Evaluation of structural build-up rate from RRT data

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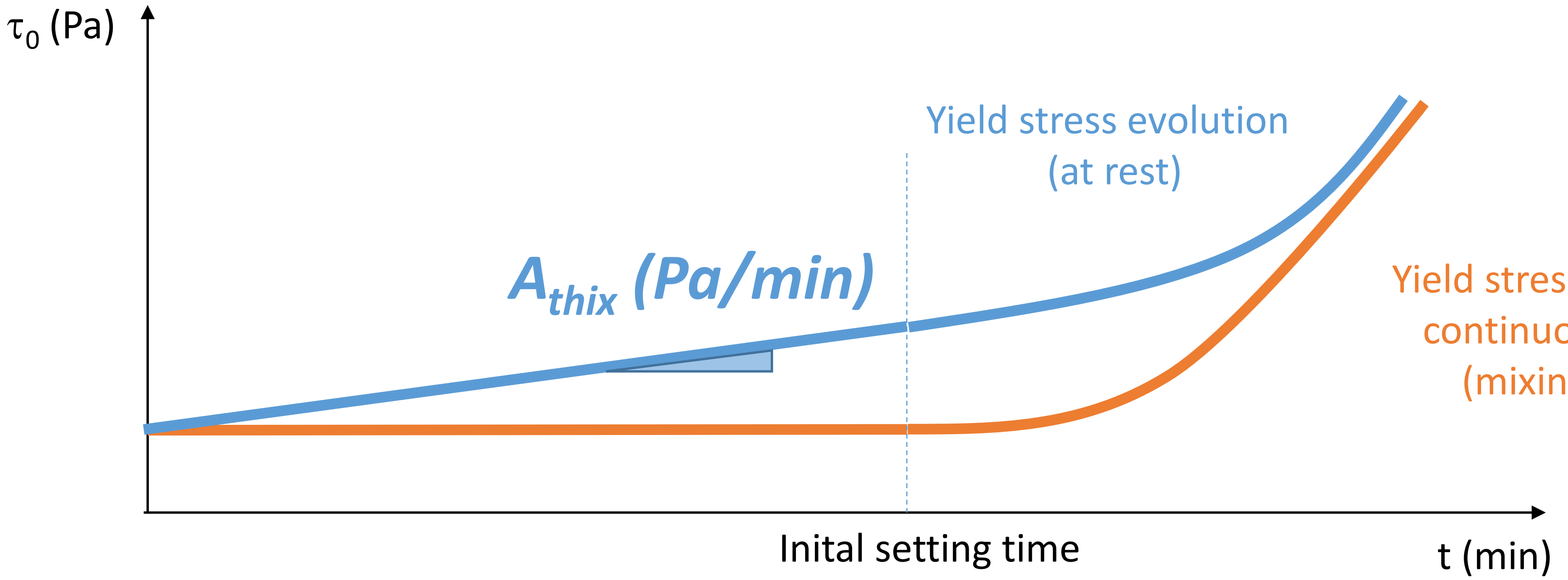
What is structural build-up rate A_{thix}?

- Structural build-up rate: **Increase of the static yield stress of the concrete left at rest**

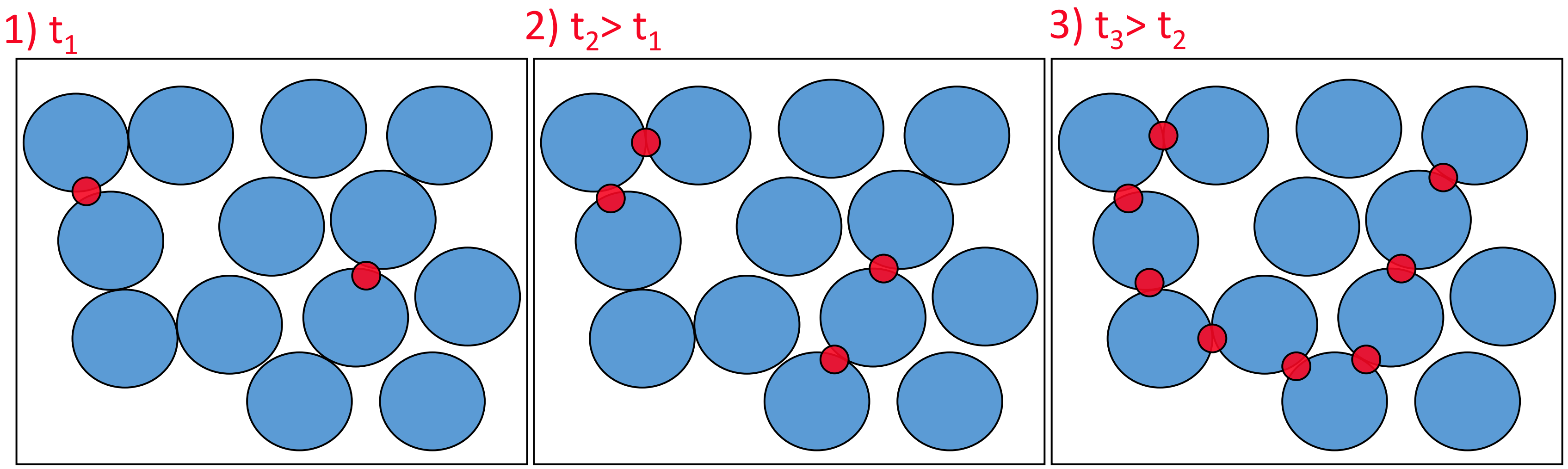
- Structural build-up ≠ Workability loss

reversible *irreversible*



What is structural build-up rate A_{thix}?

