SAOS as a **predictive tool** to assess the residual **reactivity** in **recycled** cementitious binders

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32th Conference of Rheology of building materials

Cement
Chemistry
&
Particle
Interaction

Oscillatory
Rheology

Sustainability

Cement Chemistry & Particle Interaction

Origin of Cement Paste Cohesion

Cement composition: 55-65% of **C_3S** (15-25% of C_2S)

tricalcium silicate: model system for cement

C_3S (≈ cement) hydration:

1. C_3S grains dissolution and Calcium Silicate Hydrates (C-S-H) precipitation
2. Attractive electrostatic force development between C-S-H surfaces
3. C-S-H gel network formation (until cement setting)

C=CaO, S=SiO_2, H=H_2O

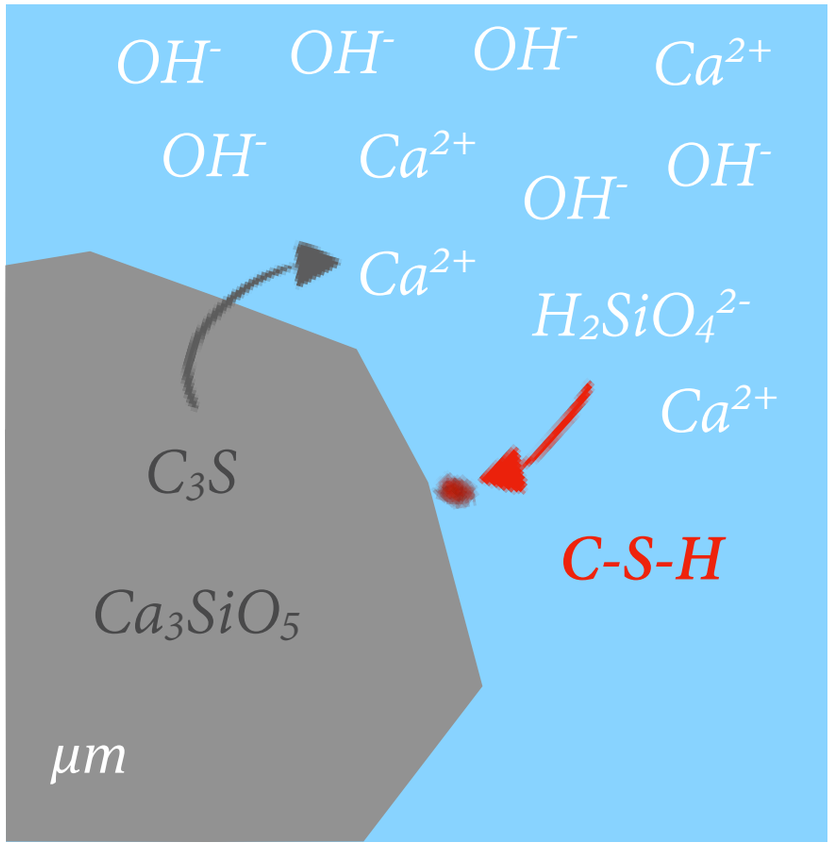
Taylor, H. F., Cement chemistry, 1997.

Jennings, CCR, 2000
Jönsson et al. Langmuir, 2005
Thomas et al. CCR, 2006

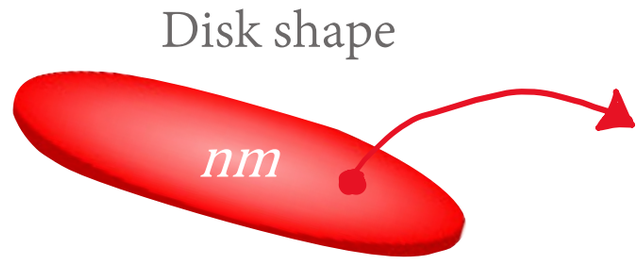
Origin of Cement Paste Cohesion

Phase 1: C_3S dissolution & C-S-H precipitation

Tricalcium silicate — Calcium Silicate Hydrate



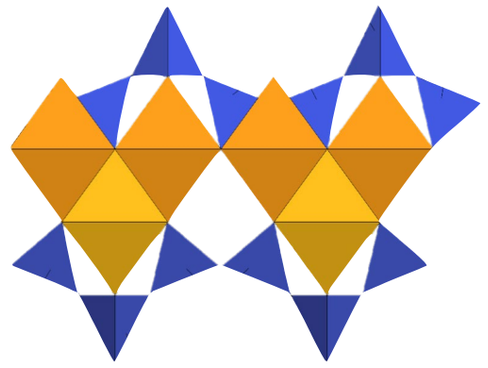
Immediately after contact with water the $[OH^-]$ increases resulting in a **pH>12**



Del Sasso et al., *Nanomaterials* (2022)

$CaO:SiO_2:H_2O$

C-S-H model structure

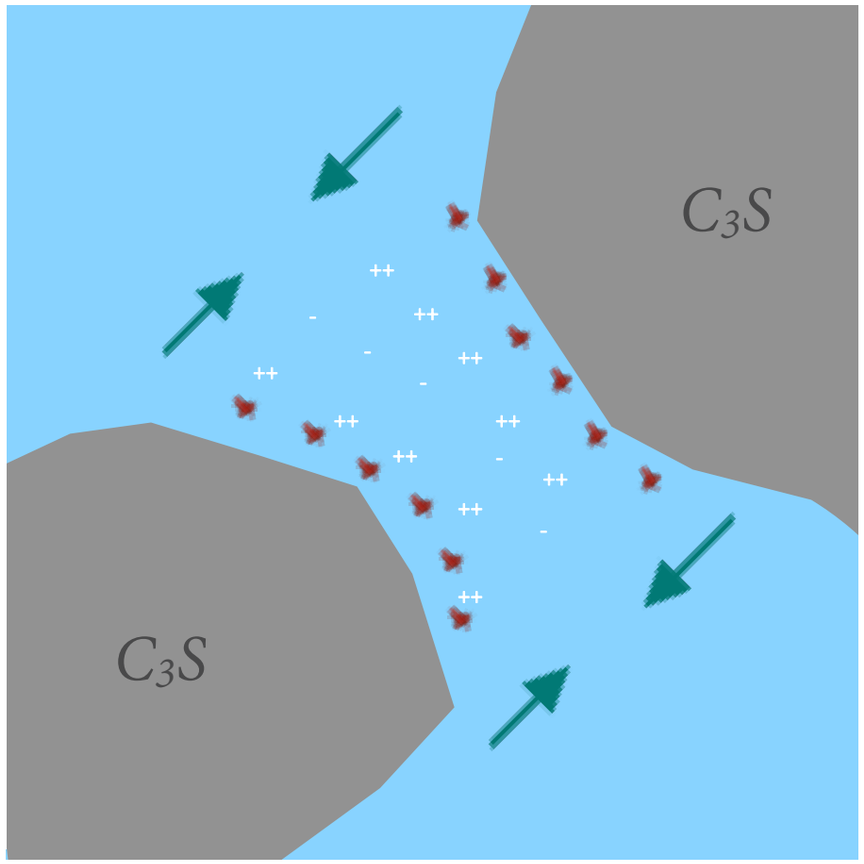


Si tetrahedra chain

CaO layer

Origin of Cement Paste Cohesion

Phase 2: Attractive electrostatic force development between C-S-H surfaces …and C_3S grains!

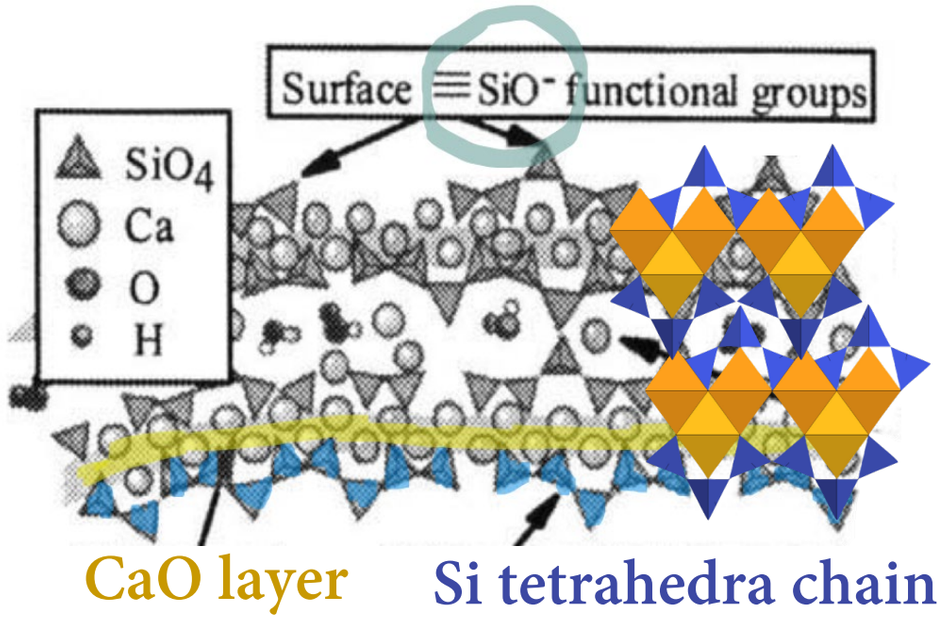


Attractive force & cohesion
f(pore solution concentration)

