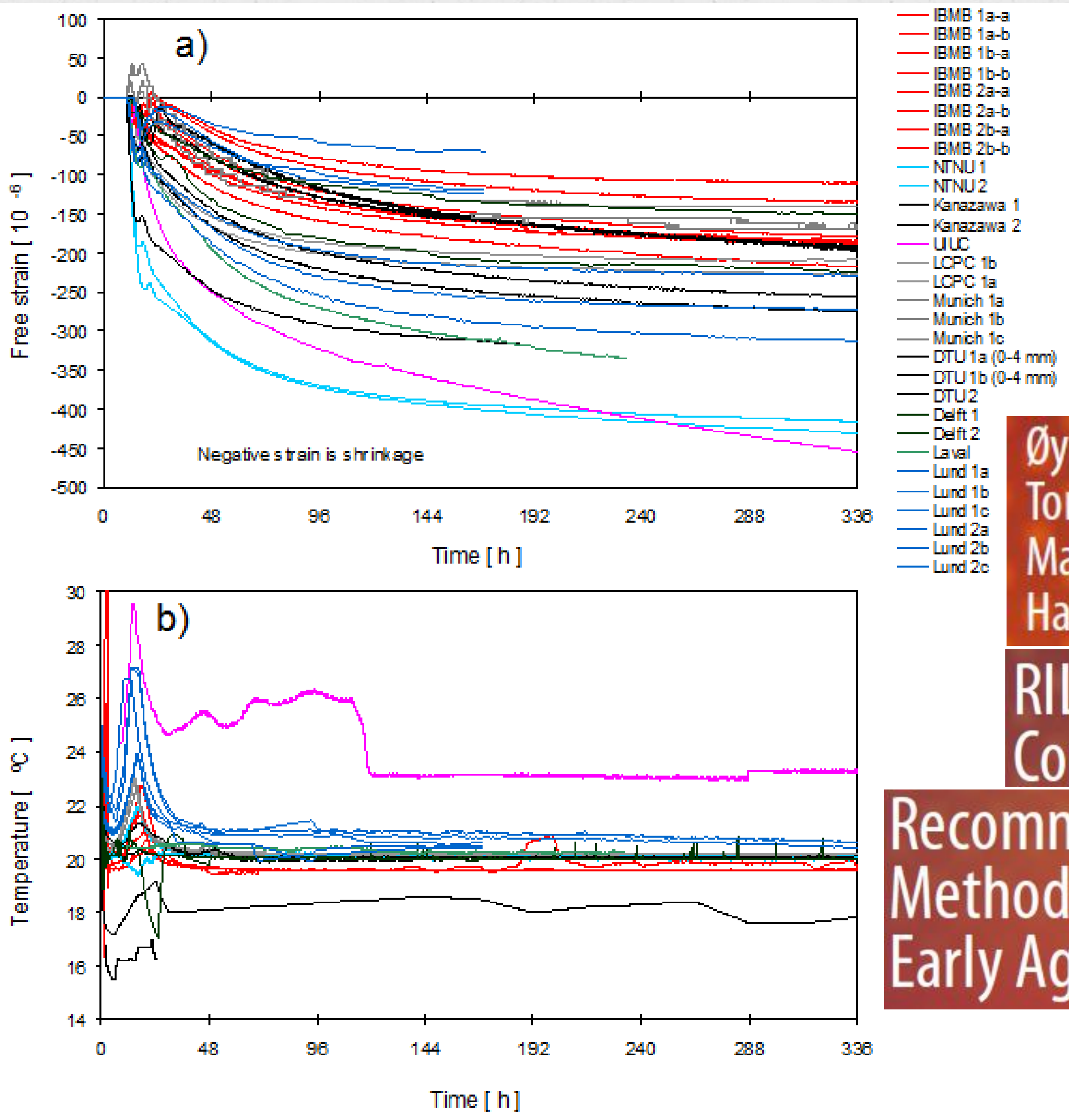
E. Rozière, A. Loukili- GeM – Centrale Nantes, Nantes, France

S. Eppers - VdZ – Stuttgart, Germany

ULB ECOLE POLYTECHNIQUE DE BRUXELLES BATir vdz. ECN Centrale Nantes GeM Institut de Recherche en Génie Civil et Mécanique


…stress-inducing phenomena in early-age concrete
Autogenous shrinkage…


…risk of cracking at early-age in concrete
If autogenous shrinkage restraint…



Øyvind Bjøntegaard
Tor Arne Martius-Hammer
Matias Krauss
Harald Budelmann

RILEM Technical Committee 195-DTD

Recommendation for Test Methods for AD and TD of Early Age Concrete

back to GP1.e overview

Laboratory of Civil Engineering – TU 1404 cost action

GP1.a, f

Calorimetry measurements (cement paste, mortar or concrete)

TAM Air Isothermal Calorimeter


Semi-Adiabatic Calorimeter


Adiabatic Calorimeter

- Heat flow, cumulated heat release
- Degree of hydration
- Adiabatic temperature rise
- Comparison paste-mortar-concrete

Ultrasonic transmission measurements (cement paste, mortar or concrete)


FreshCon setup for the simultaneous measurement of P-wave and S-wave transmission


Smart Aggregates : embedded piezoelectric transducers (P-wave)
left : piezoelectric patch; center : waterproof coating; right : smart aggregate

- P+S wave transmission information (energy, frequency, amplitude, velocity)
- Setting time determination
- Dynamic elastic properties
- Development of damage index with embedded sensors

LGC Laboratory of Civil Engineering – TU 1404 cost action

GP1.d, e, f

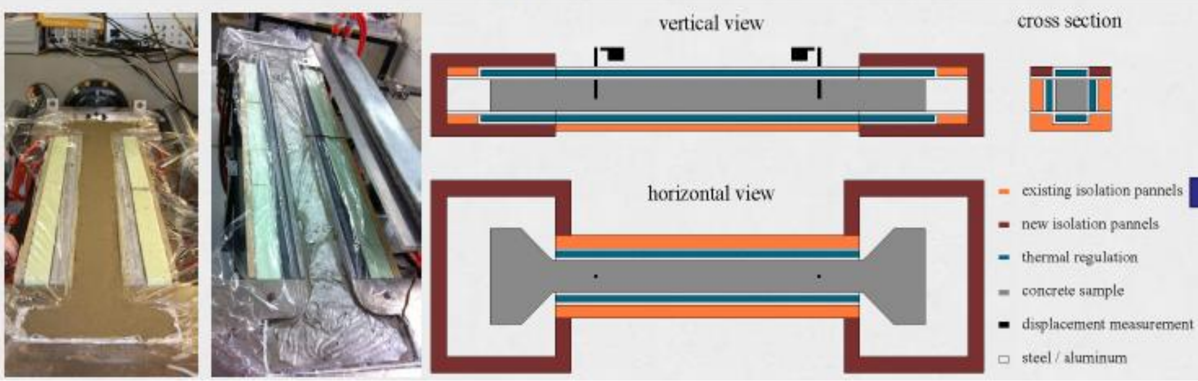
Autogenous deformations (cement paste, mortar or concrete)

Left : vertical linear measurement, middle: volumetric measurement, right : horizontal linear measurement

Autogenous deformations
- isothermal conditions
- specific temperature history
- since before the setting time

Coefficient of thermal expansion
- since the setting time
- cyclic methodology

Temperature Stress Testing Machine (mortar or concrete)



Isothermal / realistic temperatures (5-50° C)
Sealed / unsealed conditions (50%-100% RH)

Elastic modulus
- tension/compression
- since the setting time
- cyclic methodology

Creep / Relaxation (dummy mould)

Free / Restrained deformations tests

AUTOGENOUS SHRINKAGE MONITORING

- **NO REAL CONSENSUS** due to many practical difficulties
- **ARTEFACTS TO BE AVOIDED**
  - **Specimen perfectly sealed** (no external drying or water uptake)
  - **Temperature must be kept constant** (need of an external control since the hydration of cement releases heat)
  - **Test rig designed to limit friction** with the specimen
- **NUMEROUS METHODS: volumetric and linear measurements**

VOLUMETRIC MEASUREMENT

- **AUTOGENOUS SHRINKAGE:** isotropic volume change

	• **Measure of the amount of liquid displaced by the submerged sample…artefacts**
Water level in a capillary tube	– **Absorption of water by the membrane to take into account** (Mitani, 2003)
Weight change of submerged sample	– **Water replaced by other liquids as paraffin oil to avoid water uptake** (Lura and Dunant, 2006) – **Bleeding prevented by rotating the specimen** (Justnes et al, 1998, Lura et al, 2003, Mounanga, 2003, Bouasker, 2007)

- **For CEMENT PASTES and MORTARS:** reliable measurements can be provided by volumetric methods

LINEAR MEASUREMENT: horizontal testing

- **RIGID MOULDS:** minimization of the friction
- **FLEXIBLE MOULDS:** isotropic volume change

Rigid moulds	• **If friction between the specimen and the mould, then underestimation of the magnitude of shrinkage…artefacts** – **Use of a membrane such as plastic foil with talcum powder** • **If temperature is not controlled…artefacts** – **Use of a water circulation in the walls of the mould** (Lokhorst, 1996; Bjontegaard, 1999, Turcry et al., 2006)
Flexible moulds	• **If temperature is not controlled…artefacts** – **Use of a thermostatic bath** (Jensen and Hansen, 1995)

LINEAR MEASUREMENT: vertical testing

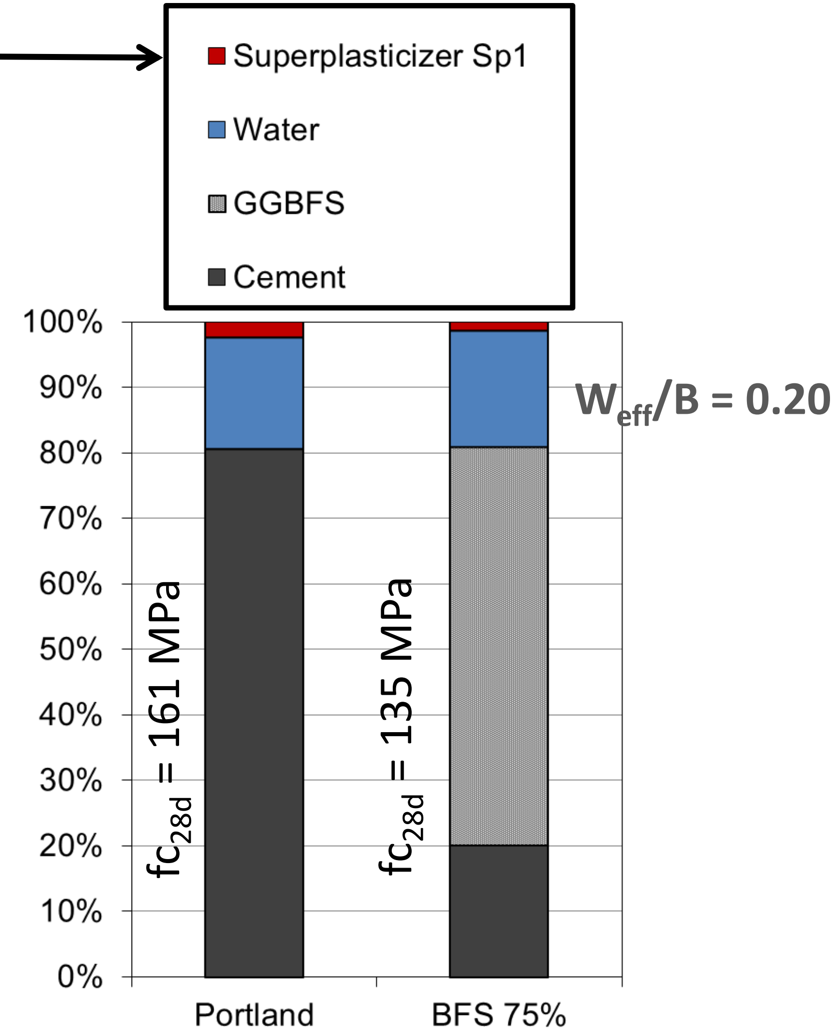
- **RIGID MOULDS:** isotropic volume change
- **FLEXIBLE MOULDS:** isotropic volume change

Vertical testing	
Rigid moulds	• **If friction between the specimen and the mould, then underestimation of the magnitude of shrinkage…artefacts** – **Use of a Teflon moulds** (Le Roy, 1996, Brooks, 2001, Craye, 2006, Darquennes, 2009)
Flexible moulds	• **…artefacts** – **Use of a corrugated mould to reduce the stiffness of the mould (**Boulay, 1993) - **Use of dislacement transducers without contact**

TIME ZERO OF AUTOGENOUS SHRINKAGE

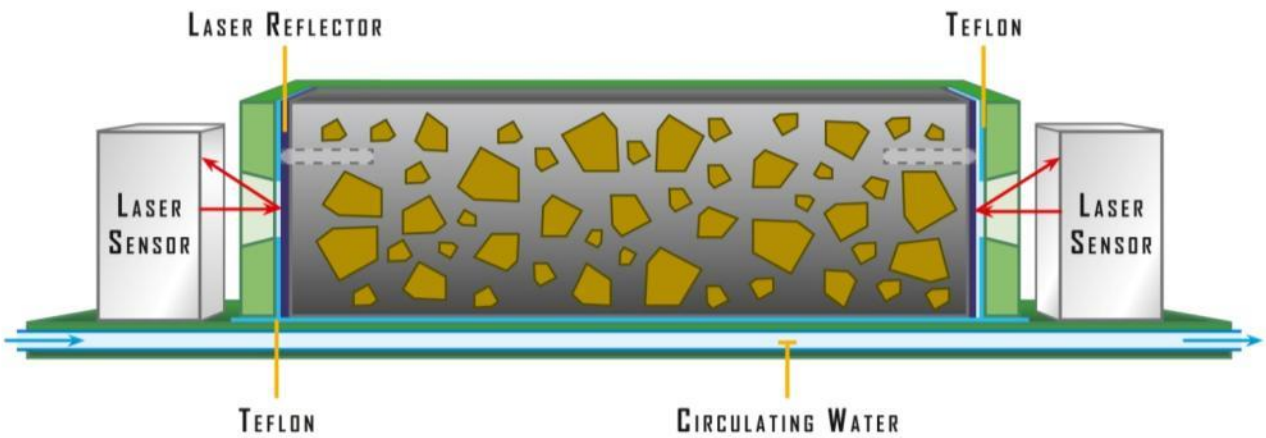
- **RESTRAINED SHRINKAGE TESTS USING TSTM:** Start of the increase of measured stress
- **SETTING TIME**
  - **Initial** (Tazawa et al. 2000, Boulay 2007, Cusson et al. 2007)
  - **Final** (Turcry et al. 2002, Holt 2005, Sant et al. 2006)
  - **Experimental assessment:** EN 196-3, ASTM C403, Robeyst 2007
- **MINIMUM OF SHRINKAGE RATE** (Fontana et al. 2006, Eppers 2008): **No additionnal test required**

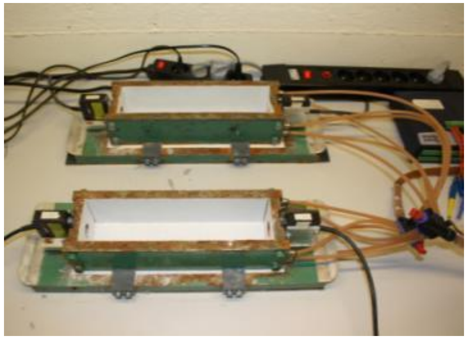
ULTRA-HIGH STRENGTH CONCRETE

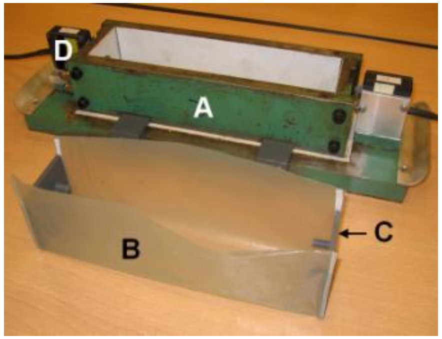


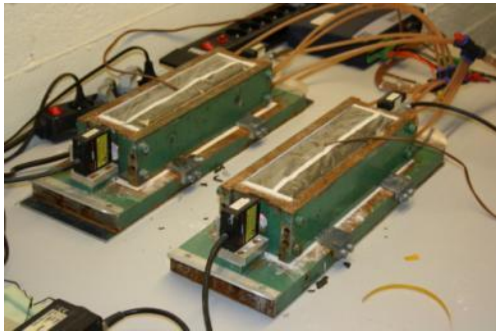
TESTING METHODS: PRISM

- **HORIZONTAL, RIGID MOULD:** 70x70x280 mm









A. mould
B. plastic sheet
C. PVC reflecting plates
D. laser sensor (2 µm)

TESTING METHODS: CORRUGATED TUBES

- **HORIZONTAL, FLEXIBLE MOULD:** Ø29 x H420 mm

B. Dilatometer benches

Sensor (2,5 µm/m)

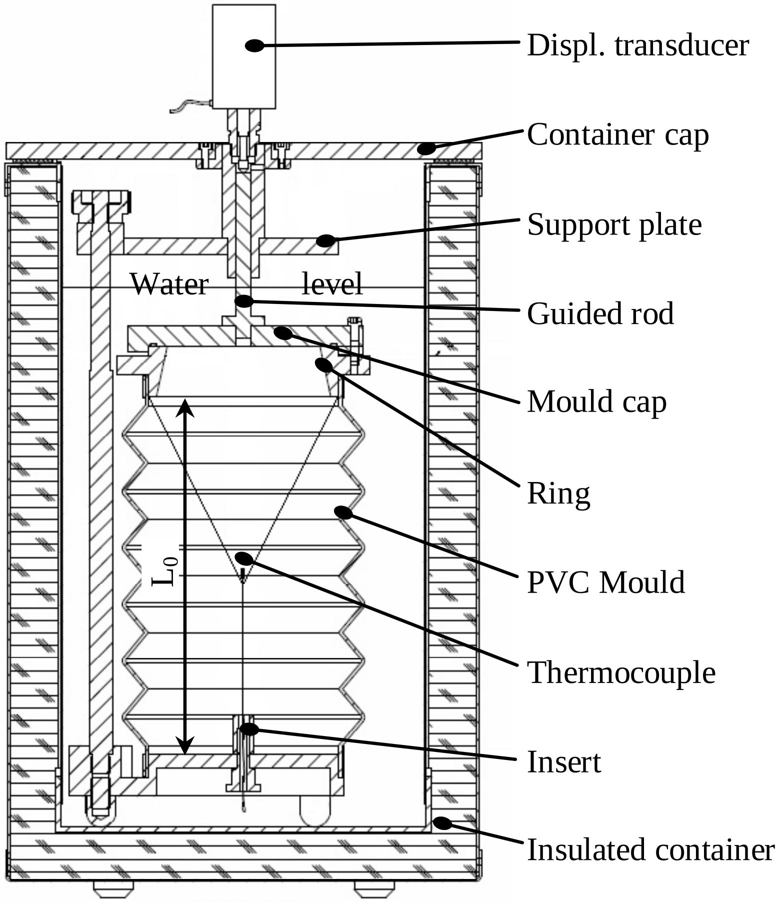
Metallic cap

Opposite end fixed with a magnet

A. Applicator gun

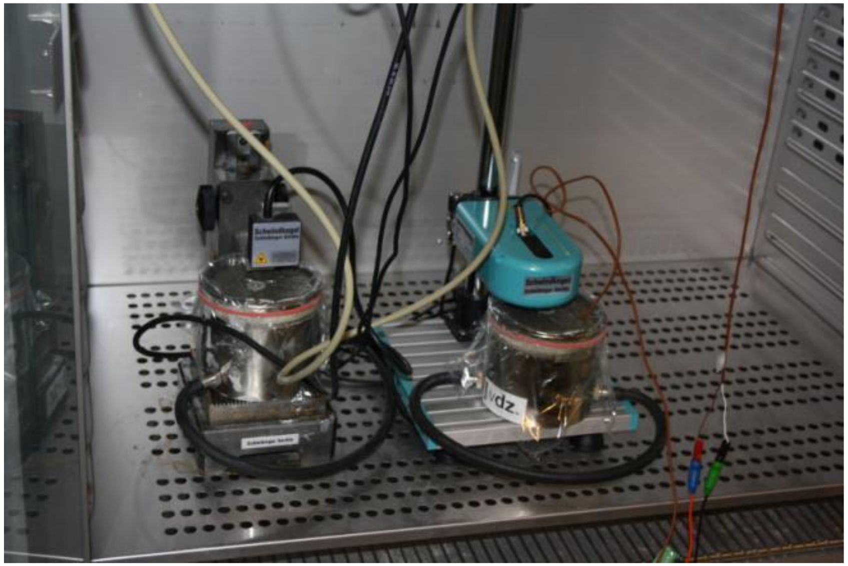
TESTING METHODS: BTJADE

- **VERTICAL, FLEXIBLE MOULD:** Ø125 x 250 mm

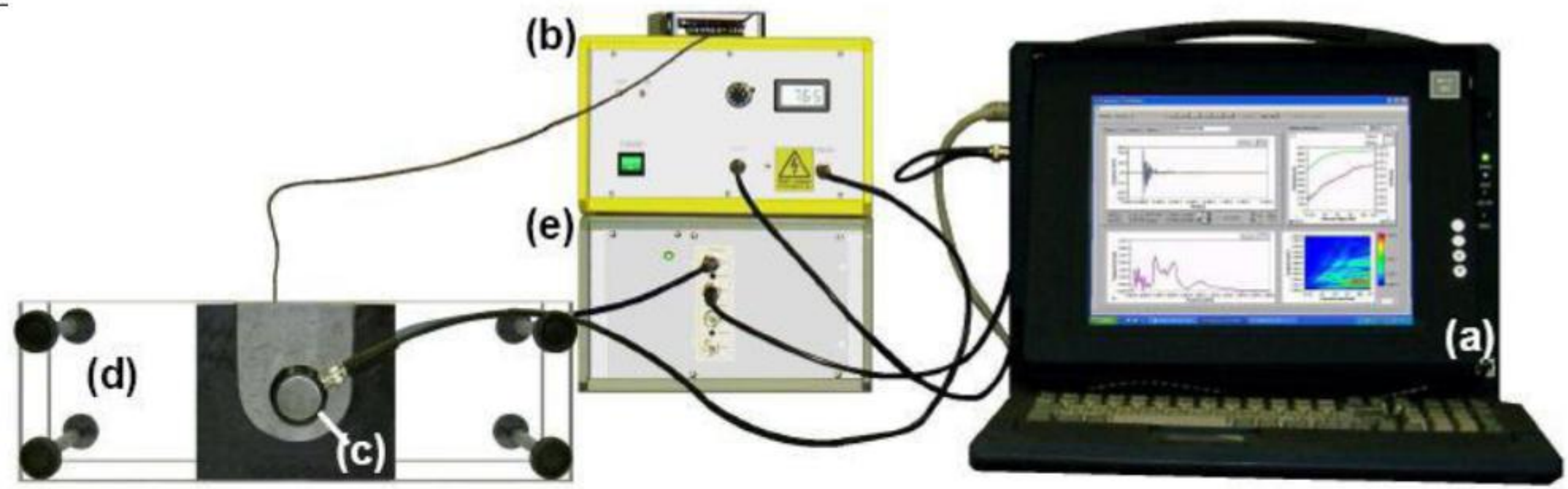


TESTING METHODS: CONE

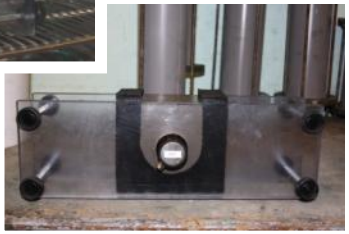
- **VERTICAL, RIGID MOULD:** Ø115 x H100 mm (max. particle size : 2mm)



TESTING METHODS: ULTRASONIC MONITORING

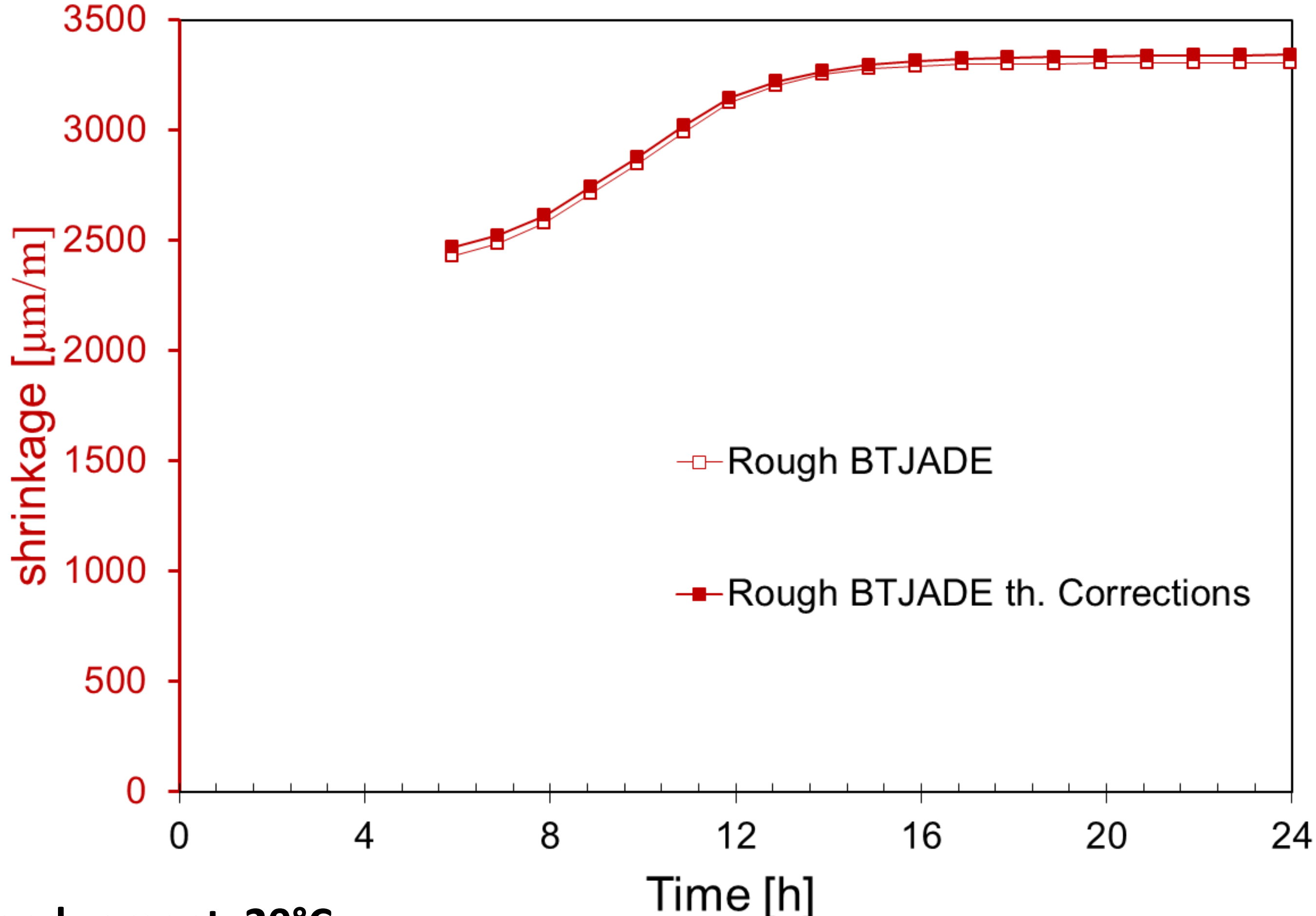


a) Computer with DAQ card,
b) Amplifier,
c) Piezoelectric sensor,
d) Container,
e) Preamplifier



ANALYSIS OF EXPERIMENTAL RESULTS

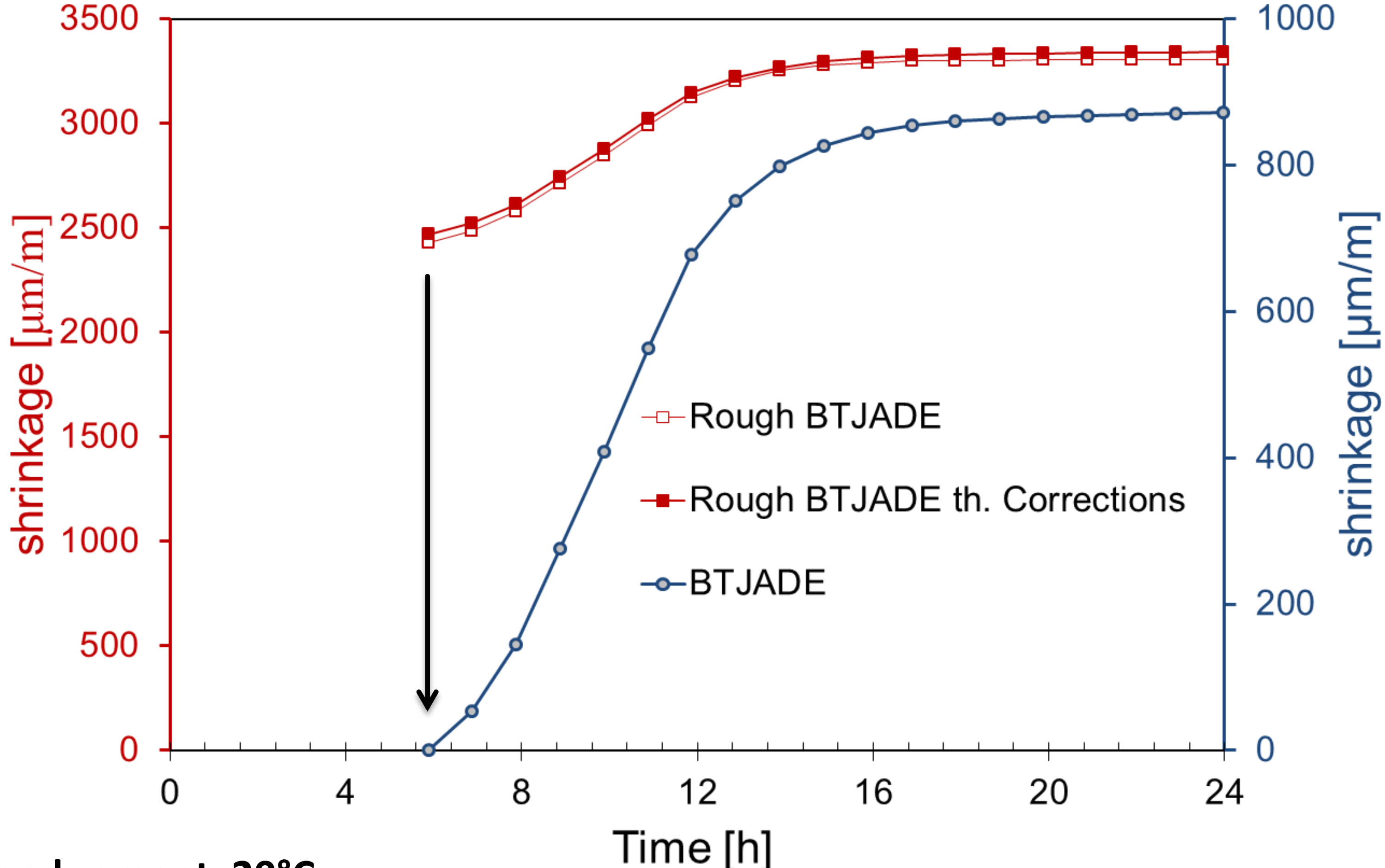
AUTOGENOUS SHRINKAGE: Times for correlations of concrete properties



Portland cement, 20°C

ANALYSIS OF EXPERIMENTAL RESULTS

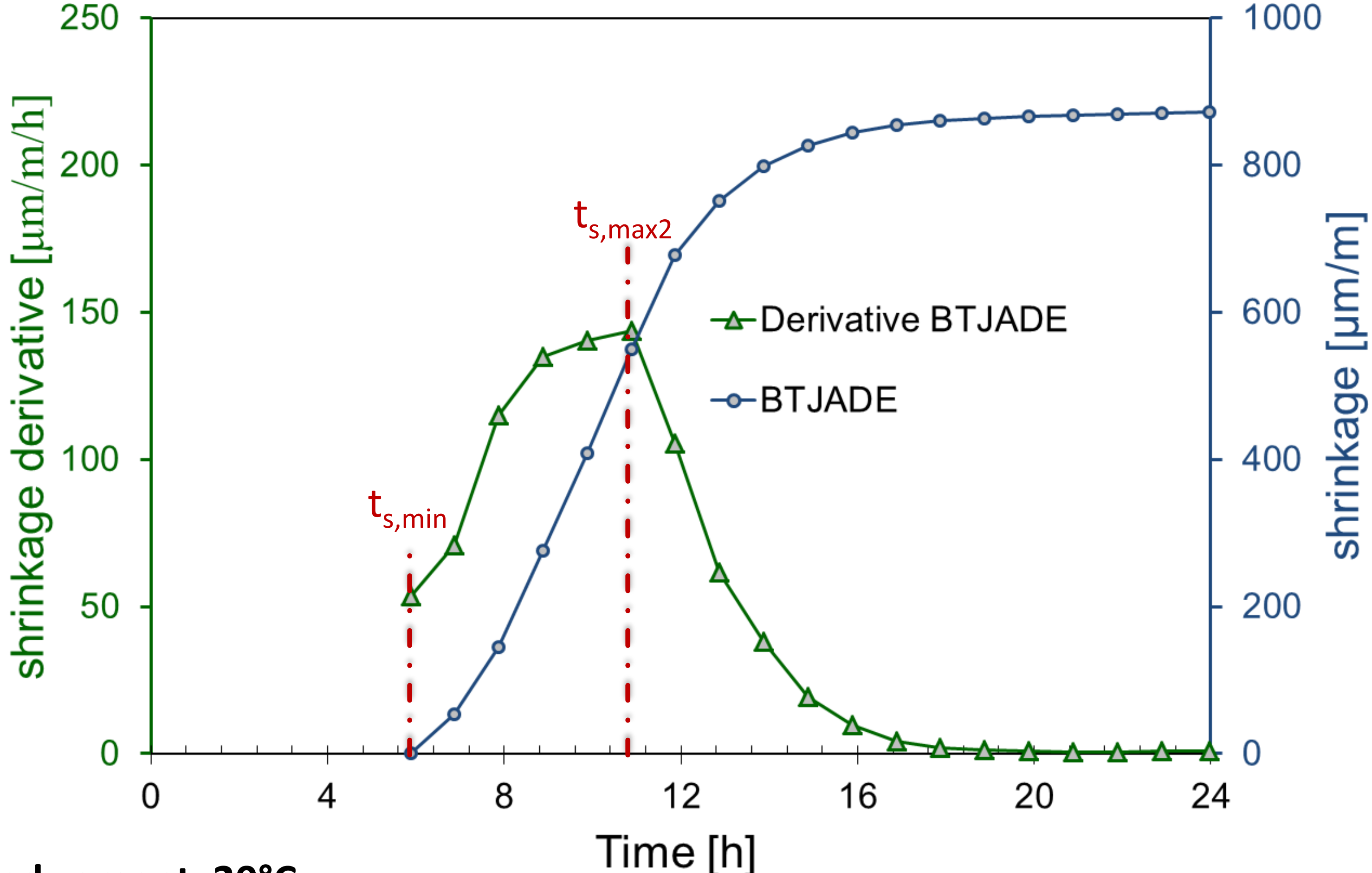
AUTOGENOUS SHRINKAGE: Times for correlations of concrete properties



Portland cement, 20°C

ANALYSIS OF EXPERIMENTAL RESULTS

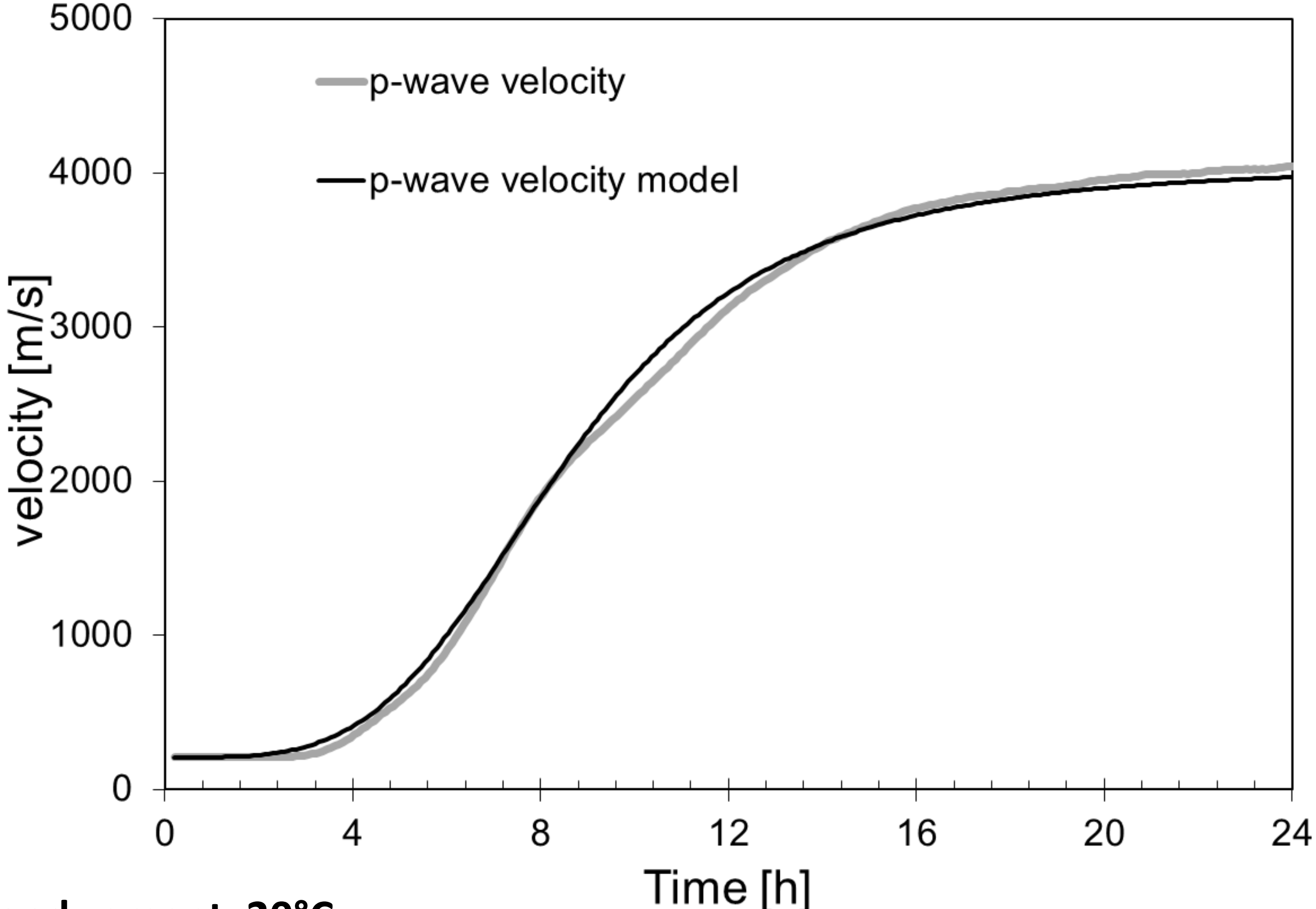
AUTOGENOUS SHRINKAGE: Times for correlations of concrete properties



Portland cement, 20°C

ANALYSIS OF EXPERIMENTAL RESULTS

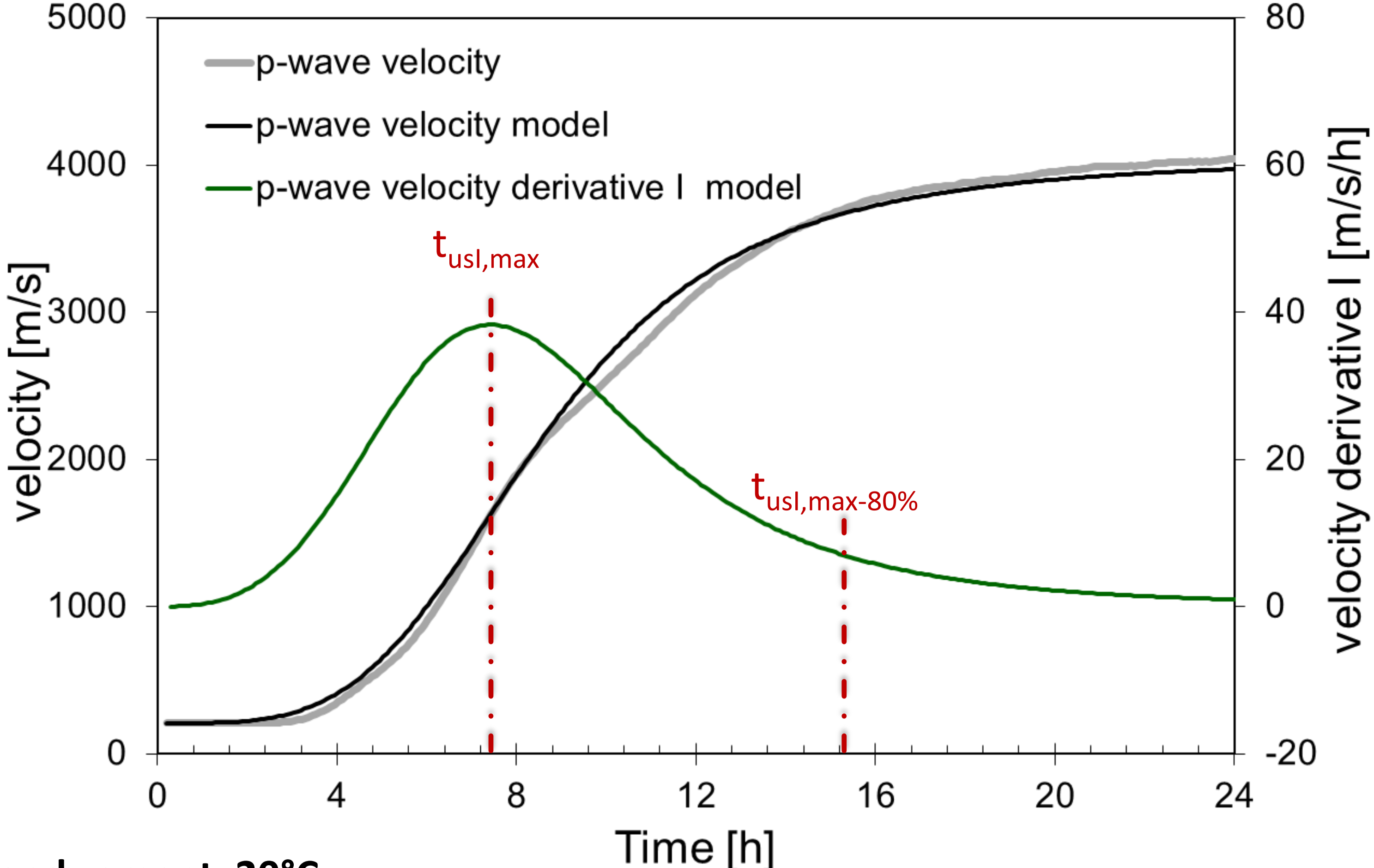
ULTRASONIC MONITORING: Times for correlations of concrete properties



Portland cement, 20°C

ANALYSIS OF EXPERIMENTAL RESULTS

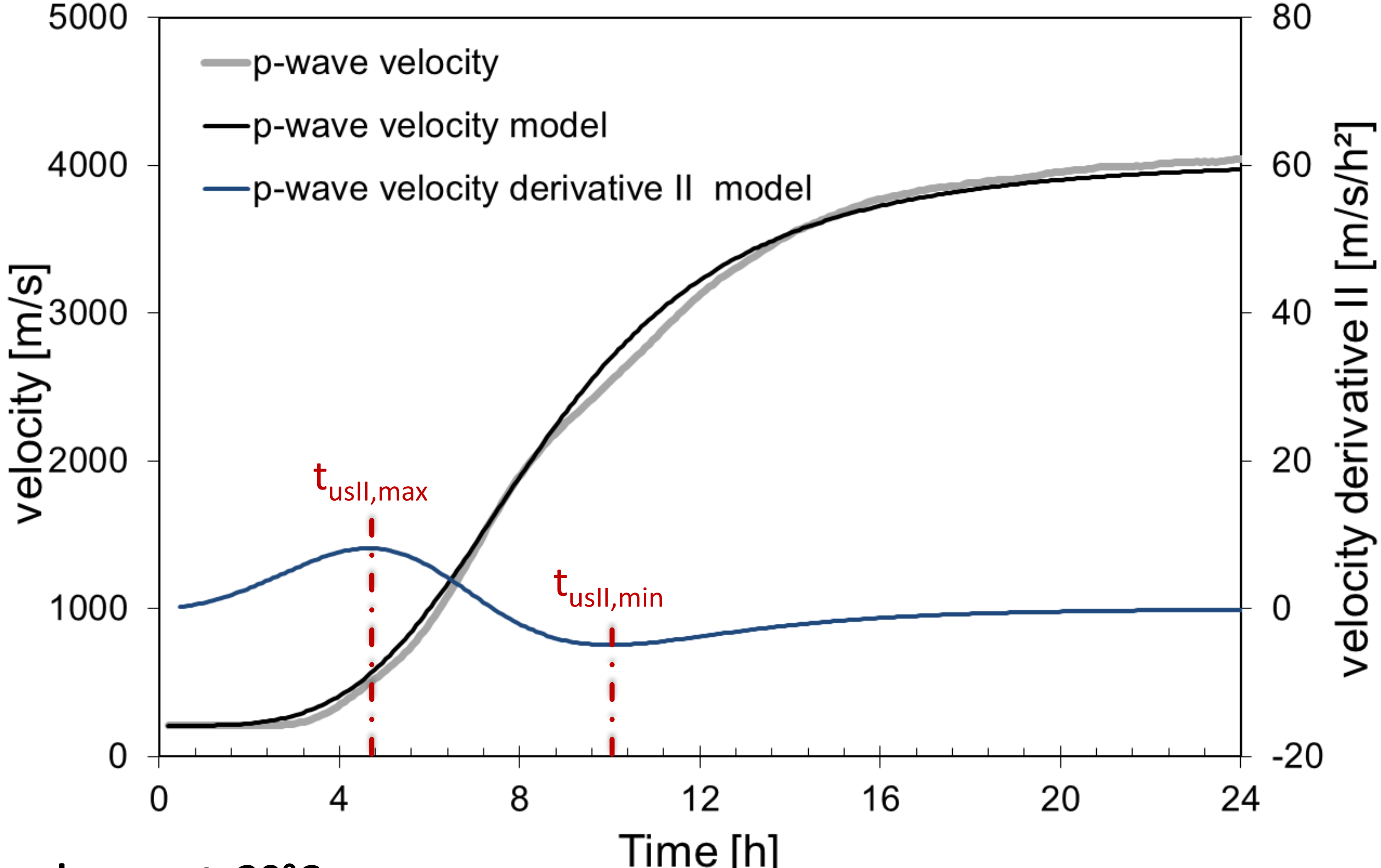
ULTRASONIC MONITORING: Times for correlations of concrete properties



Portland cement, 20°C

ANALYSIS OF EXPERIMENTAL RESULTS

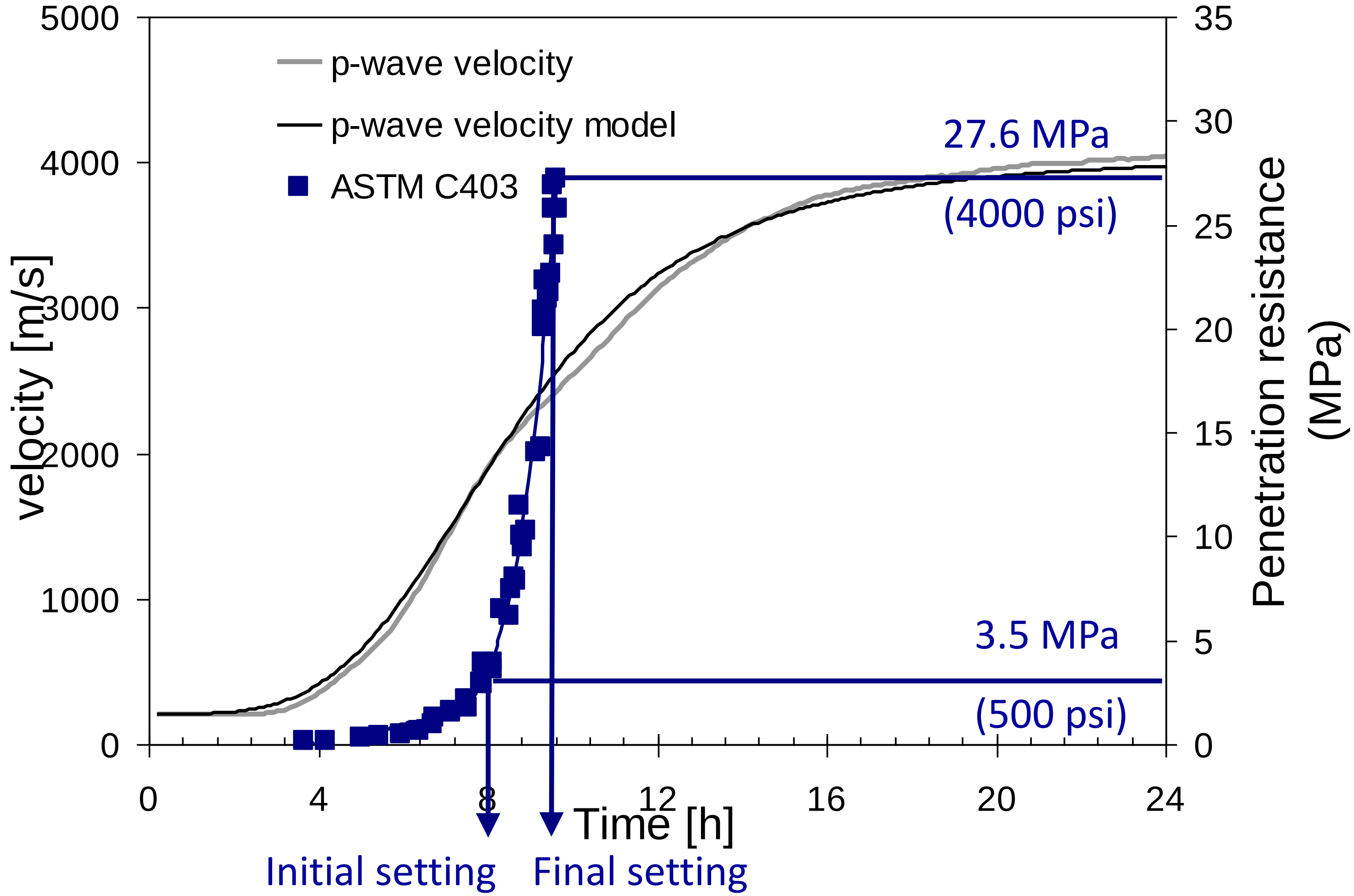
ULTRASONIC MONITORING: Times for correlations of concrete properties



Portland cement, 20°C

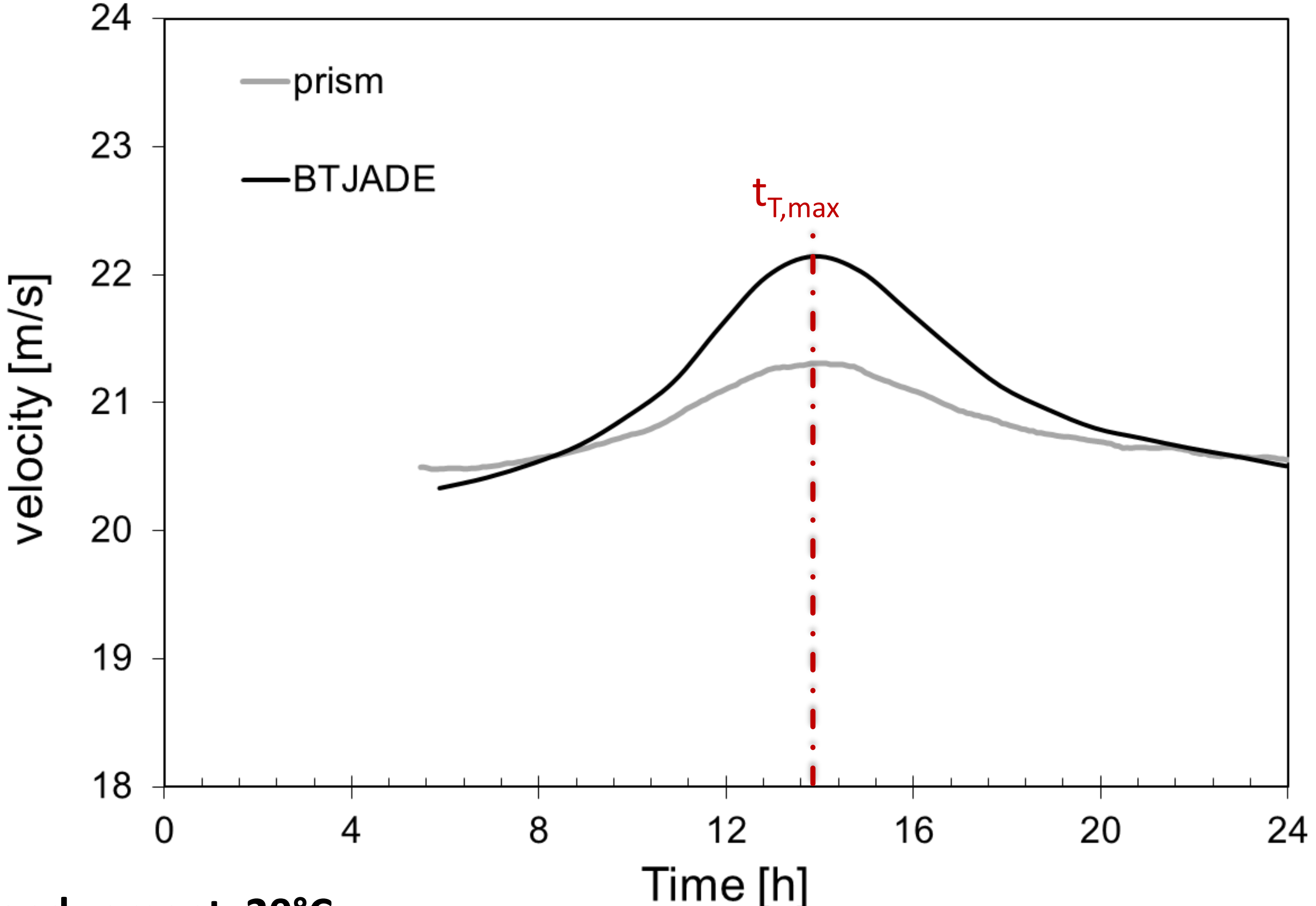
ANALYSIS OF EXPERIMENTAL RESULTS

ULTRASONIC MONITORING AND SETTING (ASTM C403)



ANALYSIS OF EXPERIMENTAL RESULTS

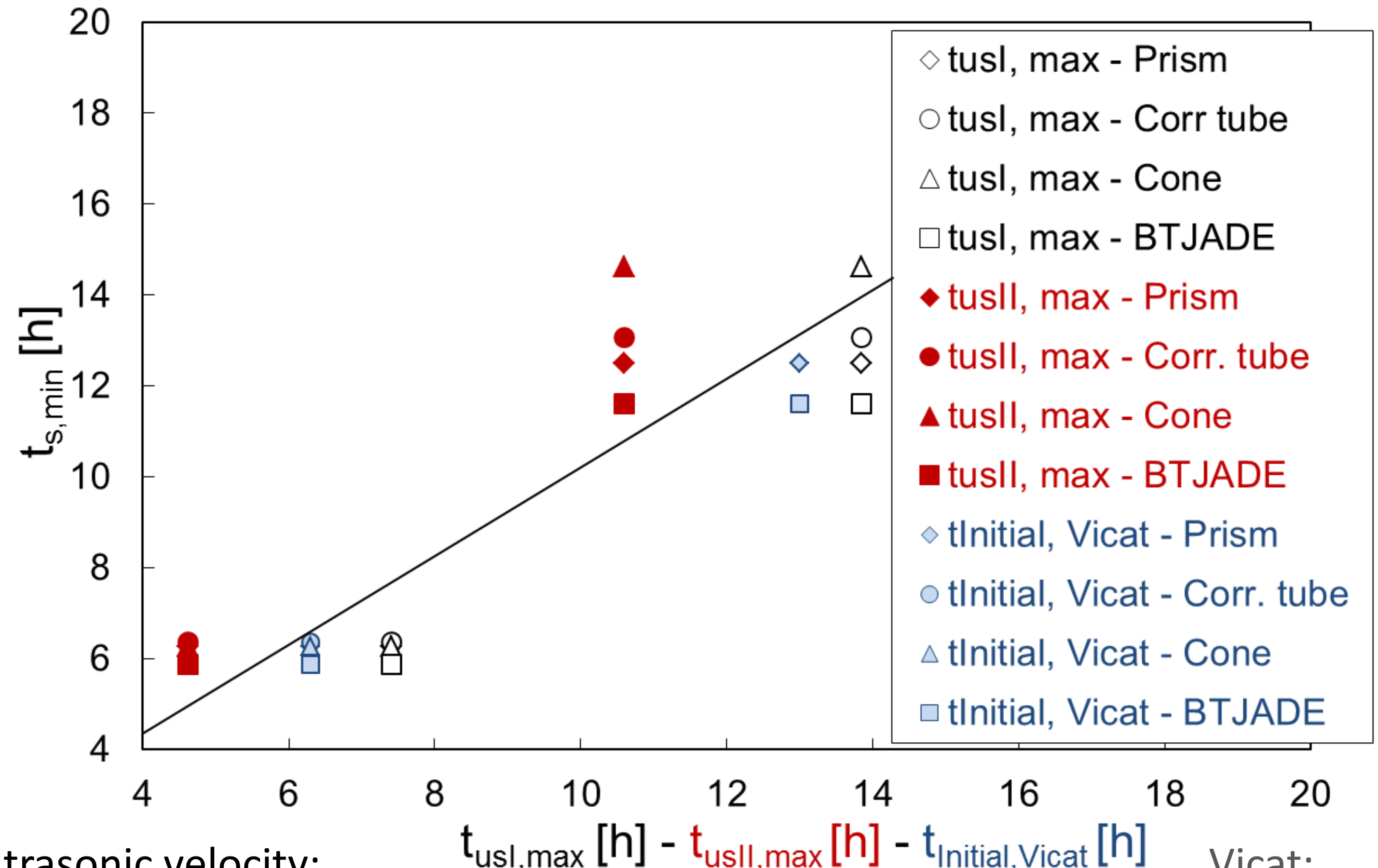
TEMPERATURE: Times for correlations of concrete properties



Portland cement, 20°C

ANALYSIS OF EXPERIMENTAL RESULTS

CORRELATIONS: Time of minimum shrinkage rate $t_{s,min}$



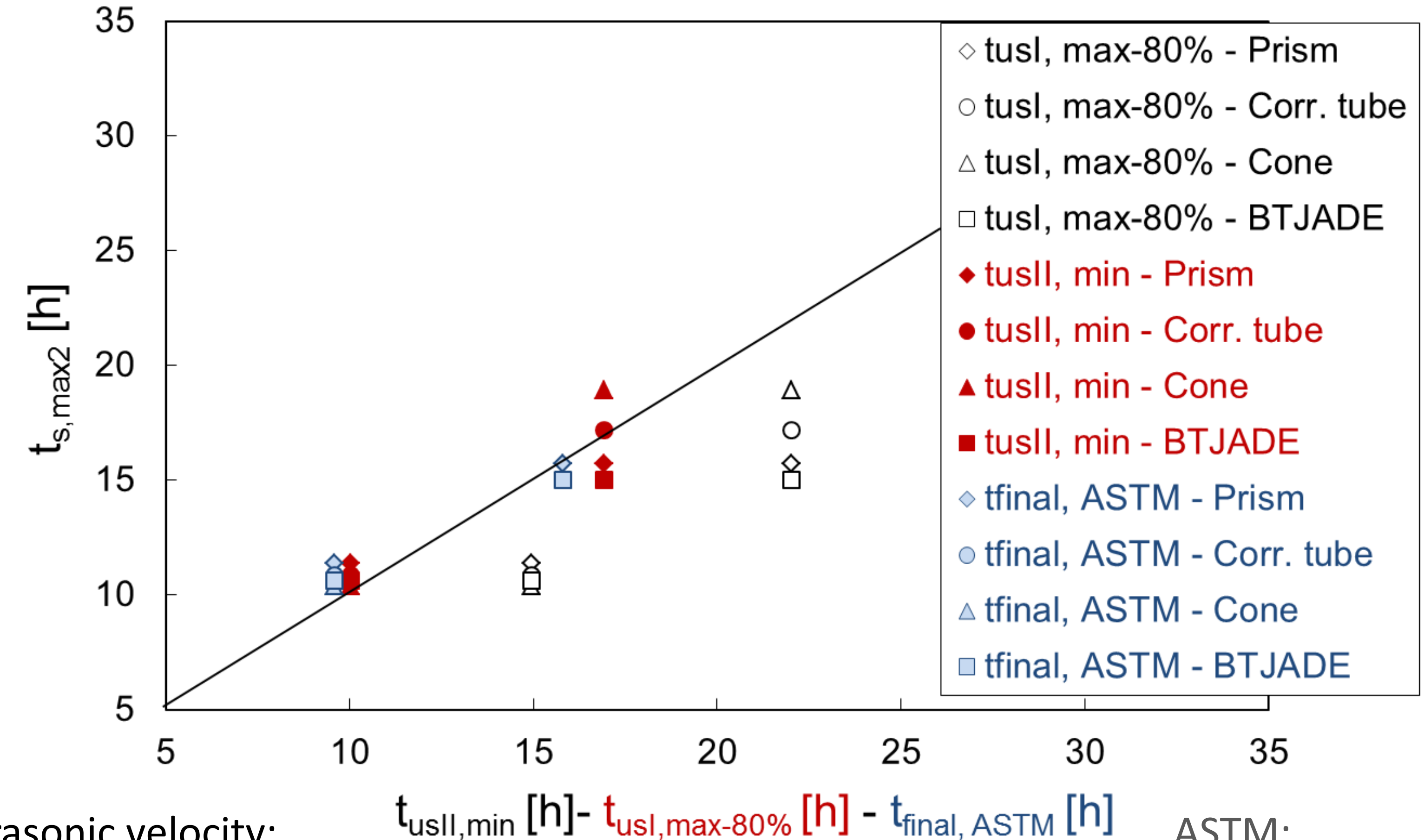
Ultrasonic velocity:
Maximum of 1st derivative

Max. of 2^{nd} derivative

Vicat:
Initial setting

ANALYSIS OF EXPERIMENTAL RESULTS

CORRELATIONS: Time of maximum shrinkage rate $t_{s,max2}$

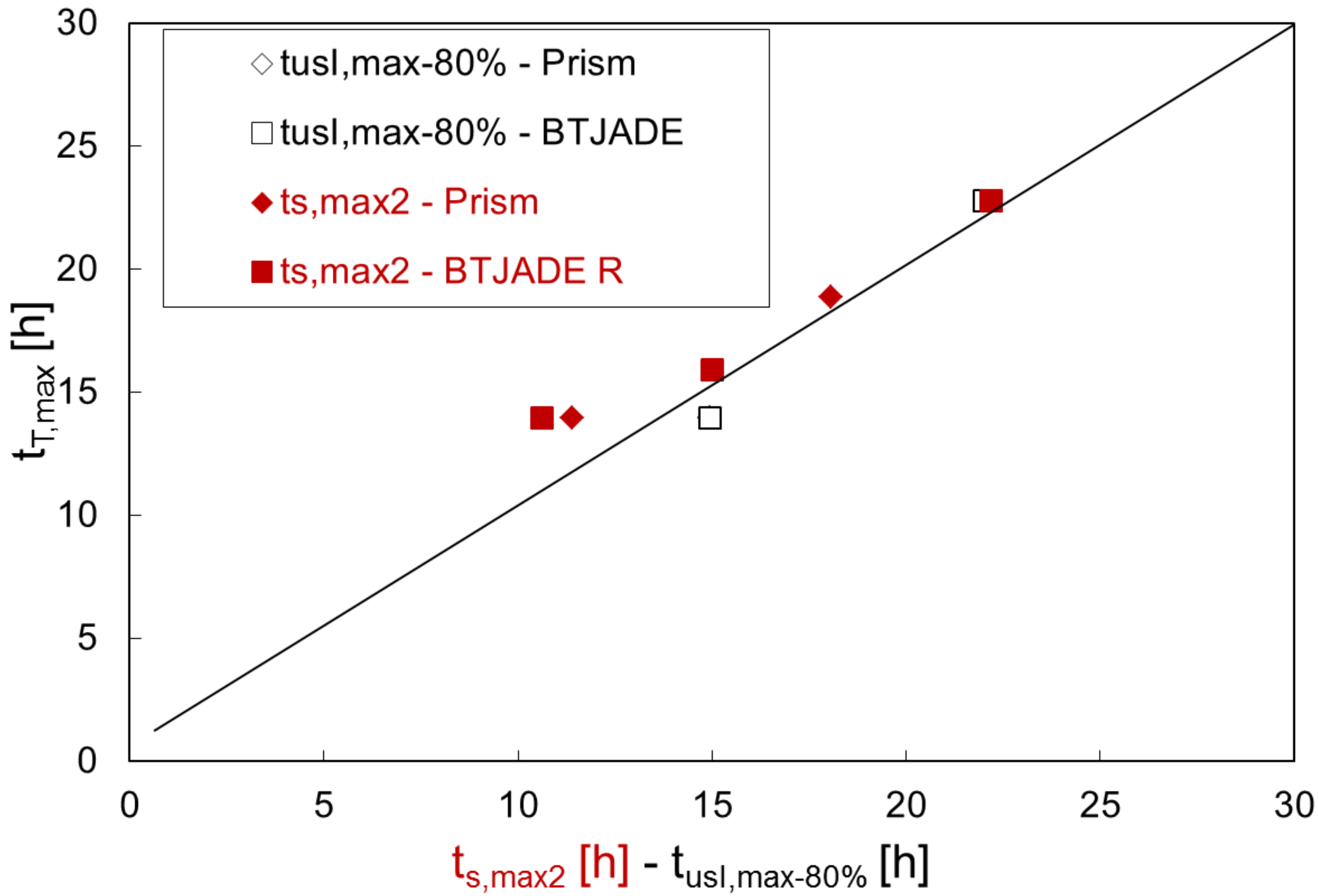


Ultrasonic velocity:
Minimum of 2nd derivative 80% of max. of 1st derivative

ASTM:
Final setting

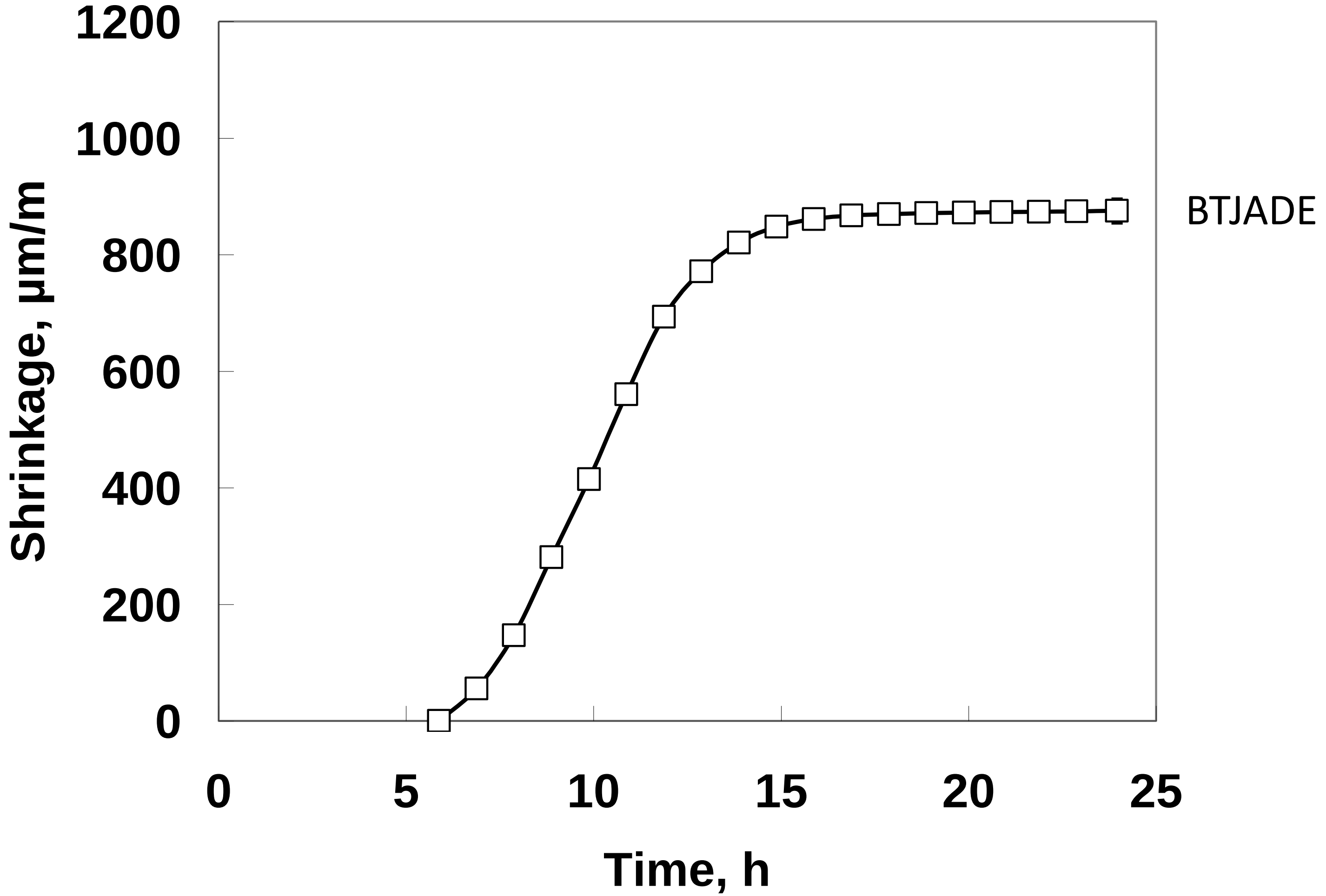
ANALYSIS OF EXPERIMENTAL RESULTS

CORRELATIONS: Time of maximum temperature $t_{T,max}$



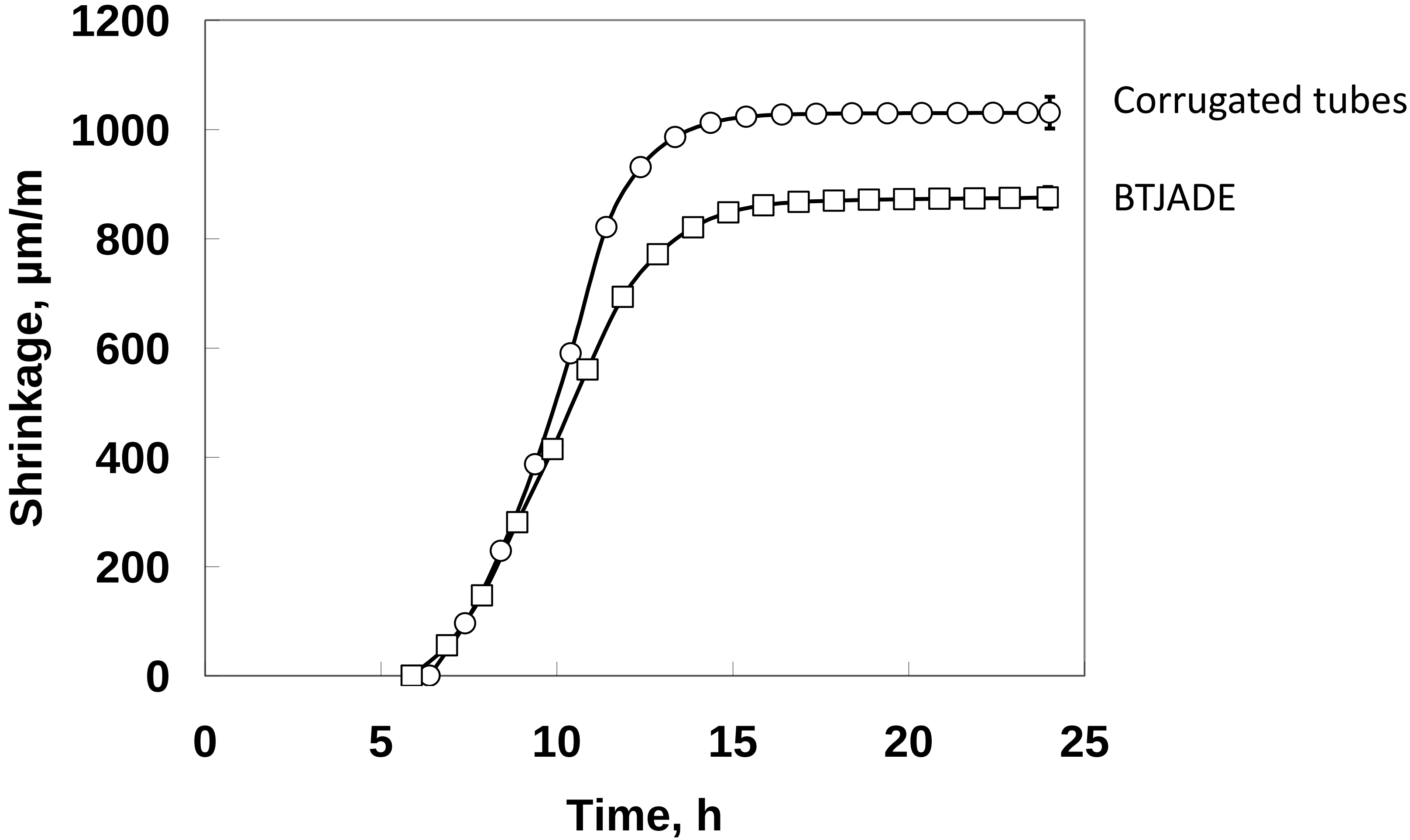
Max. of 1st derivative of shrinkage 80% of max. of 1st derivative of velocity

INFLUENCE OF THE MEASUREMENT TECHNIQUE



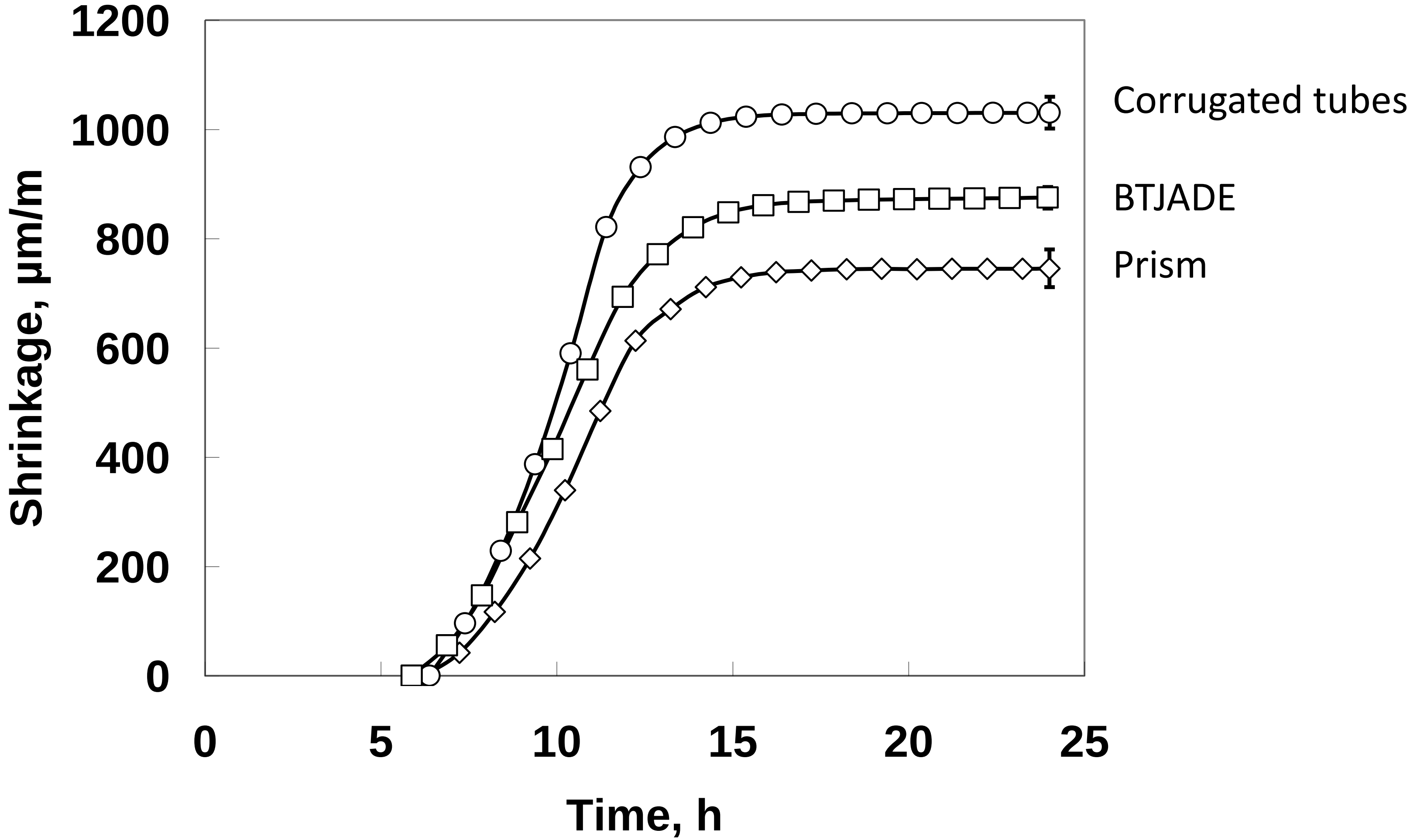
Portland cement, 20°C

INFLUENCE OF THE MEASUREMENT TECHNIQUE



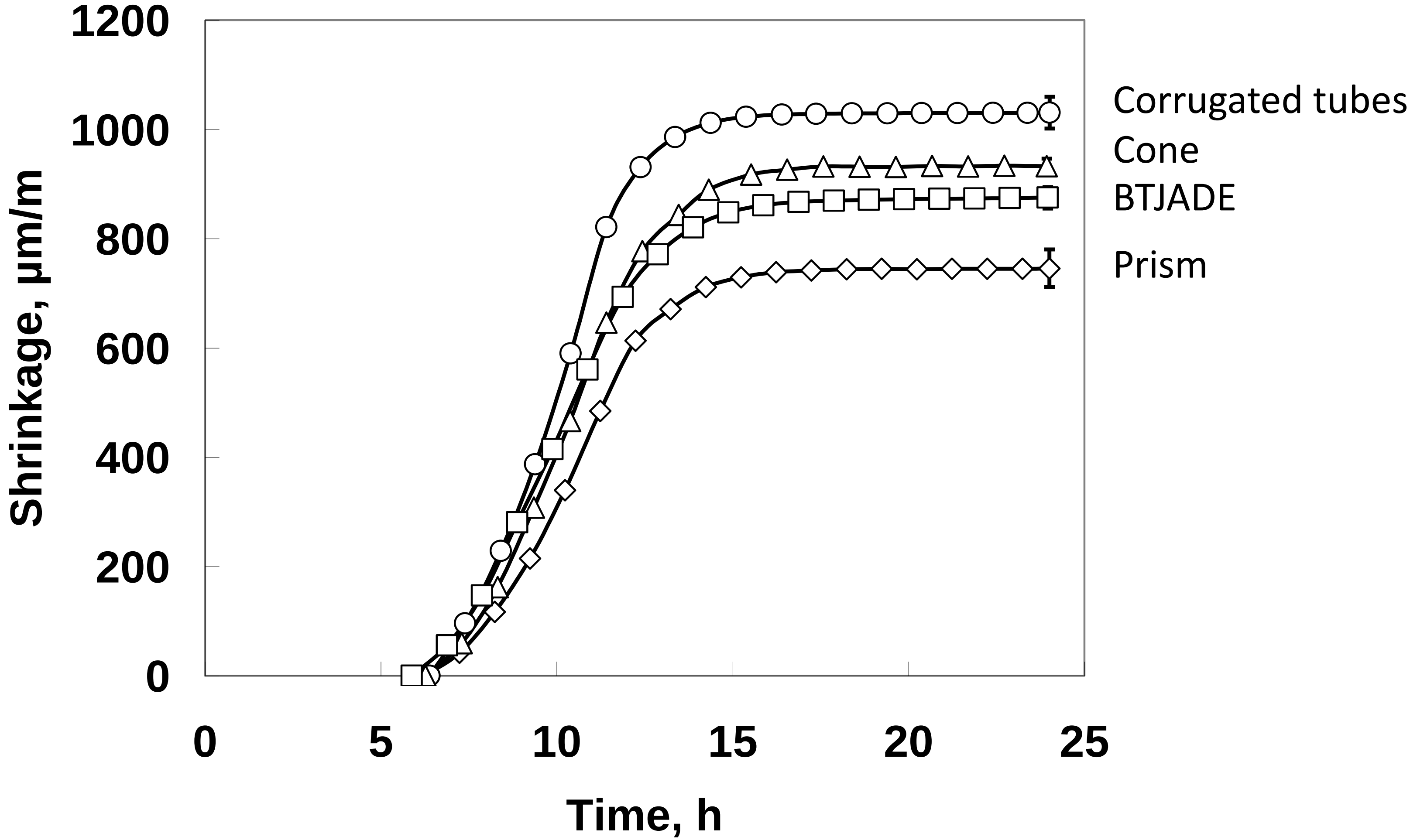
Portland cement, 20°C

INFLUENCE OF THE MEASUREMENT TECHNIQUE



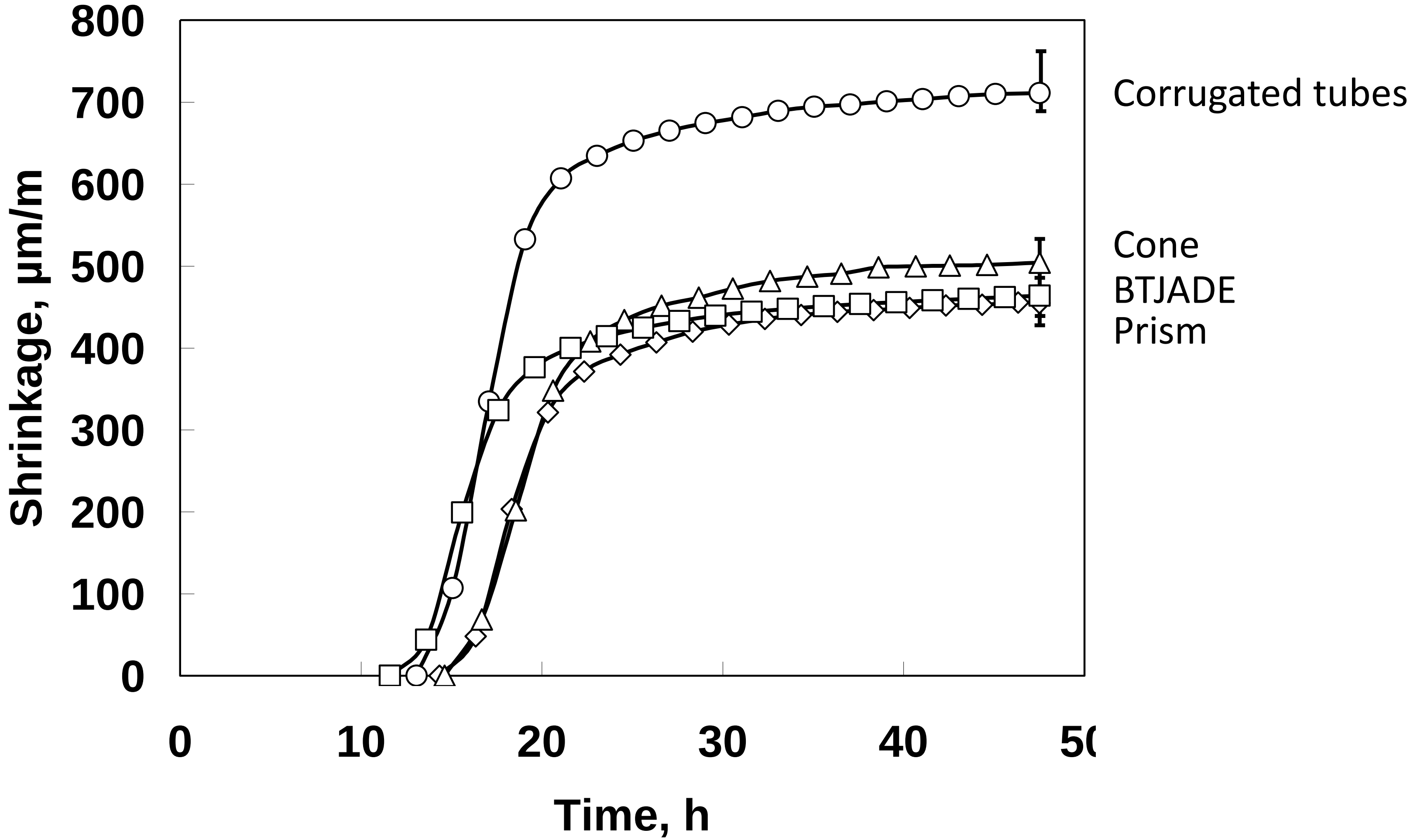
Portland cement, 20°C

INFLUENCE OF THE MEASUREMENT TECHNIQUE



Portland cement, 20°C

INFLUENCE OF THE MEASUREMENT TECHNIQUE



BFS75%, 20°C

CONCLUSIONS

- **Good repeatability** of each measurement technique
- **Constant ranking** of magnitudes as a function of the test method, namely: 1. Corrugated tubes, 2. Cones, 3. BTJADE, 4. Prisms
- **Time of minimum autogenous deformation rate** chosen as "time-zero": mathematical analysis but good correlations with the physical evolution of the materials, especially initial setting period
- **Time of maximum autogenous shrinkage rate** showed good correlations with the **final setting time from ASTM, the minimum of second derivative of ultrasonic velocity, and the maximum temperature**

  => The accelerating period of autogenous shrinkage actually corresponds to the acceleration period of hydration.


ULB
Les bétons à ultra hautes performances, de la théorie à la pratique

THANK YOU !

Test methods for assessing restrained shrinkage effects on cracking

Benoit Parmentier – Belgian Building Research Institute
Petra Van Itterbeeck – Belgian Building Research Institute

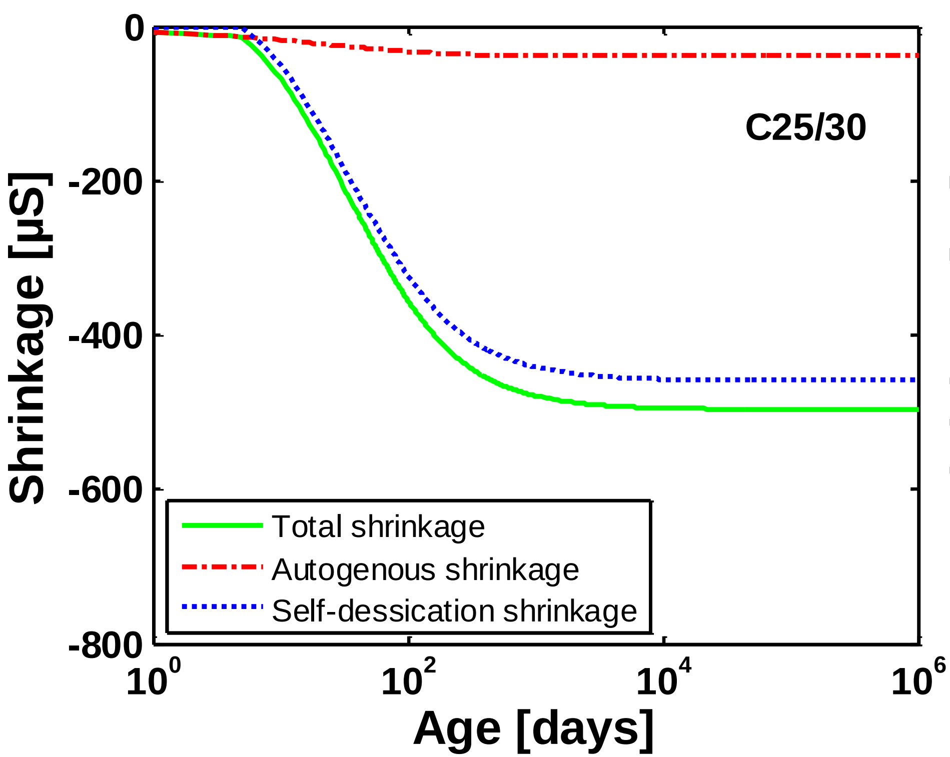

ZONA
ZONA
NCA
NCA

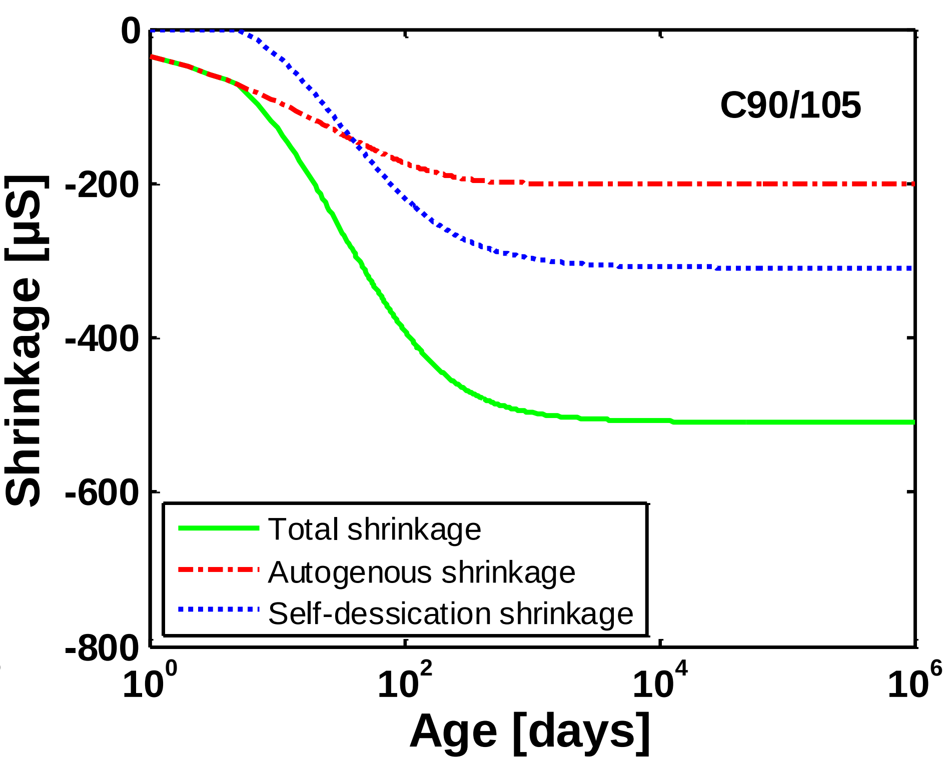
Some thoughts for this workshop

- **Deformations vs. Restrain : what are the rules…?**
- **Cracking tendency assessment : A) Ring tests**
- **Cracking tendency assessment : B) Dog-bone tests**

The context

- **Cemend-based materials (mainly) shrink due to**
  - Different types of shrinkage (autogenous, drying,…)
  - Thermal deformations





Free deformations are not a problem but...

Almost all structures are somewhat **restrained**

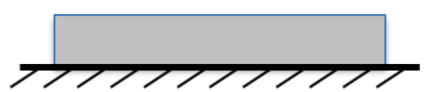
Internal restraint

- Aggregates
- Rebars
- Geometry (volume deformations)

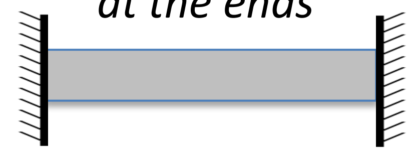
External restraint

- Different casting phases
- Composite structures

along one edge



at the ends



Some concretes are more sensitive [?]

(shrinkage, strength development)

- UHPC (autogenous shrinkage)
- SCC (paste volume)
- New Mix composition ?

Some concretes can mitigate the consequences

(post-cracking residual strength, relaxation)

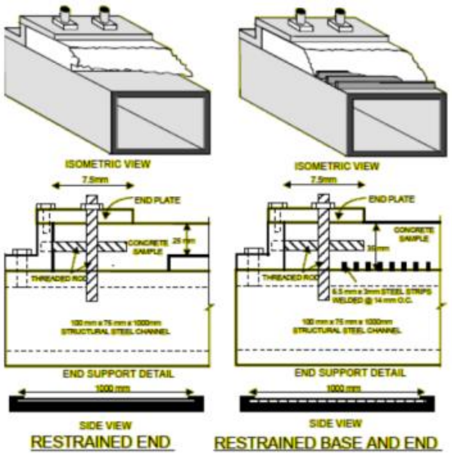
- FRC
- New Mix composition ?