- Structural build-up rate: **Microscopic origins**
- Concrete = chemically active material (cement hydration)
  - « Reversible » evolution at rest – so called « thixotropy »
    - First minutes – flocculation
    - Before cement setting – nucleation of cement particles (CSH bridges)



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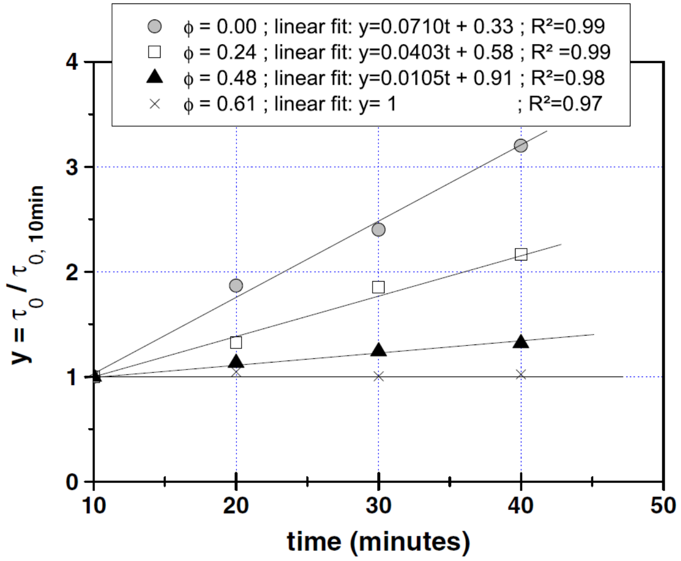


$$\tau_0(t_{rest}) = \tau_0(0) + A_{thix}.t_{rest}$$

Structural build-up rate (Roussel, 2006)

Why is structural build-up rate important?

- SCC formwork pressure
  - Pressure decrease due to concrete shearing at the interface
  - Competition between casting rate *R* and structural build-up rate A_{thix}

- 3D printing
  - Compressive failure of the base layer
  - Competition between casting rate *R* and structural build-up rate A_{thix}

- Other aspects
  - Distinct layers casting

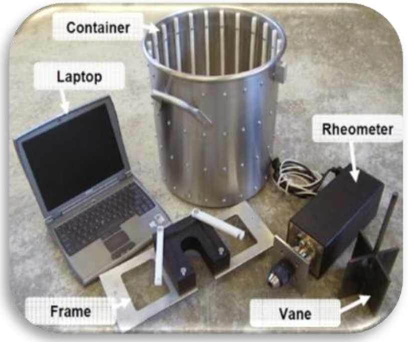
Measurements of structural buil-up rate

- Methods used in the RRT

Instantaneous static yield stress

Constant low shear rate test: negligible viscosity effect
(rotational velocity 0.025 rpm)

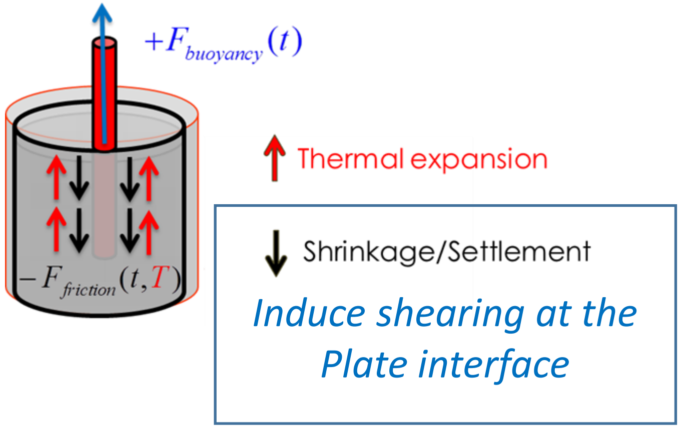
Peak torque measured:
Start of the material flow = ***Static yield stress***

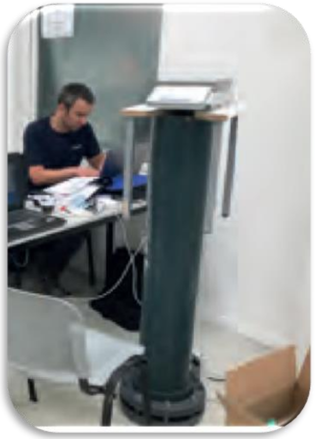


5 Rheometers: 2 ICARs, Viscomat, EBT, rheocad

Plate tests

Continuous measurement of the weight of immersed plate





$$\tau_0(t) = \frac{g\left(\Delta m_{plate}(t) + \rho_{concrete} V_{plate}\right)}{S_{plate}}$$

$$A_{thix} = \frac{g\Delta(\Delta m_{plate}(t))}{S_{plate}\Delta t_{rest}}$$

Measurements of structural buil-up rate

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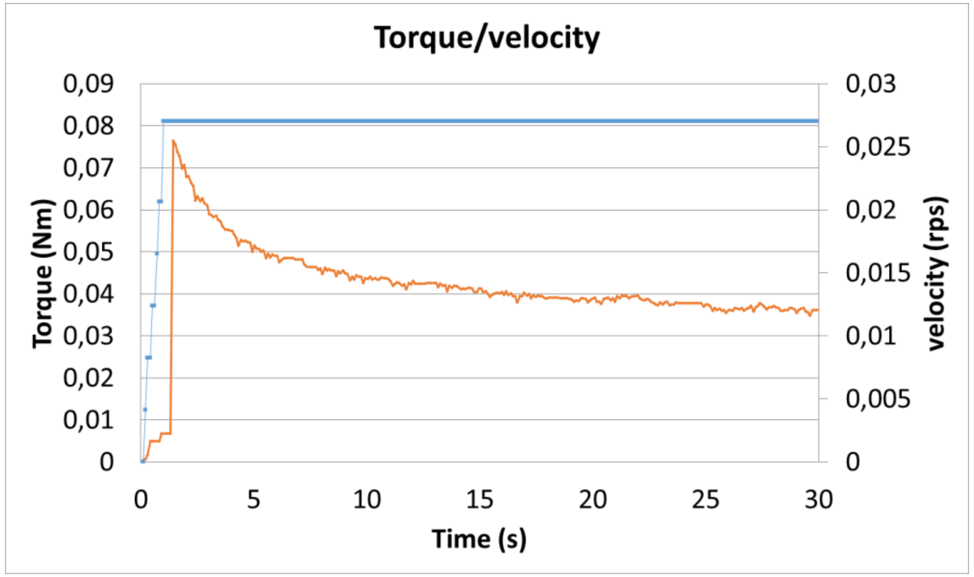
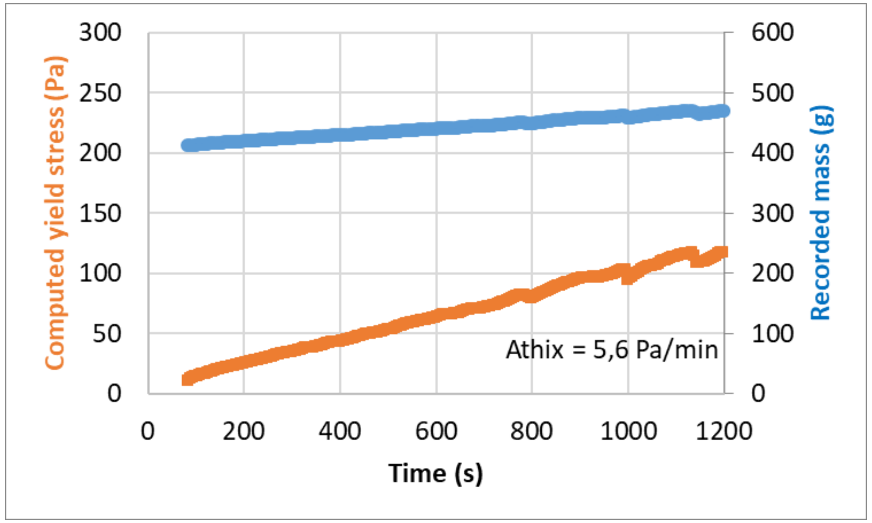