Lesko et al., Ultramicroscopy, 2001
Jönsson et al. Langmuir, 2005

C-S-H model structure

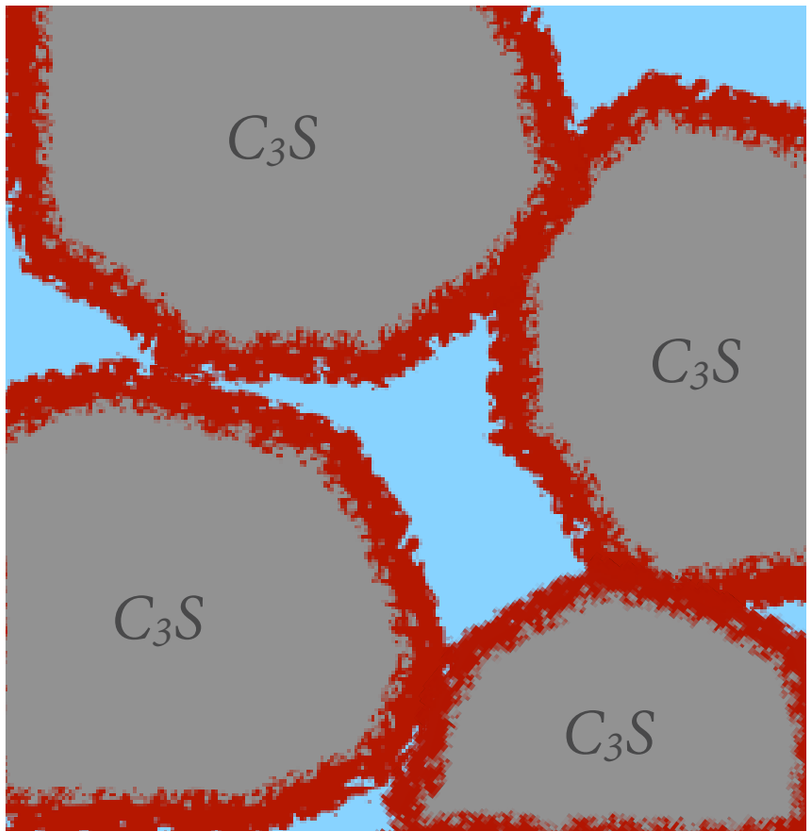
This negatively charged group forms after contact with water reacting with OH^- (at high pH)



Iwaida et al. *Studies in Surface Science and Catalysis* (2001)

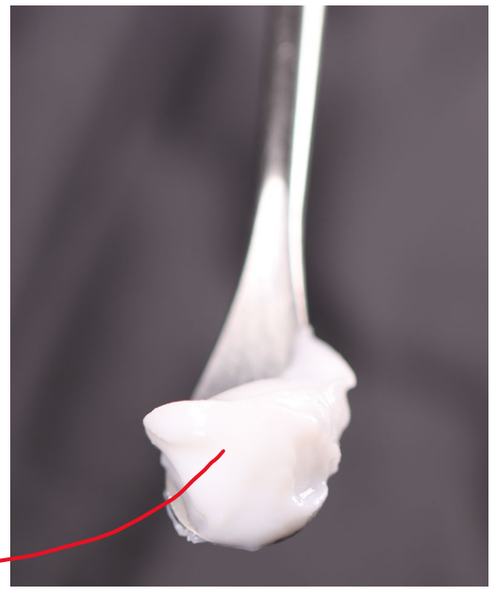
Origin of Cement Paste Cohesion

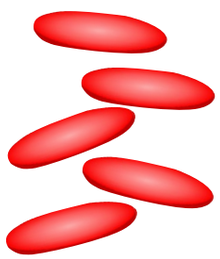
Phase 3: C-S-H gel network formation (until cement setting)



C-S-H gel:

- nano crystalline/nano structurate
- layered structure highly disordered at longer distances (µm)

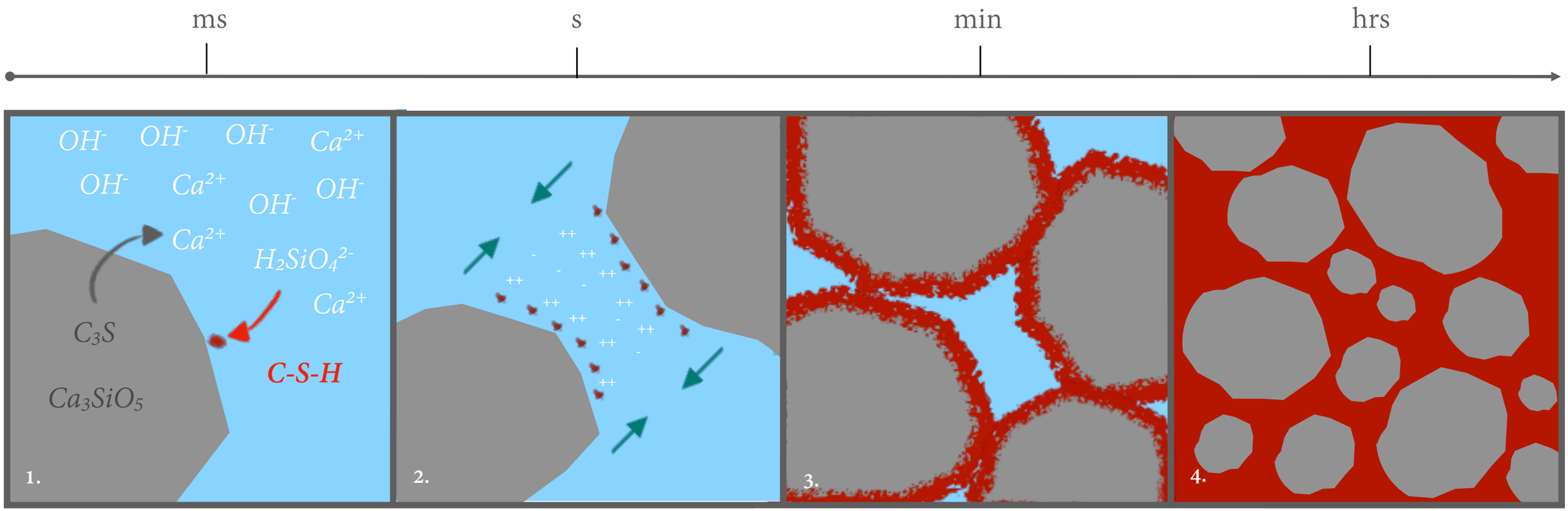




Liberto et al. *Langmuir* (2022)
Del Sasso et al., *Nanomaterials* (2022)

Origin of Cement Paste Cohesion

Why does cement set?



1. C_3S grain dissolution and Calcium Silicate Hydrate (C-S-H) precipitation
2. Attractive electrostatic force development between C-S-H surfaces
3. C-S-H gel network formation (until cement setting 4.)

C-S-H the "glue" of cement

After complete hydration ca. 80% of the C_3S has been dissolved

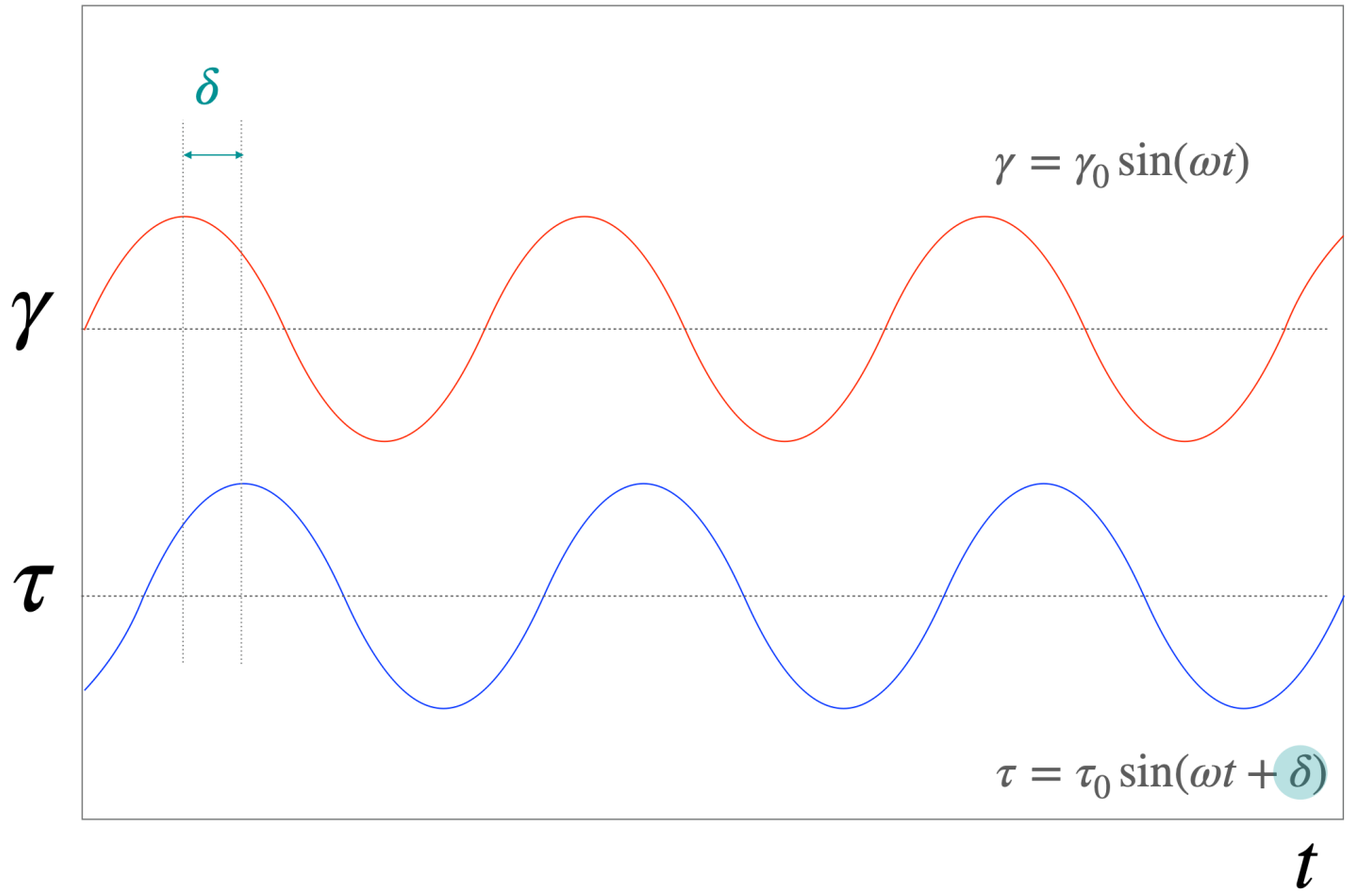
Cement Chemistry & Particle Interaction

Oscillatory Rheology

Oscillatory rheology

γ (%)

f (Hz)