We need test methods to assess the cracking tendency

Cracking tendency – The influence factors

- Shrinkage evolution
- (Tensile) Strength development
- E-modulus development
- Creep in tension
- …
- Boundary conditions :
  - Degree & Type of restrain
  - Shrinkage distribution
- …

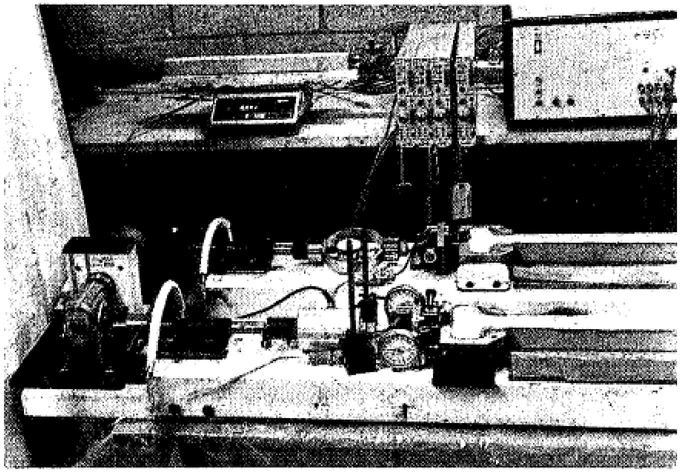
Test methods for restrained shrinkage

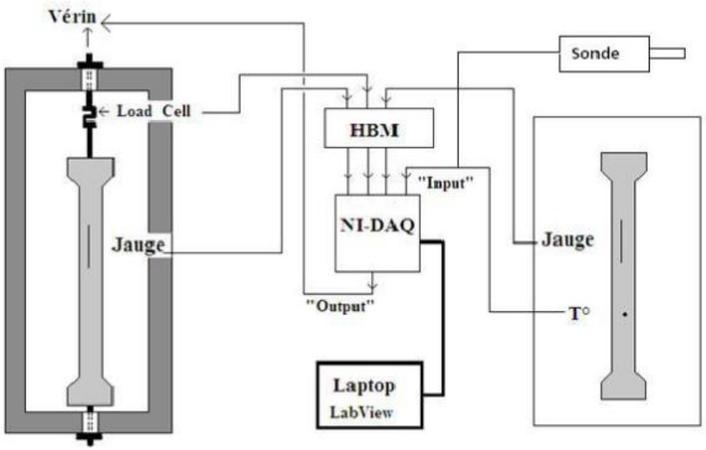


Weiss (1998)

Uni-axial restrain tension tests :

- Difficult to produce full restraint
- So let us compensate…





Kovler (1994)

bbri.be Researches • Develops • Informs

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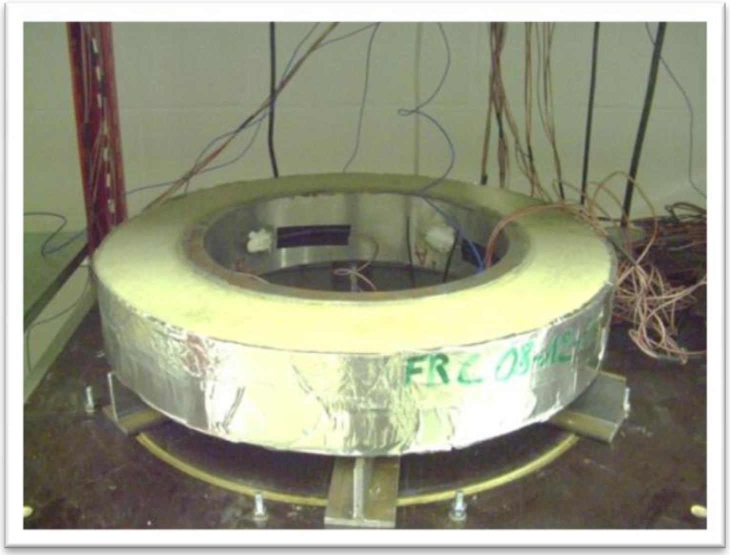
Restrained deformation test setups

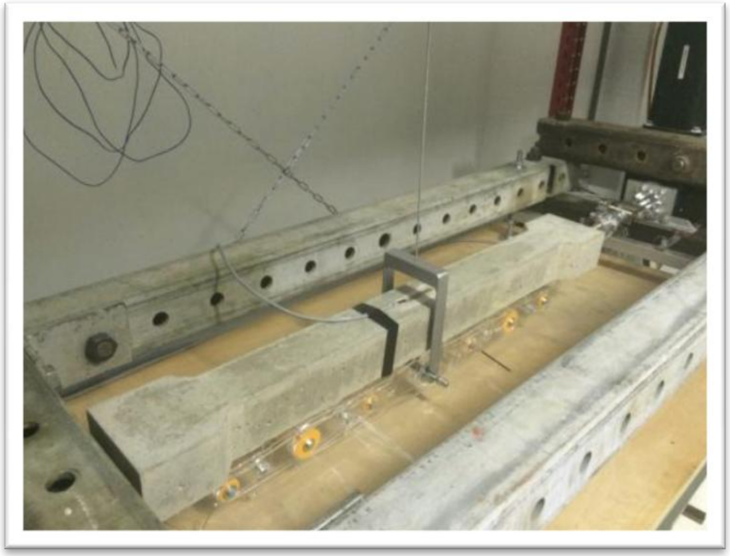
Ring test

- Passive
- Not fully restrained
- Standards :
  - ASTM C1581
  - AASHTO PP-34



Dog-bone (restrained) test

- Active
- Almost fully restrained
- No standard



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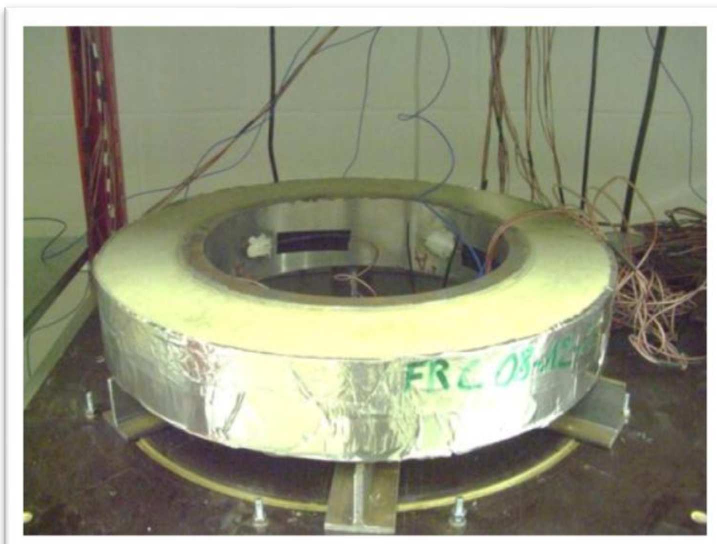
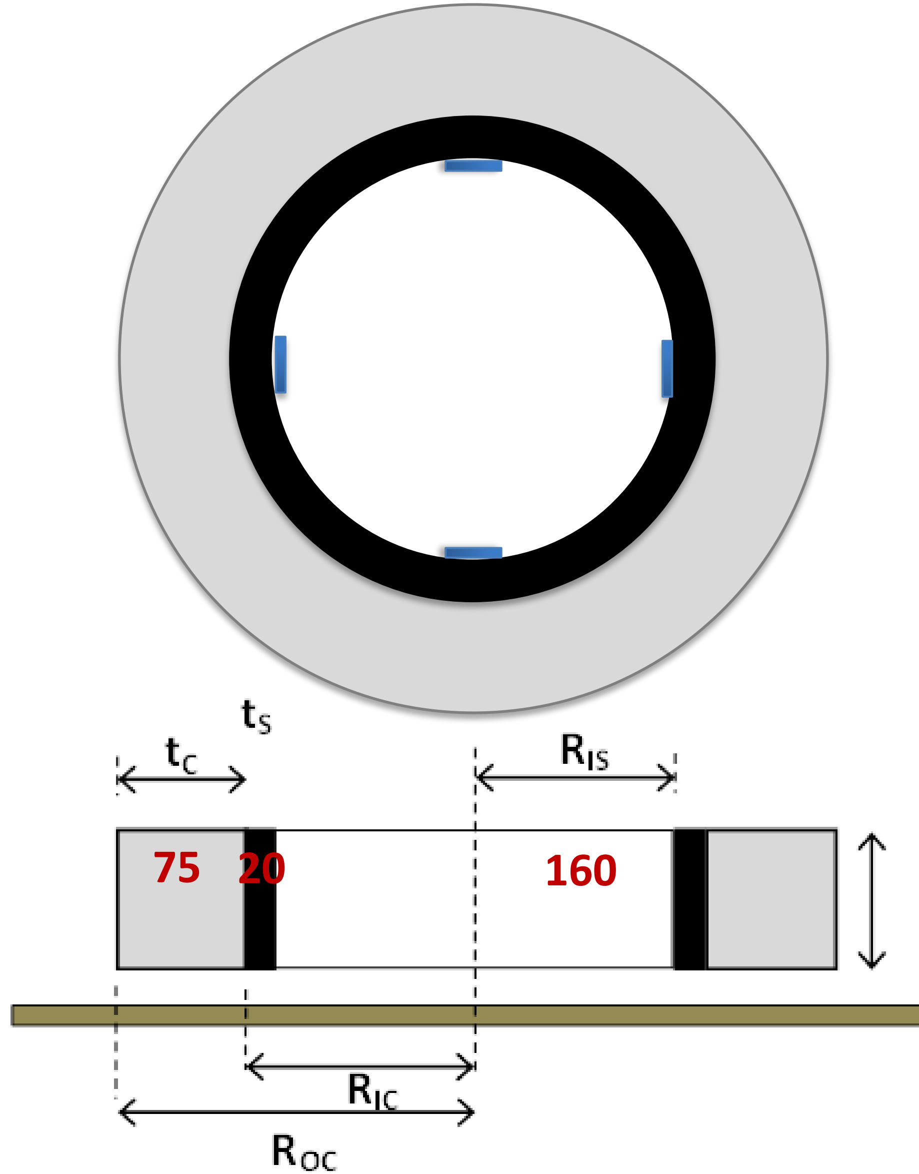
Ring tests

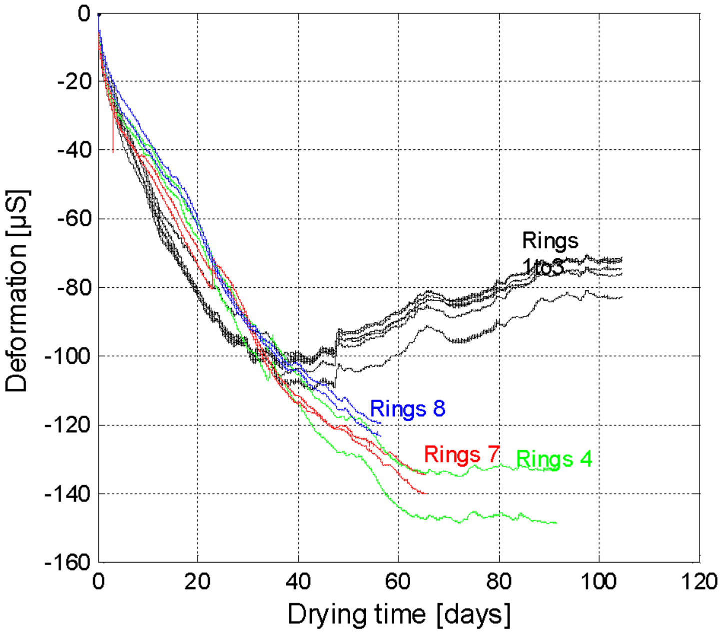
- Geometry
- Drying conditions
- Theoretical models to predict
  - Cracking (moment, amplitude)
  - Relaxation
  - Restrain





Geometry & Drying conditions

	AASHTO
Internal radius steel (R_{IS}) [mm]	140
Internal radius concrete ($R_{IC} = R_{OS}$) [mm]	152,5
External radius concrete (R_{OC}) [mm]	228,5
Height (h) [mm]	152
Thickness steel (t_s) [mm]	12,7
Thickness concrete (t_c) [mm]	75
Notional size h_0	150
RH / Temperature	50% | 21°C
Drying direction	Circumference



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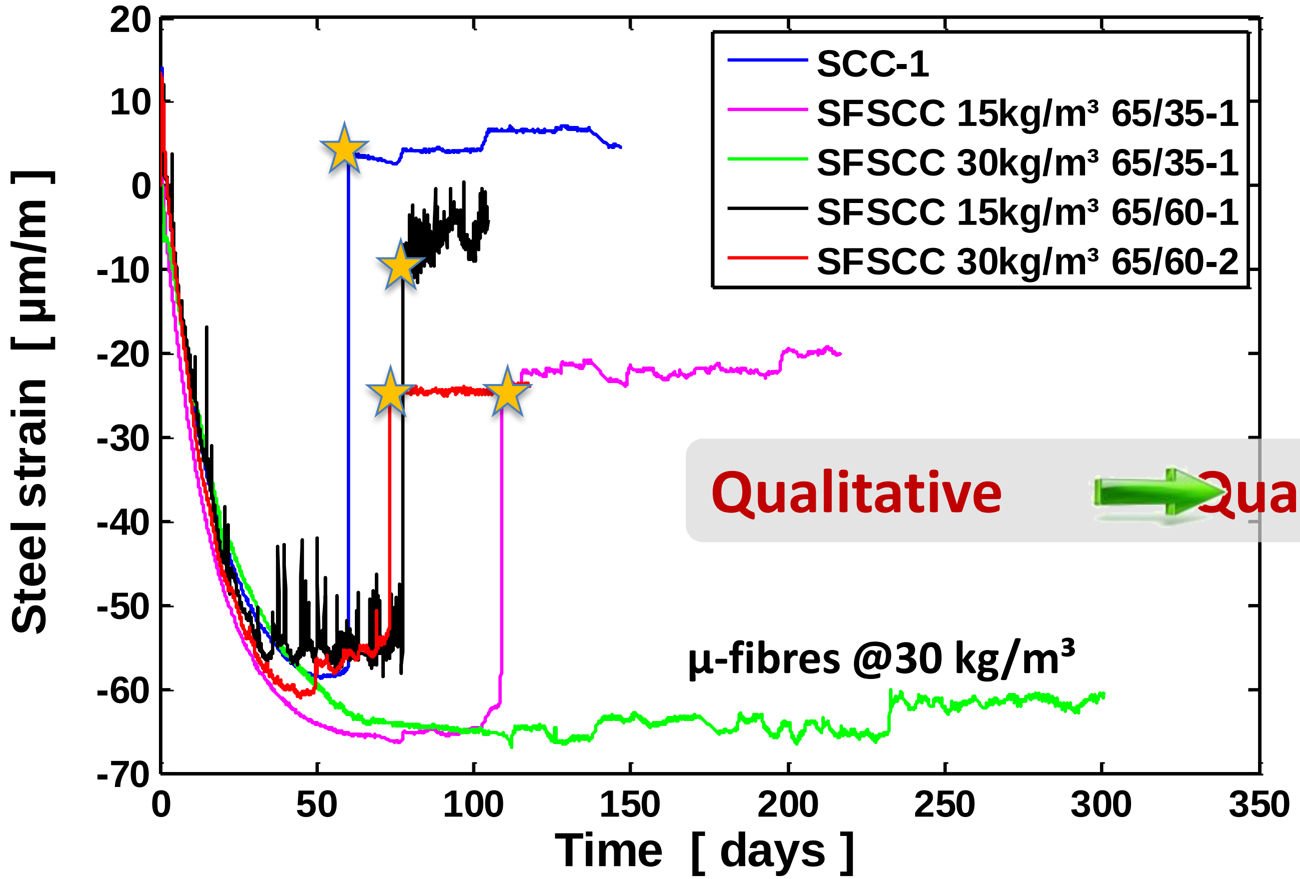
Ring tests : influence of (micro-)fibres



Qualitative → Quantitative ?

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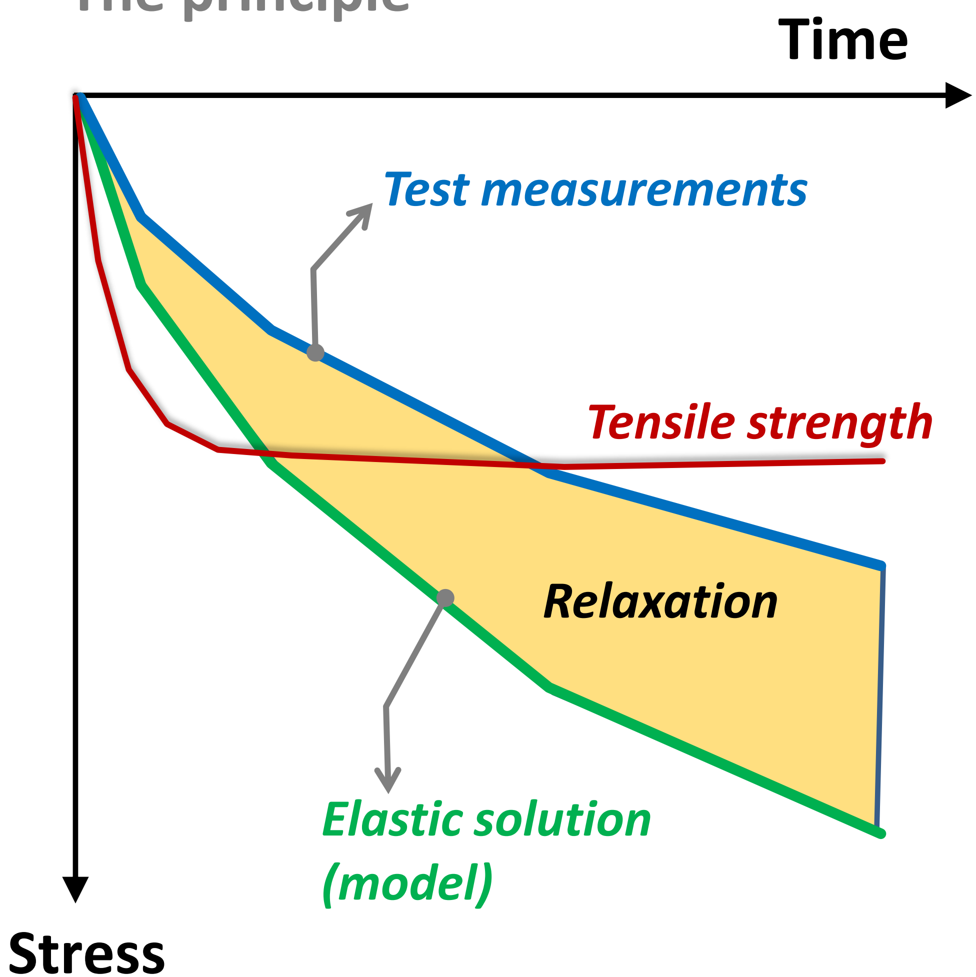
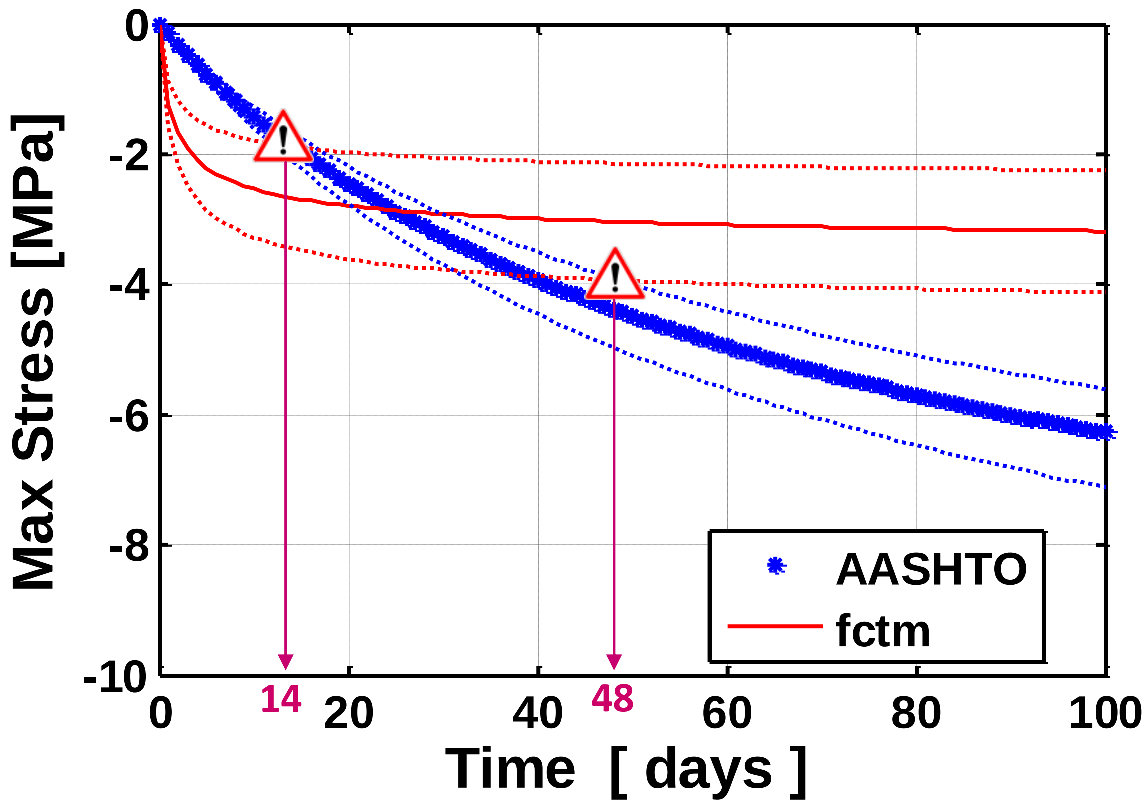
Ring tests : towards more quantitative results

The principle



Ring tests : stress prediction model

Probabilistic vs. Deterministic



Age @cracking

14 → 48 days

Theoretical models

$$\sigma_{actual} = -\varepsilon_{st} \cdot E_s \left(\frac{R_{IC}^2 - R_{IS}^2}{2R_{IC}^2}\right) \cdot \left(\frac{R_{OC}^2 + R_{IC}^2}{R_{OC}^2 - R_{IC}^2}\right)$$

$$\sigma_{elastic} = \frac{\varepsilon_{sh}(t) \cdot E_c \cdot C_{3R}}{\frac{E_c}{E_s} \cdot C_{1R} + C_{2R}}$$

Stress calculation

$$\emptyset = \frac{\sigma_{Elastic-max} - \sigma_{Actual-max}}{\sigma_{Elastic-max}}$$

Relaxation

$$k_\phi = \frac{1 - e^{-\phi}}{\phi}$$

CUR n°36

$$\psi = 100\left(1 - 0.5\frac{\varepsilon_{ST}(t)}{\varepsilon_{SH}(t)}\left[\frac{R_{IS}^2}{R_{OS}^2}(1+\nu_s) + (1-\nu_s)\right]\right)$$

Restraint factor (from tests)

$$\psi = 1 - \frac{E_c}{E_s}\frac{1}{\left(\left(\frac{E_c}{E_s}\right) - \frac{\left(1 - \left(\frac{R_{IS}^2}{R_{IC}^2}\right)\right)\left[(1+\nu_c)\left(\frac{R_{OC}^2}{R_{IC}^2}\right) + (1-\nu_c)\right]}{\left(1 - \left(\frac{R_{OC}^2}{R_{IC}^2}\right)\right)\left[(1+\nu_s)\left(\frac{R_{IS}^2}{R_{IC}^2}\right) + (1-\nu_s)\right]}\right)}$$

Restraint factor (theoretical)

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The ring test

We can taylor the degree of restrain :

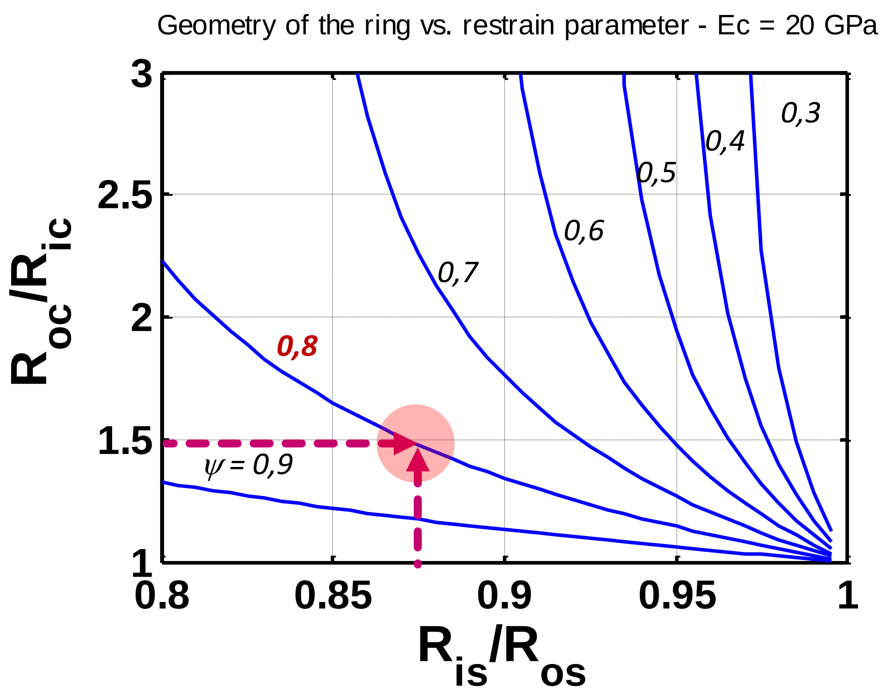

Table L.1 — Restraint factors for central zone of walls shown in Figure M.1(a)

Ratio L/H (see Fig A.3.1)	Restraint factor at base	Restraint factor at top
1	0,5	0
2	0,5	0
3	0,5	0,05
4	0,5	0,3
>8	0,5	0,5

EUROCODE 2

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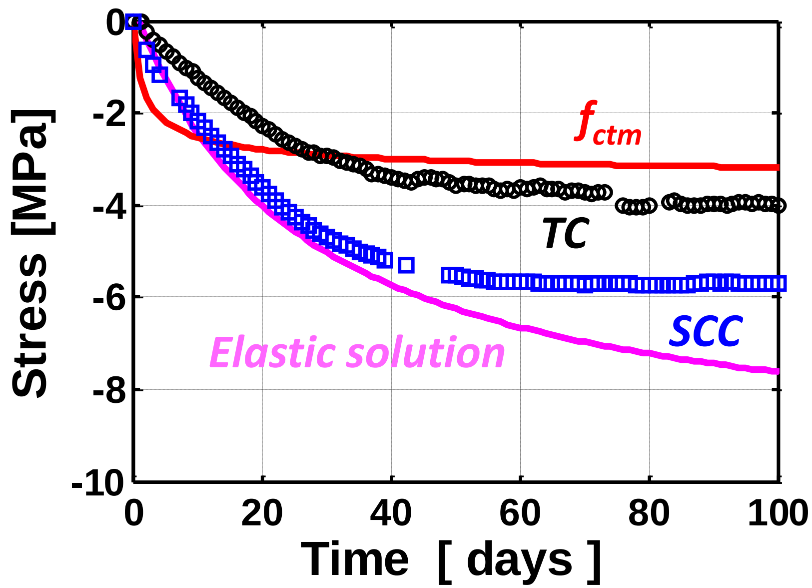
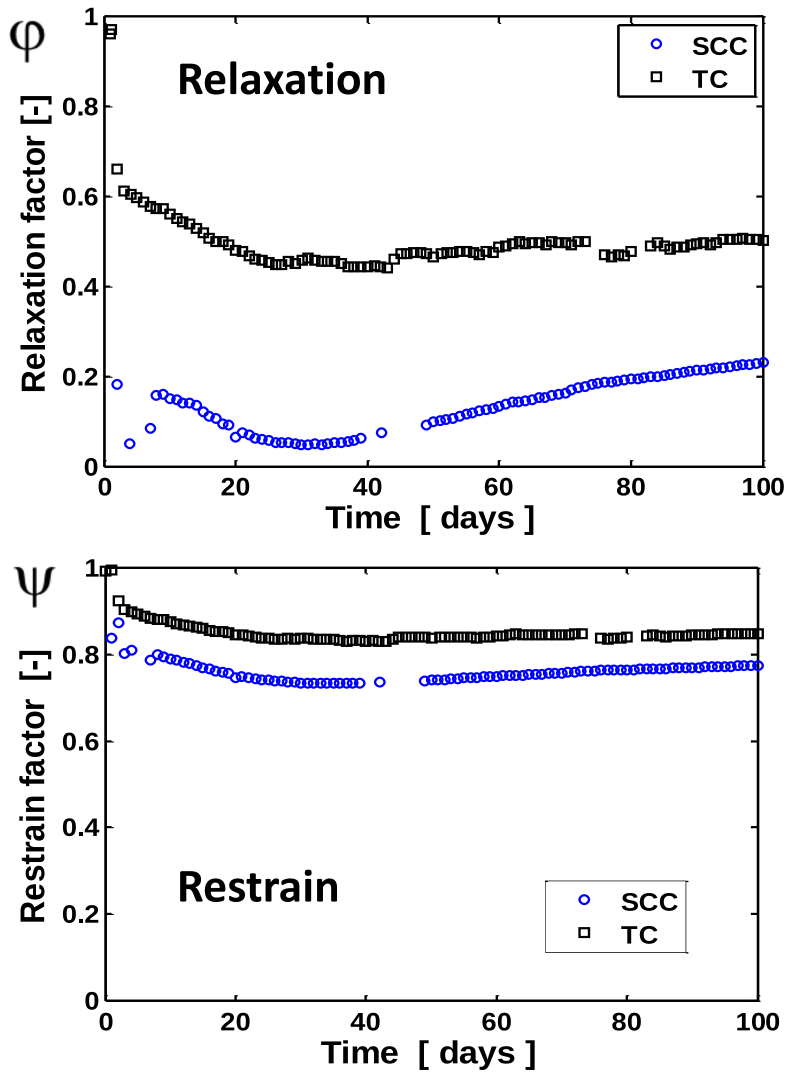
Ring tests : results illustrating the interdependency





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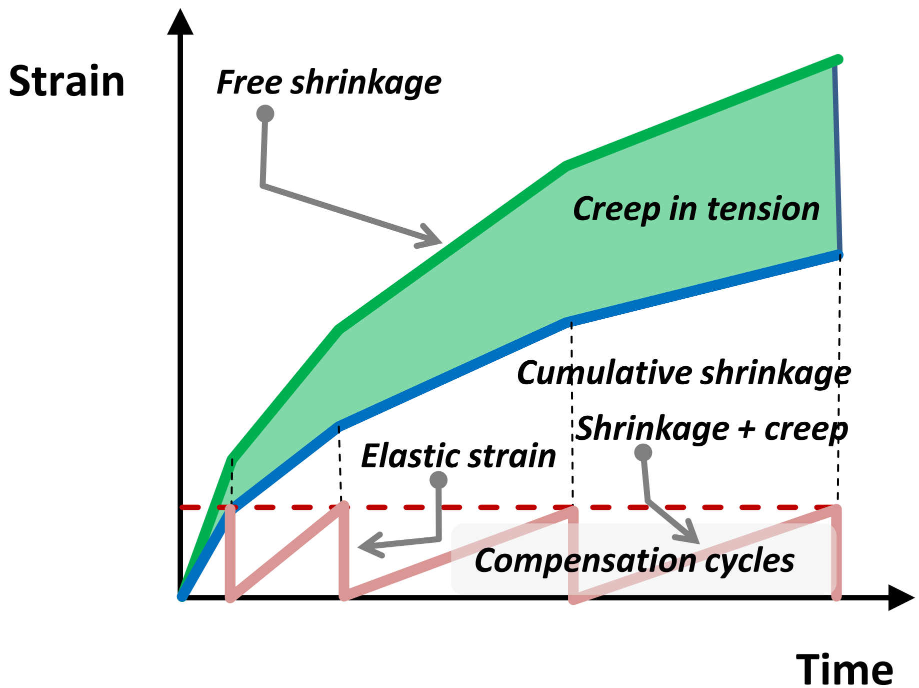
The dog-bone (restrained) test

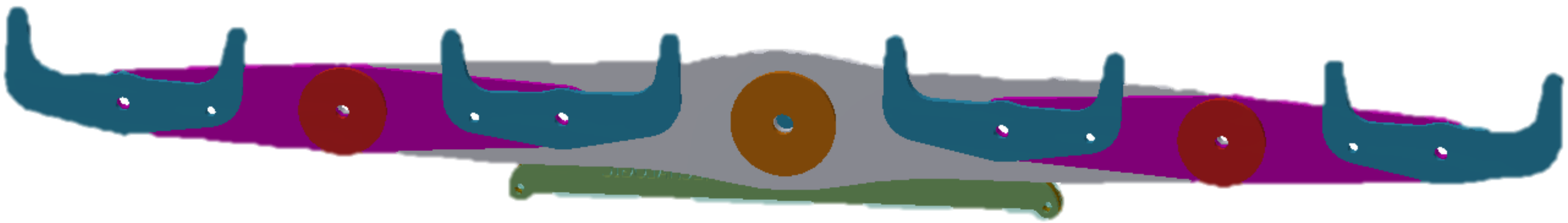


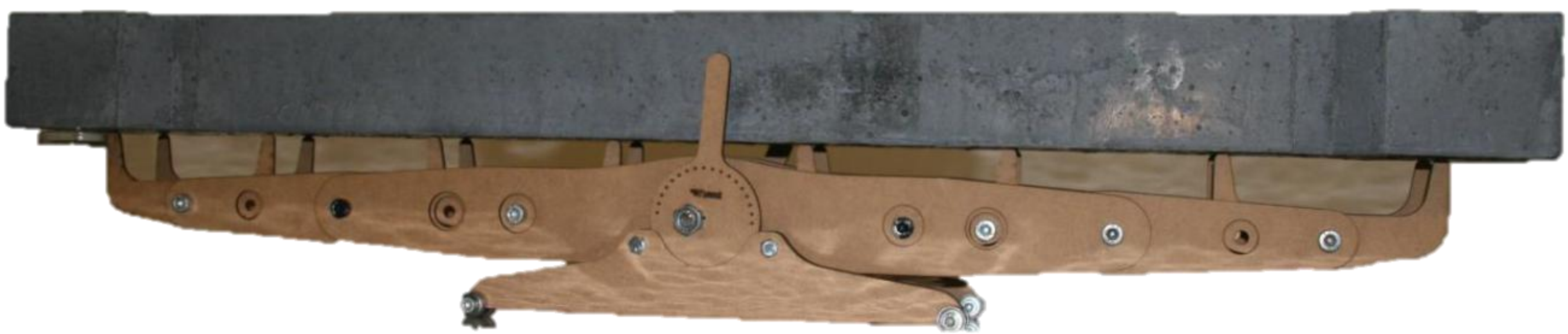
- Active system (manual/automatic)
- Dimensions of samples
- Curing
- Starting time t_0
- Thermal regulation
- Displacement measurement
- Gauge length
- Compensation criterium [0.05–10 µm/m]

No standard

Can we adapt it for studying for all faces drying ?

Some development ideas





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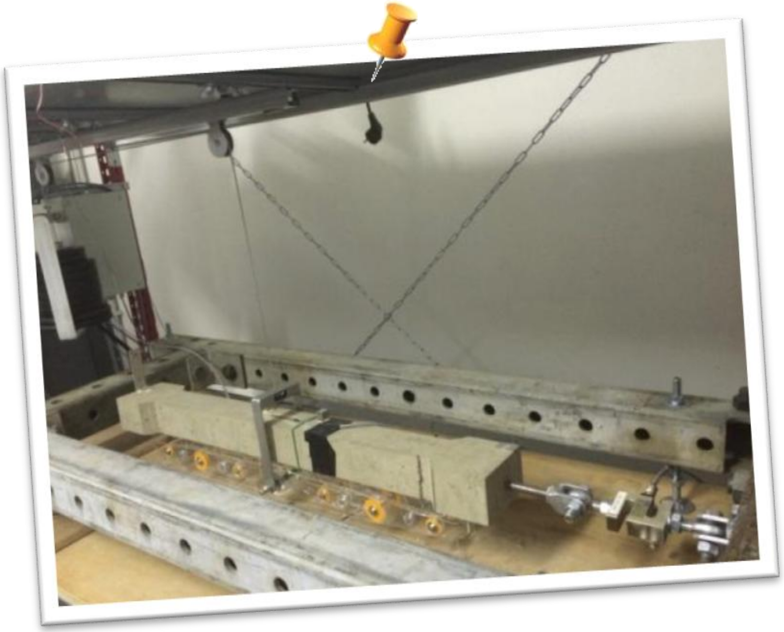
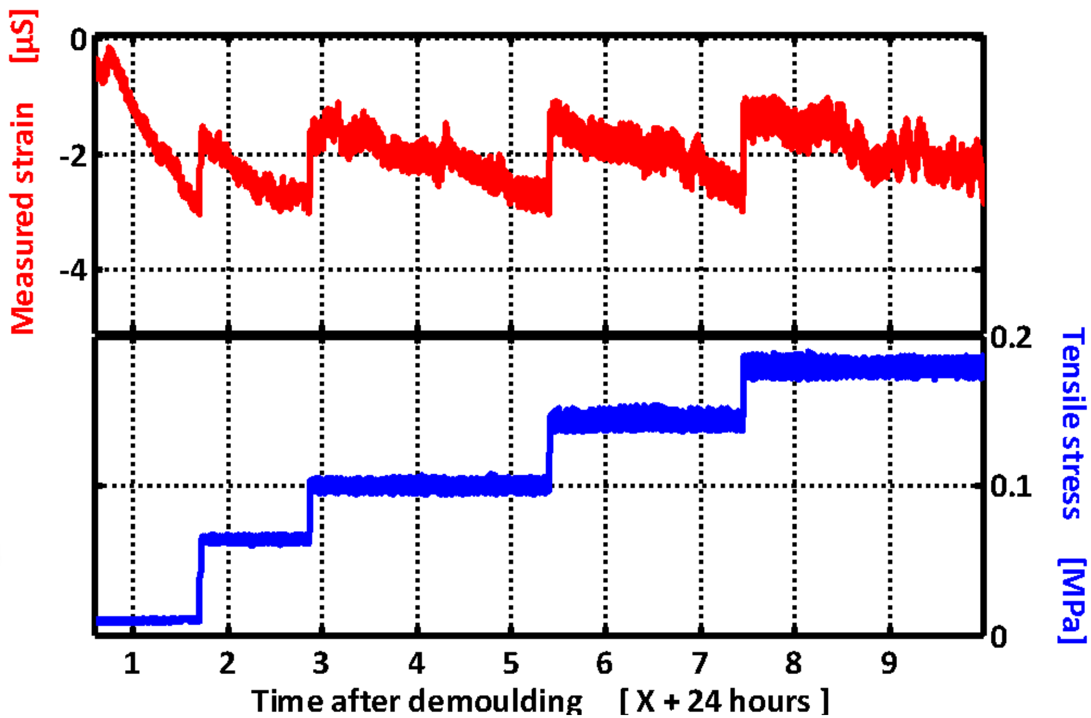
Dog-bone with all drying faces

First results





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SESSION for GP1.f – Fracture properties
Chairman: Dimitrios Exarhos

Theodore Matikas: Fracture properties and cracking - experimental plan for GP1f

Dimitris Aggelis: Use of acoustic emission and ultrasound to characterize curing and fracture of cementitious media

Cédric Dumoulin: Real-time ultrasonic monitoring of cracking in concrete structures using embedded piezoelectric transducers

Jaime Gálvez: Fracture behaviour of polyolefin fibre reinforced concrete mss•nde LABORATORY

UNIVERSITY OF IOANNINA
DEPT. OF MATERIALS SCIENCE AND ENGINEERING

Proposed Round-Robin Test (RRT) series for GP1.f (fracture properties and cracking)

Prof. Theodore Matikas
University of Ioannina, Greece

WG1 –TESTING OF CEMENT-BASED MATERIALS

1st Workshop of COST TU1404 “Focus on experimental testing of cement based materials”, University of Ljubljana, Slovenia, 16-17 April 2015

Proposed properties of cementitious materials and testing techniques for GP1f RRT.

FRACTURE PROPERTIES	MATERIALS	TESTING TECHNIQUES
Fracture toughness, K_I	Mortar, Concrete	Three-point bending, CMOD test with load control, AE
Fracture energy	Mortar, Concrete	Three-point bending test at constant deformation, AE
Bending strength	Fiber-reinforced concrete	Four-point bending test with deflection control, AE
Fracture toughness index $T_{100,2.0}$	Fiber-reinforced concrete	Four-point bending test with deflection control, AE

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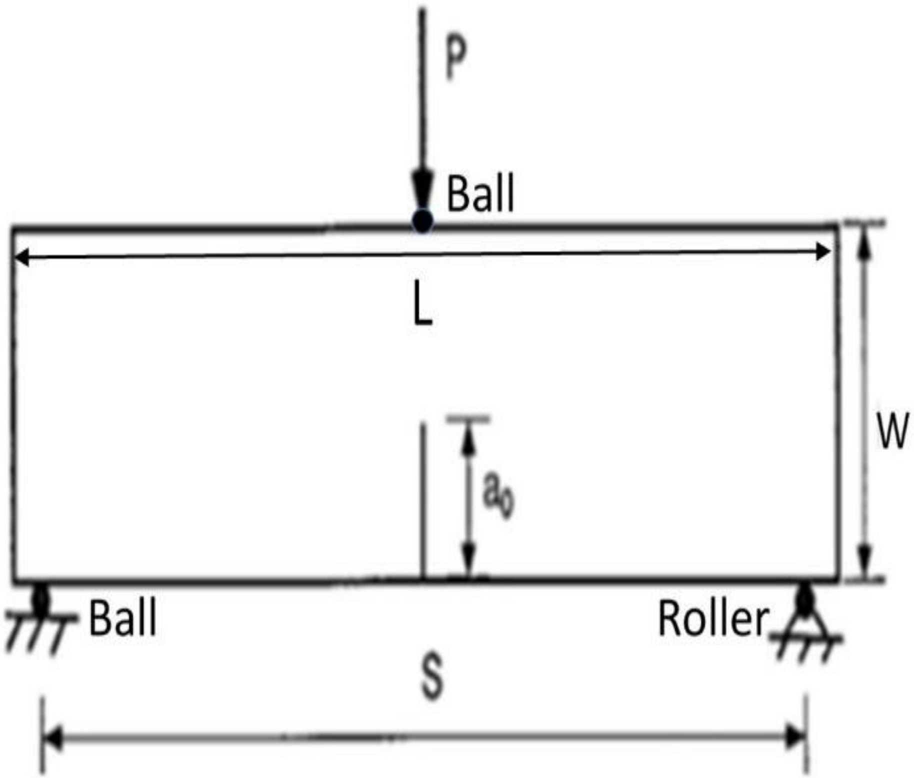
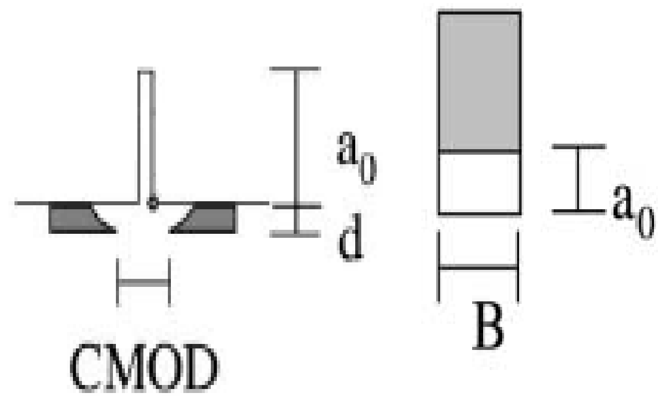
Determination of the fracture toughness by means of three-point bend test on notched beams



$$K_I = \frac{1{,}5\, P\, S \sqrt{\pi\, a}}{B\, W^2}\, f(\alpha)$$



P–CMOD response

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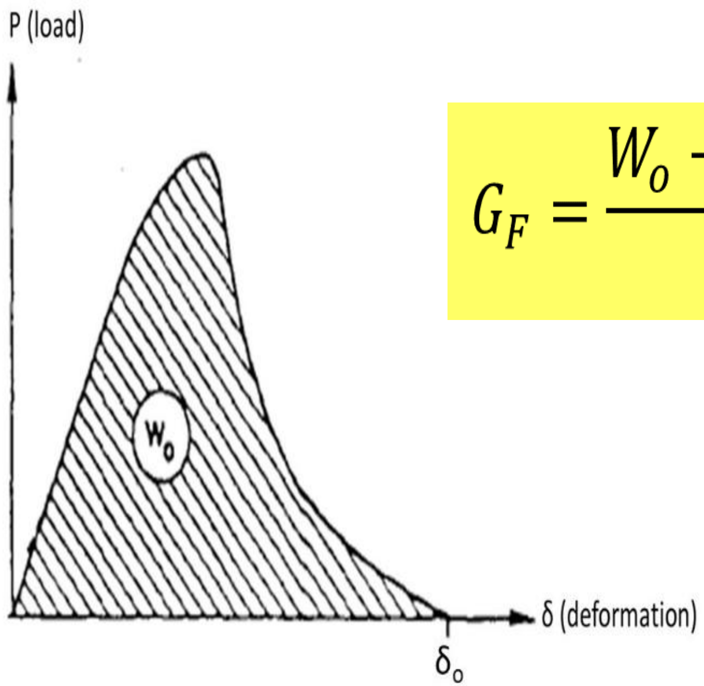
Determination of the fracture energy by means of three-point bend test on notched beams



$$G_F = \frac{W_o + m\,g\,\delta_o}{A_{lig}}$$

m = weight
g = acceleration due to gravity
δ_o = deformation of the beam at fracture
A_{lig} = area of the ligament (projection of the fracture zone on a plane perpendicular to the beam axis)

P–deformation response

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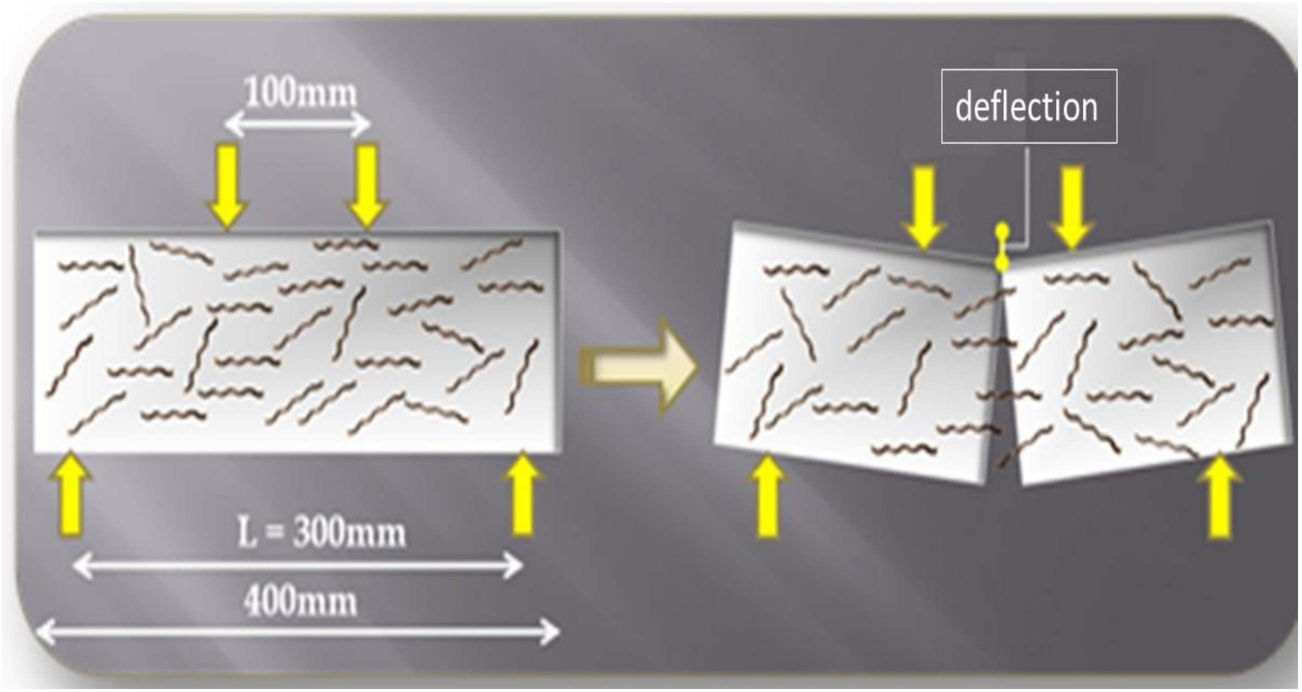
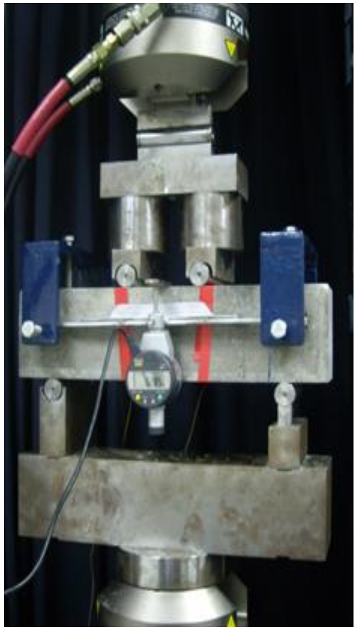
Determination of bending strength and fracture toughness of fiber-reinforced concrete





P–deflection during four-point bending test

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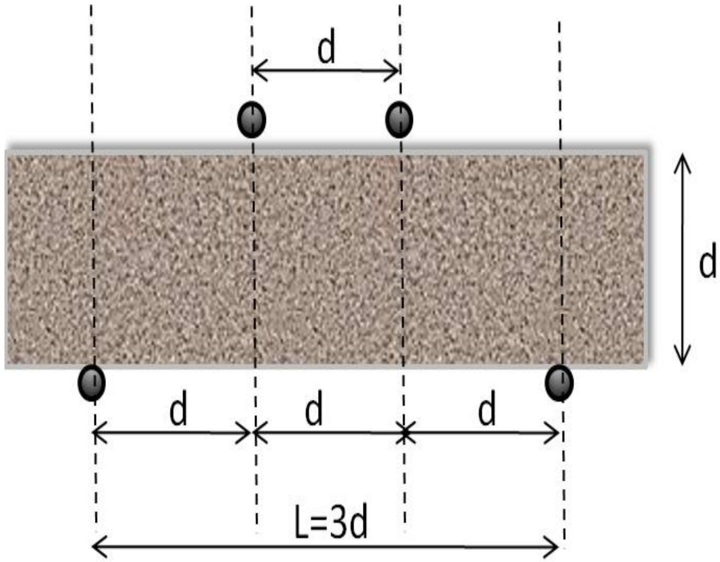
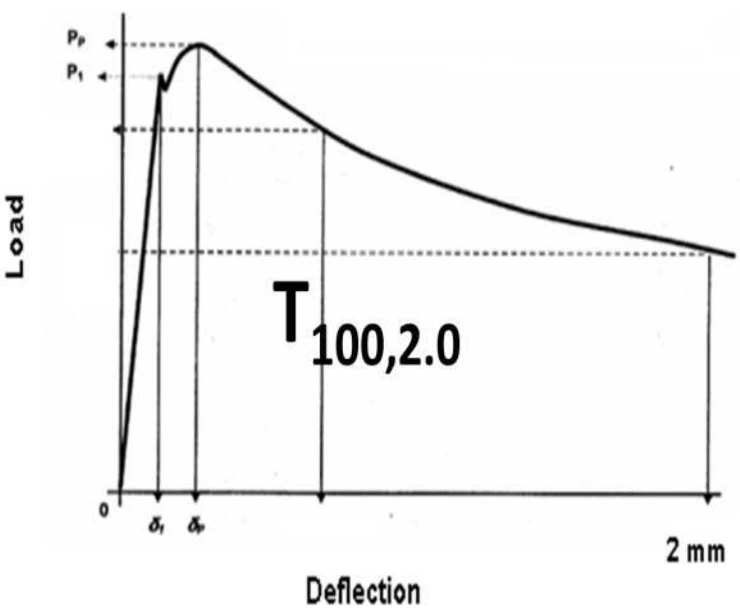


$$f = \frac{PL}{bd^2}$$

Bending strengt



Load-Deflection curve
during four-point bending test

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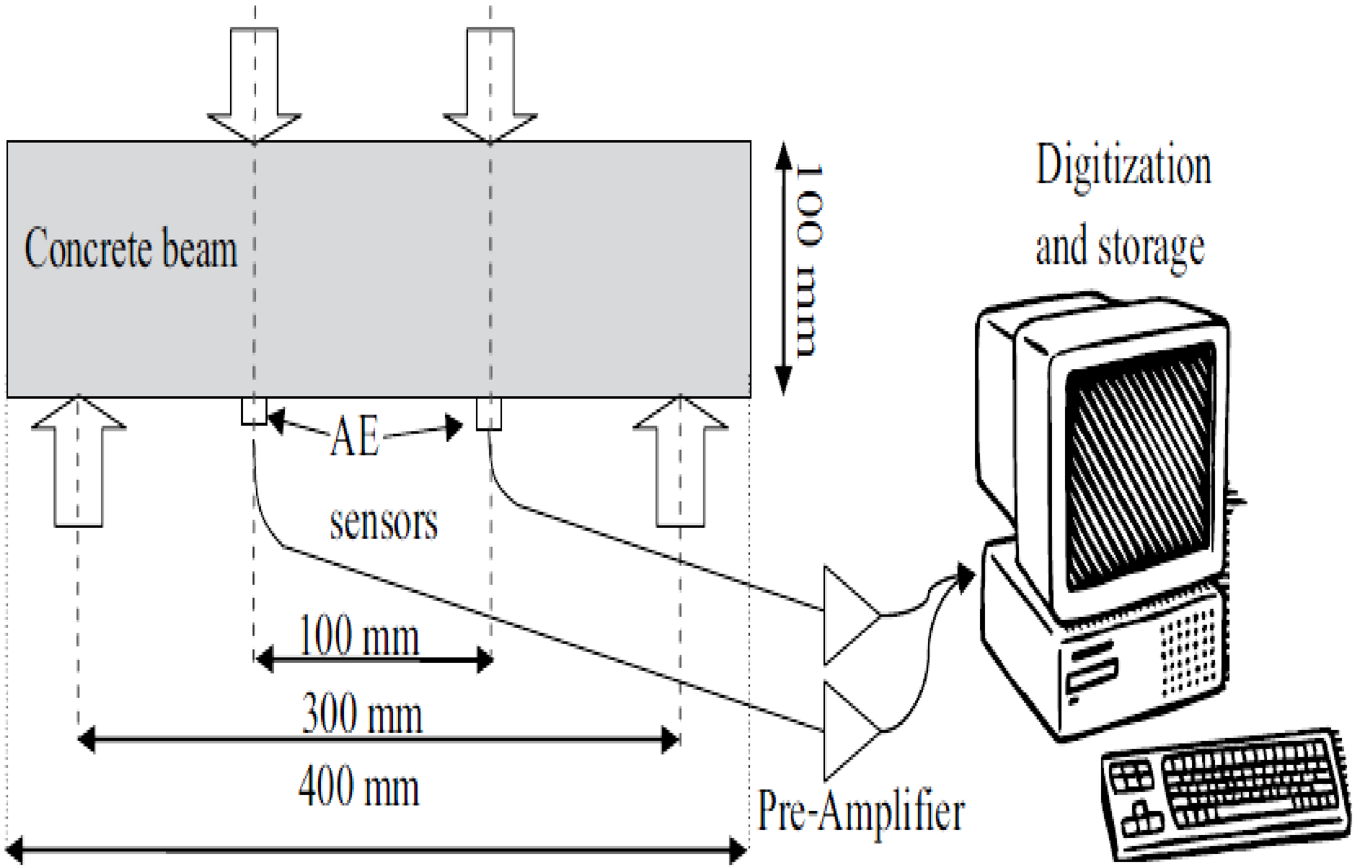
Acoustic emission (AE) monitoring of fracture and cracking



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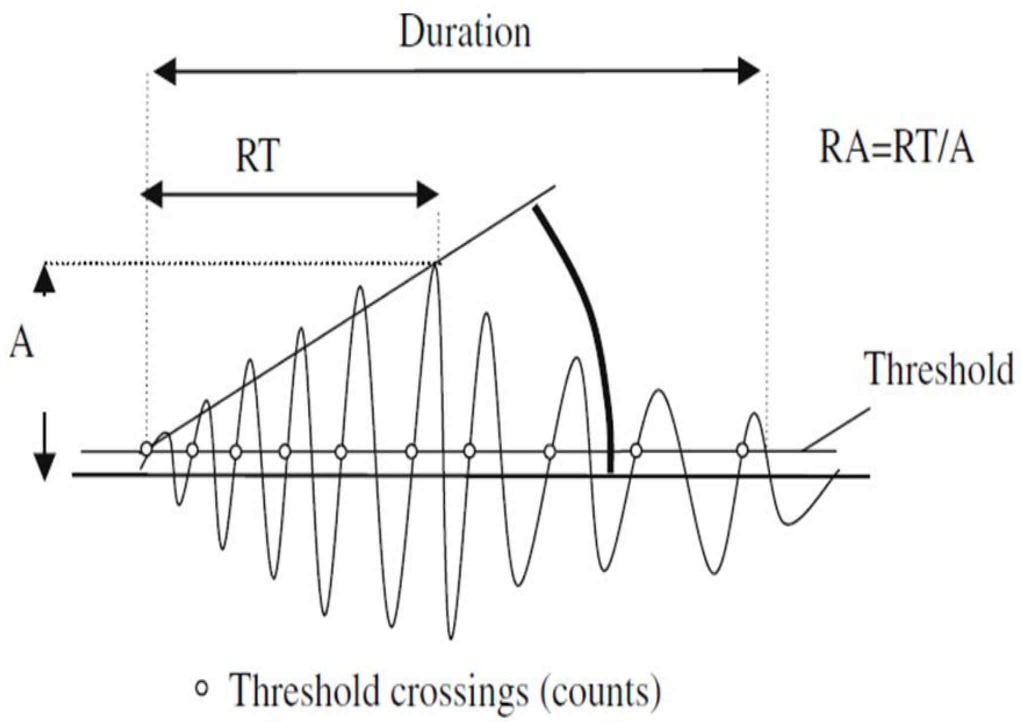
Basic parameters of AE to be recorded



1) Threshold: A pre-set voltage that should be overpassed in order for acquisition to start.
2) Peak amplitude: Maximum voltage of the waveform.
3) AE energy: Measured Area under the Rectified Signal Envelope, MARSE.
4) Rise time: Delay between first thr. crossing and maximum peak.
5) Duration: Delay between first and last thr. crossing and last one.
6) External parameters: load, strain and so forth are preferably recorded in the system each moment a "hit" is received.

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UNIVERSITY OF IOANNINA
DEPARTMENT OF MATERIALS SCIENCE ENGINEERING

MECHANICS, SMART SENSORS & NONDESTRUCTIVE EVALUATION (MSS-NDE) LABORATORY

http://mss-nde.uoi.gr/

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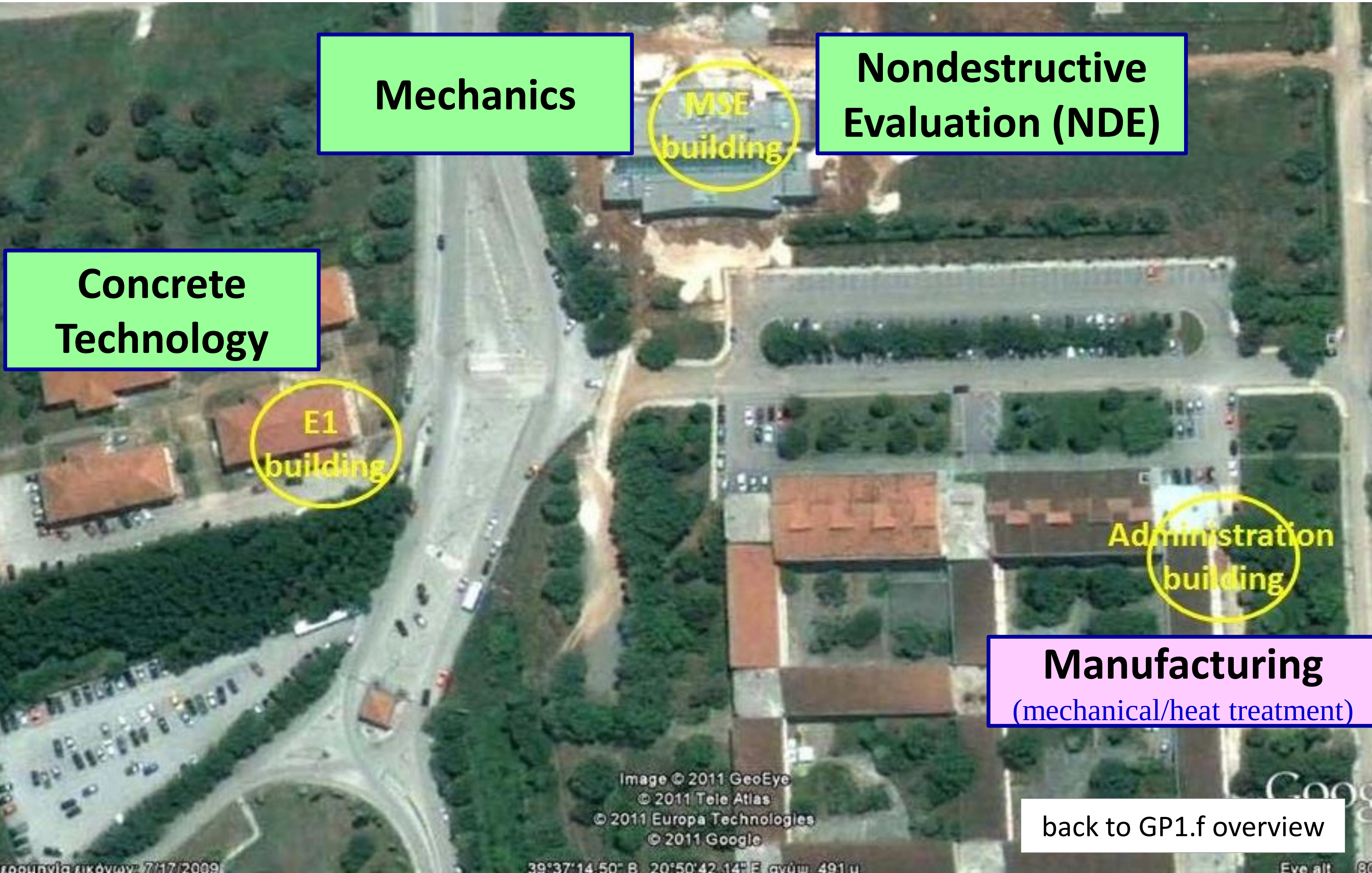
MSS-NDE Lab Research Areas



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MSS-NDE Laboratory Infrastructure

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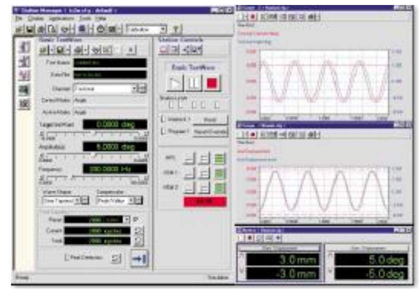
MSS-NDE Laboratory Equipment – Mechanics

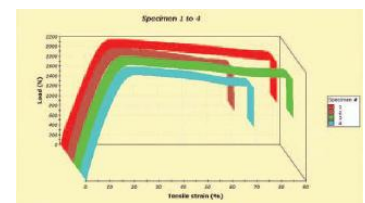
Metals, Ceramics, Polymers, Composites, Nano-materials, Coatings, F-R Concrete

- A dynamic ±100 kN servo-hydraulic mechanical system for cyclic loading, dynamic bending and fracture mechanics testing, max frequency 1 kHz
- A 30 kN electro-mechanical testing system, for performing a variety of static testing procedures (tensile, compressive, bending, creep, friction, relaxation) through load, displacement, and deflection control
- Advanced Video Extensometer for non-contact 2-D deformation measurements (elasticity modulus, Poisson's ratio).

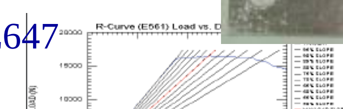
- Mechanical Fatigue (ASTM E606, E466)



- 3-point Dynamic Bending (ASTM C293, C1161, C1341)



- Fracture Mechanics Testing:
  - ✓ 4-point flexure toughness (ASTM C1609)
  - ✓ Fracture Toughness (K1C), ASTM E399, E1820
  - ✓ J1C integral, ASTM E813, E1737
  - ✓ R Curve , ASTM E561
  - ✓ Crack Growth Rate, ASTM E647
  - ✓ COD ASTM E1290



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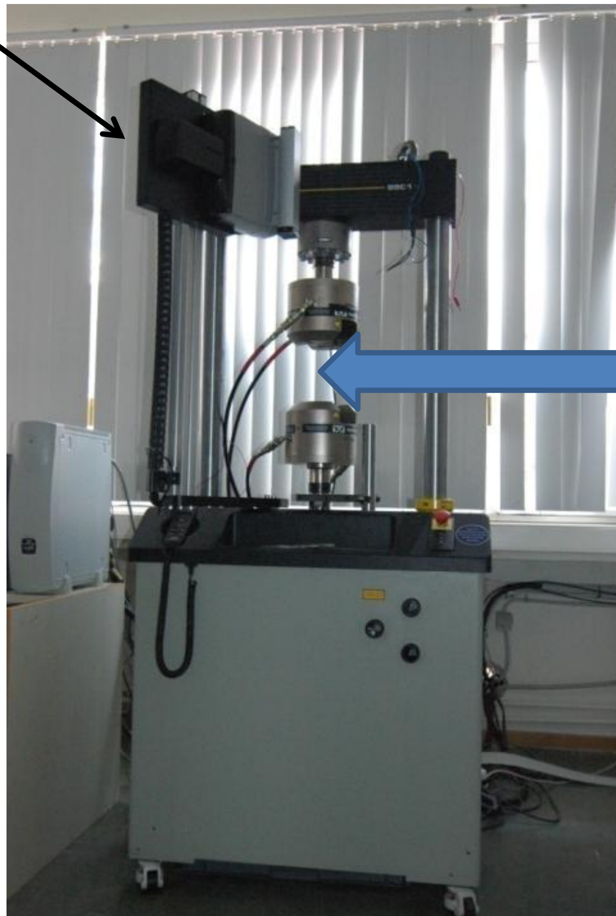
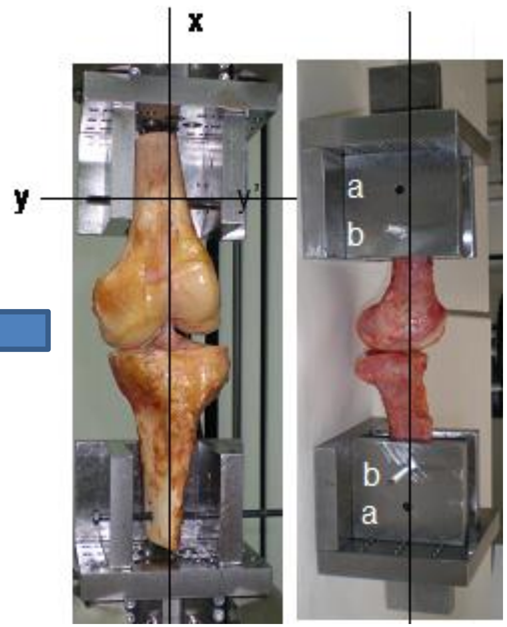
MSS-NDE Laboratory Equipment – Mechanics

Bio-Mechanics

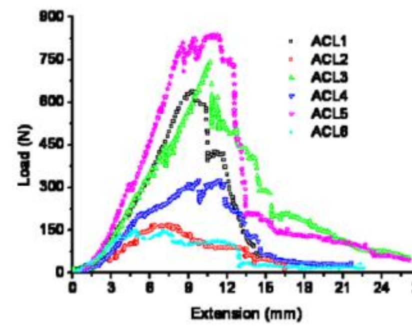
NSTRON non-contact Advanced Video Extensometer





Load-cells

- 5 KN
- 10 KN



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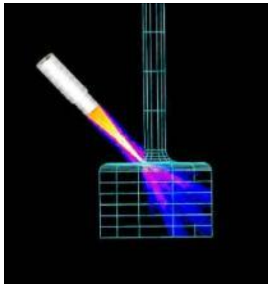
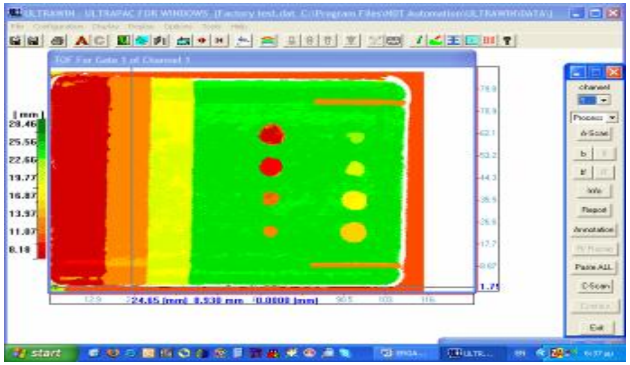


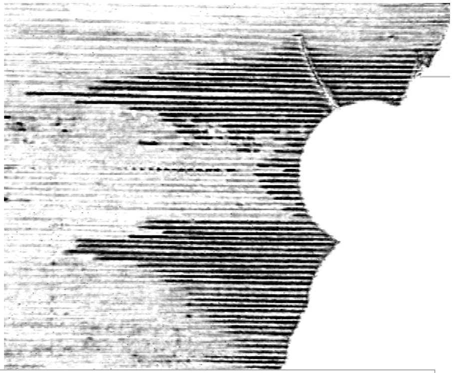
MSS-NDE Laboratory Equipment – NDE

Acoustics



- Single bridge ultrasonic immersion system with 5 computer controlled axes (x, y, z, gimbal, swivel), 1μm step size, computer controlled R/R, high-speed A/D converter with 100Msps digitizing rate, and multiple software gates: A-, B-, and C-scans, PE/TT modes, pulsed and continuous waves, contact ultrasound for material bulk elastic property characterization, Lamb wave scanning.
- Scanning Acoustic Microscopy system: HF 50MHz transducer, 75 MHz P/R with 39dB RF gain, and A/D Converter 8 bit 1.5 GHz.
- Nonlinear acoustics system consisting of a linear P/R, 250 kHz - 20 MHz RF synthesizer, 8 kW gated linear power amplifier, DC power supply, power filters for various excitation frequencies, high and low pass filters for the harmonics, dual channel 100MHz function generator, 2-channel digital oscilloscope
- Acoustic emission system with a AEWIN PCI2-2 2-channel card, pre-amplifiers and NOESIS PRO and UTIA Enterprise software for analysing AE signals

Metallurgy
Welds
Cracks
Corrosion
Thermal damage
Bridges
Ducts, ect.



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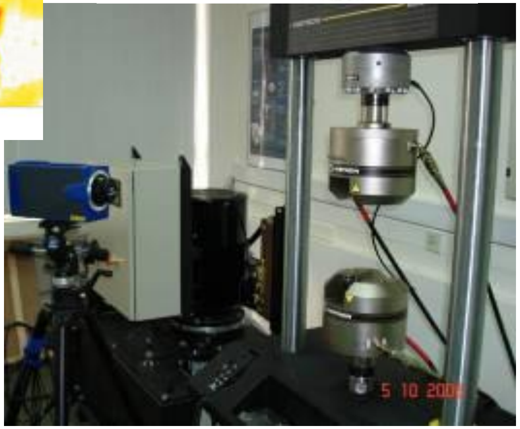
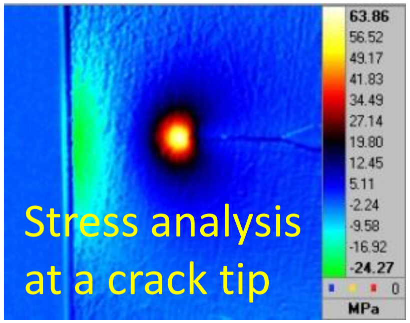
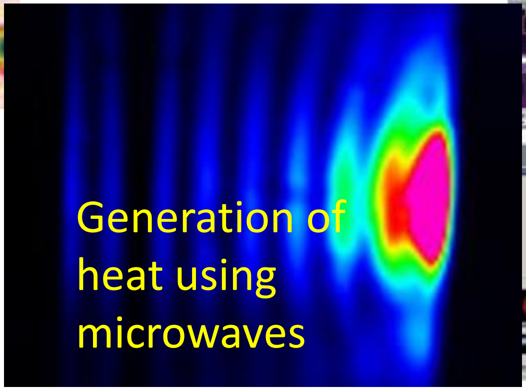
MSS-NDE Laboratory Equipment – NDE

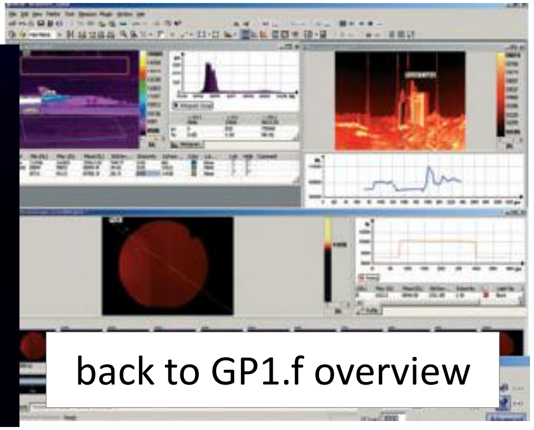
Thermography

- CEDIP thermography system with InSb detector (320x240 element) focal plane array (ITR 30 μm), spectrum response of 3.6-5.0 μm and thermal sensitivity < 25mK at 25°C. Thermal analysis 0.001°C. Modes:
  - Real-time thermography
  - Stress analysis
  - Optical lock-in thermography
- FLIR ThermaCAM T360 thermal camera with Focal Plane Array 320x240 detector (78.000 pixels) and Thermal Fusion capability for the characterization of large-scale structures.









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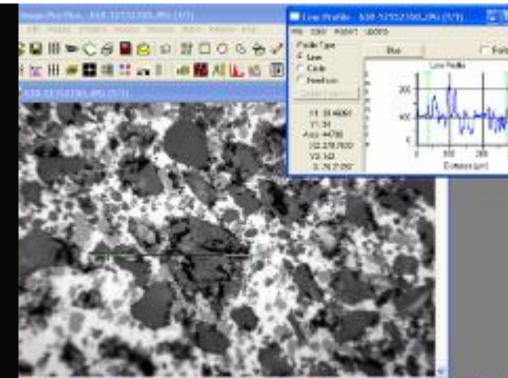
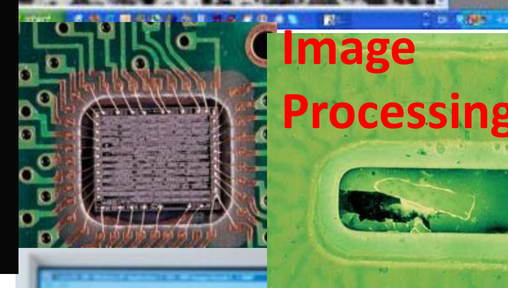
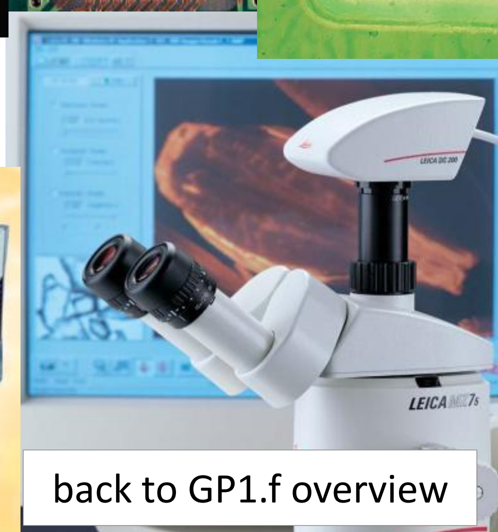
MSS-NDE Laboratory Equipment – NDE

Interferometry & Optical microscopy

- Laser Doppler Vibrometer for non-contact acoustics measurements, which includes interferometer controller, high resolution and high frequency digital displacement and velocity decoders, laser sensor head, and 12-Bit data acquisition unit.
- Optical microscope Leica DM-4000M 1000x, bright field, dark field, polarization, inverse differential interference) with image processing.
- Leica MZ75 high-performance 100x stereomicroscope with zoom 7.9:1, ErgoTube™ 10° – 50°, transmitted-light (bright field) and focusing drive (coarse/fine)

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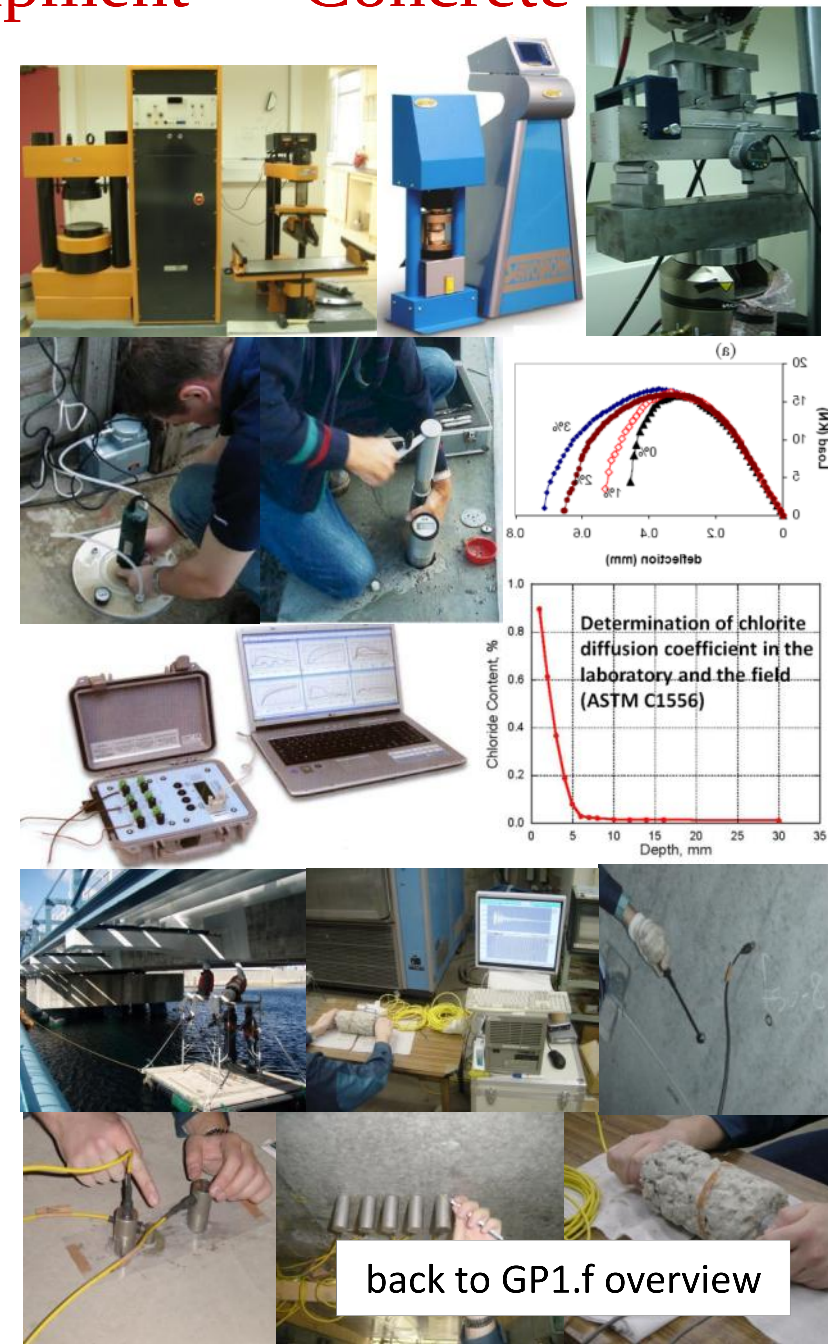
MSS-NDE Laboratory Equipment – Concrete

- 100 lt, 50 lt, 5 lt mixers for concrete and mortar, 400 W HIELSCHER ultrasonic mixer for nono-particle mixing in cement-based materials.
- 440 lt furnace, automatic sieving machine, vibration tables 100x100 and 50x50mm
- Mechanical system TONI TECNICK for concrete testing, load up to 3000KN (compression), 250KN (bending)
- Mechanical system MATEST for mortar testing. load up to 250KN (compression), 15KN (bending)
- Balances 60kg, 30kg with accuracy 1g, 6.5kg with accuracy 0.1g, 220g with accuracy 0.1mg, density measurement.
- Complete set of apparatuses for fabrication and testing of cement-based materials (cutter, maturity chamber, VEBE, VICAT, air content, covermeter, vibro-consistometer, shrinkage, permeability, flow tables, V-funnel, L-box, J-ring, slump test, molds, etc.)
- In-situ measurement of compressive strength (LOK-TEST system for fresh concrete and CAPO-TEST system for existing concrete structures ASTM C 900, EN 12504.
- Chloride penetration resistance measurement devices:
  - PROOVE-it system AASHTO T 277, ASTM C 1202
  - Profile Grinder system for in-situ measurements in large scale concrete structures ASTM C1556.
- 6-temperature channels CONReg system for concrete strength based on the maturity principal ASTM C 1074.
- Rapid Chloride Testing System (RCT) in concrete.



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MSS-NDE Laboratory Equipment - Manufacturing

Specimens and parts (mechanical / heat treatment)

- Vertical CNC (Computer Numerical Control) Mill HASS TM-1HE, 3-axes. Axes: 762 x 305 x 406 (X/Y/Z). Milling velocity up to 5100 mm/min
- 45mm 400V Bulle MD45G milling machine
- Thermo Fisher/ Heraeus M110 Muffle 9 lt. Furnace, max temperature 1100°C, with Thermicon® P temperature controller
- Thermo Electron LED GmbH / Heraeus VT6025 25 lt. digital Vacuum oven with double pane safety glass viewing window, temperature 10oC above RT - 200oC, 10-2 mbar pressure.

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back to GP1.f overview

Collaborations

List of selected collaborations of the MSS-NDE Lab with Laboratories, Universities, Research Centers, Companies:

- **Technical Chamber of Greece TEE** (G. Stamoulakis, etc.)
- **Center of Research and Standards of the Public Electricity Company** (A. Sakelariou)
- **Greek Atomic Energy Commission** (Dr. A. Maltezos, etc.)
- **International Atomic Energy Agency** (A. Nilson, K. Mrabit, etc.)
- **University of Dayton research Institute, USA** (Dr. M. Khobaib)
- **Materials Science & Engineering, Drexel University, USA** (Prof. A,. Zavaliagos)
- **Collaboration of T. Matikas, D. Aggelis and C. Dassios with other Faculty of the Department of Materials Science & Engineering** (Profs. A. Paipetis, N.-M. Barkoula, A. Charalambopoulos, L. Gergidis, A. Avgeropoulos, C. Beltsios, A. Charalambopoulos, M. Karakassides, A. Lekatou, V. Kalpakides, P. Patsalas, S. Agathopoulos, E. Skouras)
- **Laboratory of Public Works of the Epirus Region** (G. Stamoulakis)
- **Faculty of Chemical Engineering – Technical Univ. of Athens** (Prof. Moropoulou, etc.)
- **Department of Mechanical & Aerospace Engineering – Univ. of Patras** (Prof. Kostopoulos, etc.)
- **Faculty of Metallurgical Engineering – Technical Univ. of Athens** (Prof. Ch. Panagopoulos, etc.)
- **Department of Civil Engineering – Aristotle Univ. of Thessaloniki** (Prof. N. Charalambakis, etc.)
- **Department of Civil Engineering – Univ. of Thessaly** (Prof. Ph. Perdikaris, etc.)
- **Orthopedic Clinic, Faculty of Medicine, Univ. of Ioannina** (Prof. A. Georgoulis, etc.)
- **Sheffield–Hallam University, UK** (Prof. S. Hasan, Dr. D. Myriounis)
- **Optical Instrumentation and NDE Branch, NASA Glenn Research Center** (Dr. G. Baaklini, etc.)
- **US Air Force Materials Directorate, Ohio, USA** (Dr. J. Blackshire, Dr. T. Moran, etc.)
- **Fraunhofer Institute, Germany** (Dr. N. Meyendorf, etc.)
- **Civil Engineering Dept., Univ. of Arizona** (Prof. G. Frantziskonis, Prof. T. Kundu)
- **TITAN S.A.** (D. Papageorgiou, Ch. Leptokarides. etc.)
- **LAFARGE S.A.** (P. Deleplanque)
- **SPIDER S.A.** (C. Petsios)
- **AKTOR S.T.A.**
- **SIDENOR S.A.**

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Collaborations

- **GEOTEST S.A.** (N. Zoides)
- **New Discovery Bricks Hellas** (M. Krabokoukis)
- **ET.AL S.A.** (G. Periers)
- **Envirocoustics A.B.E.E.** (Dr. N. Athanasopoulos, etc.)
- **MICHANIKI S.A.**
- **TERNA S.A.**
- **OSSA Hellas S.T.A.**
- **Epirus Lab. Test** (M. Prapides)
- **EGNATIA Odos S.A.**
- **BASF C.C. Hellas S.A..** (L. Marki)
- **AGET Heracles S.A**. (J. Marinos)
- **LAFARGE BETON S.A.** (Dr. P. Nicolaou)
- **Dika Isolier Glass S.A.** (M. Mitsikas)
- **Orthopedic Sports Medicine Center of Ioannina** (Prof. A. Georgoulis, N. Paschos)
- **SNECMA Aircraft Engines, France** (A. Lasalmonie, etc.)
- **MC-21, USA** (D. Schuster)
- **Physical Acoustics Corporation, USA** (Dr. S. Vahaviolos, etc.)
- **Materials and Metallurgical Engineering Department, New Mexico Tech** (Prof. B. Majumdar)
- **Aerospatiale Espace Defense, France** (Dr. J. Jamet)
- **Airbus Deutschland, Germany** (Dr. Henrik Rosner)
- **Germann Instruments S.A., Denmark** (C. Germann)
- **Intel Corporation** (Dr. P. Karpur)
- **Materials Science & Engineering Dept., Ohio State University, USA** (Prof. S. Rokhlin)
- **School of Aerospace Systems, University of Cincinnati, USA** (Prof. P. Nagy)
- **Physics Dept., University of Athens** (Prof. N. Stefanou)
- **Office National d'Études et de Recherches Aérospatiales – ONERA, France** (J.F. Stohr)
- **General Electric Aircraft Engines**, Cincinnati OH, USA
- **Kioto University, Japan** (Prof. T. Shiotani)

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TU 1404 COST ACTION

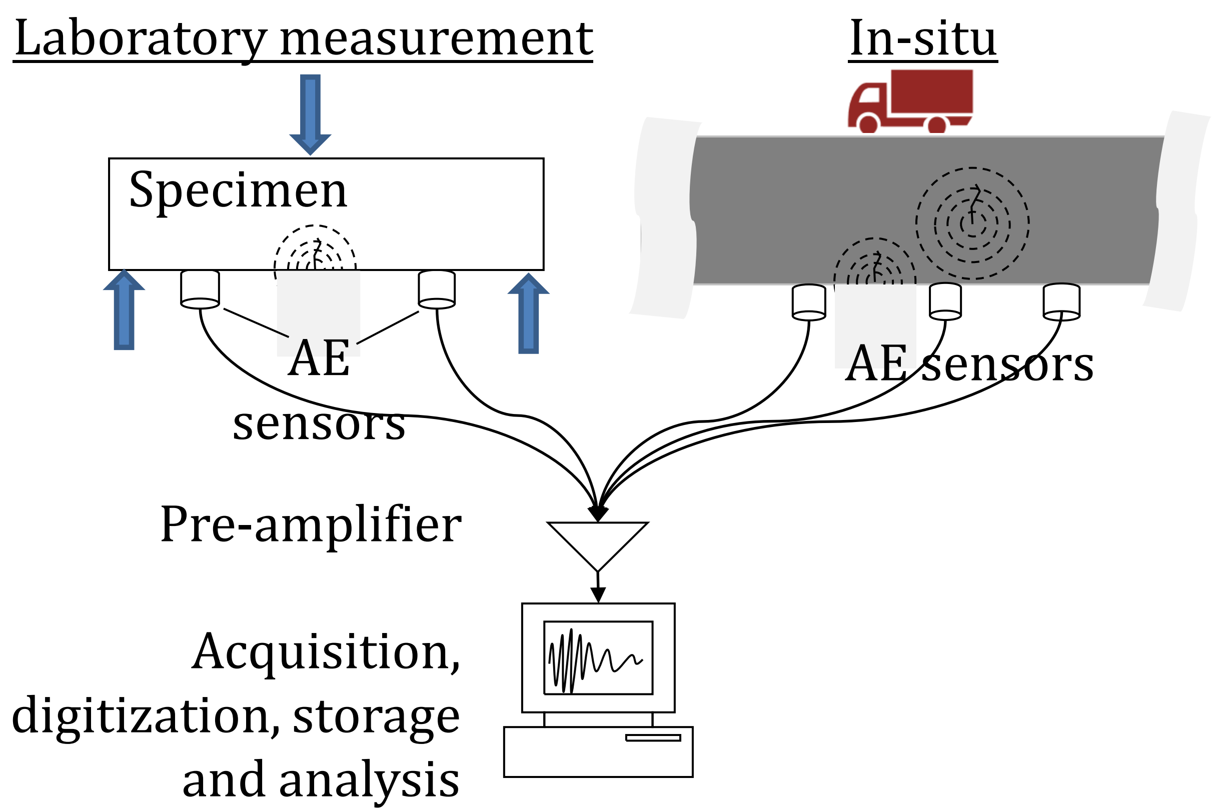
USE OF ACOUSTIC EMISSION AND ULTRASOUND TO CHARACTERIZE CURING AND FRACTURE OF CEMENTITIOUS MEDIA

Dimitris G. Aggelis, Sokratis Iliopoulos, Danny Van Hemelrijck Department of Mechanics of Materials and Constructions (MEMC), Vrije Universiteit Brussel (VUB), Belgium

VRIJE UNIVERSITEIT BRUSSEL MeMC MECHANICS OF MATERIALS AND CONSTRUCTIONS

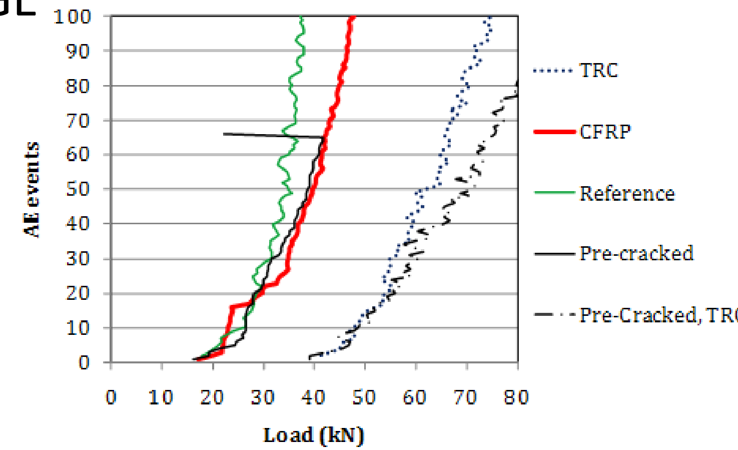
OVERVIEW OF THE TECHNIQUES

Acoustic emission (AE) is used for several decades for inspection of concrete materials and structures. Piezoelectric sensors detect the elastic waves after crack propagation events

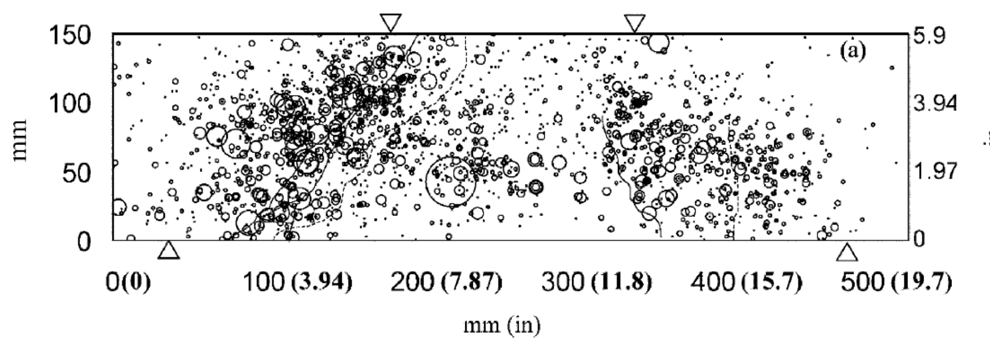


BASIC INFORMATION OBTAINED BY AE

- TIME AND LOAD OF THE ONSET OF DAMAGE

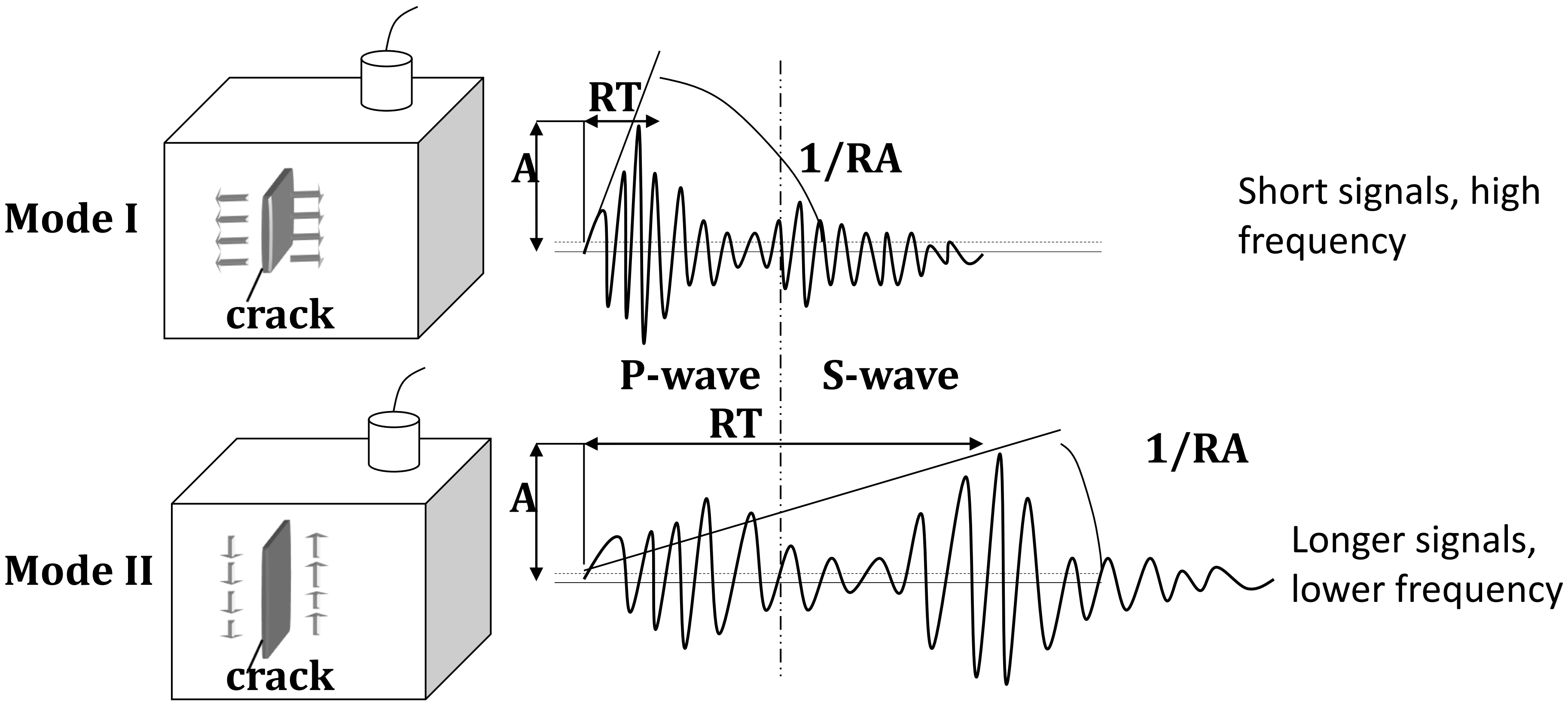


- LOCATION OF DAMAGE



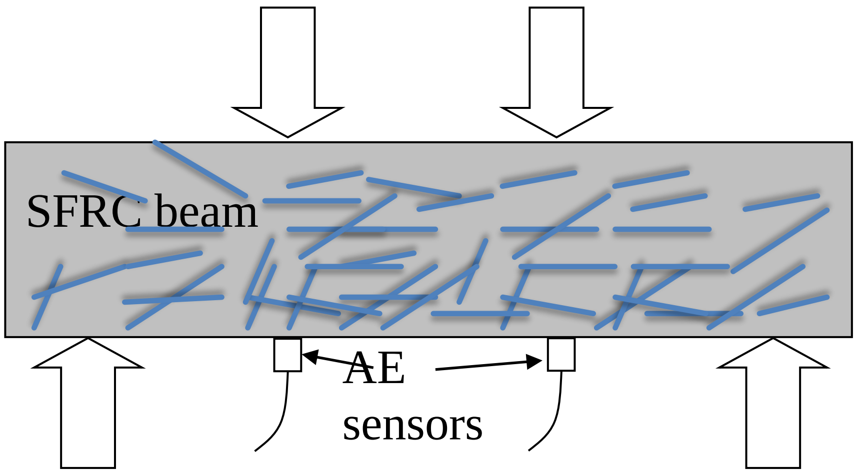
- POSSIBLE DETERMINATION OF THE FRACTURE MODE

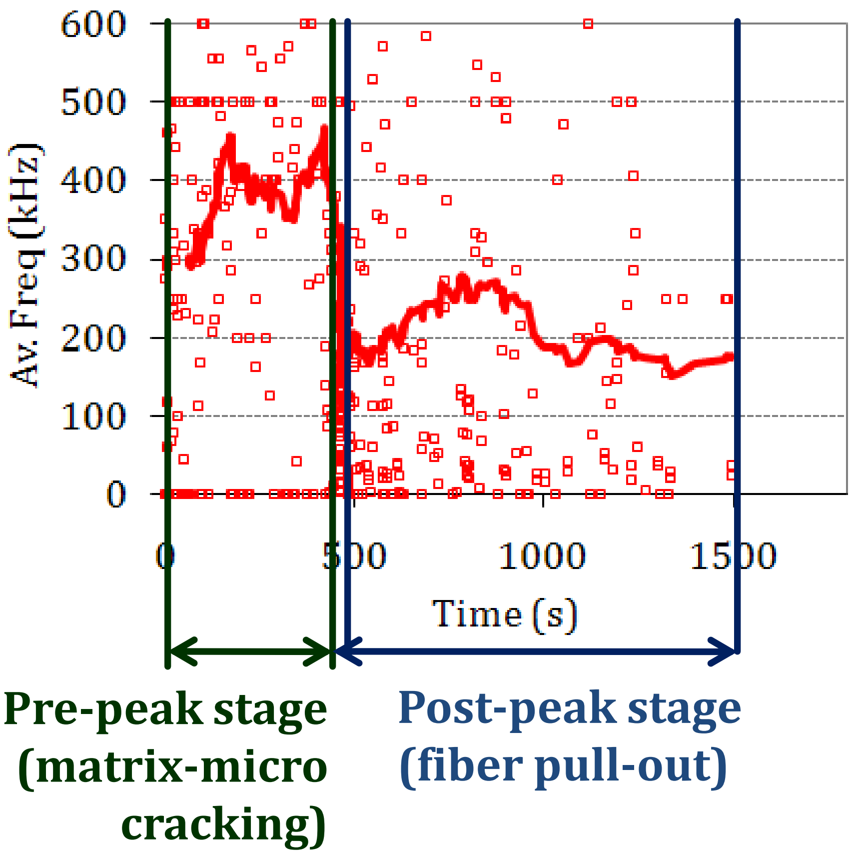
AE SIGNATURE OF DIFFERENT CRACK MODES



•Recommendations of RILEM Technical Committee 212- ACD: Test method for classification of active cracks in concrete structures by acoustic emission. Mater Struct 43(9) (2010) 1187–1189.