Example of viscomat results

$$\tau_0(t) = \frac{T_{peak}}{2\pi R_{vane}{}^2 H_{vane}}$$

Plate tests



$$\tau_0(t) = \frac{g\left(\Delta m_{plate}(t) + \rho_{concrete} V_{plate}\right)}{S_{plate}}$$

Measurements of structural buil-up rate

- Measurements sequence and details

Static yield stress measurements

Rheometer test

+ Flow curves: Dynamic yield stress
= static yield stress with no rest

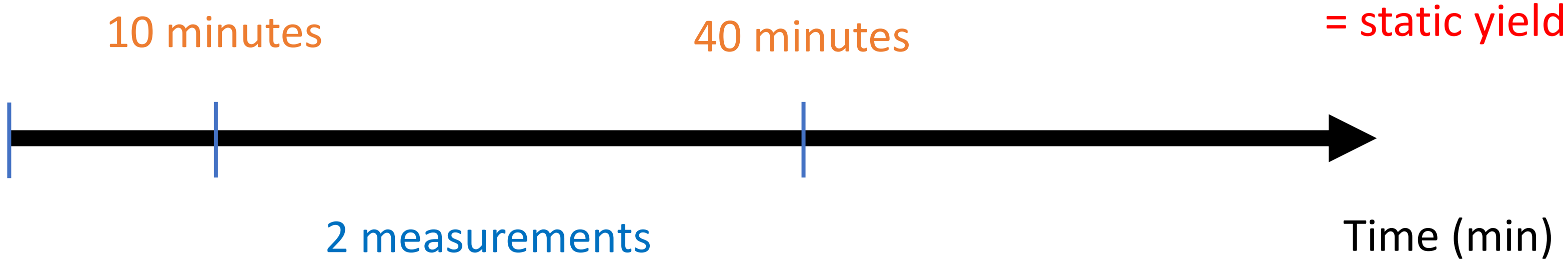


Plate tests

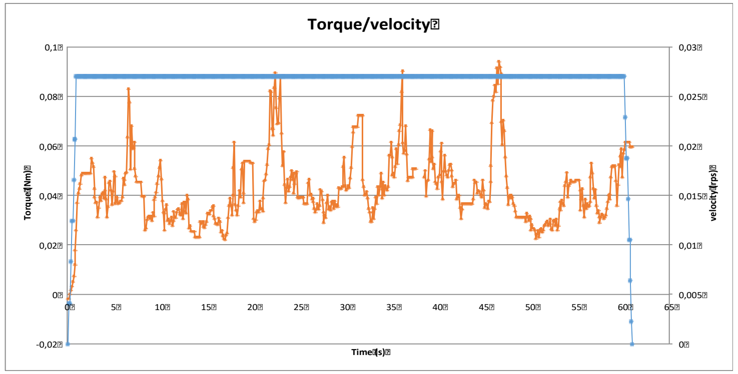
Measurements of structural buil-up rate

- Measurement issues: rejected data

Instantaneous static yield stress

Noises in recorded data

Gap size?



Unrecorded Peak torque

Frequency of Data collection?

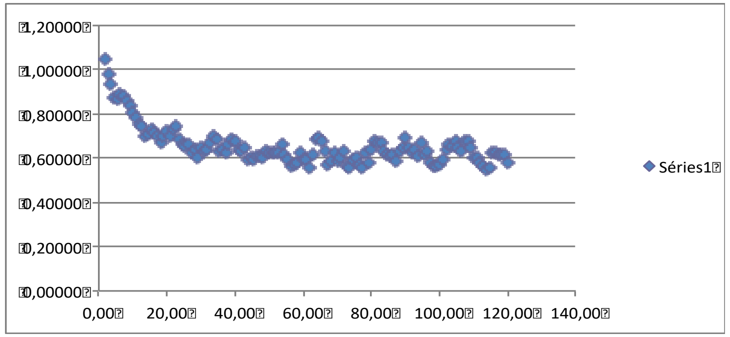


Plate tests

Bleeding at the top of the sample.

Sample height?

Vibration of the sample – Drop in recorded mass

Protection of the measuring stage?