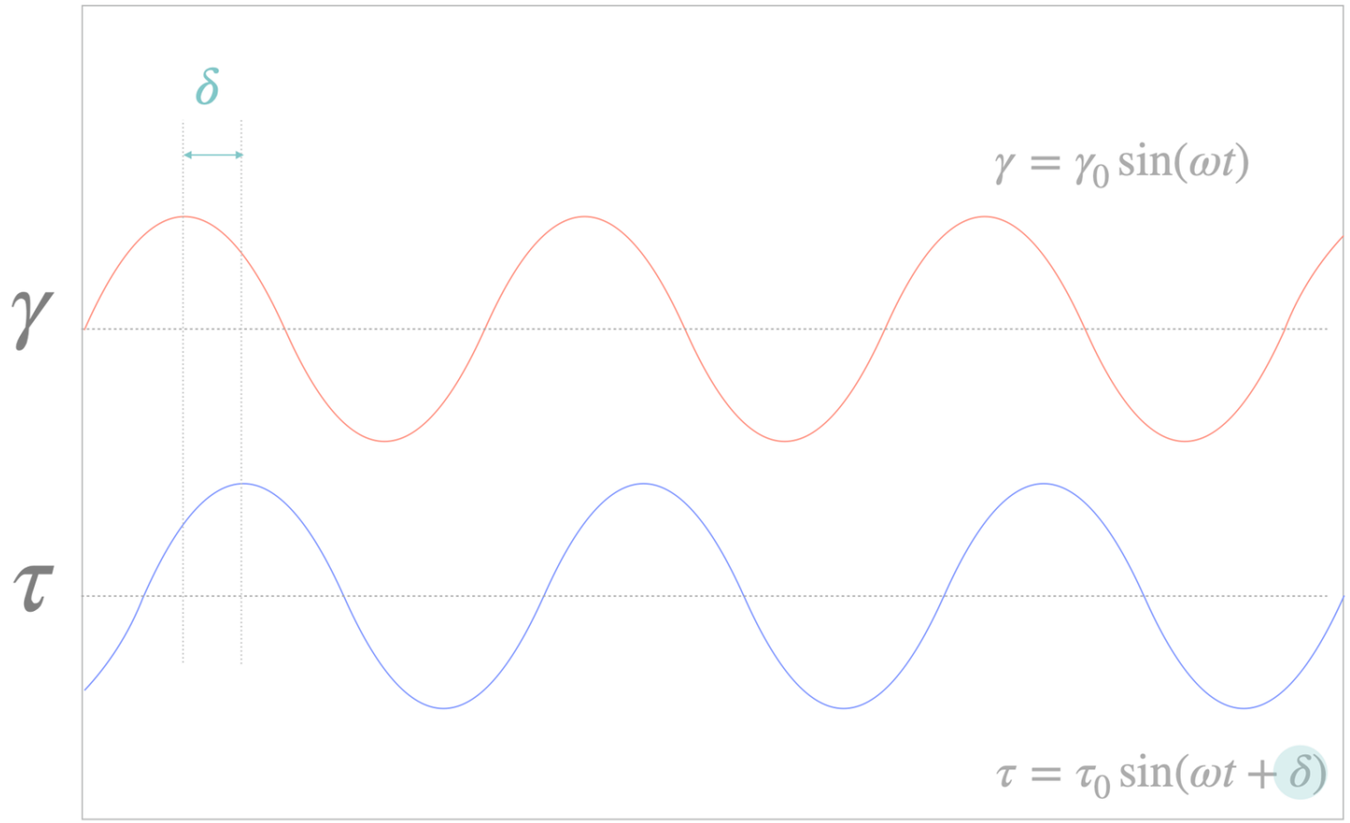


$\delta = 0$	purely elastic
$\delta = \pi/2$	purely viscous
$0 < \delta < \pi/2$	**viscoelastic**

Oscillatory rheology

γ (%)

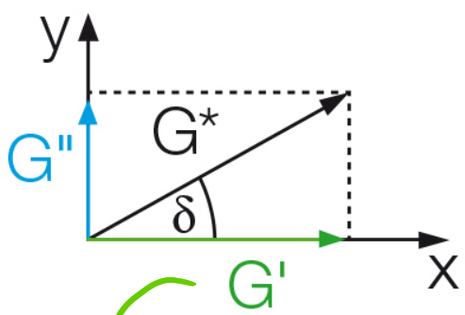
f (Hz)



$$G^* = \tau^*(t)/\gamma^*(t)$$

$$G^* = G' + iG''$$

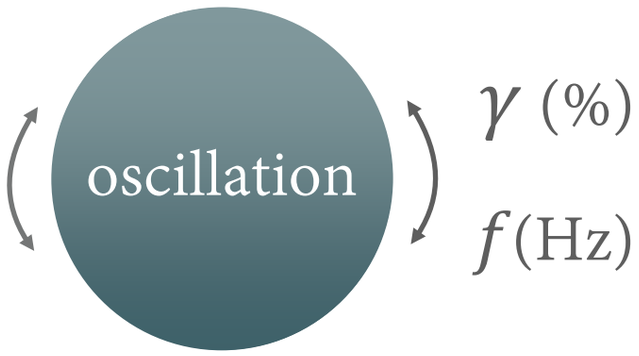
Viscous or loss modulus



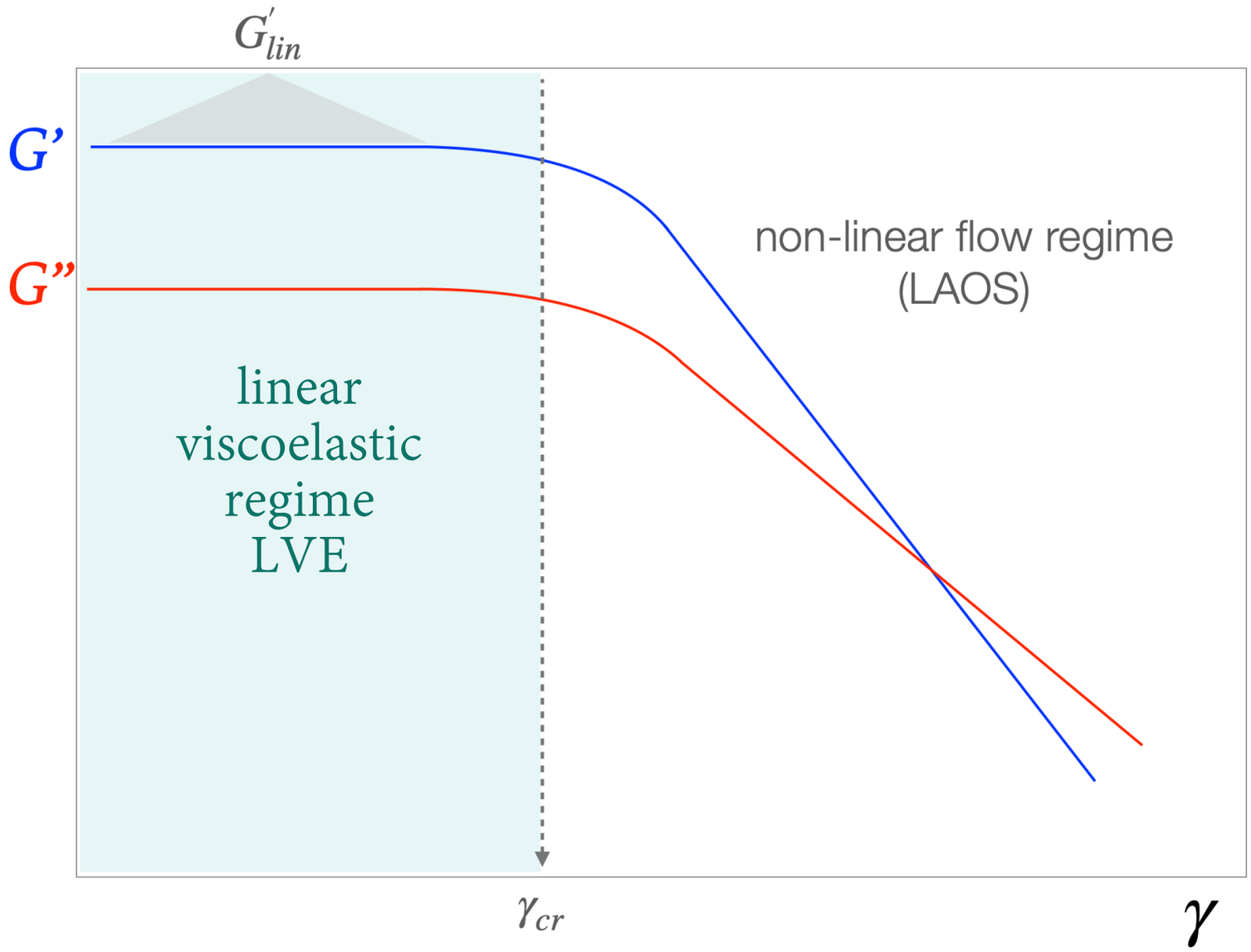
Storage or elastic modulus

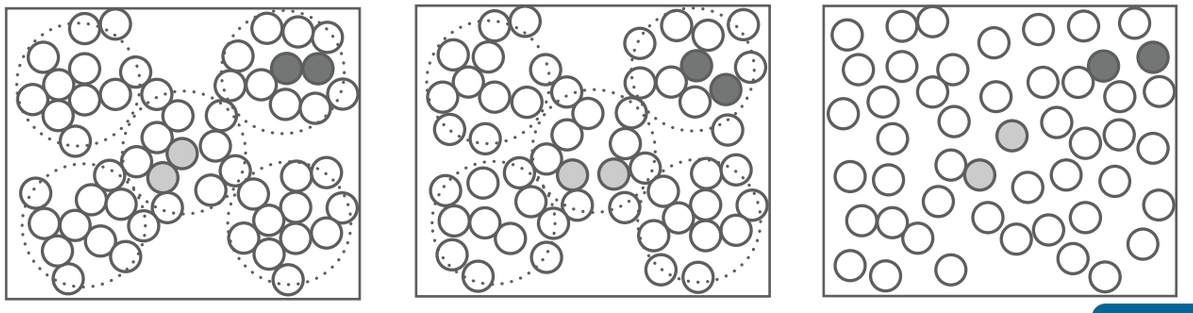
$\delta = 0$	purely elastic
$\delta = \pi/2$	purely viscous
$0 < \delta < \pi/2$	**viscoelastic**