EXAMPLES FROM SFR CONCRETE



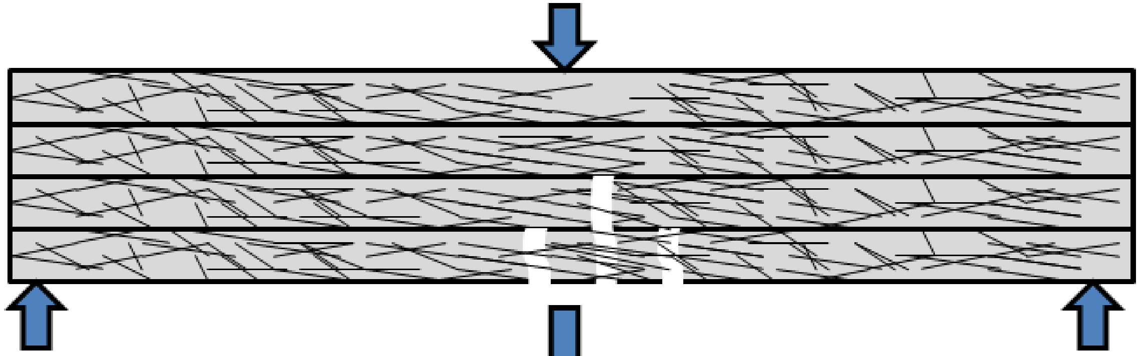


AE parameters indicate the shift between fracture mechanisms (in this case concrete crack -> fiber pull-out)

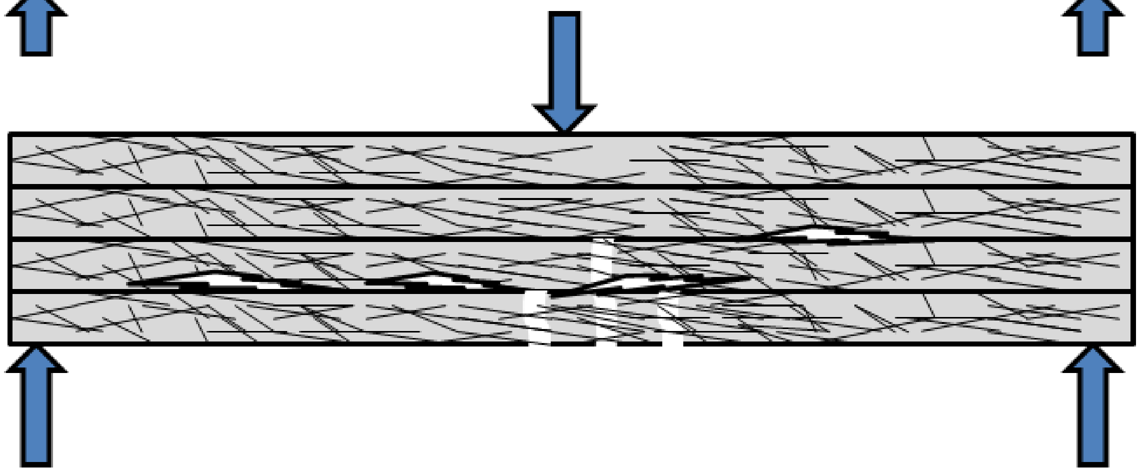
Construction and Building Materials 48 (2013) 1255–1260

FRACTURE OF TRC UNDER BENDING

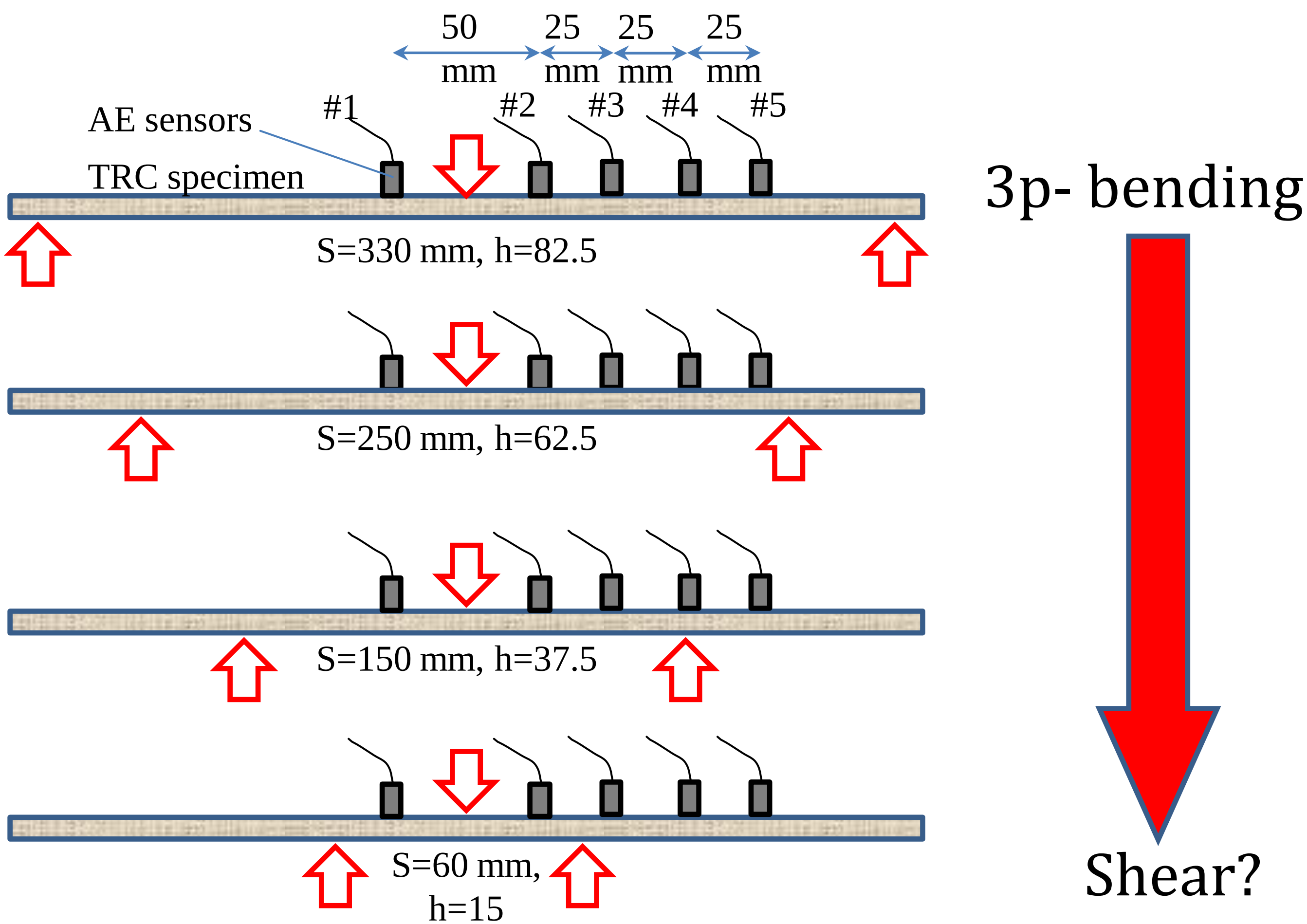
Low load
Matrix cracking



Higher load
Matrix cracking
Pull-out
Debonding



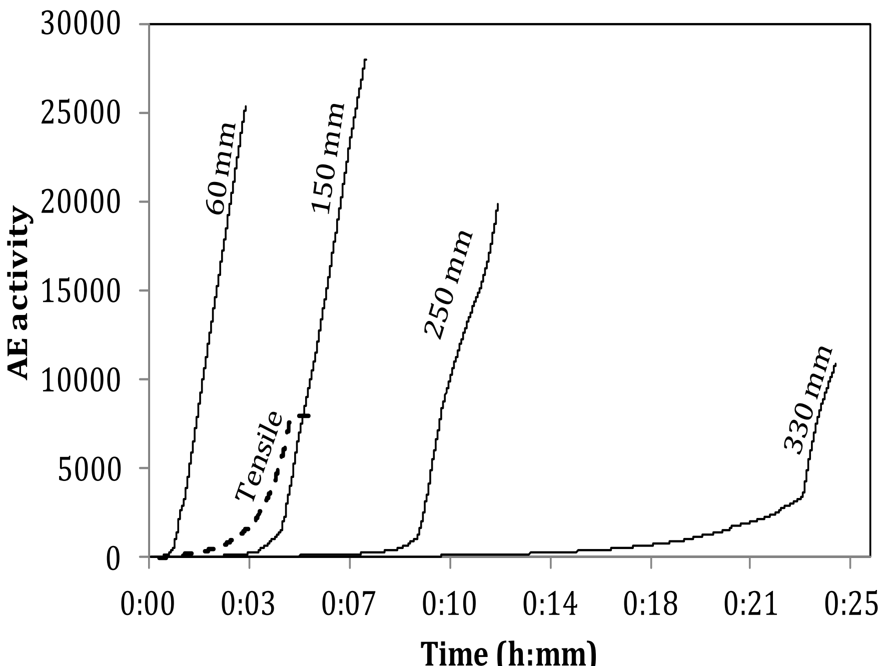
MODIFICATION OF THE STRESS FIELD



Pico sensors (broadband, peak at 450 kHz)

5 sensors to check for the plate wave dispersion and attenuation

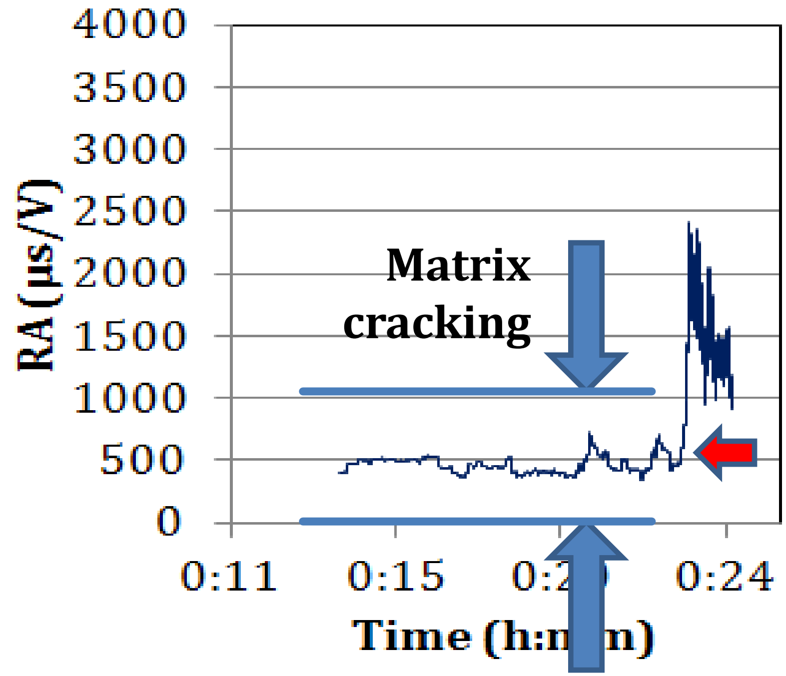
TOTAL ACTIVITY



The short spans exhibited constant rate for most of the experiment and higher population than the long spans.

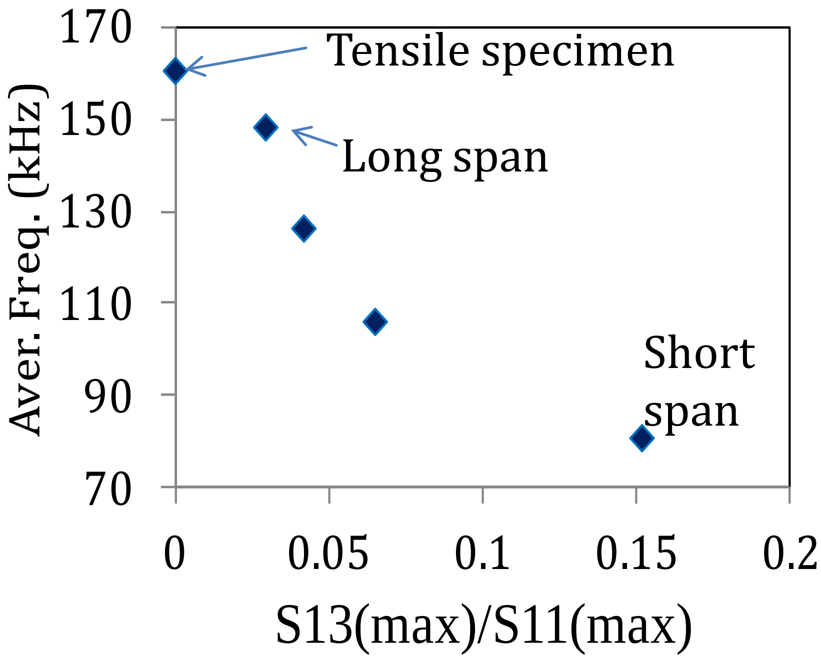
The moment of major fracture (peak load) is evident for the long spans.

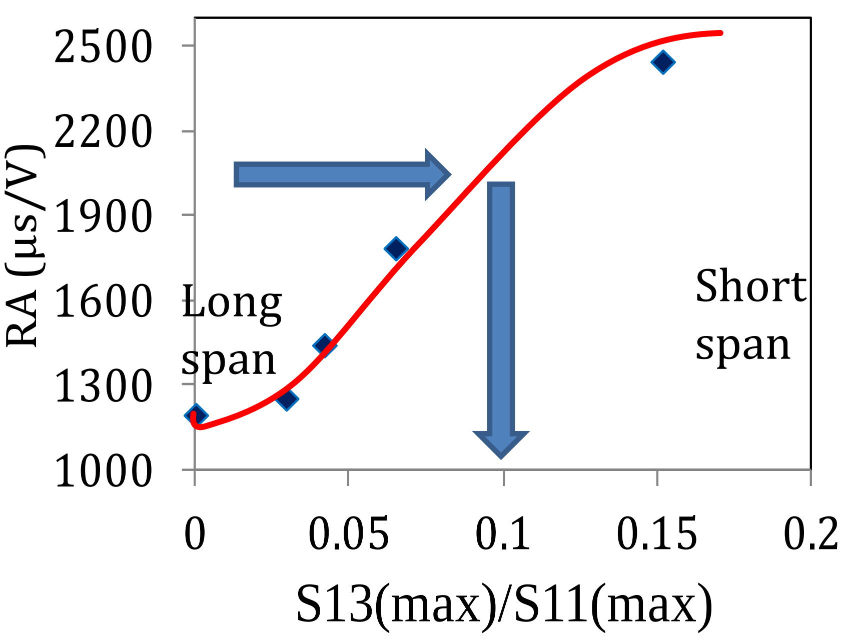
RA-VALUE



Shift of AE parameters indicates change of dominant mechanism

AE WAVEFORM PARAMETERS FOR DIFFERENT STRESS RATIOS



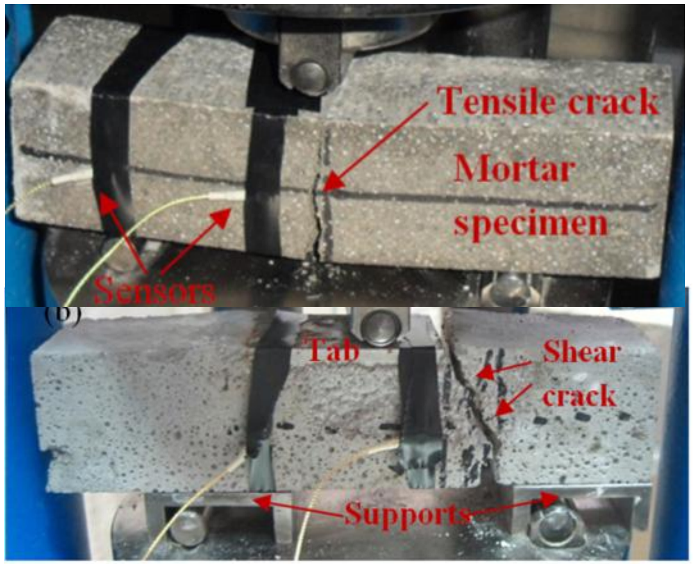


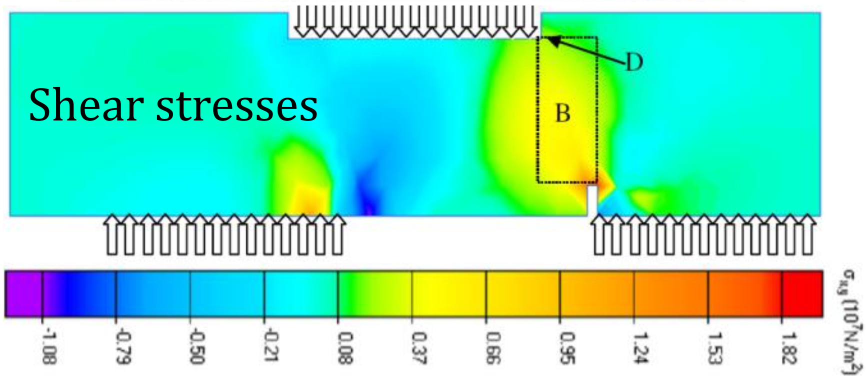
As the shear/normal stress ratio decreases, AE parameters obtain characteristics closer to tensile matrix cracking (high frequency – low RA value).

With passive AE monitoring it is possible to evaluate the stresses ratio

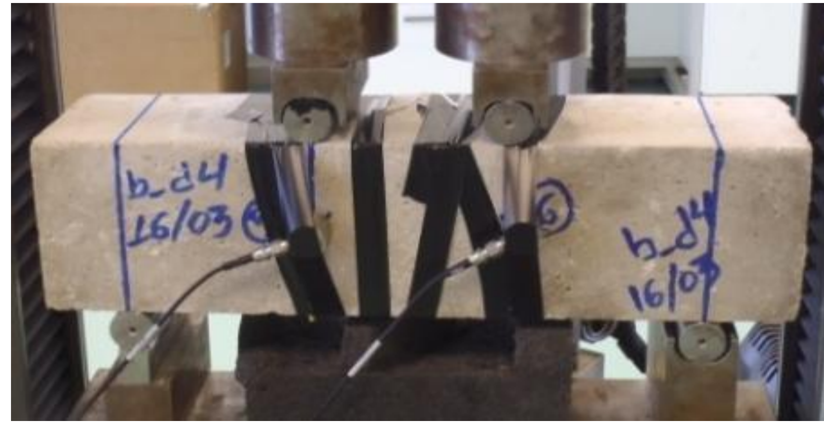
Construction and Building Materials 70 (2014) 370–378

TESTS HAVE BEEN APPLIED IN MORTAR AND CONCRETE



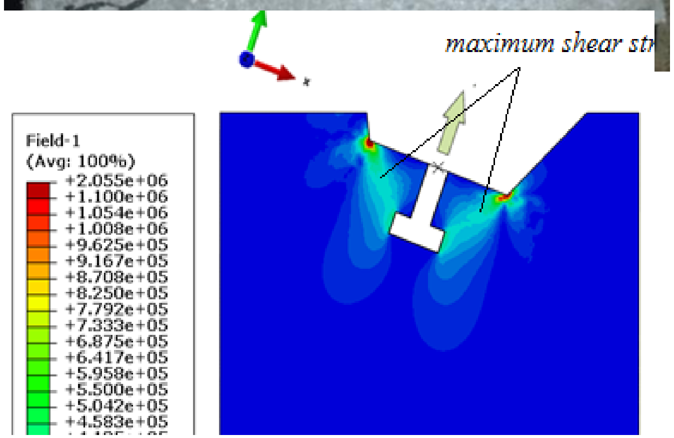


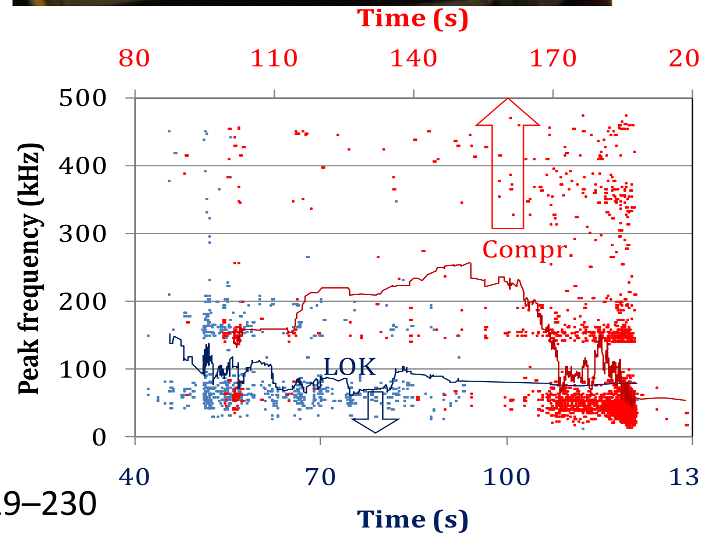
Cement and Concrete Research 48 (2013) 1–8



http://spie.org/Publications/Proceedings/Paper/10.1117/12.2044750

AE PARAMETERS FOR DIFFERENT FRACTURE MODE (PULL-OUT VS. COMPRESSION)

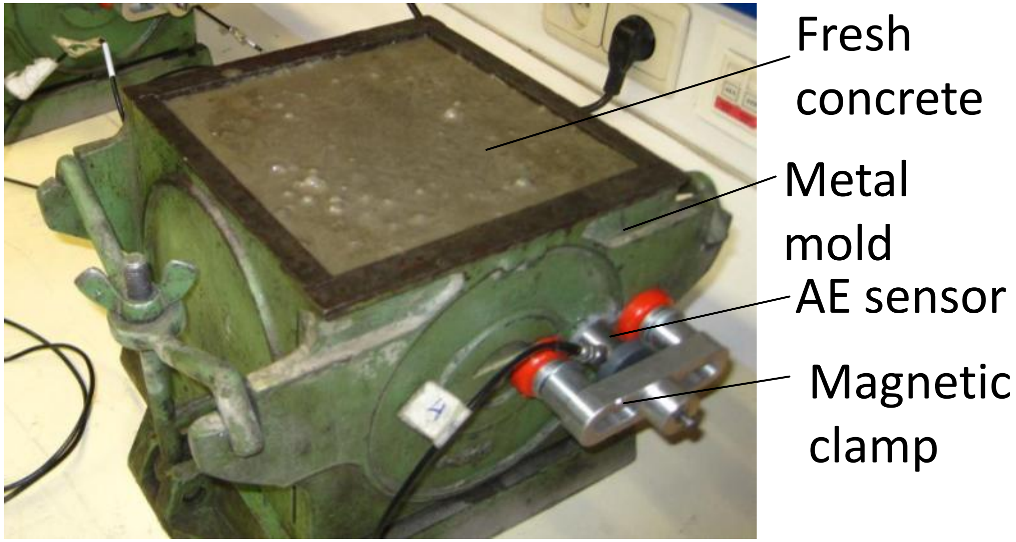




Lower frequency during fracture for the pull-out (LOK) test

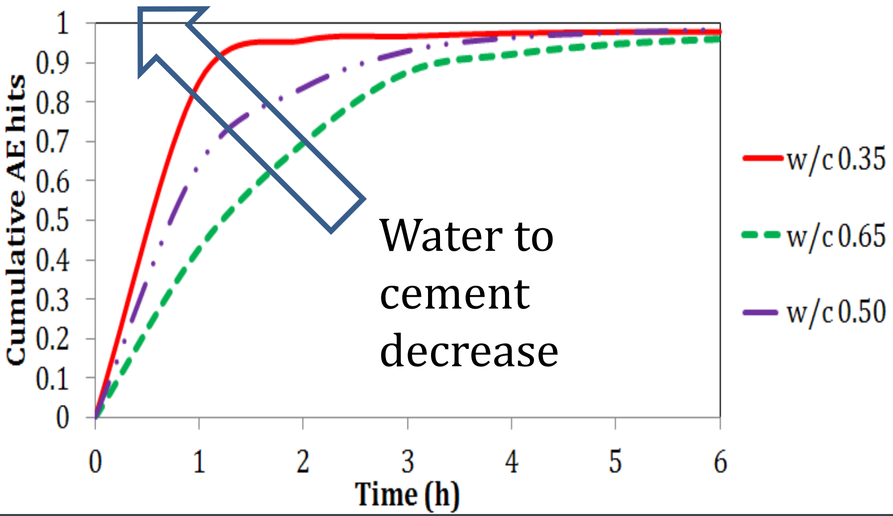
Engineering Fracture Mechanics 128 (2014) 219–230

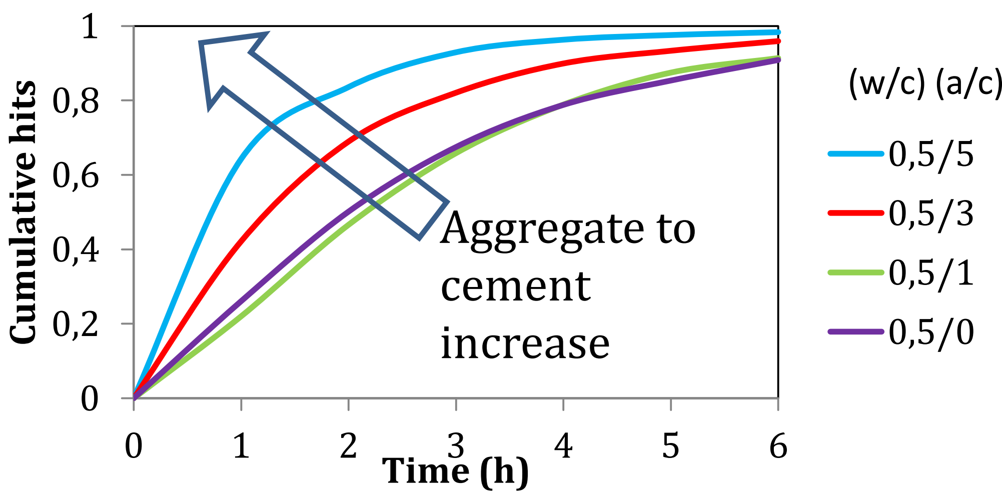
ACOUSTIC EMISSION MONITORING OF FRESH CONCRETE



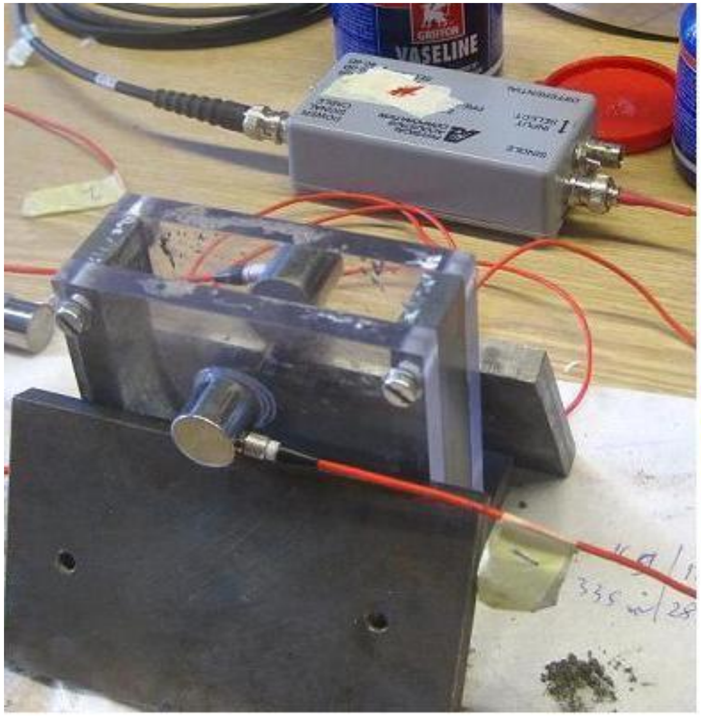
AE activity in fresh concrete can be due to several reasons Segregation, bubble release, cavitation, water migration, early shrinkage cracking.

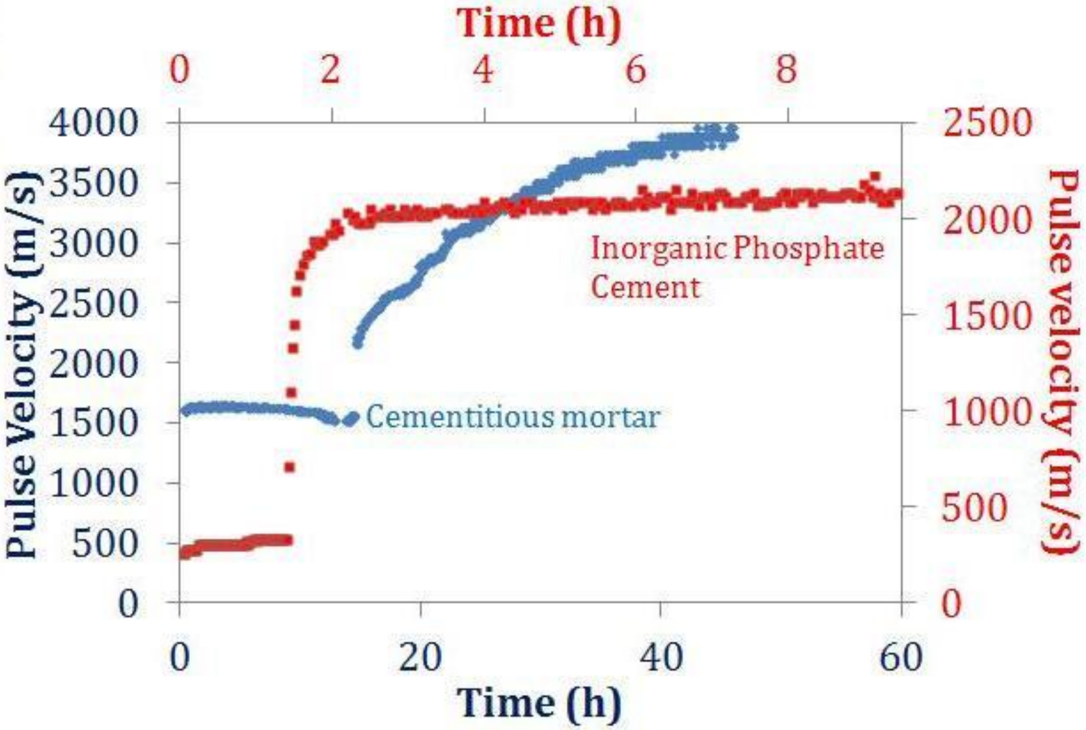
AE activity is saturated earlier for low water content and higher aggregate to cement ratio





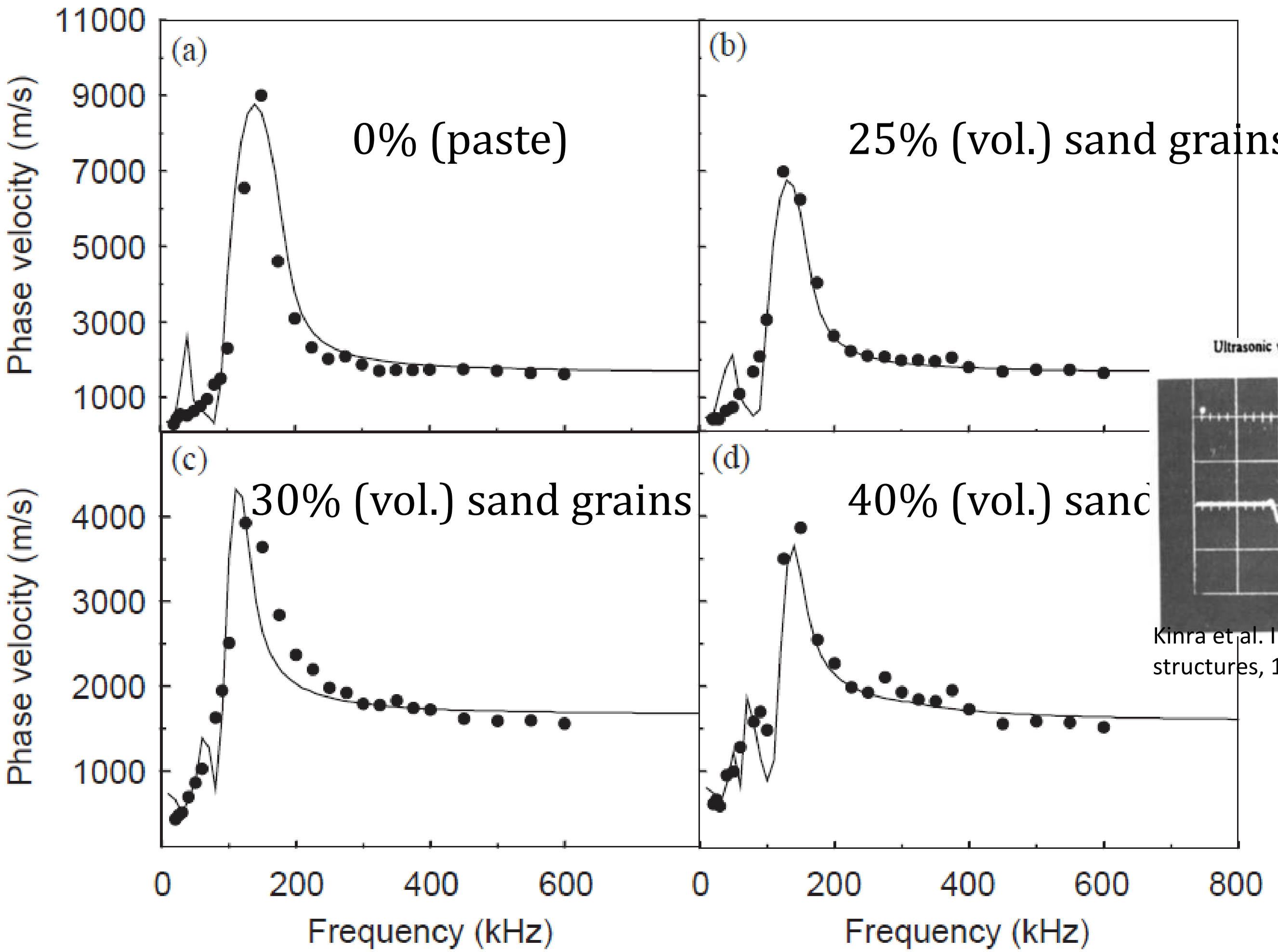
ULTRASONIC MONITORING OF FRESH CONCRETE





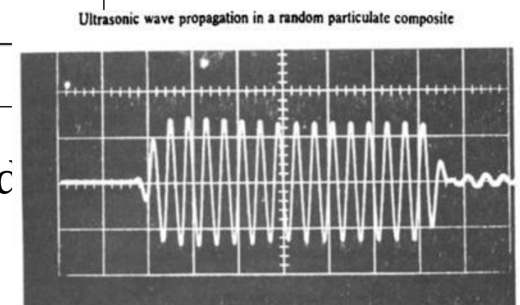
Our device can be applied to paste and mortar. For concrete small modifications are needed.

ULTRASONIC MONITORING OF FRESH CONCRETE
Phase velocity vs. frequency



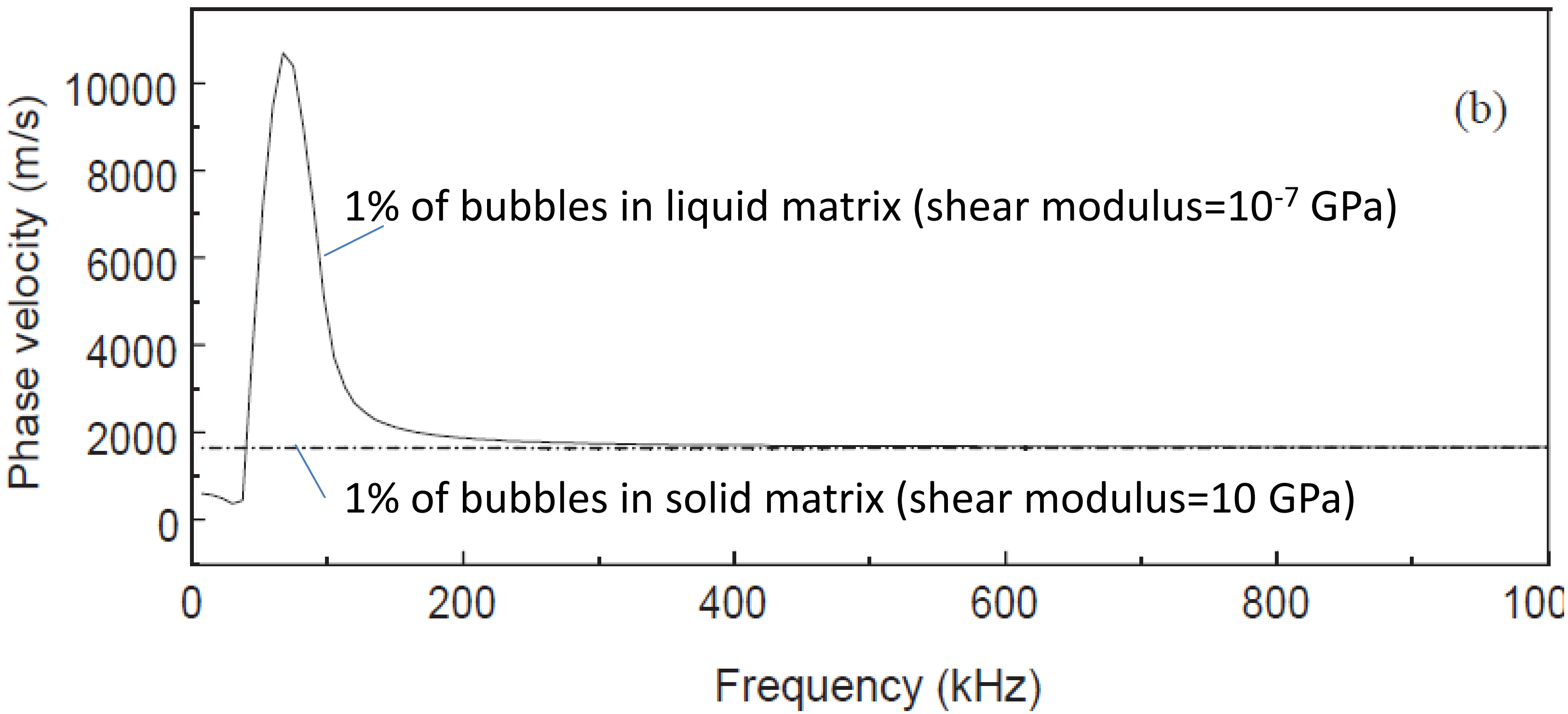
Journal of the Mechanics and Physics of solids, 53 (2005) 857–883

Bubbles of 1 mm produce this peak below 200 kHz.



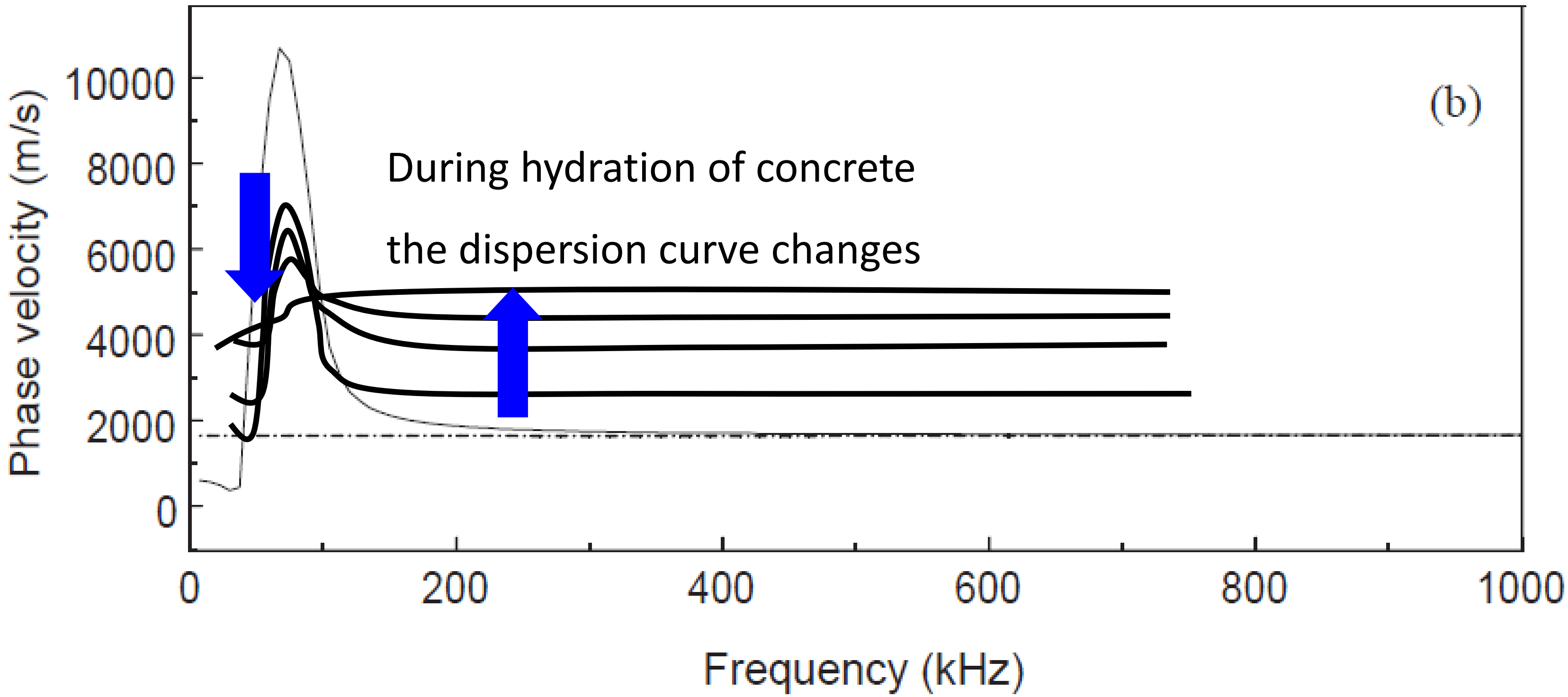
Kinra et al. International journal of solids and structures, 1980, 16, 301-312

ULTRASONIC MONITORING OF FRESH CONCRETE
Fresh concrete is very dispersive in contrast to hardened



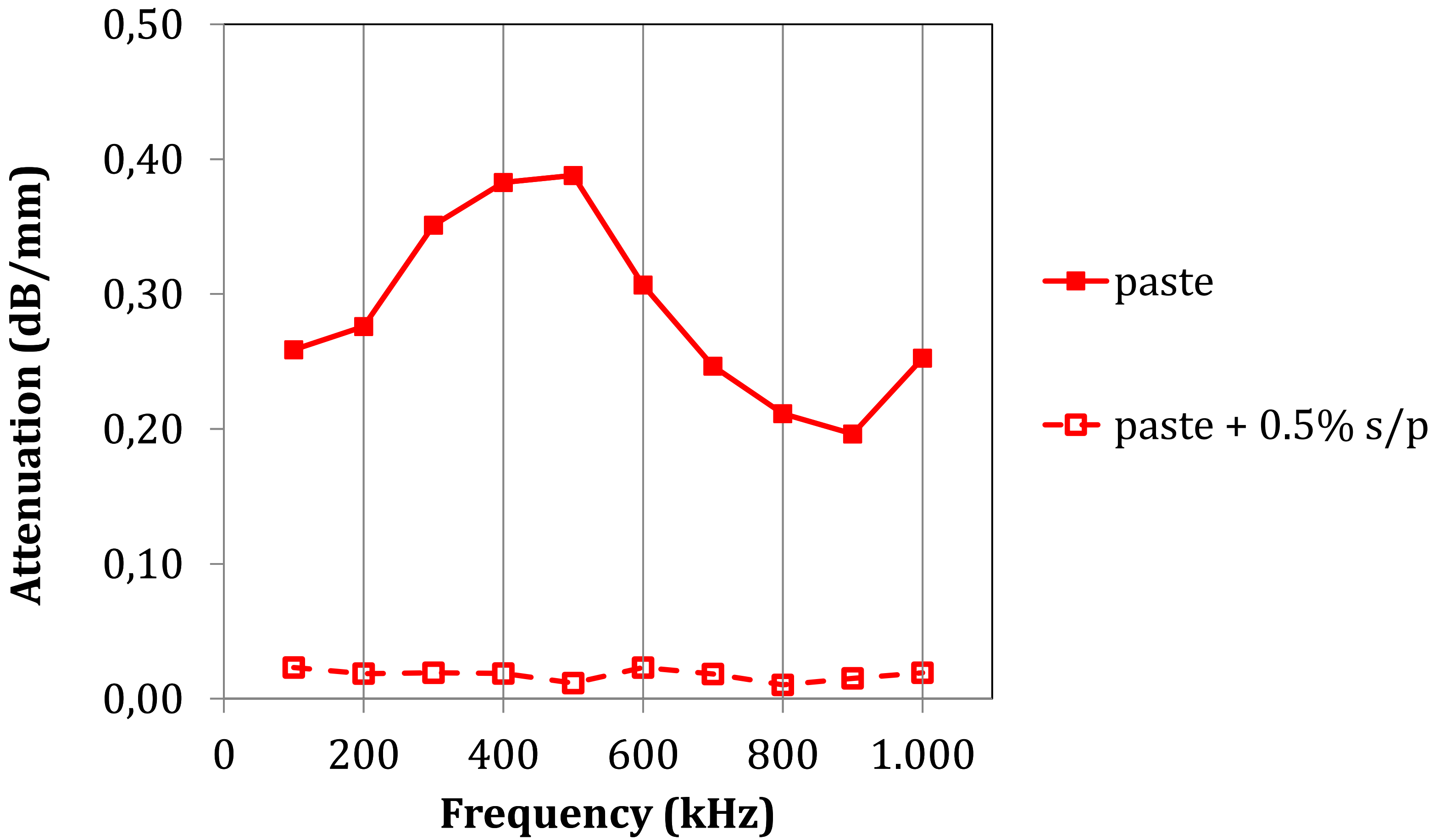
Journal of the Mechanics and Physics of solids, 53 (2005) 857–883

ULTRASONIC MONITORING OF FRESH CONCRETE
The dispersion curve shape changes during hydration



The change of shape of the curve may indicate the setting point!

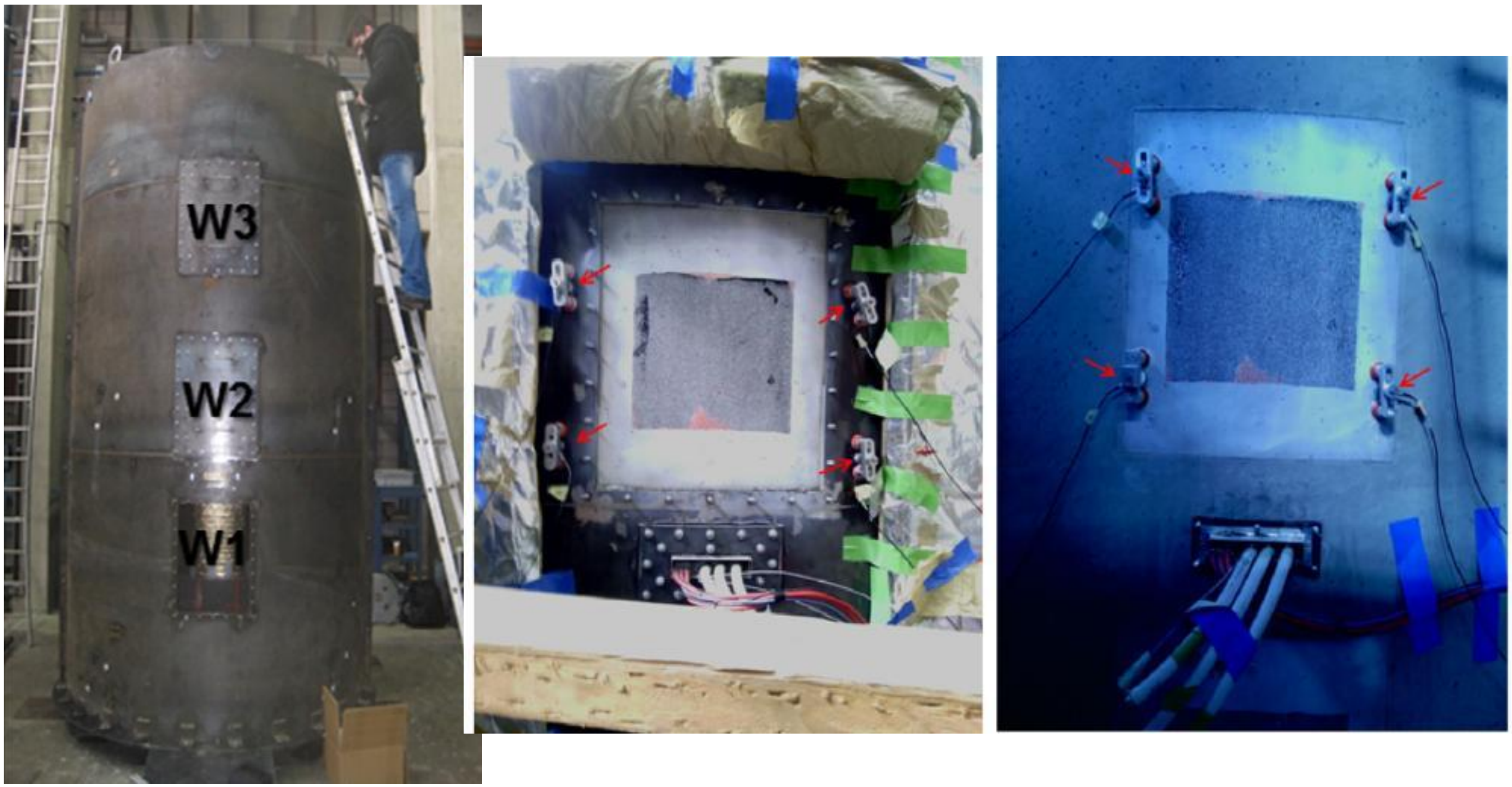
ULTRASONIC MONITORING OF FRESH CONCRETE
Attenuation function measurement



Substantial effect of superplasticizer on attenuation

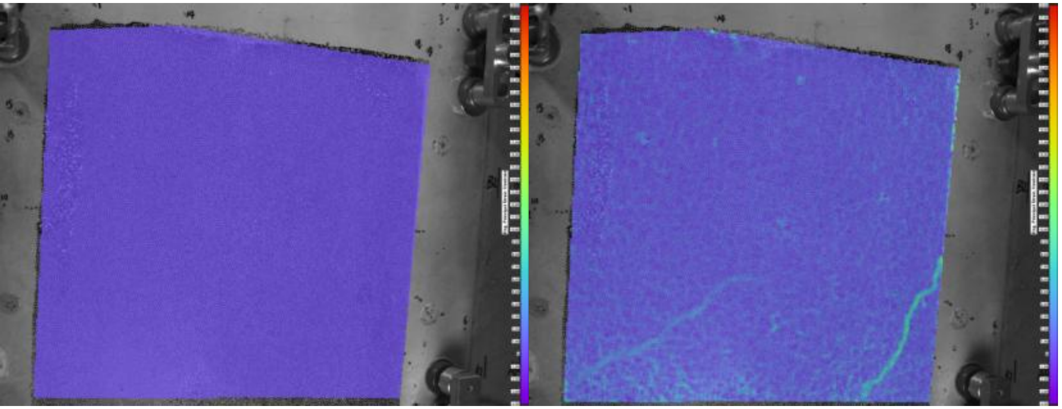
Monitoring the efficiency of plasticizer in fresh cement using ultrasound, D. G. Aggelis; D. Grammenou; T. E. Matikas, Proc. SPIE 8346, Smart Sensor Phenomena, Technology, Networks, and Systems Integration 2012, 83460H (30 March 2012); doi: 10.1117/12.915023

Applications: Monitoring of the heating phase of nuclear waste container
Acoustic emission and DIC were applied



Construction and Building Materials 78 (2015) 369–378

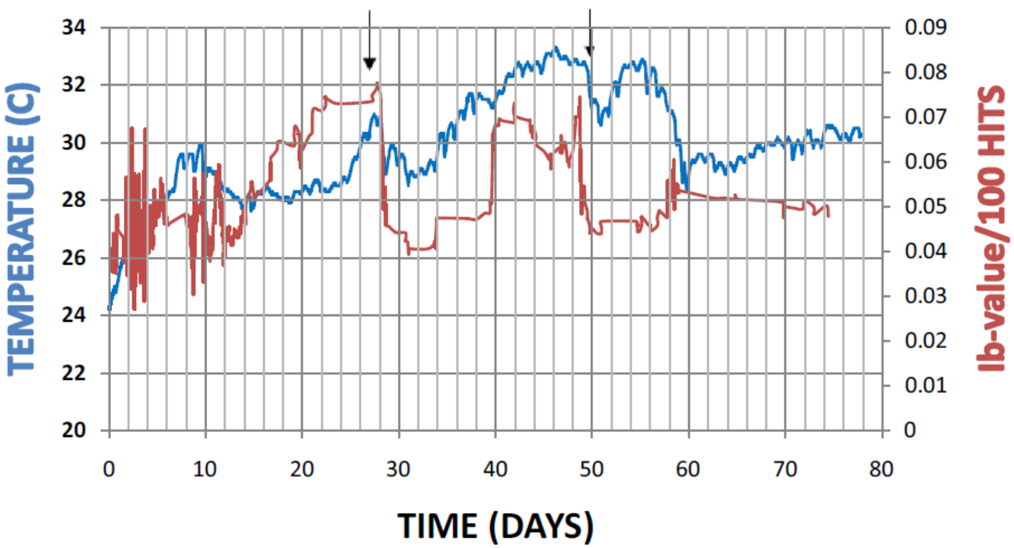
Applications: Monitoring of the heating phase of nuclear waste container



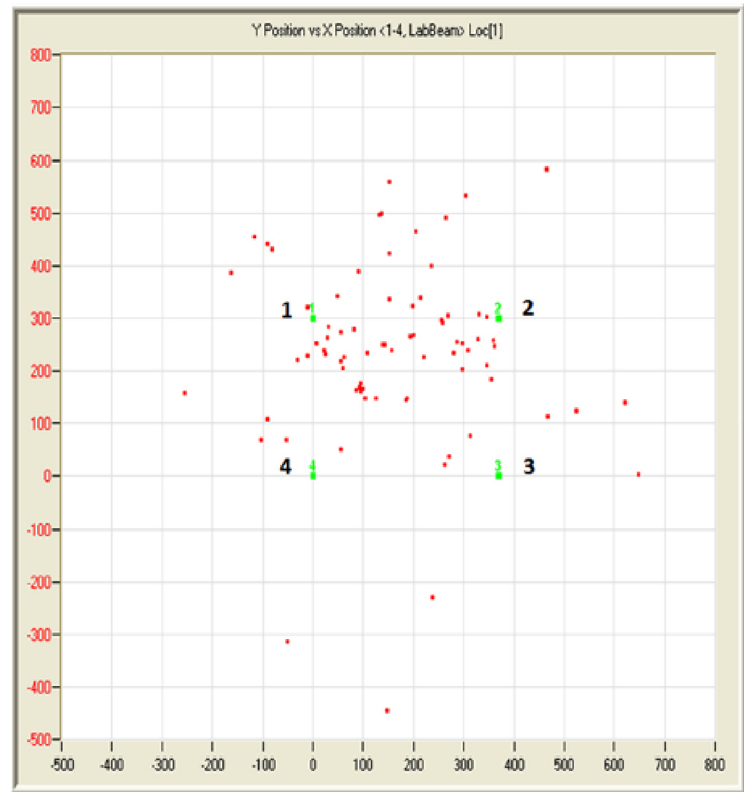
DIC strain fields

11/06/2013

12/06/2013



AE localization of sources



Conclusions

- Acoustic emission can give information on

(i) the location of failure

(ii) the necessary load for first cracking

(iii) the mode of the failure under controlled conditions

(iv) can be used for characterization of fresh concrete as well

- Ultrasound can characterize

(i) the curing and stiffness development of fresh cementitious material

(ii) the development of cracking and degradation

(iii) Dispersion features can provide information in the microstructure level

6th ETNDT

Emerging Technologies in NonDestructive Testing

Brussels 27-29 May 2015
Vrije Universiteit Brussel
Campus Etterbek, Aula Q,
Pleinlaan 2, 1050 Brussels

Topics include (among others) :

- Development in all different NDT techniques
- Advancements in combined use of NDT techniques
- Decision making systems about structural maintenance based on engineering criteria
- Use of modern materials like recycled, nanomodified, textile-reinforced matrices, structural wood and how they respond to usual monitoring techniques
- Numerical simulation as a tool for NDT methods
- Proper design of structures to simplify and aid NDT/SHM
- Wireless monitoring technology and energy harvesting for SHM
- Studies and development of sensor technology for NDT/SHM

Invitation

The organizing committee has the pleasure to invite you to the 6th International Conference on Emerging Technologies in NDT to be held on May 27-29, 2015 in Brussels, Belgium. This series of conferences was initiated in 1995 in Patras, Greece, followed by the organization in Athens 1999, Thessaloniki 2003, Stuttgart 2007 and Ioannina 2011. The aim of the conference is to bring together researchers from academia and industry for exchanging ideas, latest achievements and for establishing new collaborations in view of the increasing need for reliable nondestructive testing and structural health monitoring in all engineering fields. The program includes special sessions organized by leading experts, plenary and keynote lectures, technical papers and poster sessions. The list of special sessions will be available on the website. Suggestions for other topics are welcome and can be forwarded to the organizers. We are looking forward to meet you in Brussels for an exciting 6ETNDT.

Organizing committee:

Dimitrios G. Aggelis, Vrije Universiteit Brussel (chairman, daggelis@vub.ac.be)
Danny Van Hemelrijck, Vrije Universiteit Brussel
Steve Valanduit, Vrije Universiteit Brussel
Athanasios A. Anastasopoulos, Mistras Group Hellas
Theodore P. Philippidis, University of Patras

One page abstracts should be sent to the following address until October 1st 2014
<u>Conference secretariat:</u> Katja Bosman (Katja.Bosman@vub.ac.be)

VRIJE UNIVERSITEIT BRUSSEL
MeMC
MECHANICS OF MATERIALS AND CONSTRUCTIONS

http://www.vub.ac.be/MEMC/en

REAL-TIME ULTRASONIC MONITORING OF CRACKING IN CONCRETE STRUCTURES USING EMBEDDED PIEZOELECTRIC TRANSDUCERS

Cédric Dumoulin - Université Libre de Bruxelles (ULB), Belgium
Arnaud Deraemaeker*- Université Libre de Bruxelles (ULB), Belgium

***aderaema@ulb.ac.be / batir.ulb.ac.be**

VIBRATION BASED

STRUCTURAL HEALTH MONITORING

Foster and partners.

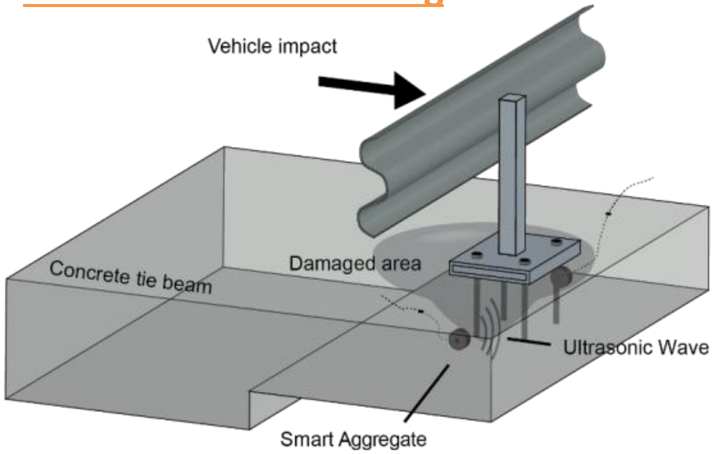
Ambient vibration sensing

Jason Lee/Reuters

Low frequency (<20kHz)

Only detects significant damage

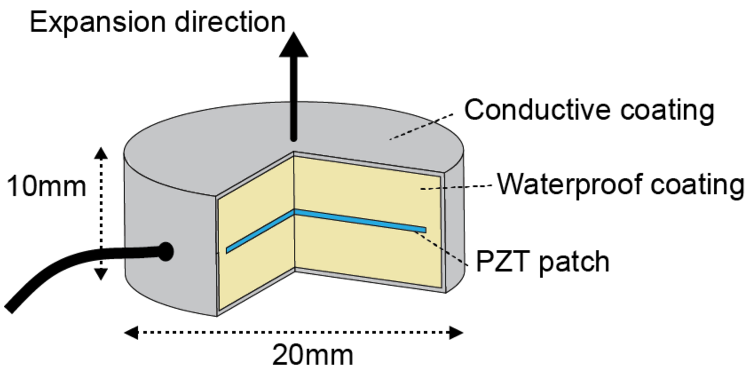
Active vibration sensing

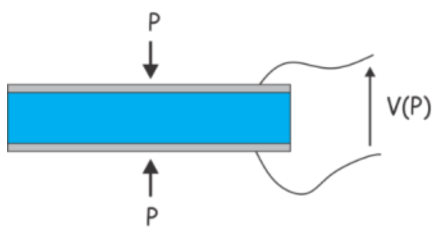


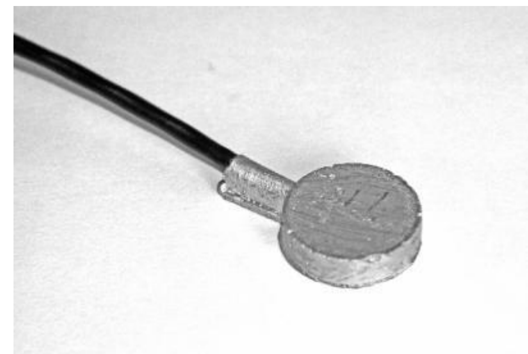
High frequency (up to 1 [MHz)

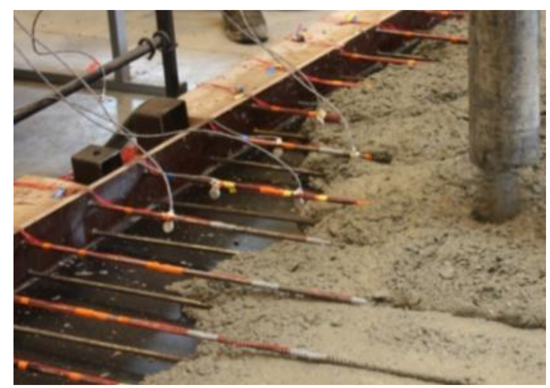
Strong interaction with local and small damage

THE ULTRASONIC TRANSDUCERS USED IN THIS STUDY ARE EMBEDDED PIEZOELECTRIC TRANSDUCERS







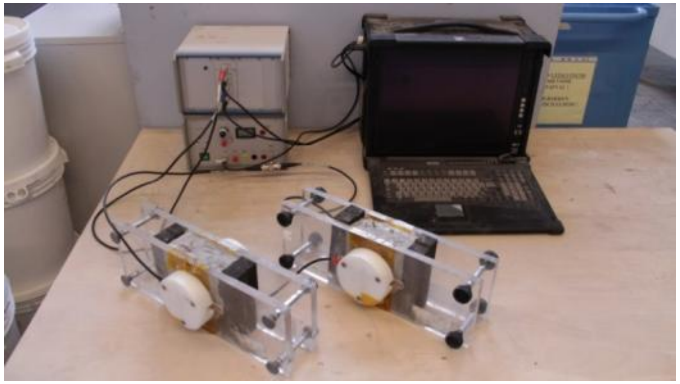


PZT ▶ Small size, Low cost, Broadband

\+

EMBEDDED ▶ Efficiency, Flexibility, Durability

THE MAIN PURPOSE OF EMBEDDING TRANSDUCERS IN THE STRUCTURE IS TO IMPROVE THE EFFICIENCY OF ULTRASONIC TESTING

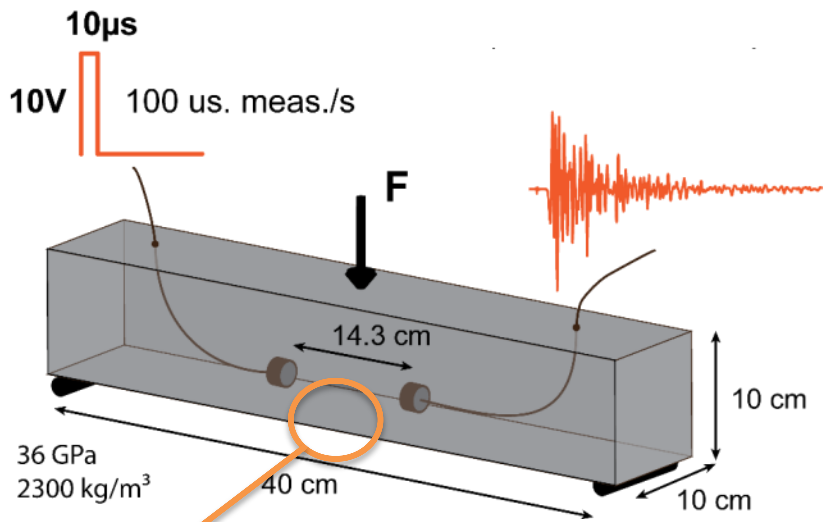


VERY EARLY AGE

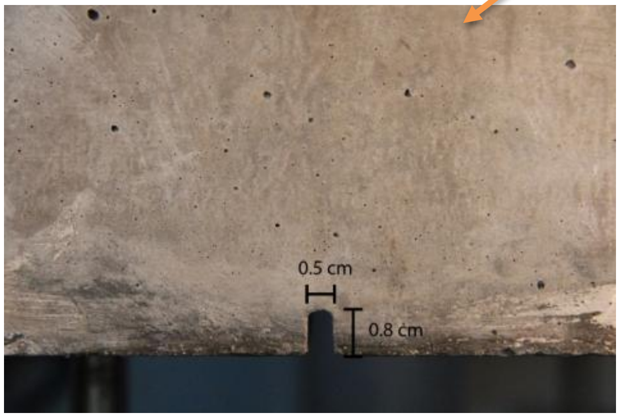
IN SERVICE

direct

A 3-POINTS BENDING TEST HAS BEEN PERFORMED ON TWO CONCRETE BEAMS MONITORED BY SMAGS

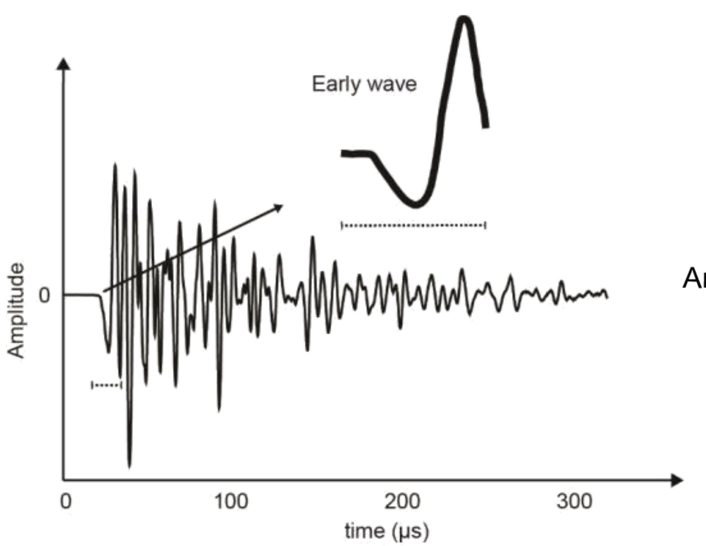


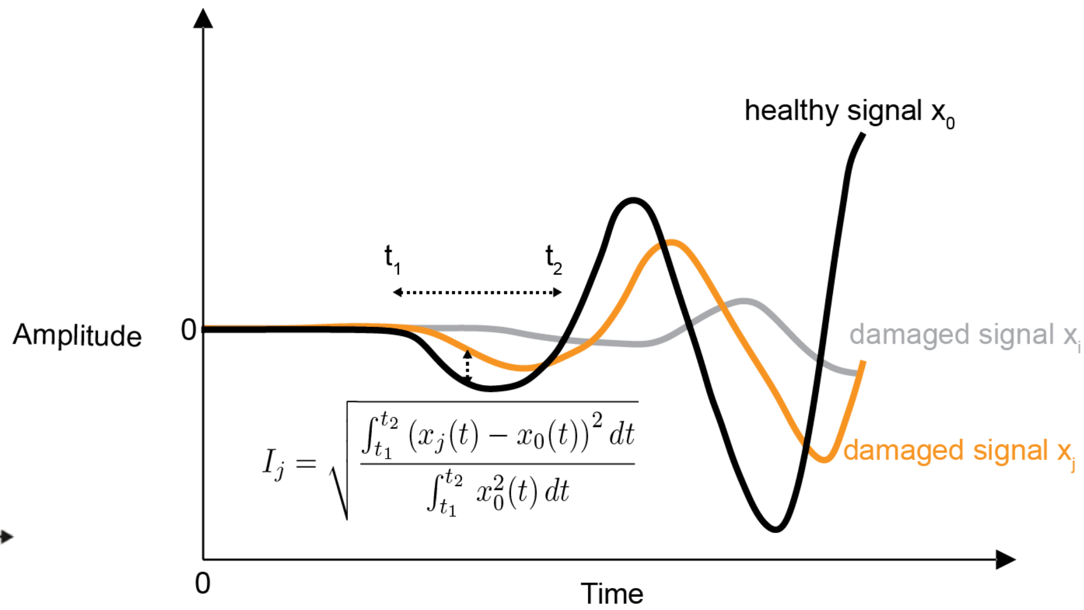
E-modulus	36 GPa
Density	2300 kg/m^3



A SPECIFIC DAMAGE INDEX BASED ON THE EARLY WAVE HAS BEEN DEFINED

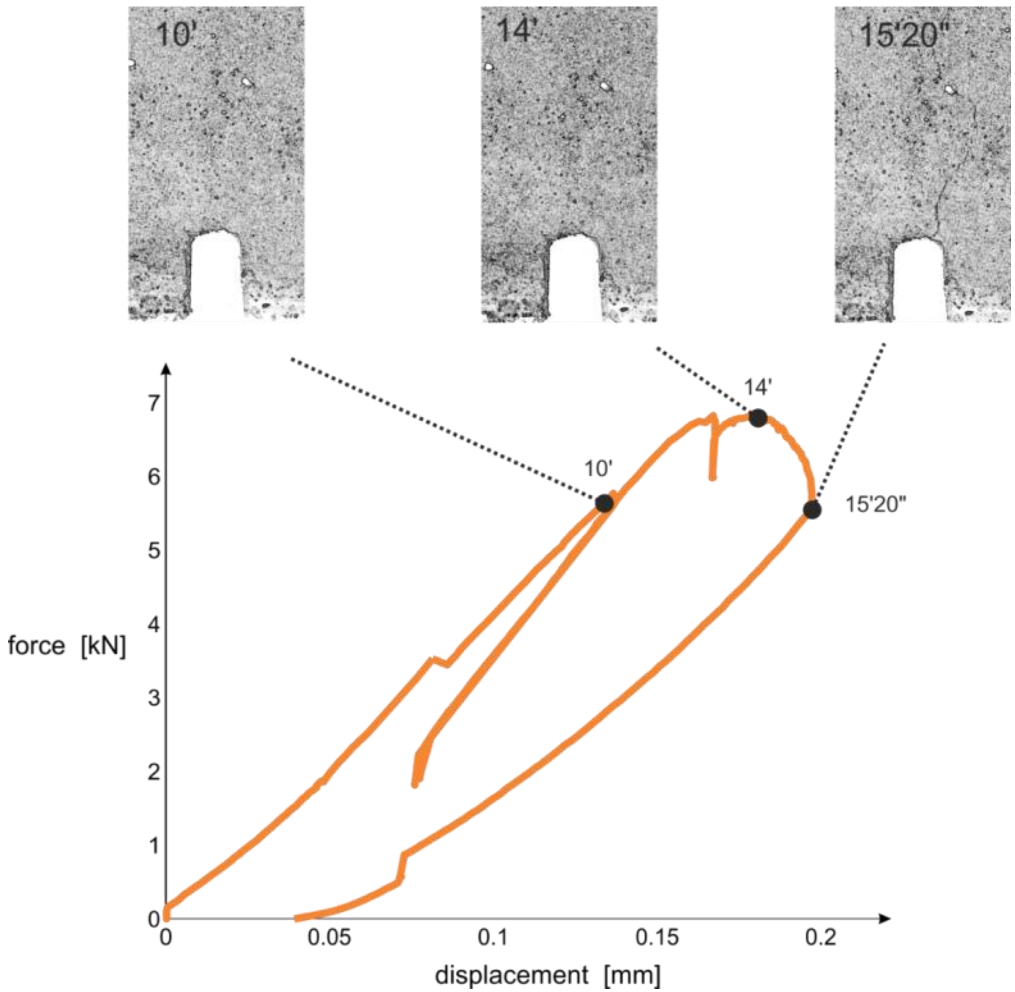
- Dumoulin C, Karaiskos G, Sener J-Y and Deraemaeker A 2014 Online monitoring of cracking in concrete structure using embedded piezoelectric transducers Smart Mater. Struct. 23 115016 (10pp)



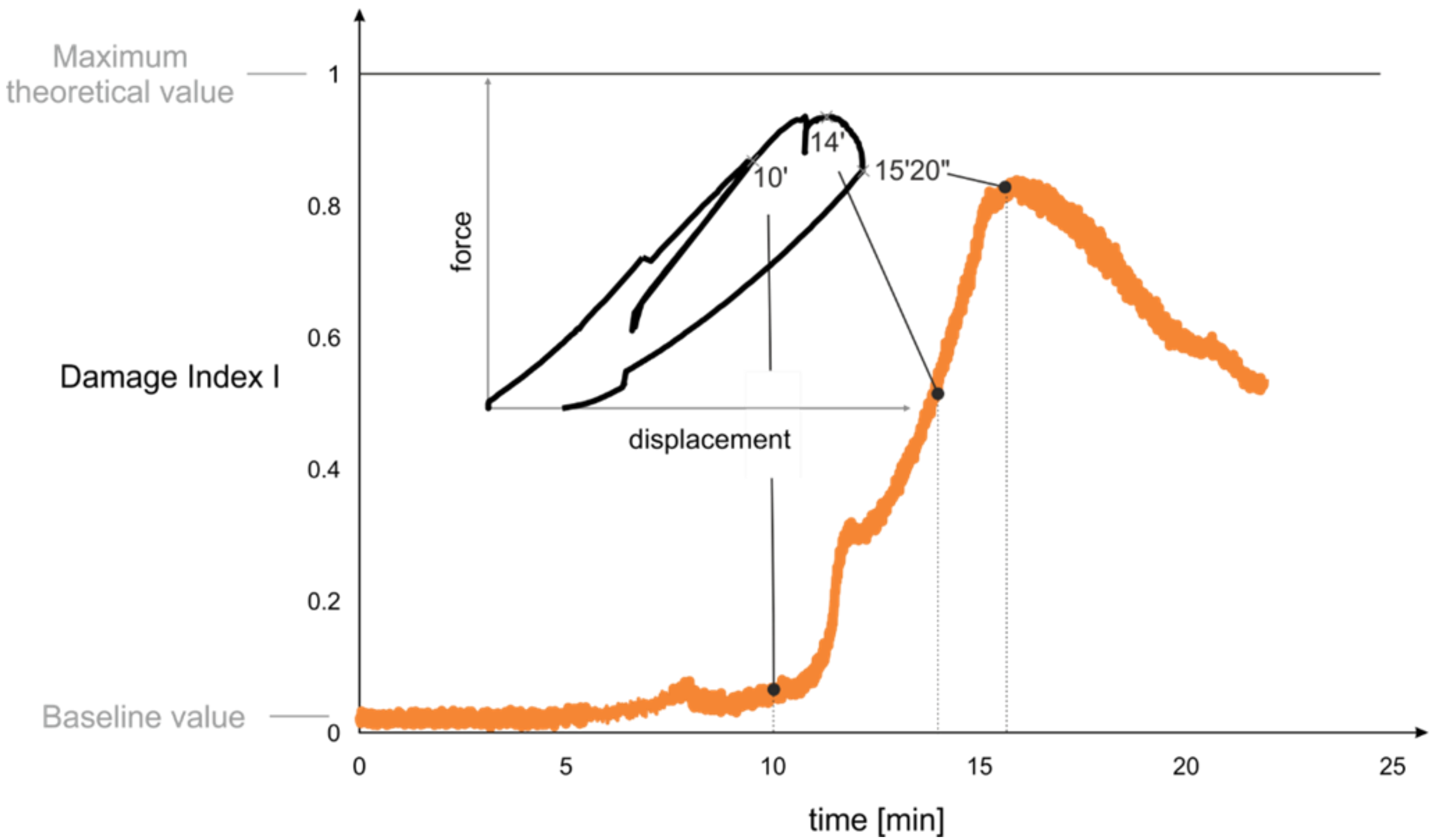


$$I_j = \sqrt{\frac{\int_{t_1}^{t_2} (x_j(t) - x_0(t))^2 \, dt}{\int_{t_1}^{t_2} x_0^2(t) \, dt}}$$

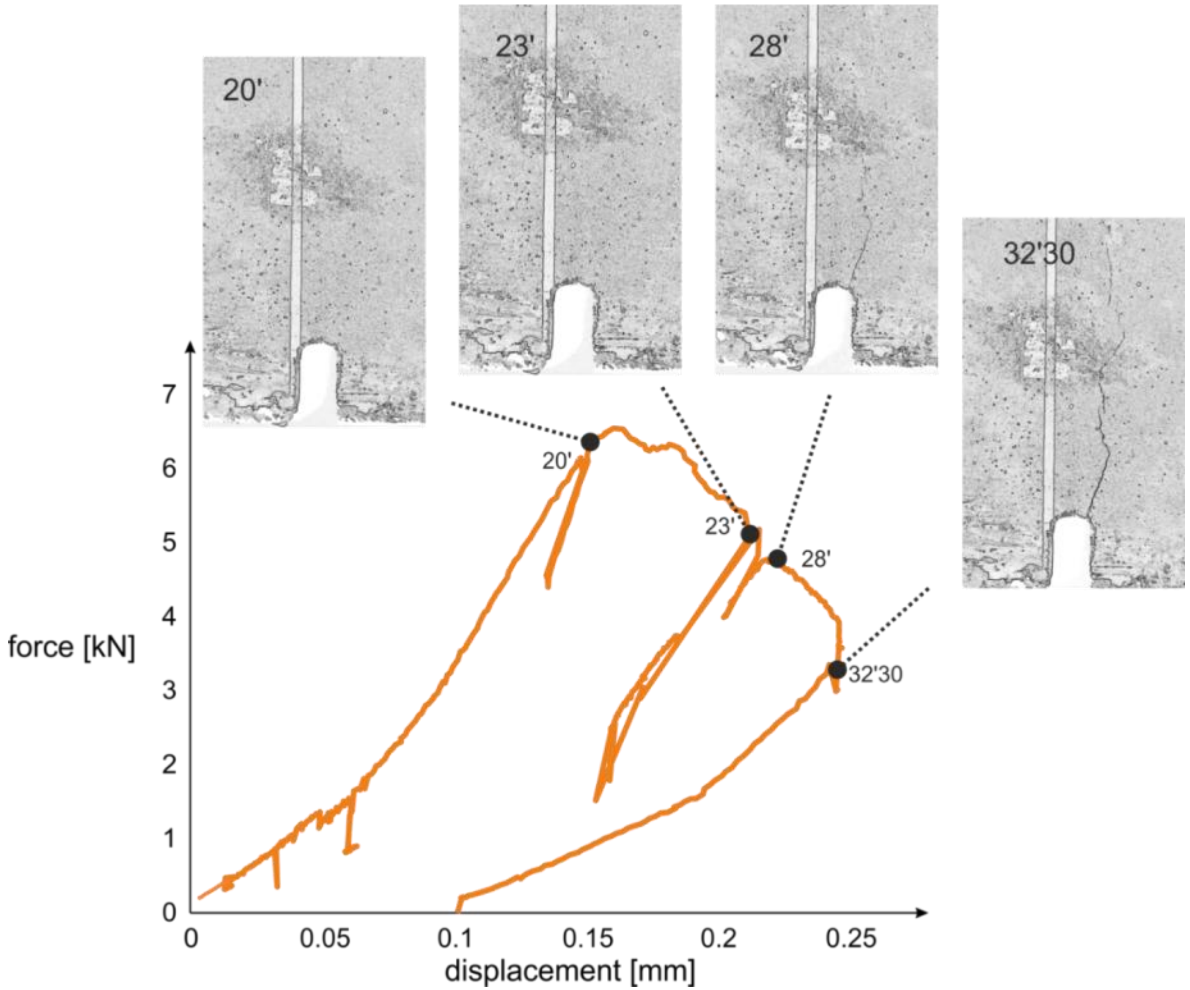
BEAM 1 | THE MAIN OBJECTIVE WAS TO INITIATE THE CRACK



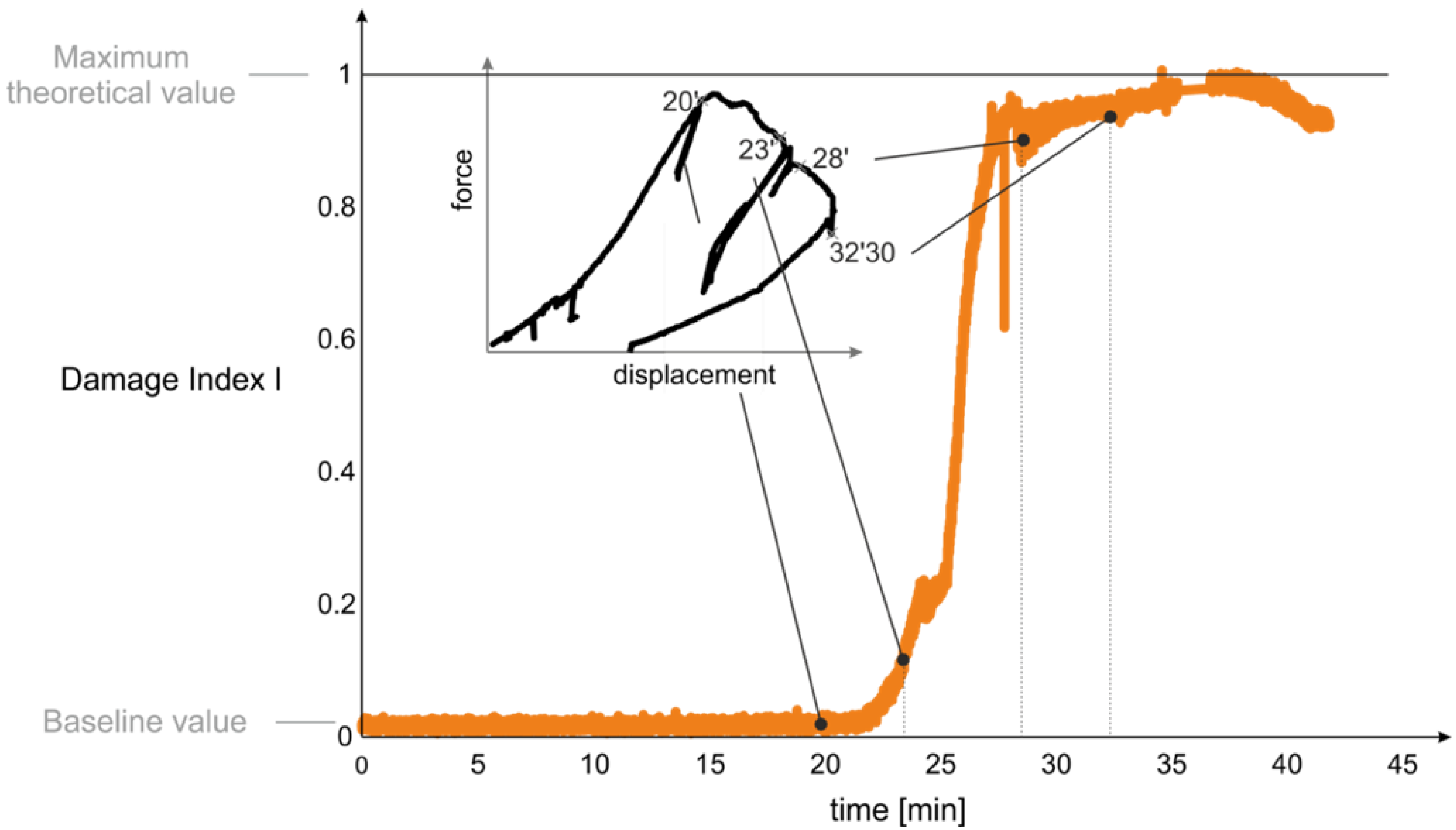
BEAM 1 | **THE DI EVOLVES CONTINUOUSLY BEFORE ANY CRACK HAS BEEN OBSERVED**



BEAM 2 | THE CRACK WIDTH IS SIGNIFICANTLY LARGER

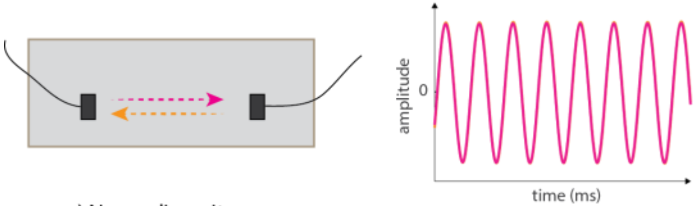


BEAM 2 | AFTER COMPLETE UNLOADING
THE RESIDUAL VALUE OF THE DI REMAINS CLOSED TO THE MAX VALUE

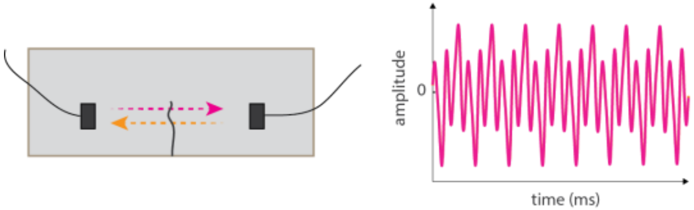


CONCLUSION AND OUTLOOK

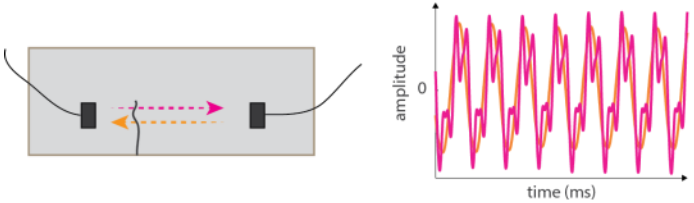
- Fast Ultrasonic Testing can help to deeper understand fracture mechanic
- A very sensitive damage indicator has been defined, but…
- The number of interactions increases with the distance…
  - The early wave is strongly attenuated
  - A new method must be implemented
- Use information contained in the coda (late arrival)
- Appearance of cracks induces NL effects!
  - E.g. the use of SMAGs is perfectly suited for the "Loss of reciprocity" method [1]
- New design of SMAGS are being studied in order to increase their efficiency!



a) No nonlinearity



b) Tansducers located symmetrically to the source of nonlinearity



c) Tansducers located asymmetrically to the source of nonlinearity

[1] Scalerandi, et. Al (2012) : Detection and location of cracks using loss of reciprocity in ultrasonic waves propagation.

TU1404 COST ACTION

Fracture behaviour of polyolefin fibre reinforced concrete

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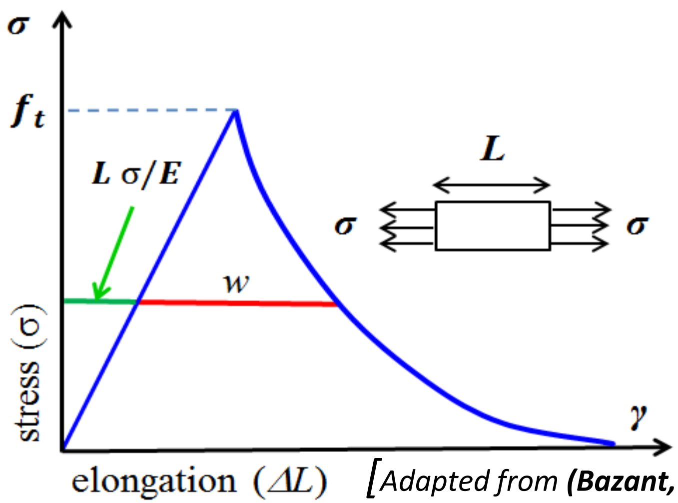
A Enfedaque - Universidad Politécnica de Madrid, Spain
JC Gálvez - Universidad Politécnica de Madrid, Spain

Summary of contents

Fibre reinforced concrete

Concrete is a composite quasi-brittle material (weak in tension)

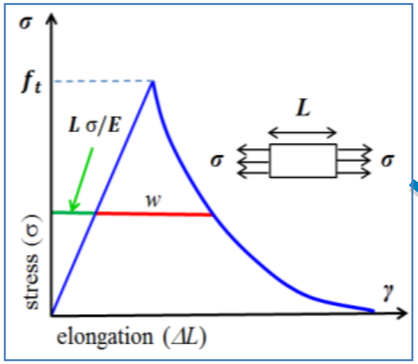


[Adapted from **(Bazant, et al., 1997)**]

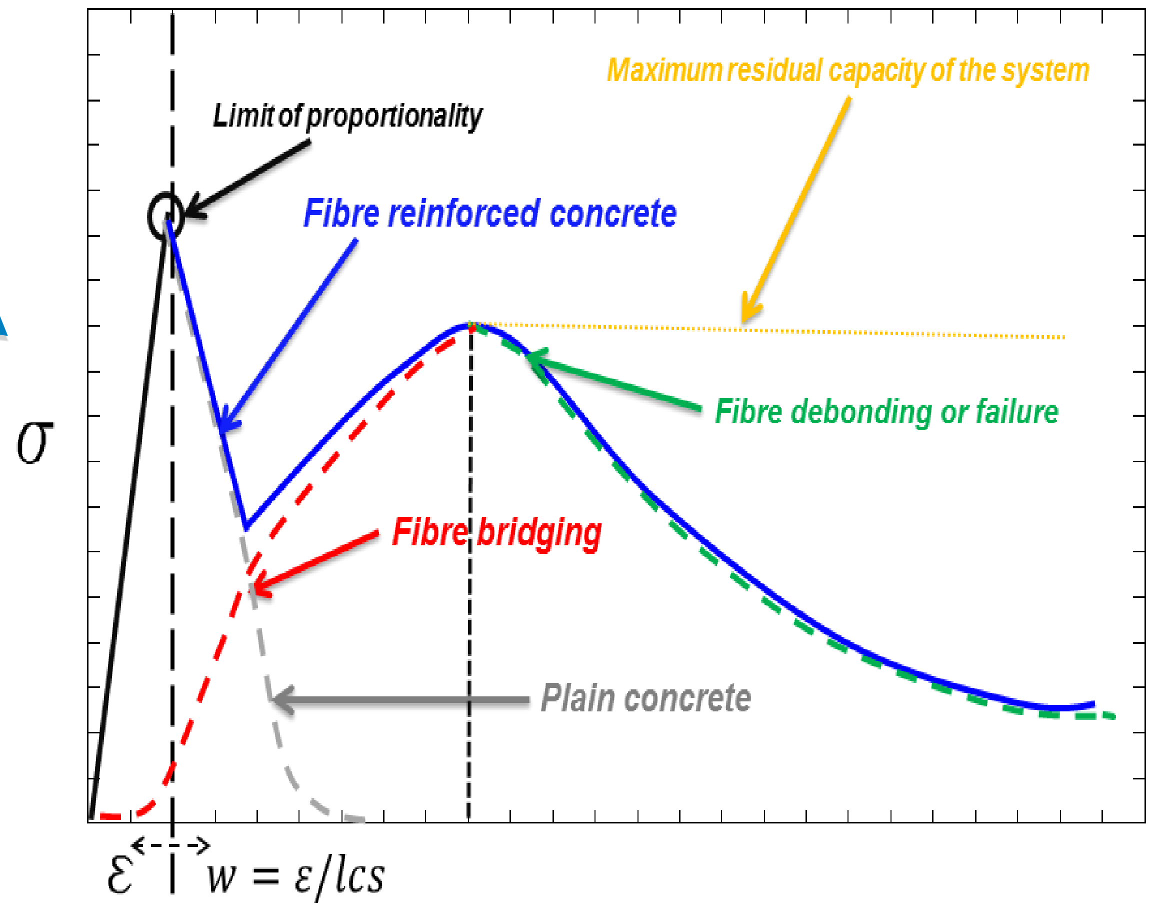
Water
+
Cement
+
Fine aggregate
+
Coarse aggregate
+
Others

Why not reinforce the matrix by adding a new component of similar size of the aggregates, randomly distributed in the mix, maintaining the properties of fresh concrete and improving its structural response under tensile and bending?