Measurements of structural build-up rate

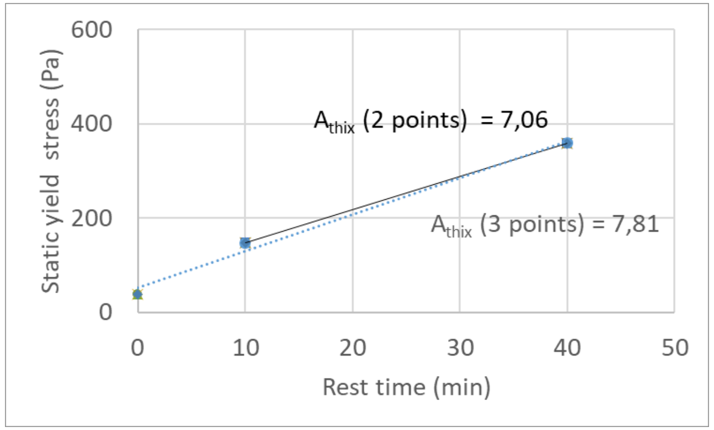
- Data of Round Robin Test
  - 1) A_{thix} computed with static yield stress measurements at 10 and 40 minutes

$$A_{thix}(Pa/\min) = \frac{\tau_{0,40\min} - \tau_{0,10\min}}{30}$$

  - 2) A_{thix} computed with linear regression including dynamic yield stress (3 points)

Athix values (2 points)	Team SA/AP ICAR 1	Plate Test	Team HK/MG VISCOMAT	E-BT Vane	Team YV *RheoCAD*	Team EQIOM ICAR4	Average
Concrete 1	5,20	5,73		8,72	*2,19*	7,70	5,91
Concrete 2	9,27	5,65	6,89	5,58	*3,93*	4,20	5,92
Concrete 3	33,47	11,22	14,64	13,90		24,70	19,59
Concrete 4	18,50	10,80		11,80	*2,26*	5,90	9,85
Concrete 5	27,40	17,40	3,55	2,89	*2,08*	18,40	11,95
Mortar 1	6,07	6,90		1,97		4,10	4,76
Mortar 2	9,27	8,80	7,44	3,55		6,20	7,05
Mortar 3	20,30	16,50	13,53	5,37		19,30	15,00

Max torque missed



Three different structural build-up indices

1/ The structural build-up rate, A_{thix}

2/ The critical time to double the initial yield stress value,

(time when $t_{0,s}(t_c) = 2\tau_{0,s0}$)

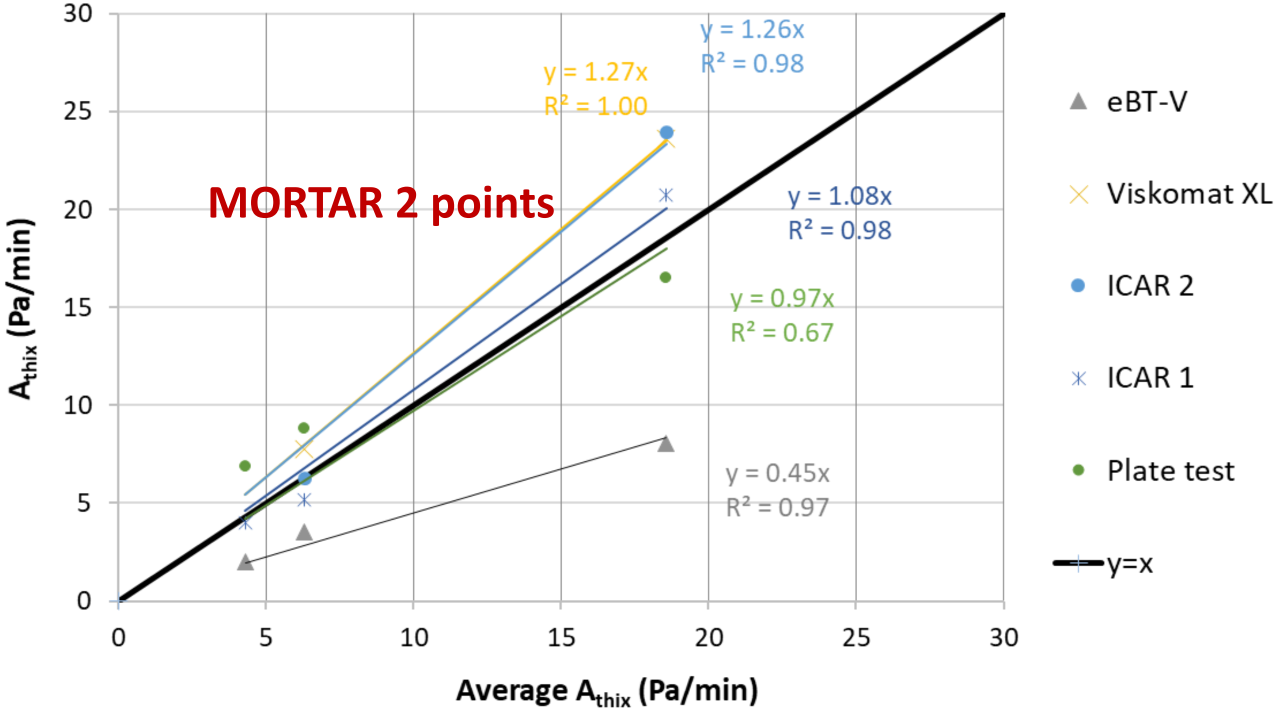
$$2 \times \tau_{0,s}(t) = \tau_{0,s}(0) + A_{thix} t_c$$