Oscillatory rheology

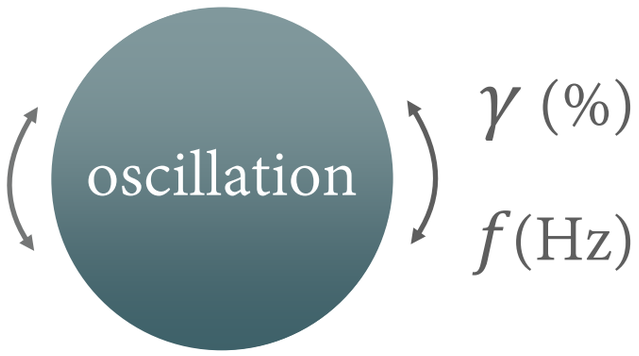


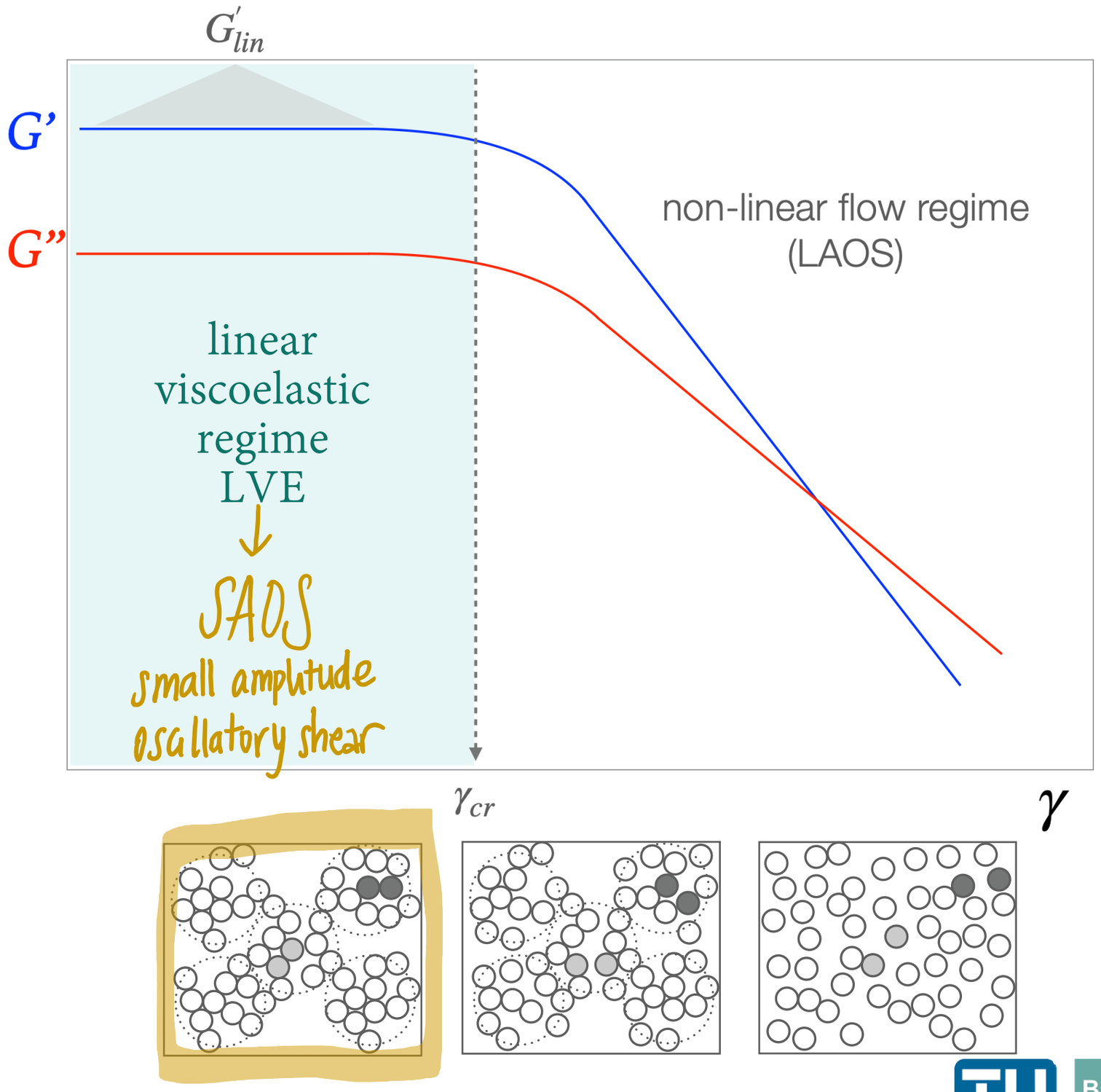
Typical behavior for a paste or gel





Oscillatory rheology



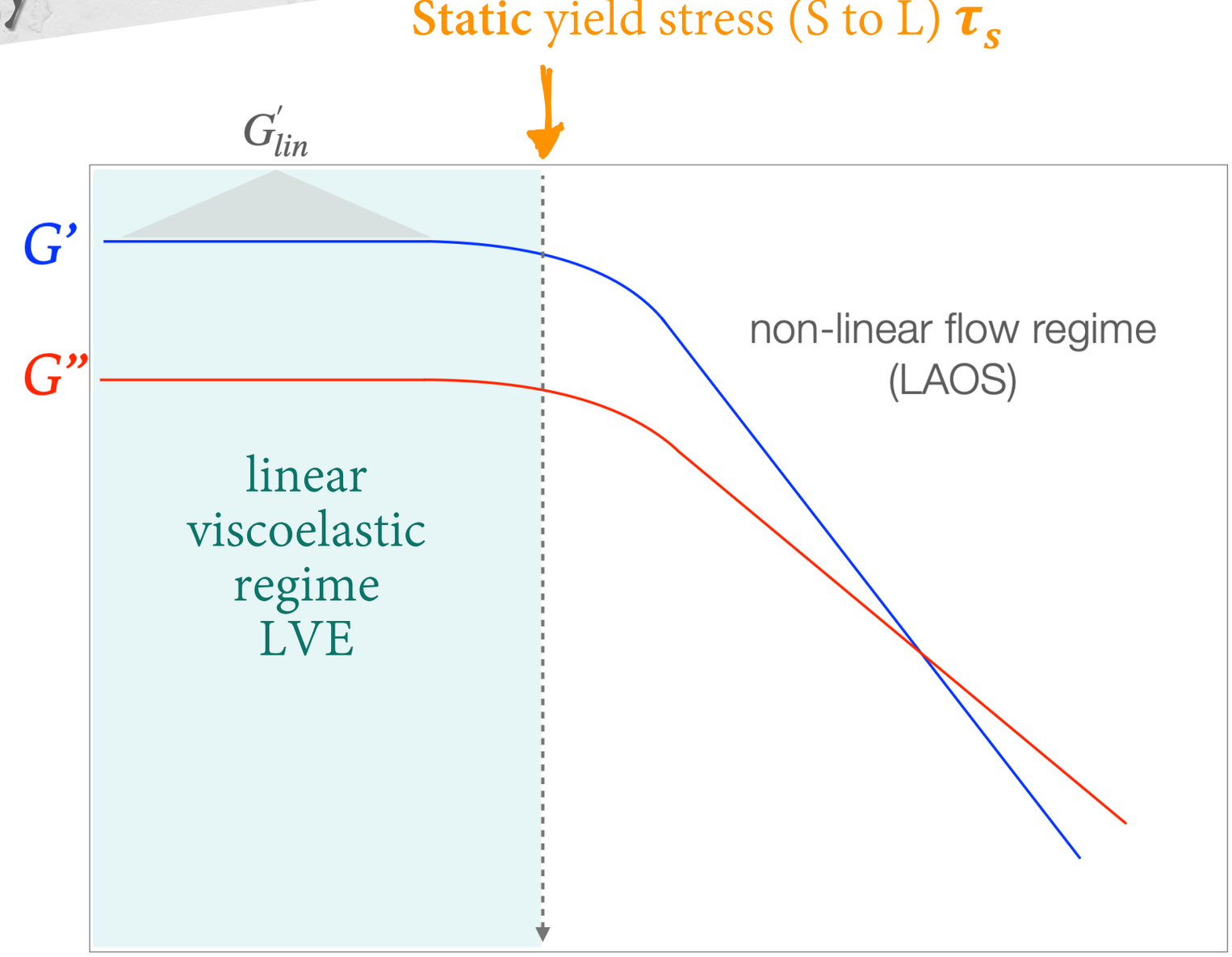


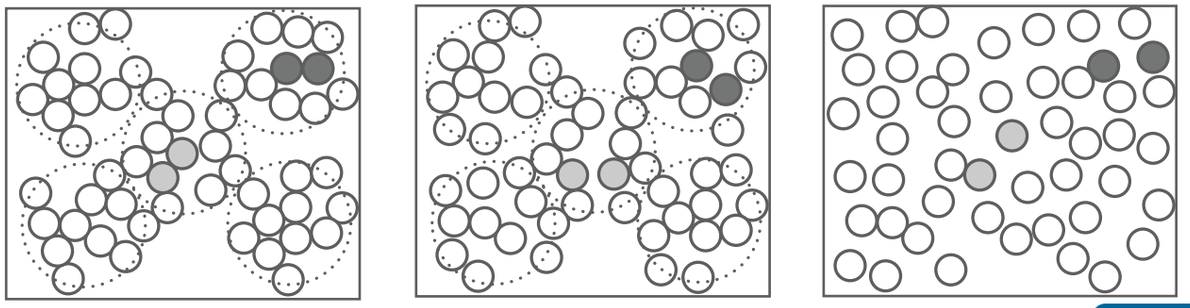
Oscillatory rheology

γ (%)