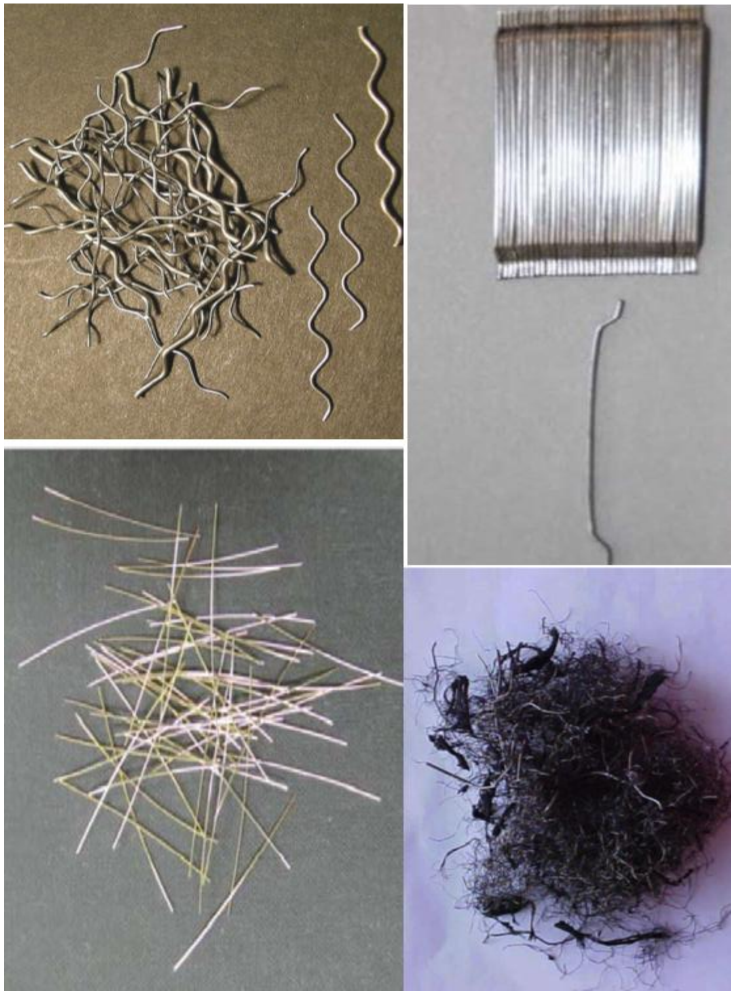
Fibre reinforced concrete

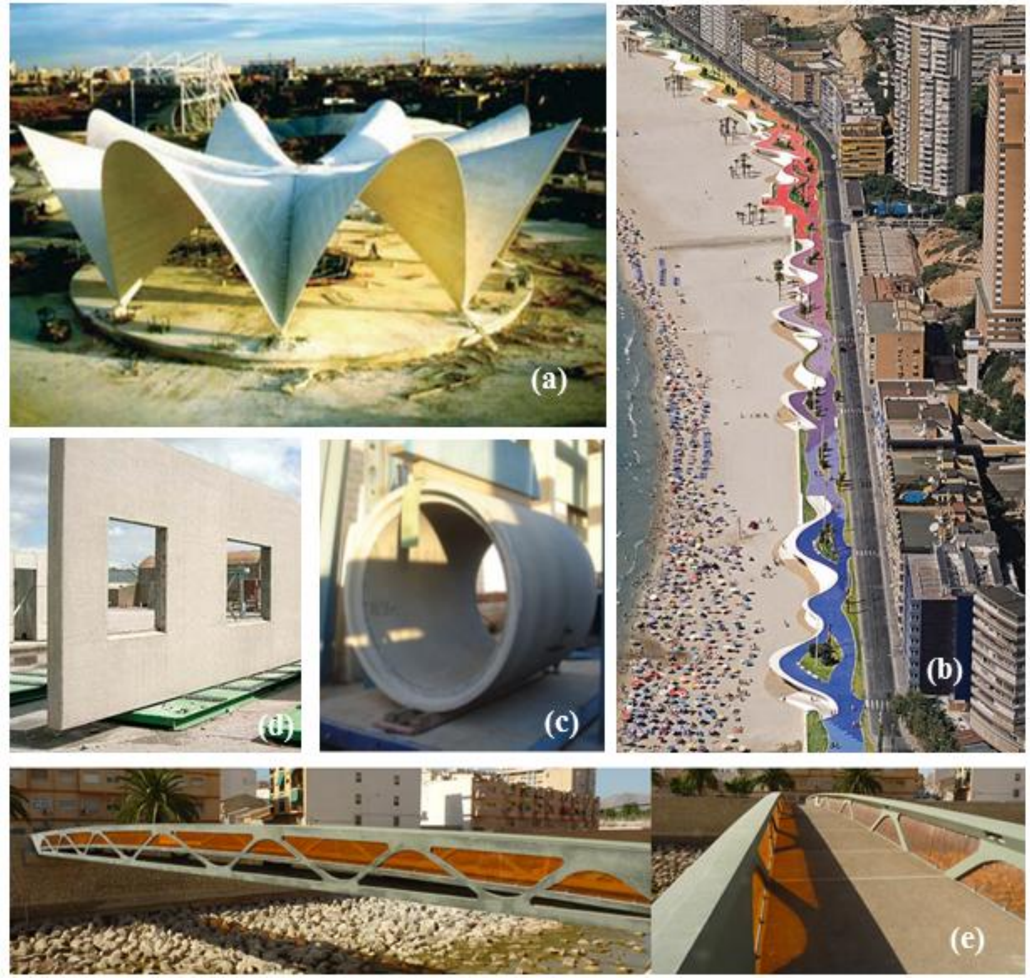


[Adapted from ***(Bazant, et al., 1997)****]*



Applications





Applications

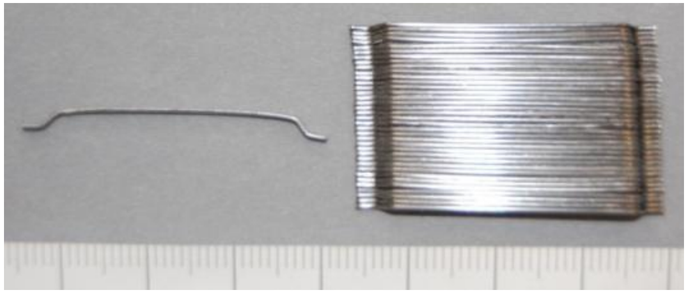
Fibre reinforced concrete

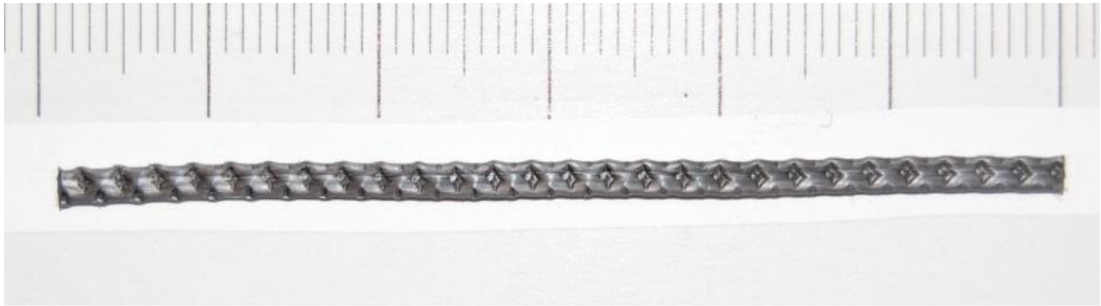
Type of Fibre	*Diameter (mm)*	*Specific gravity*	*Tensile strength (GPa)*	*Modulus of elasticity (GPa)*	*Ultimate elongation (%)*
Acrylic	0.02-0.35	1.1	0.2-0.4	2	1.1
Asbestos	0.0015-0.02	3.2	0.6-1.0	83-138	1-2
Cotton	0.2-0.6	1.5	0.4-0.7	4.8	3-10
Glass	0.005-0.15	2.5	1.0-2.6	70-80	1.5-3.5
Graphite	0.008-0.009	1.9	1.0-2.6	230-415	0.5-1.0
Kevlar	0.010	1.45	3.5-3.6	65-133	2.1-4.0
Nylon (high tenacity)	0.02-0.40	1.1	0.76-0.82	4.1	16-20
Carbon PAN	0.007-0.009	1.7	2.5-4.0	230-390	0.5-1.5
Carbon Pitch	0.009-0.018	1.6	0.5-3.1	30-32	0.5-2.4
Polyester (high tenacity)	0.02-0.40	1.4	0.72-0.86	8.3	11-13
Polypropylene	0.02-0.40	0.95	0.55-0.76	3.5	15-25
Rayon (high tenacity)	0.02-0.38	1.5	0.4-0.6	6.9	10-25
Rock wool	0.01-0.8	2.7	0.5-0.76	---	0.5-0.7
Sisal	0.01-0.10	1.5	0.8	---	3.0
Steel	**0.1-1.0**	**7.85**	**0.3-2.0**	**200**	**0.5-3.5**
Polyolefin	**0.15-0.635**	**0.91**	**0.2-1.1**	**2.7-20.5**	**7 - 15**
Concrete matrix	---	1.5-2.5	0.003-0.007	10-45	0.02

Fibre reinforced concrete

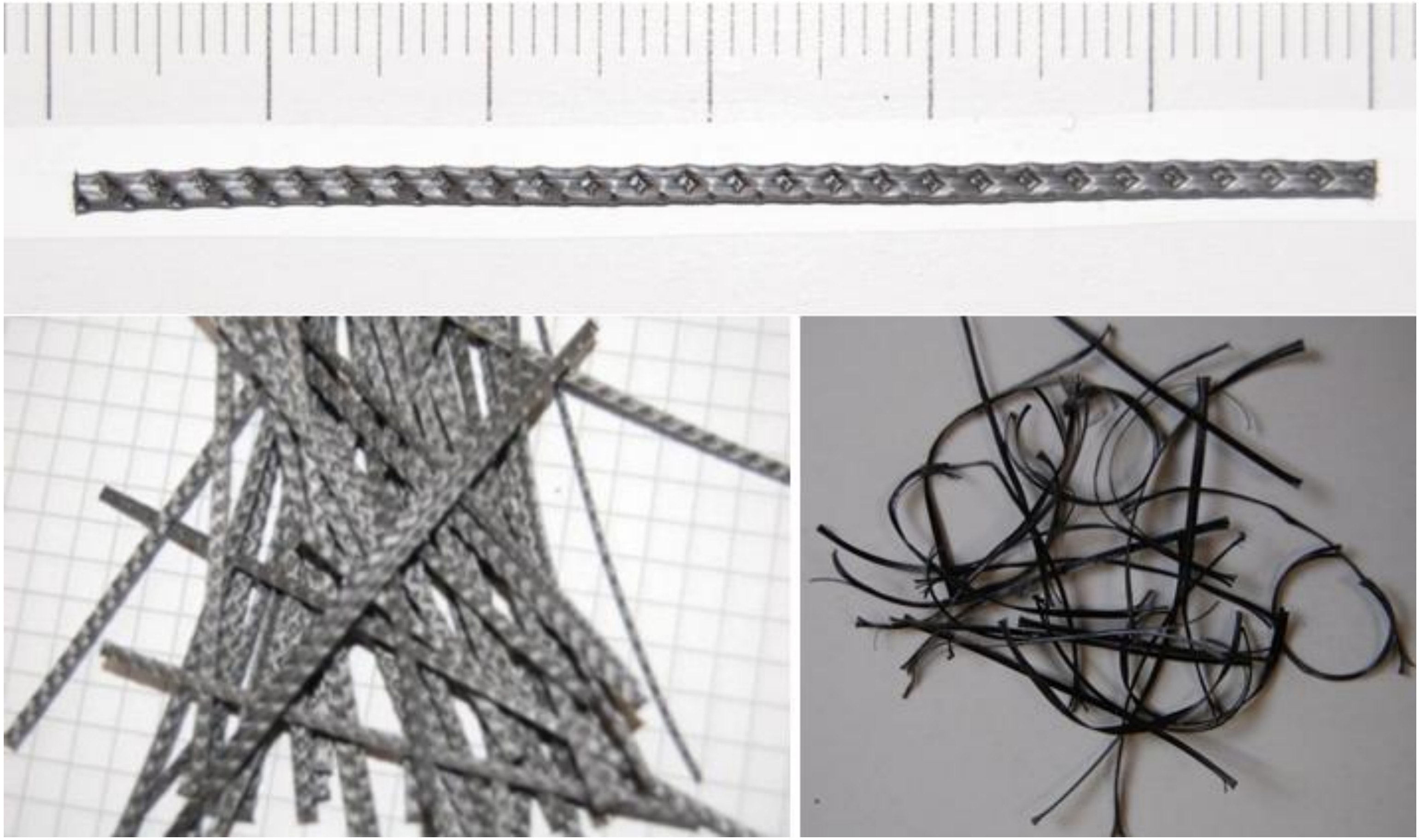
Typical shapes and sizes of steel and polyolefin based macro-fibres

Common geometry	Shape/texture	Length (mm)	Eq. diameter (mm)
Steel fibres	Smooth surface, hooked ended	65/35	0.75
Micro-synthetic fibres	Straight and smooth surface	12	0.02 -0.023
Synthetic macro-fibres	Embossed surface	60/48	0.5 - 1





Polyolefin fibres



Polyolefin fibres

- Chemically stable
- Main possible advantages of structural synthetic macro-fibers:
  - Lower dosage in terms of weight [kg/m³]
  - Pump wear reduced
  - Safety increased
  - Low risk of corrosion and degradation
  - Cost reduction for m³
  - Slightly reducing workability and better behavior in fresh state as compared with steel fibers.

Contents

Standards, codes and tests

- Have boosted their use in structural and non-structural applications
- Provide tools to assess the structural ability of the fibres and how to consider their contributions in the structural design (requirements)
- Based on research and applications of FRC with steel fibres
- The concept of structural fibre is introduced

Standards, codes and tests

EN 14889:2008
Fibre types

Part I : Steel fibres
Mainly focussed on carbon although includes galvanised and stainless steel

- **I Cold drawn wire**
- **II Cut sheet**
- **III Melt extract**
- **IV Shaved cold drawn wire**
- **V Nilled from blocks**

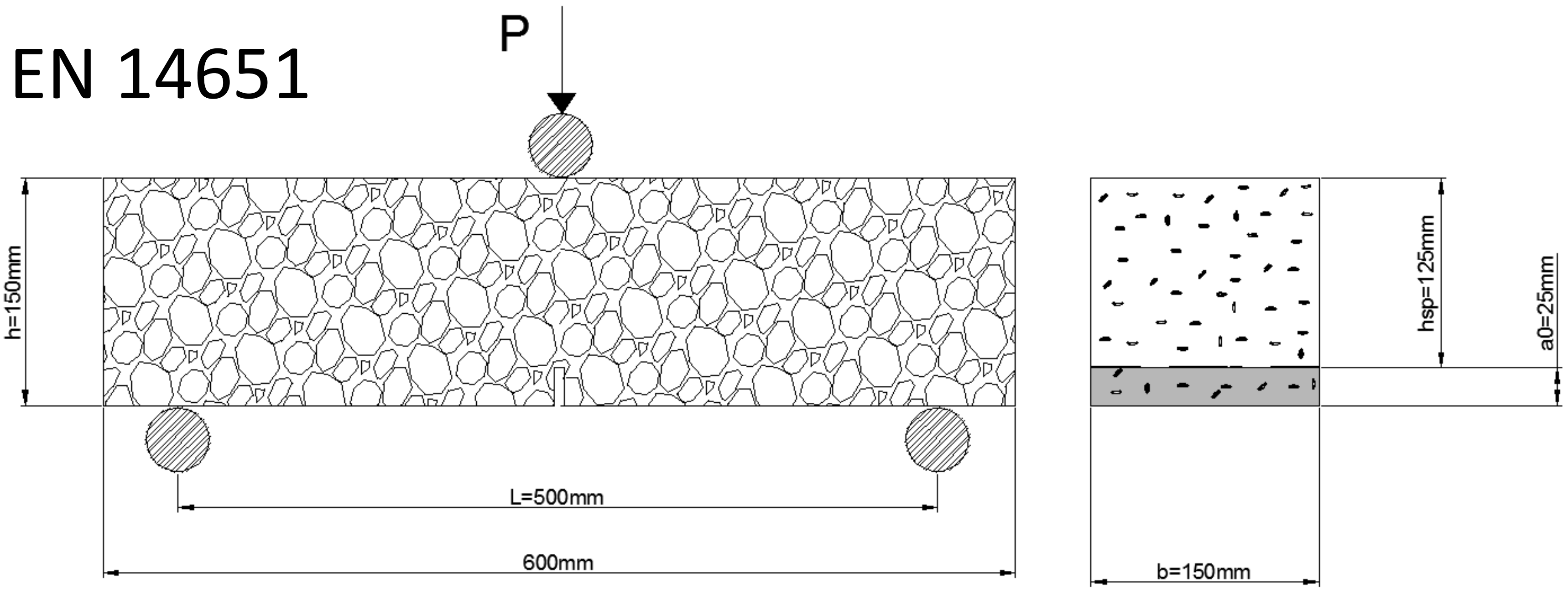
Part II: Synthetic fibres
Mainly composed by **polyolefin** (polypropilenes and others)

Class I:
Micro-fibres
d_e<0.3mm
Non structural
Ia Mono-filament
Ib Fibrilated

Class II :
Macro-fibres
d_e>0.3mm
Structural fibres:
EN 14651:2007
$Vf \rightarrow f_{R1} \geq 1.5$ *MPa*
Reference concrete:
EN 14845: 2008

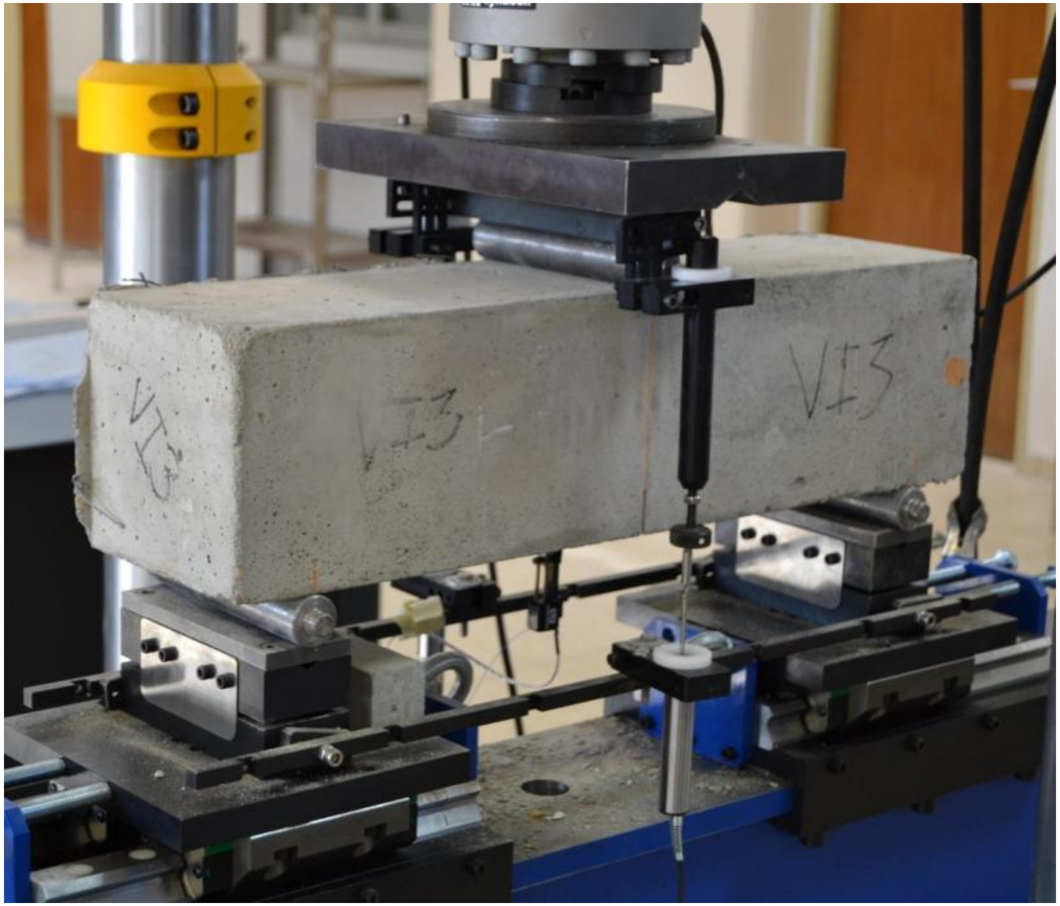
Fracture tests and residual strengths

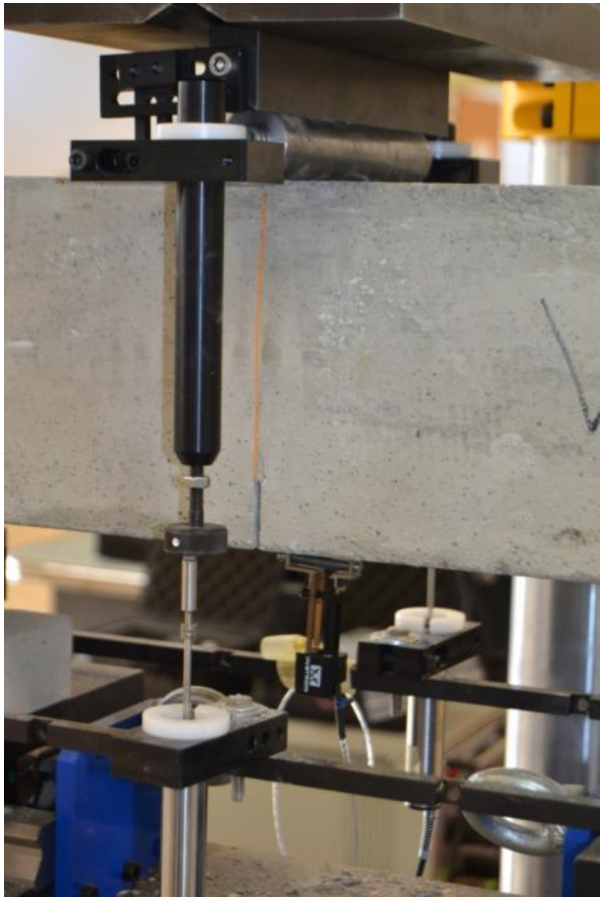
EN 14651



Fracture tests and residual strengths

EN 14651



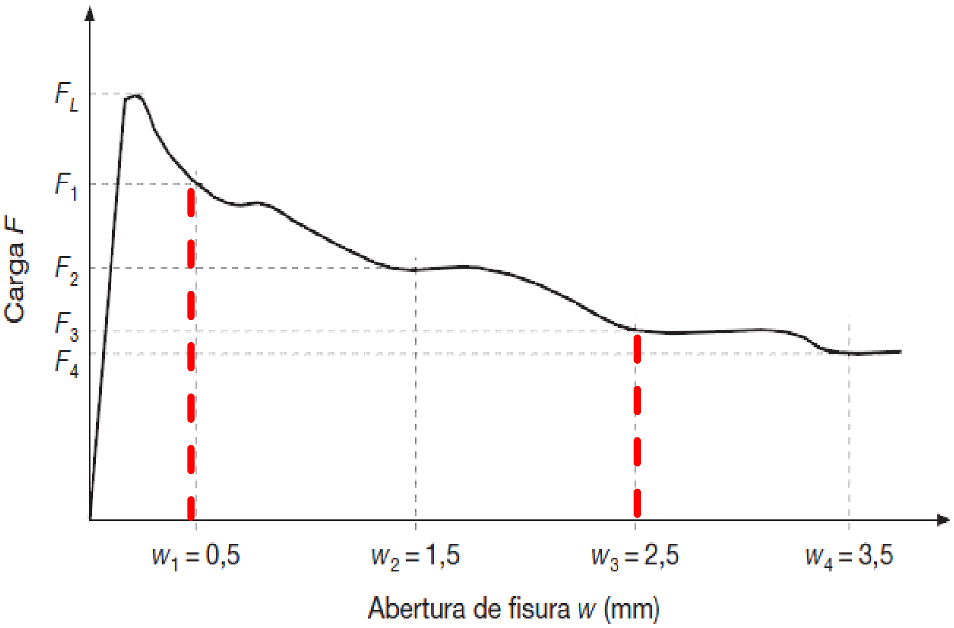


Fracture tests and residual strengths

EN 14651:
the test in 18 seconds

Fracture tests and residual strengths

$$f_{ct,j} = \frac{3}{2}\frac{F_j \cdot L}{b \cdot h_{sp}^2}$$



The structural requirements in EHE-08 and Model Code are in terms of residual strengths proportional to the strength in the limit of proportionality (***f_{lop}***) obtained in three-point bending tests of EN 14651:

- Stress for a crack opening equal to **0,5mm (*f_{R1}*) equal or greater than 40% *f_{lop}***
- For a crack opening of **2,5mm (*f_{R3}*)** surpassing **20% of *f_{lop}***

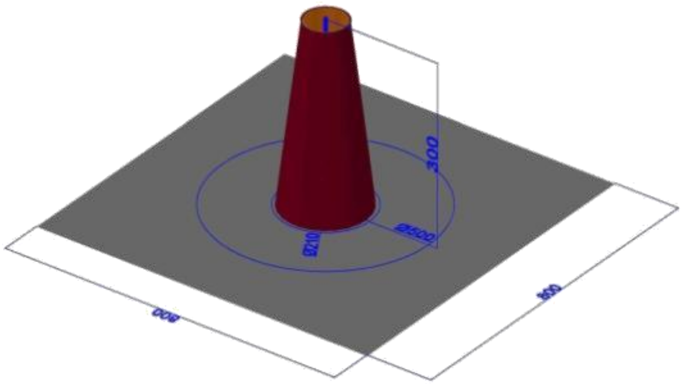
Contents

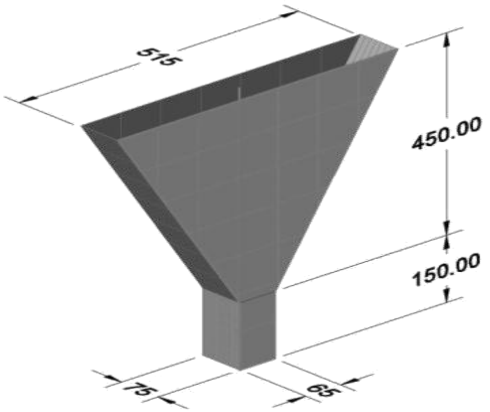
Fresh-state properties of PFR-SCC

Assessment of SCC fresh state properties

Slump flow spread EN 12350-8

V-Funnel test EN 12350-9



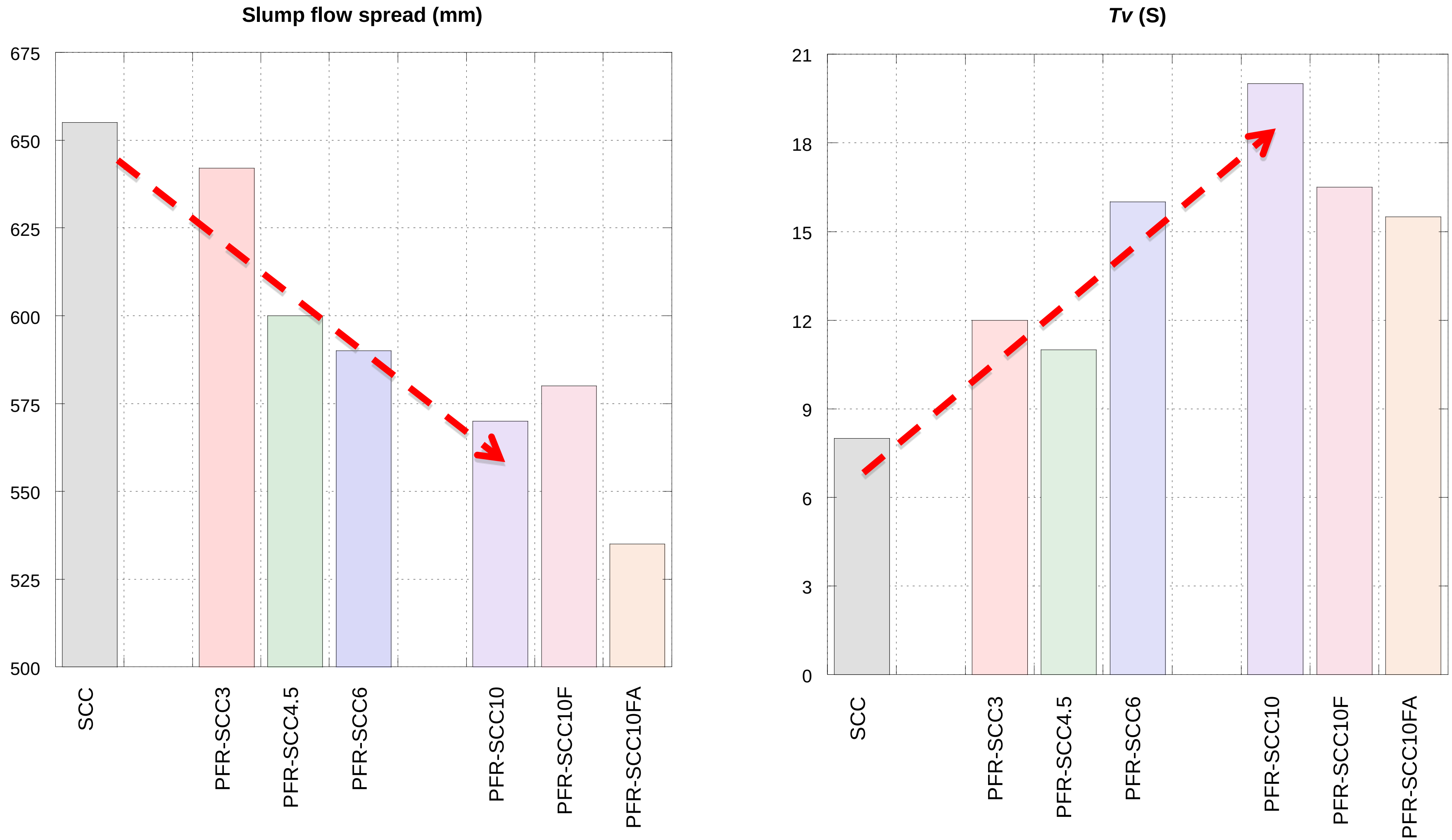


Fresh-state properties of PFR-SCC

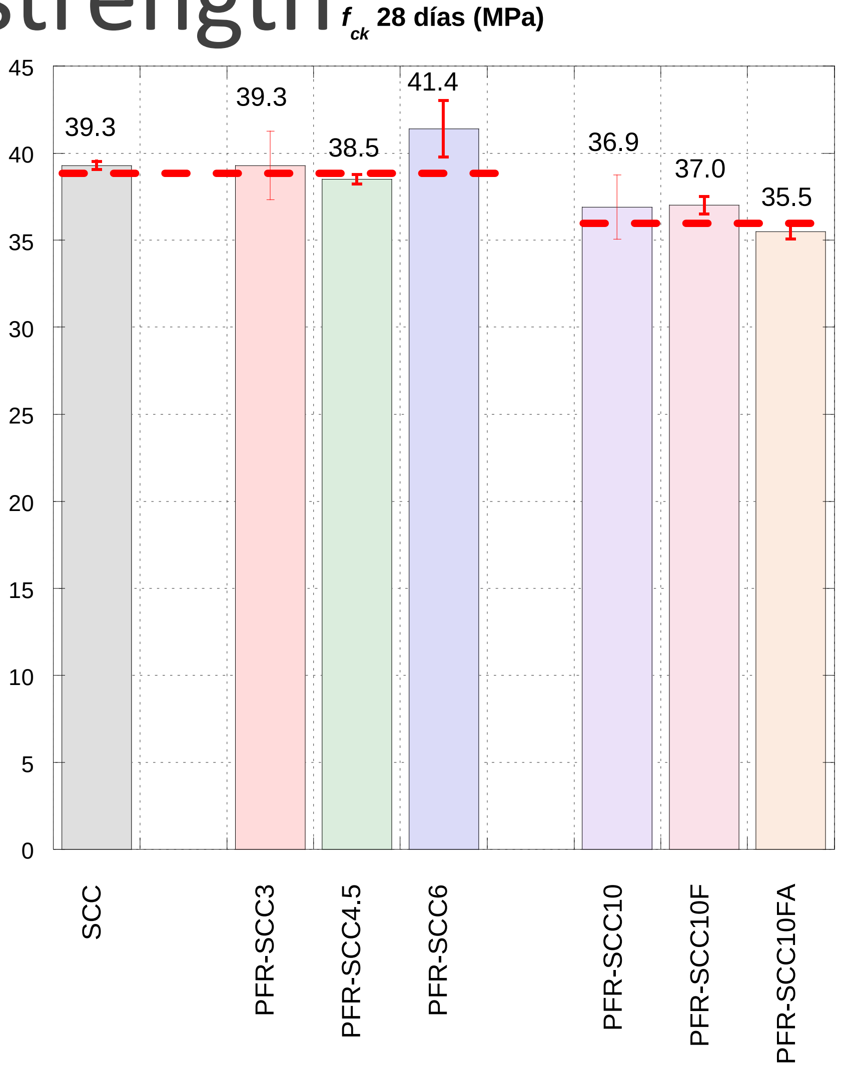
Assessment of SCC fresh state properties

	Slump flow spread		*V- Funnel*
	T_{50} (s) ✓	d_f(mm) ✓	Tv (s) ✓
SCC	3,5	655	8
PFR-SCC3	3	642	12
PFR-SCC4.5	3,5	600	11
PFR-SCC6	4	590	16
PFR-SCC10	6	570	20
PFR-SCC10F	4	580	16,5
PFR-SCC10FA	7	580(535)	15,5

Fresh-state properties of PFR-SCC



Compressive strength



Compressive stren…

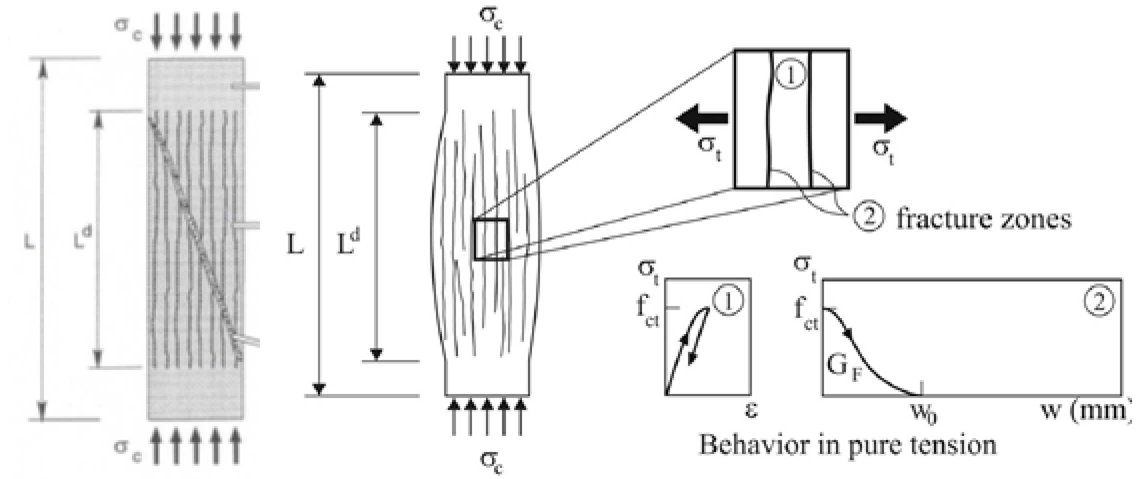
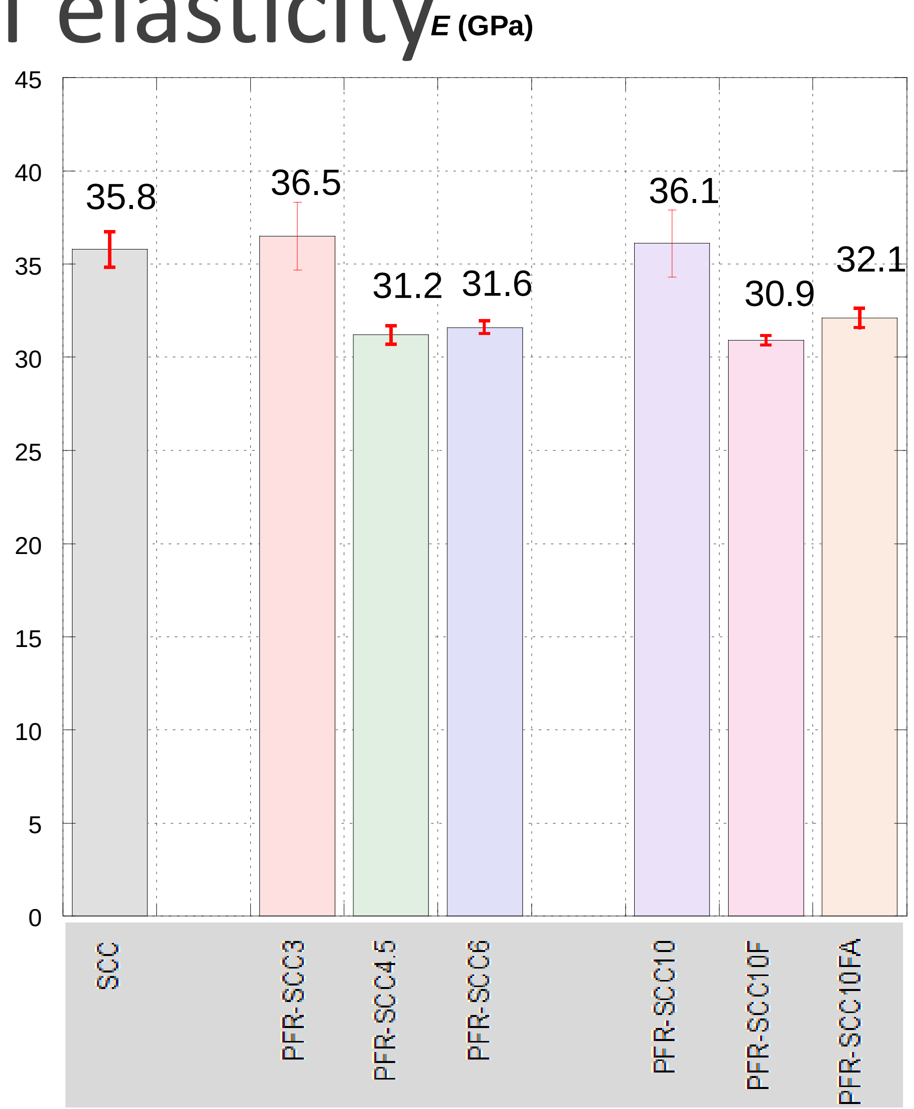


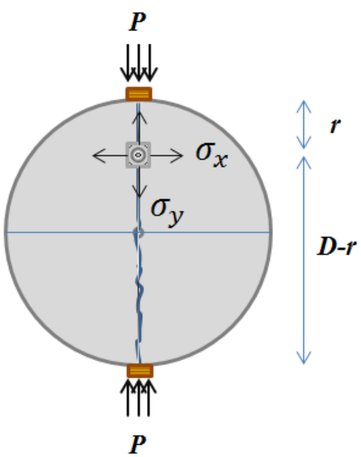
Figure 2-24. Illustration of the Compressive Damage Zone model for plain concrete (Markeset, 1993; Schumacher, 2006)

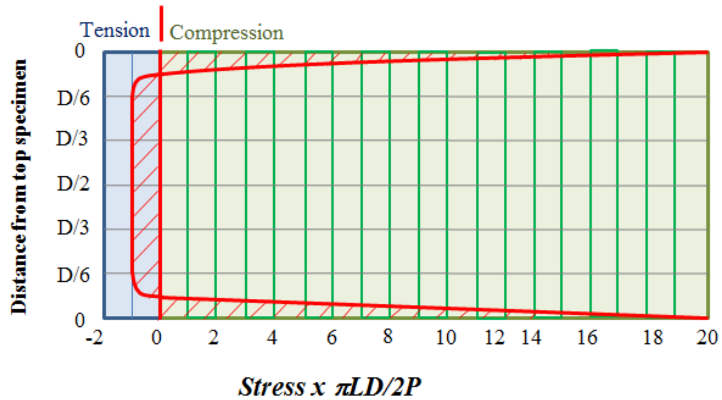
Modulus of elasticity

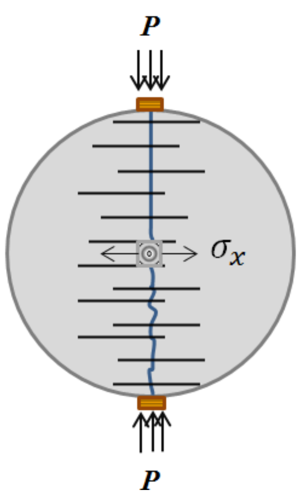
- No clear trend
- Slight decreasing with the change of the aggregate skeleton

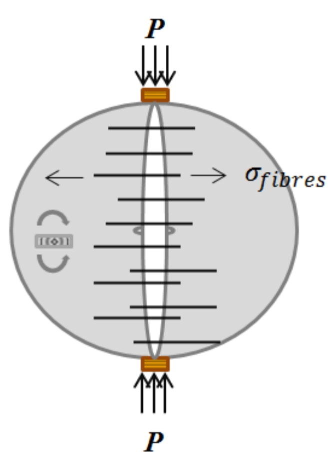


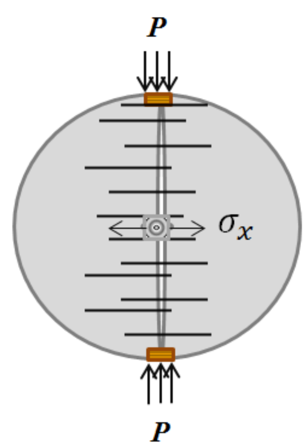
Indirect tensile strength



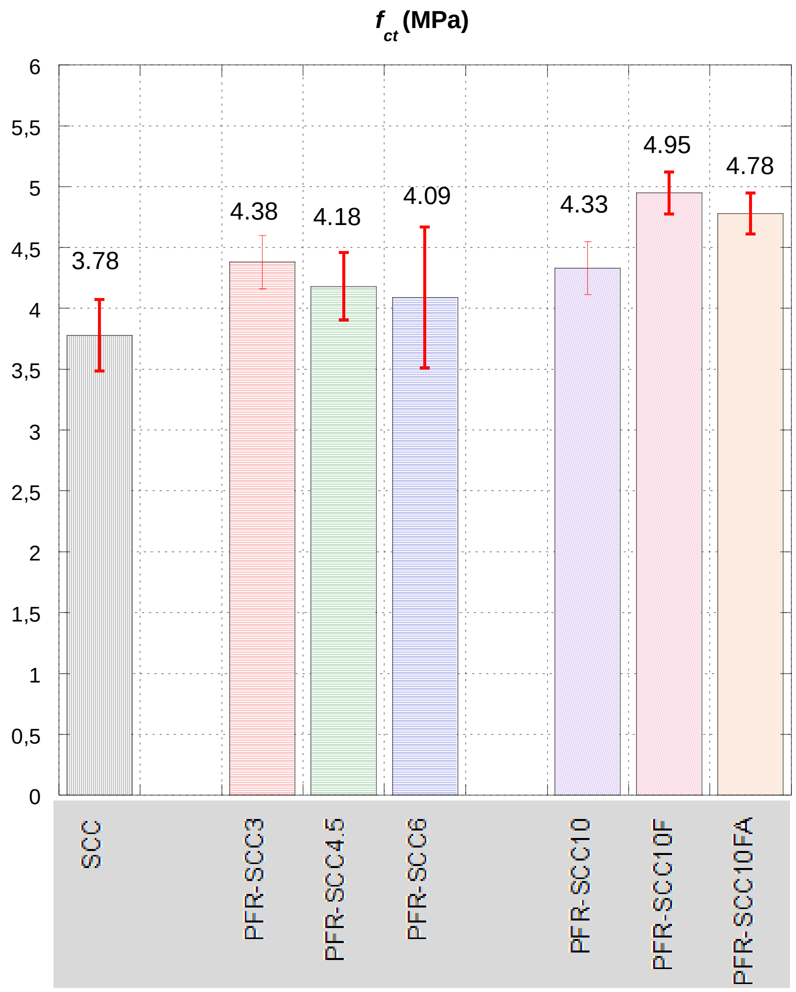


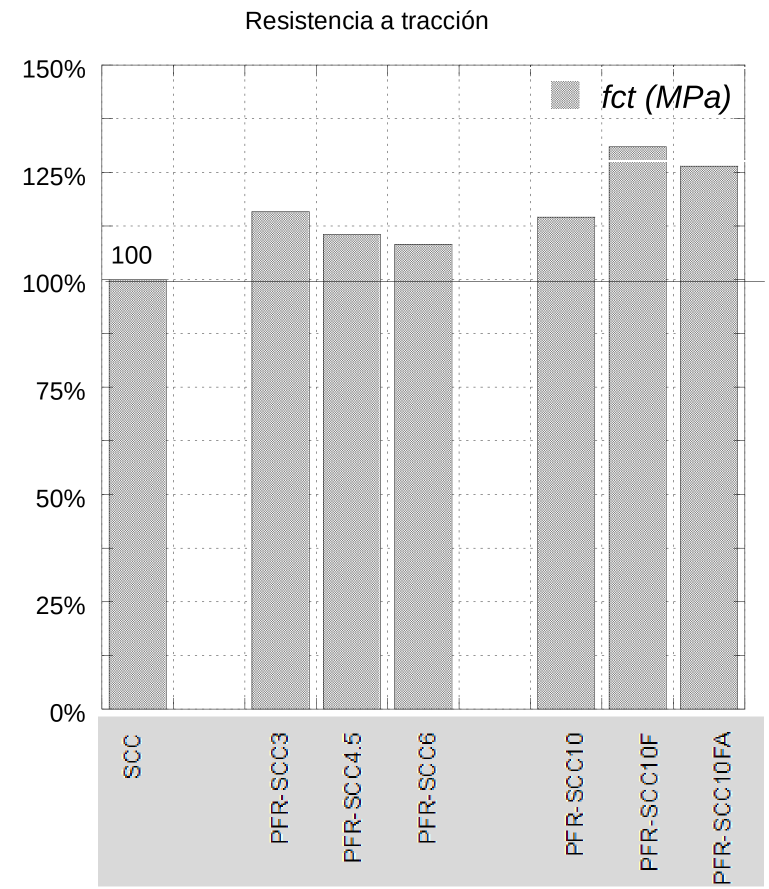




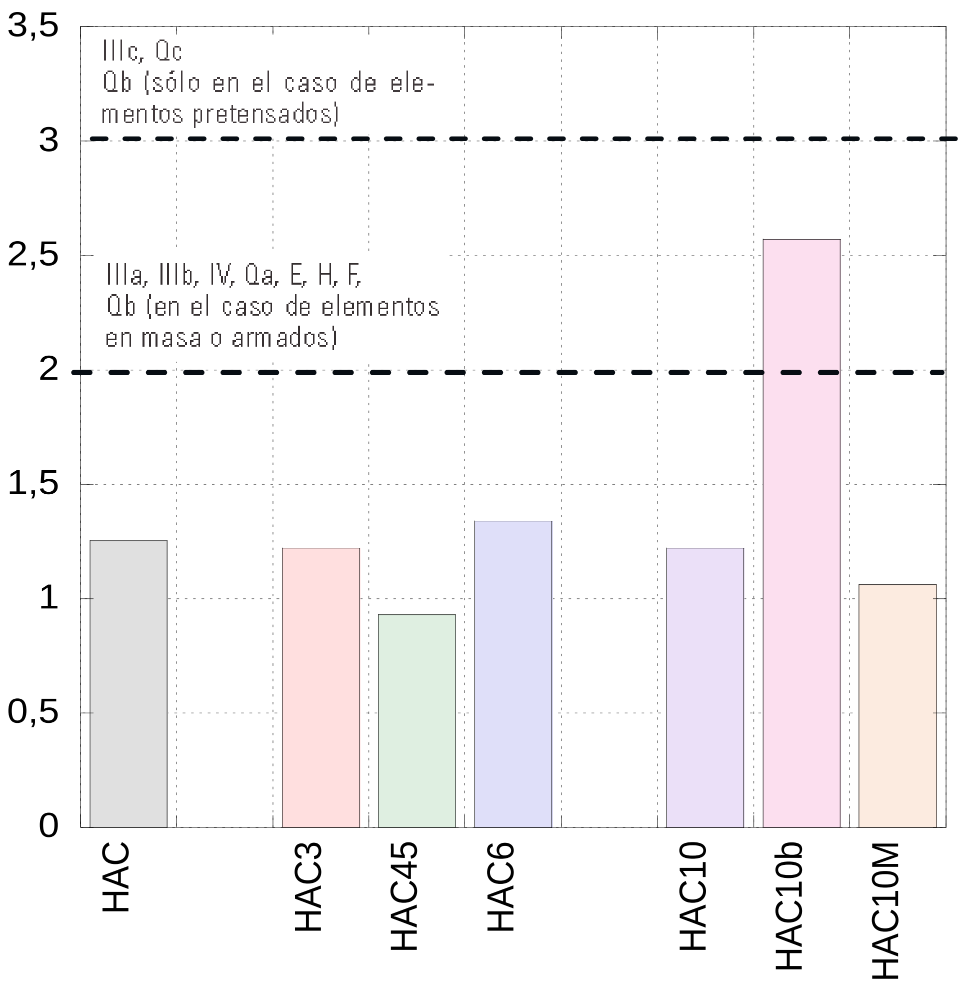


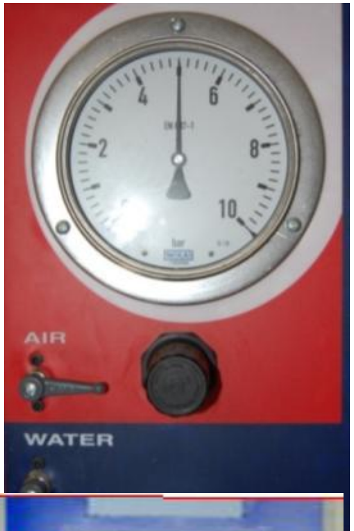
Indirect tensile strength

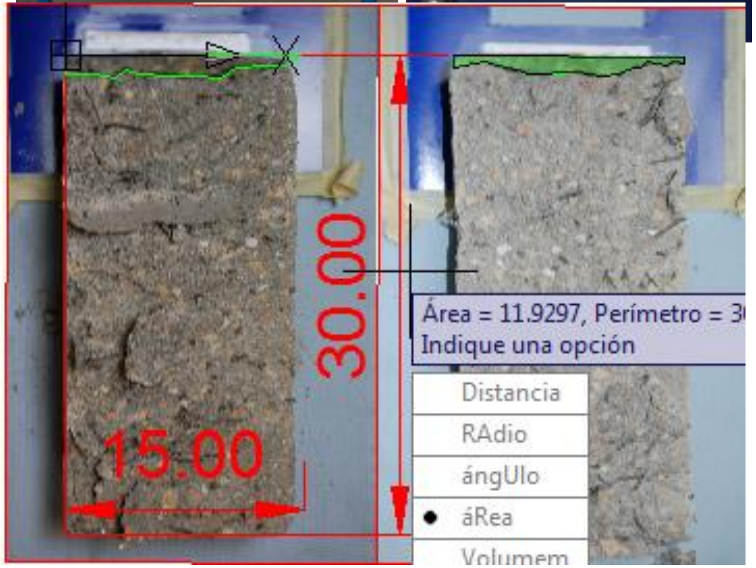




Depth of penetration of water under pressure

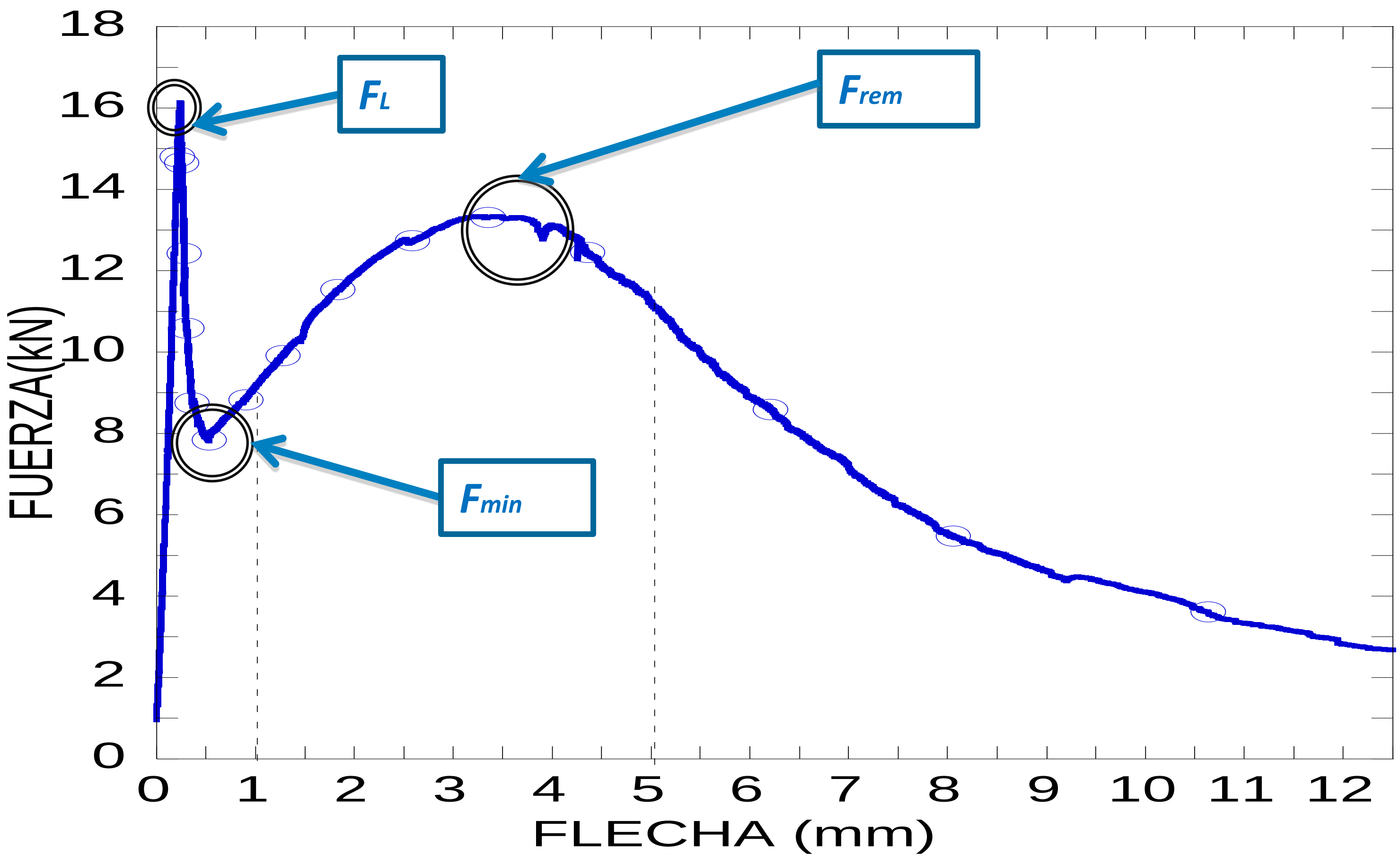




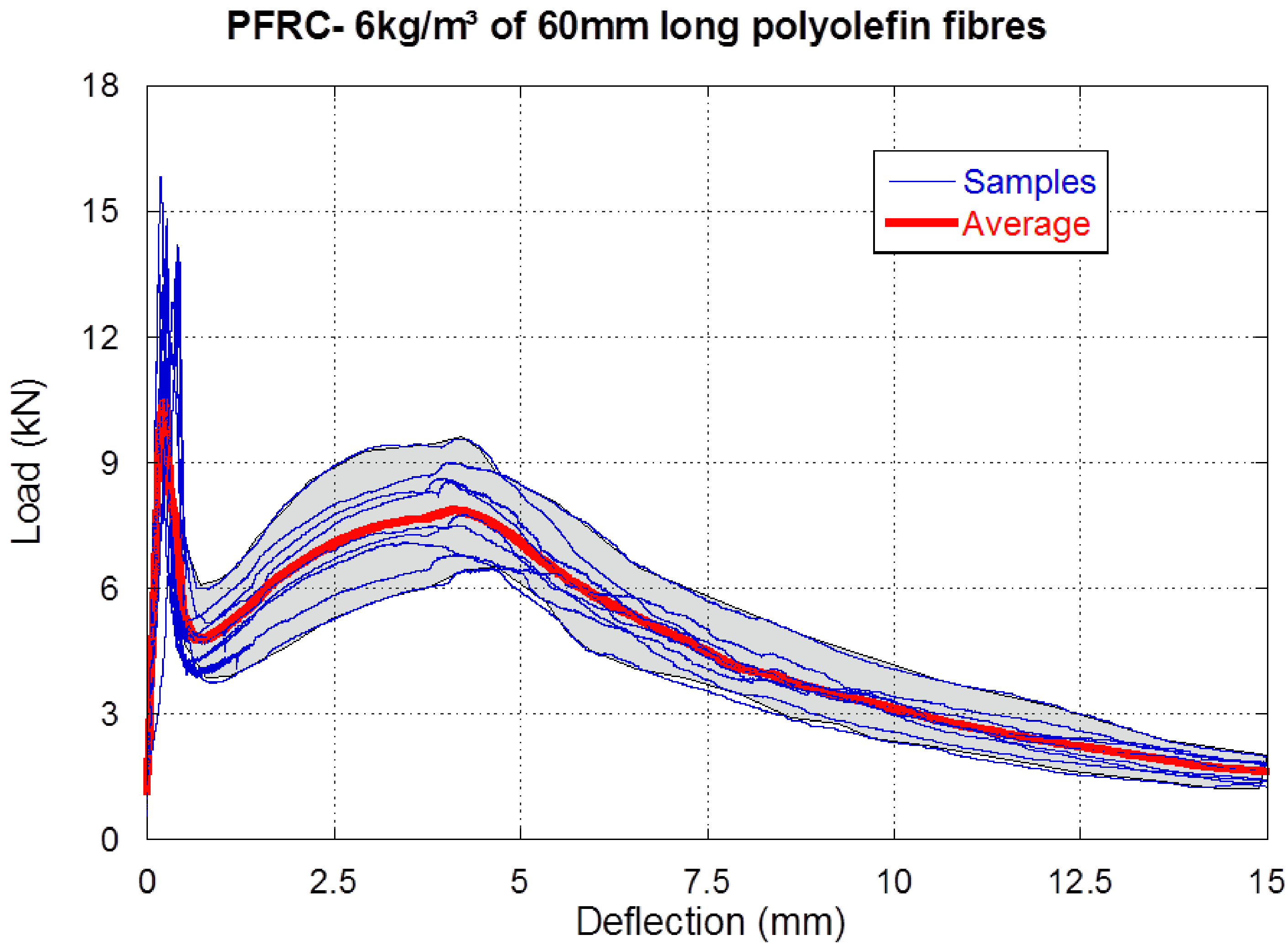


Contents

Overview of PFRC fracture behaviour



Overview of PFRC fracture behaviour



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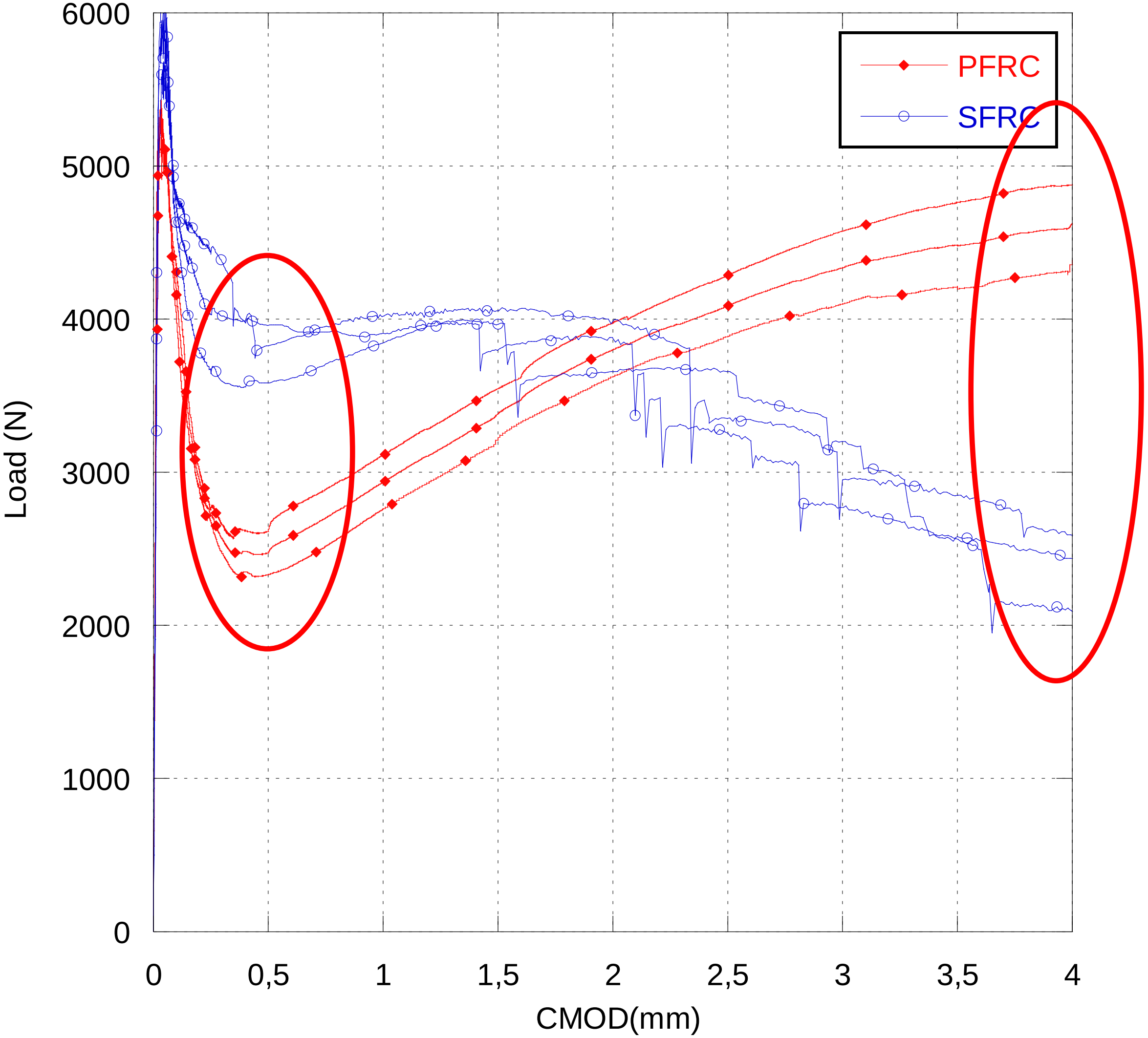
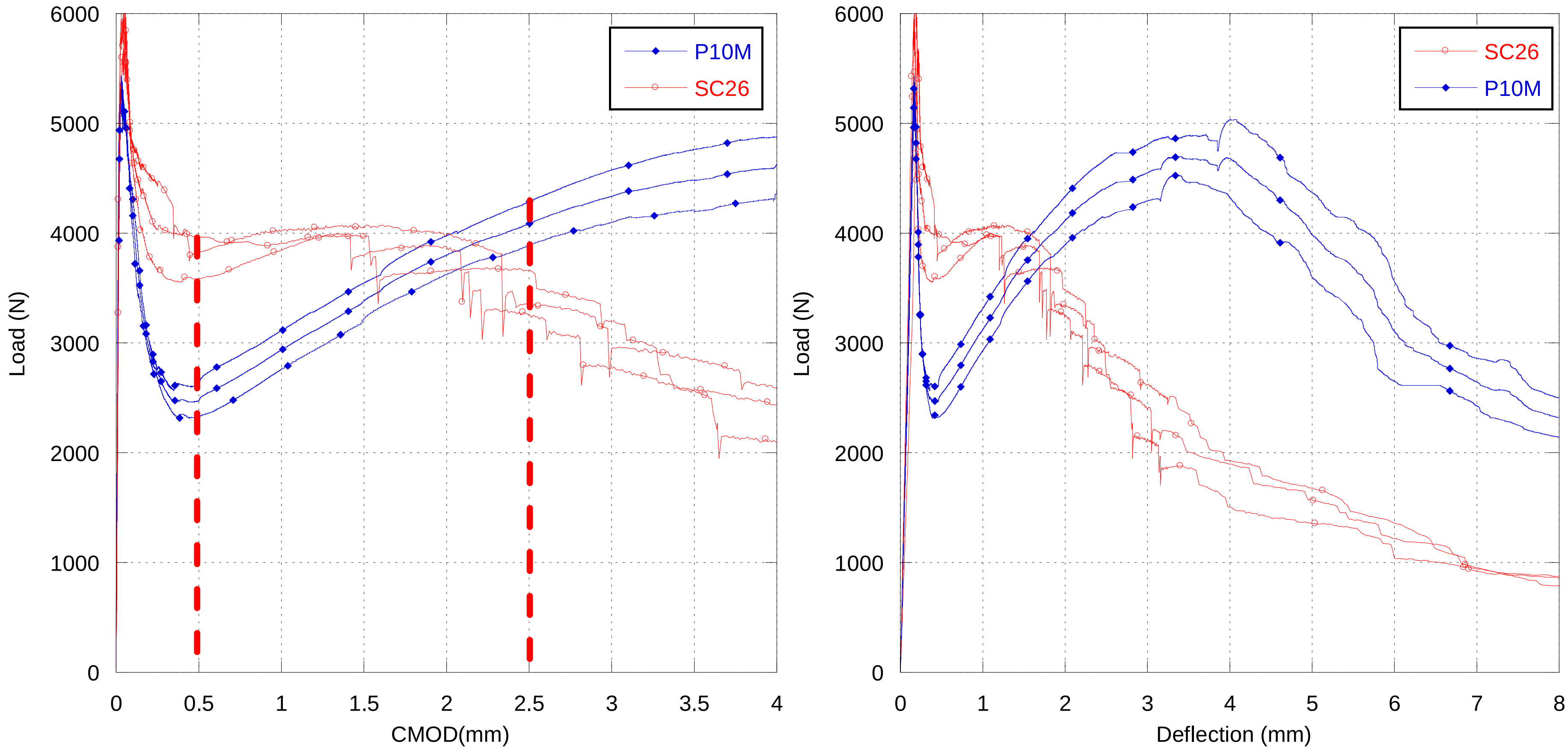


M.G. Alberti, A. Enfedaque, J.C. Gálvez, *"On the mechanical properties and fracture behavior of polyolefin fiber-reinforced self-compacting concrete"*, Construction and Building Materials, Volume 55, 31 March 2014, Pages 274-288.

Overview of PFRC fracture behaviour

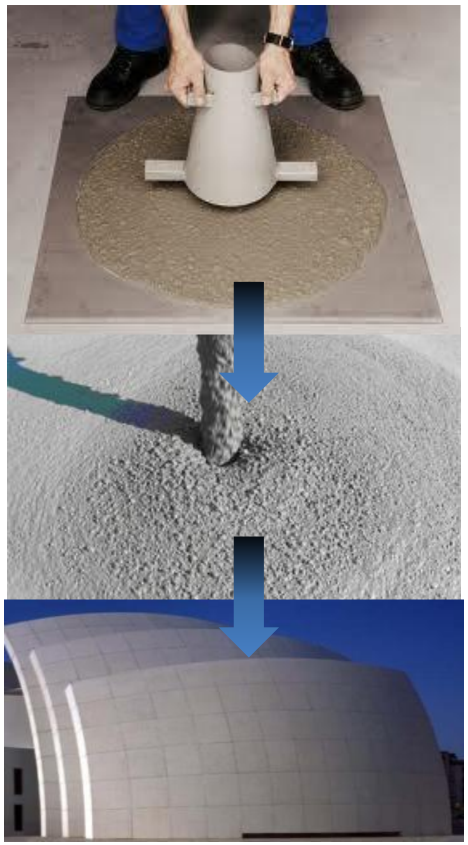


Contents

Self-compacting polyolefin fibre reinforced concrete

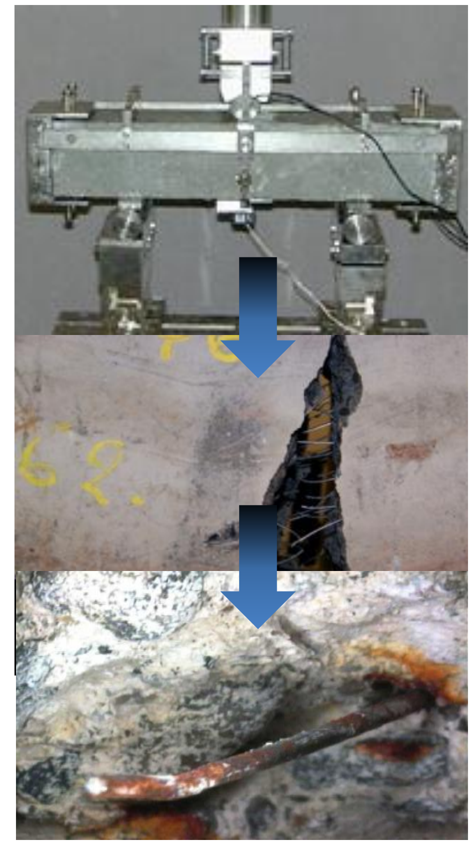
Self-Compacting Concrete (SCC)

Fiber-Reinforced Concrete (FRC)



The combination of both technologies has shown to be effective to improving fiber alignment, fracture results and reliability

Fiber-Reinforced Self-Compacting Concrete (FR-SCC)



Self-compacting polyolefin fibre reinforced concrete

Main objectives of the study:

- Production of PFR-SCC with moderate contents of cement and admixtures
- Evaluation of the evolution of the fresh state behavior and hardened mechanical properties by increasing progressively fiber dosage

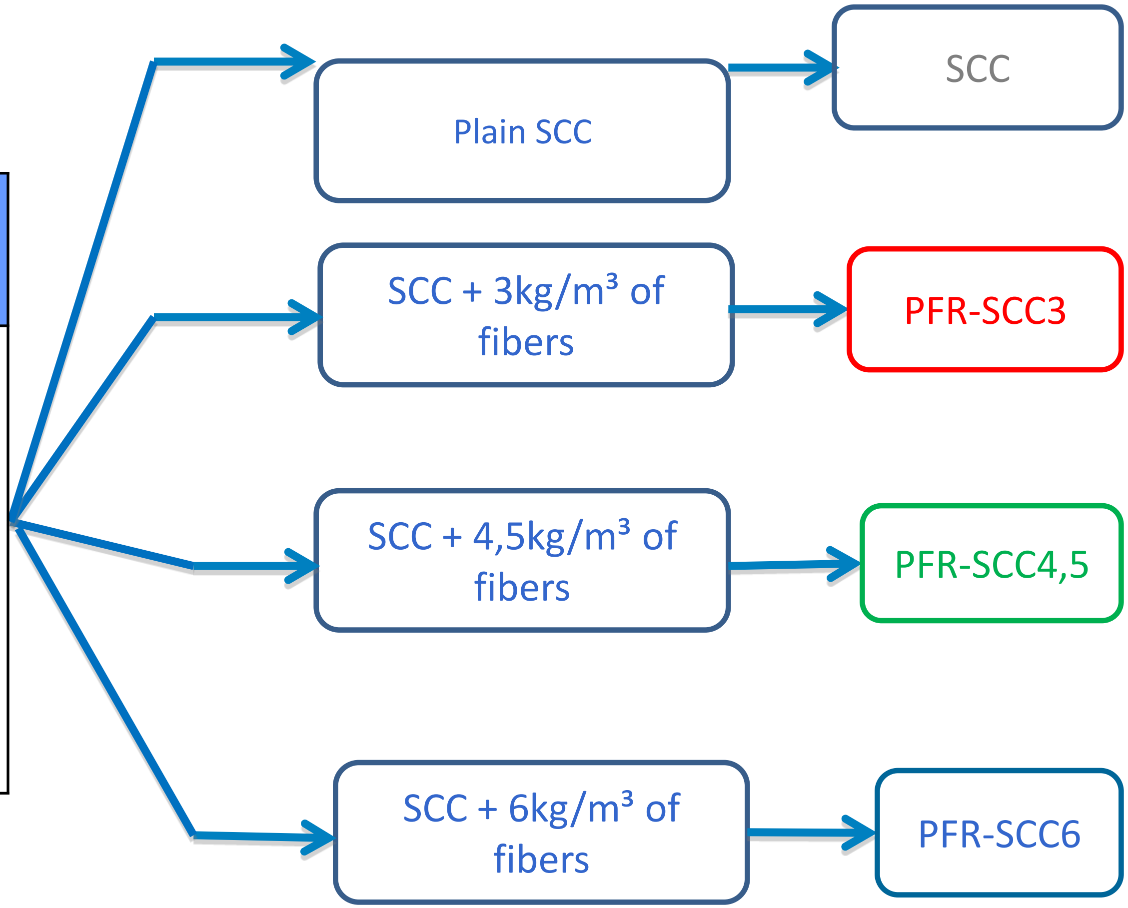
- Assessment of the fracture properties of the composite material: analysis of the residual load-bearing capacity varying fiber dosages

- Production of PFR-SCC with high amount of fiber capable to fulfill the requirements to take in account the contribution of fibers in the structural design

Self-compacting polyolefin fibre reinforced concrete

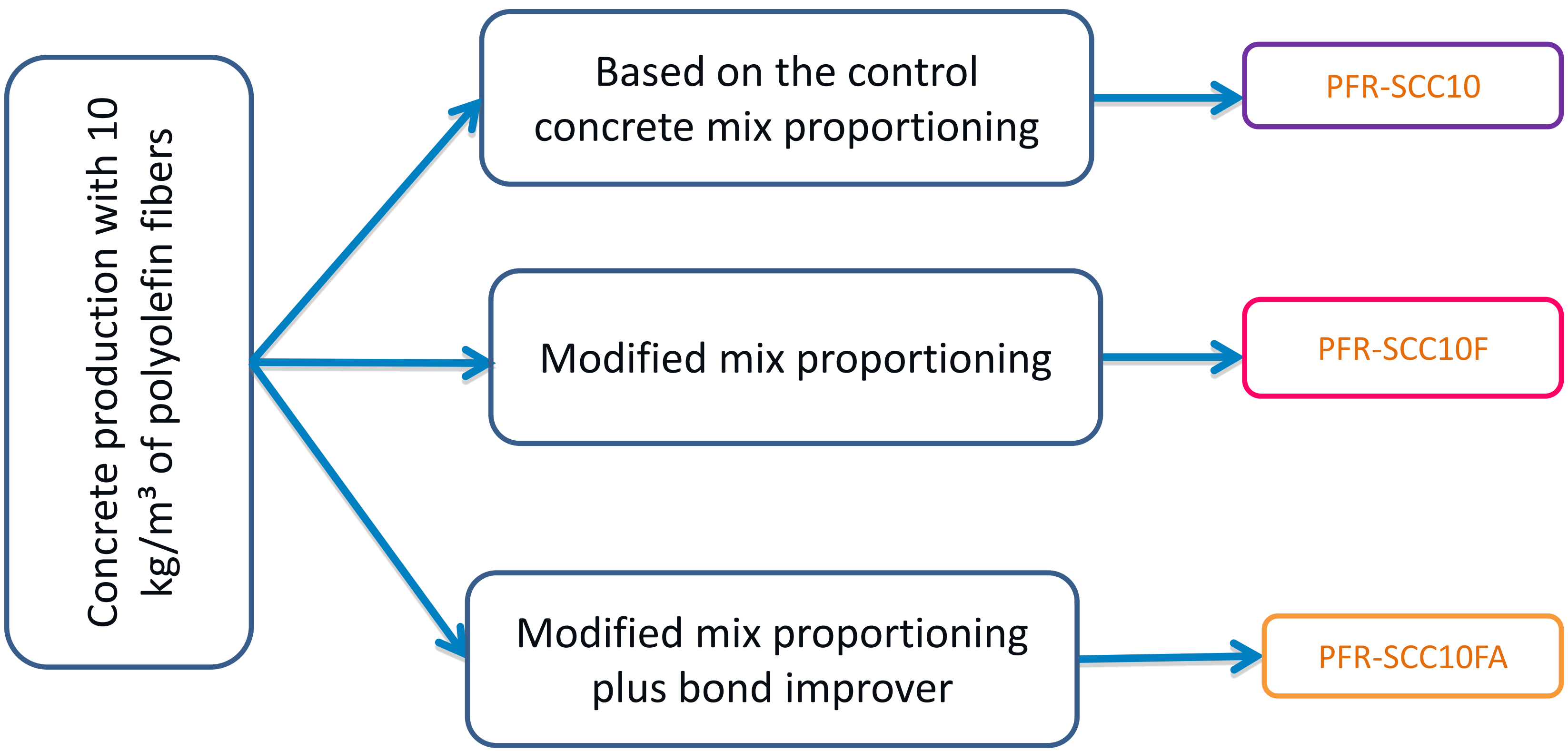
Concrete production

	Weight (kg/m³)
Cement	**375,0**
Water	187,5
a/c	0,50
Limestone powder	**200,0**
Sand	917,7
Grit	244,7
Gravel	367,1
Superplasticizer	1,25%



Self-compacting polyolefin fibre reinforced concrete

- High polyolefin fiber content mixtures

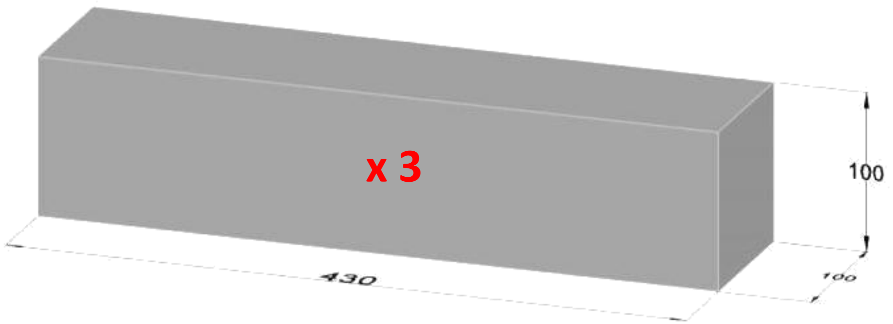


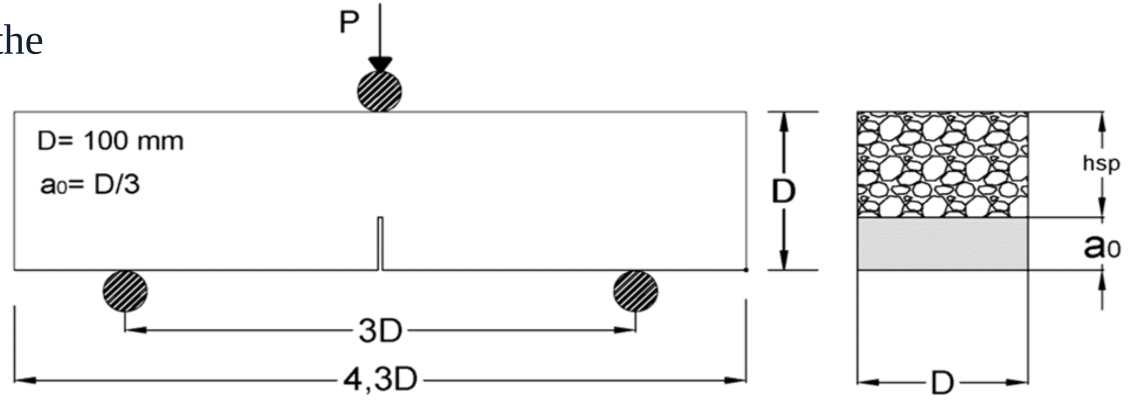
Self-compacting polyolefin fibre reinforced concrete

Fracture tests

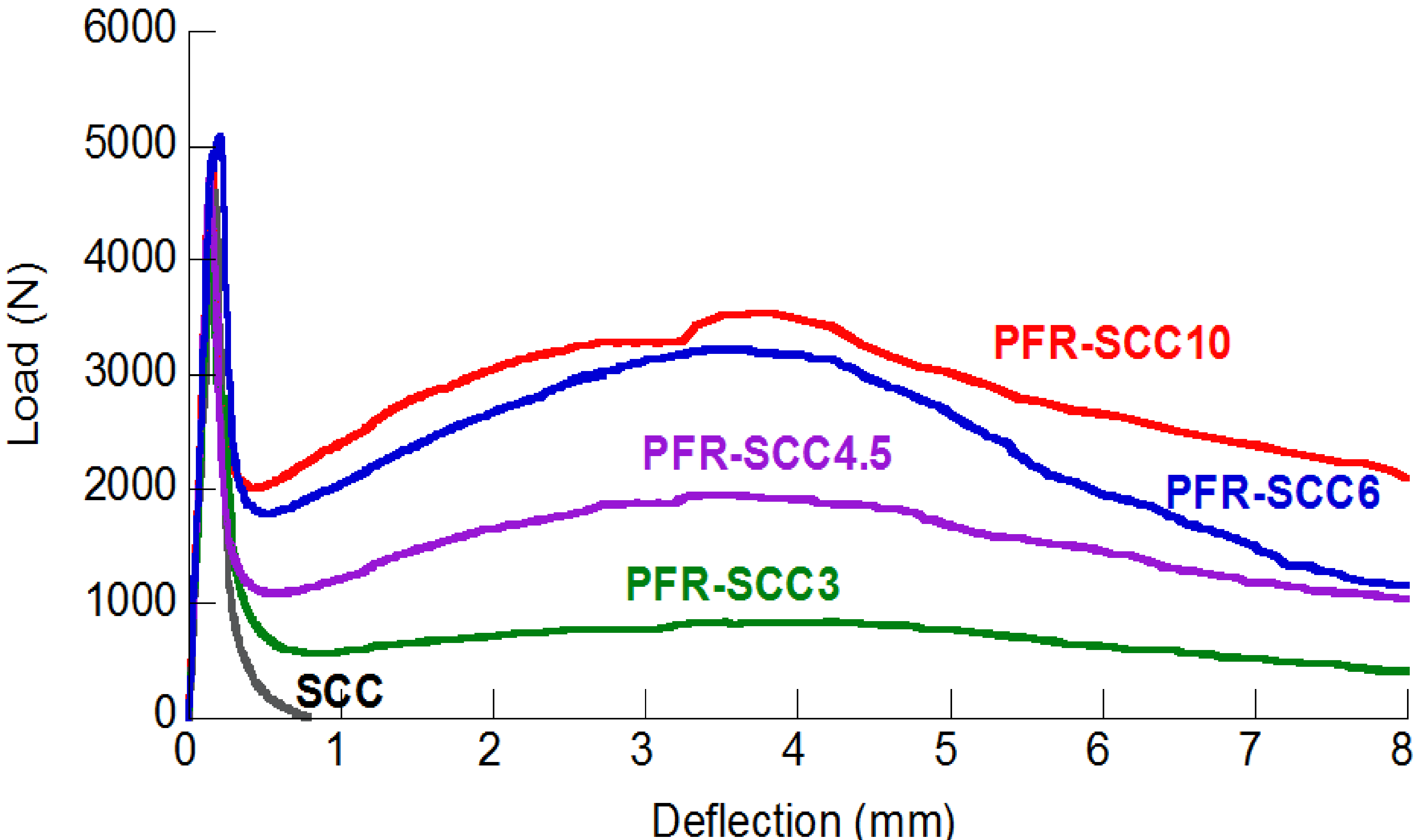
3 prismatic specimens of each mixture size: 430x100x100 mm³

- Three-point bending tests on notched specimens following specifications of RILEM TC-187-SOC
- Dimensions 430x100x100 mm³, span 3D = 300 mm
- Notch D/3= 33,33 mm
- 2 lateral LVDT and control with CMOD device
- Load, time and displacement of the actuator also recorded





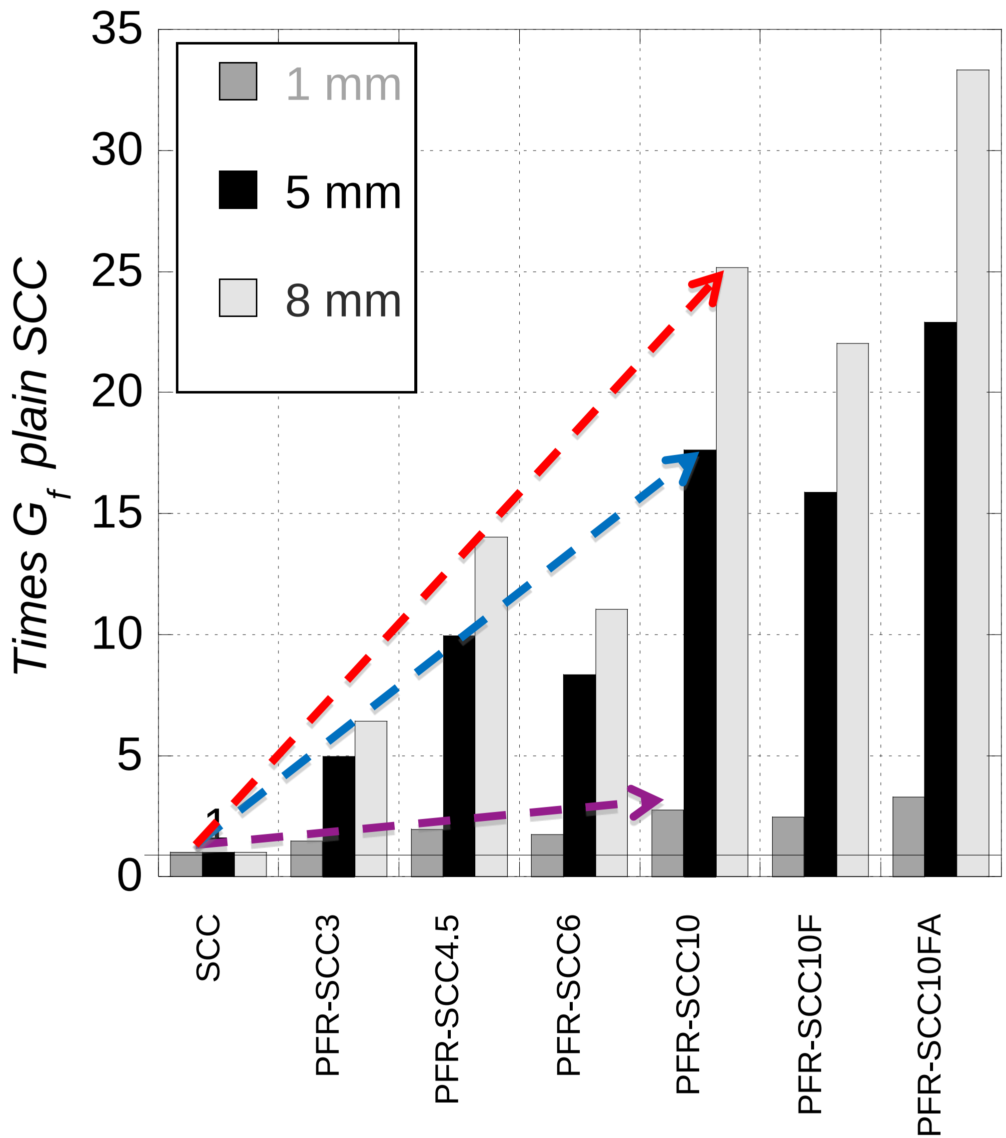
Self-compacting polyolefin fibre reinforced concrete



Fracture Energy

G_F (N/m) for 8 mm of deflection

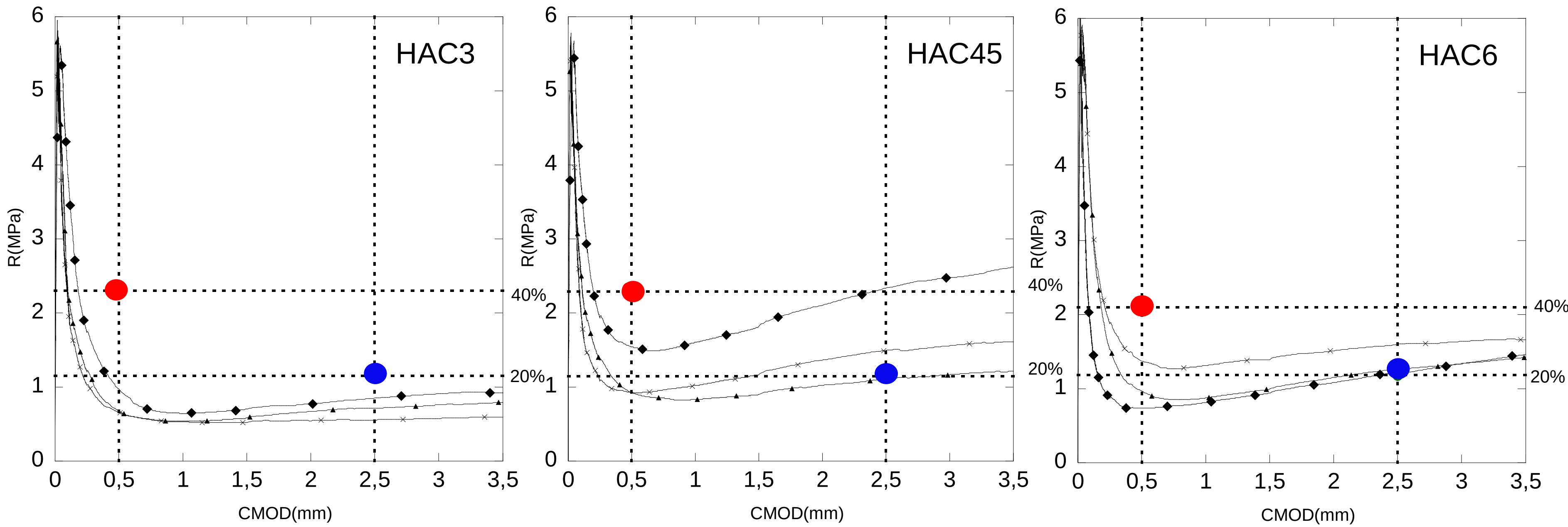
SCC	PFR-SCC3	PFR-SCC4.5	PFR-SCC6	PFR-SCC10	PFR-SCC10F	PFR-SCC10FA
130 (0.05)	835 (0.07)	1825 (0.42)	2781 (0.24)	3271 (0.20)	2865 (0.26)	4330 (0.10)



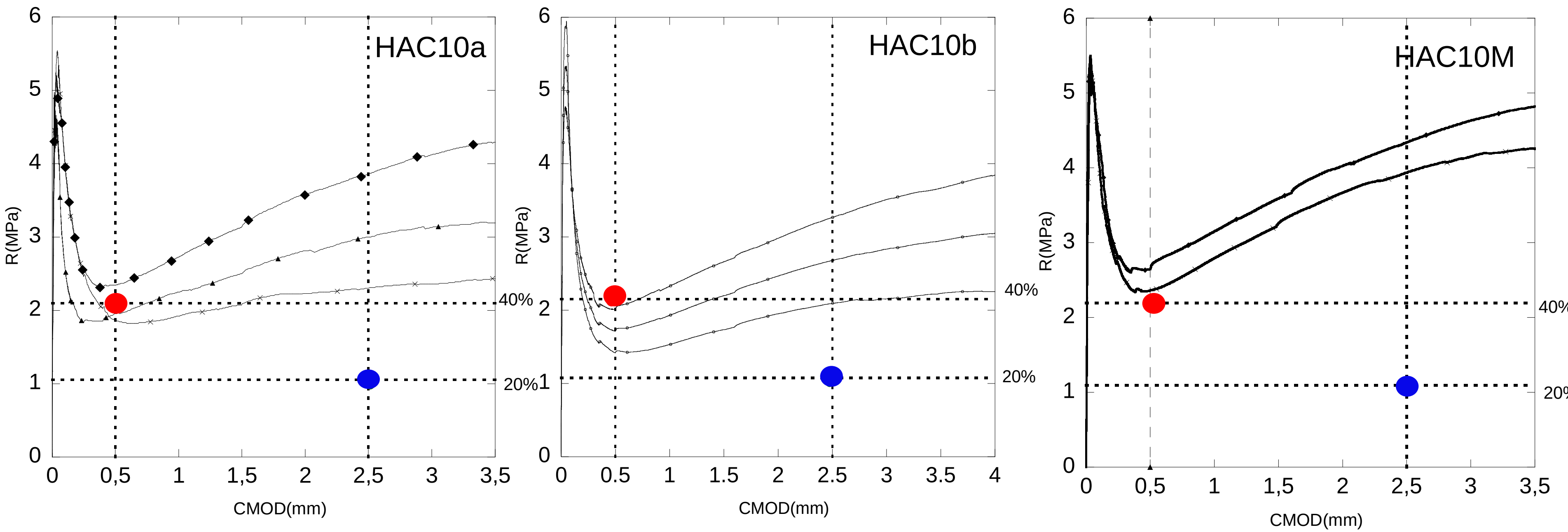
Residual strength

Mixture	f_L	f_{R1}	$\%f_L$	f_{R2}	$\%f_L$	f_{R3}	$\%f_L$	f_{R4}	$\%f_L$
CMOD(mm)	<0.05	0.50		1.50		2.50		3.50	
PFR-SCC3	5.75 (0.04)	0.76 (0.17)	13%	0.64 (0.10)	11%	0.66 (0.09)	11%	0.81 (0.14)	14%
PFR-SCC4.5	5.73 (0.01)	1.13 (0.35)	20%	1.30 (0.47)	23%	1.64 (0.62)	29%	1.82 (0.73)	32%
PFR-SCC6	6.20 (0.01)	1.82 (0.35)	29%	2.19 (0.58)	35%	2.67 (0.72)	43%	3.06 (0.73)	49%
PFR-SCC10	5.25 (0.05)	2.05 (0.26)	39%	2.59 (0.54)	49%	3.05 (0.78)	58%	3.30 (0.93)	63%
PFR-SCC10F	5.38 (0.15)	1.72 (0.42)	32%	2.20 (0.66)	41%	2.68 (0.83)	50%	2.95 (1.02)	55%
PFR-SCC10FA	5.48 (0.01)	2.50 (0.20)	46%	3.43 (0.23)	63%	4.14 (0.28)	76%	4.53 (0.41)	83%

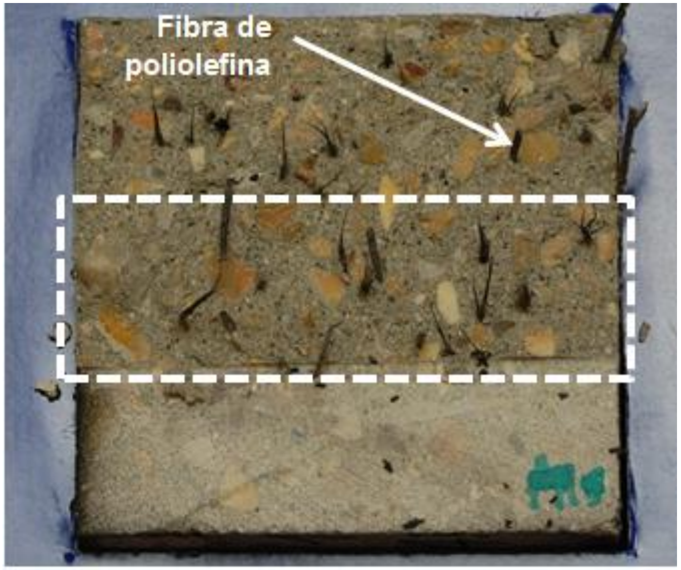
Residual strength

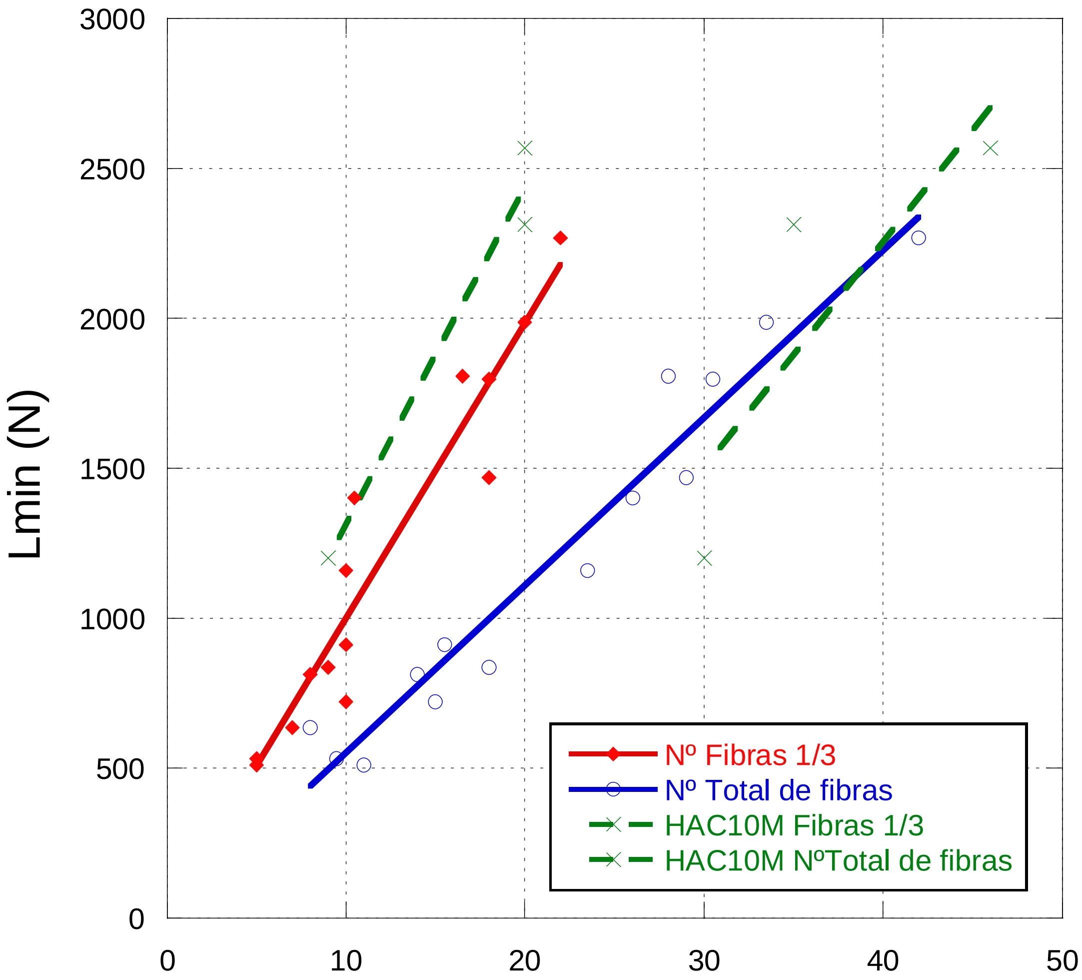


Residual strength



Fracture surface analysis





Contents

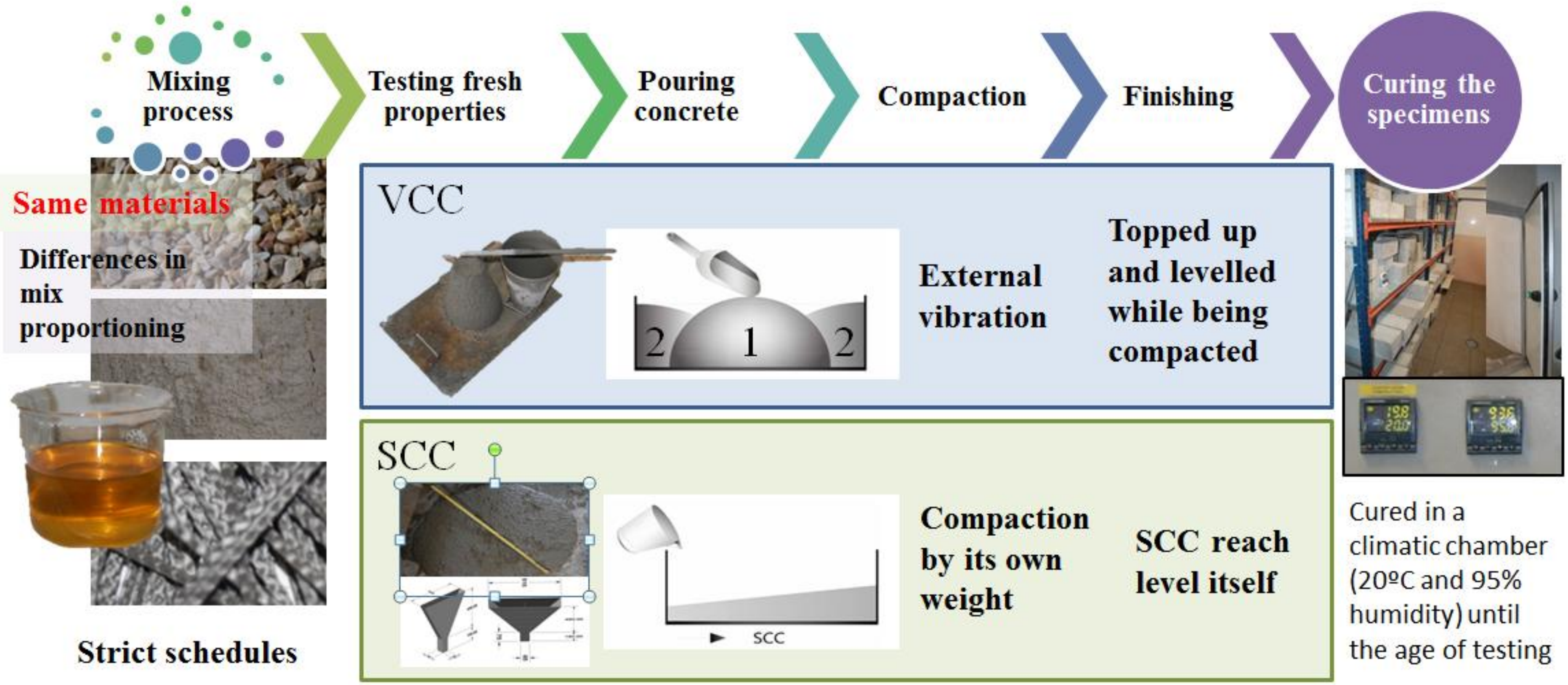
Vibrated conventional concrete (VCC)

- It is still the most commonly used type of concrete
- Compacted by vibration
- Know-how and well-known by the construction industry
- Conventional methods for mix proportioning
- Lower material costs adapted to structural and design requirements

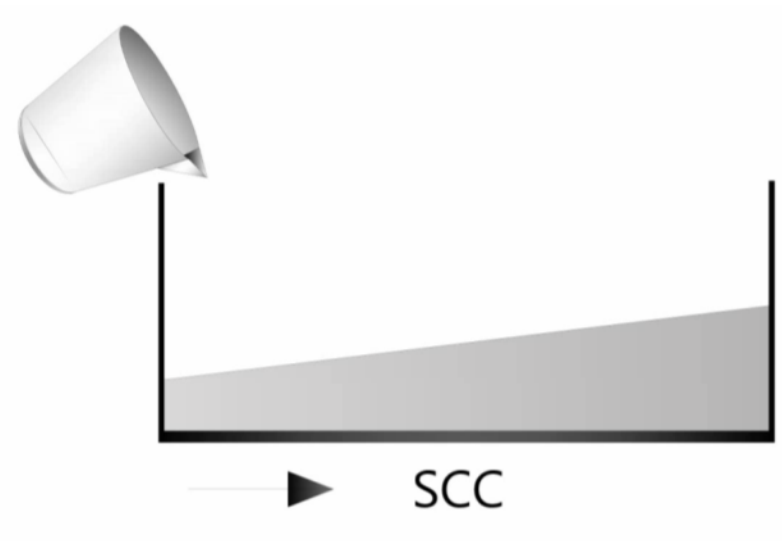
↓

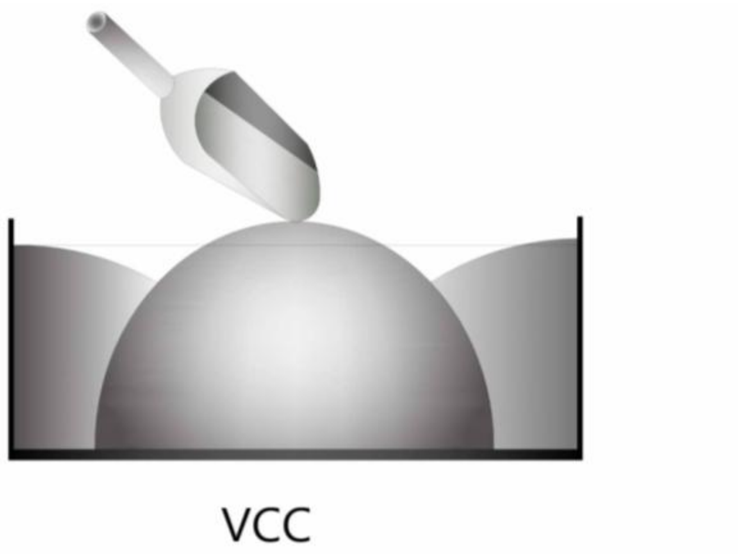
VCC+PFRC

Comparison of production stages with VCC and SCC



Comparison of production stages with VCC and SCC





¿Cómo afecta el flujo o el vibrado a la distribución de las fibras?