$$t_c = \tau_{0,s0}/A_{thix}$$

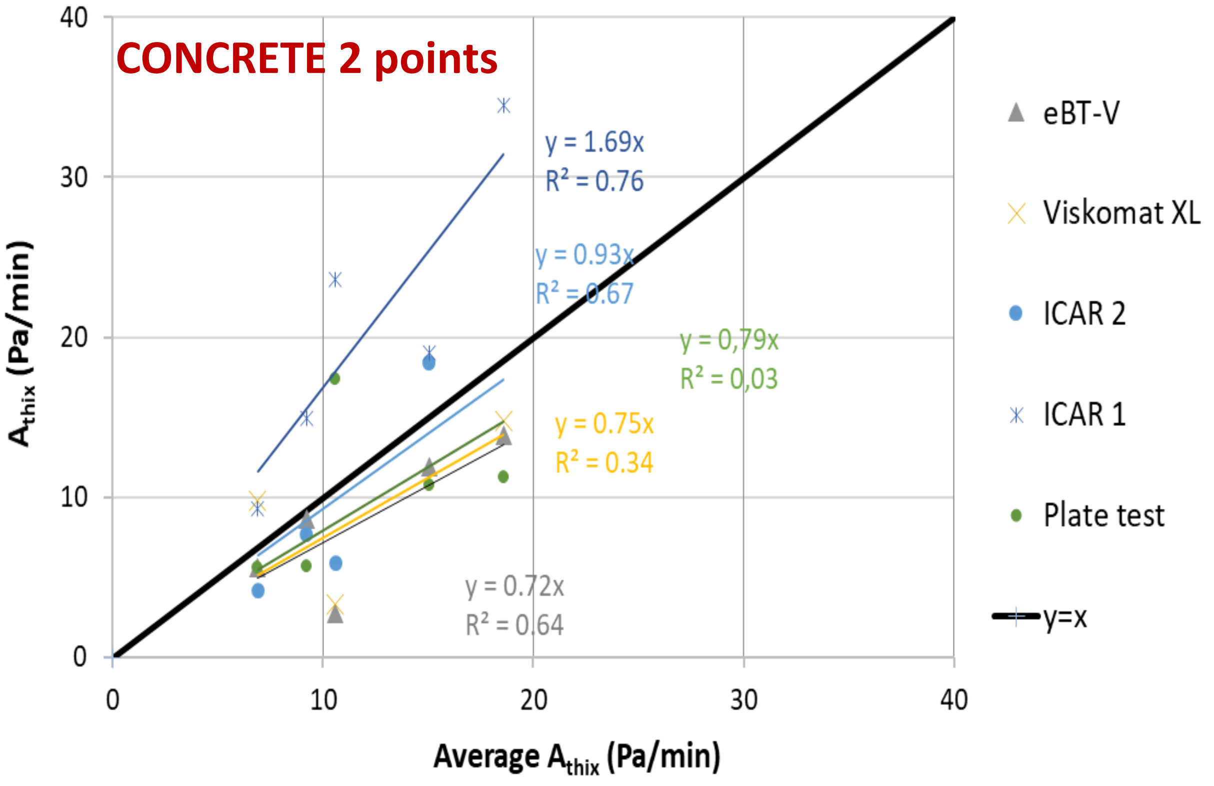
3/ The coupled effect of static yield stress at 10 minutes of rest and A_{thix} that describes the consistency of the concrete at a given time. This index is equal to $C = \tau_{0,s10} \cdot A_{thix}$

I/ Measurements of structural build-up rate with Athix method

- Computation of structural build-up rate from RRT data (Vane/Plate tests)



Measured Athix obtained with static yield stress measurements at 10 and 40 minutes (two values) vs. average Athix values for each mortar.



Measured Athix obtained with static yield stress measurements at 10 and 40 minutes (two values) vs. average Athix values computed for each concrete.