f (Hz)

$$\tau_s = G'_{lin} \cdot \gamma_{cr}$$

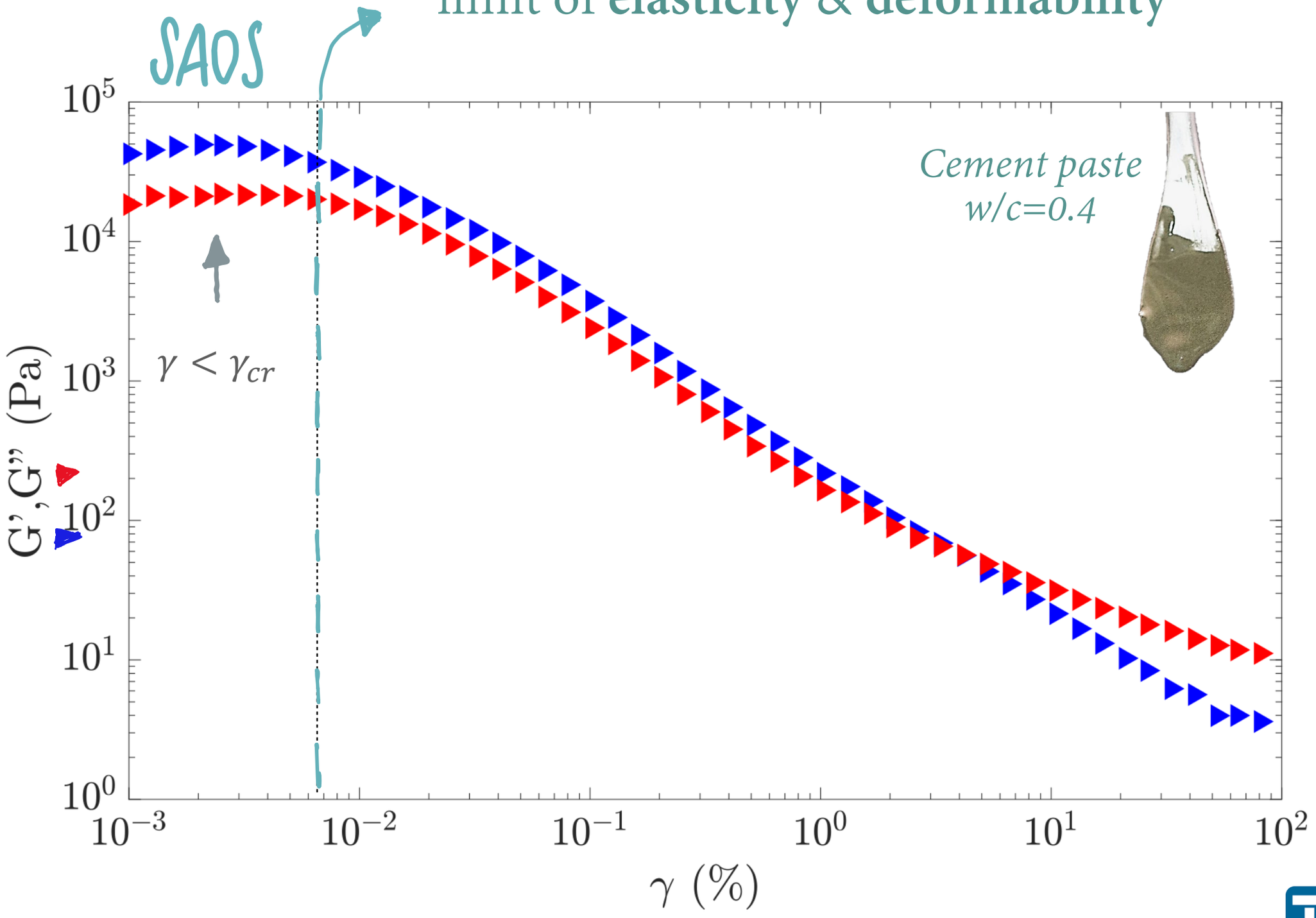




Oscillatory rheology

small

limit of **elasticity** & **deformability**



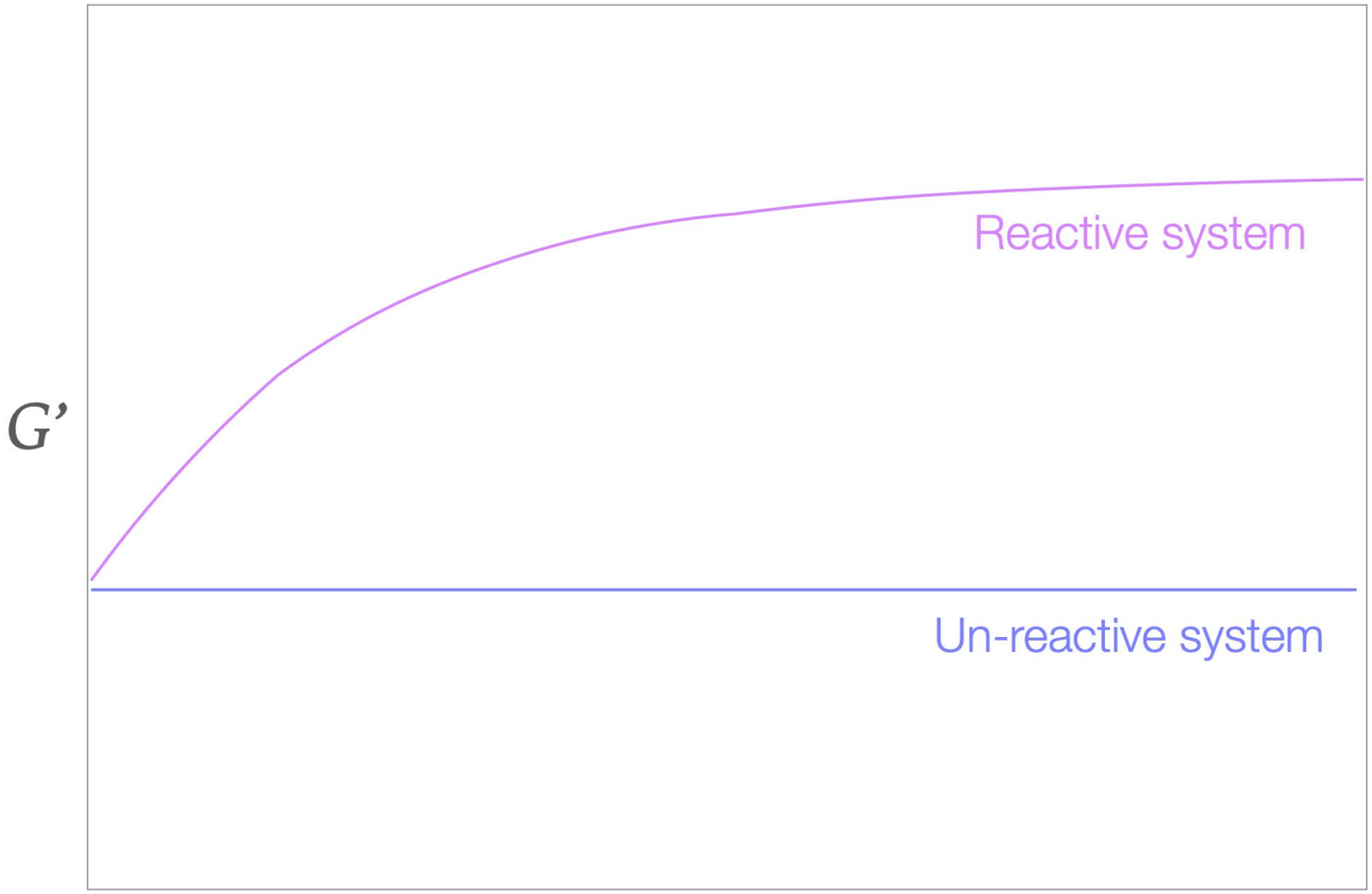
small oscillatory rheology
SAOS

γ (%)