Scope of the study

- Production of two types of concrete that met the structural requirements of EHE-08:
  - ✓ SCC with 10 kg/m³ of polyolefin fibres
  - ✓ VCC with 10 kg/m³ of polyolefin fibres
- Assess their fracture properties
- Evaluation of the difference in fibre positioning with the two compaction methods

Mix proportioning of VCC and SCC

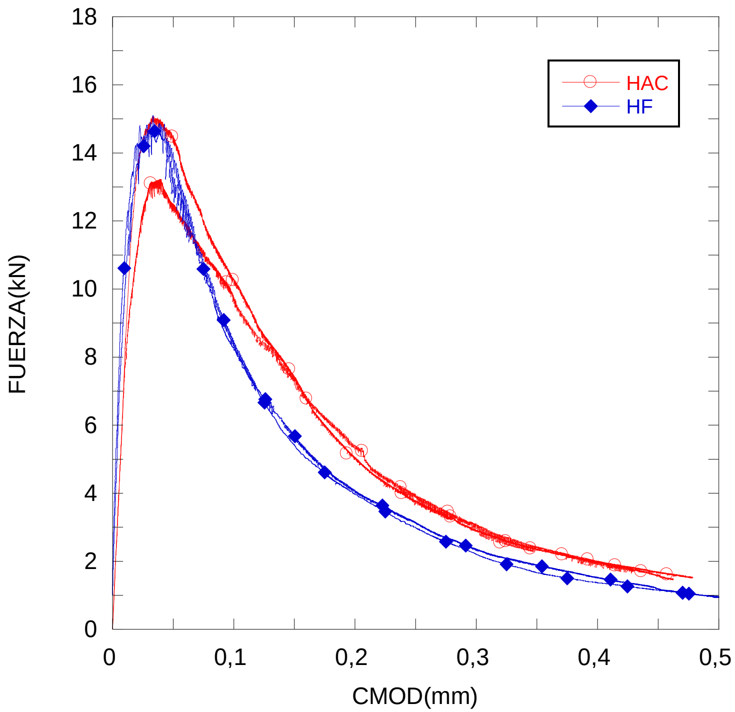
- In order to compare the two types of PFRC it was sought to produce two plain concrete mixtures with similar fracture energy

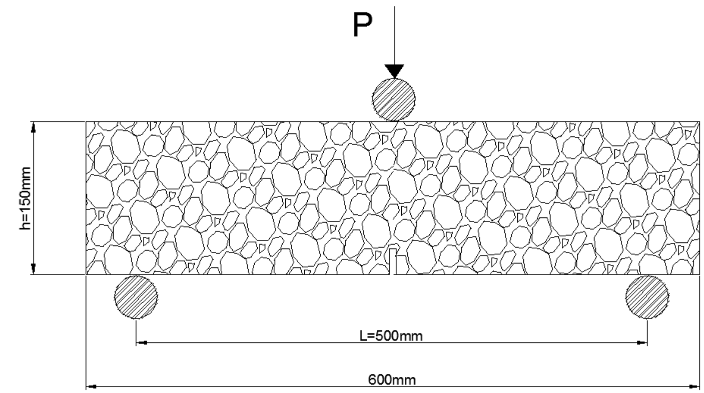
SCC	Dosage (kg/m³)
Cement	**375**
Water	188
a/c	0,50
Limestone powder	**200**
Sand	918
Grit	248
Gravel	367
Superplasticizer	1,25%

→

VCC	Dosage (kg/m³)
Cement	**375** =
Water	188
a/c	0,50
Limestone powder	**100** ↓
Sand	916
Grit	300 ↑
Gravel	450 ↑
Superplasticizer	0,75% ↓

- Fracture behaviour of plain VCC and SCC

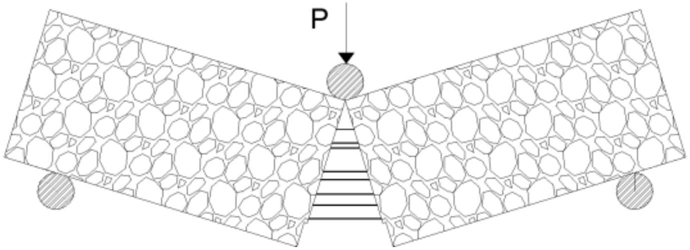


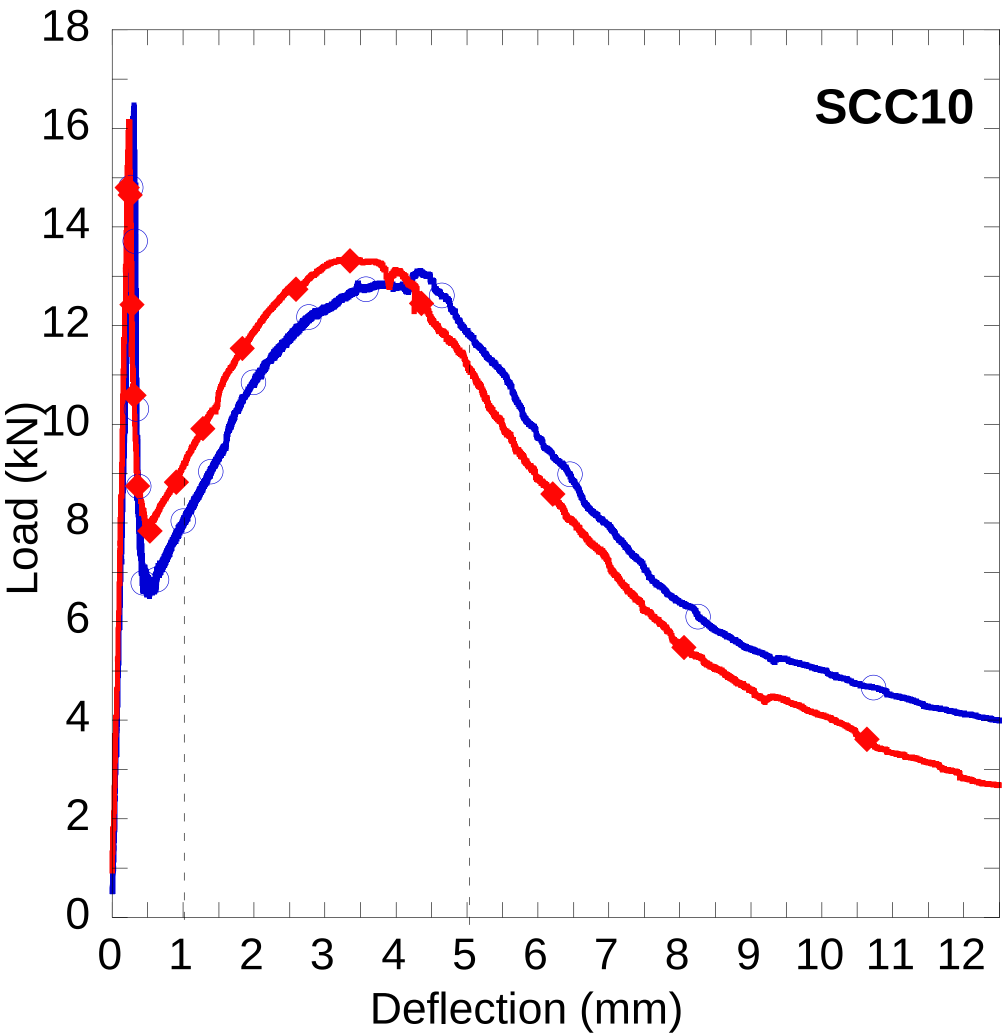


$$G_f = W_f / b \cdot h$$

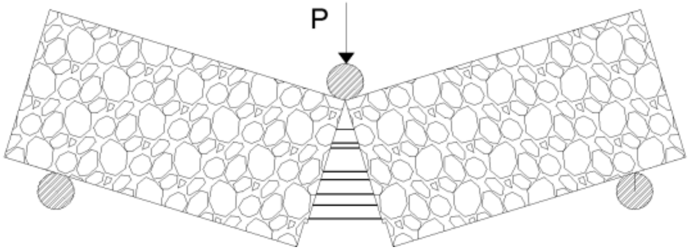
	G_f hasta 1 mm (c.v.)
HAC (N/m)	152 (0,10)
HF (N/m)	153 (0,10)

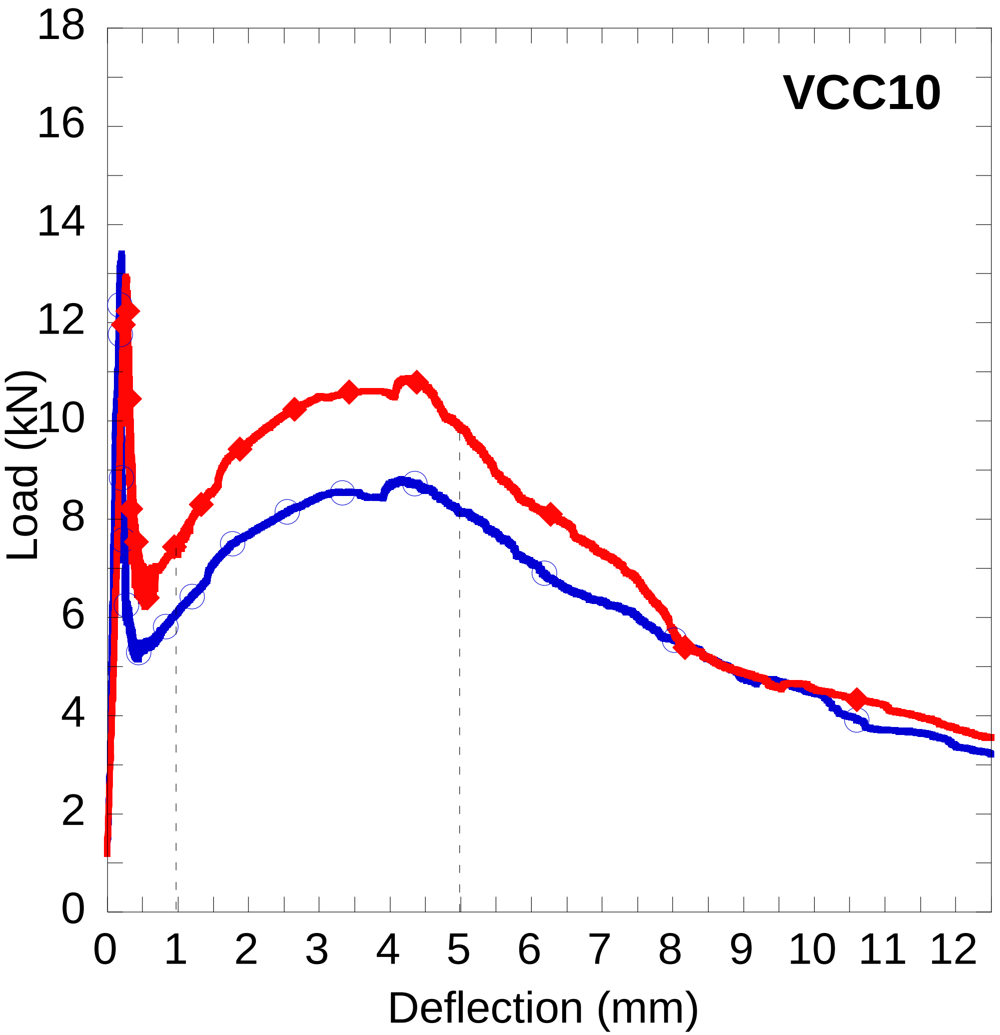
Fracture results of SCC10





Fracture results of VCC10



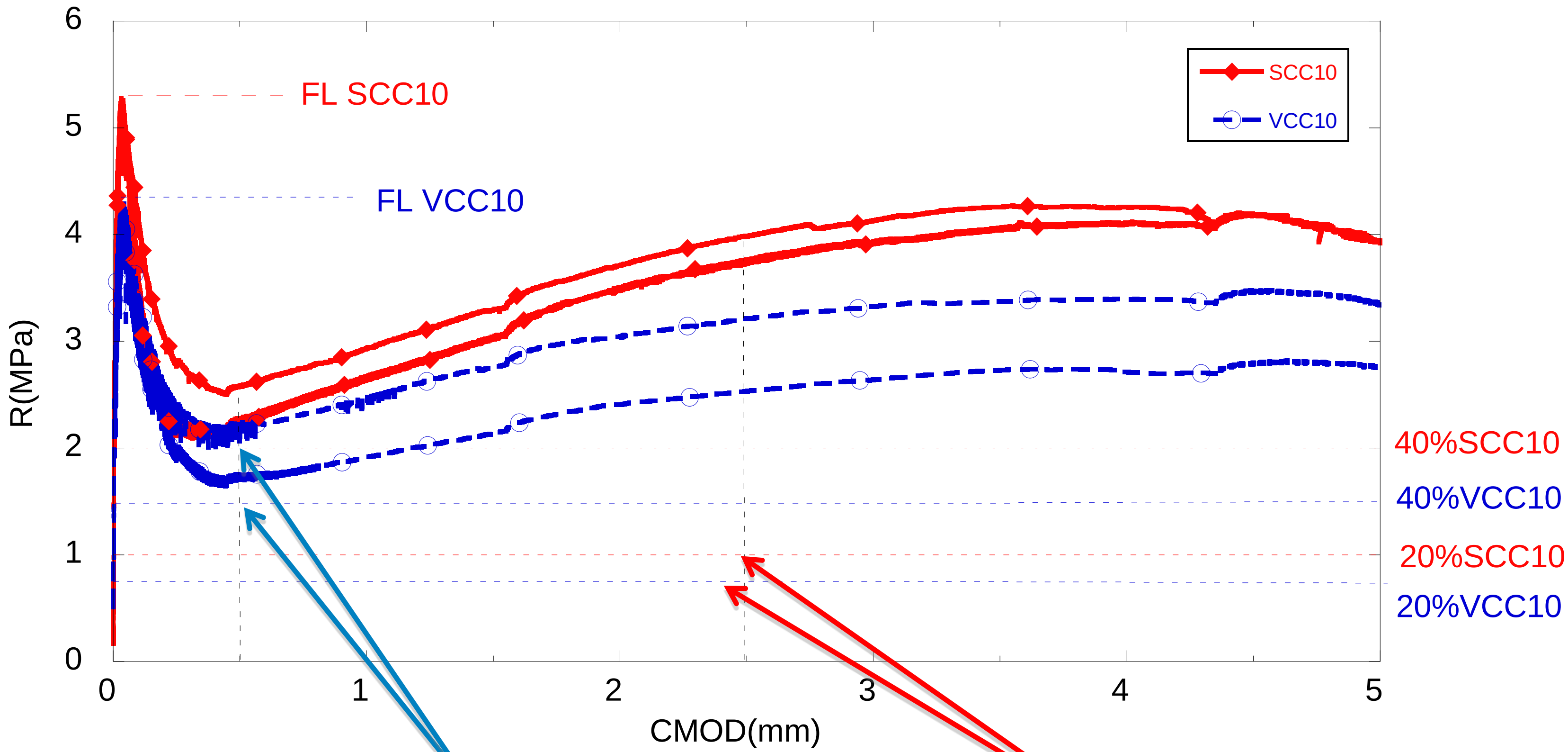


Fracture Energy

		G_f hasta 1 mm (c.v.)	G_f hasta 5mm (c.v.)	G_f hasta 12,5mm (c.v.)
SCC	(N/m)	152 (0,10)	-	-
VCC	(N/m)	153 (0,10)	-	-
SCC 10	(N/m)	454 (0,05)	2992 (0,04)	5420 (0,03)
VCC 10	(N/m)	377 (0,14)	2296 (0,15)	4510 (0,11)

Residual strengths

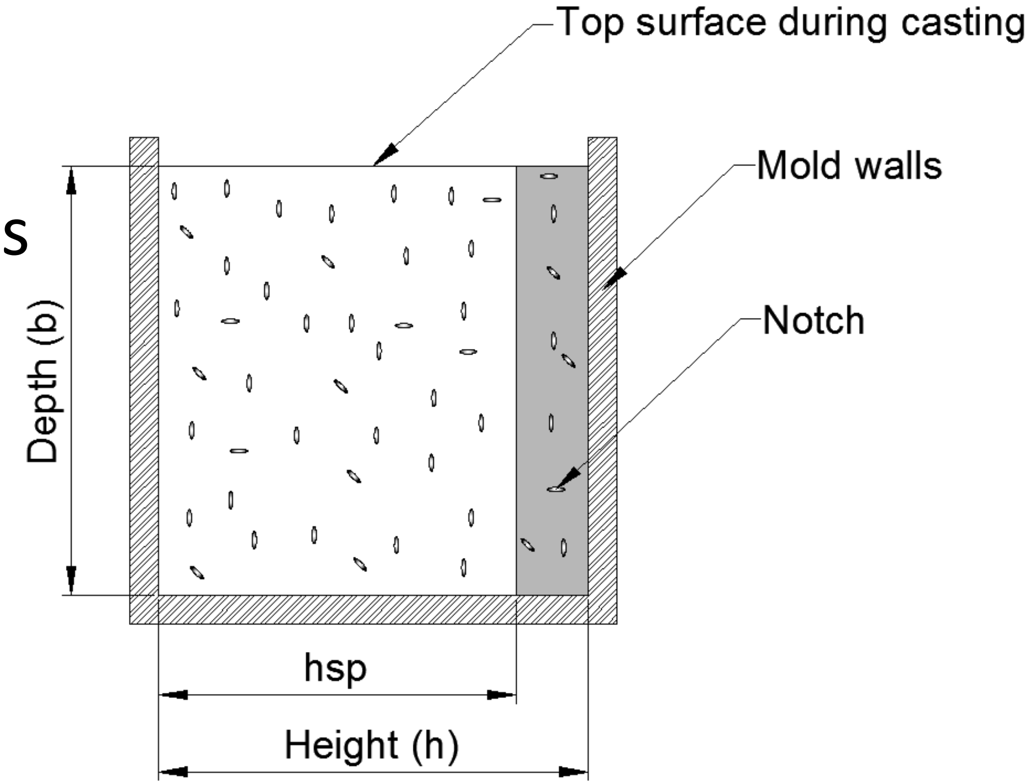
$f_{ct,j} = 3/2 \, F_j$

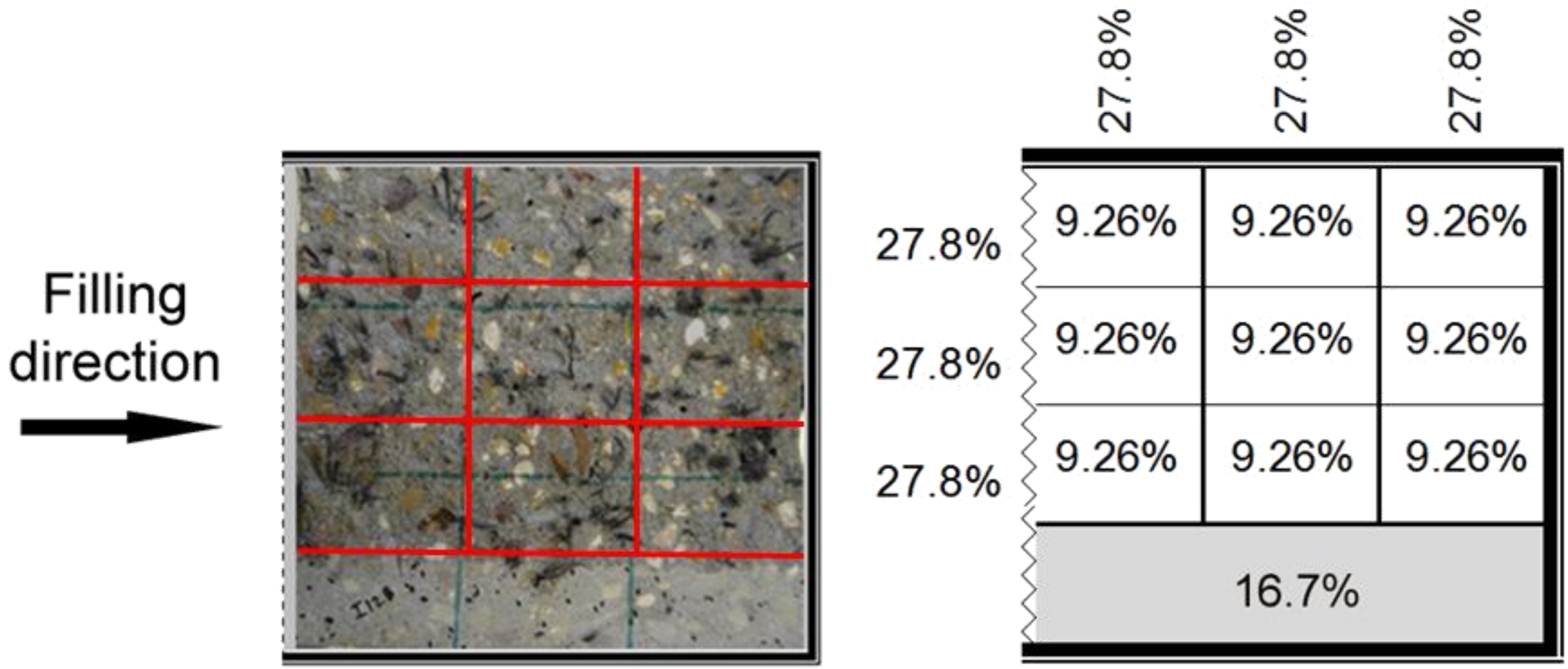


	$f_{ct,l}$ (MPa)	f_{R1}(MPa)	% $f_{ct,l}$	f_{R2} (MPa)	% $f_{ct,l}$	f_{R3} (MPa)	% $f_{ct,l}$	f_{R4}(MPa)	% $f_{ct,l}$
HAC10	5,22	2,41	46%	3,16	61%	3,87	74%	4,16	80%
HF10	4,21	1,98	47%	2,45	58%	2,87	68%	3,05	72%

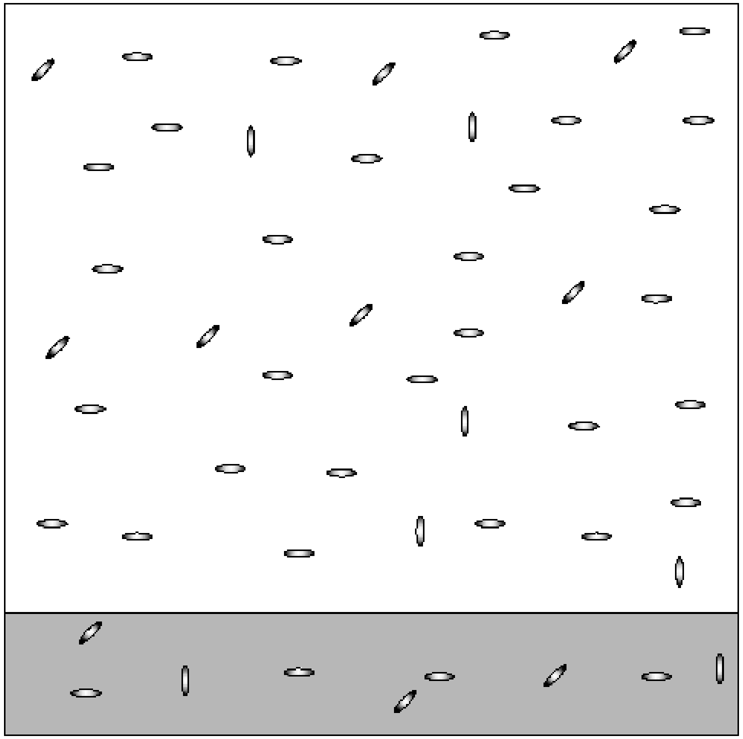
Fracture surface analyses

- ✓ Surfaces were eminently plane
- ✓ About 35% of the fibres had been pulled-out a




Filling direction
27.8%
27.8%
27.8%
27.8%
27.8%
27.8%
9.26%
9.26%
9.26%
9.26%
9.26%
9.26%
9.26%
9.26%
9.26%
16.7%

Fracture surface analyses



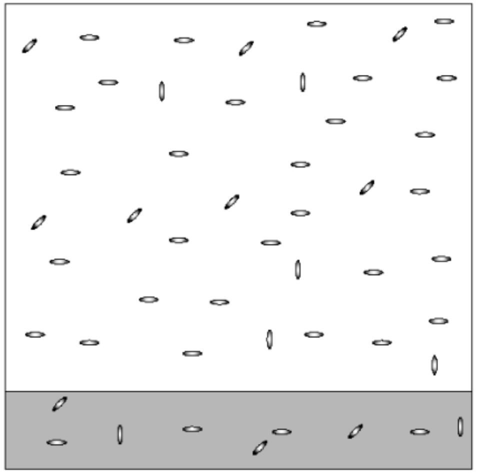
th = theoretical number of fibres crossing
Ac = fracture surface
A_f = fibre cross section

$th = Ac \cdot V_f / A_f = 372$
fibras

$\theta = n/th = n A_f / V_f A$

n = number of fibres actually counted
θ = Orientation factor

Fracture surface analyses



	# of fibres	c.v.	θ
SCC10	222	4,0%	0,60
VCC10	204	5,4%	0,55

SCC 10

	26,6%	23,8%	25,9%
25,6%	8,9%	7,3%	9,3%
25,9%	8,8%	8,0%	9,1%
24,9%	8,9%	8,5%	7,5%
Entalla	23,7%		

Medido

-3%	-21%	0%
-5%	-13%	-2%
-3%	-8%	-19%
42%		

Medido/ teórico

VCC 10

	24,0%	24,0%	28,9%
31,3%	9,8%	9,3%	12,3%
23,7%	8,8%	5,7%	9,3%
21,8%	5,5%	9,1%	7,3%
Entalla	27,6%		

Medido

5%	1%	33%
-5%	-39%	0%
-41%	-2%	-21%
66%		

Medido/ teórico

Contents

PFRC enhanced with small amount of steel-hooked fibres

- Polyolefin fibers properties

The physical and mechanical properties of fibers

Fiber type	Density (g/cm³)	Length (mm)	Eq. Diameter (mm)	Tensile strength (MPa)	Modulus of elasticity (GPa)	Fibers per kg	Surface structure	Anchorage
Polyolefin fiber	0.910	60	0.903	>500	> 9	27000	Rough	Bond
Steel-hooked fiber	7.850	35	0.550	1100	210	14500	Smooth	Hooked

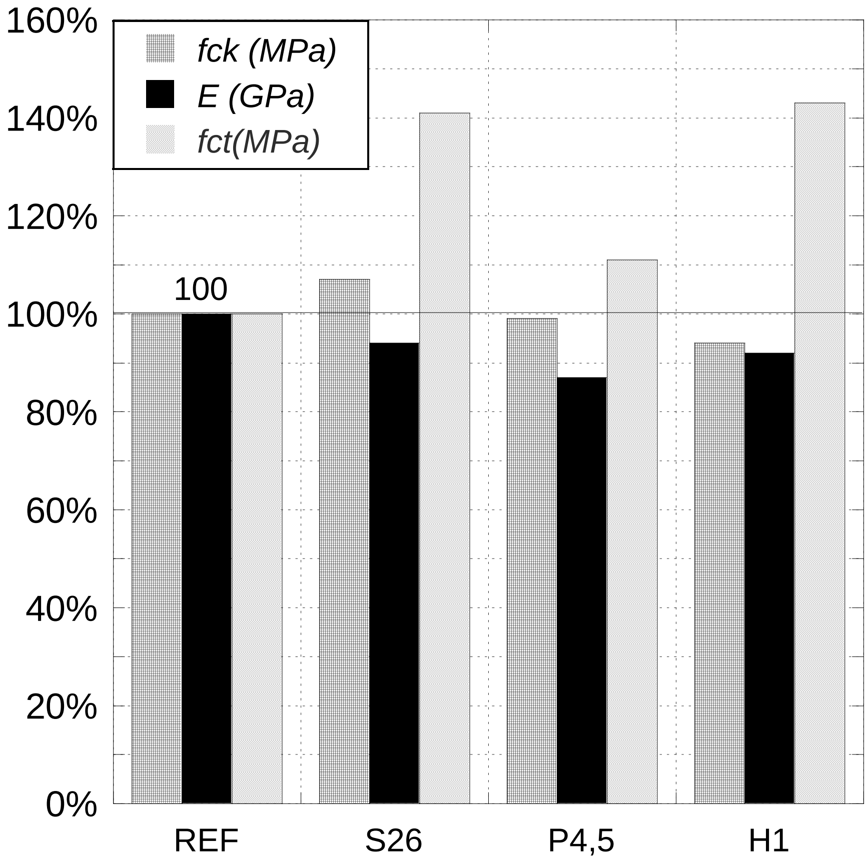
PFRC enhanced with small amount of steel-hooked fibres

Material	REF	S26	P4.5	H1
water/cement	0,5	0,5	0,5	0,5
Cement *(kg/m³)*	375	375	375	375
Limestone powder *(kg/m³)*	200	200	200	200
Water *(kg/m³)*	187,5	187,5	187,5	187,5
Sand *(kg/m³)*	918	918	918	918
Grit *(kg/m³)*	245	245	245	245
Gravel *(kg/m³)*	367	367	367	367
Steel fibres	-	26	-	26
Polyolefin fibres	-	-	4,5	4,5
Superplasticizer (%)	1,25	1,25	1,25	1,25

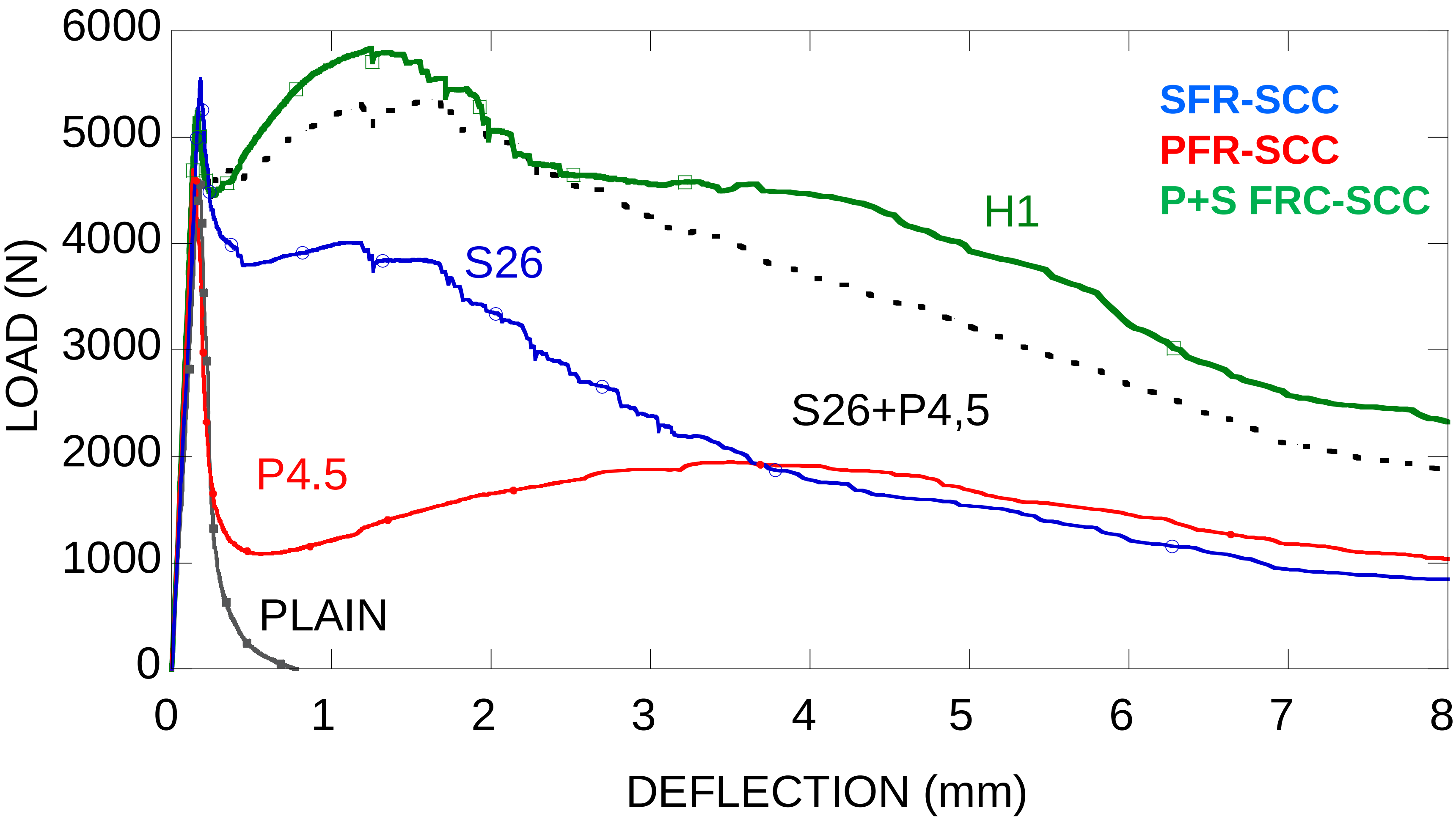
PFRC enhanced with small amount of steel-hooked fibres

Mechanical properties

	REF	S26	P4.5	H1
Módulo de elasticidad (GPa)	35,8	33,7	31,2	33,0
fck, 28 días (MPa)	39,0	41,7	38,5	36,5
fct indirecta (MPa)	3,80	5,30	4,20	5,41



SFR-SCC
PFR-SCC
P+S FRC-SCC

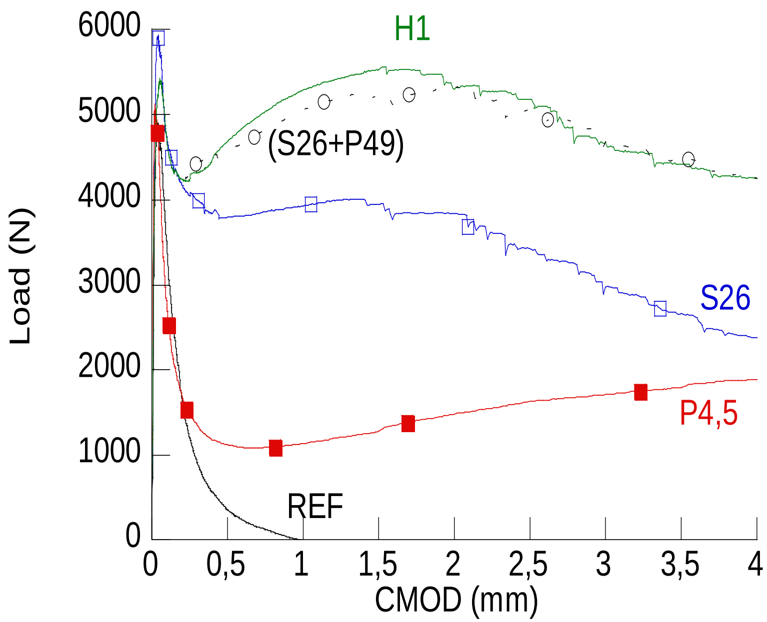

LOAD (N)
DEFLECTION (mm)
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
8
SFR-SCC
PFR-SCC
P+S FRC-SCC
H1
S26
S26+P4,5
P4.5
PLAIN

PFRC enhanced with small amount of steel-hooked fibres

Concrete	L_{PEAK} (N)	L_{MIN} (N)	$L_{R0.5}$ (N)	$L_{R1.5}$ (N)	$L_{R2.5}$ (N)	$L_{R3.5}$ (N)
REF	4970	-	-	-	-	-
S26	**5975**	**3733**	**3764**	**3943**	**3406**	**2689**
P4,5	**5655**	**1064**	**1131**	**1301**	**1640**	**1810**
H1	**5412**	**4454**	**4893**	**5827**	**5294**	**4627**

Concrete	Fracture Energy, G_F (N/m)		
	1mm	5mm	8mm
REF	130	-	-
S26	**570**	**2135**	**2621**
P4,5	**254**	**1292**	**1846**
H1	**709**	**3577**	**4931**

PFRC enhanced with small amount of steel-hooked fibres



Hormigón	R_{PEAK} (MPa)	$R_{R0.5}$ (MPa)	%	$R_{R2.5}$ (MPa)	%
REF	5,03	-		-	
S26	6,05	3,81	**63%**	3,45	**57%**
P4,5	5,73	1,15	**20%**	1,66	**29%**
H1	5,48	4,95	**90%**	5,36	**98%**

Hormigón reforzado con fibras de acero
Hormigón reforzado con fibras de poliolefina
Hormigón con ambas fibras

PFRC enhanced with small amount of steel-hooked fibres

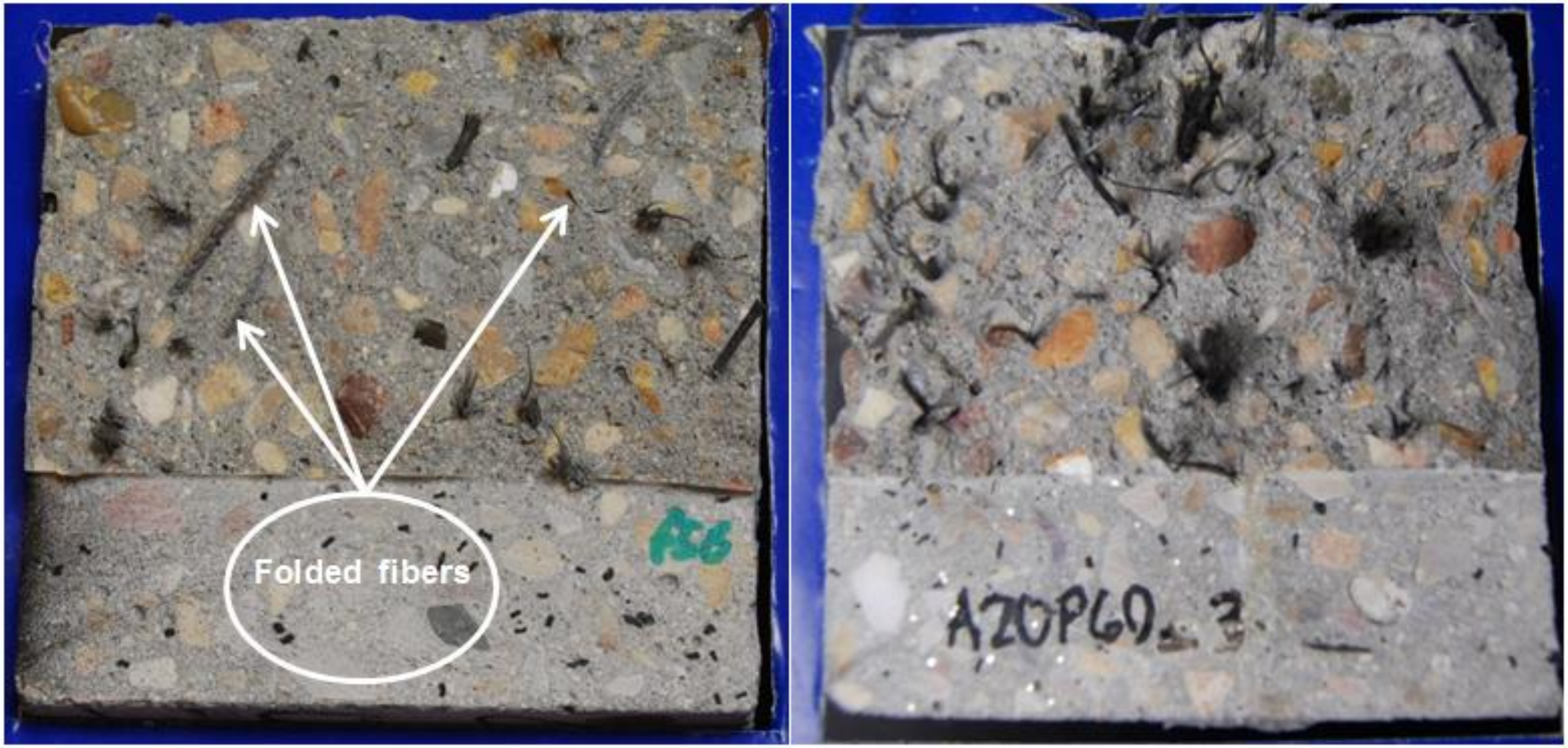
Residual strengths

Concrete	L_{PEAK} (N)	L_{MIN} (N)	$L_{R0.5}$ (N)	$L_{R1.5}$ (N)	$L_{R2.5}$ (N)	$L_{R3.5}$ (N)
REF	4970	-	-	-	-	-
S26	**5975**	**3733**	**3764**	**3943**	**3406**	**2689**
P4,5	**5655**	**1064**	**1131**	**1301**	**1640**	**1810**
H1	**5412**	**4454**	**4893**	**5827**	**5294**	**4627**

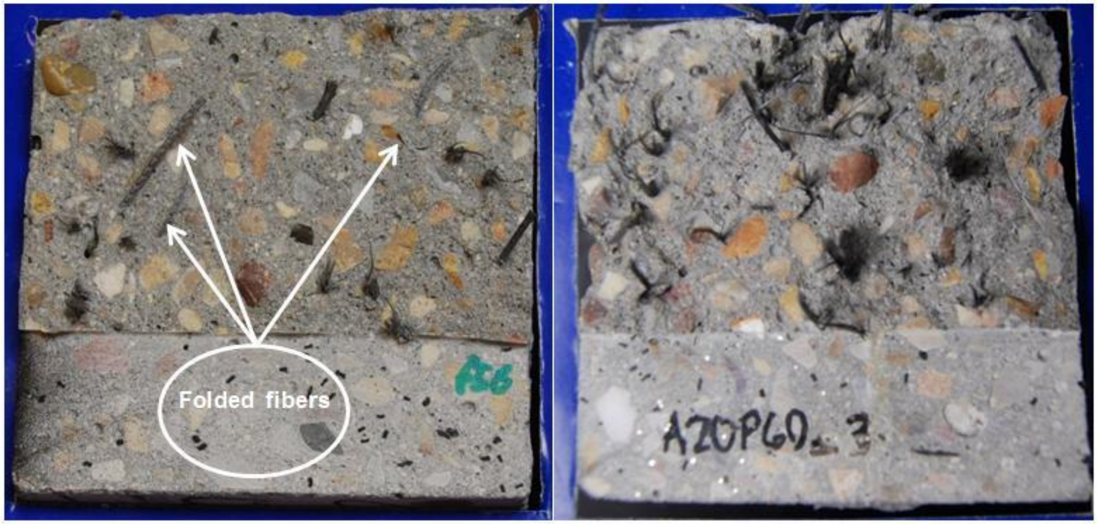
Concrete	Fracture Energy, G_F (N/m)		
	1mm	5mm	8mm
REF	130	-	-
S26	**570**	**2135**	**2621**
P4,5	**254**	**1292**	**1846**
H1	**709**	**3577**	**4931**

PFRC enhanced with small amount of steel-hooked fibres

Fracture surface analyses



PFRC enhanced with small amount of steel-hooked fibres



(a) (b)

PFRC enhanced with small amount of steel-hooked fibres

Fracture surface analyses

Concrete	th		Counted		c.v. (%)		θ	
	SF	PF	SF	PF	SF	PF	SF	PF
S26	139	-	94	-	14%	-	**0.68**	-
P49	-	74	-	45	-	13%	-	**0.61**
H1	139	74	104	47	4%	7%	**0.75**	**0.63**

SFR-SCC
PFR-SCC
P+S FRC-SCC

Contents

Most relevant conclusions

- Polyolefin fibres have a significant performance in fresh state allowing to produce PFR-SCC with volume fractions surpassing 1%
- Mechanical properties remained in similar values as compared to a plain SCC. For high polyolefin fibre content mixtures, compressive strength slightly decreased and tensile strength increased 30% compared with a control plain self-compacting concrete
- Fracture toughness and ductility improvements are quite reliable even for the medium polyolefin fiber content mixtures.

Most relevant conclusions

- With 10 kg/m³ of polyolefin fibers, the residual strengths exceeded the requirements of the EN-14651, RILEM- TC 162-TDF, Model Code and Spanish code for structural concrete EHE-08

- Comparing SCC and VCC, fibre distribution was improved in SCC while wall effect was higher in VCC

Most relevant conclusions

- The combination of stiff and heavy fibre with a low density flexible synthetic macro fibre showed an additional advantage that enhances the orientation of the polyolefin fibers.
- The steel fibers enhanced the alignment of the polyolefin fibers, tending to place both types of fibers with the preferential orientation of the flow of self-compacting concrete.
- This improving effect was observed on the fracture surface of the specimens that showed the same preferential orientation for both types of fibers and a more uniform distribution of the polyolefin fibers.

Future work

- Influence of the fibre legnth and placing conditions on the orientation and distribution of the fibres
- SEM analysis
- Pull-out behaviour of the polyolefin fibres
- Constitutive models and numerical simulations of the fracture behaviour of PFRC

Recent publications

- *On the mechanical properties and fracture behavior of polyolefin fiber-reinforced self-compacting concrete*, M.G. Alberti, A. Enfedaque, J.C. Gálvez, Construction and Building Materials, Volume 55, 31 March 2014, Pages 274-288, ISSN 0950-0618, http://dx.doi.org/10.1016/j.conbuildmat.2014.01.024.

- *Polyolefin fiber-reinforced concrete enhanced with steel-hooked fibers in low proportions*, M.G. Alberti, A. Enfedaque, J.C. Gálvez, M.F. Cánovas, I.R. Osorio, Materials & Design, 60, pp. 57-65, ISSN 0261-3069, http://dx.doi.org/10.1016/j.matdes.2014.03.050

- Comparison between polyolefin fibre reinforced vibrated conventional concrete and self-compacting concrete, *Construction & Building Materials,* Accepted, 2015; M. G. Alberti, A. Enfedaque y J. C. Gálvez; http://dx.doi.org/10.1016/j.conbuildmat.2015.03.007

Acknowledgements

- To Sika

- To Ministerio de Economía y Competitividad

TU 1404
COST ACTION

MUCHAS GRACIAS POR SU ATENCIÓN

Invited Speaker SESSION

Steinar Leivestad: CEN TC250

Willem S. Kroese: ConSensor - from idea to the market

Anneke Geyzen: *Horizon 2020 – Getting started (not authorized for publication)*

CEN TC250/SC2

Eurocde 2 - EN 1992

Service life design of concrete structures

COST TU 1404
Ljubljana

Steinar Leivestad
Standard Norge
2015-04-16

TC 250 Structural Eurocodes

Chairman: S Denton
Vice Chair: M Fardis
Secretary: T Wilkins [BSI]
CEN PM: G Ascensao

Management Group

Chairman: S Denton

Chairman's Advisory Panel(s)

TC 250 Coordination Group

Chairman: S Denton
Secretary: T Wilkins [BSI]

Horizontal Group Bridges
Convenor: P Croce

Horizontal Group Fire
Convenor: B Zhao

WG1 – Policy and guidelines
Convenor: J Moore

SC/WG for Existing Eurocodes

WG7 – EN 1990
Convenor: P Formichi
Secretary: V Meløysund [SN]

SC1 – EN 1991
Chairman: N Malakatas
Secretary: A Schleifer [DIN]

SC2 – EN 1992
Chairman: H Ganz
Secretary: A Schleifer [DIN]

SC3 – EN 1993
Chairman: U Kuhlmann
Secretary: S Kempa [DIN]

SC4 – EN 1994
Chairman: G Couchman
Secretary: B Borchert [BSI]

SC5 – EN 1995
Chairman: S Winter
Secretary: A Stenmark [SIS]

SC6 – EN 1996
Chairman: R Van der Pluijim
Secretary: P Rauh [DIN]

SC7 – EN 1997
Chairman: A Bond
Secretary: M Lurvink [NEN]

SC8 – EN 1998
Chairman: P, Bisch
Secretary: E Coelho [IPQ]

SC9 – EN 1999
Chairman: F Mazzolani
Secretary: R Saegrov [SN]

Other WG

WG2 – Existing Structures
Convenor: P Lüchinger [SNV]

WG3 – Structural Glass
Convenor: M Feldmann [DIN]

WG4 – Fibre reinforced polymer
Convenor: L Ascione [UNI]

WG5 – Membrane Structures
Convenor: M Mollaert [NBN]

WG6 – Robustness
Convenor: R Van der Pluijm [NEN]

We are challenged to simplify our standards

- We shall recognise that our profession is complex
  - We are safeguarding millions of people
  - We are safeguarding a major portion of the national wealth
  - We shall be cost effective and competitive, extra material for simplification is not *sustainable*
- Standards should be as simple as technically justified, not simpler
- Standards should use an effective language
  - Say things only once, and in the right place
  - Be on general principles not object focused
  - Say shall when you mean shall
  - Design and execution is a technical and not a SME matter (what is a SME shear force?)

Presentation in TC 250 Helsinki 2010 by SL

Ease of use is a notion, it can be "measured", but not with an answer with two solid lines under.

- It reflects the feeling of being “home”
- Finding the way to the information you need
- Feeling comfortable that there are nothing hidden somewhere that you can not find
- That things are not made more complicated than they actually are
- !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

PROPOSAL(S)

BT

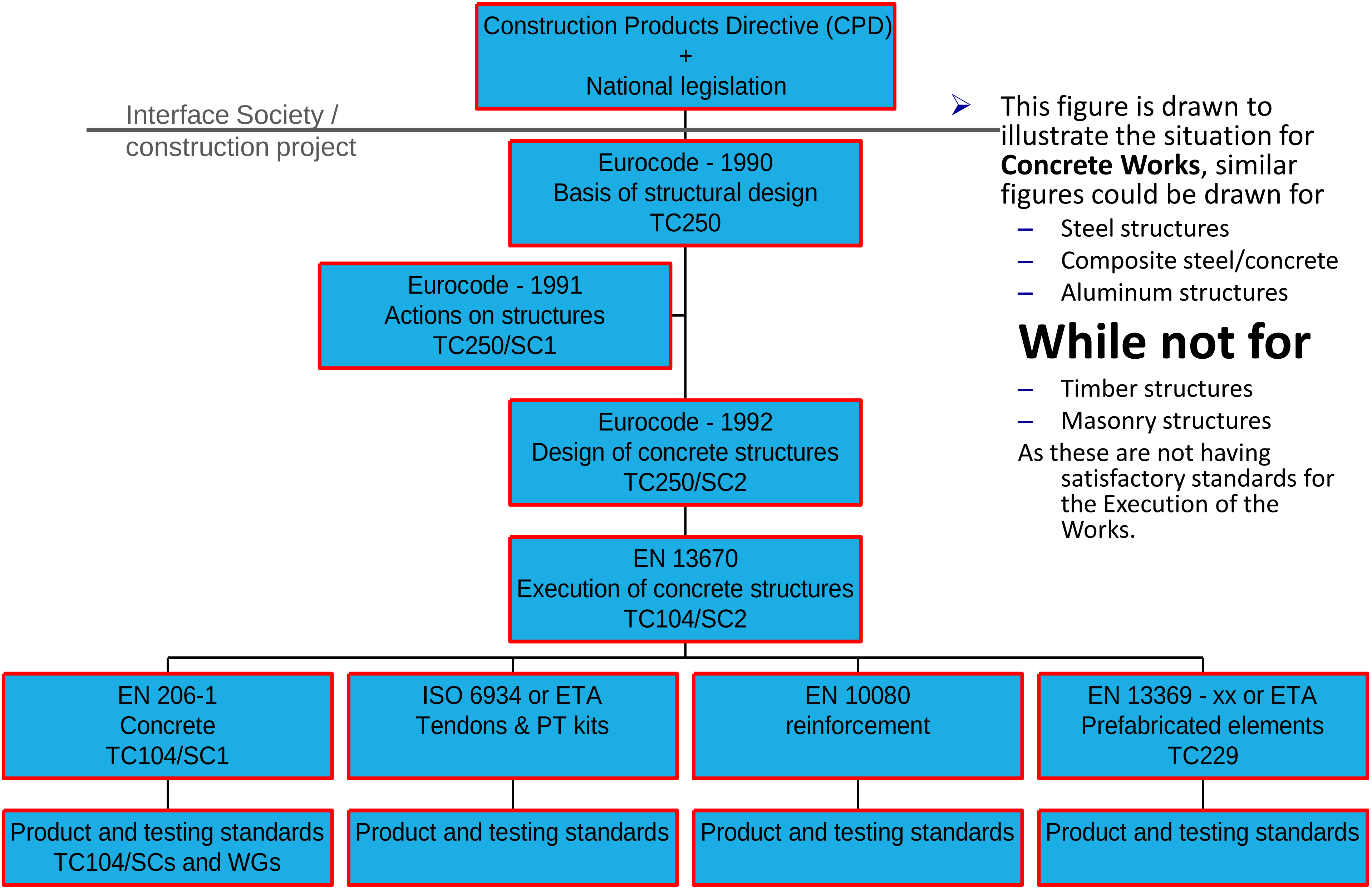
- noting
  - resolution BTS1 11/1992, BT 23/1992 and BT C2/2001 as given in Annex 1 to BT N 9545;
  - CEN/TC 250 Decision 329 as given in annex 2 to BT N 9545;
  - Mandate M/515 requirements for further development of the existing Eurocodes as well as development of new Eurocode parts;
  - the need for coordination and consistency between product TCs and CEN/TC 250 'Structural Eurocodes',
- decides
  - to confirm to CEN/TC 250 the overall responsibility for structural and geotechnical design rules for building and civil engineering;
  - that CEN/TCs (products, execution) should refer in their standards (when possible) to the relevant Eurocodes parts, when reference to structural and geotechnical design rules are needed;
  - that rules relating to structural and geotechnical design should only be included in standards under other CEN/TCs' responsibility following agreement with CEN/TC 250;
  - that, in cases where rules relating to structural and geotechnical design have been included in standards by other CEN/TCs, a mode of cooperation should be established with CEN/TC 250 to transpose design rules to the relevant Eurocode part where agreed or, as a minimum, eliminate any incompatibilities or ambiguities,
- invites
  - CEN/TC 250 to contact other CEN/TCs setting out their planned work programme and inviting the reconfirmation and/or establishment of effective liaisons between product TCs and CEN/TC 250 to support the implementation of this decision;
  - CEN/TC 250 to report to CEN/BT at least annually on the effectiveness of coordination with other CEN/TCs as well as the existing liaisons;
  - CEN/TCs (products, execution) having in their standards rules relating to structural and geotechnical design or developing rules relating to structural and geotechnical design to liaise closely with CEN/TC 250.

This decision is applicable as from: <result release date>

BT Resolution N9545

Approval 30
Abstain 3 with comments
AFNOR, DIN, Elot

System of European standards for WORKS



- This figure is drawn to illustrate the situation for **Concrete Works**, similar figures could be drawn for
  - Steel structures
  - Composite steel/concrete
  - Aluminum structures

While not for

- Timber structures
- Masonry structures

As these are not having satisfactory standards for the Execution of the Works.

WHO USE WHAT TECHNICAL STANDARD

Standard etc.	Designer	Constructor	Concrete producer	Material producer.
Building law and regulations	**PU**			
Interface between society and construction project				
EN 1990 Basis of design	**PU***			
EN 1991 Actions	**PU***			
EN 1992 Design of concrete	**PU***			
National Standards for quantity, cost and bidding	**PU***Interface Design/Constructor	**PU** Interface Design/Constructor		
EN 13670 Execution of concrete str., incl Execution spec EN's for special tasks, bored piles, diaphragm walls etc.	**PU** Interface Design/Constructor	**PU*** Interface Design/Constructor		
EN 206-1+ NA Concrete	**SU**	**PU** Interface Constructor/producer	**PU***Interface Constructor/producer	
EN for concrete constituents EN 12620 EN 197, NS 3086 EN 1080	**SU**	**SU**	PU Interface Producer/material	PU* Interface Producer/materialpro
EN for testing concrete EN 12350 Fresh concrete EN 12390 Hardend concrete	**SU**	**SU**	**PU***	**PU**
EN for testing constituents			**SU**	**PU***

PU* = Primary user, who the standard is "written for"
PU = Primary user, one who needs to know the standard in detail
SU = Secondary user, one who needs to be aware of the standard
Interface standard are standards that are used for communication between the parties who are both primary users (PU)

Standards shall fit into a system like a drawer in a chest of drawers

Standards shall fit into a system like a drawer in a chest of drawers

It is not for everybody to seize their own drawers, that gives both overlap and uncovered areas,

autonomous committees and

Revision of Eurocode 2.

CEN TC250/SC2
Chair : H.R. Ganz
Technical Secretary : A. Schleifer

WG1 – Coordination and Editorial Panel
Convenor : S. Leivestad
Technical Secretary : F. Fingerloos
Administrative secretary : A. Schleifer

TG1 K. Zilch	TG2 M. Di Prisco	TG3 G. Dieteren	TG4 J. Hegger	TG5 F. Robert	TG6 S. Wijte	TG7 H. Müller	TG8 P. Jackson	TG9 G. Mancini	TG10 S. Leivestad
Strengthening and reinforcing with fibre reinforced polymers	Fibre reinforced concrete	Existing Structures	Shear, punching torsion	Fire	Structural Analysis	Time depend-ant effects	Fatigue design	Bridges	Durability SLD
Scope: General + Annex	Scope: §13 or Annex	Scope: §general + Annex Intact and deterio-rated	Scope: §6.2 + Strut & tie	Scope: Part 2	Scope: §5 + Annex	Scope: Annex Shrinkage Creep Relaxation Strength Load effect	Scope: §6.8 + Annex	Scope: §General + Annex	Scope: § 4 + Annex

Proposed structure of Eurocode 2

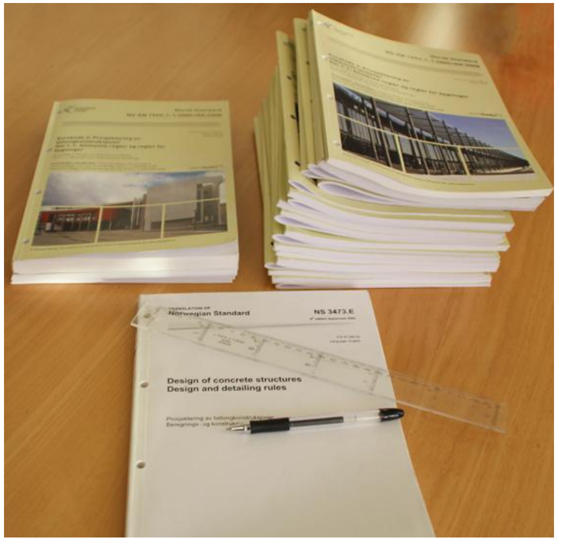
Present version of Eurocode 2 consists of four parts and roughly 450 pages. In the original plans Eurocode 2 was intended with eleven parts and would probably been in the order of 1000 pages.

In the future it would be considered very helpful if Eurocode 2 could be further condensed to consist of only two parts;

Part 1 *General rules - rules for buildings, bridges and civil engineering structures*

Part 2 *Structural fire design*

And a volume of in total less than 350 pages



Chapters in main part

Ch.	Title	Items for revision	Responsible	Pages today/aim
General for all revision is; CEN rules, simplification by removing unnecessary text, use tables where helpful, say things only once and in the right place, use Annexes to organise only the essentials in the main text.				
1	General	Review terms and symbols	WG1	7 / =
2	Basis of design	Review, in particular object rules	WG1	6 / =
3	Materials	Move info for t≠28 to Annex Introduce fibres, FRP, stainless steel	WG1 + TG7 + TG1 + TG6	20 / -
4	Durability (and cover to reinforcement)	Introduce exposure resistance classes	TG10/JWG + WG1	6 / =
5	Structural Analysis	Review, include ref to Annex on non-linear analyses	TG6 + WG1	30 / -
6	Ultimate limit states (ULS)	Review shear and punching incl. pull out cone, extend fatigue	WG1 + TG1 TG4 + TG7	35 / =
7	Serviceability limit states (SLS)	Simplify simple method for crack-control and minimum reinforcement	WG1 + TG8	13 / -
8	Detailing of reinforcement (and prestressing tendons)	Review, simplify detailing rules where possible, incl. added grouted bars.	WG1	21 / =
9	Detailing of members and particular rules *for various types of structures*	Review and extend rules to apply for all minimum reinforcement.	WG1	20 / =
10	Additional rules for precast concrete elements and structures	Review, remove unnecessary text	WG1 + JWG-TC229	13 / -
11	Lightweight aggregated concrete structures	Review, consider if text can be transferred to Ch. 3	WG1	8 / -
12	Plain and lightly reinforced structures	Review, remove unnecessary text	WG1	6 / -
13	Steel fibres reinforced	Consider chapter or Annex.	TG2 + WG1	0 / 10

Annexes

Annex	Title (tentative)	Responsible	Source doc	Pages (tentative)
A	Modification to design parameters for concrete and reinforcement (material factors and material properties etc.)	WG1	EC2-1	2
B	Time dependent effects (shrinkage, creep, relaxation, strength development etc.)	TG6	MC2010	5
C	Durability and service life design of concrete structures, advanced methods	TG10 JWG 250/104	New + ISO	5
D	Early age thermo-mechanical design	TG7	Nordic	3
E	Fatigue design of structures, including equivalent stress design for bridges	TG8	MC2010	5-10
F	Non-linear analyses procedures and safety format	TG6	Fib	2
G	Design for in-plane stress conditions, shell elements	WG1	EC2-2	4
H	Design of structures for tightness against water leakages etc.	WG1	EC2-3	4
I	Assessment of resistance of existing concrete structures (intact and deteriorated)	TG3	Fib + Swiss	5-10
J	Strengthening of existing concrete structures with FRP	TG1	Fib + WG4	5-10
K	Bridges, particular design conditions, discontinuity regions, stay cables, extradosed cables, external prestressing etc.	TG9	EC2-2	5
§13/L	Fibres reinforced concrete	TG2	MC2010	5-10

A JWG was established in 2010 with the following representation for the two Sub-Committees including a representative for CEN TC 229, in addition the JWG has established an Ad-hoc Group of experts for help in calibrating and establishing numerical values;

JWG		**Ad-hoc Group**	
Name	**Representing**	**Name**	**Country**
Breitenbücher, Rolf	TC104/SC1	Andrade, Carmen	Spain
Cangiano, Stefano[*]	TC104/SC1	Baroghel-Bouny, Veronique	France
Delort, Michel[*]	TC104 (TC51)	Gehlen, Christoph	Germany
Georgescu, Dan	TC250/SC2	Greve-Dierfeld, Stefanie von	Germany
Gijsbers, Jan	TC250/SC2	Harrison, Tom	UK
Harrison, Tom	TC104/SC1	Helland, Steinar	Norway
Helland, Steinar	TC104/SC1	Leivestad, Steinar - Convenor	Norway
Leivestad, Steinar -Convenor	-		
Lopez, David I	TC250/SC2		
Mancini, Giuseppe	TC250/SC2		
Rougeau, Patrick	TC229		

[*] TC104 has agreed to supplement their participation by taking the following Decision

DECISION 431 by CEN/TC 104/SC 1 (Vienna 7)
Subject: Durability design concept

CEN/TC 104/SC 1 welcomes the willingness of CEN/TC 51 and CEN/TC 51 - CEN/TC 104/JWG 12 to participate in the development of the durability design concept and decides to appoint **Stefano Cangiano** and **Michel Delort** to CEN/TC 250/SC2 - CEN/TC 104/SC 1/JWG “Durability Design”.

The decision was taken by unanimity.

EN 1990 Basis of design of structures

1.5.2.8
design working life

assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary

2.3 Design working life

(1) The design working life should be specified.

Proposed new text in the revision of EN 1990

(1)P The design working life shall be specified, and be the basis for appropriate items including the durability design and the basis for sustainability

NOTE Indicative categories are given in Table 2.1. The values given in Table 2.1 may also be used for determining time-dependent performance (*e.g.* fatigue-related calculations). See also Annex A.

Table 2.1 - Indicative design working life

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures (1)
2	10 to 25	Replaceable structural parts, e.g. gantry girders, bearings
3	15 to 30	Agricultural and similar structures
4	50	Building structures and other common structures
5	100	Monumental building structures, bridges, and other civil engineering structures
(1) Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.		

2.4 Durability (EN 1990 cont.)

(1)P The structure shall be designed such that deterioration over its design working life does not impair the performance of the structure below that intended, having due regard to its environment and the anticipated level of maintenance.

Proposed new note in the revision of EN 1990;
NOTE Durability is an essential parameter when assessing sustainability, durability of structures are however a designed property and not a tested property like for many construction products.

(2) In order to achieve an adequately durable structure, the following should be taken into account :

–the intended or foreseeable use of the structure ;
–the required design criteria ;
–the expected environmental conditions ;
–the composition, properties and performance of the materials and products ;
–the properties of the soil ;
–the choice of the structural system ;
–the shape of members and the structural detailing ;
–the quality of workmanship, and the level of control ;
–the particular protective measures ;
–the intended maintenance during the design working life.

NOTE The relevant EN 1992 to EN 1999 specify appropriate measures to reduce deterioration.

(3)P The environmental conditions shall be identified at the design stage so that their significance can be assessed in relation to durability and adequate provisions can be made for protection of the materials used in the structure.

System for design for durability of concrete structures in EN 1992 and EN 206

Illustration of system

Structure, consider exposure conditions for various members;
- under ground
- external
- internal

etc.

↓

Exposure Classes for various members;
EC2 to cover basis for selection

↓

Exposure resistance classes for various members
EN206 to define the classes and specify their composition
EC2 to give basis for selection among classes

↓

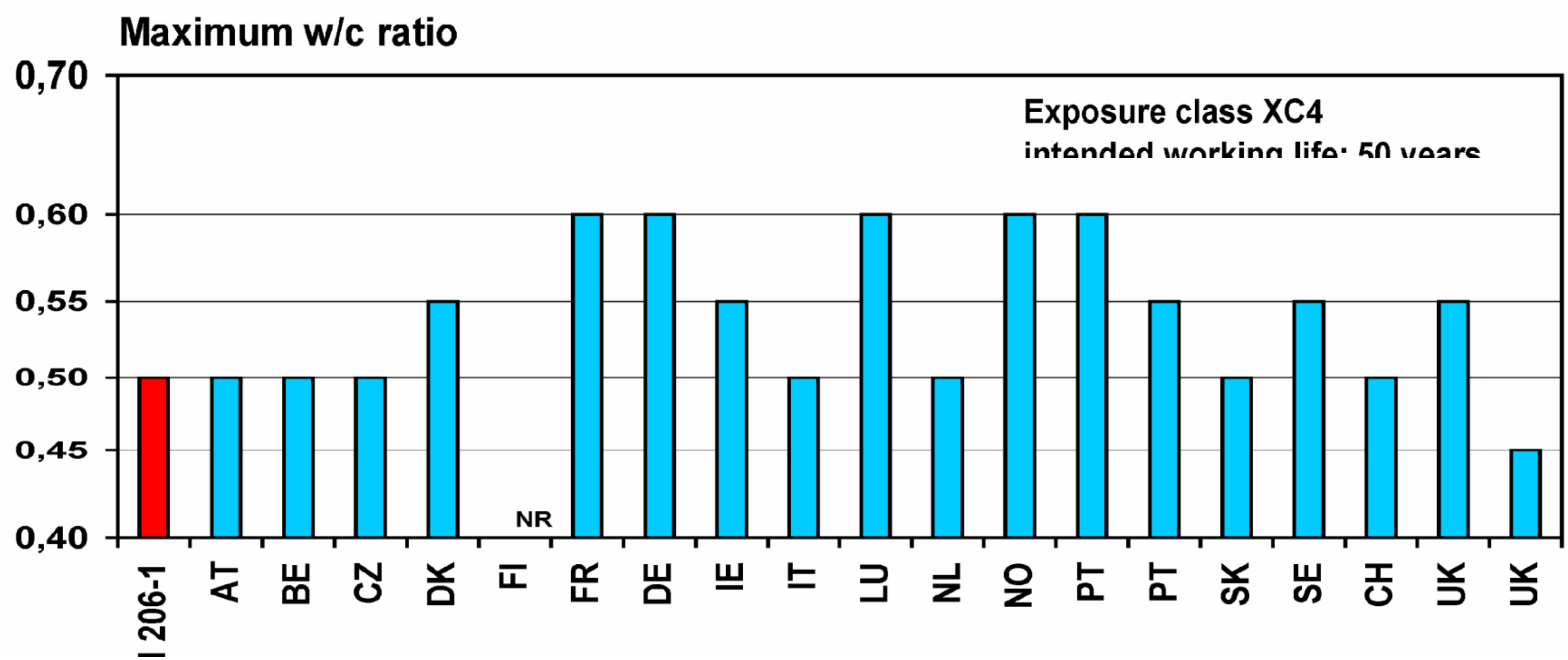
Concrete cover
EC2 to give requirements

↓

Execution specification, drawings
EC2/EN13670

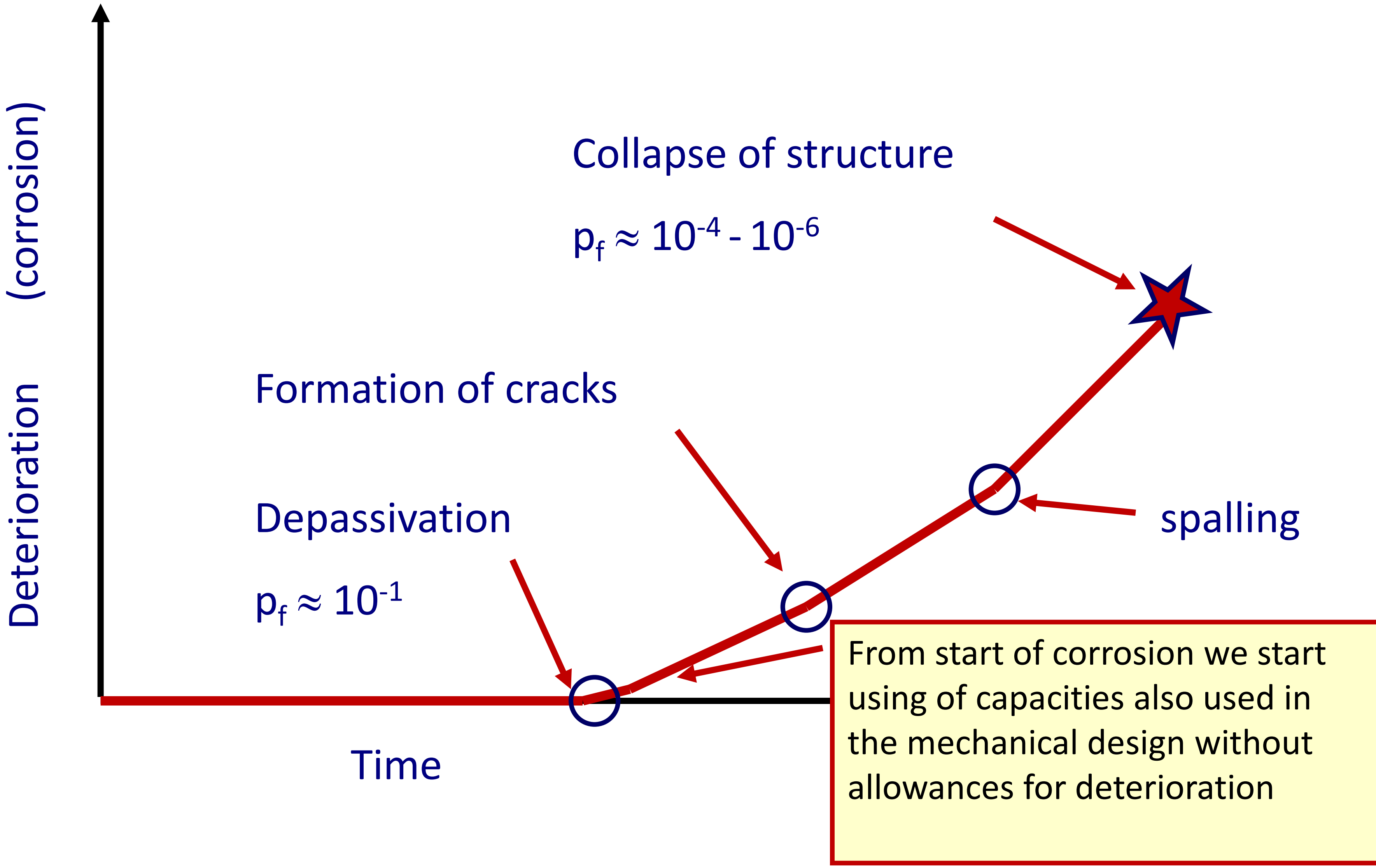
CEN TR

comparison of w/c-ratio for Exposure class XC4



Various Limit States – corresponding reliabilty

Example: corrosion of rebars



Two examples showing;

Deemed-to-satisfy requirements in Europe

(50 year service life)

Range of XC3 (carbonation, moderate moisture)

provisions for Portland Cement, CEM I

UK → w/c < 0.55 and 25 mm minimum cover

DE → w/c < 0.65 and 20 mm minimum cover

They can not achieve the same durability,

have they intended the same?

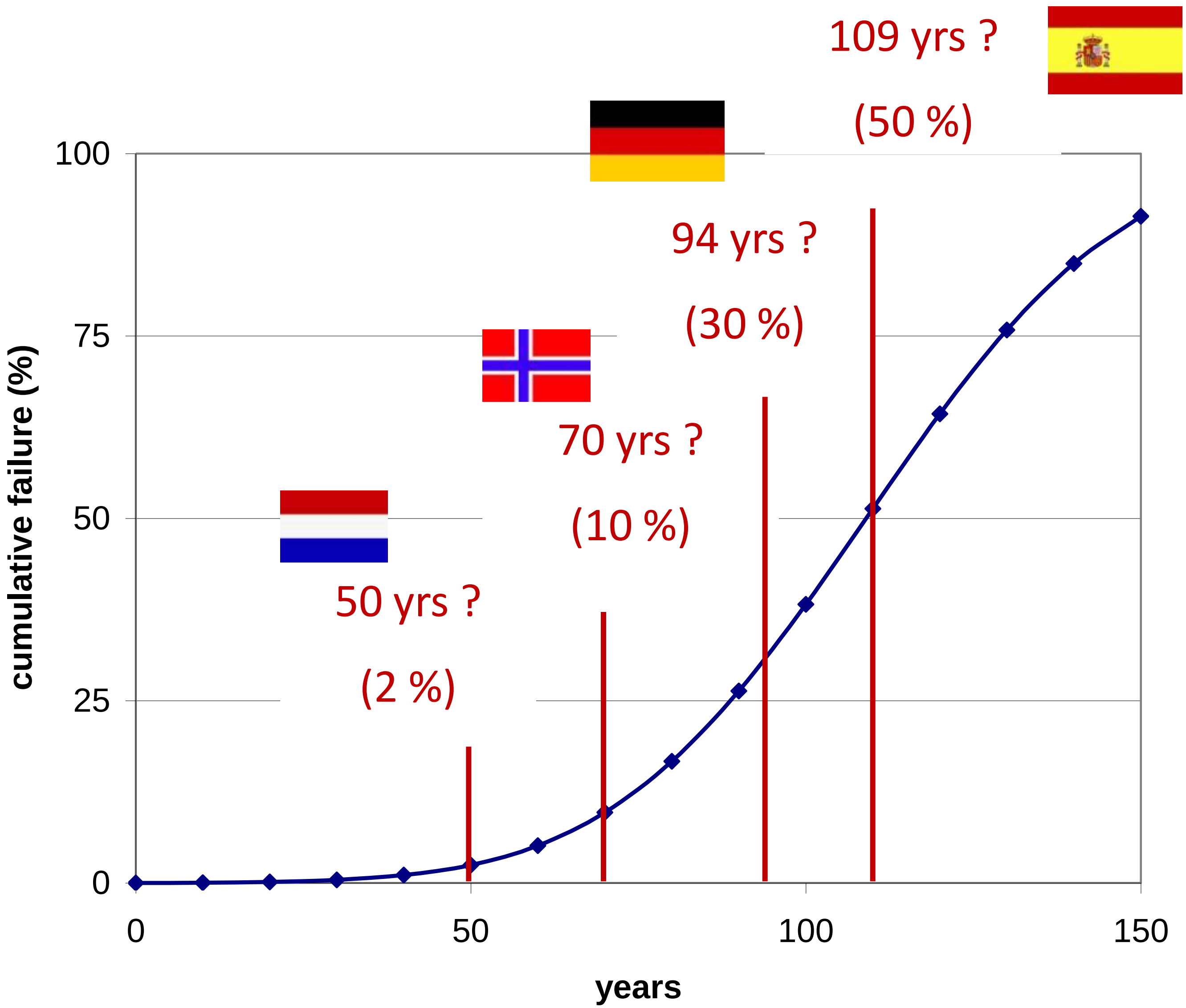
Range of XS2 (submerged in sea-water)

provisions for CEM I

DE → w/c < 0.50 and 40 mm minimum cover

NO → w/c < 0.40 (+ silica fume) and 40 mm minimum cover

What is the service life of this structure ??



Example:

Depassivation of reinforcement

[The probabilities are not given as explicit values (except for Norway) but are information obtained when asking national experts from these countries and demonstrates that there is not a common understanding of what durability actually implies across Europa]

Our ambition is to;

Develop a well coordinated system for durability design between;
Eurocode 2 Design
EN 13670 Execution
EN 206 Concrete material

Establish a system that is related to performance and that can serve as basis for achieving a consistent reliability with respect to service life prediction.

Define end of service life, depassivation
Define adequate performance, extent of depassivation etc.

Find a format that is both scientific, analytic and easy to apply in practice.

Table 1 Illustration of a system of resistance classes

Corrosion of reinforcement						Deterioration of concrete			
Carbonation Resistance Class			Chloride Resistance Class			Freeze/thaw Resistance Class		Chemical Aggressiveness Class	
Low	Medi-um	High	Low	Medi-um	High	Medium	High	Medium	High

Exposure resistance classes system and definitions

System

Corrosion of reinforcement						Deterioration of concrete			
Carbonation Resistance Class			**Chloride Resistance Class**			**Freeze/thaw Resistance Class**		**Chemical Aggressiveness Class**	
Low	Medi-um	High	Low	Medi-um	High	Medium	High	Medium	High

Definitions

Corrosion of reinforcement						Deterioration of concrete			
Carbonation Resistance Class			**Chloride Resistance Class**			**Freeze/thaw Resistance Class**		**Chemical Aggressiveness Class** (for later)	
RC (Low)	**RC** (Medi-um)	**RC** (High)	**RSD** (Low)	**RSD** (Medi-um)	**RSD** (High)	**RF** (Medium)	**RF** (High)	**RCA** (Medium)	**RCA** (High)
Definition of class is 50-years of exposure to XC3 (Rh 65%) with 10%-probability of carbonation front exceeding (mm)			Definition of class is 50-years of exposure to XS2, with 10%-probability of chloride concentration exceeding 0,5% at depth (mm)			Definition of class is 50-years of exposure to XF4, with 10%-probability of scaling loss exceeding (kg/m^2)		Definition of class is 50-years of exposure to XA3, ground water with SO^2_4 6000mg/l and 10%-probability of loss exceeding (g/m^2)[??]	
40	30	20	75	60	45	10	2	?	?

Exposure resistance classes, technical requirements and deemed to satisfy rules for EN 206 – a wide approach

Classes	Carbonation resistance class			Chloride resistance class			Frost resistance class	
	RC40 **RCL**	**RC30** **RCM**	**RC20** **RCH**	**RSD75** **RSDL**	**RSD60** **RSDM**	**RSD45** **RSDH**	**RF10**	**RF2**
Definition of class depth of front after 50 years	XC3 < 40mm	XC3 < 30mm	XC3 < 20mm	XS2 < 75mm	XS2 < 60mm	XS2 < 45mm	XF4 Scaling loss < 10(kg/m^2)	XF4 Scaling loss < 2(kg/m^2)
Accepted accelerated test condition and interpretation/use	EN XXX[1]	EN XXX[1]	EN XXX[1]	EN YYY[2]	EN YYY[2]	EN YYY[2]	EN ZZZ[3]	EN ZZZ[3]
Deemed to satisfy								
CEM I fly ash silica slagg	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = Air = n%	w/c = w/(c +kp) = Air = nn%
CEM II fly ash silica slagg	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = Air = n%	w/c = w/(c +kp) = Air = n%
CEM III fly ash silica slagg	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = w/(c +kp) = w/(c +kp) =	w/c = w/(c +kp) = Air = n%	w/c = w/(c +kp) = Air = n%
Deemed to satisfy Binders, additions								

1, 2 and 3) Consider the applicability of existing EN standards and Technical Specifications developed in TC104, and their need for supplementing rules on interpretations and application. EN 13295 and TS 12390-9, TS 12390-10, TS 12390-11,TS 12390-12

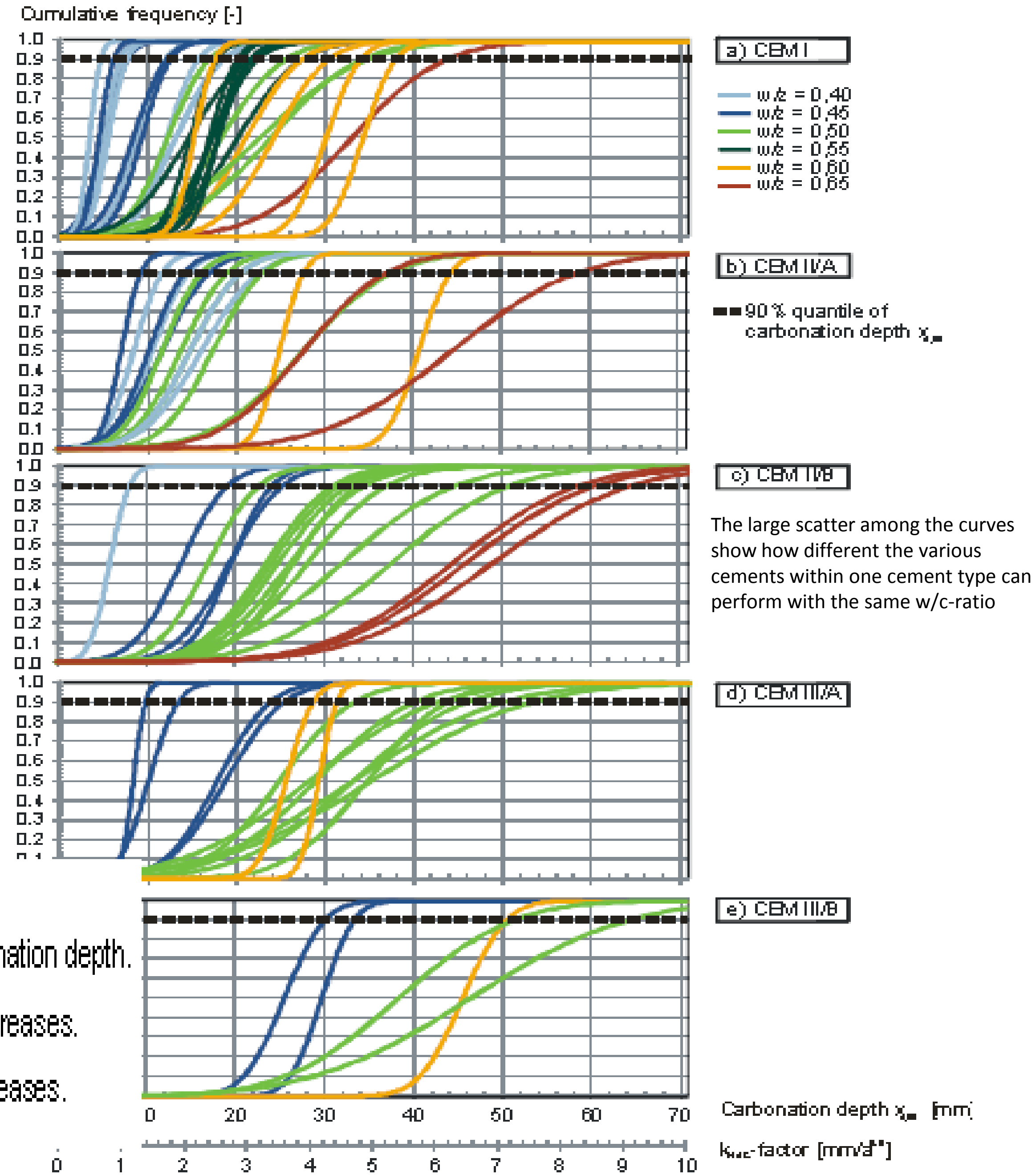
3.2 Grouping material with similar behavior (b)

3.2.1 Suggestions for discretization

Discrete steps for the clinker content and w/c-ratio shall be define material compositions with similar behavior. As a starting point the foll are considered, c. p. table 1.

Table 1: Discretization sheme

Clinker content	Related type of cement	w/c-ra
[wt.-%/c]	[-]	[-]
100 - 95	CEM I	0.40 -
84 - 80	CEM II/A	Withir
79 - 65	CEM II/B	Δw/c
64 - 35	CEM III/A, CEM II/X	
34 - 20	CEM III/B, CEM II/X	



The large scatter among the curves show how different the various cements within one cement type can perform with the same w/c-ratio

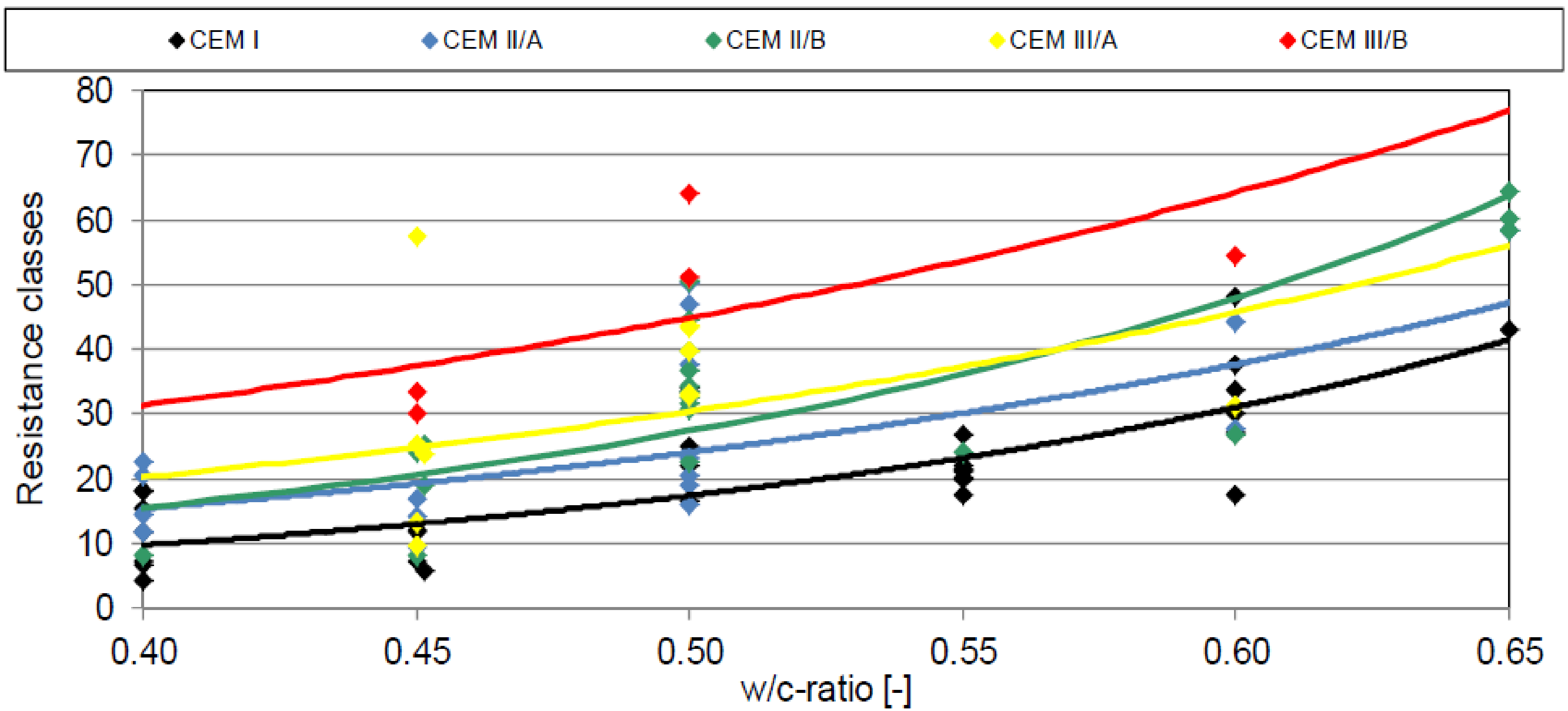
Figure 3: Distribution function of carbonation depths after 50 years $x_{c,50}$ respectively k_{NAC}-factor

To summarize, from figure 3 it can be concluded, that:

- the lower the clinker content, the higher the carbonation depth.
- with increasing w/c-ratio the carbonation depth increases.
- with increasing carbonation depth, the scatter increases.

Dependency between type of cement, w/c-ratio and resistance class

Additionally, the 90% fractile value of each concrete composition (crossing points of frequency function with the dotted line) is plotted versus the w/c-ratio in figure 4 above natural carbonation. Furthermore, results from accelerated carbonation, transferred in natural carbonation are plotted (below). For each group of types of cement from table 1 an exponential function may be fitted.



PROPOSAL FOR TEXT IN EN 206

4.2 Exposure resistance classes related to environmental actions

(1) Where concrete is classified with respect to durability by its exposure resistance the classes and definitions given in Table 2 apply.

Table 2 Definition of exposure resistance classes

Corrosion of reinforcement						**Deterioration of concrete**			
Carbonation Resistance Class			**Chloride Resistance Class**			**Freeze/thaw Resistance Class**		**Chemical Aggressiveness Class** (for later)	
RC40 (Low)	**RC30** (Medi-um)	**RC20** (High)	**RSD75** (Low)	**RSD60** (Medi-um)	**RSD45** (High)	**RF10** (Medium)	**RF2** (High)	**RCA** (Medium)	**RCA** (High)
Definition of class is 50-years of exposure to XC3 (Rh 65%) with 10%-probability of carbonation front exceeding (mm) NOTE;			Definition of class is 50-years of exposure to XS2, with 10%-probability of chloride concentration exceeding 0,5% at depth (mm)			Definition of class is 50-years of exposure to XF4, with 10%-probability of scaling loss exceeding (kg/m^2) *or more probably it should be given in loss after N-cyles tested according to EN ZZZ*		*Definition of class is 50-years of exposure to XA3, ground water with SO$^2_4$ 6000mg/l and 10%-probability of loss exceeding (g/m^2)[??]*	
40	30	20	75	60	45	10	2	?	?

NOTE;
Low resistance - high ingress
High resistance - low ingress

4.2 Exposure resistance classes, continued

(2) Concrete can be documented for the various classes in Table 2 by testing in accordance with the listed testing standards and with the limiting values given in Table 3.