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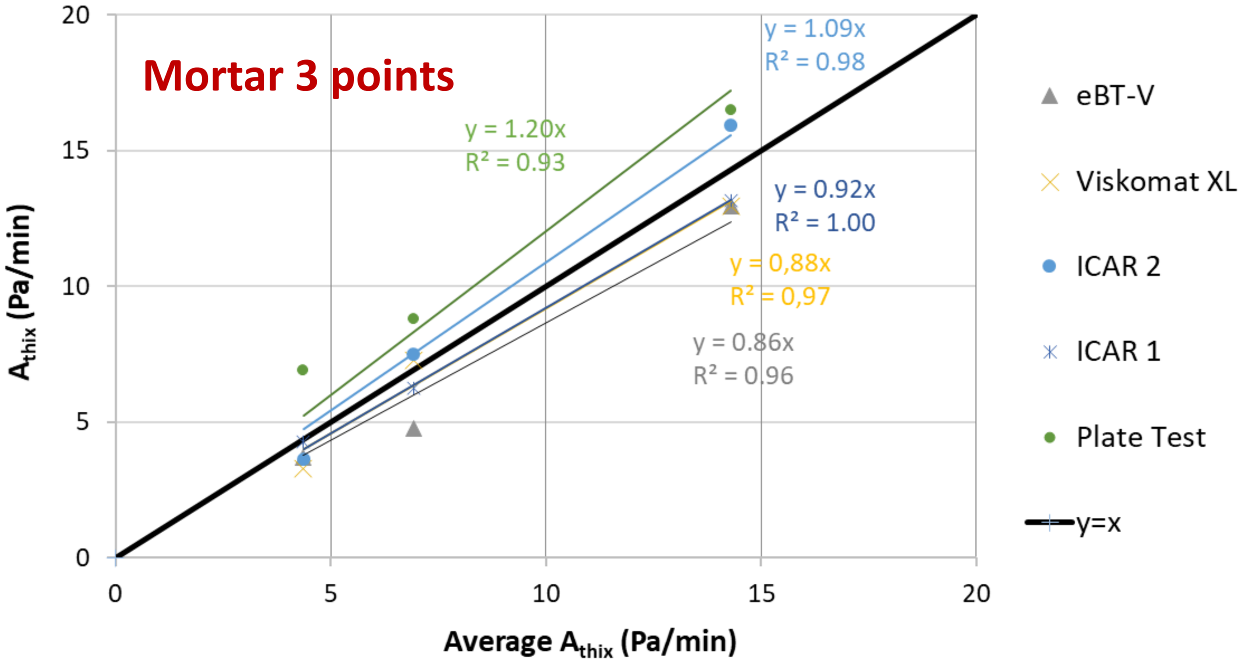
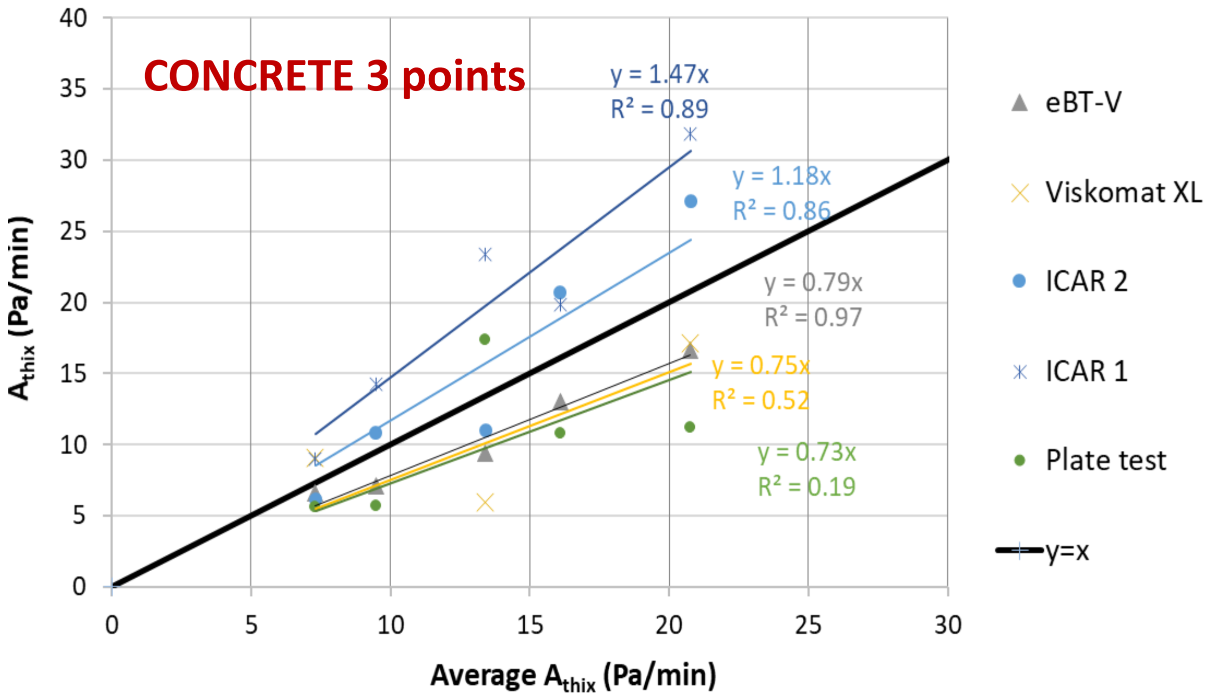
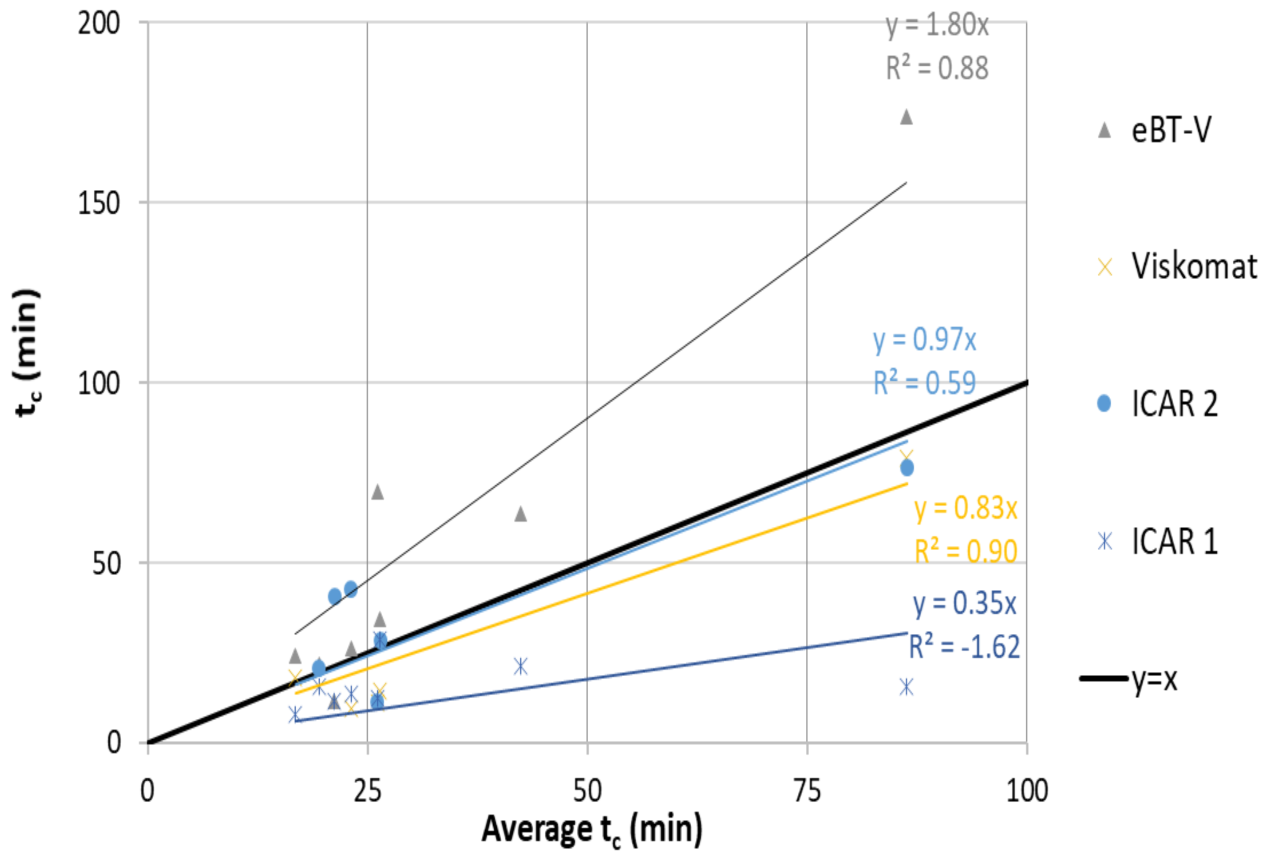