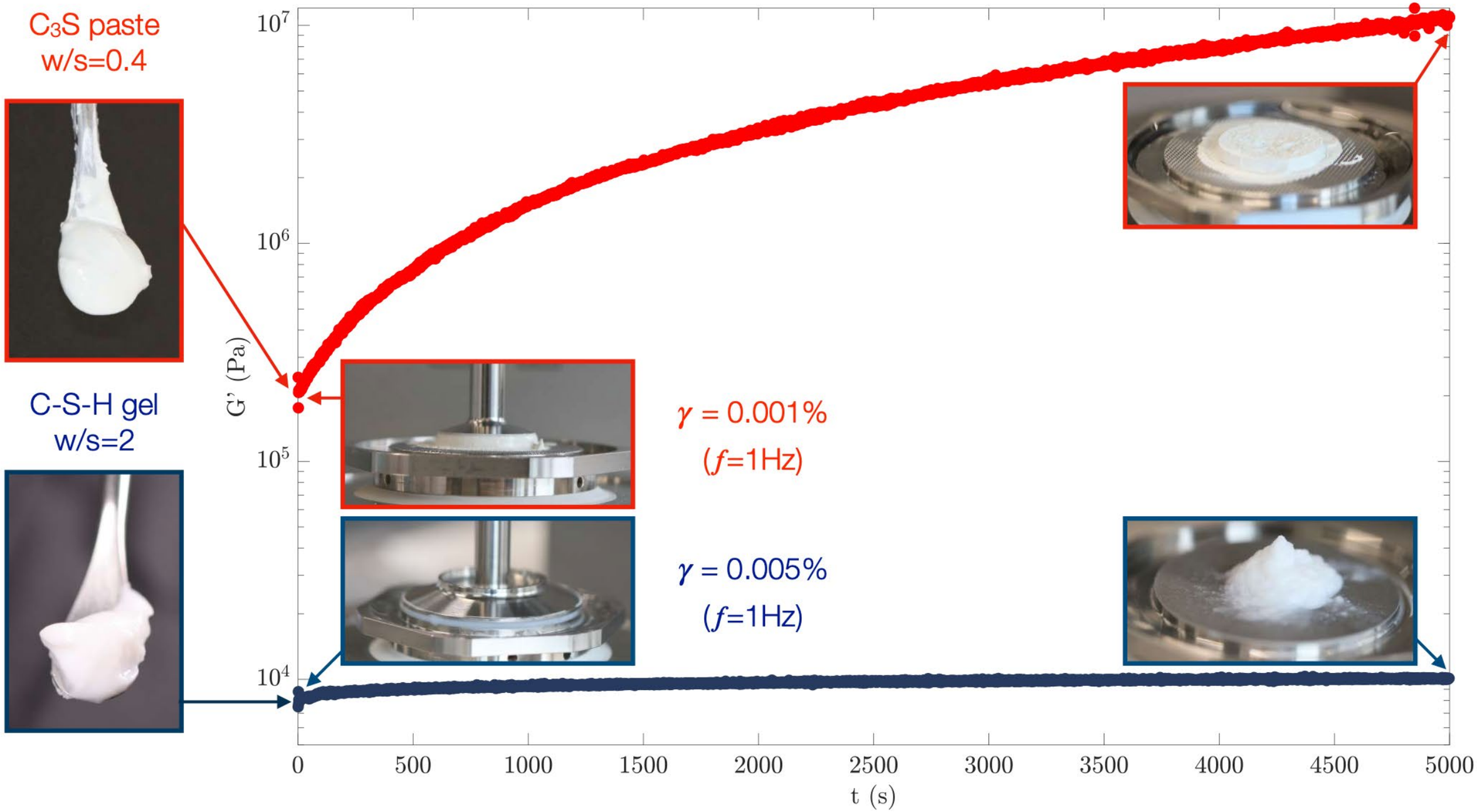
f (Hz)

At a fix: $\gamma < \gamma_{cr}$

SAOS tracks the **cohesion (G')** development of a paste **at rest** !



small oscillatory rheology
SAOS



Liberto et al. *Langmuir* (2022)

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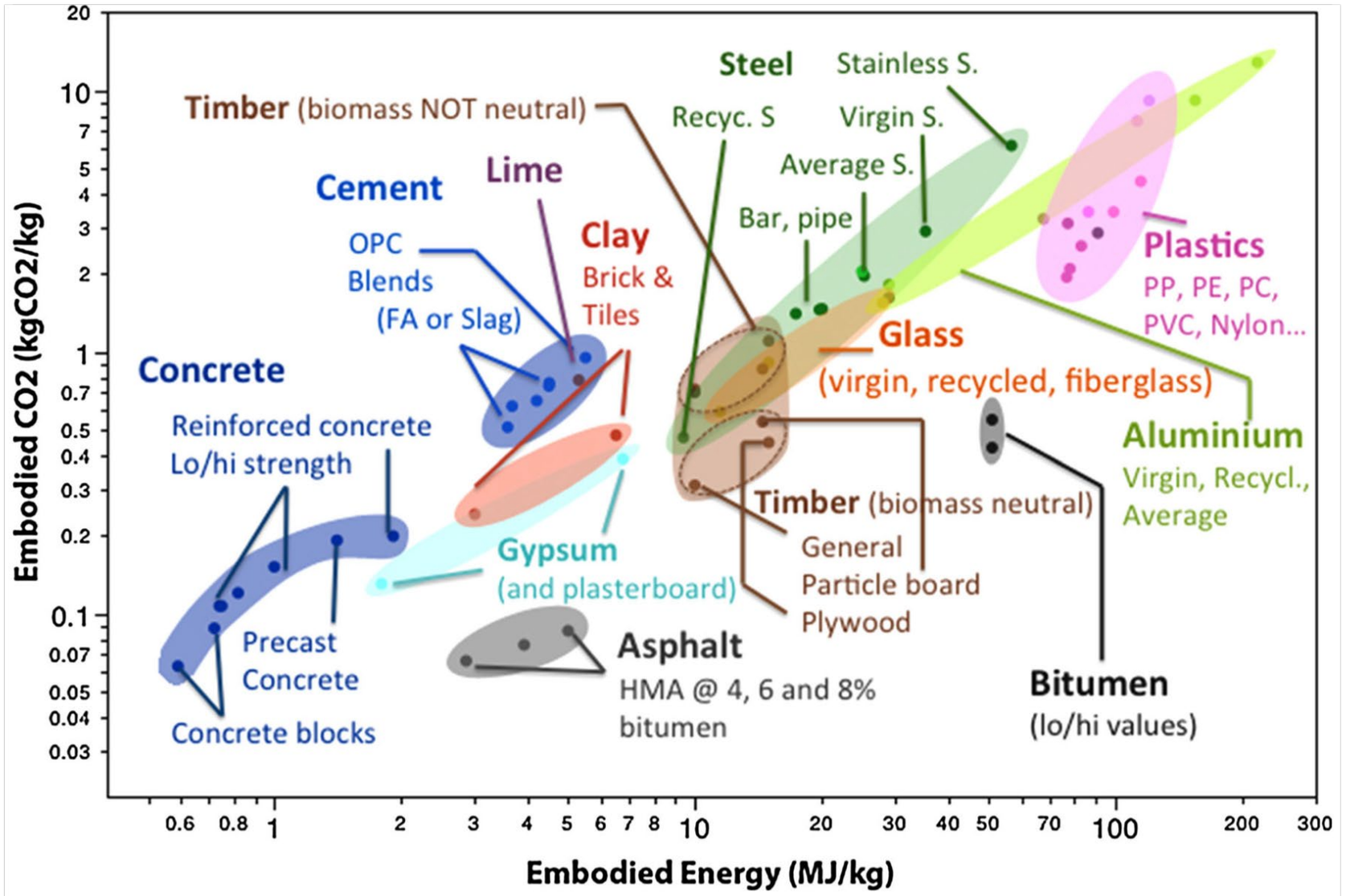
Interaction

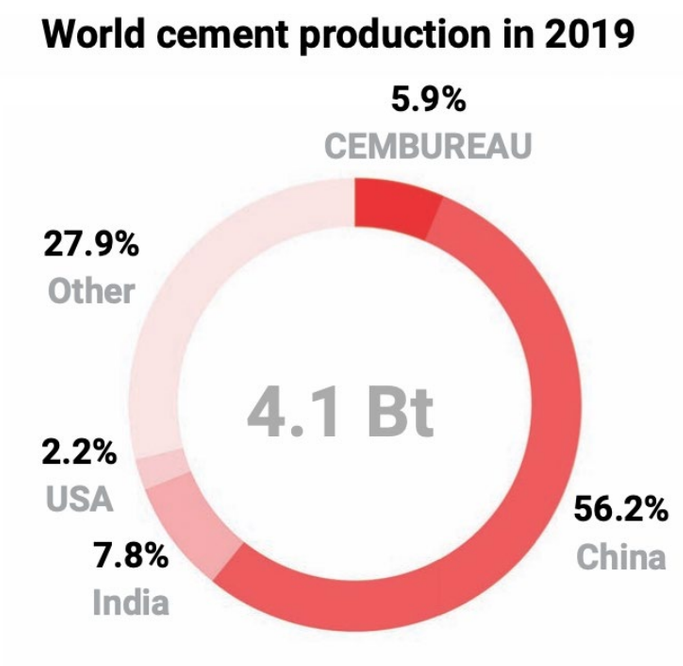
Rheology
SAOS

Sustainability

Cement sustainability



Barcelo et al. Mater Struct. (2014)