Table 3 Exposure resistance classes, limiting values and applicable test standards

	Carbonation resistance class RC				**Chloride resistance class RSD**			**Frost resistance class RF**	
	RC20	**RC30**	**RC40**	**RCX0**[1]	**RSD45**	**RSD60**	**RSD75**	**RF2**	**RF10**
Limiting value, estimated after 50 years (mm) or kg/m^2	20	30	40	-	45	60	75	2	10
Classification standard	EN xxx	EN xxx	EN xxx	EN xxx	EN yyy	EN yyy	EN yyy	EN zzz	EN zzz

[1] Class RCX0 shall only be allowed in exposure class X0

(3) Concrete may also as an alternative to testing according to (2) be documented by applying the deemed to satisfy values in Annex F for the various cement/binders, water/binder ratios and minimum binder content.

PROPOSAL EN 206 Annex F

Table F.1 Exposure resistance classes; deemed to satisfy values for various binder *compositions* (example, preliminary values)

Tentative - Preliminary values	**Carbonation resistance class RC**				**Chloride resistance class RSD**			**Frost resistance class RF**	
	RC20	**RC30**	**RC40**	**RCX0[1]**	**RSD45**	**RSD60**	**RSD75**	**RF2**	**RF10**
Cement type or equivalent binder combination	Maximum w/b-ratio b is the sum of cement and additions in the concrete, within the limits defining the cements according to EN 197-1								
CEM I	0,55	0,60	0,65	0,90	NA	NA	0,45[2]	0,40	0,50
CEM II-A	0,45	0,55	0,65	0,90	0,40	0,50	0,60		
CEM II-B	0,40	0,50	0,60	0,75	0,40	0,50	0,60		
CEM III-A	NA	0,45	0,55	0,75	?	?	?		
CEM III-B	NA	NA	0,45	0,65	0,38	0,45	0,55		
Minimum binder content (kg/m^3)	280	280	280	240	280	280	280		
Minimum air entrainment								4%	

[1] Class RCX0 shall only be allowed in exposure class X0

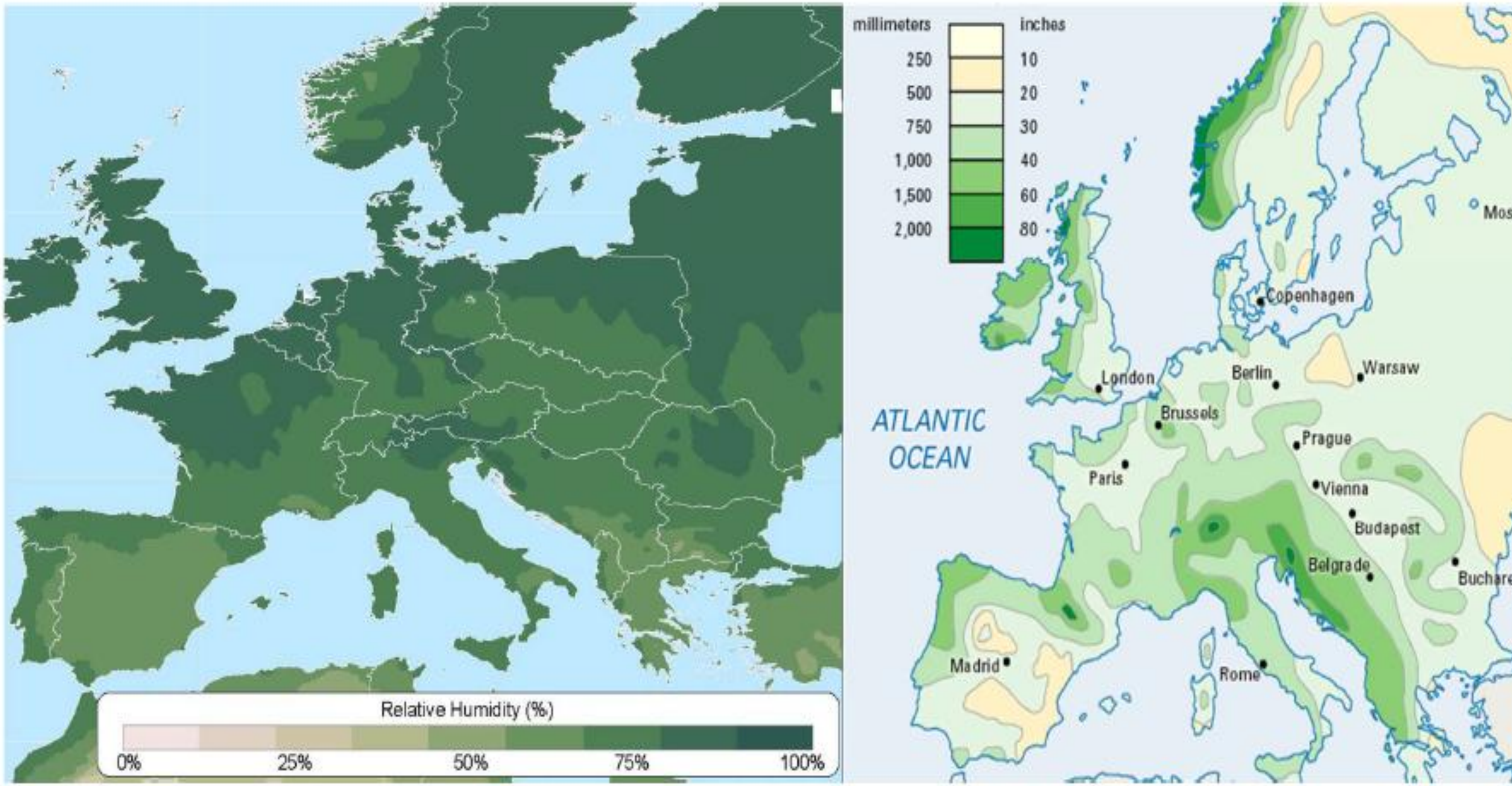
[2] CEM I shall only be used with minimum 4% silica fume

NA means that no deemed to satisfy values are given for that combination of binder and resistance class

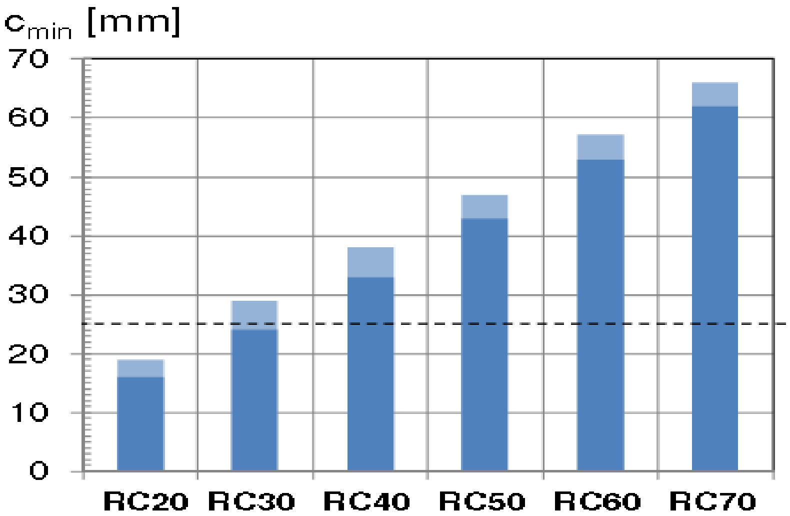
Concrete Cover – design targets

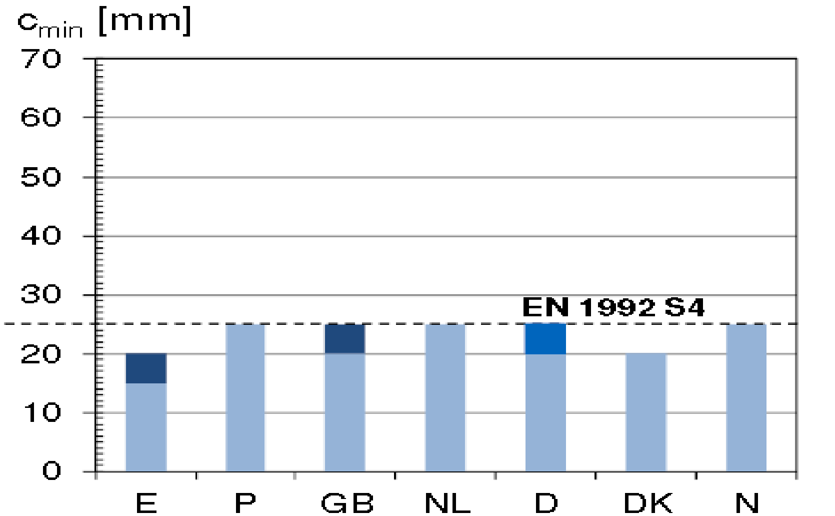
	Corrosion due to carboantion t_{SL} = 50 years				
	XC1		XC2	XC3	XC4
Definition EN 1992	dry	permanently wet	wet, rarely dry	moderate humidity	cyclic wet and dry
Carbonation rate	moderate	slow	slow	fast	moderate
Corrosion rate	slow (High electrolytic resistivity)	negligible (Lack of oxygen)	high	slow (High electrolytic resistivity)	high
Proposed β_{target} requirements	**none**	**none**	**β = 1.5**	**0.5 ≤ β ≤ 1.5**	**β = 1.5**

Distribution of European environmental conditions

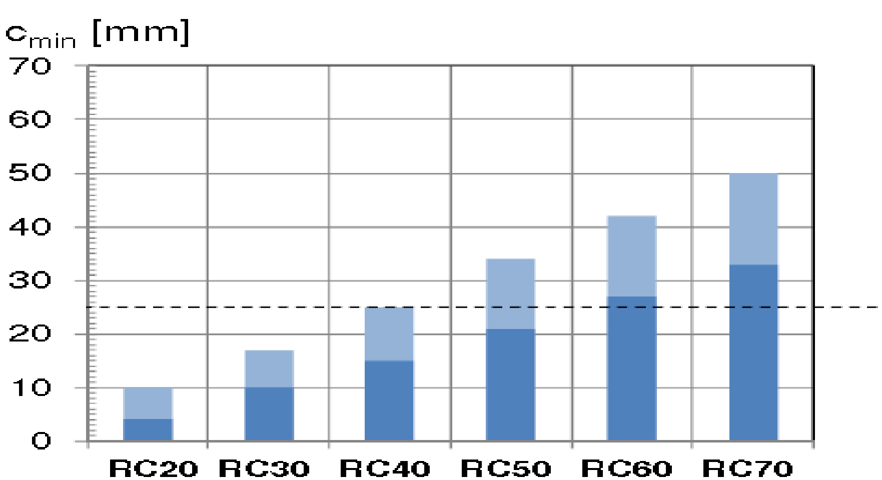


XC3 $\beta_{target} = 1.5$ $t_{SL} = 50$ years





XC3 $\beta_{target} = 0.5$



Criterion	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1	XD2 / XS1	XD3 / XS2 / XS3
Design Working Life of 100 years	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2
Strength Class [1) 2)]	≥ C30/37 reduce class by 1	≥ C30/37 reduce class by 1	≥ C35/45 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C45/55 reduce class by 1
Member with slab geometry (position of reinforcement not affected by construction process)	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1
Special Quality Control of the concrete production ensured	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1

•Environmental Requirement for $c_{min,dur}$ (mm)

Structural Class	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1 / XS1	XD2 / XS2	XD3 / XS3
S1	10	10	10	15	20	25	30
S2	10	10	15	20	25	30	35
S3	10	10	20	25	30	35	40
S4	**10**	**15**	**25**	**30**	**35**	**40**	**45**
S5	15	20	30	35	40	45	50
S6	20	25	35	40	45	50	55

PROPOSAL in EN 1992-1-1

Table 4.4: Minimum concrete cover $c_{min,dur}$ dependant on design service life, exposure class and exposure resistance class

Preliminary values		**Minimum cover for 50, 100 and 200 years design working life, recommended values (preliminary values)**						
Exposure Class		**RC20** [2]			**RC30** [2]		**RC40** [2]	
	(S4)[6]	50	100	200(?)	50	100	50	100
X0[1]	(10)	$c_{min,b}$	$c_{min,b}$	$c_{min,b}$	$c_{min,b}$	$c_{min,b}$	$c_{min,b}$	$c_{min,b}$
XC1	(15)	10	15	20	10	20	10	20
XC2	(25)	15	20	30	20	30	25	35
XC3	(25)	15	20	30	20	30	25	35
XC4	(30)	15	20	30	20	30	25	35
XD1[5]	(35)	30	35	45	35	45	40	50
XS1[5]	(35)	30	35	45	35	45	40	50
		RSD45			**RSD60**		**RSD75**	
XD1[5]	(35)	25	30	35	30	40	35	50
XS1[5]	(35)	25	30	35	30	40	35	50
XD2	(40)	45	55	65	55	70	70	NA
XS2[3]	(40)	45	55	65	55	70	70	NA
XD3[4]	(45)	55	65	75	70	NA	80	NA
XS3[3]	(45)	55	65	75	70	NA	80	NA

[1] In exposure class X0 concrete in carbonation resistance class RCX0 may be used with a minimum cover of $c_{min,b}$

[2] On the tension side of beams the cover shall be increased by 5mm in RC20 and by 10 mm in RC30 and RC40 for exposure classes XC2, XC3, XC4, XS1 and XD1.

[3] In saline waters with chloride level below 2,0 % the minimum cover may be reduced by 10 mm, with a chloride level below 1,0 % the cover may be reduced by 15 mm.

[4] Structures in regions with only short periods of use of de-icing salts, or low quantities annually, the minimum cover may be reduced by 15 mm, in agreement with provisions valid in the place of use.

[5] Structures in exposure classes XS1 and XD1 can have satisfactory performance using concrete in both RC and RSD classes, the use should be in agreement with provisions valid in the place of use.

[5] *Values for minimum cover in EN1992-1-1 given as "base case" S4 given for illustration only*

Crackwidth limitations , recomended values

Table 7.1N Recommended values of w_{max} (mm)

Exposure Class	Reinforced members and prestressed members with unbonded tendons	Prestressed members with bonded tendons
	Quasi-permanent load combination	Frequent load combination
X0, XC1	0,4[1]	0,2 {k_c}
XC2, XC3, XC4	0,3 {k_c}	0,2[2] {k_c}
XD1, XD2, XS1, XS2, XS3		Decompression {?}

Note 1: For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions this limit may be relaxed.

Note 2: For these exposure classes, in addition, decompression should be checked under the quasi-permanent combination of loads.

Consider using factor k_c to allow for correction due to cover larger than $c_{min,dur}$ with
$k_c = c_{actual}/c_{min,dur} \leq 1{,}3$ and
$w_{max}^* = w_{max} \cdot k_c$

There are many comments in TC250/SC2 on these values, in particular
- the effect of extra cover and
- the need for decompression.

Effect of cracking on carbonation, relevant on tension side of beams?

Indication is that cracks will affect rate of carbonation, crack-widths larger than 0,05 mm will not block carbonation in the cracks, the larger the cracks the faster the rate of carbonation of the entire cover-zone up to a certain crack-width. See also the tests by Vasanelli et al.

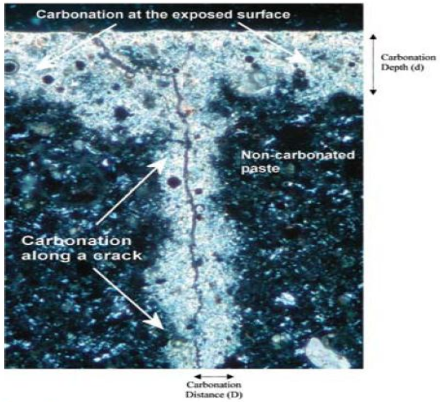


Fig. 5: Photomicrograph showing carbonation zones near an exposed surface and flanking a crack

Fig. 4: Lapped cross section of concrete showing carbonation flanking a 2.5 in. (65 mm) deep vertical crack. The V-shaped carbonation zone does not extend to the end of the crack

Long term behavior of FRC flexural beams under sustained load

Emilia Vasanelli[a,1], Francesco Micelli[a,*], Maria Antonietta Aiello[a], Giovanni Plizzari[b]

Table 11
Carbonation coefficients (*K*) and estimated time to reach steel bars (*T*) for uncracked and cracked concrete.

Beam	K (mm/year$^{0.5}$)		T (years)	
	Uncracked concrete	Crack section	Uncracked concrete	Crack section
TQ1-E	8.06	19.38	13.8	2.4
ST1-E	8.46	12.69	12.6	5.6
ST2-E	8.18	13.44	13.4	5
POL1-E	9.11	12.49	10.9	5.8
POL2-E	9.05	14.67	11.0	4.2

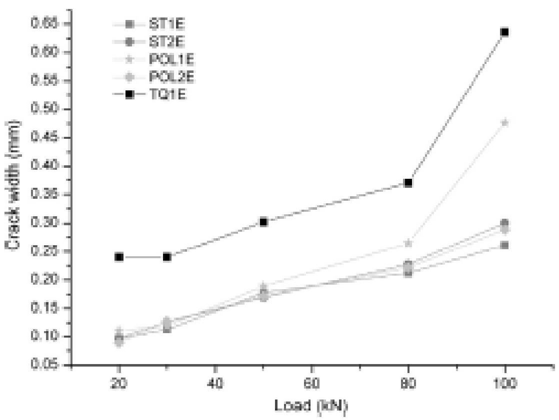


Fig. 13. Average crack with-load curves of exposed beams.

Average carbonation depth;
Uncracked regions 10mm
Cracked regions 15-23mm

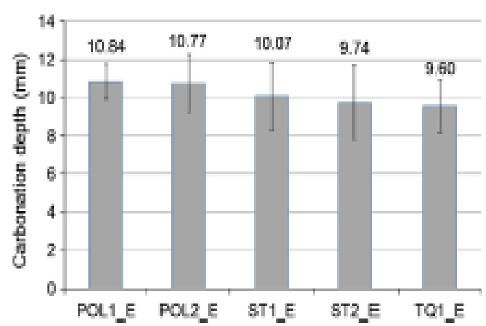


Fig. 14. Average carbonation depth as measured in uncracked regions.

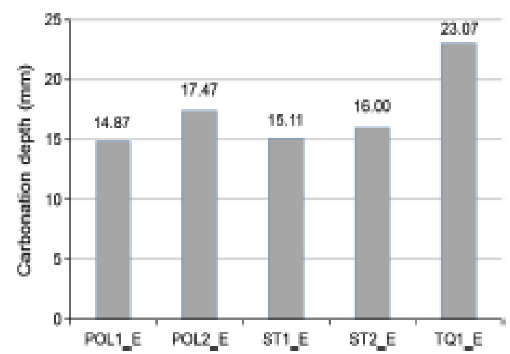


Fig. 15. Average carbonation depth as measured at the cracked sections.

Exposure resistance classes for concrete deterioration mechanisms;

- Freeze thaw
- Chemical aggressiveness

Table 4.5: Deterioration of concrete, permitted exposure resistance classes for exposure classes XF and XA in table 4.1 *(Illustration)*

Freeze thaw action			**Chemical aggressiveness**	
Exposure Class	**Freeze thaw resistance class** Minimum permitted resistance class		**Exposure Class**	**Aggressiveness resistance class** Minimum permitted resistance class
	Mild frost climate	Severe frost climate		
XF1	RF10	RF10	XA1	RC30
XF2	RF10	RF2	XA2	RALow
XF3	RF10	RF2	XA3	RAHigh
XF4	RF2	RF2		

Quality Management

2.1.2 Reliability management

(1) The rules for reliability management are given in EN 1990 Section 2.

(2) A design using the partial factors given in this Eurocode (see 2.4) and the partial factors given in the EN 1990 annexes is considered to lead to a structure associated with reliability Class RC2.

Note: For further information see EN 1990 Annexes B and C.

The Annex B of EN 1990 propose a QM-system, see also Execution Classes in EN 13670

Table B9 – Quality management classe (QM)

Quality Management Class	**Classes related to Design**		**Classes related to Execution**	
	Design Quality Level	**Design Supervision Level**	**Execution Class**	**Inspection Level**
QM3	DQL 3	DSL3	EXC3	IL3
QM2	DQL2	DSL2	EXC2	IL2
QM1	DQL 1	DSL1	EXC1	IL1

PROPOSED NEW DURABILITY CONCEPT;

SUMMARY OF COMMENTS from TC104 member bodies (11) and organizations in liaison (2)

Comments from	General position	Performance based classes	Deemed to satisfy	Prefer present approach	Alternative approach	Proposals	Resistance classes	Test methods	Conformity	Organiz-ation	Comments
Belgium	positive	positive	negative	no	no	Two options A&B	positive				Performance based requirements are the future
Cembureau	positive	positive		no	no	no	positive	needed	Type tests and rapid FPC tests		Pan European program on tests are needed
Denmark	Negative lack of basis	Positive to performance but not yet	Needed and the only at present	yes	no	no	Negative to RSD and RF				The scientific approach is incorrect
ERMCO	positive	positive		no			positive	Needed, great concern	Type test, limiting and values		European test program. Concept of "similar materials"
Finland	positive	positive	needed	no			Positive but too limited	Needed, rapid	Type tests and rapid FPC tests		National flexibility, testing precise not too time consuming
France	Negative, proposal premature	Appreciate attempt, but over simplistic		-							Interesting concept but excessively premature
Germany	positive	positive	needed	no	no	no	positive	needed	Rules for Initial tests and FCP		Address action side
Italy	Negative, lack basis	negative			no	no	Not realistic due to lack of test methods	Not available			No methods available to relate exposure to resistance
Norway	positive	positive	needed	no	no	no	Positive, very helpful	needed	Rules for Initial tests and FPC		
Spain	Positive, partly		Yes, only in next version	yes	Direct and indirect indicators	yes	Propose alternative classes			WG	Interesting approach but premature
Sweden	Positive, in principle	Positive, initially as alternative	Needed, strongly	no	no	List of recommended actions	positive	Needed, but poor precision	Type tests and rapid FPC tests	WG	Procedures for conformity control essential
Switzerland	positive	Positive, strongly	Needed in parallel	no	no	Improve exposure classes	positive	Needed long term and rapid	Essential to develop		European test program
UK	positive	positive	Yes, but difficult to agree	no	no	Describe deterioration models	Positive, for RC and RSD not RF and RA			WG	Recommend change in designation of classes

Our goal is to provide a concept that is technically based, based on deterioration mechanisms and demonstrated resistance
- a system that is easy to use in design, execution and concrete production where
- provisions valid in the place of use
are replaced by
- demonstrable adequate performance on the basis of governing factors and not subjective unquantifiable "things"

In the revision of the Eurocodes we are requested to remove illegitimate Nationally Determined Parameters (NDP)

This implies that concrete should be specified based on a common technical ground in future, one that will;

- allow concrete to travel between countries if it should want to!!
- allow improvements in sustainability and CO2-footprint reduction to be implemented directly once required performance is demonstrated

Status and research needs

Status is good on classification for carbonation
Status is quite good on classification for chloride ingress
Status is not too bad for freeze thaw classification
Status is poor for chemical aggressiveness

Research is wanted for verification validation of classification

Research is needed for
- improvement of test methods, rapid and long term
- proving precission and repeatability

The proposed concept;

Exposure classes

Exposure resistance classes

Design working life

Minimum concrete cover

Maximum allowable crack-width

The designer will in the *execution specification* specify;
Strength class, Exposure resistance class, chloride class, D_{upper}/D_{lower} and nominal cover as well as the Execution Class
e.g C30/37 – RC30 – Cl 0,20 – D_{upper} 32 – D_{lower} 16 – c_{nom} 30 mm (20+10) – EXC3

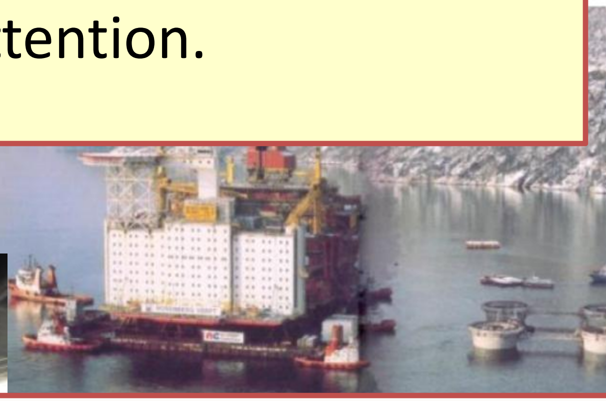
The contractor will in the *concrete specification* specify;
Strength class, Exposure resistance class, chloride class, consistence class, segregation resistance class etc.
e.g C30/37 – RC30 – Cl 0,20 – D_{upper} 32 – D_{lower} 16 – S4 – SR1 etc.

The concrete producer will produce this concrete, and get paid for that !!!!!!!


These bars
are what we
shall
protect!!!
Welcome and good luck !

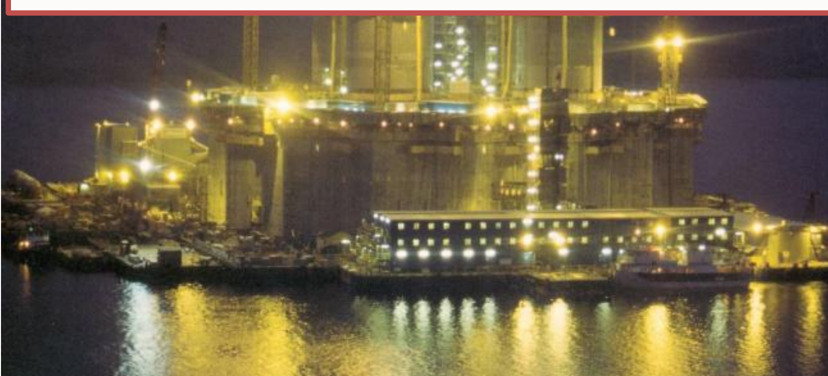
Thank you for your attention.

Steinar Leivestad



Background;
44 years as consulting engineer, Norconsult (2700 employees)
Of these 44 years
34 years with standardization
25 years with design of offshore concrete structures
15 years of administration as section head and director
10 years of design of industry, bridges etc.

Background in standardization includes;
CEN;
TC250, TC250/SC2, TC250/SC2/WG1, TC250/WG2, TC250/WG7
TC104, TC104/SC1, TC104/SC2
ISO;
TC71, TC71/SC3, TC71/SC7, TC71/SC8
TC98, TC98/SC2
National committees on concrete, reliability and loads



back to overview of invited speaker session

FROM IDEA TO MARKET

COST TU 1404

Towards the next generation of standards for service-life of cement-based materials and structures

Ljubljana, 16-17 April, 2015

ConSensor BV
Wim Stenfert Kroese

ConSensor

Part I: ConSensor from idea to market

The issue: Calculate right time for removing formwork / applying pre-stress:

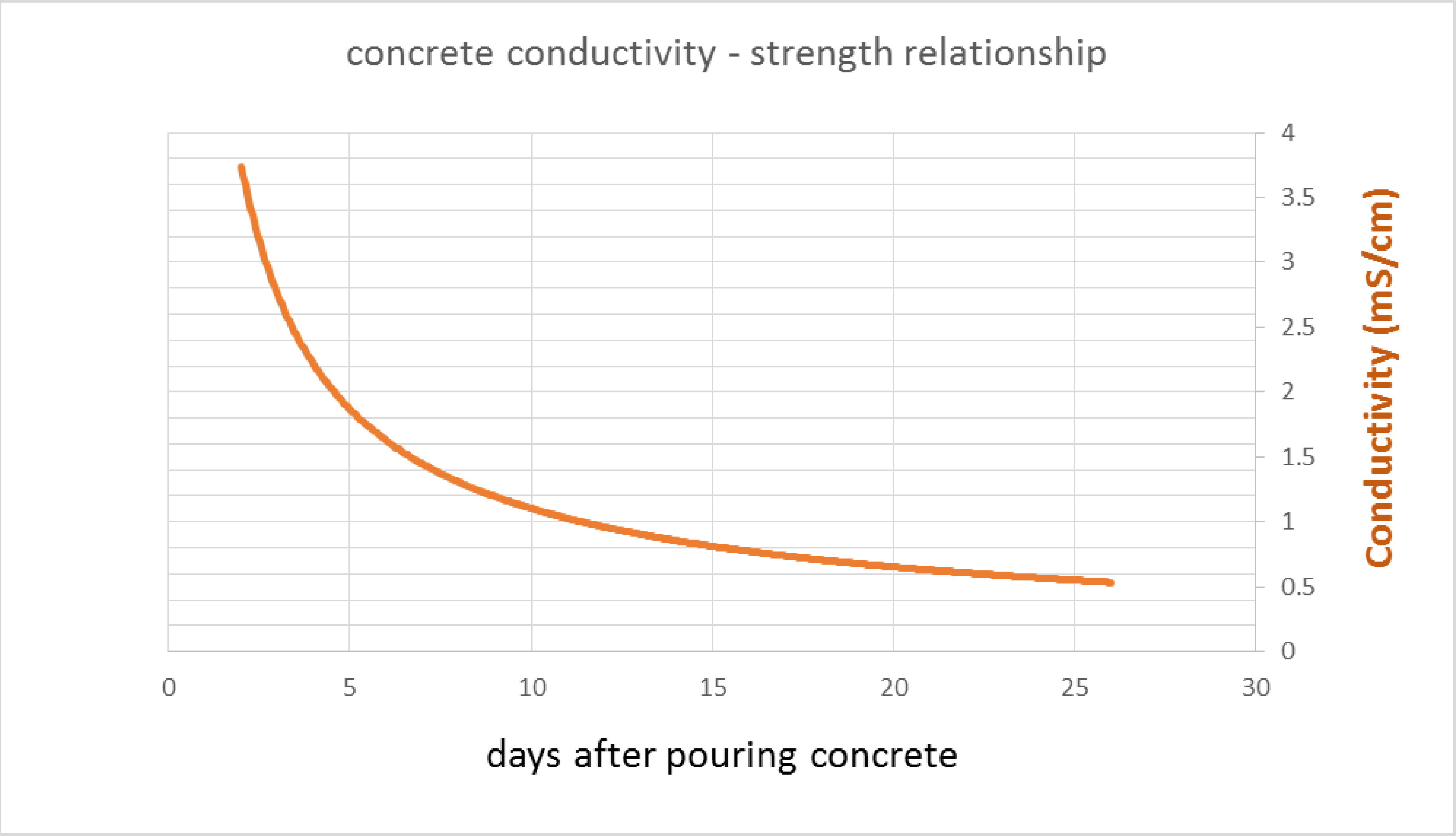
- **safety**
- save time & money
- optimize mix
- optimize planning

the problem

ConSensor

- Existing equipment (maturity based methods) need continuous measurement of temperature
- Vulnerable
- Long cables risk breaking
- Maturity method complicated, differs per country
- Indirect: Temp → Heat → Strength
- Expensive equipment

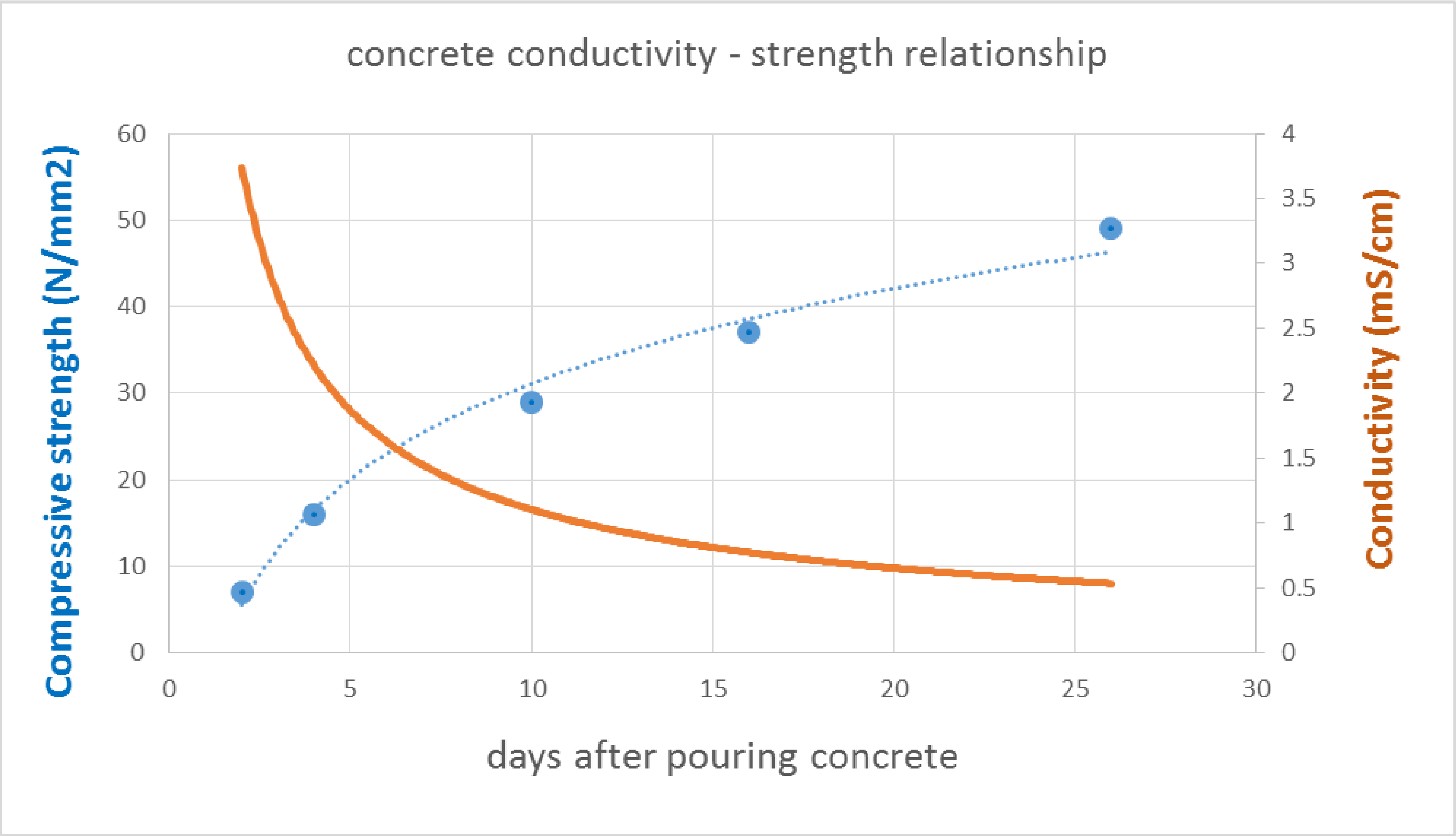
Idea (1994)



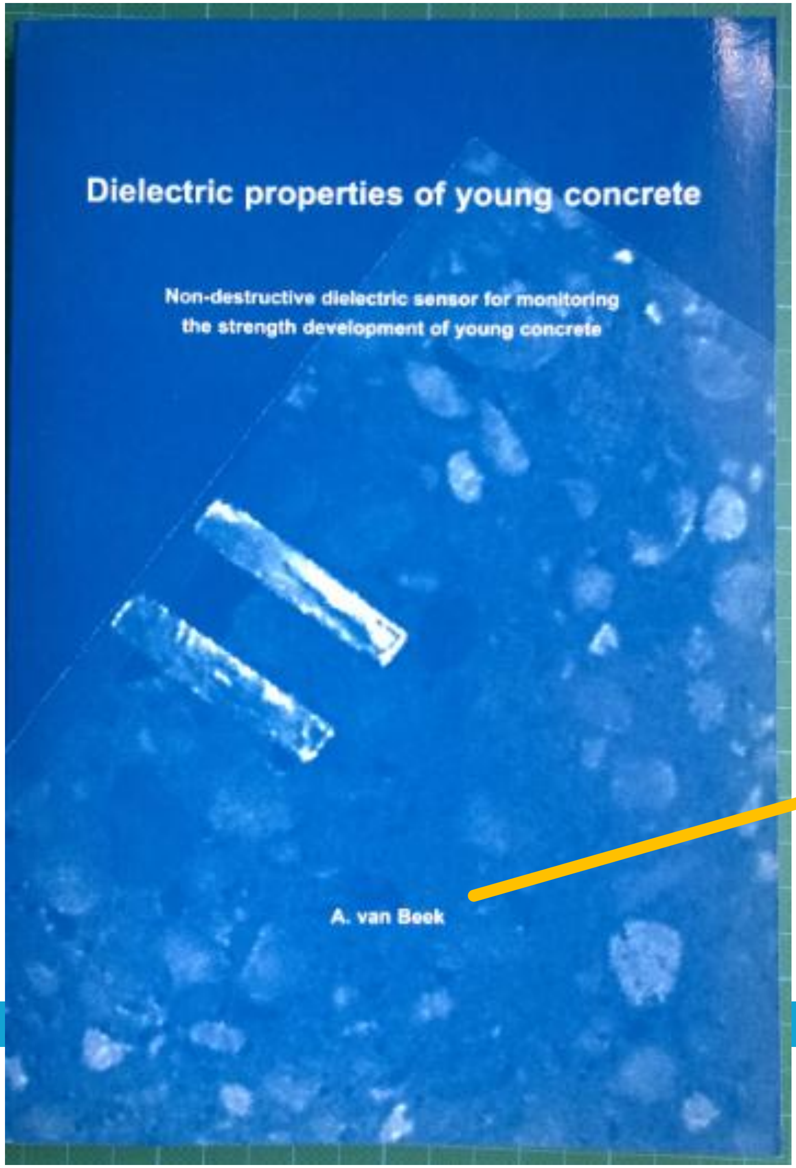
concrete conductivity - strength relationship
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
days after pouring concrete
Conductivity (mS/cm)

test of idea (~1995)

ConSensor



proof of concept (2000)

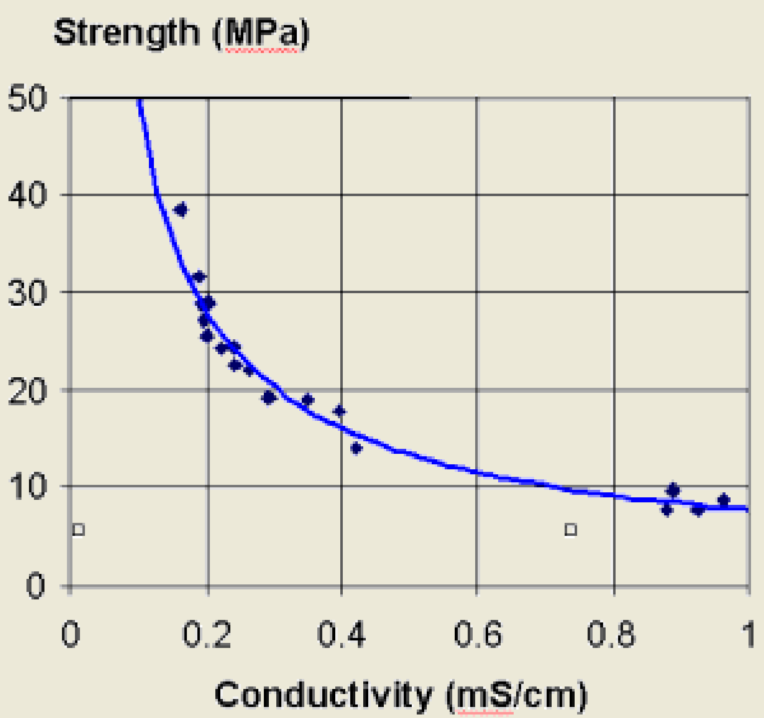


Dr. Ton van Beek, PhD

TU-Delft (1996 – 2000)

proof of concept

ConSensor



Source: Ton van Beek

first product!

Start of company, with investors: **1998**

First product: ConSensor 1.0 ready in **2002**

first product… ☹

ConSensor

No success:

- Not practical to use, not solving a problem
- Conductivity unknown = not accepted
- Sensitive to rebar

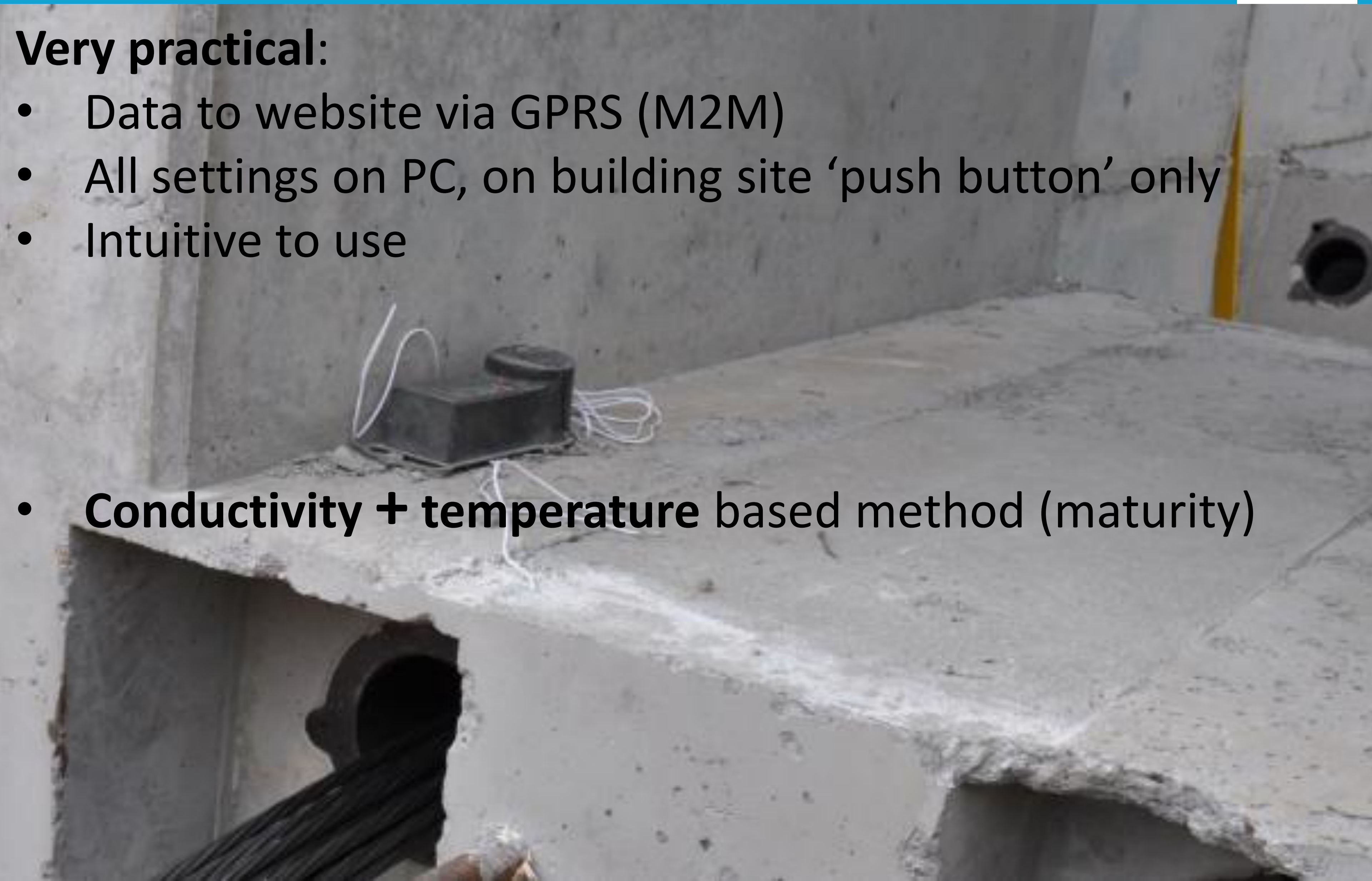
- Many attempts to improve,
  no success
- New idea in **2008**!

2011: **ConSensor 2.0** !

ConSensor

Very practical:

- Data to website via GPRS (M2M)
- All settings on PC, on building site ‘push button’ only
- Intuitive to use

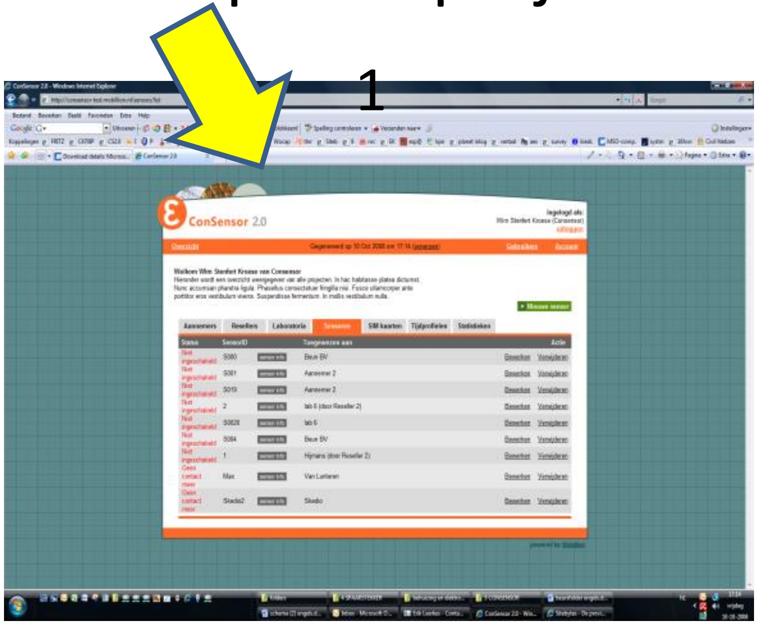


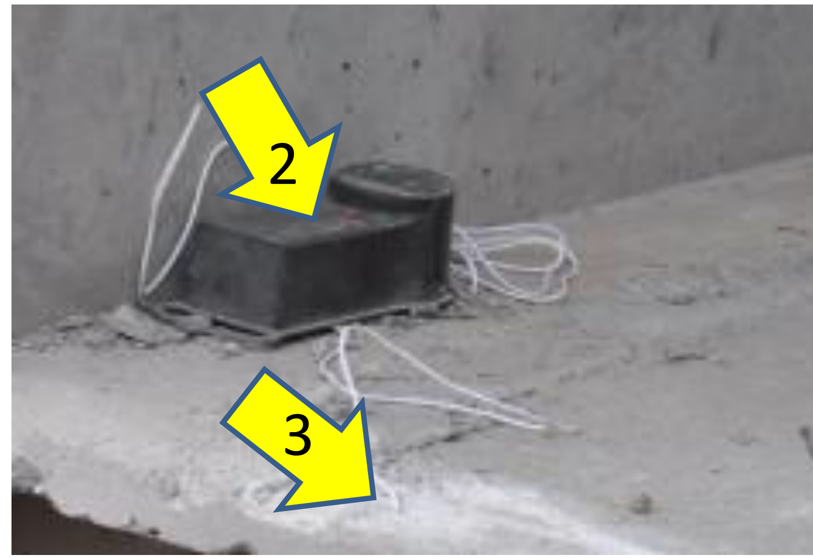
- **Conductivity + temperature** based method (maturity)

Using ConSensor

ConSensor

1. Prepare a project on the ConSensor website





2. Put the DataBox in place and turn it *ON.*
3. Put the sensor inside the form, pour the concrete.

Using ConSensor

ConSensor

1. The DataBox sends the data via GPRS the ConSensor web server
2. The web server calculates the strength
3. Data always available everywhere:

ConSensor BV

- Max Hilhorst + Wim Stenfert Kroese + 2 investors
- Technology together with TU-Delft (PhD, Ton van Beek)

Business model:

- **Product** (DataBox, sensor) (**sell** to users: ready mix producers and contractors)
- **Service**: GPRS, Website: **subscription**
- Sales through dealers (EU, China, Turkey, …)

Part II: From idea to market

ConSensor

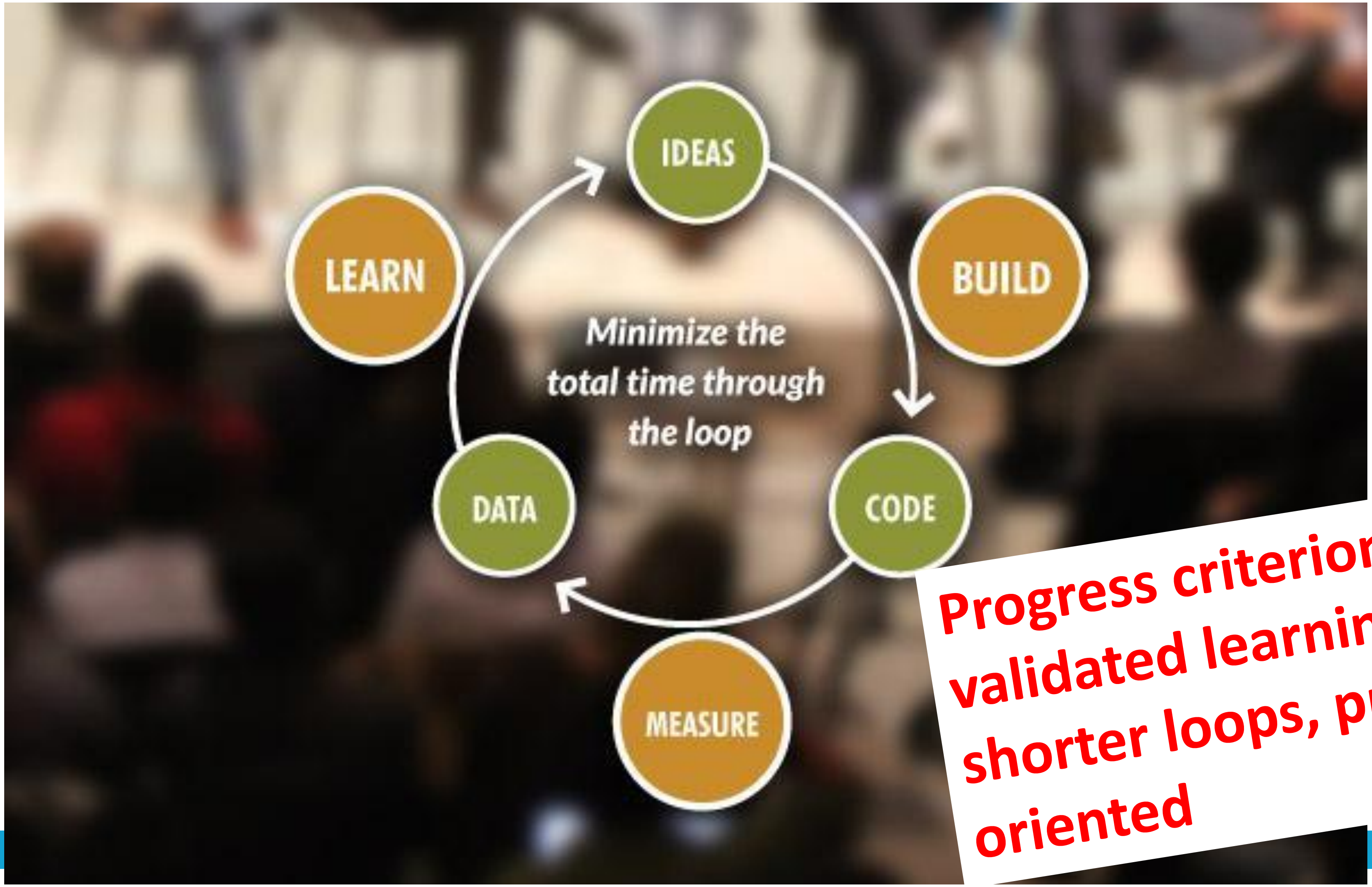
Traditional product development

1. Concept
2. Requirements
3. Technical specifications
4. Design
5. Produce
6. Sell
7. Use

Progress criterion: reach next stage, content

Process takes long time

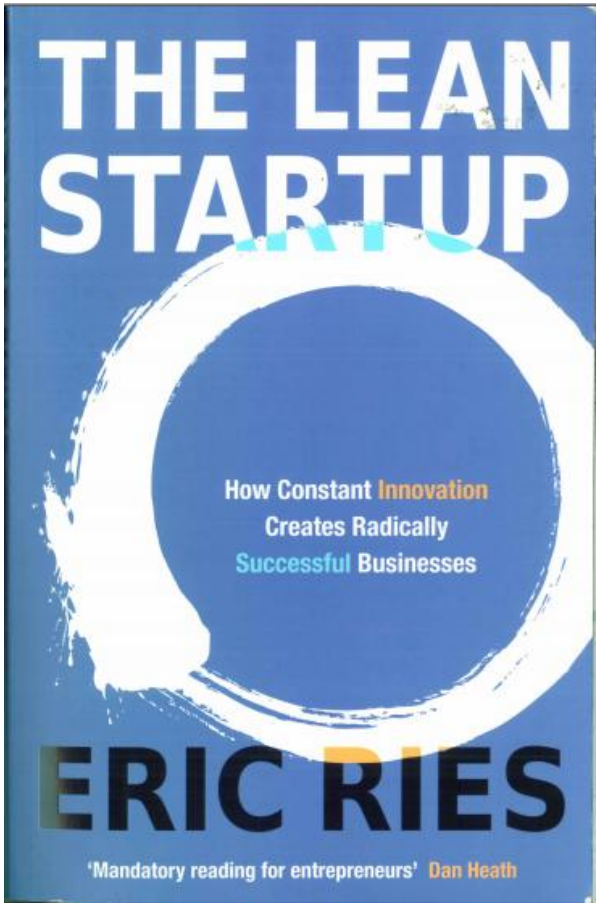
Current approach: Innovation cycle



Progress criterion: validated learning, shorter loops, process oriented

Literature

ConSensor

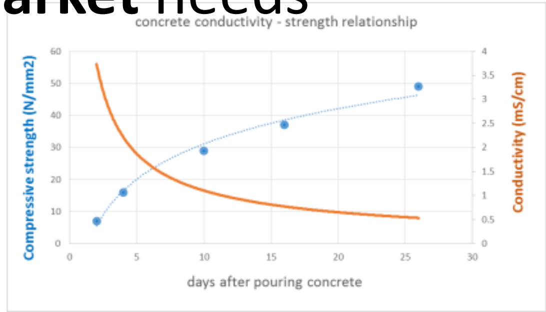


Minimum Viable Product:
{…} the first step is to enter the build phase as quickly as possible with a minimum viable product – MVP. The MVP is that version of the product that enables a full turn of the build-measure-learn loop with a minimum amount of effort and the least amount of development time.

Success is not delivering a feature; success is learning how to solve the customer's problem.

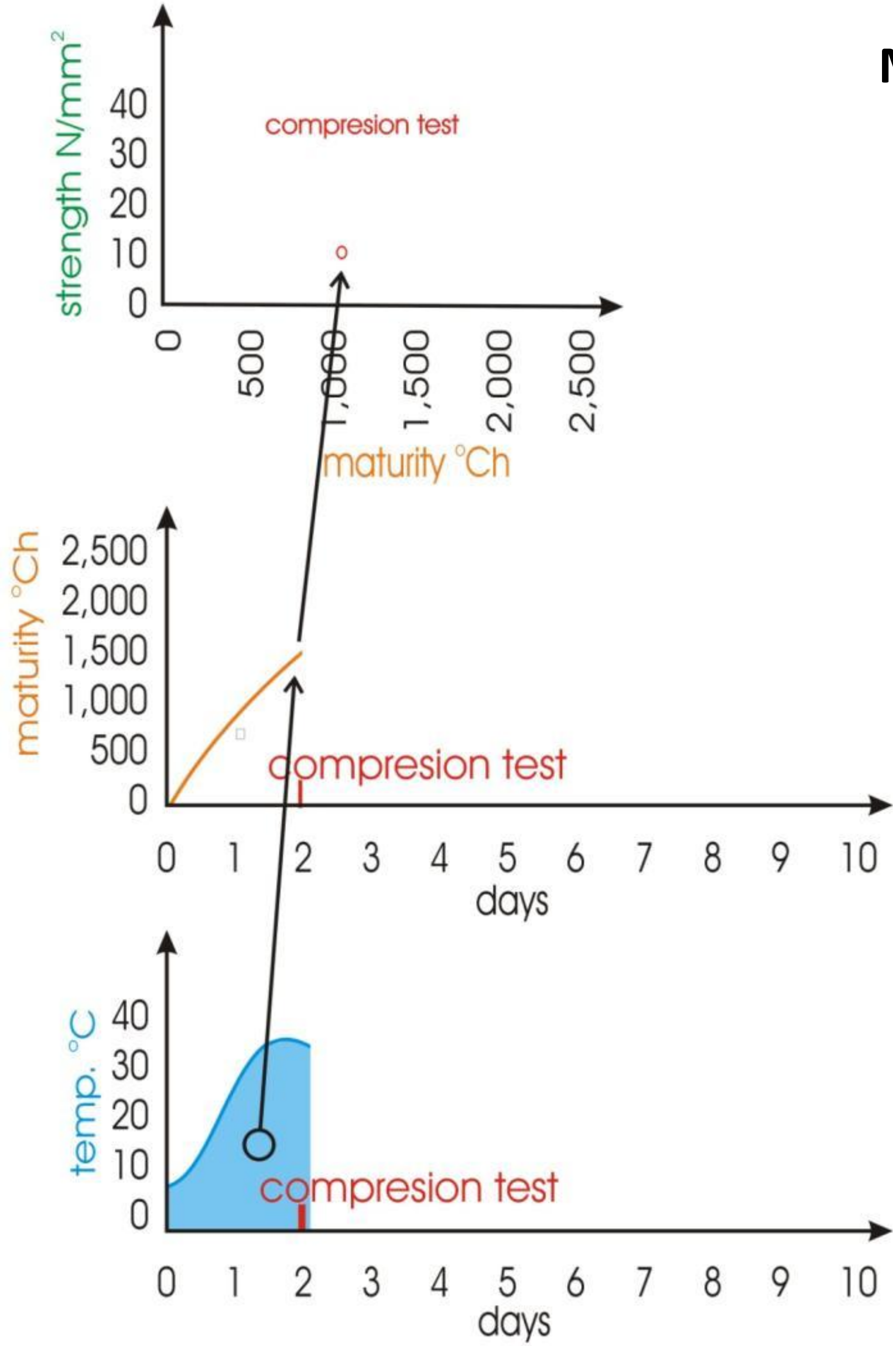
Lessons

- Huge gap between **scientific** perspective and **market** needs
  - Scientific: proof, methodologically correct
  - Practice: ease of use + technical standard
  - Try to work from both sides



- Market needs hard to determine (opinions are ambiguous)
  - Best: make, sell, improve (fast) (MVP)
  - Patience, Perseverance and Luck

MATURITY METHOD



ConSensor

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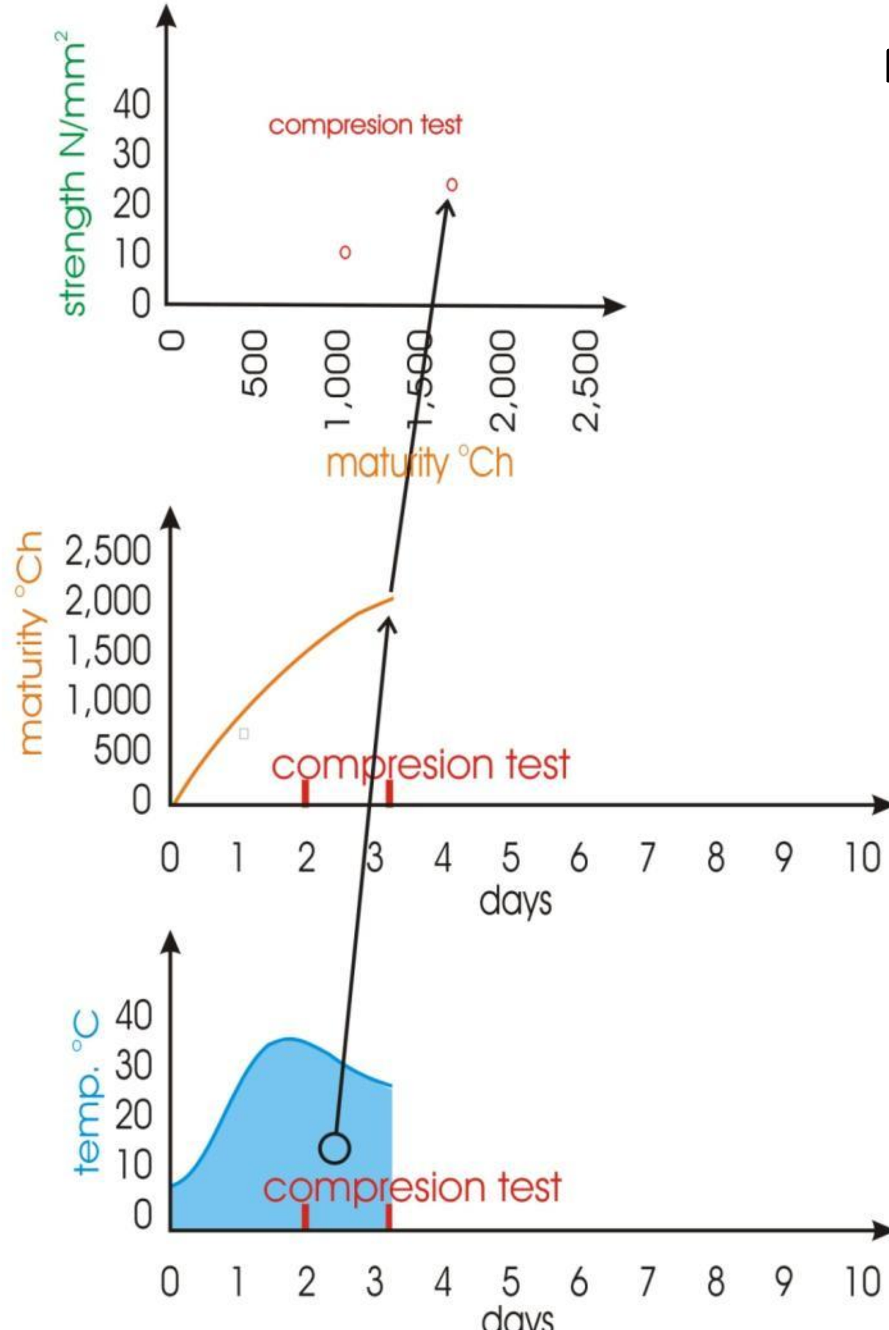

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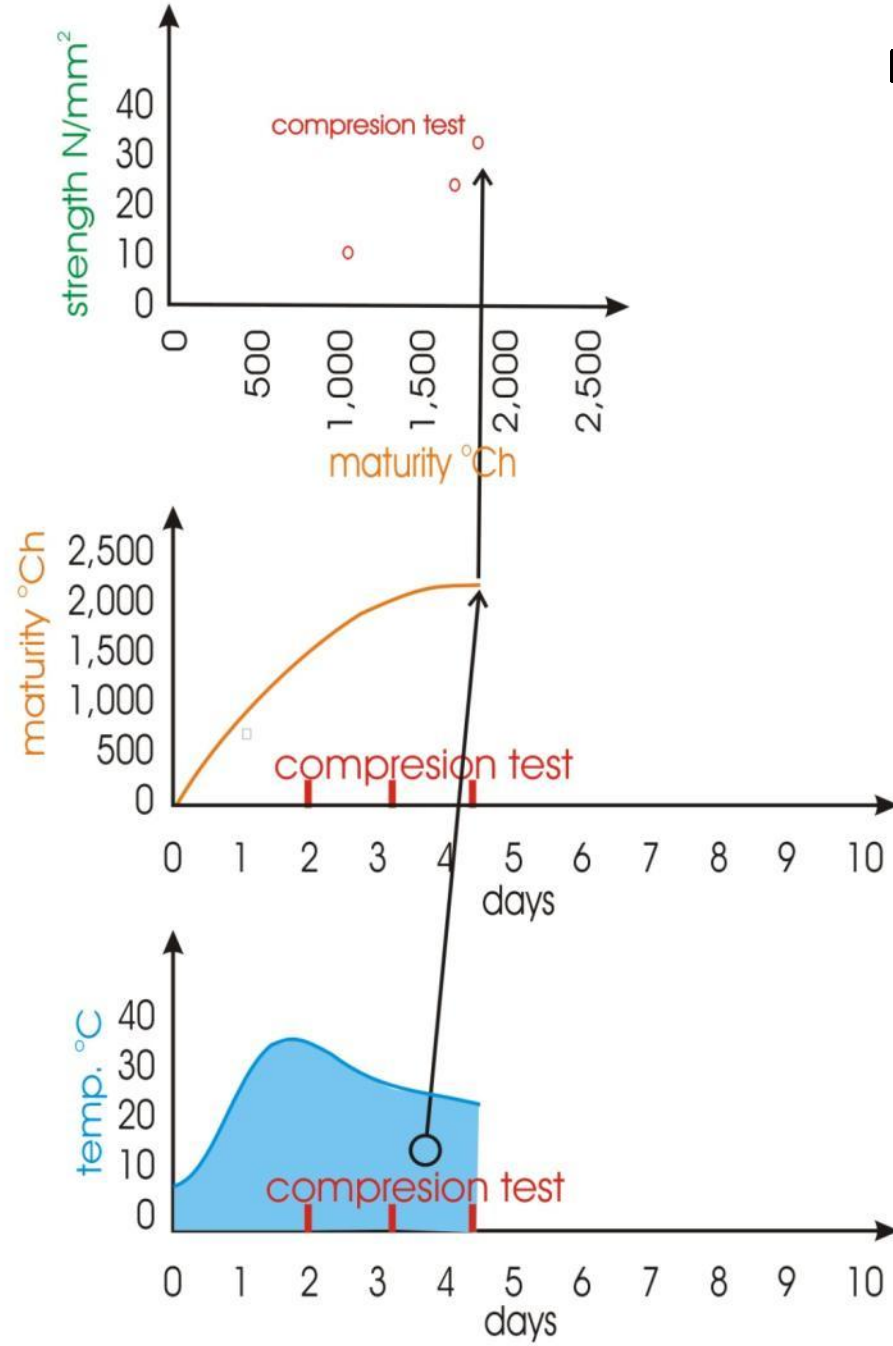

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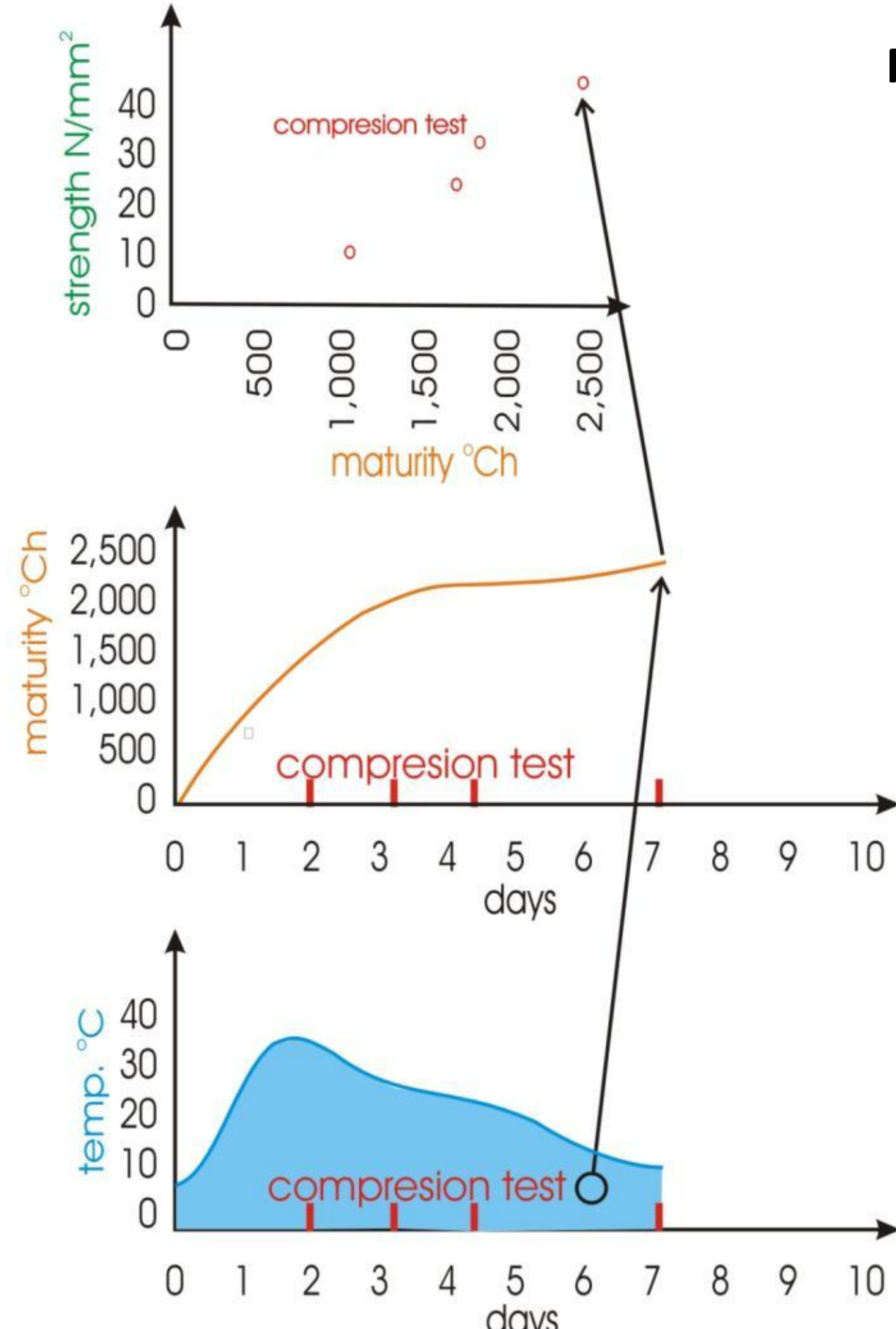

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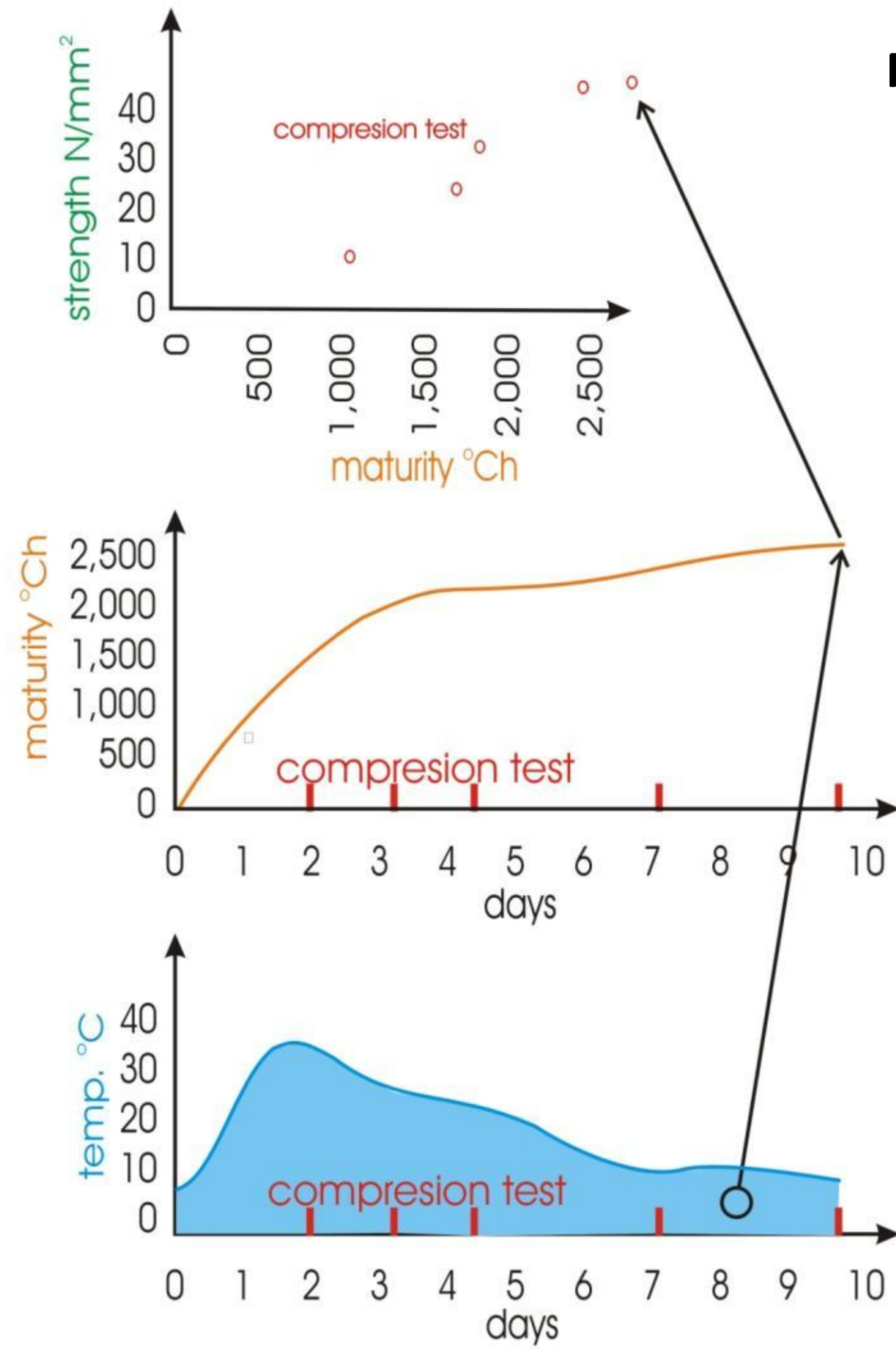

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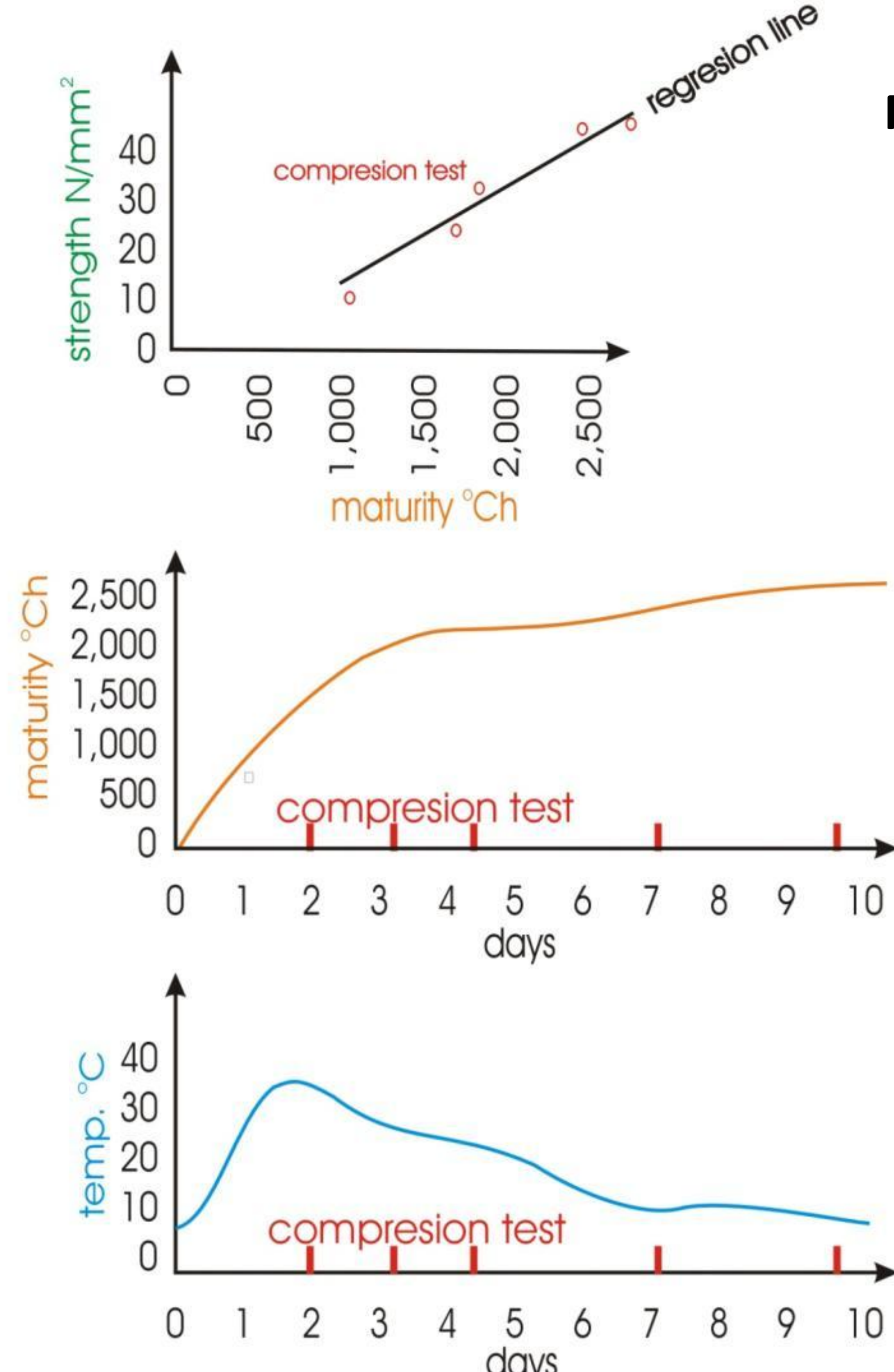

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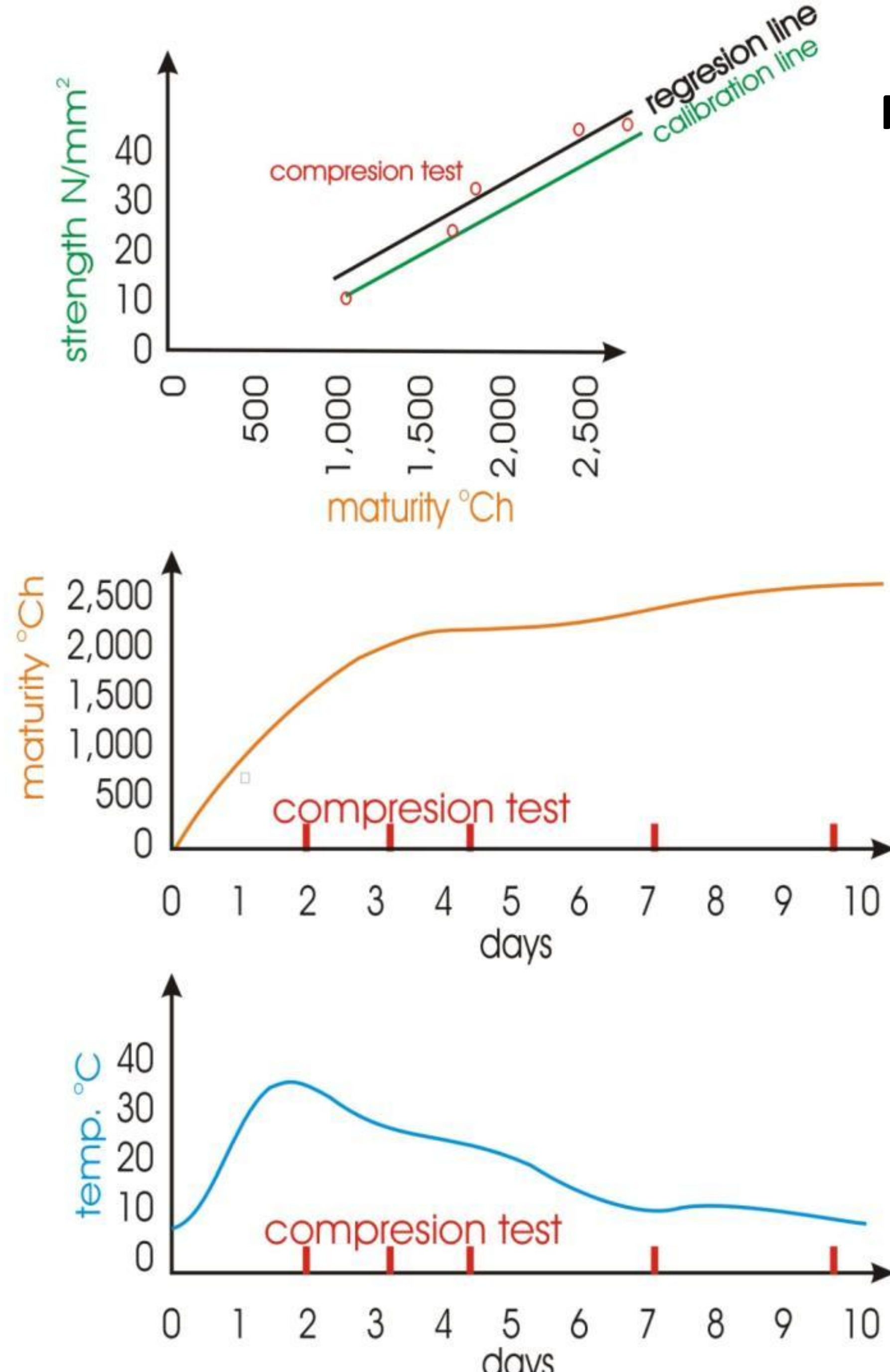

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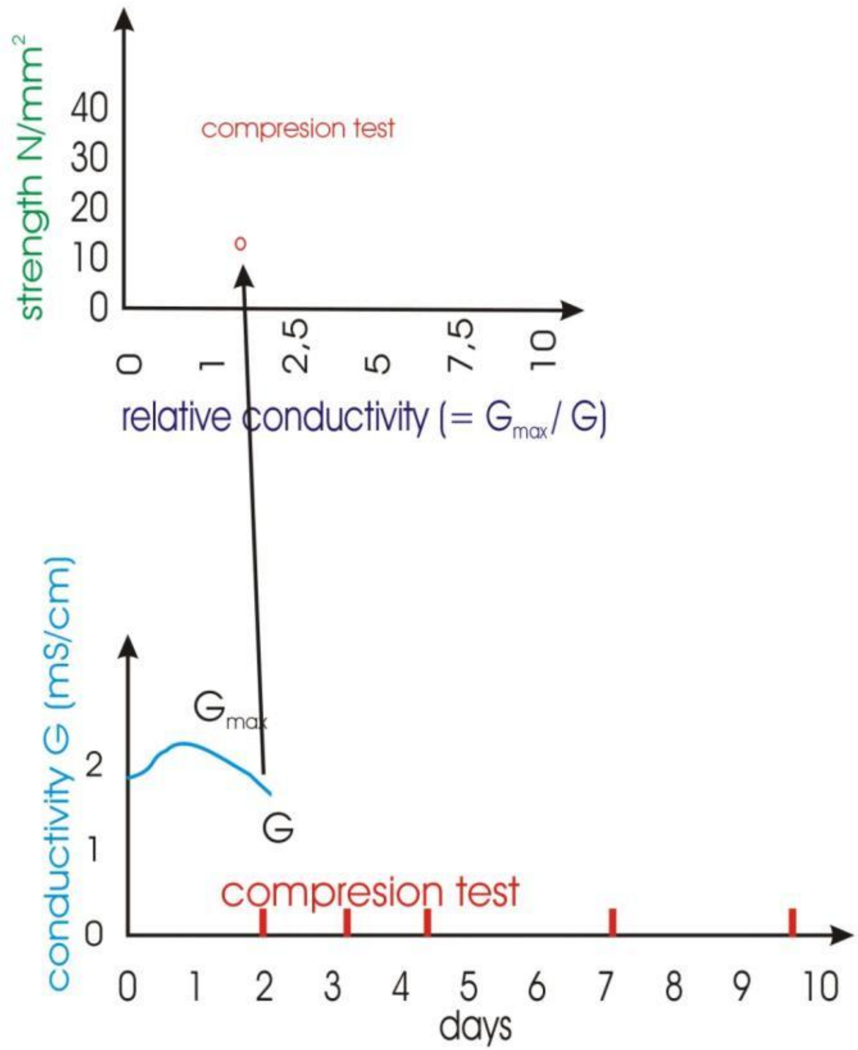

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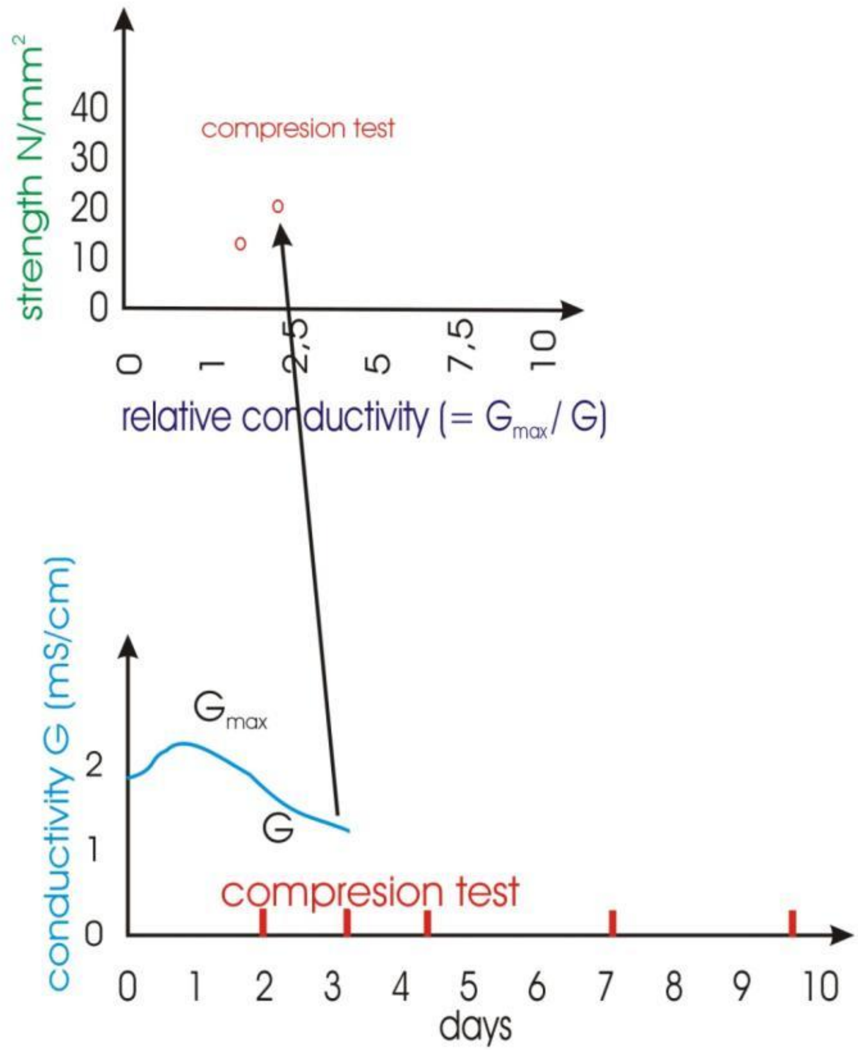

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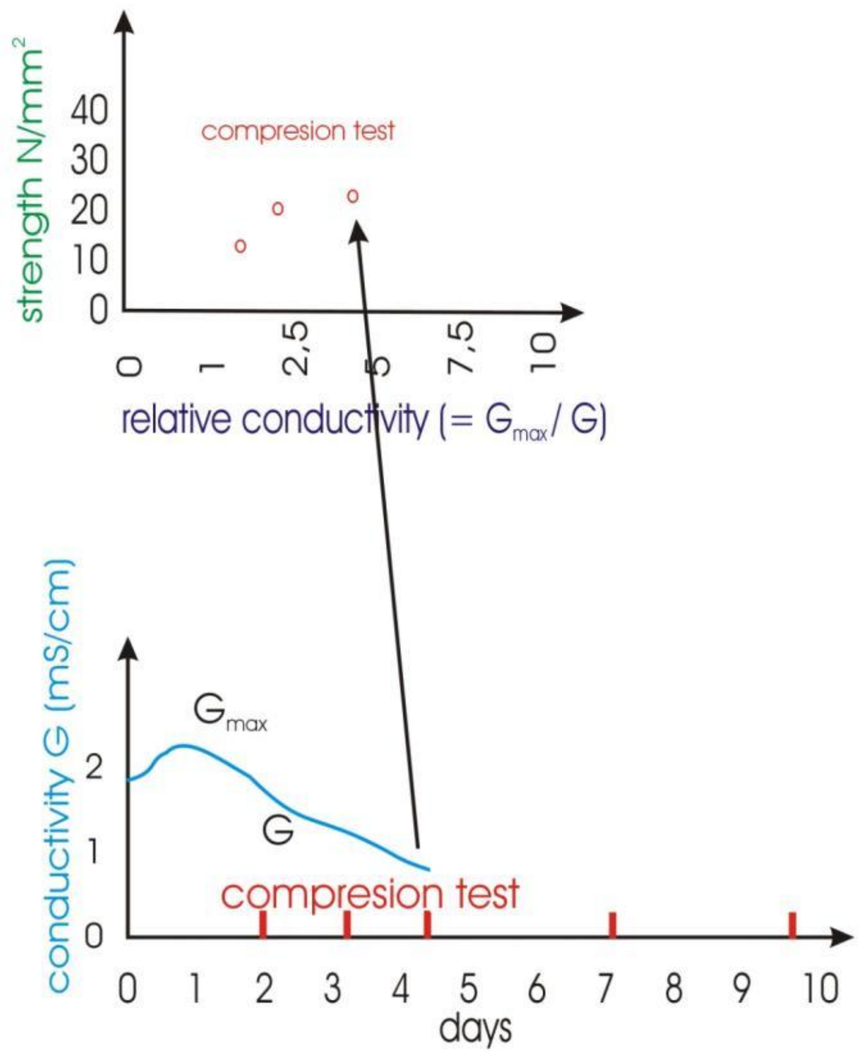

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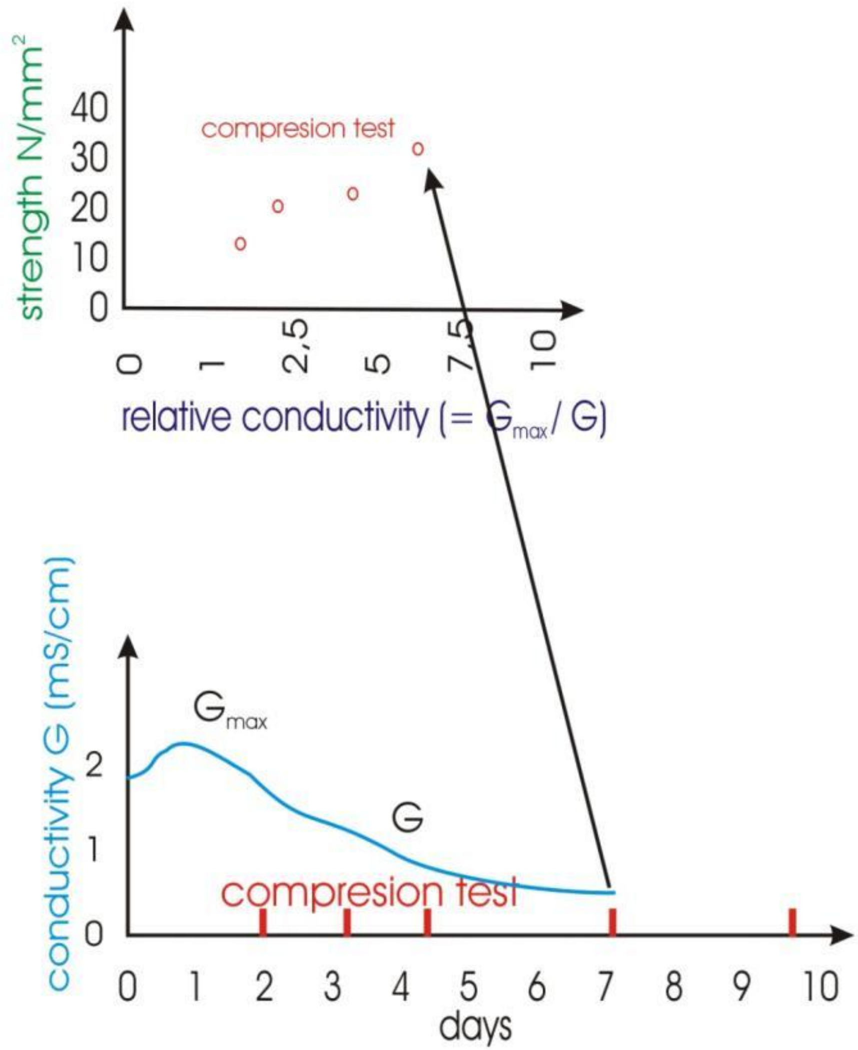

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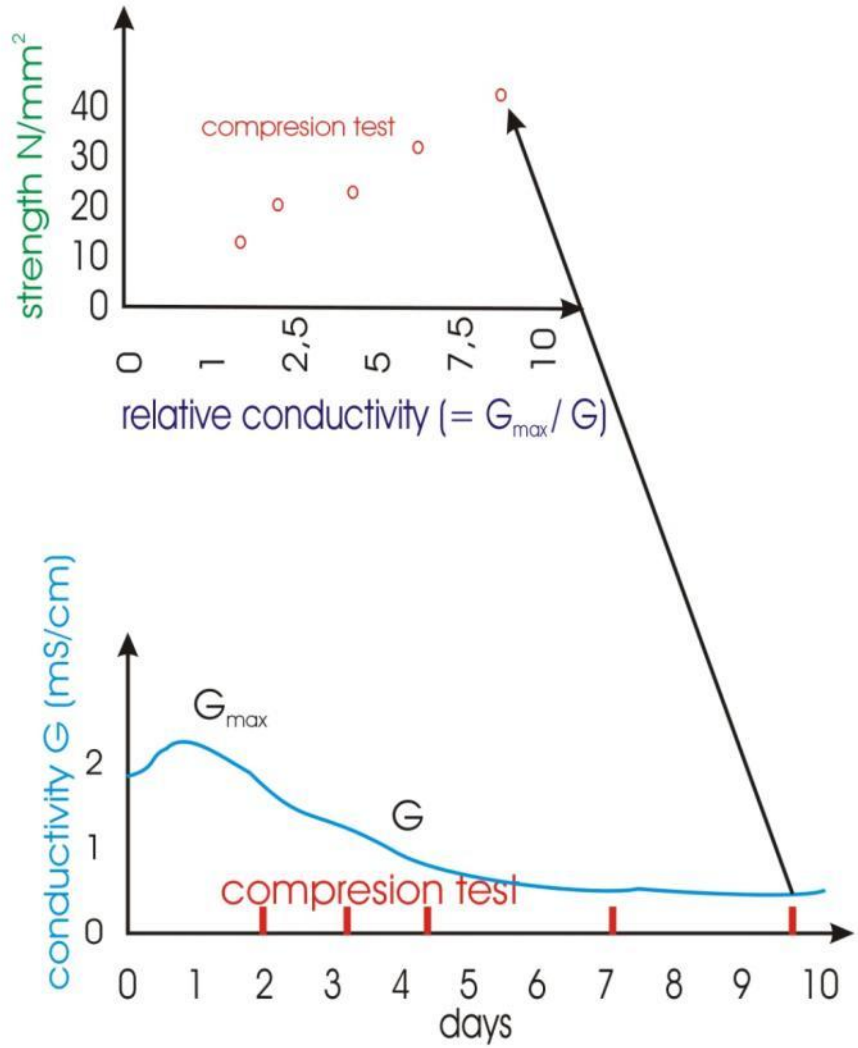

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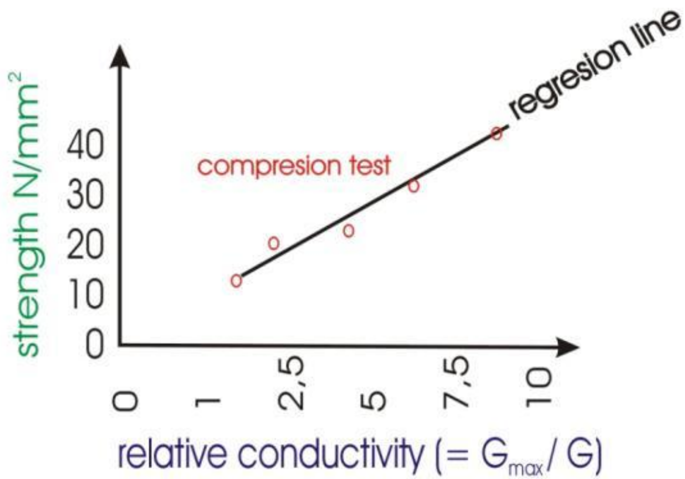

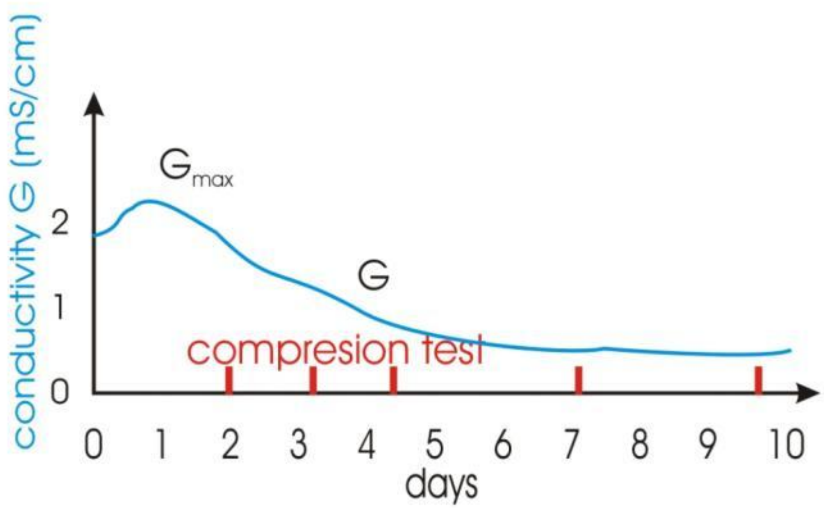

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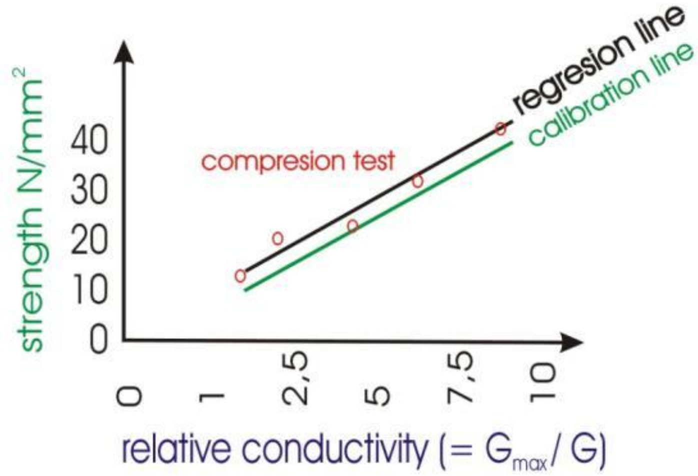

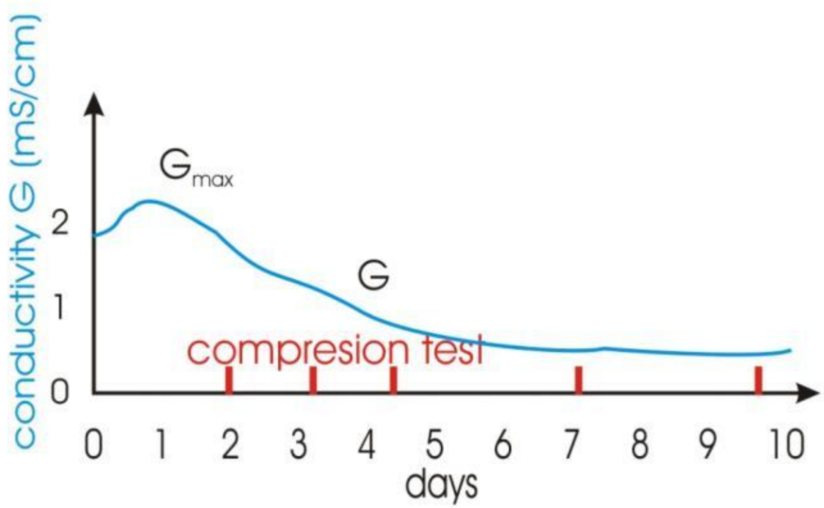

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RRT SESSION
Chairman: Gregor Trtnik

Gregor Trtnik, Marijana Serdar:

Presentation of RRT strategy and objectives

Elsie Baby: Important Vercors's concrete experimental results

ROUND ROBIN TEST AS A MAIN ACTIVITY OF WG1 OF COST TU1404 ACTION

Gregor Trtnik- IGMAT Building Materials Institute, SLO

Marijana Serdar- University of Zagreb, Faculty of Civil Engineering, CRO

SUMMARY

PART 1: BASICS OF ROUND ROBIN TEST (RRT)

- Objectives
- Organization
- Group Priorities and participants – a brief summary

PART 2: MATERIALS AND METHODS

- Experimental materials used in RRT
- Mixing procedure and curing conditions

PART 3: PERFORMANCE AND TIME SCHEDULE

- Time schedule of main activities

PART 4: INVITATION FOR DISCUSSION

PART 1: RRT – OBJECTIVES

OBJECTIVES OF RRT

INTRODUCTION OF NEW ADVANCED TESTING TECHNIQUES

To check the ability of different advanced testing techniques to determine various early age properties of CBMs and recommend them to become standard in the (near) future (relation to WG3)

INCORPORATION OF SUPPLEMENTARY (WASTE) MATERIALS IN CONCRETE MIXTURES

To improve specific properties of CBMs in order to develop sustainable, more durable material

PREPARATION OF DATABASE OF (EARLY AGE) CONCRETE PROPERTIES

To allow the designers to predict lifespan of concrete structure and to provide valuable data for WG2

PART 1: RRT – ORGANIZATION

DIVISION OF RRT

- **DIV 1: DIFFERENT PHASES OF RRT**
  - DESIGN PHASE
  - EXPERIMENTAL PHASE
    - INITIAL PHASE
    - MAIN PHASE
    - ADDITIONAL PHASE
- **DIV 2: DIFFERENT EXPERIMENTAL MATERIALS**
  - LEVEL 0: Reference mixtures (OC, MOC, OM, OCP)
  - LEVEL 1: sustainable and innovative mixtures
  - LEVEL 2: changes in basic materials
- **DIV 3: DIFFERENT INETERST OF PARICIPANTS**
  - TYPE A PARTICIPANTS: interested mainly in novel techniques
  - TYPE B PARTICIPANTS: Interested mainly in developing sustainable mixtures

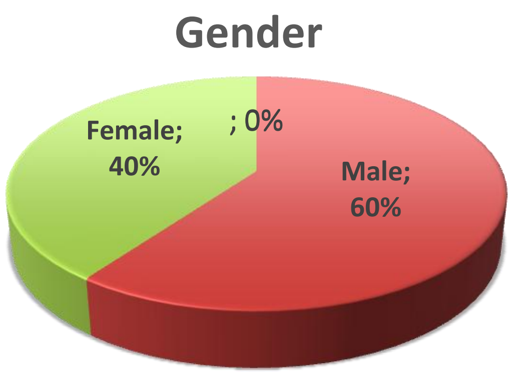
PART 1: RRT – GROUP PRIORITIES

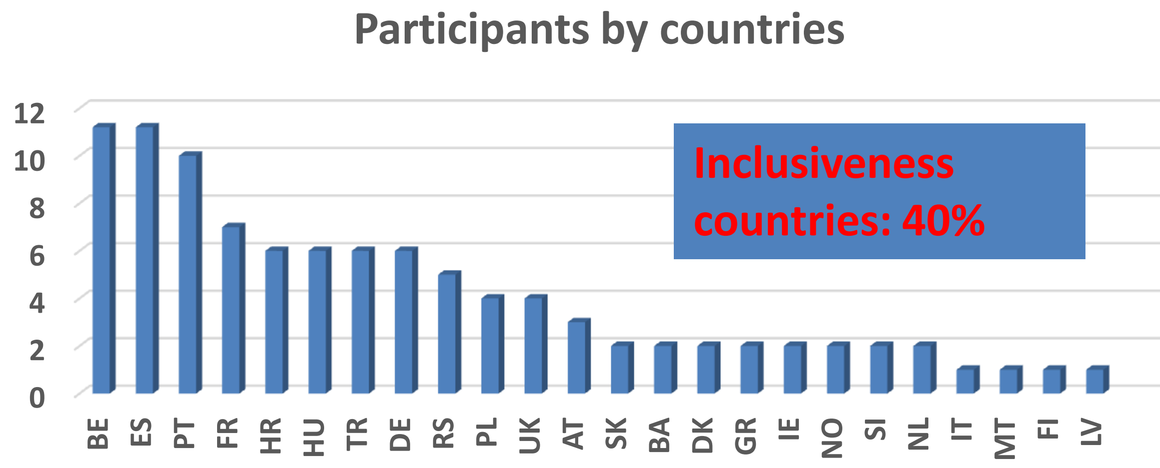
6 GROUP PRIORITIES

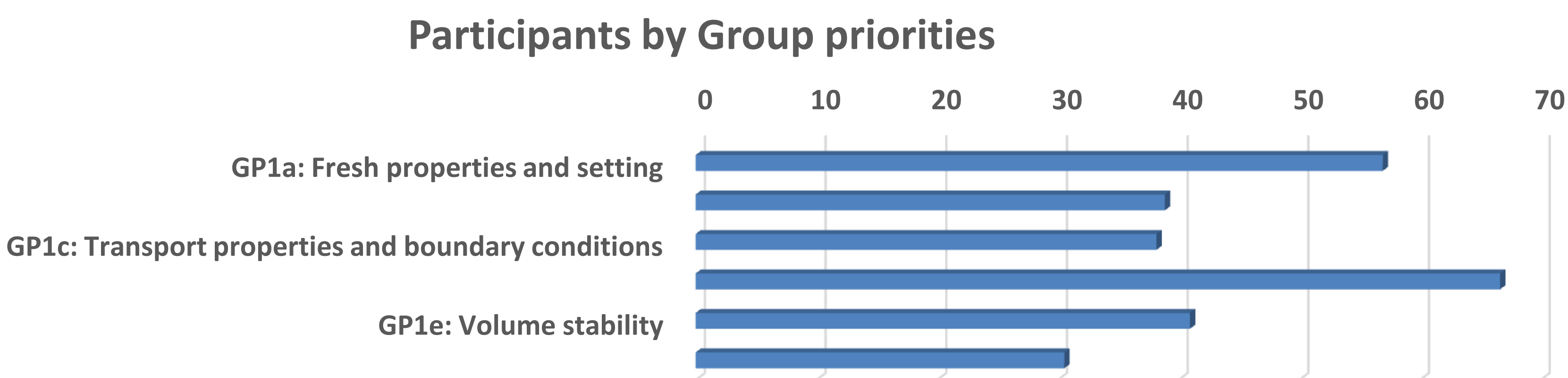
- **GP1a** – Fresh properties and setting – **Ivan Gabrijel (CRO)**
- **GP1b** – Chemical and microstructural characterization – **Ozlem Cizer (BE)**
- **GP1c** – Transport properties and boundary effects – **Sree Nanukuttan (GB)**
- **GP1d** – Mechanical properties – **Violeta B. Bosiljkov (SLO)**, **Bernhard Pichler (AUT)**
- **GP1e** – Volume stability – **Emmanuel Roziere (FR)**
- **GP1f** – Fracture properties and cracking – **Theodore Matikas (GR)**

PART 1: RRT – PARTICIPANTS

WG1 (RRT): current total number of participants: 144







PART 2: EXPERIMENTAL MATERIALS (div2)

LEVEL 0: REFERENCE MIXTURES

Ordinary concrete mixture - OC

Basic Material	Type of material	Amount [kg/m^3]
Cement	CEM I 52,5N CE CP2 NF Gaurain	320
Dry sand	0-4 mm REC GSM LGP1 (13% CaO, 72% SiO_2)	830
Dry gravel	4-11 mm, R GSM LP1 (rounded, silicate,limestone)	445
	8-16 mm R Balloy (rounded, silicate,limestone)	550
Admixtures	Plasticizer Sikaplast Techno 80	2.75
Total water	Effective + absorbed water	197.6

Modified ordinary concrete mixture – MOC

Changes in w/c ratio in order to achieve different properties of fresh and hardened concrete

Ordinary mortar (OM) and ordinary cement paste (OCP) mixture

PART 2: EXPERIMENTAL MATERIALS (div2)

LEVEL 1: ADVANCED MIXTURES

Idea of level 1:

Level 1 is focused on benchmarking of different types of concrete, found in EU labs. The idea is to develop advanced mixtures (based on OC mixture) using various locally available supplementary materials.