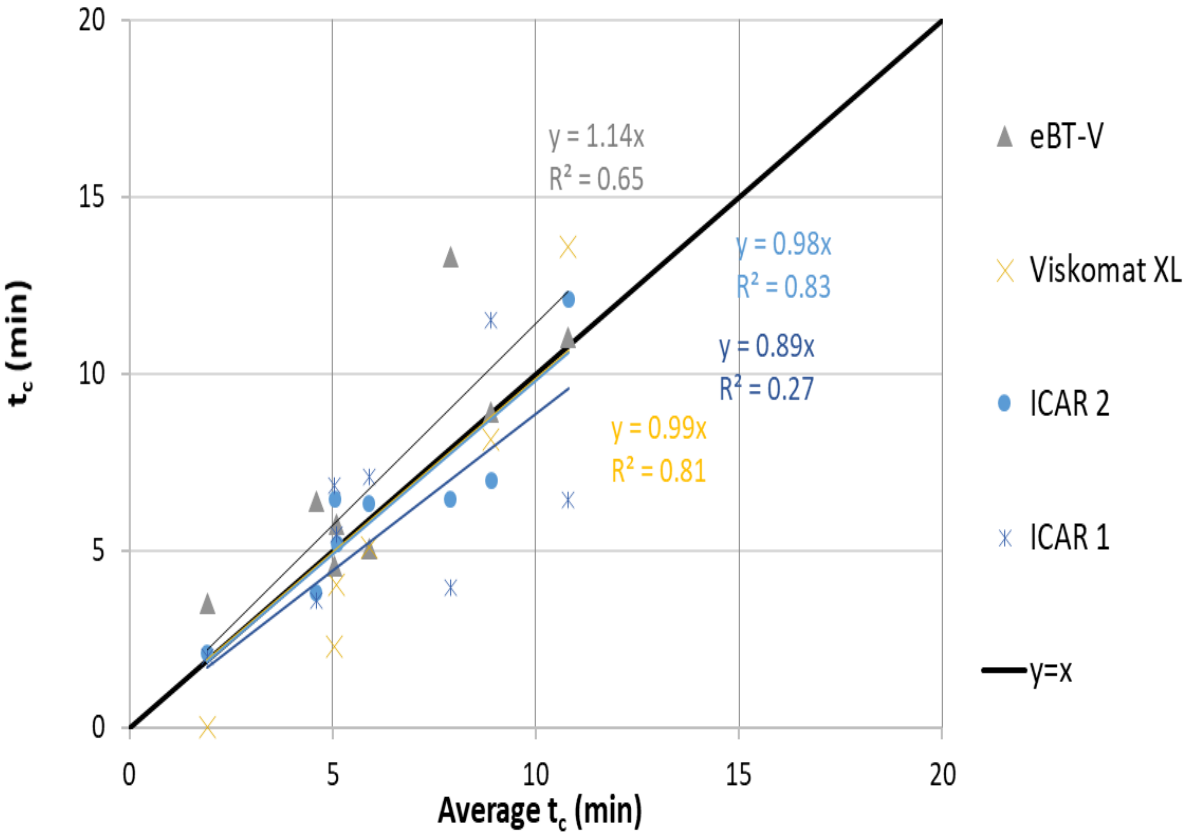
Measured Athix obtained with static yield stress measurements at 10 and 40 minutes and dynamic yield stress (three values) vs. average Athix values for each mortar.

Measured Athix obtained with static yield stress measurements at 10 and 40 minutes and dynamic yield stress (three values) vs. average Athix values computed for each concrete.

II/ The critical time to double the initial yield stress value, $t_c = \tau_{0,s0}/A_{thix}$ (time when $t_{0,s}(t_c) = 2\tau_{0,s0}$)



Measured t_c obtained with static yield stress measurements at 10 and 40 minutes (two values) vs. average t_c values computed for each tested material.



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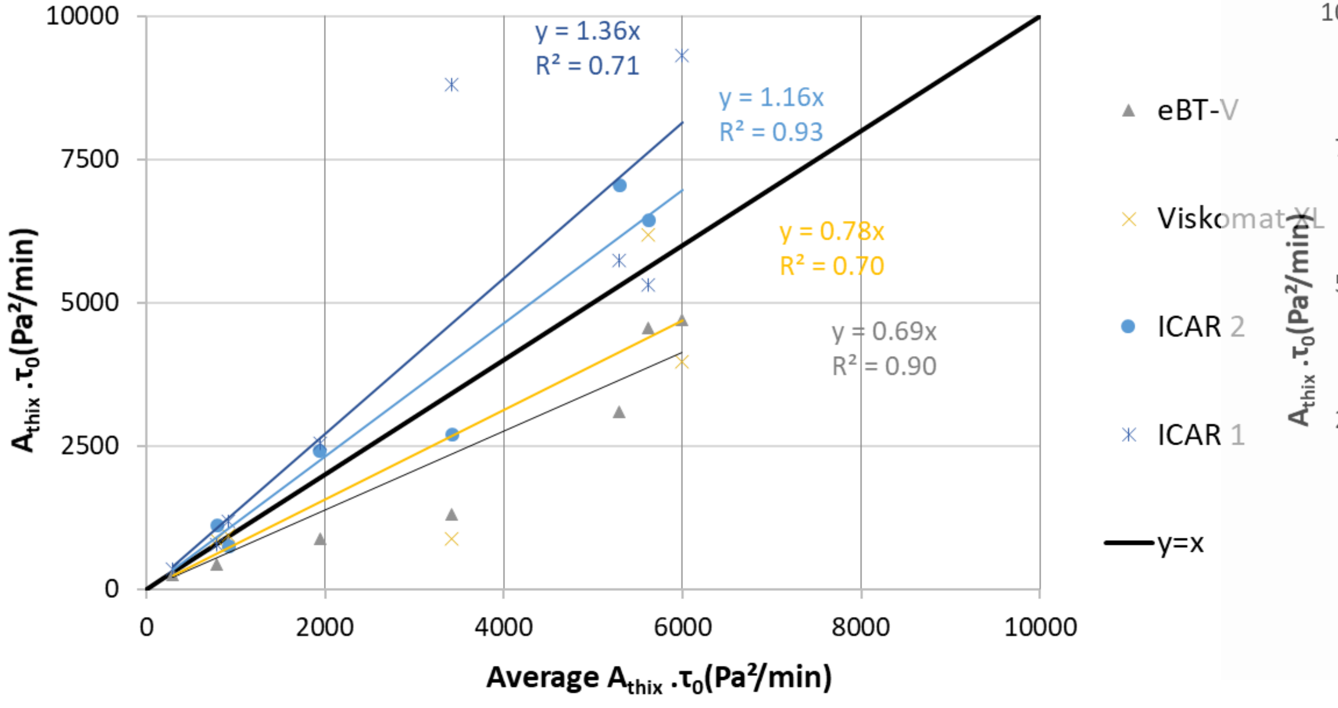
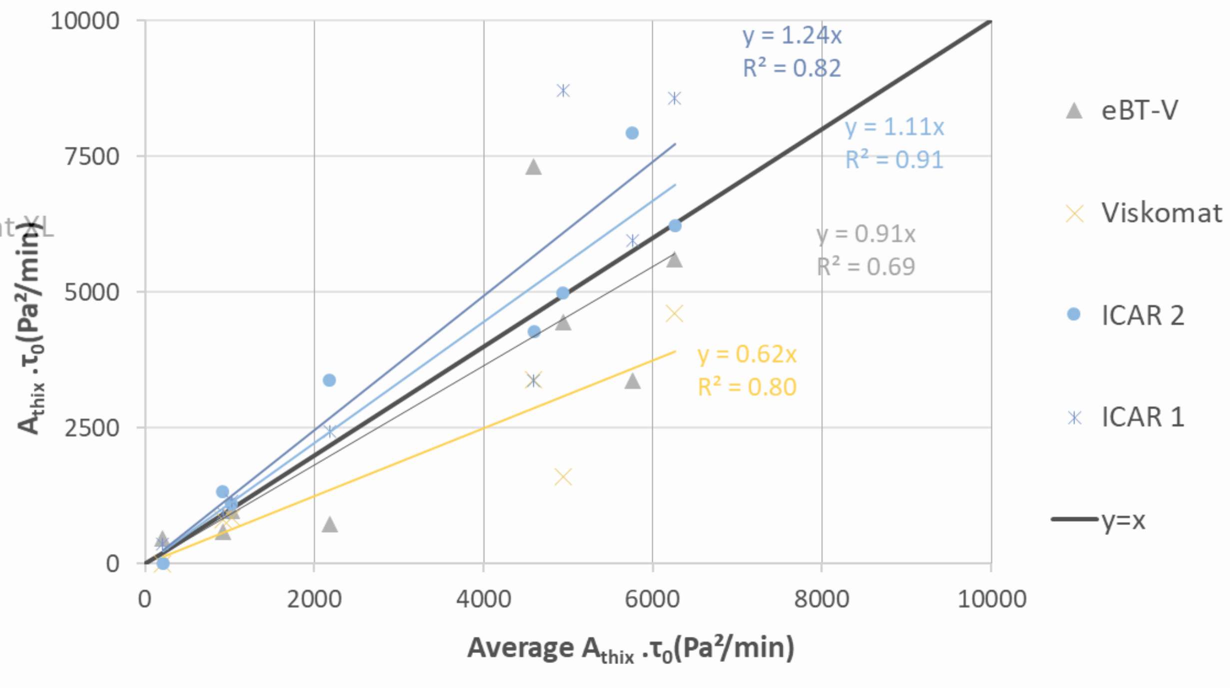
III/ The coupled effect of static yield stress at 10 minutes of rest and A_{thix} that describes the consistency of the concrete at a given time. This index is equal to $C = \tau_{0.s10}.A_{thix}$