Cembureau 2020 report

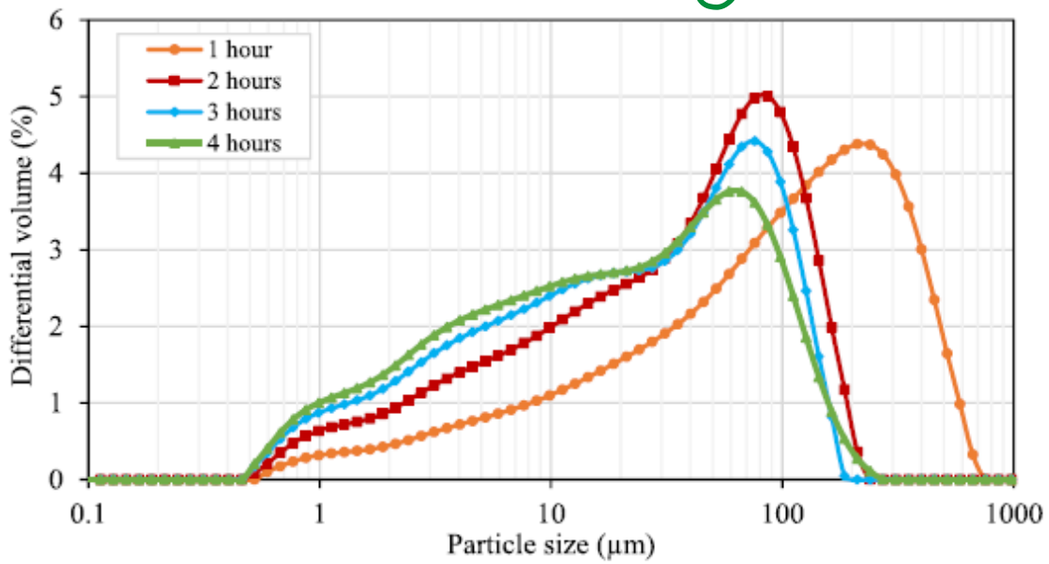
Recycled Concrete

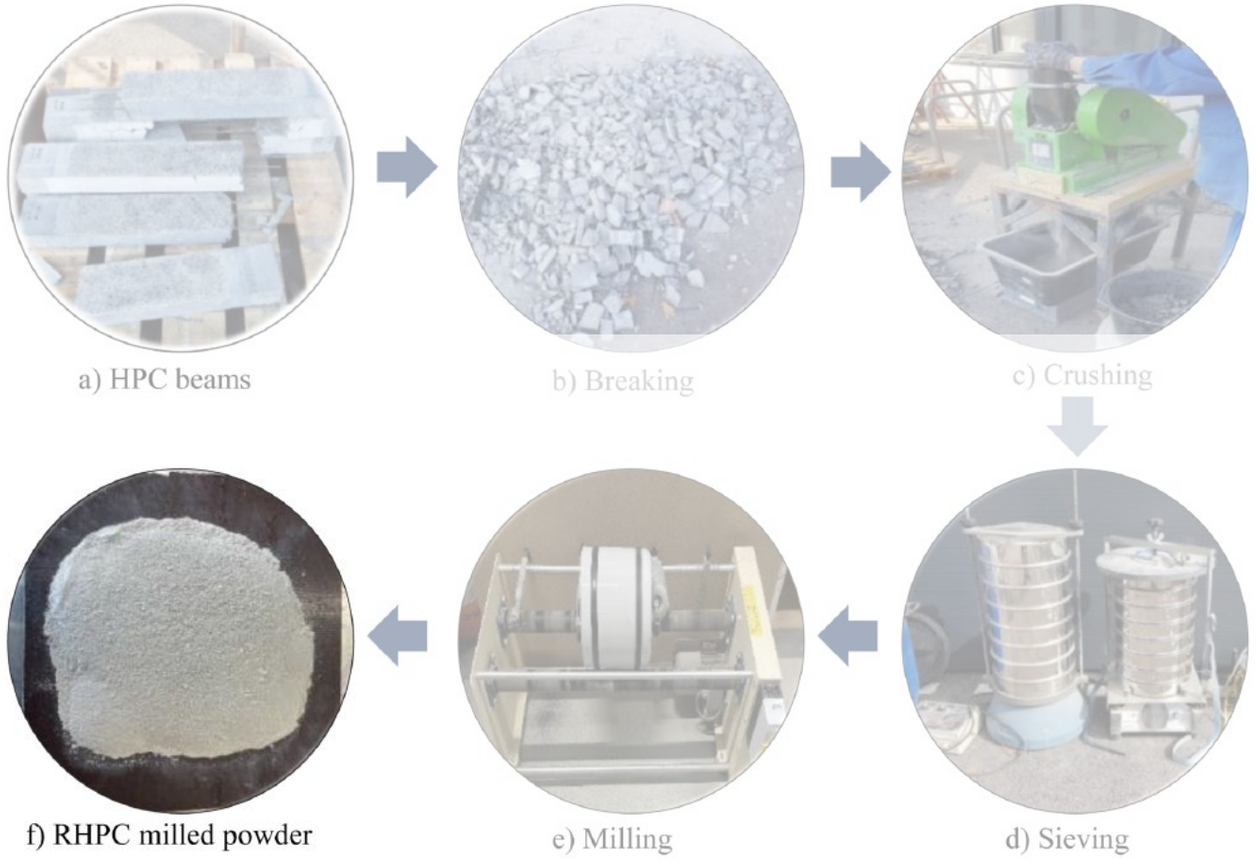
Fig. 1. Recycling process of high-performance concrete (HPC) to obtain mRHPC.

Daneshvar et al. *Case Studies in Construction Materials* (2022)

Recycled Concrete

PSD at different milling times:





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Daneshvar et al. *Case Studies in Construction Materials* (2022)

Recycled Concrete

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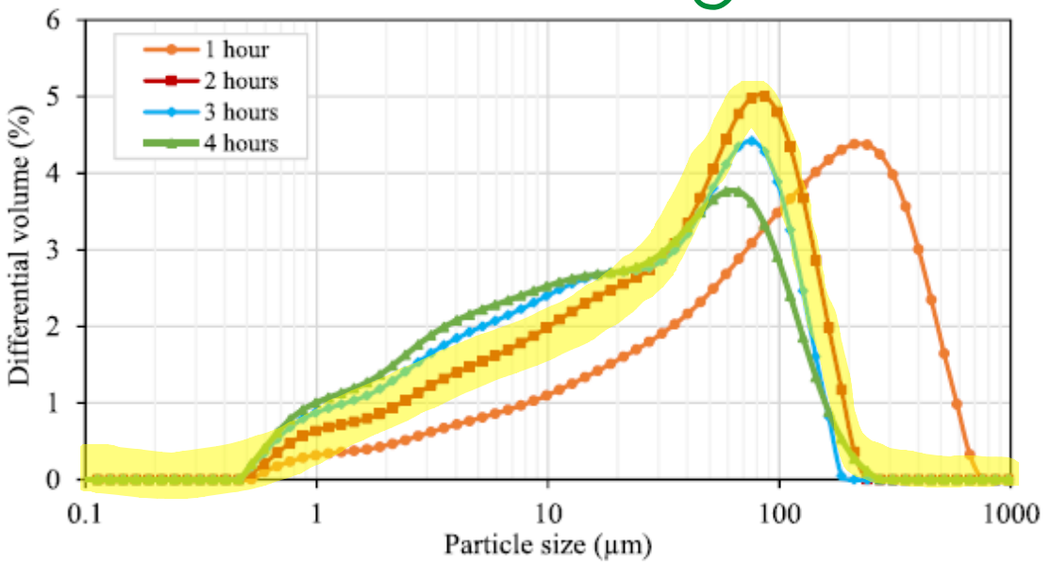

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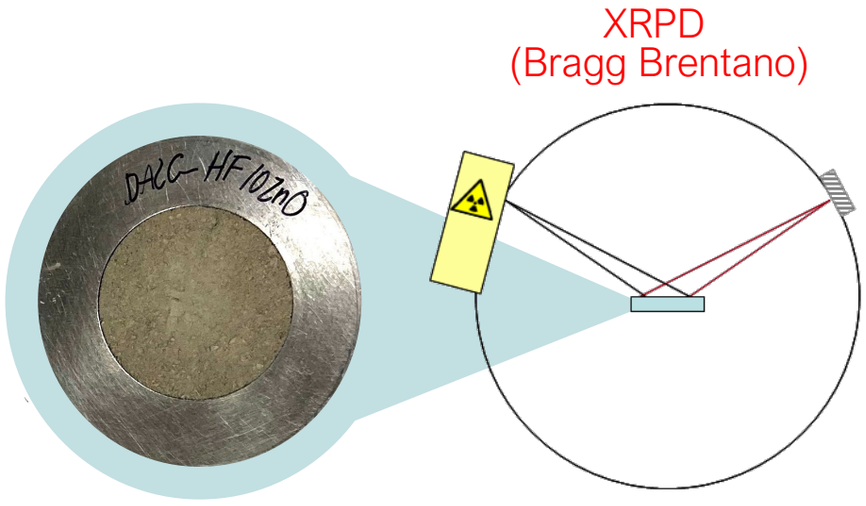
Daneshvar et al. *Case Studies in Construction Materials* (2022)