Added value of level 1:

To develop advanced concrete mixtures, e.g.:

- "ECO" concrete mixtures
- Impervious concrete
- Concrete with less (or no shrinkage)
- Concrete wit less (or no) cracks
- Other "innovative" concrete mixtures obtained by different supplementary (waste) materials

PART 2: EXPERIMENTAL MATERIALS (div2)

LEVEL 2: MODIFIED MIXTURES

Idea of level 2:

Level 2 is focused on testing ability of different advanced techniques developed by EU researchers to test various properties of cement based materials and to adequately detect changes in the material's composition. Participants are encouraged to modify reference mixtures (e.g. changes in w/c ratio, amount of aggregate, amount of admixtures, curing conditions, etc) in order to show the "power" of their techniques.

Added value of level 2:

- To present newly developed advanced techniques and to find the most suitable technique to monitor specific properties of cement based materials,
- To recommend such techniques to become standard in the (near) future,
- To present newly developed experimental equipment

PART 2: MIXING PROCEDURE AND CURING CONDITIONS

Arrival of the materials

Acclimatization phase

under controlled environment at least 7 days before mixing

- Ambient temperature: 20±2°C,
- Relative humidity: RH ≥ 60%,
- Special attention to reactive materials

Saturation of aggregate

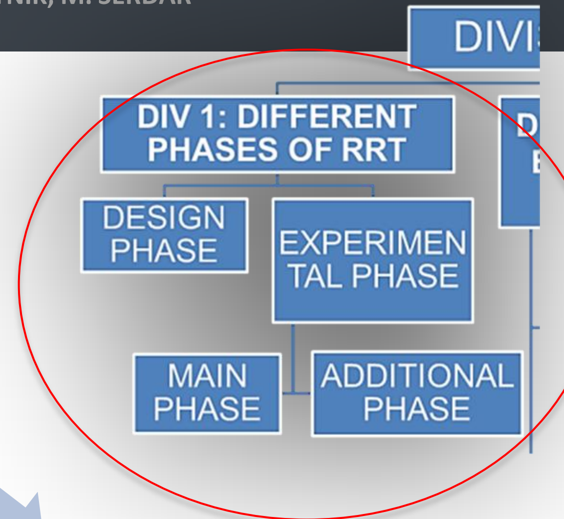
- fully saturated aggregate , dry aggregate, something in the middle – to be discussed...

DETAILS WILL BE PROVIDED IN RRT DOCUMENT

Mixing procedure and basic tests

- Under controlled environment (20±2°C, RH≥60%)
- **MIXING PROCEDURE IS DESCRIBED IN RRT DOCUMENT**
- Determination of consistency, temperature, and density

PART 3: PERFORMANCE



We are here now.

DESIGN PHASE

(Core Group, WG1 leaders, GP leaders)

- 1st RRT document with a special focus on GP plans prepared by GP leaders
- WorkShop in Ljubljana
- Finalizing RRT document
- Dissemination of 1st RRT document

MAIN PHASE

(all the participants, managed by GP and WG1 leaders)

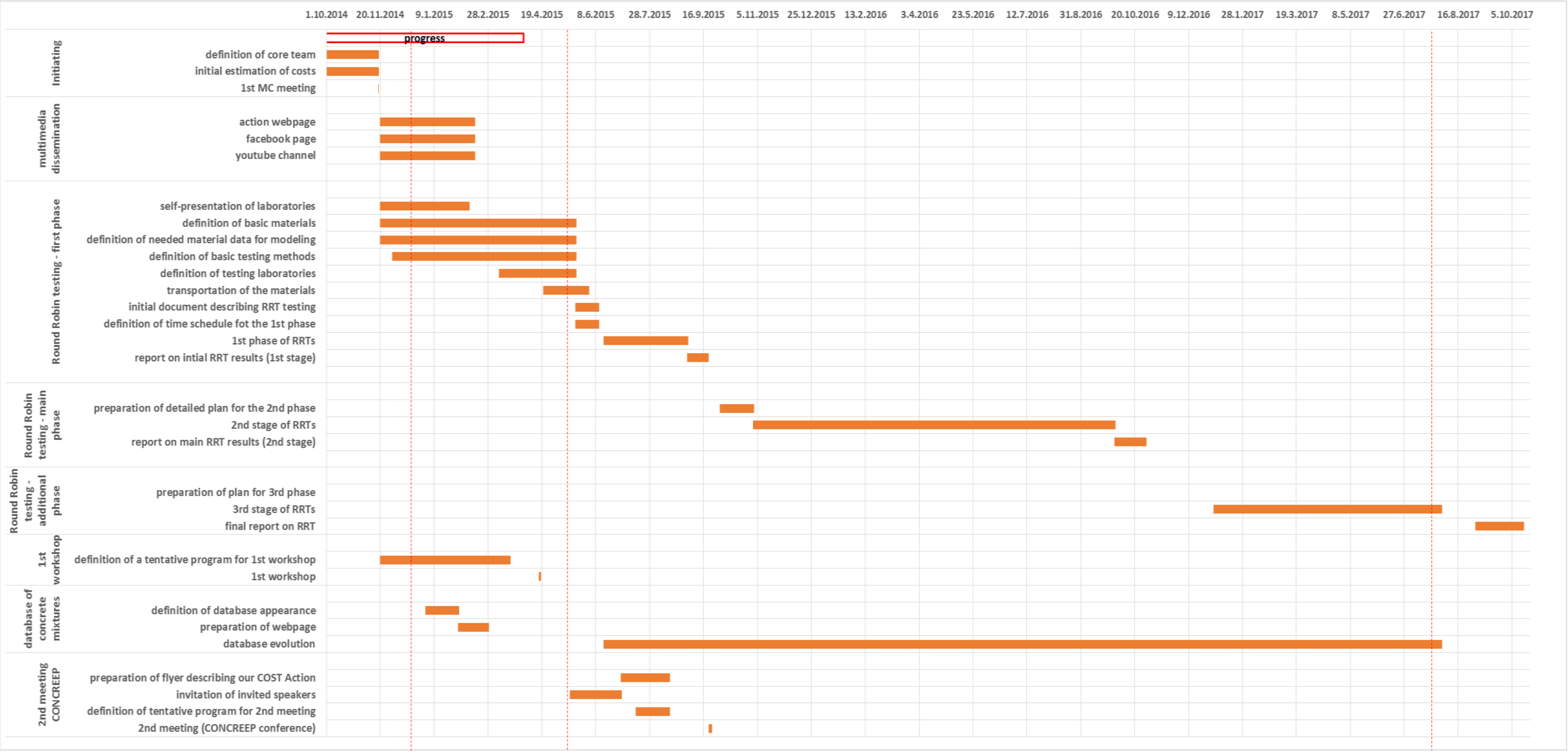
- Transportation of basic materials,
- Acclimatization of the materials,
- Definition of experimental packages by GP leaders,
- Definition of time-schedules by GP leaders
- Analysis of the results

ADDITIONAL PHASE

- Additional experiments based on the results of main phase

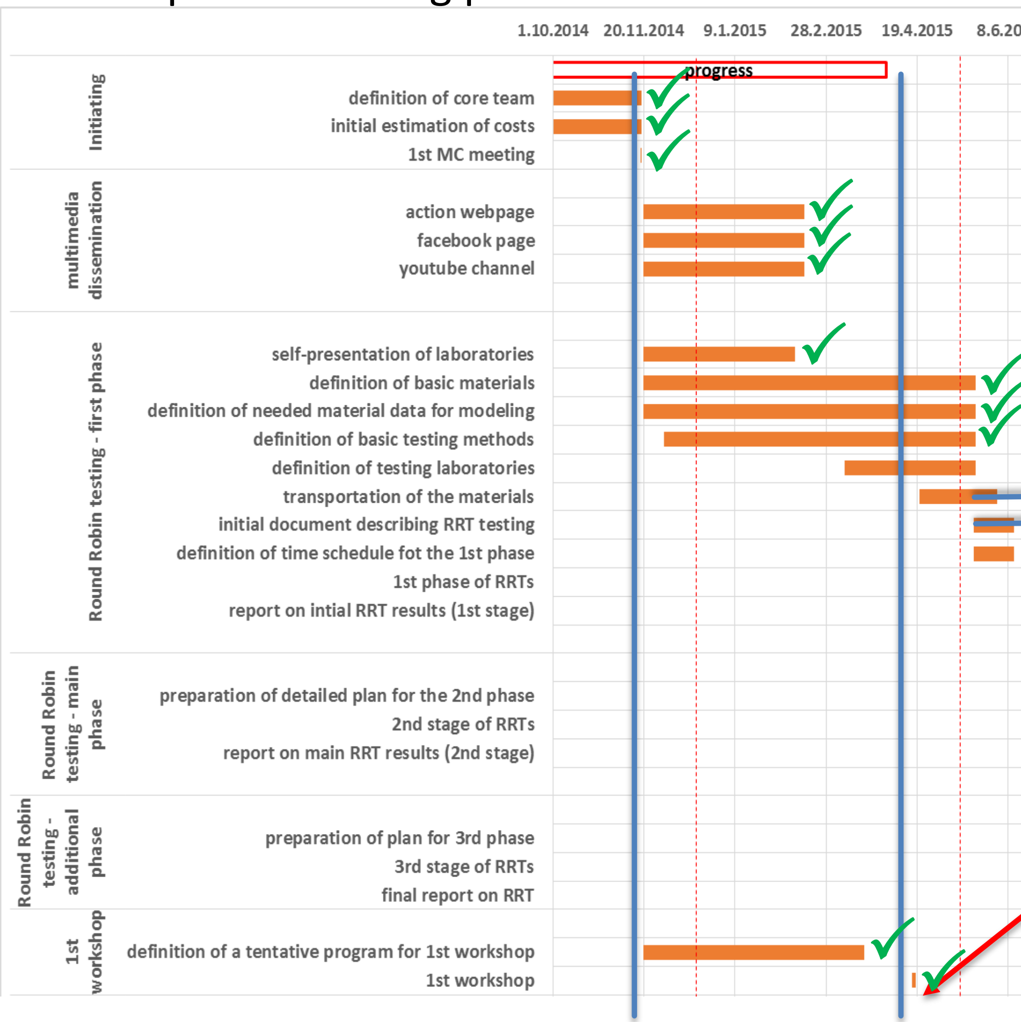
PART 3: TIME SCHEDULE

Overview – already presented in Brussels in November, 2014



PART 3: TIME SCHEDULE

1st part – defining phase



planned to start in May, 2015 and finish by June, 2015

already at its final stage, dissemination is planned to start at the beginning of May, 2015

We are here now.

PART 3: TIME SCHEDULE

2nd part – testing phase

We are here now.

Main experimental phase
July, 2015 – October, 2016

VeRCoRs project: focus on experimental program and first concrete results

Elsie BABY - civil engineer at EDF R&D
French national Electricity Company, France

Context for EDF

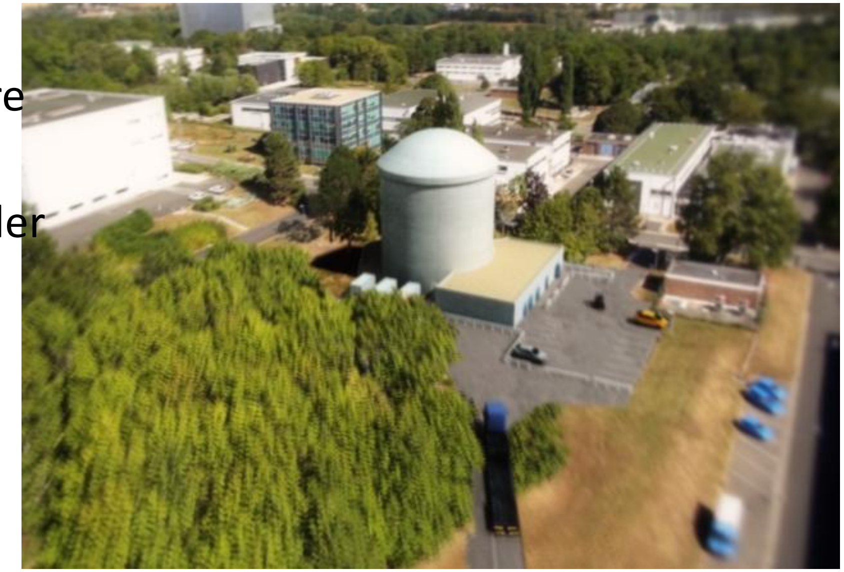
VeRCoRs means Vérification réaliste du Confinement des Réacteurs
(= Realistic Verification of Reactor Building Confinement)

EDF Target

Continuous effort on the safety and life extension of the nuclear power plant

Main objectives of the VeRCoRs Mock up

- Give confidence in the behavior under severe accident conditions
- Study the evolution of the leak tightness under the effects of the ageing
- Study the behavior at early age
- Experiment monitoring and NDE techniques



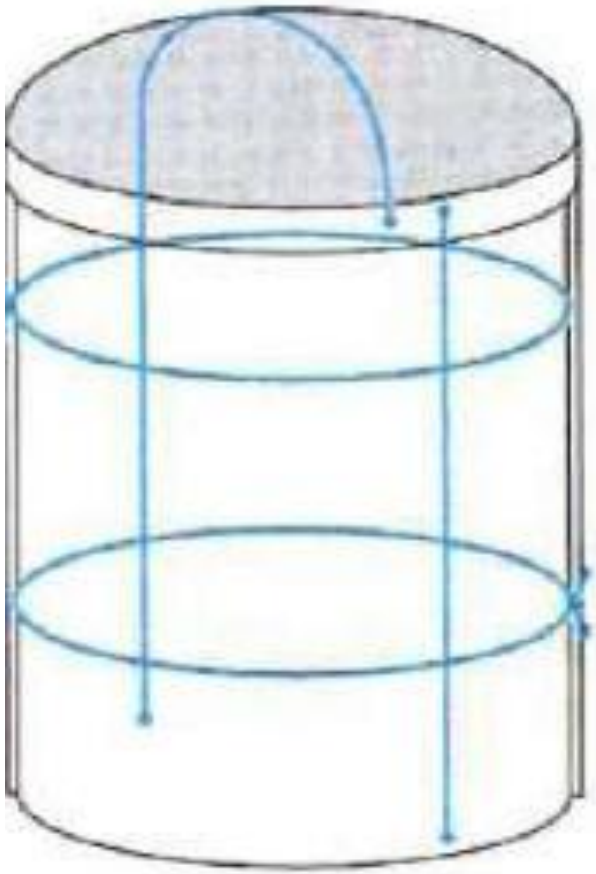
The VERCOS mock-up supports both industrial and research objectives

Design choices

- **Representativeness** : the mock-up has to be as close as possible to the real containment building
  - ***Geometry*** : the same complexities as the industrial containment structure: base raft, gusset, 3 penetrations, access hatch, dome, grouted prestressing tendons, …
  - ***Mechanical loading*** : same prestress ; periodic pressure test at 0.5 MPa as in the real case at ambient temperature

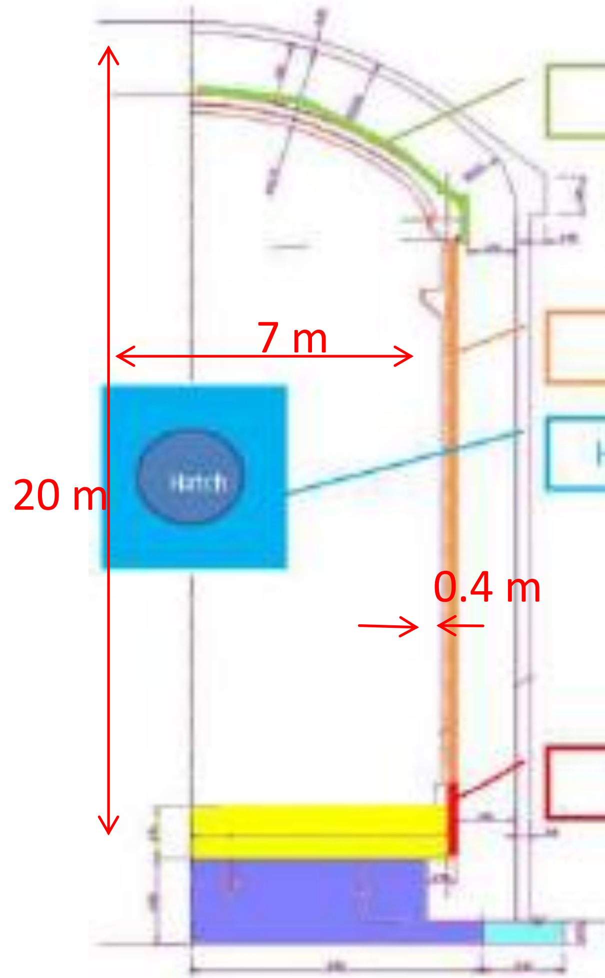
- **Accelerated aging**: in order to anticipate on the mock-up the behaviour of NPP containment walls after 40 to 60 years of operation.
  - ***Proposed solution*** : to construct the mock-up at a reduced scale (scale 1:3). The drying of the structure will be then faster, as the wall thickness will be 'only' 40 cm.
    - a faster drying creep (supposed to be the main phenomenon explaining the leak rate evolution)

General Design



VeRCoRs prestressing principle

Some orders of magnitude



VeRCoRs outline

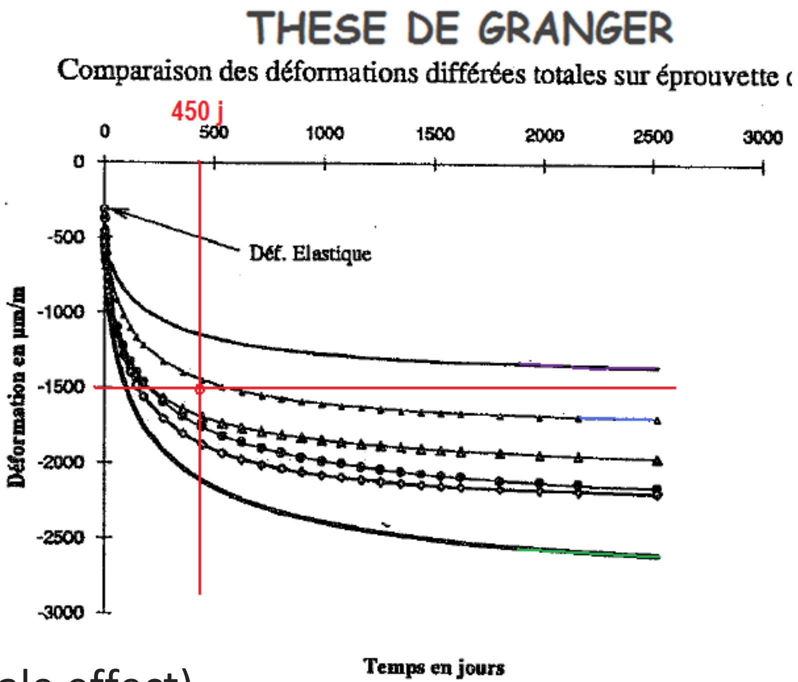
Some pictures of construction

Criterias for the choice of the concrete composition

Objective : concrete with significant creep (average of NPP's concrete creep)

Creep value at 15 months :

1500 µm/m



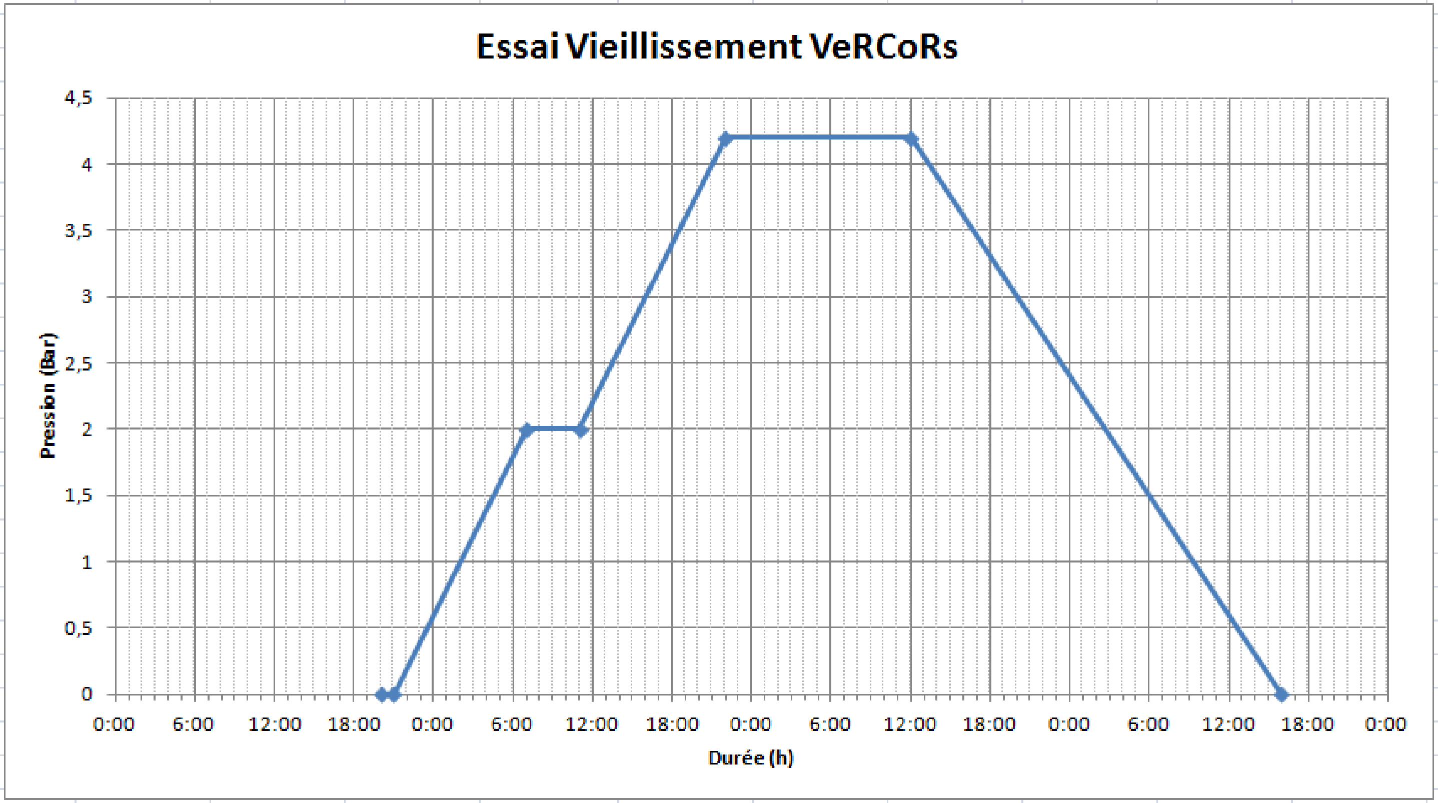
- Criteria for the size of the aggregate (due to scale effect)
- Criteria on mechanical properties (E modulus, strengths)

Concrete composition

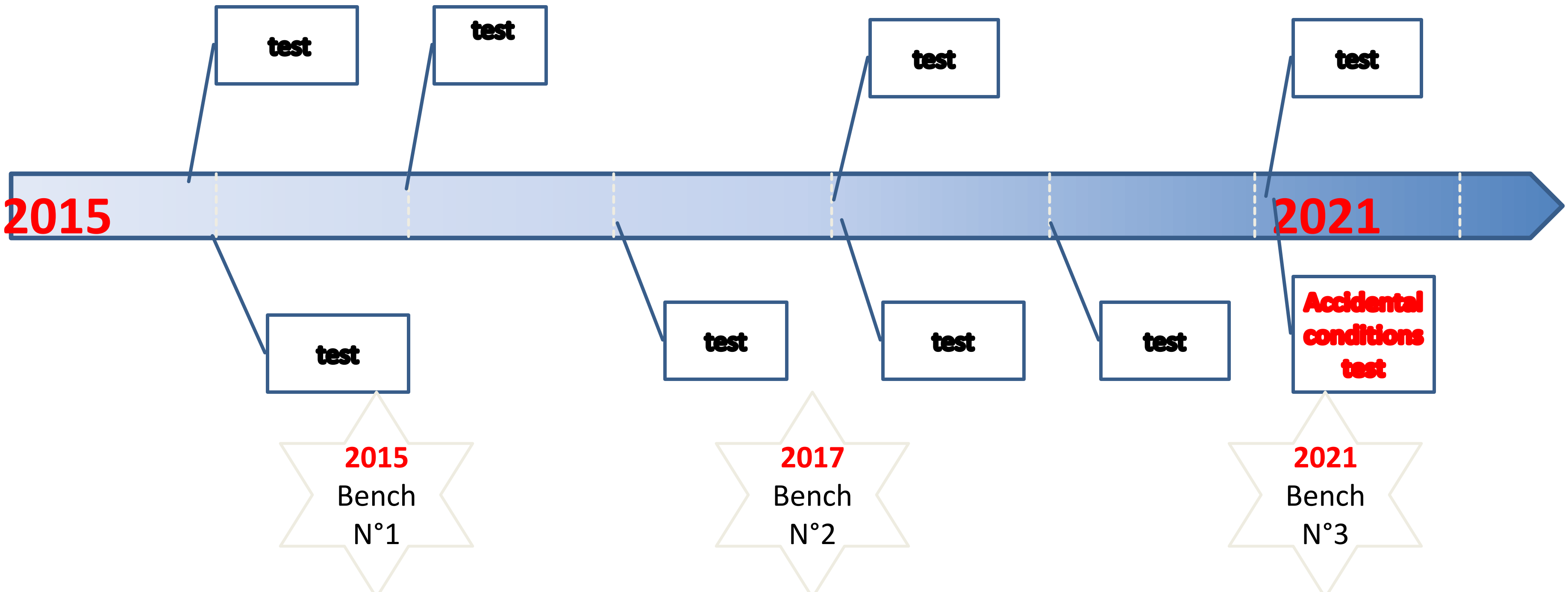
Component	kg/m^3
Cement CEMI 52,5 N CE CP2 NF Gaurain	320
Efficient water volume	167.2
Total water volume	197.6
Sand 0/4 rec GSM LGP1	830
Aggregate 4/11R GSM LGP1	445
Aggregate 8/16R Balloy	550
Admixture : Sikaplast Techno 80	2.4

Forecast schedule of a pressurization test

t	P
5/10/15 20:00	0
5/10/15 21:00	0
6/10/15 7:00	2
6/10/15 11:00	2
6/10/15 22:00	4,2
7/10/15 12:00	4,2
8/10/15 16:00	0



Agenda of pressurization tests and benchmarks



early age behaviour (cracking and leak)

ageing and effect of repeated load

mechanical behaviour under accidental conditions

Further informations on www.fr.amiando.com/EDF-vercors-project

Themes of the first benchmark

- **Theme 1 : early age**

Prediction of the gusset behavior at early age, since pouring to ten months

- **Theme 2 : containment history**

Prediction of deformations, stresses and cracking history of the whole containment wall

- **Theme 3 : leakage**

Prediction of air leakage during pressurization test

VeRCoRs experimental program

Normalized tests on fresh concrete

Conformity before concreting (consistency, air content, …)

Normalized tests on hardened concrete

Evaluation of material properties on the whole structure (E-modulus, resistance, …)

more **1 100 samples**

Complementary tests

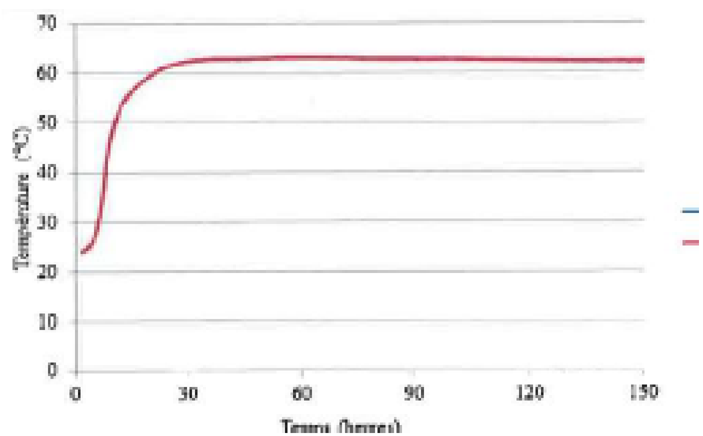
Complete map and provide data for benchmarks and effect of high temperature

Long-term tests

Effect of ageing

First test results provided for the benchmark related to early age

- Mechanical properties for each placement (air content, E-modulus, compressive and tensile strengths, porosity, permeability…)
- Hydratation heat release(semi adiabatic test QAB)



- Shrinkage (autogenous and driyng)
- Creep (basic and drying)

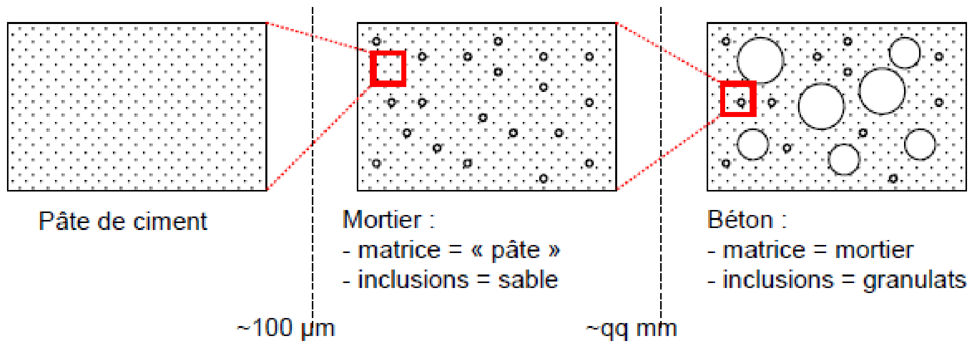
Experimental program lead at EDF R&D

- Characterization of drying and porosity
- Characterization of long term deformations
    - shrinkage
    - creep → **Influence of age of loading on concrete creep behaviour**
    - relaxation
- Evolution of mechanical properties in time



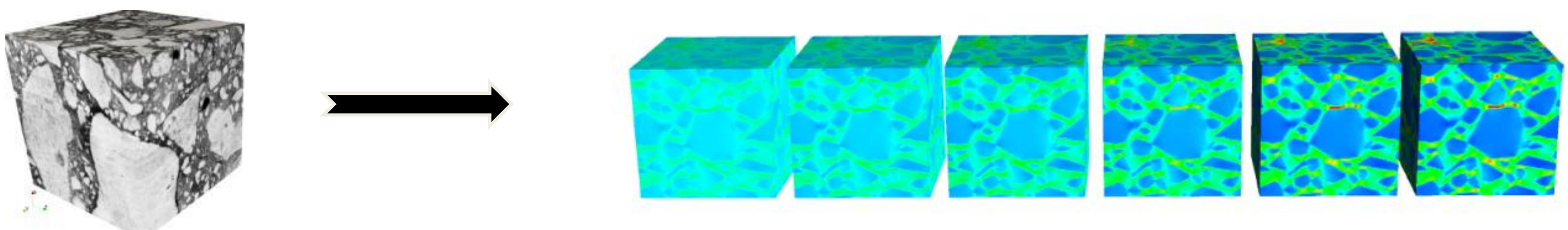

Multi-scale characterisation and modelling of concrete

- characterise cement paste and mortar scale to derive macroscopic behaviour



- Micro-structure imaging (SEM, 3D XRD) → **effective properties and local field computation**

(1)



(1) Francis Lavergne - "Méthodologies pour une prévision efficace et maîtrisée du comportement à long terme des bétons précontraints par l'imagerie et la simulation numérique"
Thèse de doctorat EDF R&D-Institut Navier (2012-2015)

Conclusion

Amibtious project

Challenges:

- Respect the whole requirements (representativity, ageing, monitoring) for construction and operating construction
- Detect more precisely leak paths and modelling leakaget
- Modelling the behaviour of the structure (accidental conditions)
- Management of the data from design, construction, monitoring and operating

VeRCoRs is already

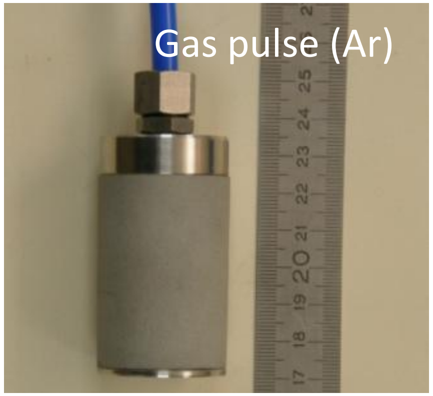
- Multi-dimensionnal and multi-disciplinary project
- Opportunity to work on real structure finely monitored and with an important characterization properties program for cementitious materials

Thermo-Mechanical monitoring

Data measured	VeRCoRs	Existing EDF NPPs
Temperature	> 200 PT100	~ 30 thermocouples
Concrete strain	> 300 vibrating wire 2 km of optic fiber	~ 50 vibrating wire -
Loss of prestess	4 cables with dynamometric cell	4 cables with dynamometric cell
Steel strain	80 gauges	-
Water content	~ 20 TDR & pulse	-

Vibrating wire

TDR



Pulse

Optic fiber

SESSION for WG2 – Modelling of CBM and structures

Chairman: Mateusz Wyrzykowski

Mateusz Wyrzykowski: Overview of the benchmarking proposal (simple benchmarking) of WG2

Farid Benboudjema: What input would I really like to get from an experiment (summary of the input of all WG2 participants, objectives and strategy of WG2)

Laurie Buffo-Lacariere: ConCrack experience or/and overview of the planned GP2e – benchmarking (case studies)

Discussion on WG2 and its benchmarking programme

Overview of the benchmarking proposal (simple benchmarking) of WG2

Mateusz Wyrzykowski – Empa, Switzerland
Farid Benboudjema- LMT-Cachan, France

TU 1404 COST ACTION

EMPA Materials Science & Technology

ENS CACHAN université PARIS-SACLAY

WG2

Modelling of CBM and the Behavior of Structures

- Objectives:
  - to support unified approaches for conducting numerical experiments for material properties of CBM, and
  - unified approaches for macroscopic modelling of CBM behaviour during the life cycle;
  - to integrate the conclusions from different modelling scales (from cement paste to structural level) to create a set of general instructions to be used in designing software for CBM and reinforced concrete structures.

WG2

Modelling of CBM and the Behavior of Structures

Structure

Group priorities		Part.	Leaders			
			Surname	Name	Country	Contact
GP2a	Microstructural modelling	36	Guang	Ye	The Netherlands	g.ye@tudelft.nl
GP2b	Multiscale Modelling	41	Dunant	Cyrille	Switzerland	cyrille.dunant@epfl.ch
			Pichler	Bernhard	Austria	bernhard.pichler@tuwien.ac.at
GP2c	Macroscopic modelling	46	Gawin	Dariusz	Poland	dariusz.gawin@p.lodz.pl
			Briffaut	Matthieu	France	matthieu.briffaut@3sr-grenoble.fr
GP2d	Probabilistic Modeling	24	Max	Hendriks	Norway	max.hendriks@ntnu.no
			Caspeele	Robby	Belgium	robby.caspeele@UGent.be
GP2e	Numerical Benchmarking	38	Buffo-Lacarrière	Laurie	France	lacarri@insa-toulouse.fr

81 participants

Benchmarking – 3 stages planned

- **Stage I – simple examples**

  - get to know and better integrate different modeling tools used by different participants; help in future implementation of new models

  The examples to be simulated will be **fully open**

  Time frame: announced April 2015, finished by the end of 2015

- **Stage II – extended examples**

  Blind (provided from WG/GP leaders) /**Open** (e.g. WG1 results)

  Time frame: announced mid-2016, finished by the end of 2016

- **Stage III – case studies (coordinated by GP2.e)**

  Blind (based on field experiments), presentation by L. Buffo-Lacariere

  Time frame: from end 2016 (also earlier – Vercors)

Stage I – simple examples

- **Stage I – simple examples**
  - **Example 1** – Heat evolution (isothermal calorimetry) and temperature evolution (adiabatic calorimetry)
  - **Example 2** – Hydration evolution, chemical shrinkage and porosity, RH
  - **Example 3** – Heat transfer and moisture transport in 1D
  - **Example 4** – Temperature field in concrete element
  - **Example 5** – Temperature evolution (boundary conditions)

Example I

Isothermal and adiabatic calorimetry (De Schutter and Taerwe CCR 1995)

Input data:

	CEM I 52.5	CEM III/B 32.5	CEM III/C 32.5
S_iO_2	19.92	26.76	27.12
Al_2O_3	5.02	7.33	9.40
Fe_2O_3	3.39	2.52	1.63
CaO	63.75	50.54	42.95
MgO	0.96	5.61	7.23
Blaine (cm^2/g)	5054	4380	4500

of three different cements

ɔf these cements

Simulate:

- hydration heat evolution at : 5°C, 20°C, 35°C
- adiabatic temperature evolution in concrete

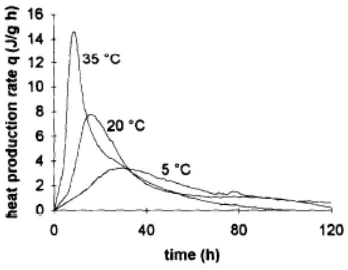


FIG. 3
Heat production rate q(t)

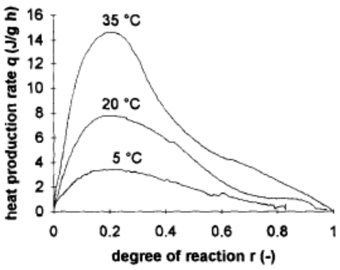


FIG. 4
Heat production rate q(r)

Example II

Hydration evolution, chemical shrinkage, porosity (Chen et al. CCR 2013)

Input data:

- composition and Blaine fineness of the cement (CEM I)
- cement pastes at w/c 0.30, 0.35, 0.40

Simulate:

- hydration heat evolution (20°C), sealed and saturated conditions
- Chemical shrinkage (saturated conditions)
- Pore size
- (Evolutio

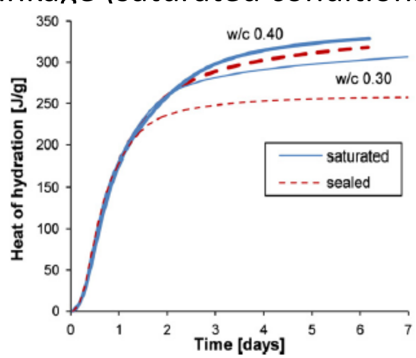


Fig. 4. Heat of hydration of w/c 0.30 and 0.40 pastes measured on samples cured in saturated and sealed conditions. The sample thickness was 4.5 mm.

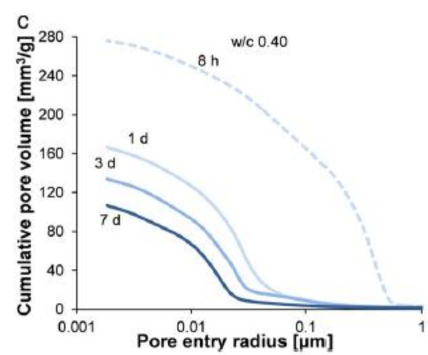


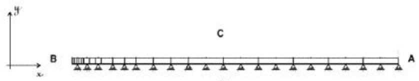
Fig. 6. Size distribution of pore entries measured with MIP for different hydration times for a) w/c 0.30, b) w/c 0.35, and c) w/c 0.40.

Example III

Heat transfer and moisture transport in 1D (Gawin et al. IJNME 2006)

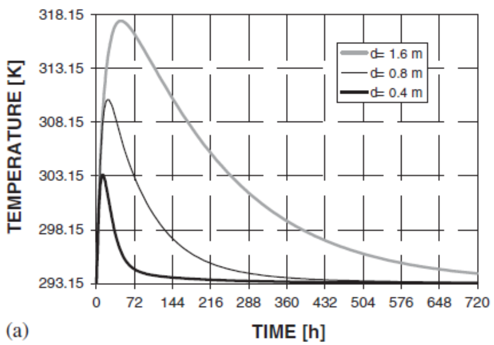
Input data:
- geometry (1D)
- Heat source formulation/moisture sink
- Adiabatic calorimetry data

Table II. Boundary conditions for the first example.



Side	Variables	Values and coefficients	BC type
A	u_x	$u_x = 0$	I
	u_y	$u_y = 0$	I
	p^g	$q_g = 0$	II
	p^c	$q_{gw} = q_w = 0$	II
	T	$q_T = 0$	II
B	p^g	$p^g = 101\,325$ [Pa]	I
	p^c	$q_{gw} = q_w = 0$	II
	T	$q_T = 0$	II
C	p^g	$q_g = 0$	II
	p^c	$q_{gw} = q_w = 0$	II
	T	$q_T = 0$	II
D	u_y	$u_y = 0$	I
	p^g	$q_g = 0$	II
	p^c	$q_{gw} = q_w = 0$	II
	T	$q_T = 0$	II

Simulate:
- Evolution of temperature and moisture content



(a)

Example IV

Temperature field in cocrete cube (Azenha et al. CBM 2011)

Input data:

- Geometry, concrete composition, environmental conditions
- Isothermal calorimetry data at 20, 30, 40, 50, 60°C

Simulate:

- Te compare to sur (thermography) and point me

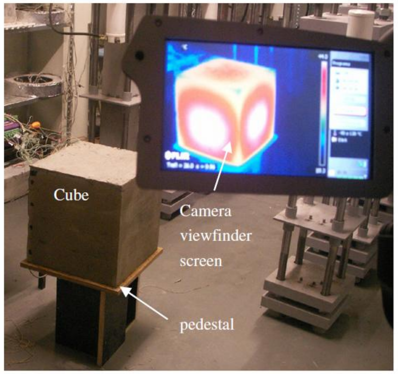
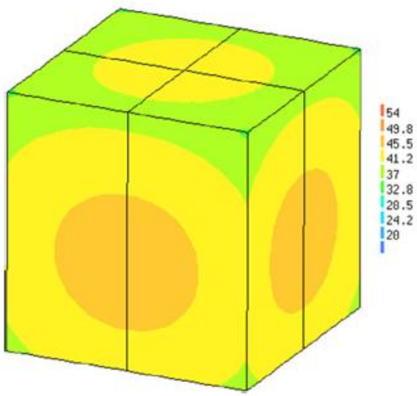


Fig. 2. View of the camera image and spatial relationship with the specimen.



Example V

Temperature field in cocrete cube (Honorio et al. Eng Struct 2014)

Input data:

- Geometry of the wall, concrete composition, different boundary conditions
- Isothermal calorimetry data at 20, 30, 40, 50, 60°C

Simulate:

- Temper ompare to numerical simulations results

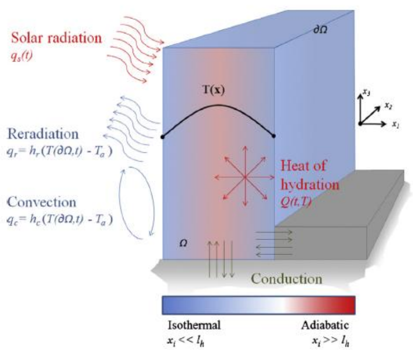
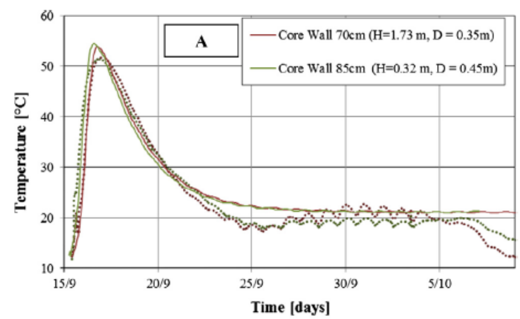


Fig. 1. Schematic representation of the phenomena involved in the chemo-thermal analysis of a concrete structure.



2nd Workshop

- **19-20 September 2015**, Vienna (before CONCREEP-10 conference)
- (registration by mid-August)

- **Objectives** (draft):
  - to promote scientific discussion on the modelling activities, models development, etc. and integrate the modelling community within the Action;
  - to discuss further developments leading to recommendations/guidelines in collaboration with WG3
  - **to share some results of simple benchmarking campaign (stage I)**
  - to discuss and define a draft of benchmarking activities related to the experimental results of WG1 (stage 2)
  - to discuss and define benchmarking activities related to case studies (stage 3)

- For details please follow: http://www.tu1404.eu/september-2015-vienna

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What input would I really like to get from an experiment

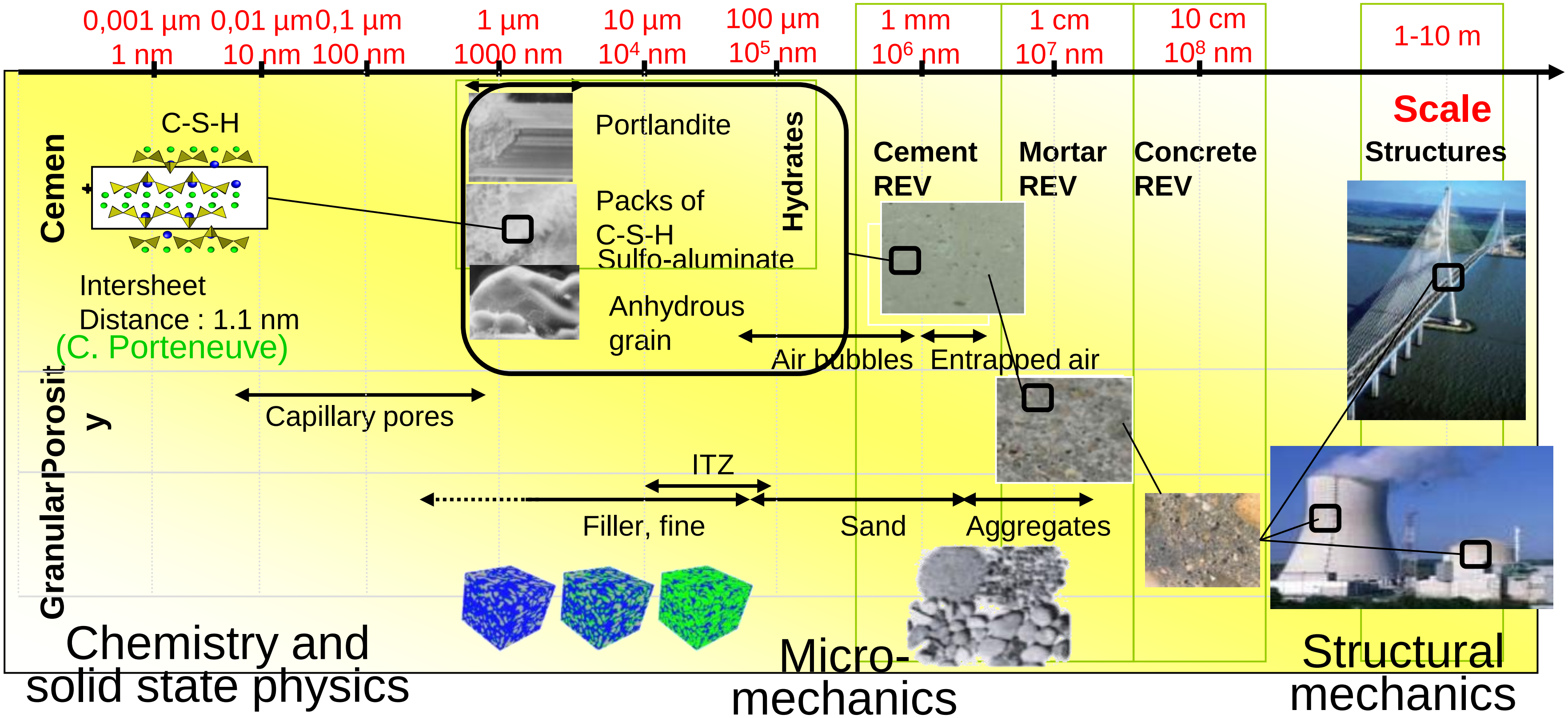
Farid BENBOUDJEMA - Laboratory of Mechanics and Technology, ENS Cachan, France

Mateusz WYRZYKOWSKI - Concrete/Construction Chemistry Lab, Switzerland

EMPA Materials Science & Technology

ENS CACHAN université PARIS-SACLAY

Concrete: a great challenge !



Prediction of macroscopic properties (numerical experiments), cracking … at different ages, scales for different concrete mix and ambient conditions in structures …

Phenomenological and macroscopic approach

Hydration (thermo-activation)

$$\dot{\xi} = \tilde{A}(\xi) e^{-E_a/RT}$$

Heat + exothermy

$$C \frac{\partial T}{\partial t} = \nabla(k \nabla T) + L\dot{\xi}$$

Thermal + Autogeneous shrinkage

$$\dot{\boldsymbol{\varepsilon}}^{th} = \alpha \dot{T} \mathbf{1} \qquad \dot{\boldsymbol{\varepsilon}}^{au} = \kappa \dot{\xi} \mathbf{1}$$

Drying and drying shrinkage

D_w = $10^{-9}/10^{-12}$ m².s^{-1} / D_{th} = 10^{-6} m².s^{-1}

$$\dot{m}_l + div(m_l \mathbf{v}_l) = -\dot{m}_{vap} - \dot{m}_{hyd}$$

$$\boldsymbol{\sigma} = \tilde{\boldsymbol{\sigma}} - bS_l p_c \mathbf{1}$$

Almost all parameters vary with hydration degree, temperature …

$$\dot{\sigma} = E(\xi)(1-D)(\dot{\varepsilon} - \dot{\varepsilon}^{th} - \dot{\varepsilon}^{au} - \cdots)$$

$$f(\sigma, \xi) \leq 0$$

A lot of equations and a lot of parameters

Couplings

$$\hat{\varepsilon} = \sqrt{\langle \boldsymbol{\varepsilon}_e + \beta \boldsymbol{\varepsilon}_{bc} \rangle_+ : \langle \boldsymbol{\varepsilon}_e + \beta \boldsymbol{\varepsilon}_{bc} \rangle_+}$$

Basic, drying creep …

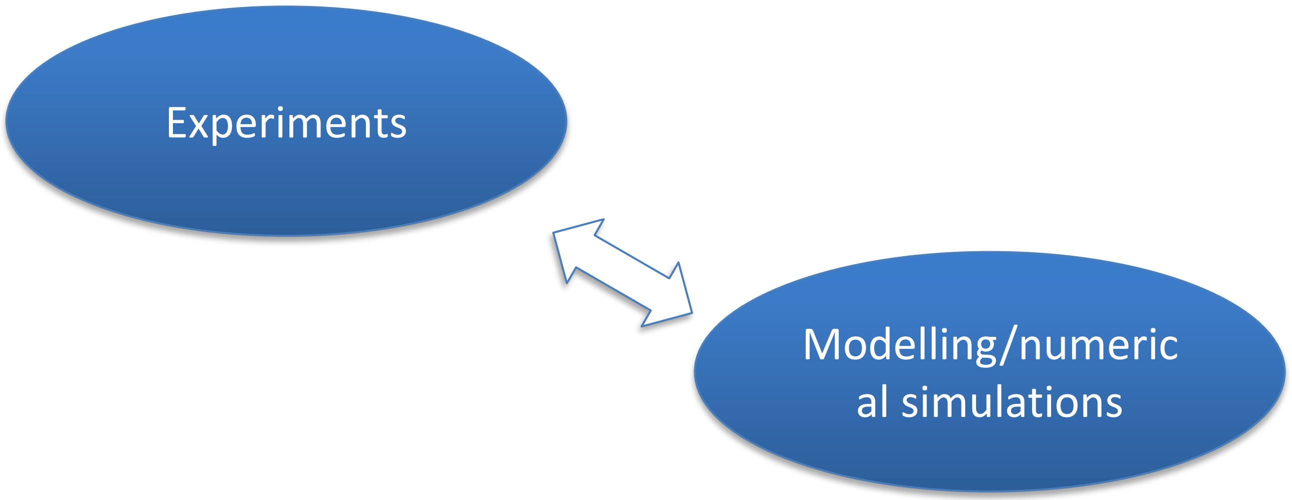
$$\tau_{bc}^i \ddot{\varepsilon}_{bc}^i + \left(\tau_{bc}^i \frac{\dot{k}_{bc}^i(\xi)}{k_{bc}^i(\xi)} + 1 \right) \dot{\varepsilon}_{bc}^i = \frac{\dot{\tilde{\sigma}}}{k_{bc}^i(\xi)} \qquad \tilde{\sigma} = \eta_{bc}^i(\xi) \dot{\varepsilon}_{bc}^j$$

STRATEGY

- Interaction with WG1 and WG2: Win/Win strategy

« Models without data have no predictive ability, but data without models bring confusion »

Prof. Jacques Louis Lion (about weather science)



What we need?

- We need everything! : T, RH, locations of sensors … some information may to seem to be useless, but can serve in the future
- Basically, we need « classical » material parameters, but …

Exemple: heat balance equation

$$C\dot{T} = div\left(k \cdot gradT\right) + \dot{q}_{hyd} + \dot{q}_{evap/cond} + \cdots$$

But non only constant value ⇨ also some evolution

$q_{hyd} = L\,\xi$? or $= Q_{\mathrm{tot}} \left(\frac{\tau}{t_e}\right)^{\beta} \left(\frac{\beta}{t_e}\right) \alpha_H(t_e)\, e^{\frac{E_K}{R}\left(\frac{1}{T_{\mathrm{ref}}} - \frac{1}{T}\right)}$ or …

Schindler and Folliard (2005)

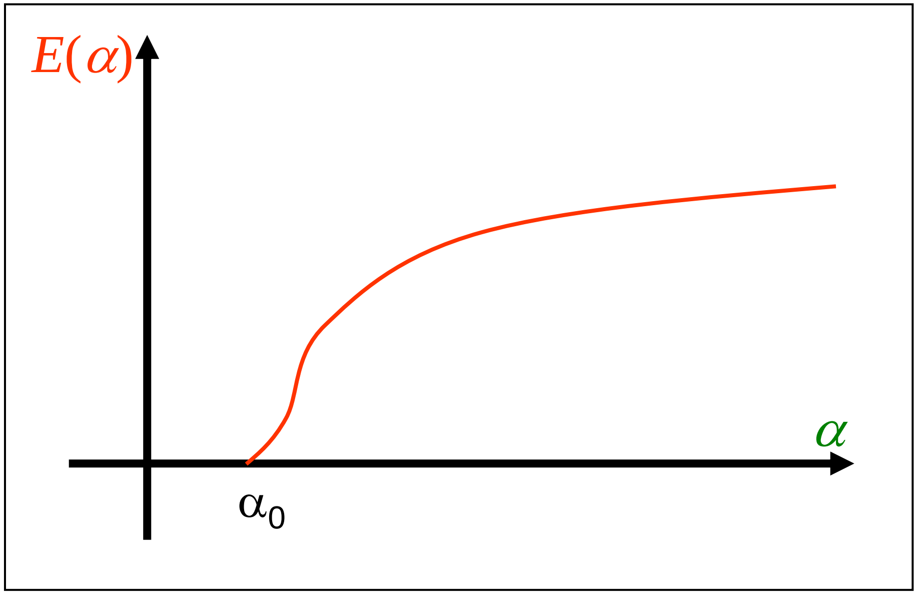
$$C(\xi, T, S_l, \cdots) = f(\xi) \cdot g(T) \cdots \text{or} = h(\xi) + i(T) + \cdots$$

Modelling is needed at this level!

Difficulty: we need to know mechanisms!

GP1a

Exemple:



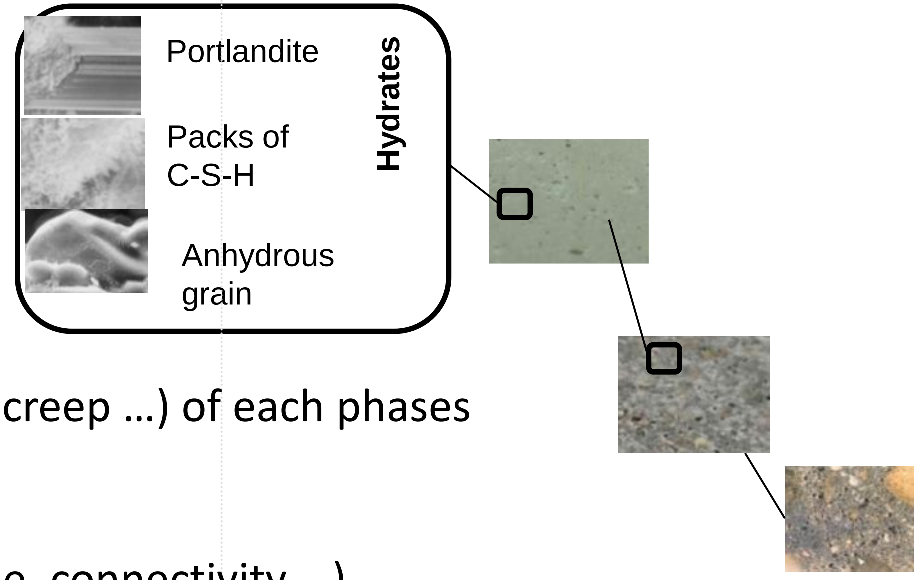
Values of α_0, evolution law

⇨ But do we express laws with respect to α or t_e, maturity …, do we take the Vicat setting information (initial or final setting time ?), do we take UPV measurements, EMM-ARM measurements?

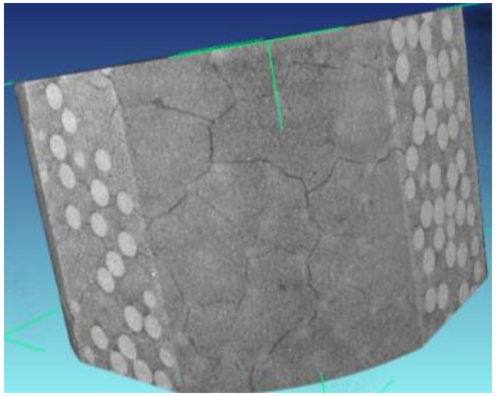
⇨ what is the effect of temperature history (massive concrete structures, do we reduce « final » values?

⇨ Do we really need to put effort in Poisson ratio (cracking in tension) ?

GP1b



- Volume fractions evolutions of hydrates, anhydrous cement grains
- Mechanical parameters (elastic, creep …) of each phases (hydrates to aggregates)
- Morphology of the phases (shape, connectivity …)
- What about the ITZ, its constitution, its properties (or gradient of properties ?)
- Is it possible to use X-ray tomography, mesh the specimen which will be tested? And compare virtual/reals testing? In-situ test in tomograph? Use of material model (glass bead)



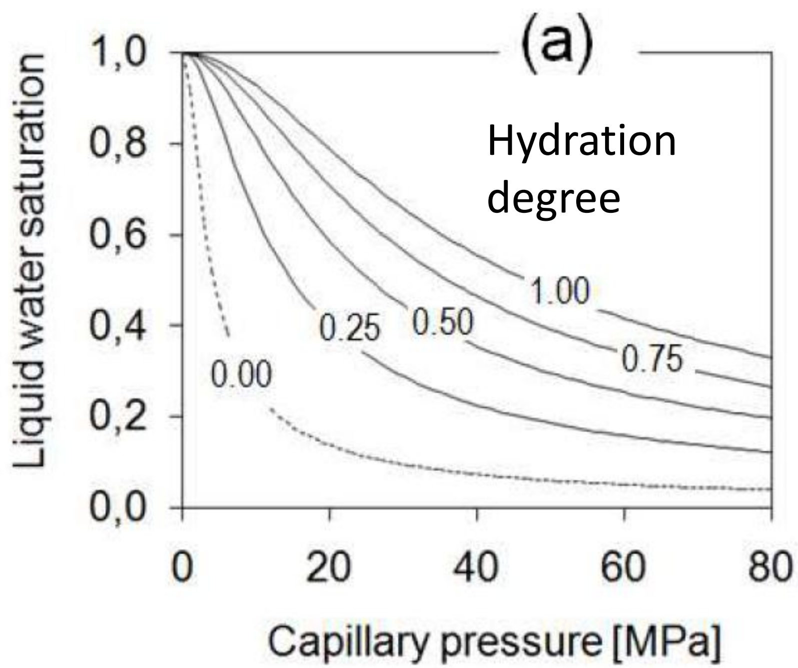
Malbois (2014)

GP1c

- Like the *heat equation*, parameters with evolution laws, dissociation of effects of temperature, relative humidity, hydration degree (and stop it to make some measurements)

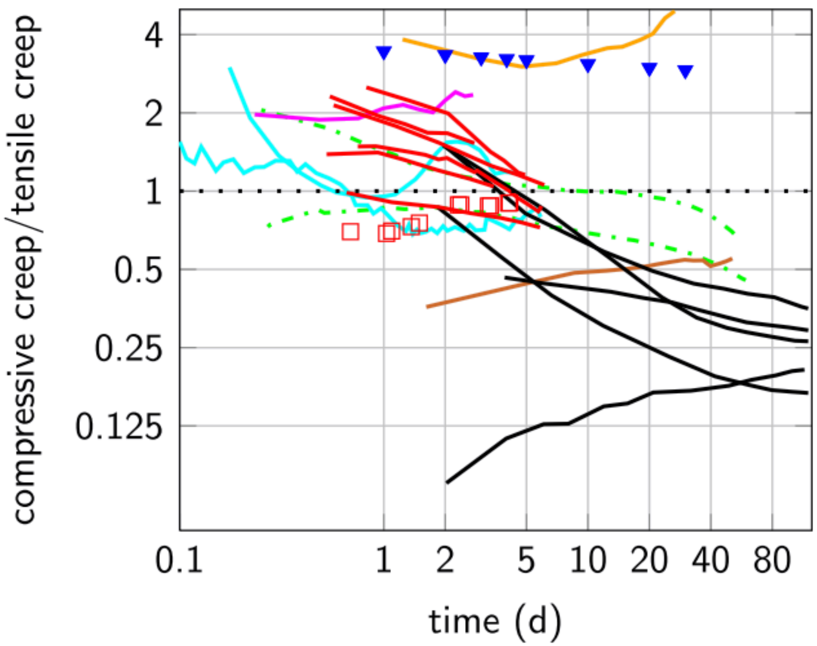
Exemple: need of desorption isotherm (water content/relative humidity) at early age, to calculate moisture transport

Sciumè (2012)



GP1d

- Creep: what are the mechanisms, is it the same in tension/compression ?



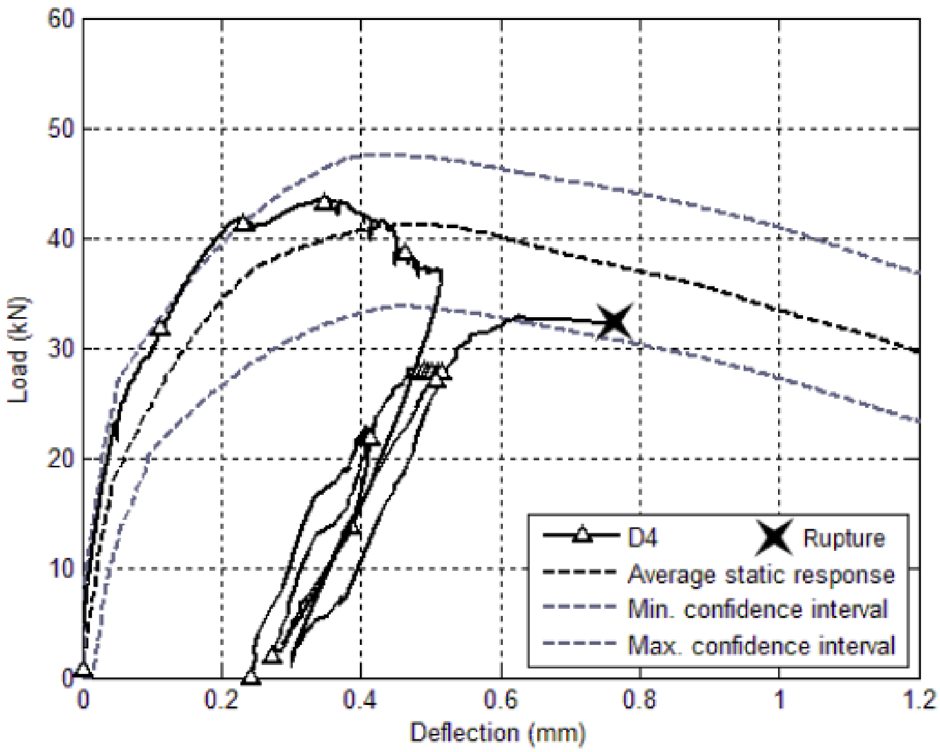
Creep in compression is higher than in tension

Creep in tension is higher than in compression

Data from different authors in autogeneous conditions, which test do we trust ?

GP1d

- Creep: coupling with cracking in tension

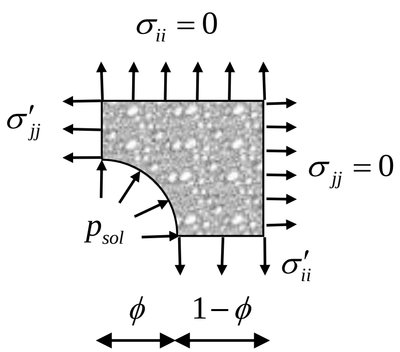


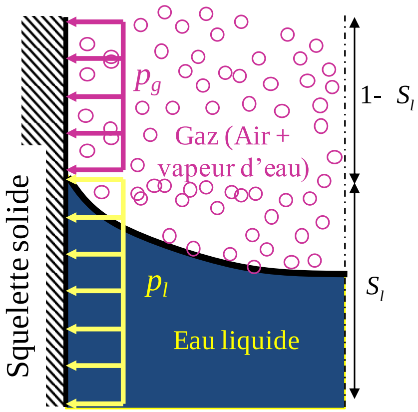
Bending tests (at Ecole Polytechnique de Montréal, Desnoyers, 2015)

GP1e

- What is the effect of temperature/hydration degree on autogeneous shrinkage?

- What are the mechanisms related to autogeneous shrinkage: capillary pressure? Effects of superficial tension of pore solution (Lura, 2003)



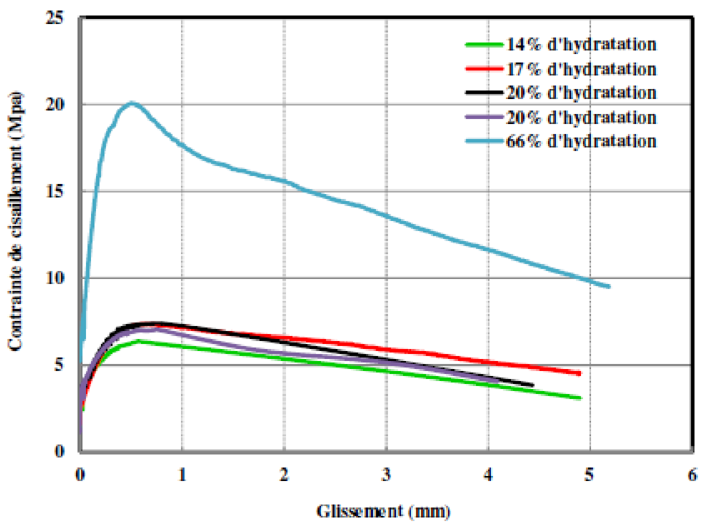


$$\boldsymbol{\sigma} = (1-\phi)\boldsymbol{\sigma}' - \phi S_l p_c \mathbf{1} = \tilde{\boldsymbol{\sigma}} - b S_l p_c \mathbf{1}$$

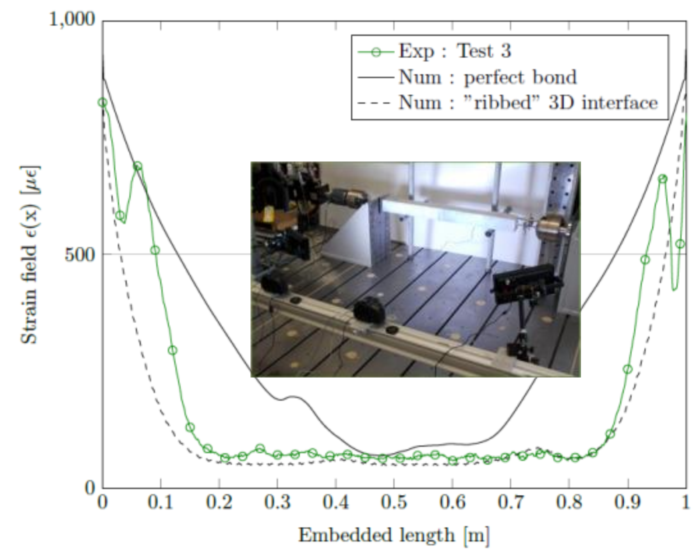
With Kelvin-Laplace equations

GP1f

- Do we use for tensile strength: splitting, direct, bending tests, what about size effect? Evolution of fracture energy?
- <u>Reinforced</u> concrete structures: effect of hydration degree and bond strength

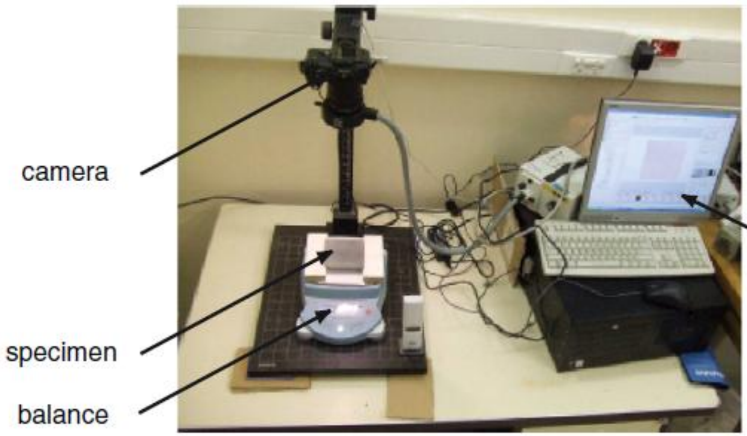


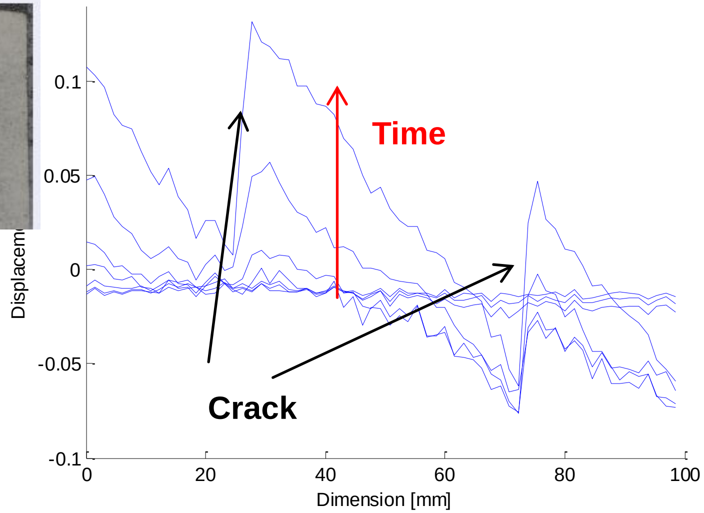
Pull-out tests (LMDC, Toulouse, Kolani (2012)



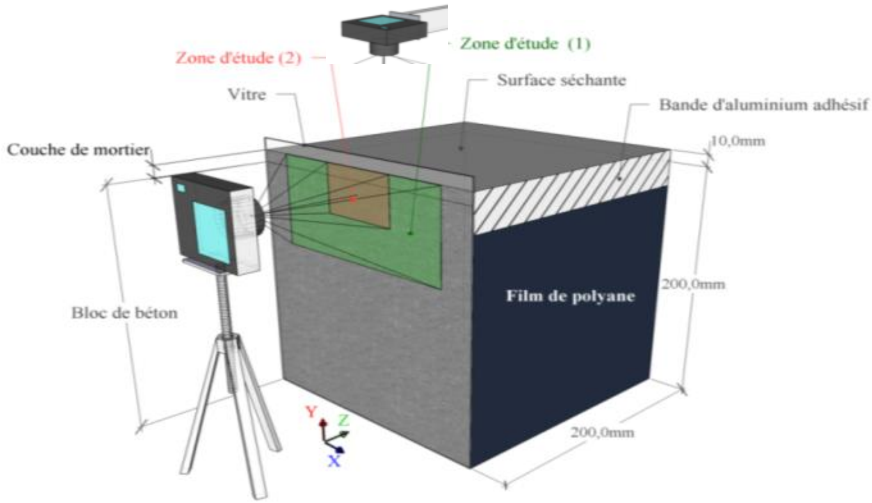
Concrete tie (Michou, 2014)
Optical fiber device from IFSTTAR

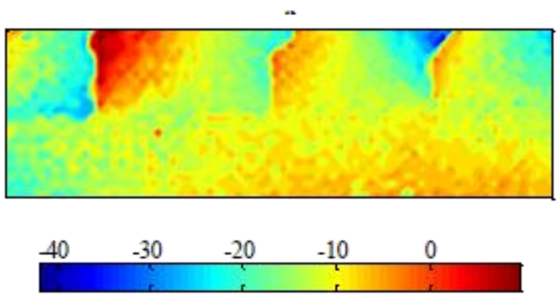
Dreams of lots of full-field measurements





Lagier (2011)



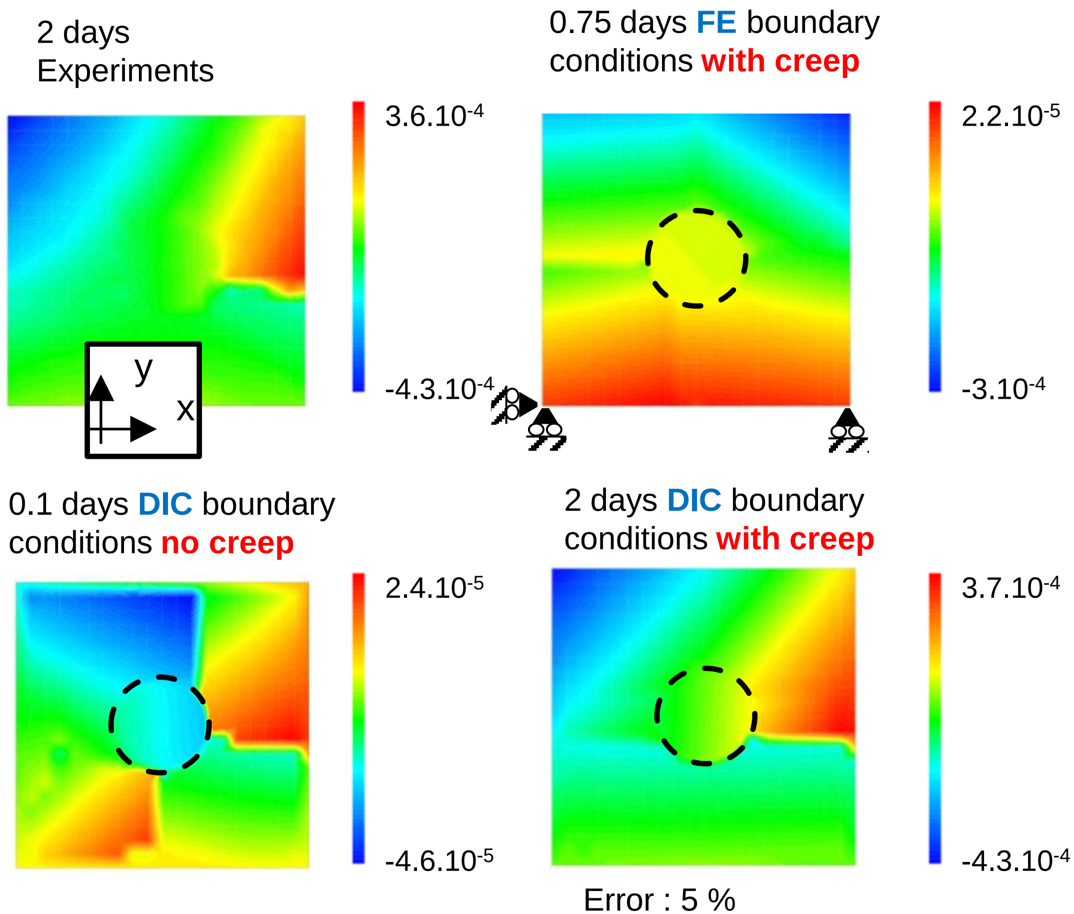


Mortar

Concrete

Mauroux (2012)

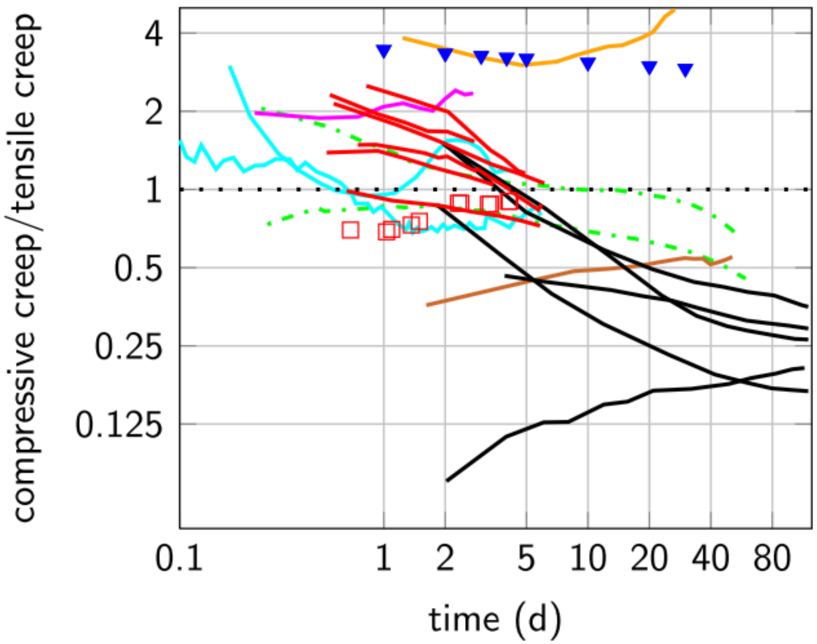
Full-field measurements



- Better results if DIC boundary conditions/creep models are used
- But discrepancies remain: creep parameters, interface behavior, shear law …?