Measured coupled effect indices (two values) vs. average coupled effect indices computed for each tested material.



Measured coupled effect indices (three values) vs. average coupled effect index values computed for each tested material.

Contrary to the previous analysis, it can be seen that for both types of material (i.e., mortar and concrete), using three values of yield stress does not help to reduce the measurements dispersion.

Slope of computed structural build-up indices vs. average values for concrete and mortar.

3 points computation – 0, 10 and 40 minutes		ICAR 1		ICAR 2		Plate Test		Viskomat		EbT-V	
		Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
A_{thix}	All	1.36	0.84	1.16	0.9	0.83	0.12	0.8	0.69	0.8	0.96
	Mortar	**0.92**	**1**	**1.09**	**0.98**	**1.2**	**0.93**	**0.88**	**0.97**	**0.86**	**0.96**
	Concrete	**1.47**	**0.89**	**1.18**	**0.86**	**0.73**	**0.19**	**0.75**	**0.52**	**0.79**	**0.96**
t_c	All	0.89	0.27	0.98	0.83			0.99	0.81	1.14	0.65
	mortar	**1.28**	**0.97**	**0.95**	**0.68**			**0.82**	**0.76**	**0.95**	**0.95**
	Concrete	**0.65**	**0.38**	**1**	**0.92**			**1.15**	**0.9**	**1.26**	**0.7**
$t_c.A_{thix}$	All	1.24	0.82	1.11	0.91			0.62	0.8	0.91	0.69
	mortar	**0.75**	**0.98**	**0.95**	**0.97**			**0.74**	**0.99**	**1.56**	**0.98**
	Concrete	**1.34**	**0.84**	**1.15**	**0.86**			**0.58**	**1**	**0.77**	**0.84**

Conclusions/Recommandations

- ✓ **The three thixotropy indices (yield stress variation with time, characteristic time, coupled effect) indicated the same thixotropic trend for the mortars and concretes, whether with the static method (plate test) or with the rheometric tests (ICAR, Viscomat XL, and eBT-V rheometers).**

- ✓ **The index values showed a good correlation for mortar mixtures. The thixotropy indices were, on the contrary, much more dispersed for the concrete mixtures.**

- ✓ **The quality of the correlations increased drastically as soon as the number of yield stress values used in the analysis increased from two to three measuring points, except for the coupled effect indices**

- ✓ **The static plate test method and rheometric methods can be adapted to evaluate the structural build-up of mortar mixtures so long that the static yield stress obtained with the stress growth method can be accurately measured immediately after the application of shear rate. Data sampling should be of the order of 1/100 of a second to ensure adequate capturing of peak torque values during shear growth testing.**

- ✓ **The plate test should be carried out carefully ensuring that the materials at the top of the tested samples (where the bar is placed) is not subjected to bleeding and that the materials do not slip at the plate interface.**

- ✓ **It is recommended to increase the number of yield stress values to at least four points over one hour after mixing to determine more accurately the various thixotropy indices. For example, t0, t0+5, t0+15, t0+30, and t0+50 minutes. Moreover, having more values allow describing non-linear evolution of static yield stress that can be encountered with modern concretes.**

- ✓ **In order to reduce the dispersion of the thixotropy indices of concrete, the use of larger rheometer containers is recommended to be more consistent with the maximum size of coarse aggregates in the sheared material. This point should be the matter of a future work or benchmark. In this objective, the use of a single batch approach appears to be a promising solution.**