Parametric study and sensitivity analysis

Creep in tension vs. creep in compression



Creep in compression is higher than in tension

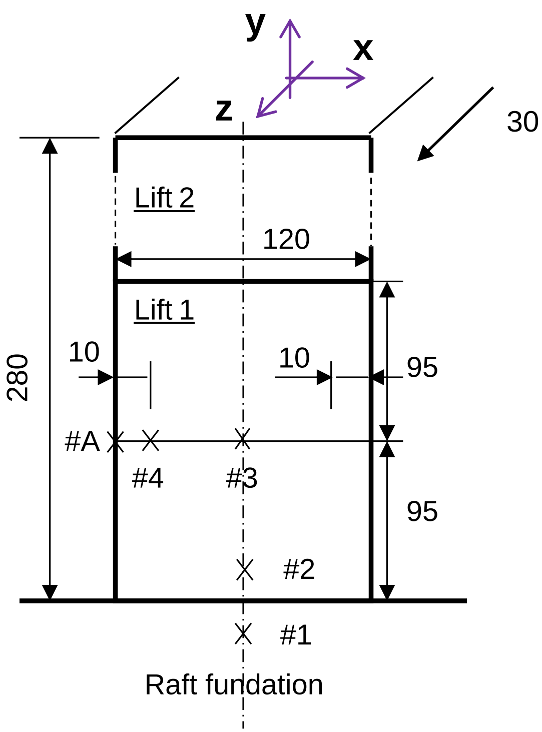
Creep in tension is higher than in compression

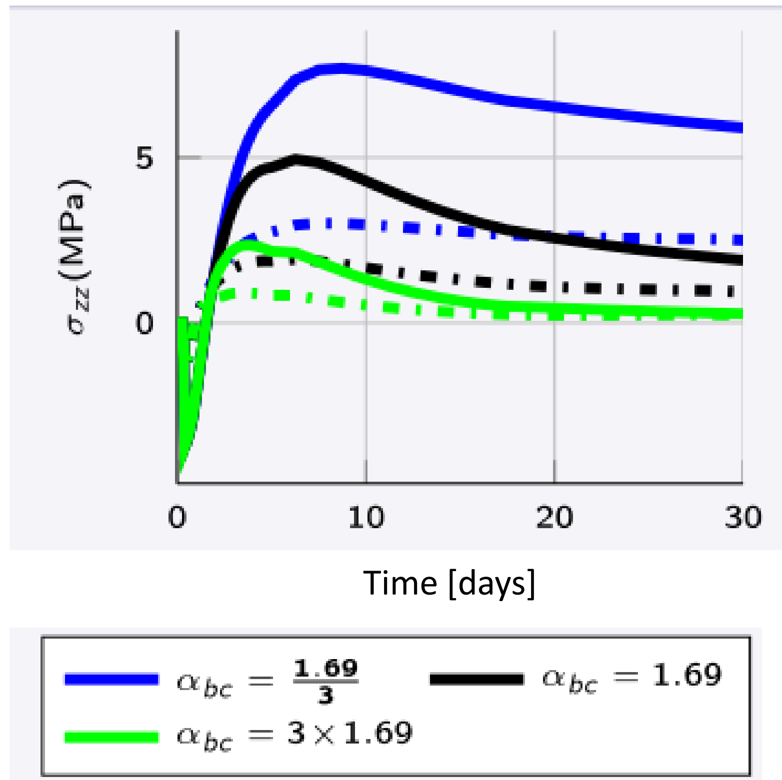
Most of time, data are available in compression
Code models suppose same creep

Parametric study and sensitivity analysis

Creep in tension vs. creep in compression

$$\alpha = \frac{\text{Creep in tension}}{\text{Creep in compression}}$$





Relaxation

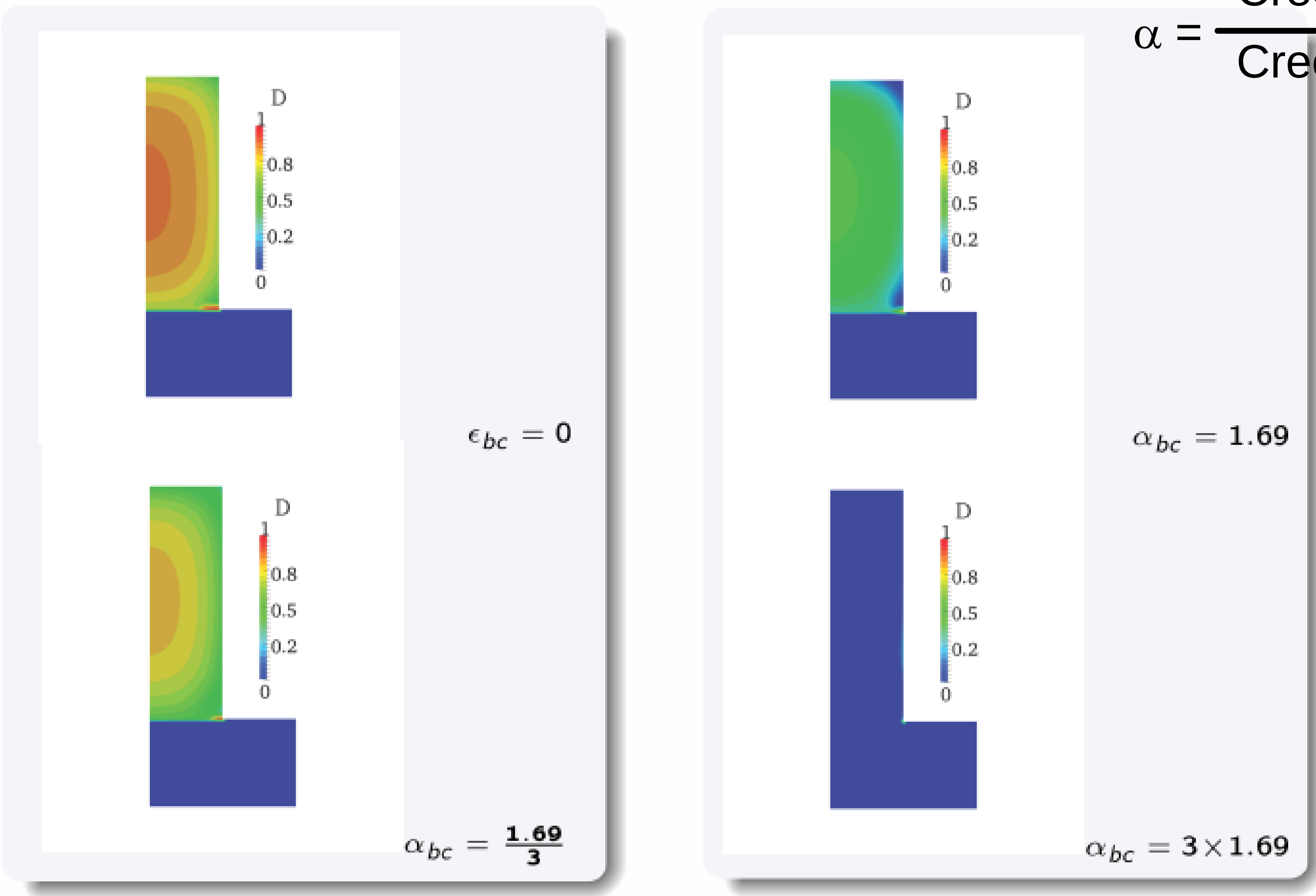
Same effects for other stresses (gradient)

Hilaire (2014)

Parametric study and sensitivity analysis

Creep in tension vs. creep in compression

$$\alpha = \frac{\text{Creep in tension}}{\text{Creep in compression}}$$

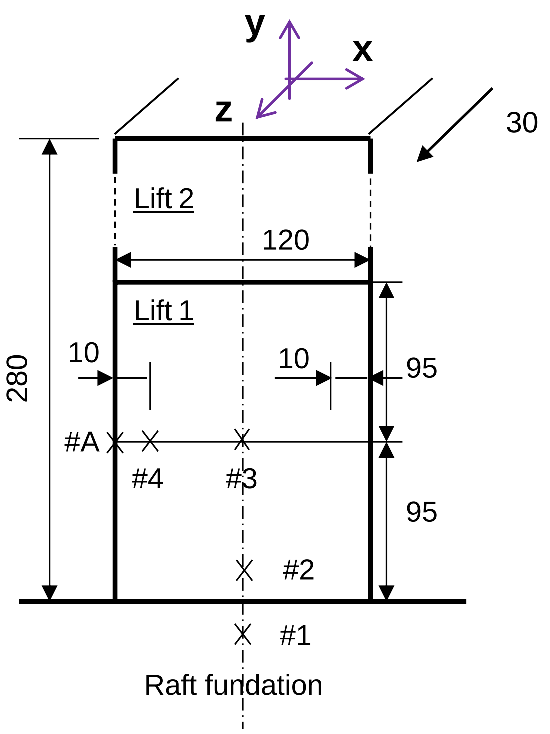


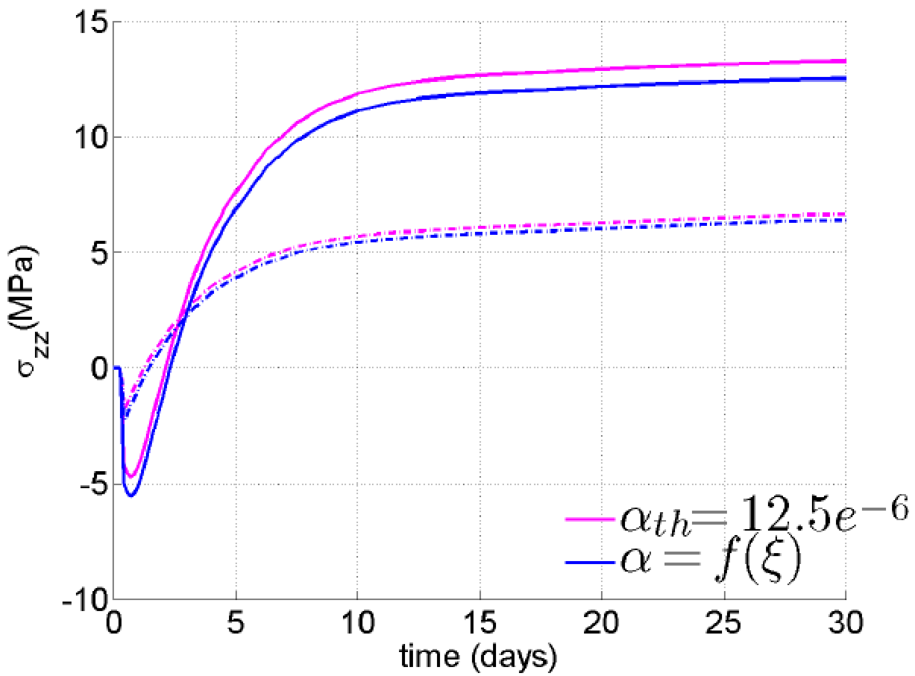
Damage (cracking) fields

Hilaire (2014)

Parametric study and sensitivity analysis

Effect of CTE variations at early age



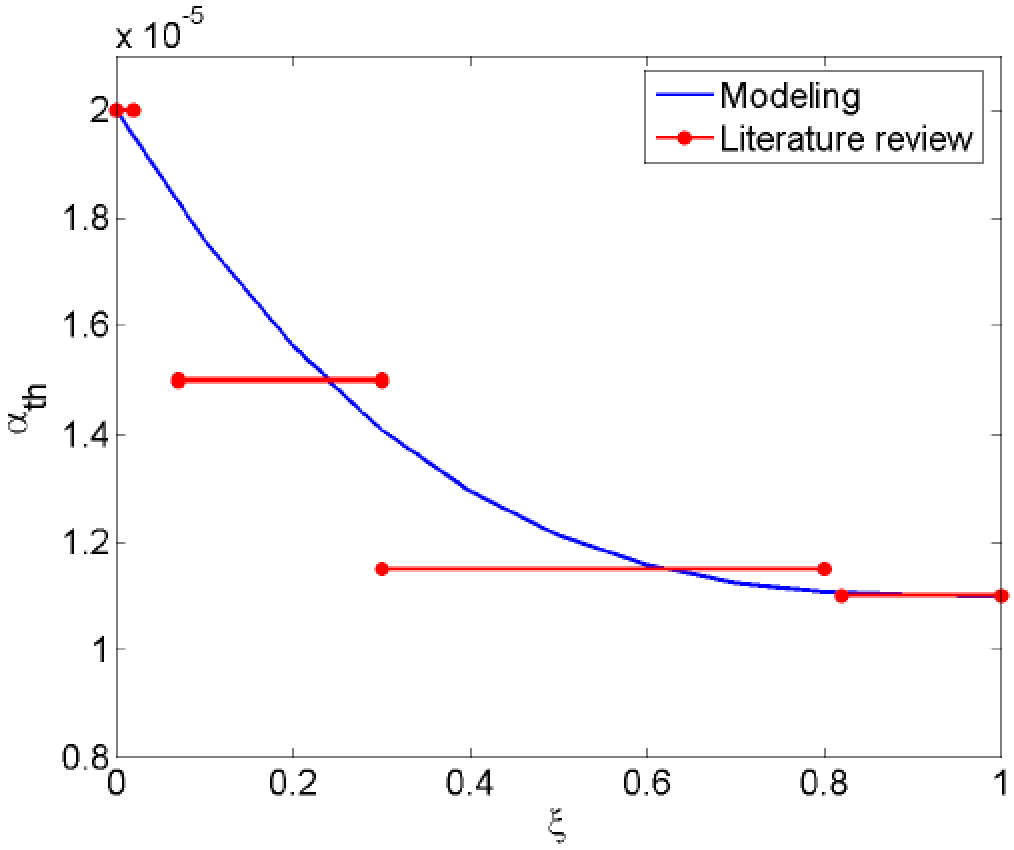


Same effects for other stresses (gradient)

Hilaire (2014)

Parametric study and sensitivity analysis

Effect of CTE variations at early age

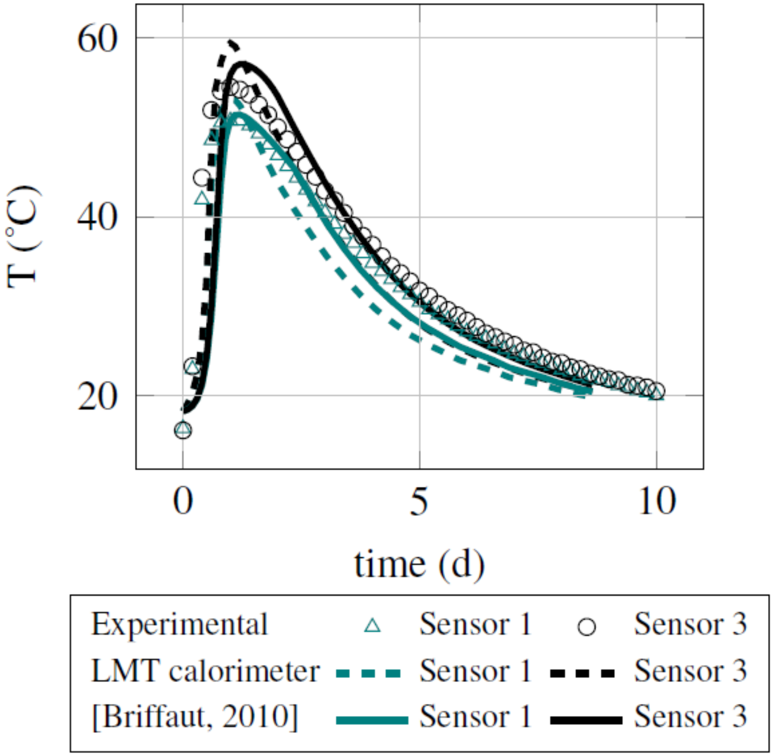


[De Schutter, 1996]

Parametric study and sensitivity analysis

Effect of CTE variations at early age

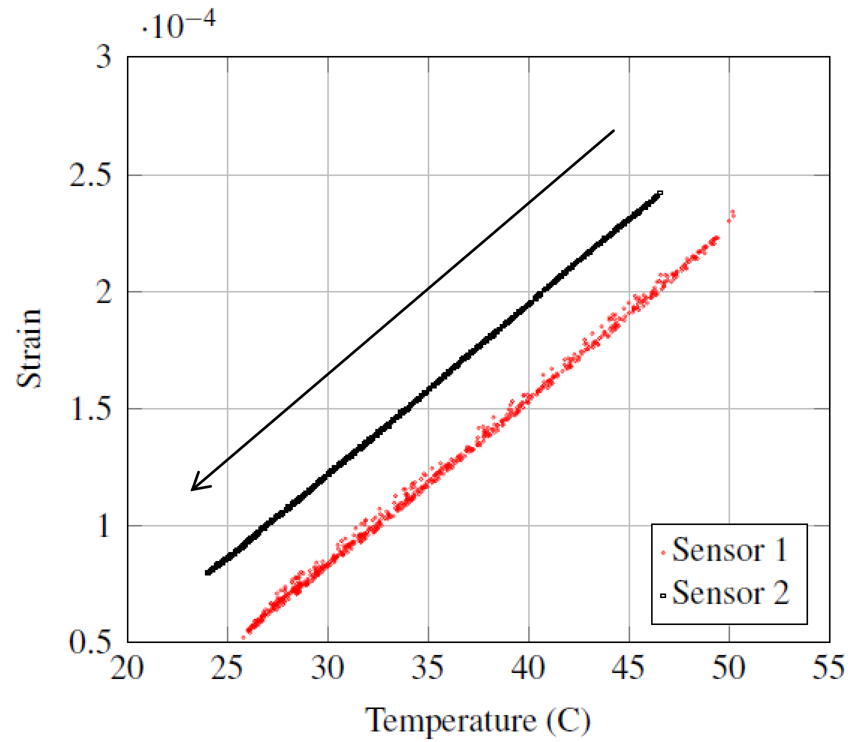
ECOBA mock-up



Parametric study and sensitivity analysis

Effect of CTE variations at early age

ECOBA mock-up



Institut de Recherche en Génie Civil et Mécanique

IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

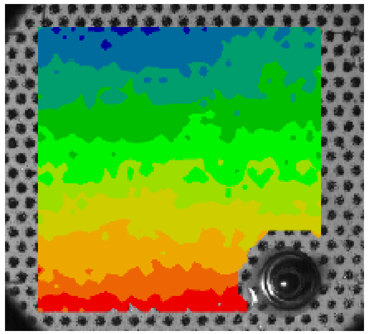
slame

LMT

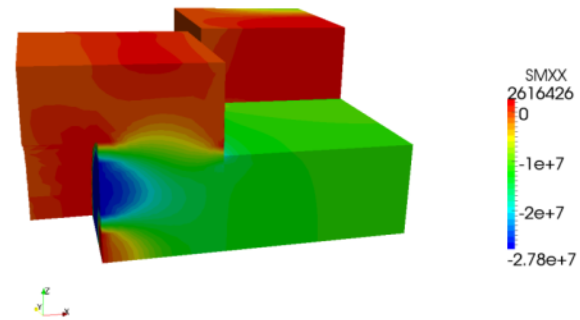
MODELLING CAN HELP TO ANALYZE TEST

- Edge effects

DIC
Vertical
displacement



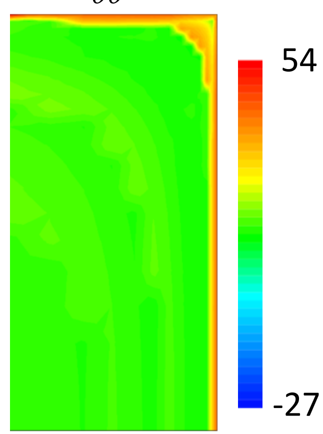
Hilaire (2014)

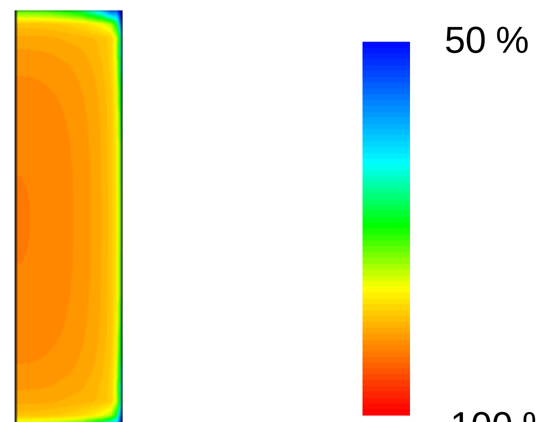


- Ring tests

Drying conditions

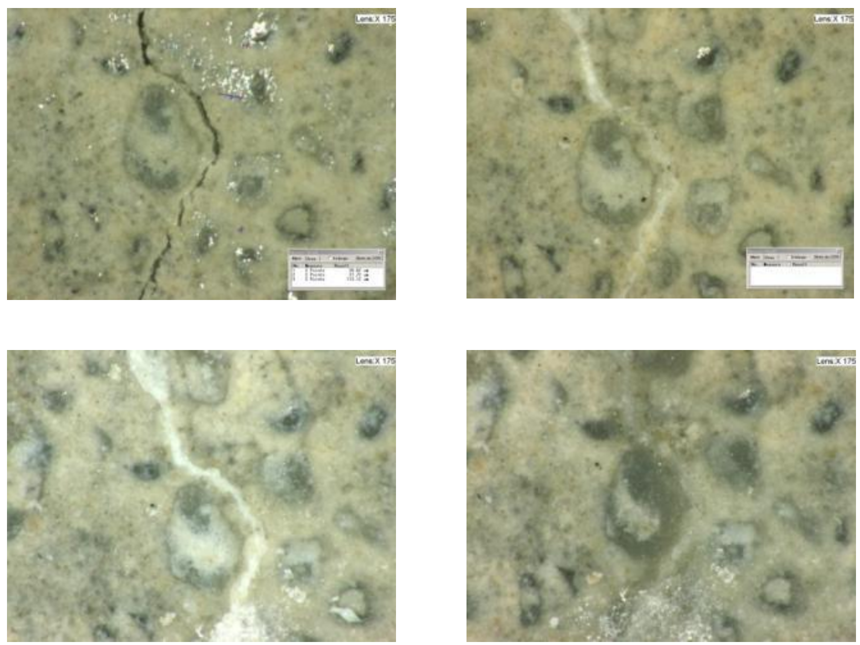
$\sigma_{\theta\theta}$





Some other important factors

- Variability inside a batch, between batches,
- Effect of mixing (duration, type of mixer …) and placing (vibration …)
- Self-healing after early-age cracking (especially when binders with low hydration rates are used), what will be the behavior of the structures ?
- …



Olivier (2015)

Is cracking due to the shrinkage restraint by the shells, the wall or gradients ?

TU 1404 COST ACTION

TU 1404 COST ACTION

Feedback of the international benchmark Concrack

Laurie Buffo-Lacarrière - University of Toulouse, France

CEOS.fr

Université de Toulouse

Lmdc toulouse

Context

IREX

COMPORTEMENT ET EVALUATION DES OUVRAGES SPECIAUX

« Behaviour and Assessment of special R.C. works – cracking & shrinkage » - www.ceosfr.org

CEOS.fr

- CEOS.fr, a French National Research Programme (2008-2011) :
  - Budget 8M€, 40 members :
    - *Companies* : EDF, Vinci, Eiffage, Bouygues, Areva, Solétanche-Bachy, Italcementi, Iosis, Setec, Co&B, Arcadis, Oxand, Necs, Advitam, Sites, Chryso, Rincent, Saipem, PX-Dam,...
    - *Lab. & Institutions* : LCPC, CSTB, CEA, IRSN, ANDRA, ATHIL, CERIB, CEBTP, LERM, CETU,...
    - *Universities* : ENS Cachan (LMT), INP Grenoble (3S-R), Insa Toulouse (LMDC), EC Nantes (GEM), U. Pau (Lasagec), Polytech' Lille (LML),...
- Aims :
  - at dealing with the control of cracking (a major concern for durability and sustainability), in particular for special works (specific use, specific shape and size, specific requirements for loading or durability...)
- Subjects :
  - Cracking under monotonic loadings
  - Behaviour under coupling loadings (THM)
  - Cracking under cyclic and seismic loadings
- Approaches :
  - Experiments on large specimens
  - Numerical modelling
  - Elaborated by engineers-practitioners
- International connection :
  - International benchmark (inscription until 15/06/10)
  - European network under construction

President : P. Labbé - Scientific director : J. Mazars – Technical director : P. Bisch

Concrack benchmark

Involved teams in the THM benchmark

⇒ 8 teams from mainly European countries

⇒ French teams not allowed to participate

Conditions of the benchmark

⇒ Totally blind benchmark (for both thermal and mechanical aspects)

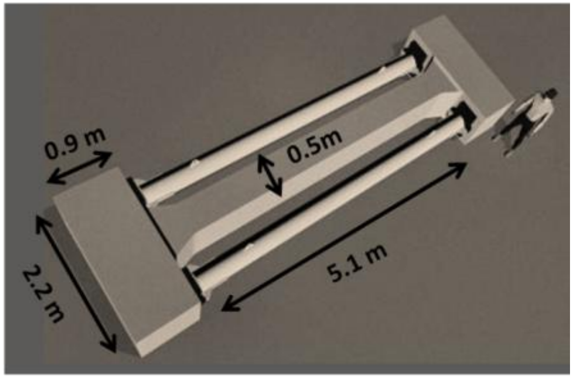
⇒ Experimental results given before the restitution workshop (to allow corrections)

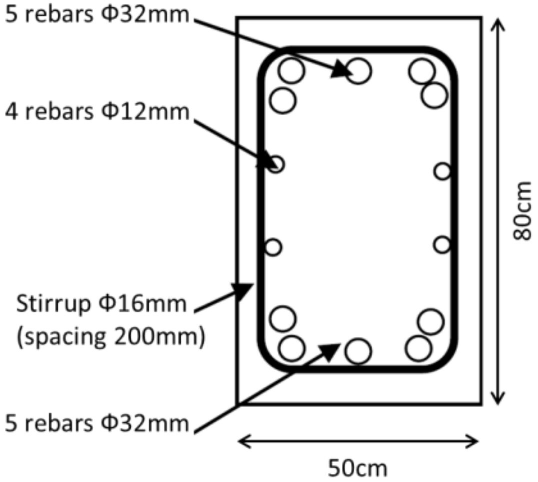
⇒ **Experimental results not analysed in detail at the period of the benchmark**

- **Brief presentation of the test on restrained structures**
- **Thermal benchmark**
- **Mechanical benchmark**
- **Conclusions**

CEOS.fr results on RG beams

Presentation of the restrained structures (RG beams)





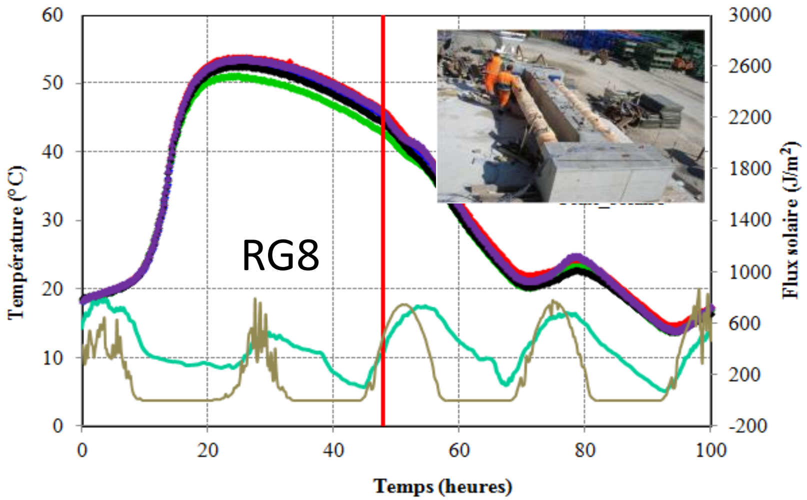
"Central" part: - 0.5 m wide
- 0.8 m high
- 5.9 m long

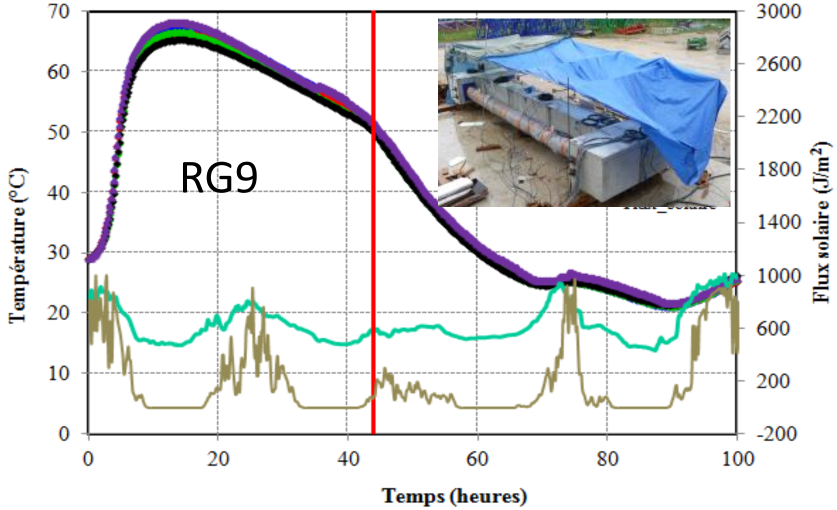
Large "heads": - 0.9 m wide
- 0.9 m high
- 2.2 m long

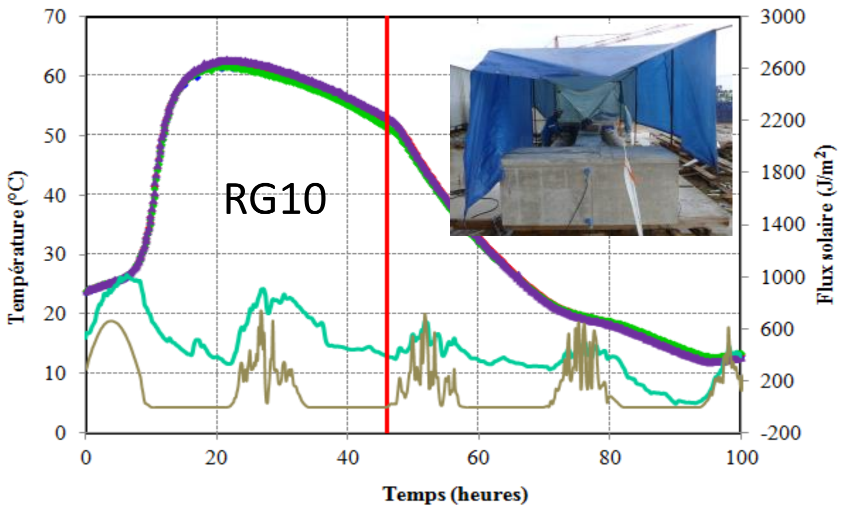
Different reinforcement

	RG8	RG9	RG10
% of longitudinal reinforcement	2%	0.56%	2%
cover	30 mm (50 mm for longitudinal rebars)	30 mm (50 mm for longitudinal rebars)	50 mm (70 mm for longitudinal rebars)

CEOS.fr results on RG beams



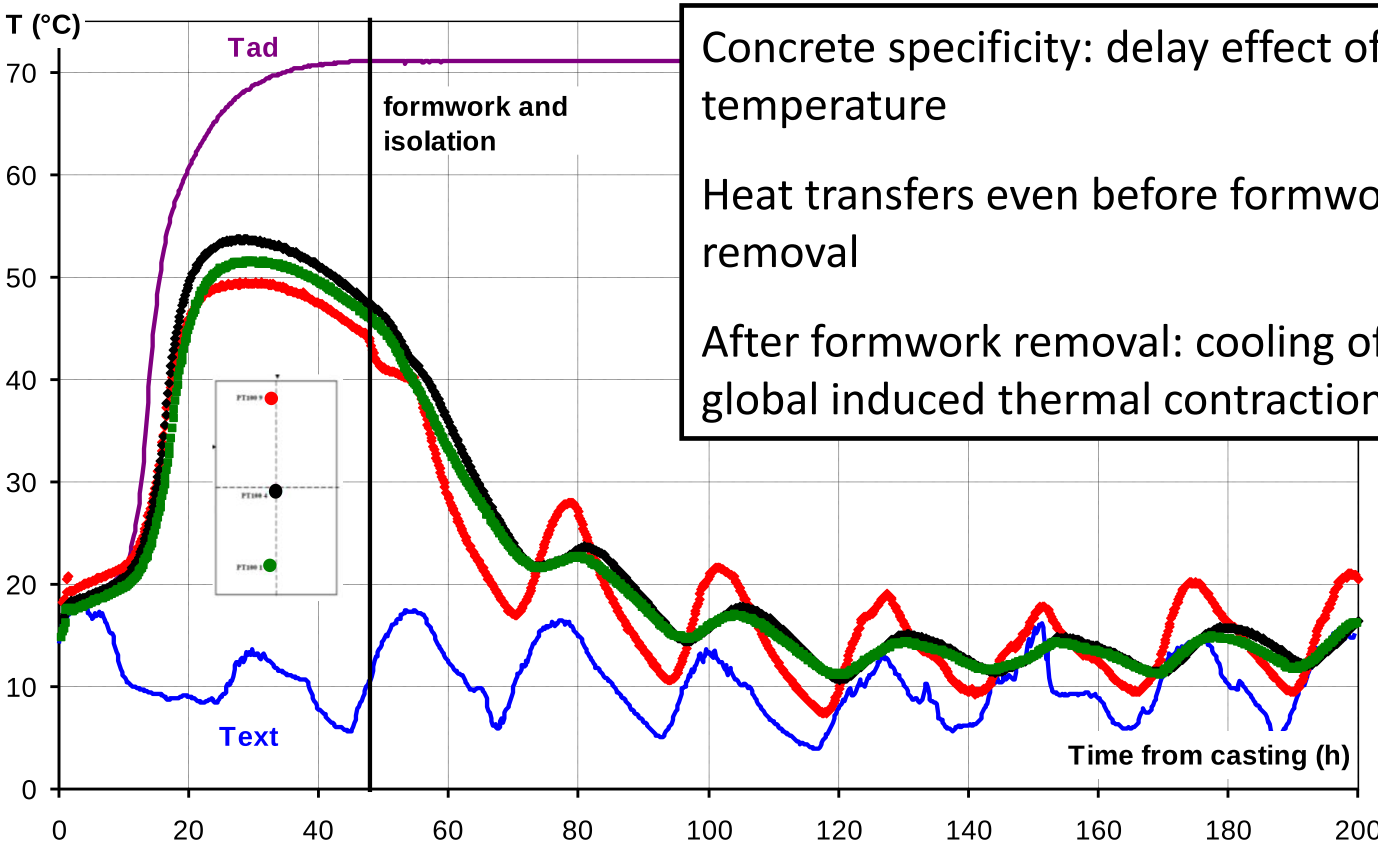




Different thermal conditions
- no protection for RG8
- partial solar protection for RG9
- no solar radiation for RG10

CEOS.fr results on RG beams

Main thermal results for RG8



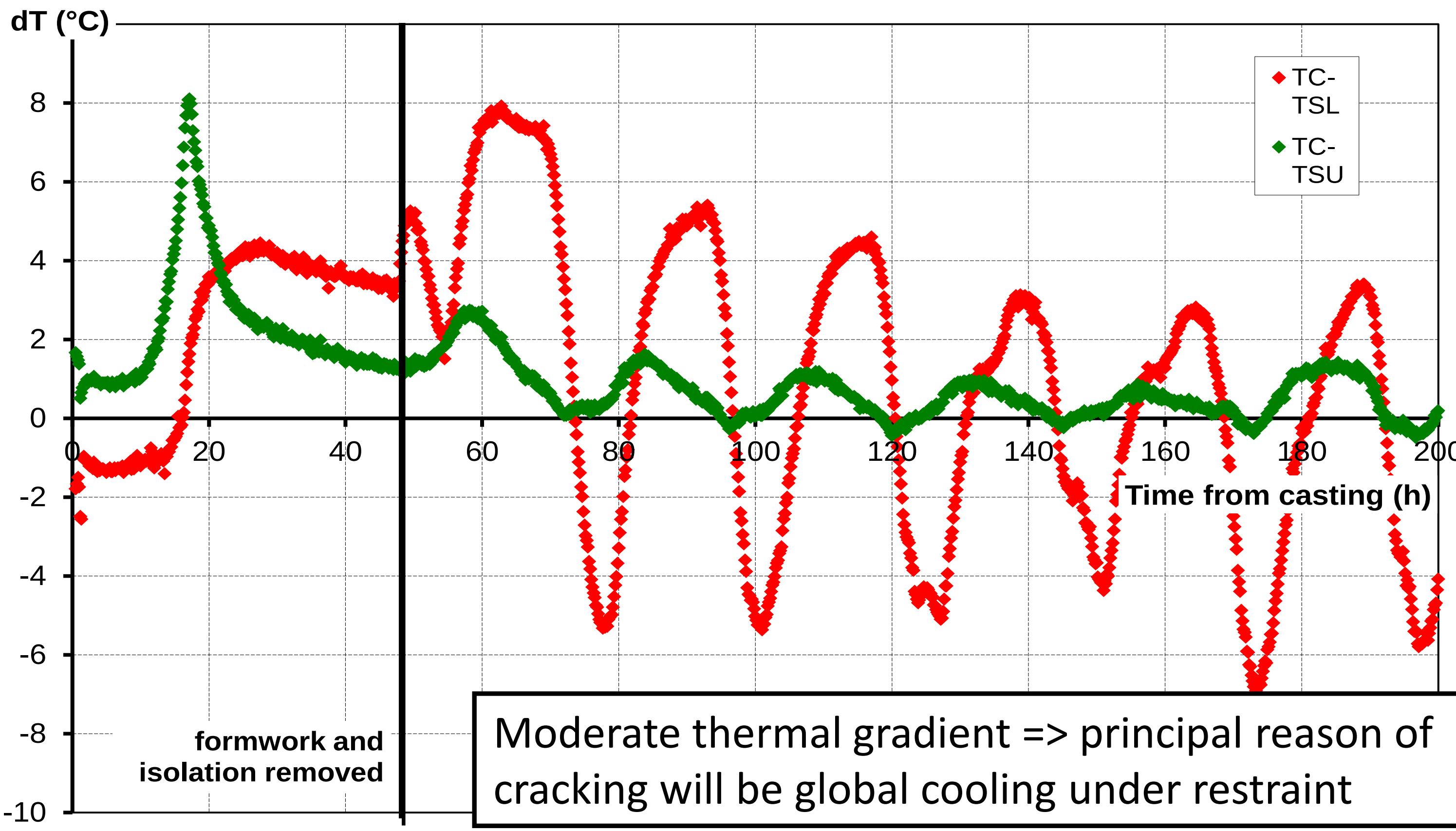
Concrete specificity: delay effect of SP function of casting temperature

Heat transfers even before formwork and insulation removal

After formwork removal: cooling of the entire section => global induced thermal contraction

CEOS.fr results on RG beams

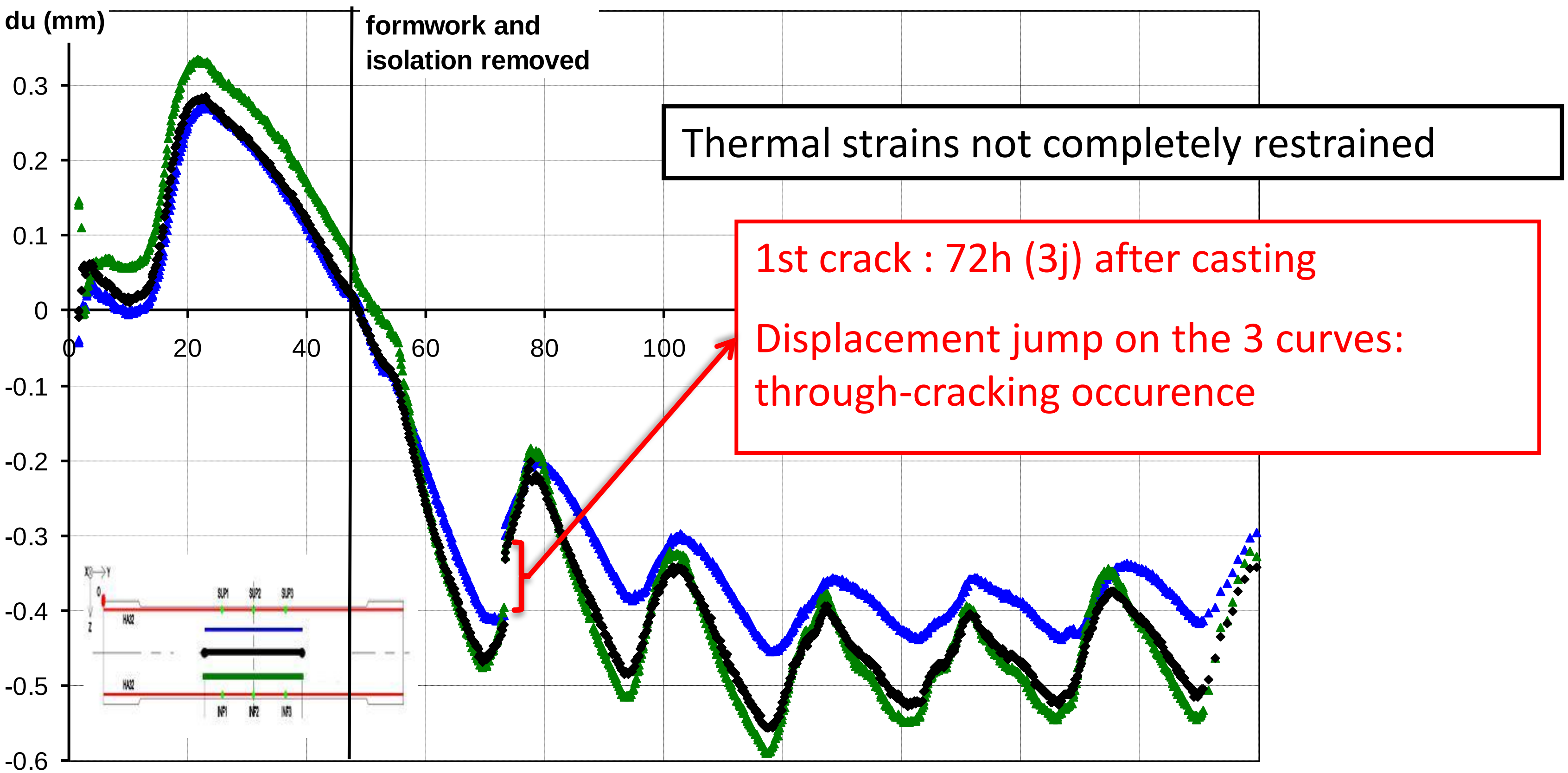
Main thermal results fr RG8



Moderate thermal gradient => principal reason of cracking will be global cooling under restraint

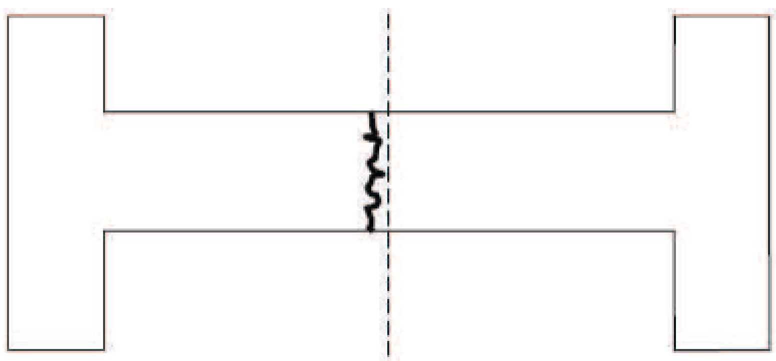
CEOS.fr results on RG beams

Main mechanical results for RG8

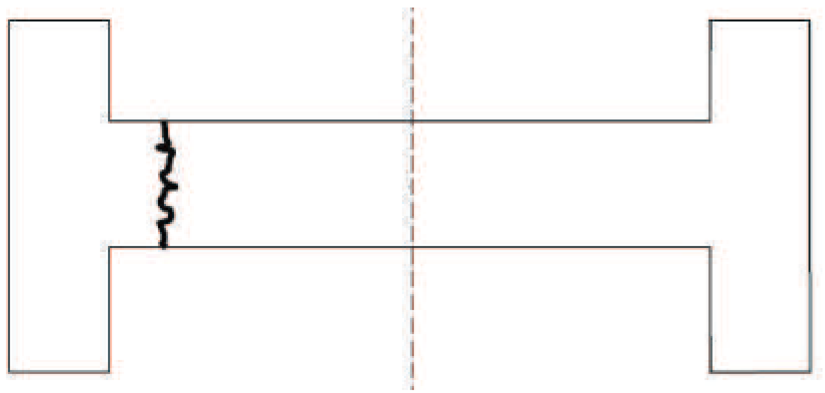


CEOS.fr results on RG beams

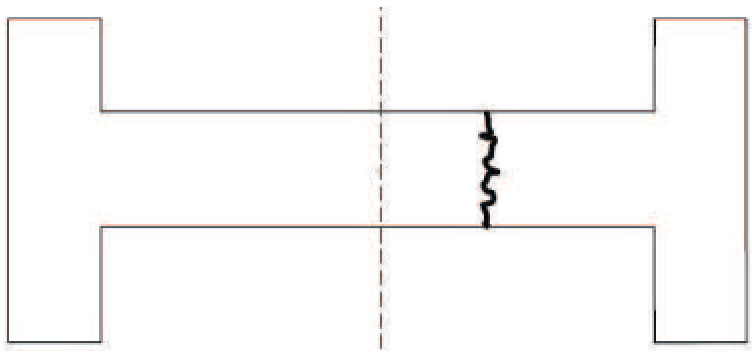
Main mechanical results for RG8



1st crack: 72 h (3 d) after casting



2nd crack: ≈170 h (7 d) after casting



3rd crack: 244 h (10 d) after casting

- **Brief presentation of the test on restrained structures**
- **Thermal benchmark**
- **Mechanical benchmark**
- **Conclusions**

Thermal benchmark

What did we know ?

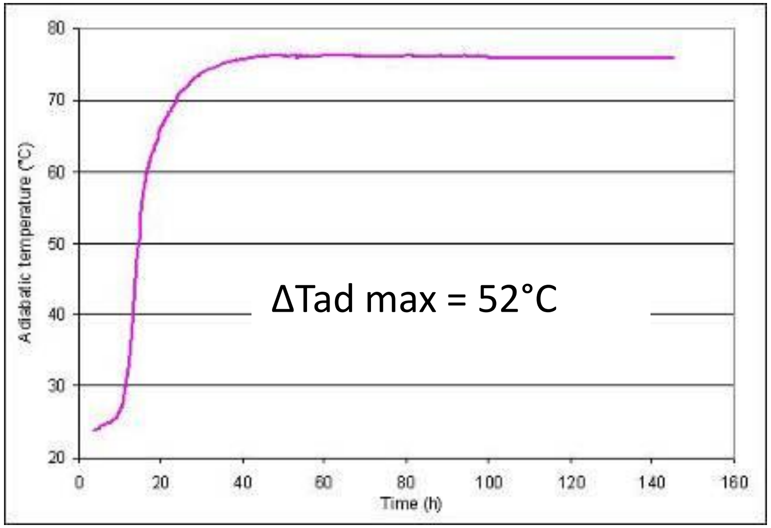
Material characteristics

⇒ Concrete composition

⇒ Heat generation (adiabatic test)

⇒ Thermal conductivity and capacity

	Content (kg/m3)
CEMI 52,5N CE CP2 NF Couvrot	400
Sand 0/4 GSM LGP	785
Gravel 4/20 GSM LGP	980
Superplasticiser Cimfluid Adagio 4019	5,4
Total water	185



Thermal benchmark

What did we know ?

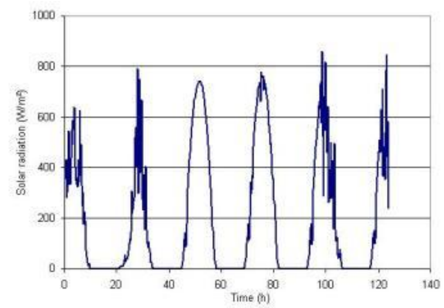
Boundary conditions

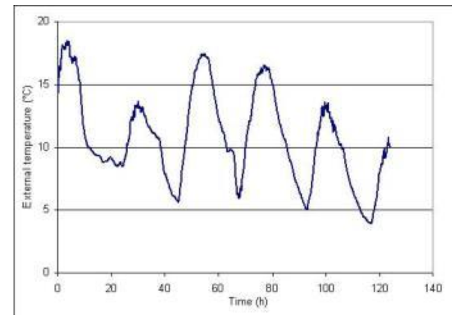
⇒ Climatic conditions

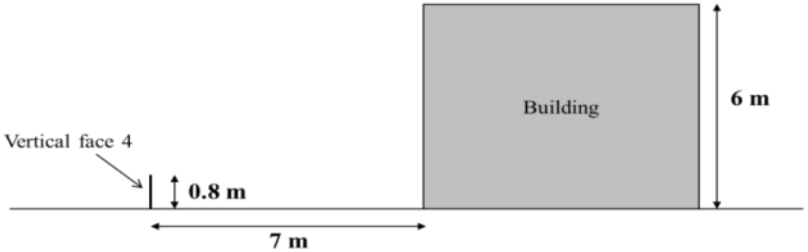
⇒ Localisation (shadows effects)

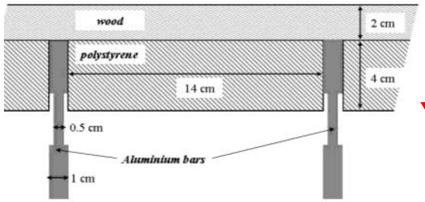
⇒ Insulation and formwork

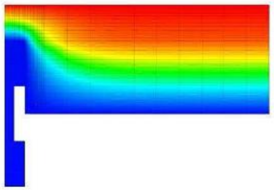
(*Particularity: weak points*)

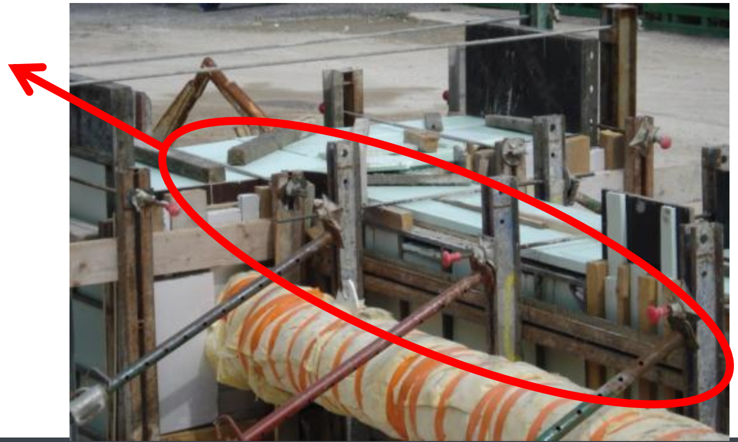


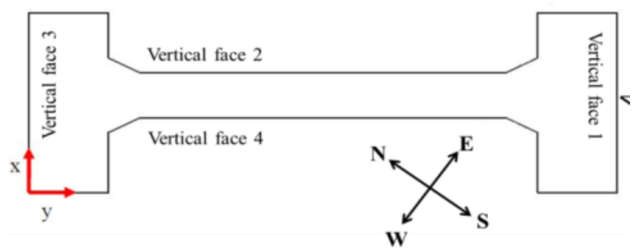












Thermal benchmark

What did we give to participants?

Material characteristics

⇒ Available data

⇒ Fixed values for non available data (Ea, …)

Boundary conditions

No imposed values for convective coefficient and solar radiation

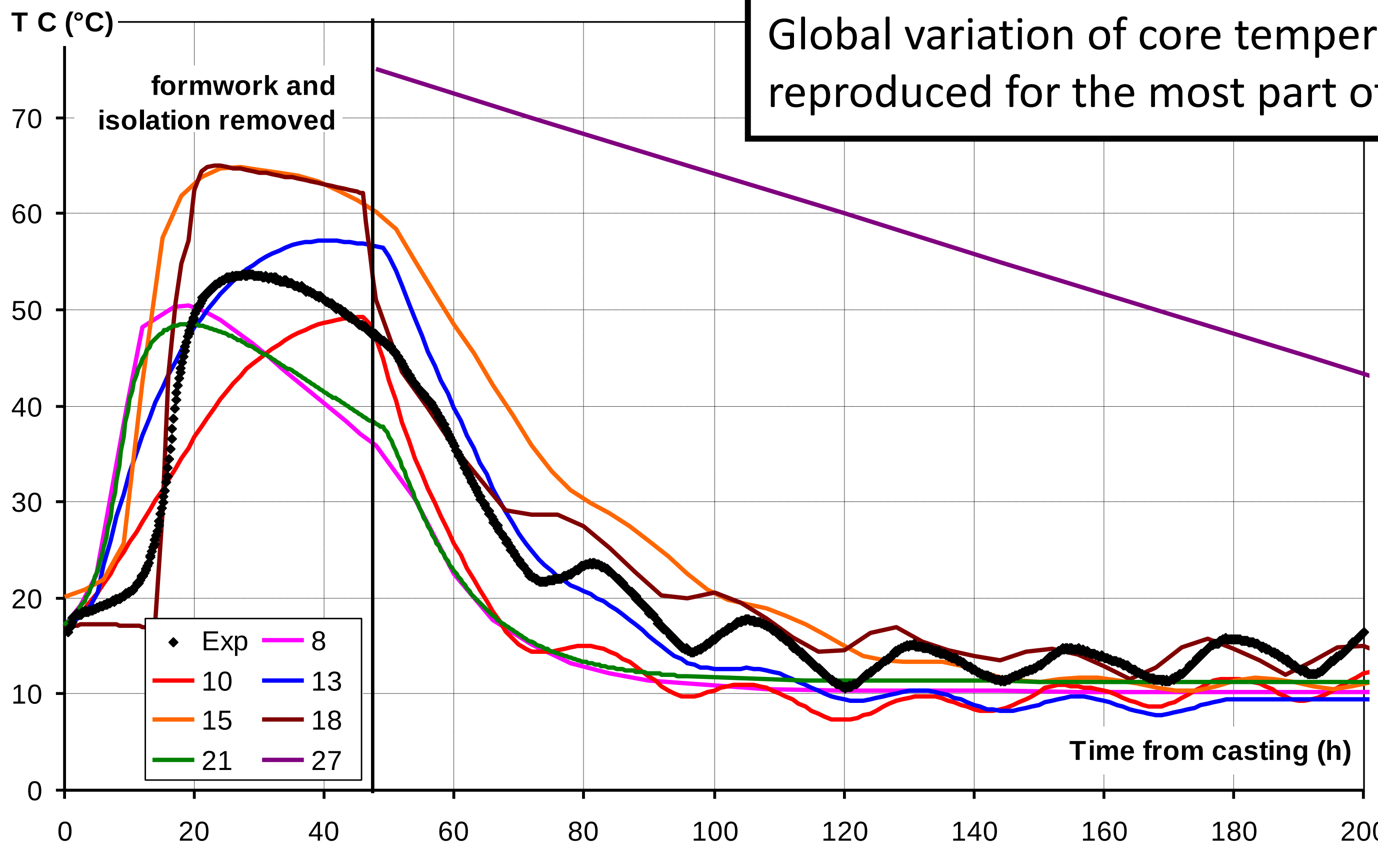
⇒ Element to calculate it (location, inclination, insulation and position of weak points, …)

More realistic prediction but also higher risk of dispersion and difficulties in the analysis

Thermal benchmark

What did we obtain?

Temperature at core

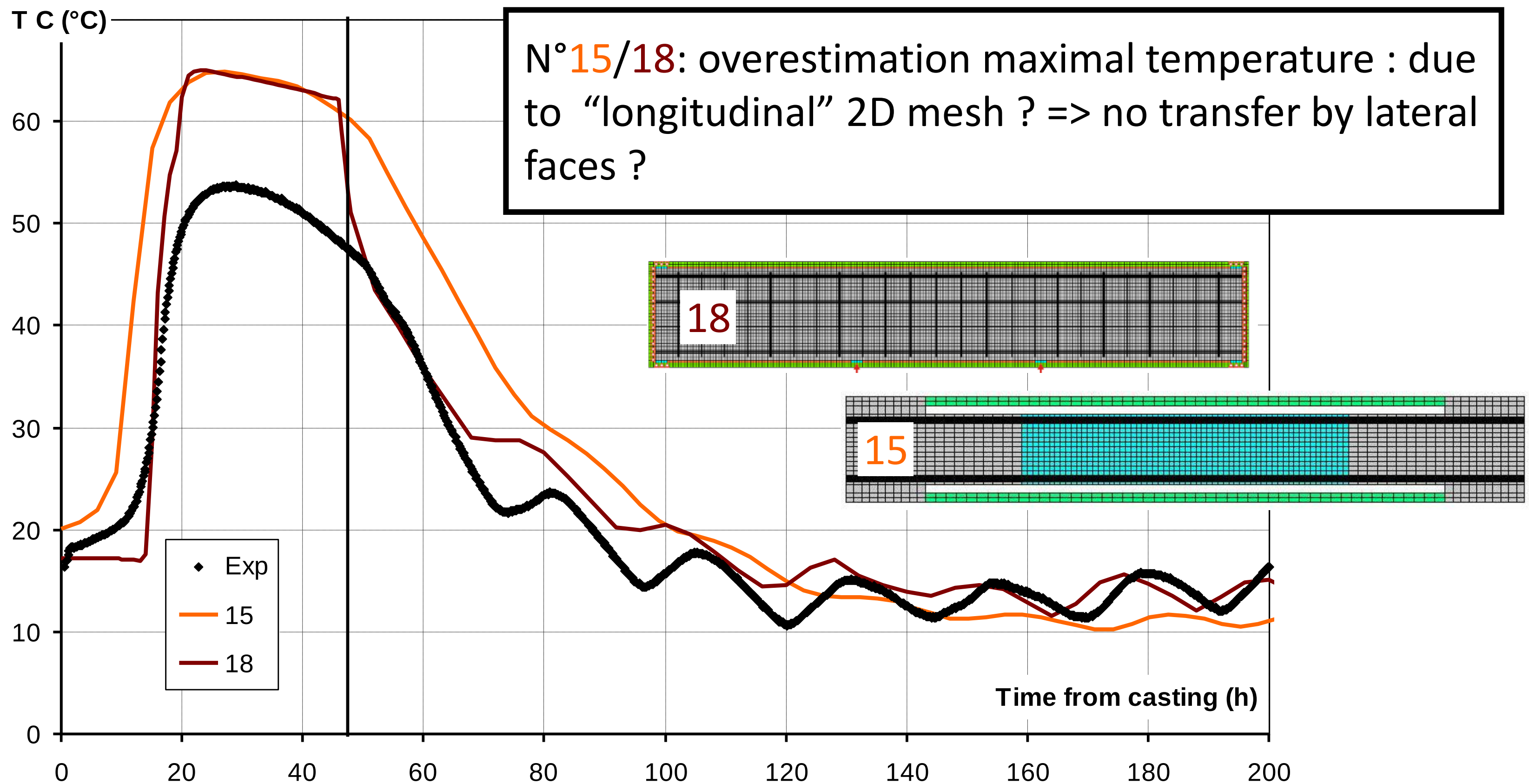


Global variation of core temperature reproduced for the most part of teams

Thermal benchmark

What did we obtain?

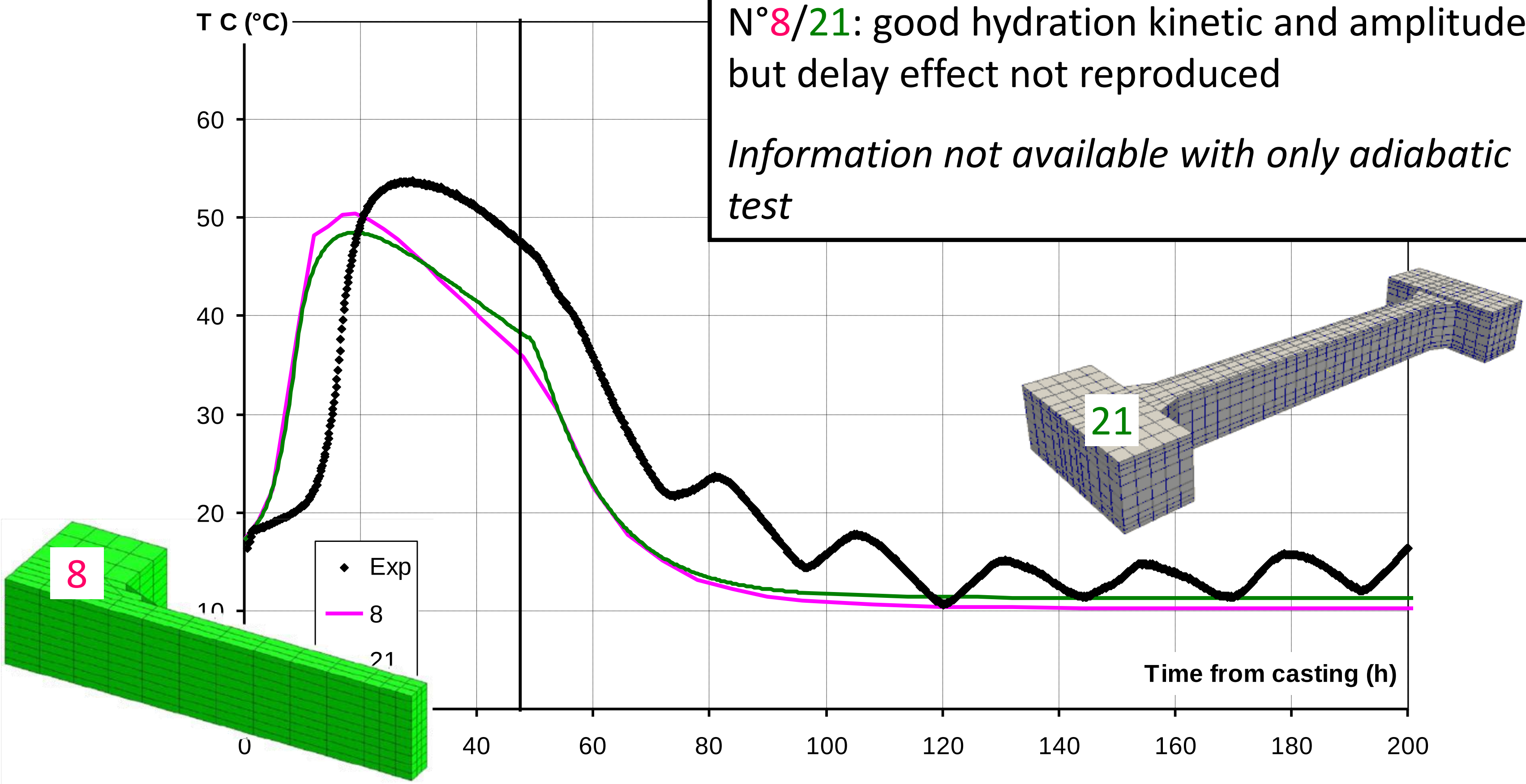
Temperature at core



Thermal benchmark

What did we obtain?

Temperature at core



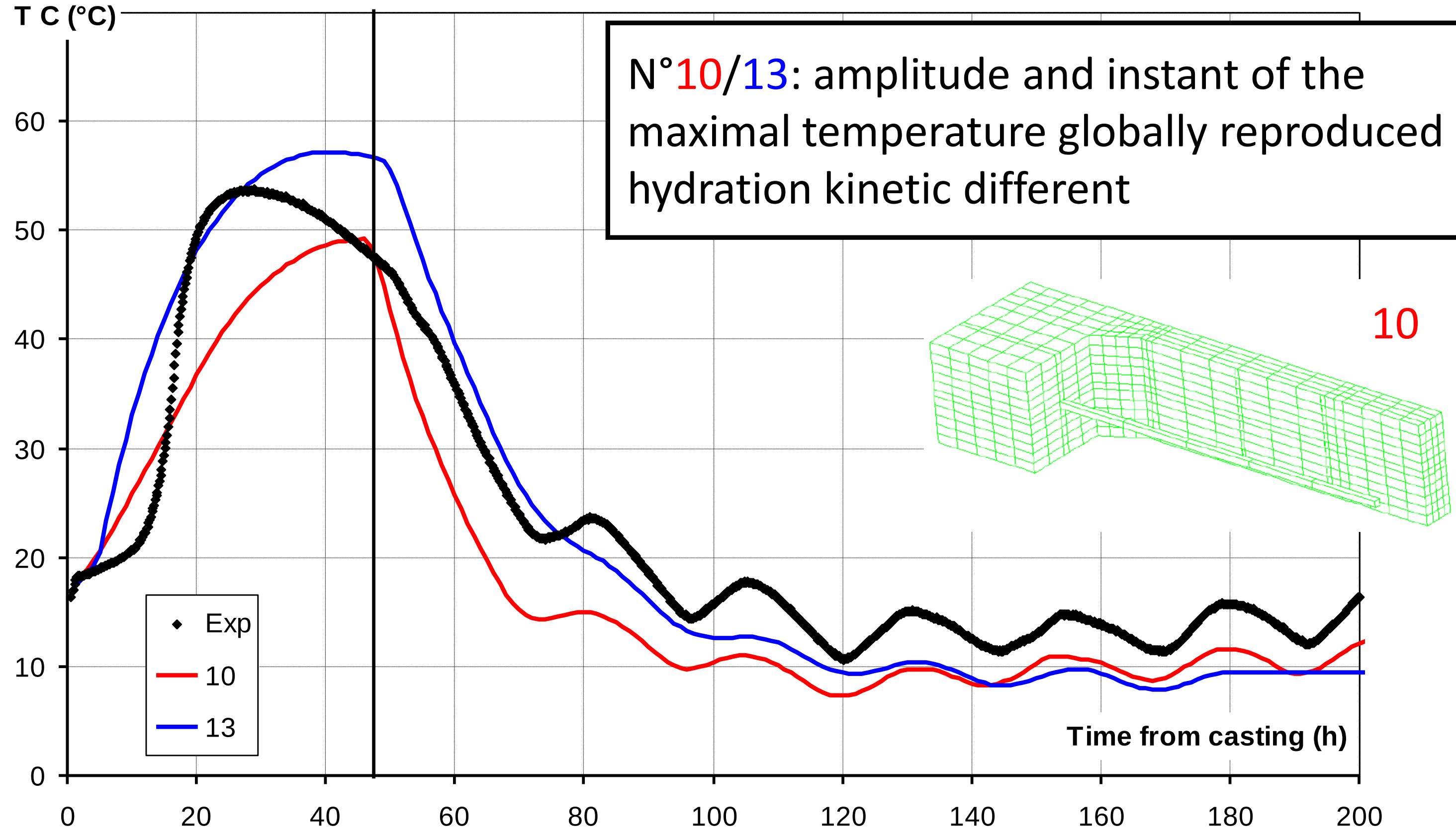
N°8/21: good hydration kinetic and amplitude but delay effect not reproduced

Information not available with only adiabatic test

Thermal benchmark

What did we obtain?

Temperature at core



N°10/13: amplitude and instant of the maximal temperature globally reproduced but hydration kinetic different

Thermal benchmark

What did we obtain?

Climatic conditions measured (Text, Wind, solar radiation)

Geometry and localisation given
Modelling of shadow effects

Insulation and formwork known
Calculation of convective coefficient

Possible wall effect between soil and lower face

Detail of insulation

Good prediction at core but misestimation on upper and lower face

- **Brief presentation of the test on restrained structures**
- **Thermal benchmark**
- **Mechanical benchmark**
- **Conclusions**

Mechanical benchmark

What did we know?

Material characteristics

⇒ Instantaneous mechanical characteristics at several ages (E, fc, ft)

⇒ Thermal history of the specimen used for the test

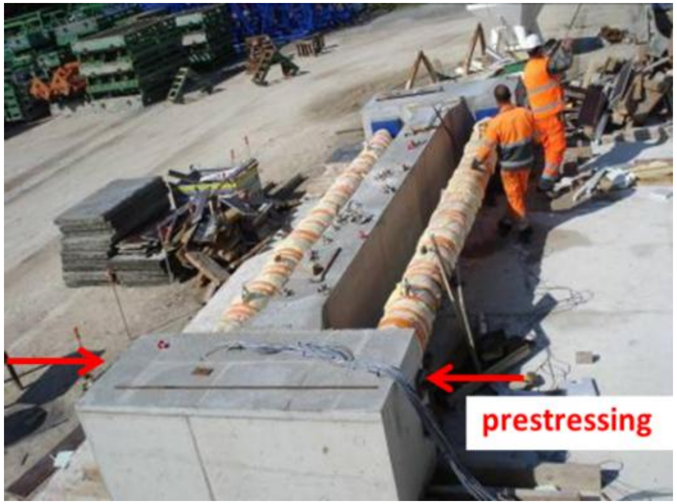
⇒ Autogenous creep and shrinkage results

Boundary conditions

⇒ Geometry and position of the struts

⇒ Characteristic of the steel

⇒ Prestressing



Mechanical benchmark

What did we give to participants?

Material characteristics

No treated information

$\Rightarrow$ Thermal history of the specimen used for the test given to determine hydration degree or equivalent time for each test age

Boundary conditions

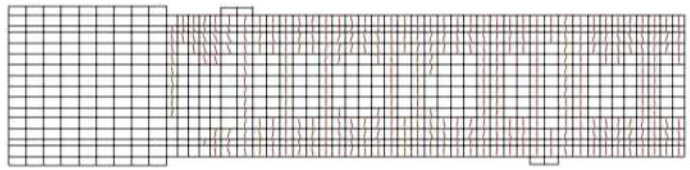
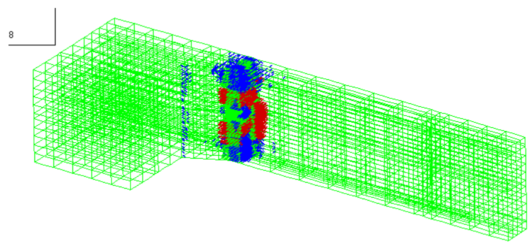
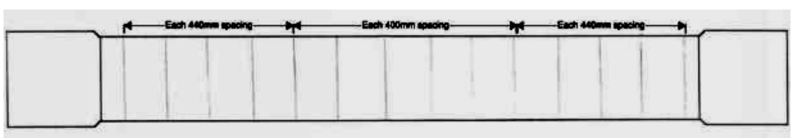
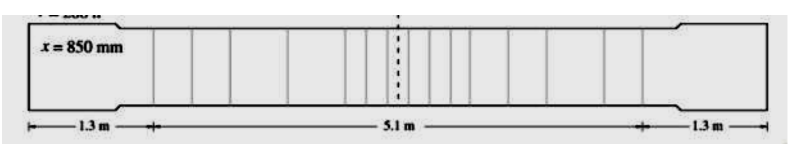
No treated information

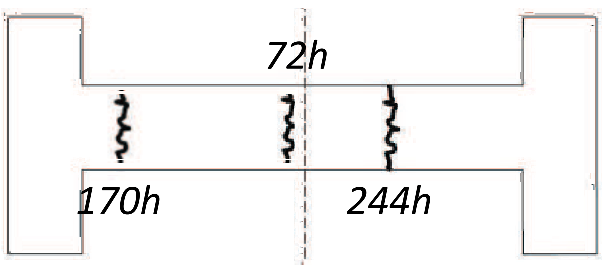
$\Rightarrow$ Modelling of the struts or use of geometry information to model restraint

More realistic prediction but also higher risk of dispersion and difficulties in the analysis

Mechanical benchmark

What did we obtain?

N°8	**1st crack 72 h** after casting	
N°10	Only 1 crack **150 h after casting**	
N°13	**1st crack 60 h** after casting	
N°27 (standard calc.)	**1st crack 120 h** after casting	



Only a few cracking results
Global overestimation of cracking

=> Combined effect of boundary conditions (partial restraining) + thermal predictions

Mechanical benchmark

What about strain/displacement measurements?

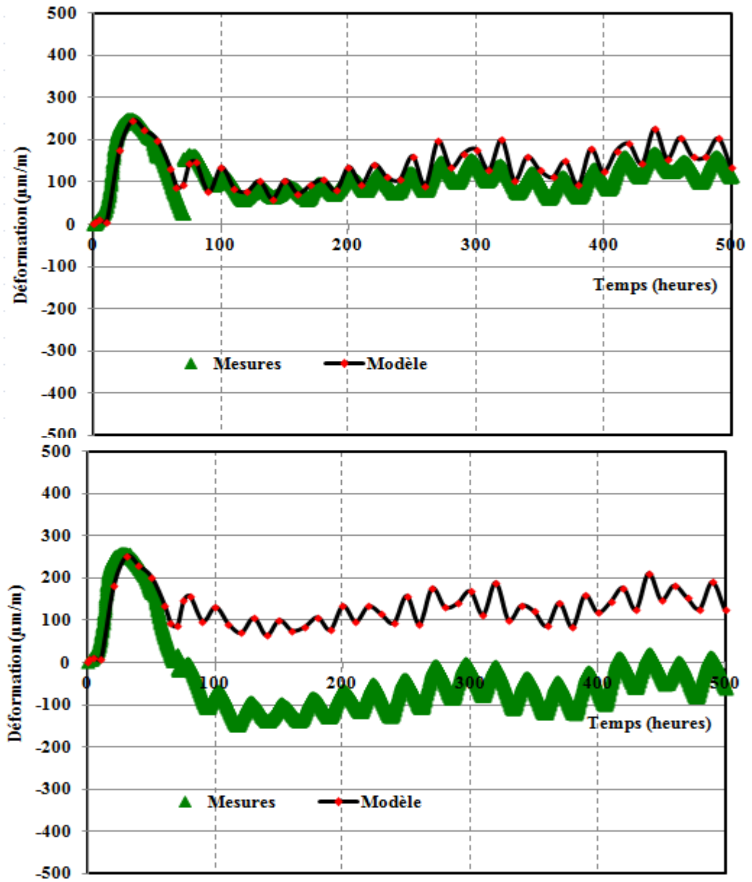
Results experimentally obtained

⇒ Local strain measured by VWE (in concrete and steel)

⇒ Global displacement along 2m in the central part

After the 1st crack

⇒ Strain gauges give too local information (difficult to compare with FEM results)



Mechanical benchmark

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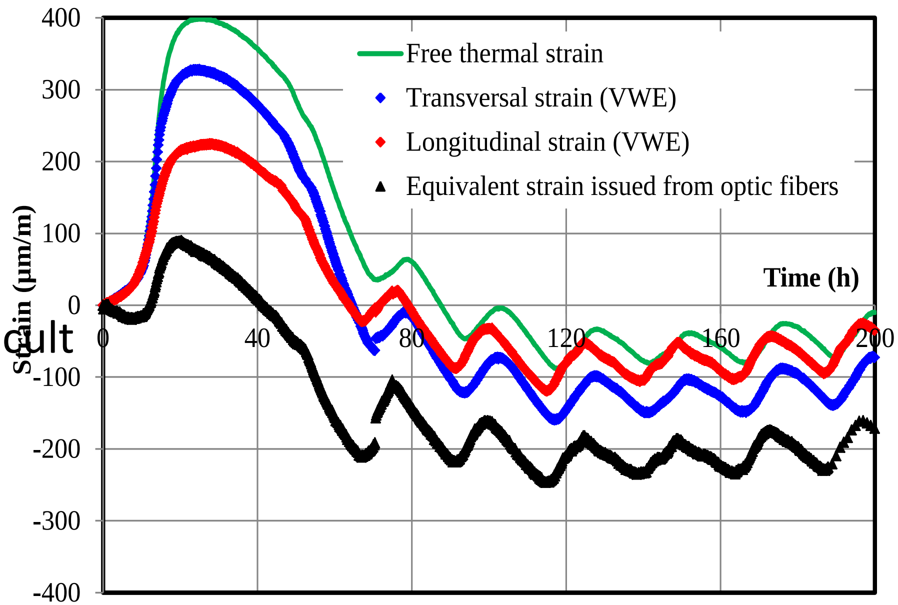
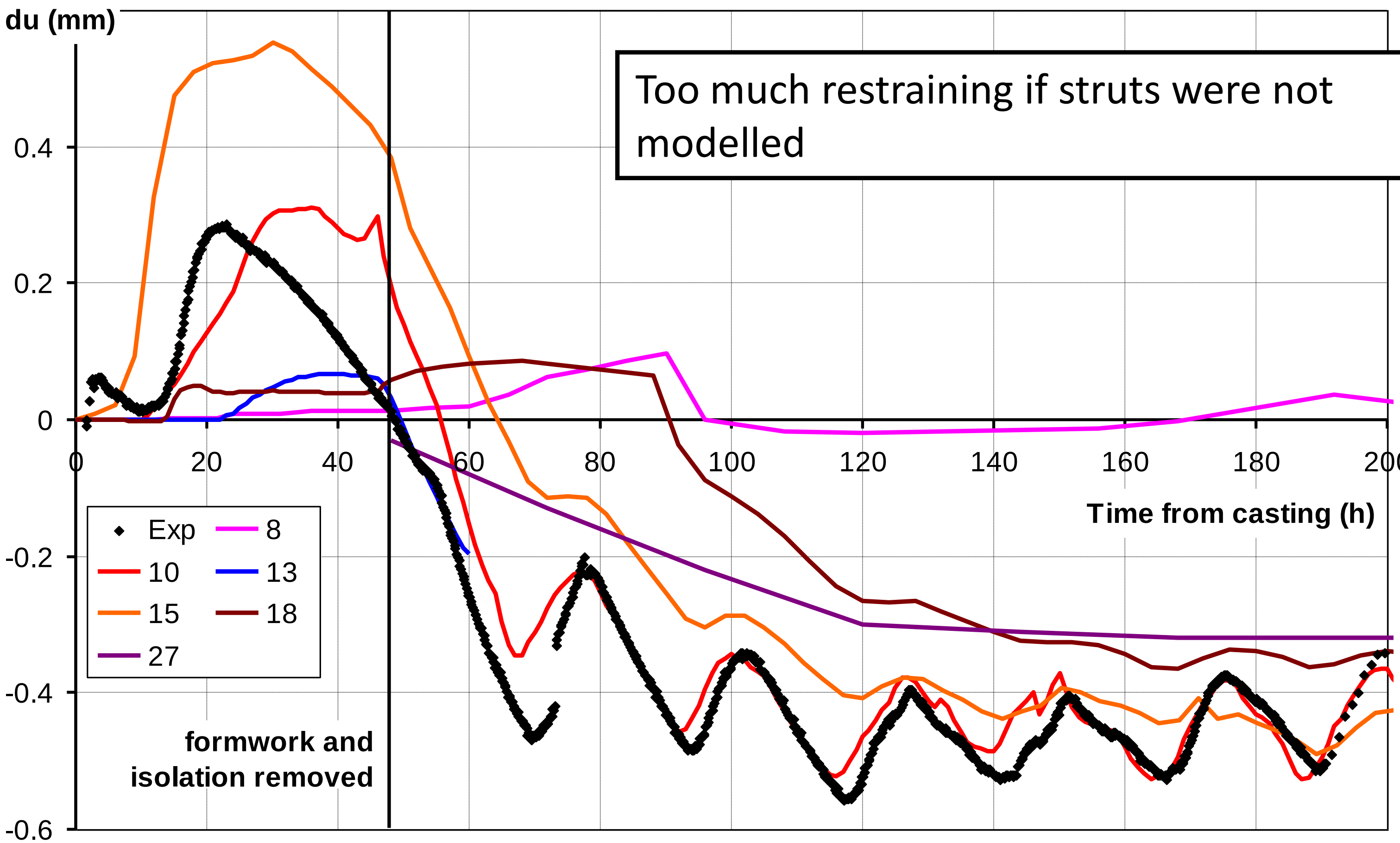


At very early age

⇒ Internal optic fibres were not able to catch strain development

Mechanical benchmark

What did we obtain?



Too much restraining if struts were not modelled

- **Brief presentation of the test on restrained structures**
- **Thermal benchmark**
- **Mechanical benchmark**
- **Conclusions**

Conclusions

On the field structure benchmarking

⇒ Stage needed for model validation and extension to standards

⇒ Difficulties induced by less controlled conditions:

- Material variability
- Boundary conditions (climatic condition, mechanical ones)

Conditions for successful benchmarking on real cases (Stage III)

⇒ Complete material characterisation available

⇒ Reflexion on lacking information: free or fixed by organizers

⇒ **Importance of feedback on mechanical results before benchmark**

Vercors structure

Material well characterized (WG1)

No feedback for the moment on in situ measurements

Other case studies ??

SESSION for WG3 – Recommendations

Chairman: François Toutlemonde

François Toutlemonde: Recommendations and products to improve concrete structures serviceability - from the idea to operational tools

Discussion on WG3 and its interaction with WG1 and WG2

TU 1404 COST ACTION

Recommendations and products to improve concrete structures serviceability: from the idea to operational tools

F. Toutlemonde – IFSTTAR

French institute of science and technology for transport, spatial planning, development and networks

IFSTTAR

To improve concrete structures serviceability

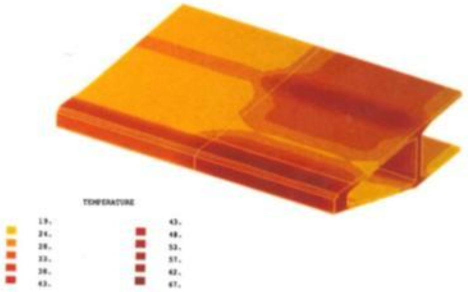
- Serviceability verifications: control of cracking, stiffness and deflection
- Major source of deviations: early age effects, imposed strains, physical couplings
  - Focus on **restrained (early age) shrinkage**
- Why? agreement on principles, no agreement on operational procedures
- How to improve?
  - Identification (input data)
  - Modeling (methods and software)
  - Implementation (optimized mixes, reinforcement)
  - Control (direct & indirect output)
  - Conformity to specification

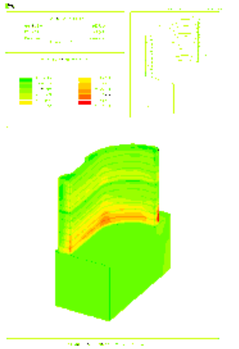
A critical issue known for a long time

Concerns for: large industrial facilities, rafts, structures with tightness requirements, composite structures with restrained parts, large structures built in successive phases, retrofitting situations etc.

EN 1992-1-1 § 2.3.3. (1) P The consequences of deformation due to temperature, creep and shrinkage shall be considered in design.

CIRIA C660 § 2.2 “it has not been common practice to add early age crack widths to those arising from structural loading, with no detriment to structural performance”… “however , long term thermal contraction and drying shrinkage may cause crack widths to increase or new cracks to form, depending on the nature of the restraint. The design should consider whether cracking due to subsequent deformations will add to early-age effects, and should design for crack widths accordingly.”





Serviceability requirements

- Tightness: control of crack openings, at short and long term
  - **Through-going cracks** due to end restraints are most critical
  - Cracks opened at early age may irreversibly re-open and widen
  - Admissible openings are related to operation requirements
- Durability and aspect: control of crack openings, at short and long term
  - **Surface crack openings** (edge restraints) are most important
  - Cover thickness and self-equilibrated stresses are critical
  - Cracks opened at early age may heal or close and stresses relax
  - Admissible openings are related to stiffness and ions transfer

Rules for crack opening verification under combined loads and (restrained) shrinkage effects shall be explicit and may differ → GP3d pre-standards

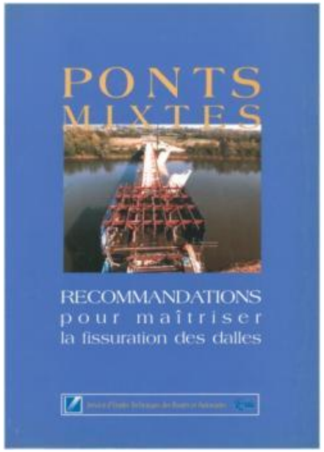
Examples of crack control requirements

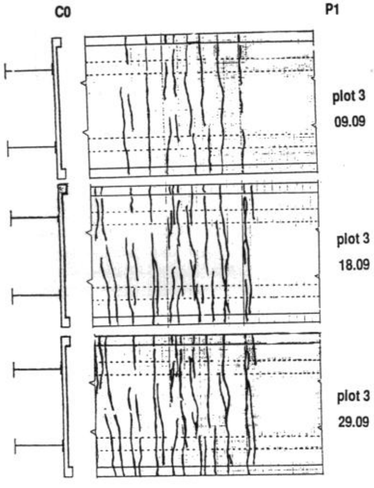
Raft of nuclear waste storage facilities (J.-M. Torrenti for ANDRA, France, 2013)

- Tightness is required for very long-term service life (risk of contamination)
- Autogenous, thermal and dessiccation shrinkage retrained without possible relaxation
- Crack widths had to be limited w.r.t. cumulated load and imposed strain effects
- This resulted in shrinkage requirements for concrete (no possibility of 2^{nd} phase keying)

Composite bridge decks (T. Kretz et al. for Highways administration, France, 1995)

- Early-age verifications including $E.\alpha.\Delta T/2$ with instantaneous value of E
- Long-term verifications with loads + only desiccation shrinkage
- Minimum non-brittleness reinforcement (corresponding to fctk = 3 MPa)
- No systemmatic superimposition of crack openings
- Majoration of design ΔT





Accounting for restrained shrinkage: models and software implementation

- Thermo-hygro-chemo-mechanical coupling:
  - at early age at least thermo-activation (T°-chemo-mechanical coupling)
  - Elastic-brittle behaviour (safe for crack prevention) or visco-elasticity?
  - Early desiccation, surface cracking and transfer alteration?
- Implementation in qualified software:
  - Validation (related to benchmarking, **WG2**)
  - User-friendliness, documentation, computation time efficiency, cost
  - Adequate parameters for physical input, boundary conditions and parameters related to concrete mix-design (dormant period, heat generation, moisture transfer coefficient, strength increase…)

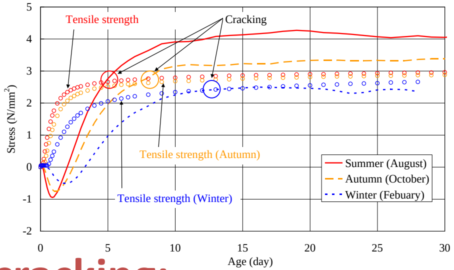
Consistency and precision of simplified / advanced tools

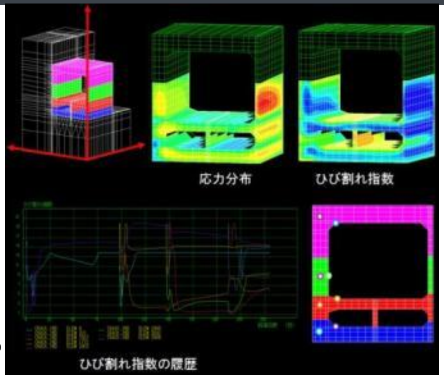
→ **GP3c methodology GP3b software development**

Implementation examples

JCI Guidelines (ConCrack3, Paris, 2012)

Cracking index and calibration





Operational analysis for preventing the risk of cracking:

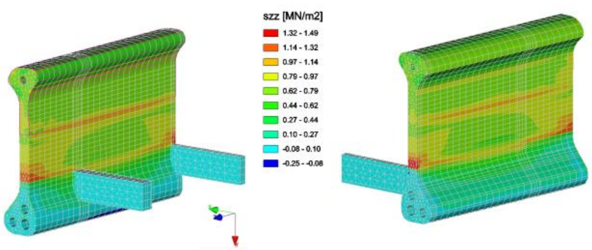
« passerelle des Anges » footbridge, Sorelli et al., 2008

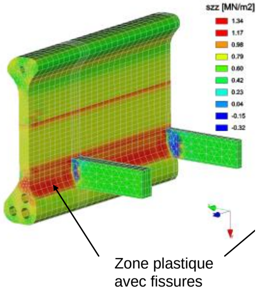
- Possibility to optimize the form removal sequence, as a help for the precast concrete factory.

-The crack possible location and onset was confirmed by thermomechanical computations :
- restraints (coincidence of successive lifts and thickness variation)
- favourable effect of early thermal treatment and early form mechanical release before complete removal

- Quantitative limits / uncertainties due to:
- Thermal sensitivity of admixtures (dormant period duration)
- Modeling of friction at the fresh/hardening concrete interface with the mould

- Improvements: viscoelastic behaviour of concrete? post-processing tool for cracks description?





Accounting for restrained shrinkage: input for appropriate analysis

- Thermo-chemo-mechanical coupling:
  - Heat generation (calorimetry), heat transfers, thermal dilation
  - Activation energy, setting time
  - Shrinkage measurement
  - Mechanical characteristics evolution
- Qualities of measurement methods and devices:
  - Relevance, reliability, reproductibiliy (related to Round Robin tests, **WG1**)
  - User-friendliness, documentation, protocol time efficiency, cost
  - Calibration when using indirect indicators (e.g. conductivity, U-Sonic…)

Consistency and precision of useful input values and measurement

→ **GP3c methodology GP3a material development**

Example: development of BTJADE device

Objective: Early Age Measurement of the Autogeneous Shrinkage of a Concrete

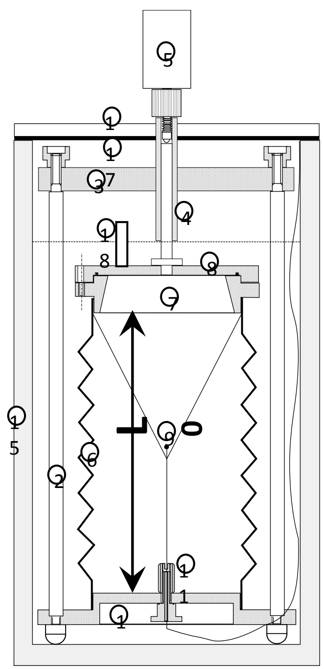
Boulay et al., IFSTTAR, 2006-2008

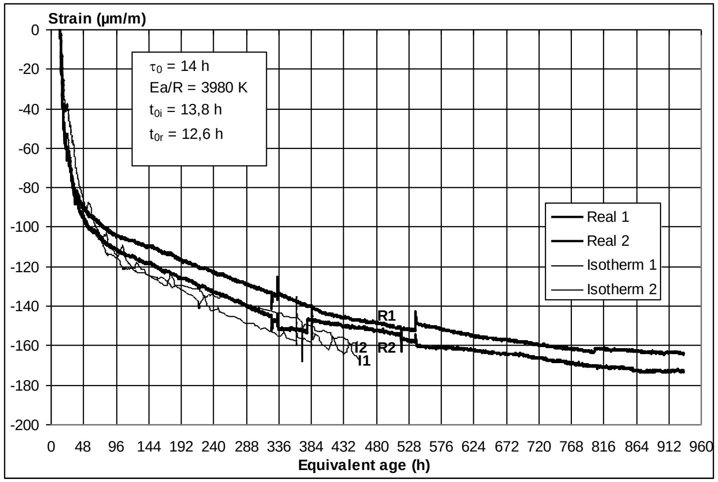
After alternative techniques and prototypes tests (1993-2003)

Protocol development and qualification

main difficulties: - determination of t_0

- consistency with associated measures: E, UPV, T°





Accounting for restrained shrinkage: implementation and engineering

- Limitation / mitigation of shrinkage effects:
    - Concrete mix-design
    - Control of thermal effects, curing
    - Casting procedure, successive slots, keying joints
    - Re-bars optimization
- Contract aspects, conformity, liability:
    - Material specific requirements (associated tests, thresholds)
    - Admitted justifications procedures
    - Admitted execution procedures, liability and control

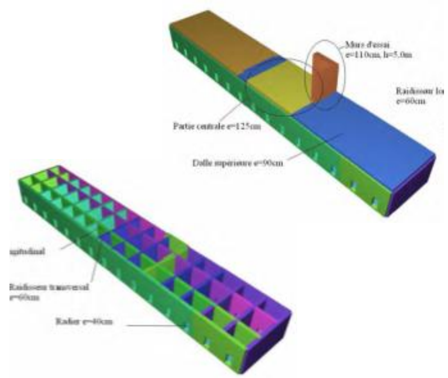
Consistency of recommendations and standards evolution

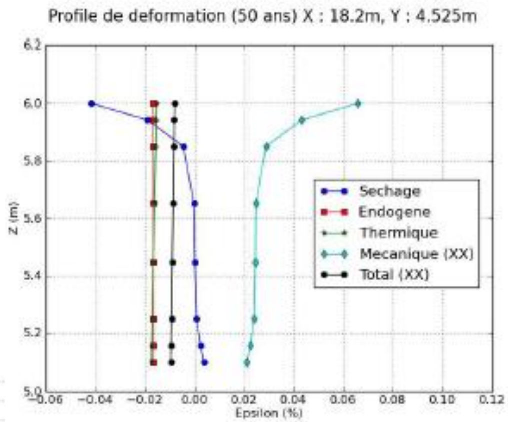
→ **GP3c methodology GP3d standards development**

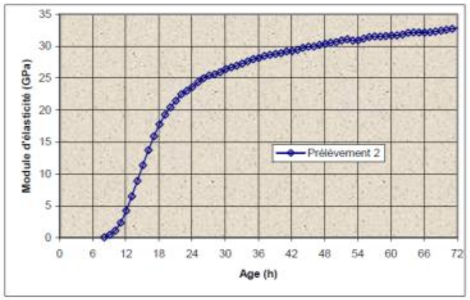
Example: IFSTTAR new strong floor

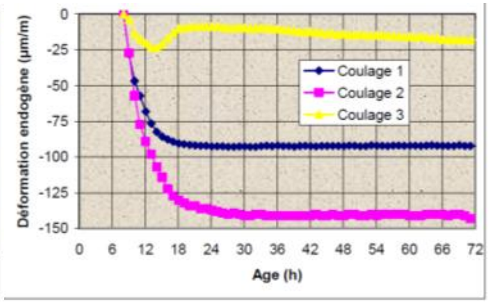
High stiffness required until 50 years design service life. 61 m x 11 m without joints.
Compromise : high Young's modulus, pumpability, low shrinkage, low creep

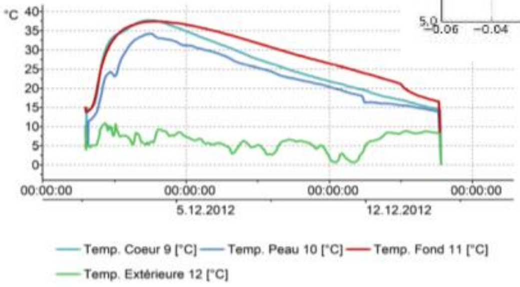
C80/95 with minimum autogenous shrinkage (optimized mix, SCM, filler)
Optimized casting procedure (5 Slots, higher reinforcement ratio along keying)
Advanced model, temperature control (concreting at night), curing

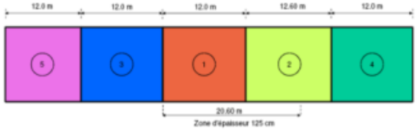












Accounting for restrained shrinkage: preparation of standards evolution

– Required drafts for new / evolutive standards

- Material requirements: EN 206
- Associated tests EN 12390-xx

  Priorities: (early age) autogenous shrinkage? Thermal expansion coefficient? Thermal transfer coefficients? Setting time? Moisture diffusion coefficient?

- Admitted justifications procedures EN 1992
- Execution EN 13670 (+ EN 13369 for precast products)

Coordination with CEN TCs and national mirror groups

→

GP3d standards development

Who is in charge? WG3 organization

Leader : François TOUTLEMONDE, IFSTTAR (France)
Co-Leader : Terje KANSTAD, NTNU (Norway)
77 participants – 22 countries

- GP3a: Product development for TESTING and MONITORING methods

Leader : Neil John CAMPBELL, Amphora Technol. Ltd (United Kingdom)
Co-Leader : Wille Stenfert KROESE, Consensor (The Netherlands)
41 participants – 19 countries

- GP3b: Product development for SOFTWARE and DESIGN methods

Leader : Jesus Miguel BAIRAN GARCIA, Univ. Politecnica Catalunya (Spain)
20 participants – 11 countries

- GP3c: Development of RECOMMENDATIONS and pre-standard METHODS

Leader : François TOUTLEMONDE, IFSTTAR (France)
Co-Leaders: Terje KANSTAD, NTNU (Norway), Konstantin KOVLER, Technion (Israel)
61 participants – 21 countries

- GP3d: Recommendations, PRE-STANDARD DOCUMENTS and associated coordination

Leader : Markus VILL, ZT-Vill (Austria)
44 participants – 17 countries

Outlook to 2nd Meeting 2015 and CONCREEP-10

Bernhard Pichler: Outlook to Vienna

COST Action TU 1404: 2nd meeting in 2015

in

Vienna, Austria

September 19-20, 2015

Vienna University of Technology

TU WIEN

Institute for Mechanics of Materials and Structures

imws

COST Action TU 1404: 2nd meeting in 2015

Tentative program

Saturday, September 19, 2015

- Working Group 2: Group Priority Sessions

Sunday, September 20, 2015

- Working Groups 1 and 3: Status Updates
- Meeting of Management Committee
- Invited Lectures

Meeting Venue

Vienna University of Technology

- located in the centre of the city; easy to reach by public transportation
- 25 min from Vienna International Airport with direct flights to 170 destinations worldwide
- WLAN access in all lecture halls
- Meeting will take place in Festival Hall and the adjacent "Boeckel-Saal"

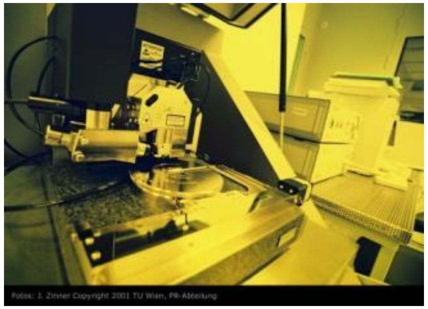
Vienna University of Technology

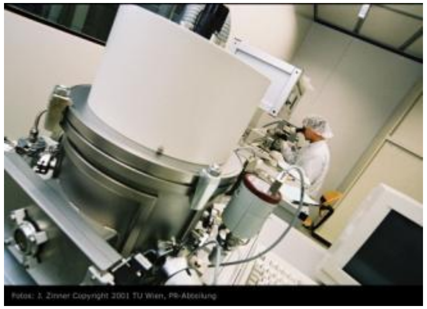
- founded in **1815** as „K.&K. Polytechnisches Institut“ (first University of Technology of today's German-speaking area)
- 8 departments organized in 54 institutes
  - Architecture and Regional Planning
  - **Civil Engineering**
  - Electrical Engineering and Information Technology
  - Informatics
  - Mechanical Engineering and Management Science
  - Mathematics and Geo-Information
  - Physics
  - Technical Chemistry

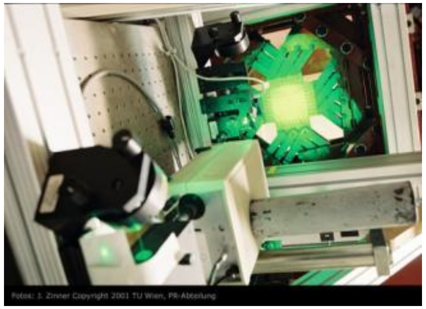



Vienna University of Technology

- ~ 155 Mio. annual ministry funds (incl. personnel and rental)
  ~ 45 Mio. annual third party funds
- ~ 3,400 scientific employees (~ 150 professors)
  ~ 1,200 administrative employees
- ~ 27,000 students
- ~ 1,500 master graduates per year
  ~ 200 PhD graduates per year







Vienna University of Technology

Alumni

Richard Zsigmondy
(Nobel prize in Chemistry)
Chemistry

Brothers Strauss (composers)
Josef, techn. dept.
Johann, comm. dept.

Christian Doppler
(Doppler-Effect)
Physics, Mathematics

Viktor Kaplan
(Kaplan-Turbine)
Mechanical Engineering

COST Action TU 1404: 2nd meeting in 2015
Vienna

Hotels

recommended hotels

Hotel Johann Strauss (****)	7 min walking
Hotel Erzherzog Rainer (****)	8 min walking
Hotel Papageno (***)	8 min walking
Austria Trend Hotel beim Theresianum (***)	15 min walking

Please make your reservations by yourself and be sure to mention that you are a guest of Vienna University of Technology (TU Wien) for getting special rates.

Vienna …

… the Conference City

tradition as a major conference site dates back to the year 1815 (peace talks following the Napoleonic Wars, the “Congress of Vienna”

outstanding reputation as conference city and ranks among most favoured destinations in the world

… the Imperial City

walk in the footsteps of the Hapsburgs (splendid baroque Schönbrunn Palace, Spanish Riding School, Imperial Palace)

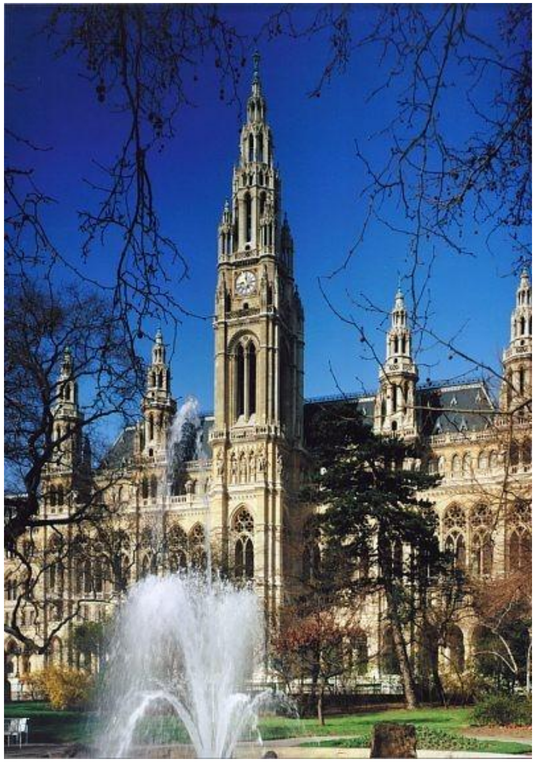
… the Metropolis of Music

first-rate concerts and unrivalled selection of music – from opera to musical
more famous composers have lived in Vienna than in any other city



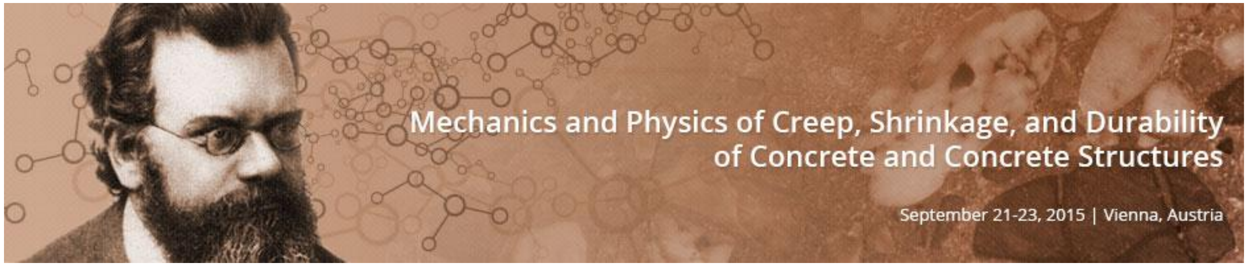






… following the COST meeting
Vienna

CONCREEP 10



Mechanics and Physics of Creep, Shrinkage, and Durability of Concrete and Concrete Structures

September 21-23, 2015 | Vienna, Austria

http://concreep10.conf.tuwien.ac.at/

248 abstracts submitted, 212 abstracts accepted, 13 plenary presentations

Extended full paper submission deadline: **April 17, 2015**