Recycled Concrete



Phase name	mRHPC (wt%)
C_2S	2.9 ± 1
C_3S	1.5 ± 1
C_4AF	2.1 ± 1

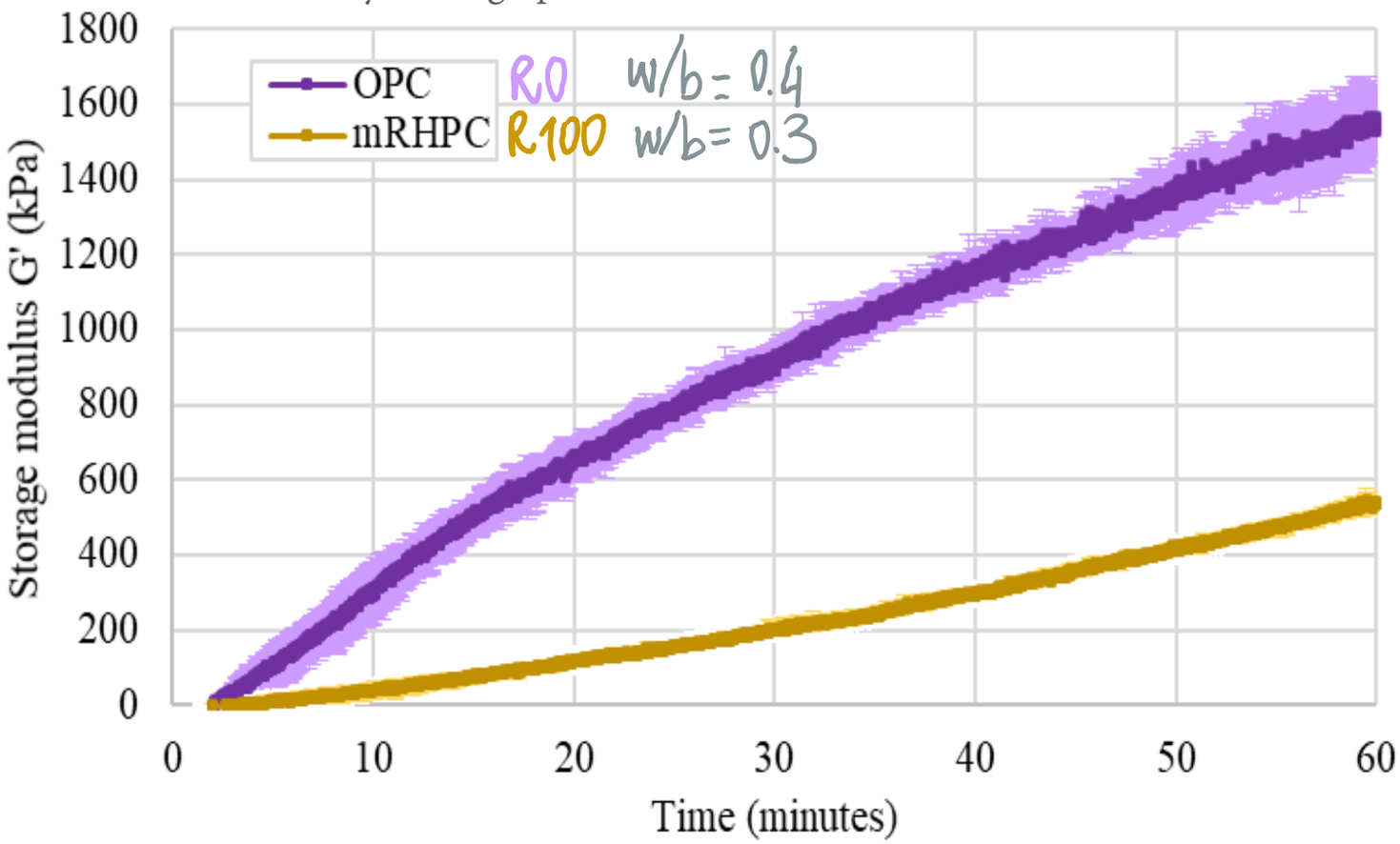
ca. 6.5 % of unreacted phases

Fig. 1. Recycling process of high-performance concrete (HPC) to obtain mRHPC.

Daneshvar et al. *Case Studies in Construction Materials* (2022)

Recycled Concrete

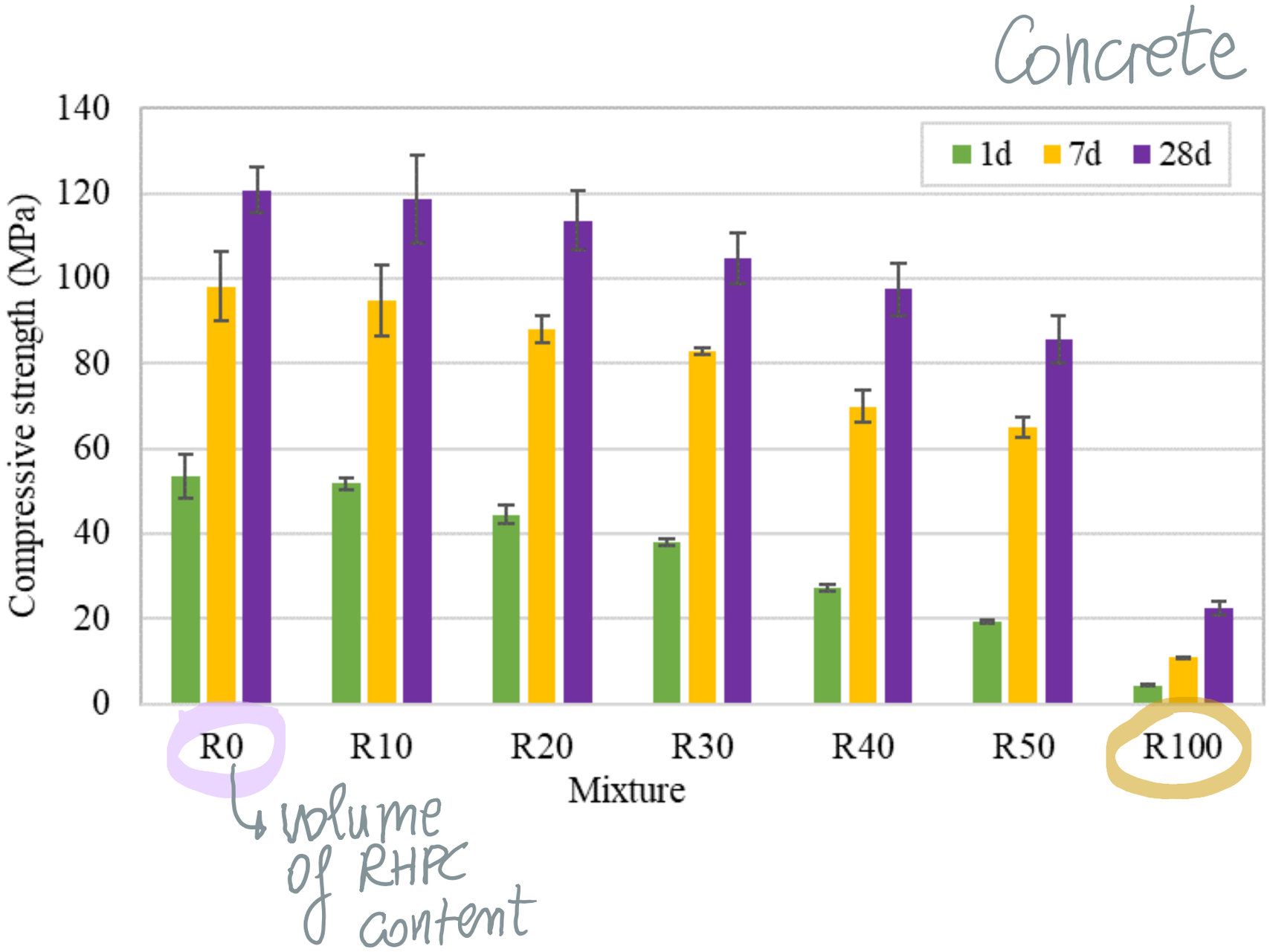
OPC = ordinary Portland cement
RHPC = recycled high performance concrete



Phase name	OPC (wt%)	mRHPC (wt%)
C_2S	12.4 ± 1	2.9 ± 1
C_3S	66.1 ± 5	1.5 ± 1
C_4AF	12.6 ± 1	2.1 ± 1

Daneshvar et al. *Case Studies in Construction Materials* (2022)

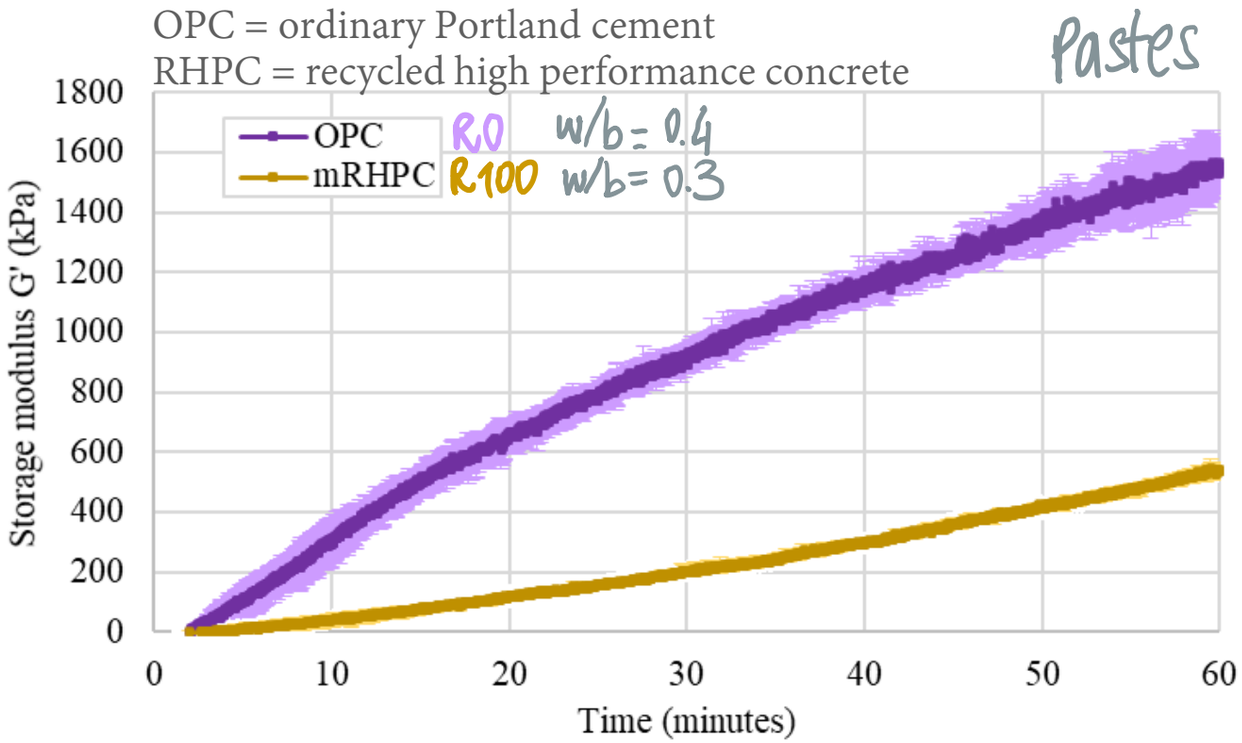
Recycled Concrete

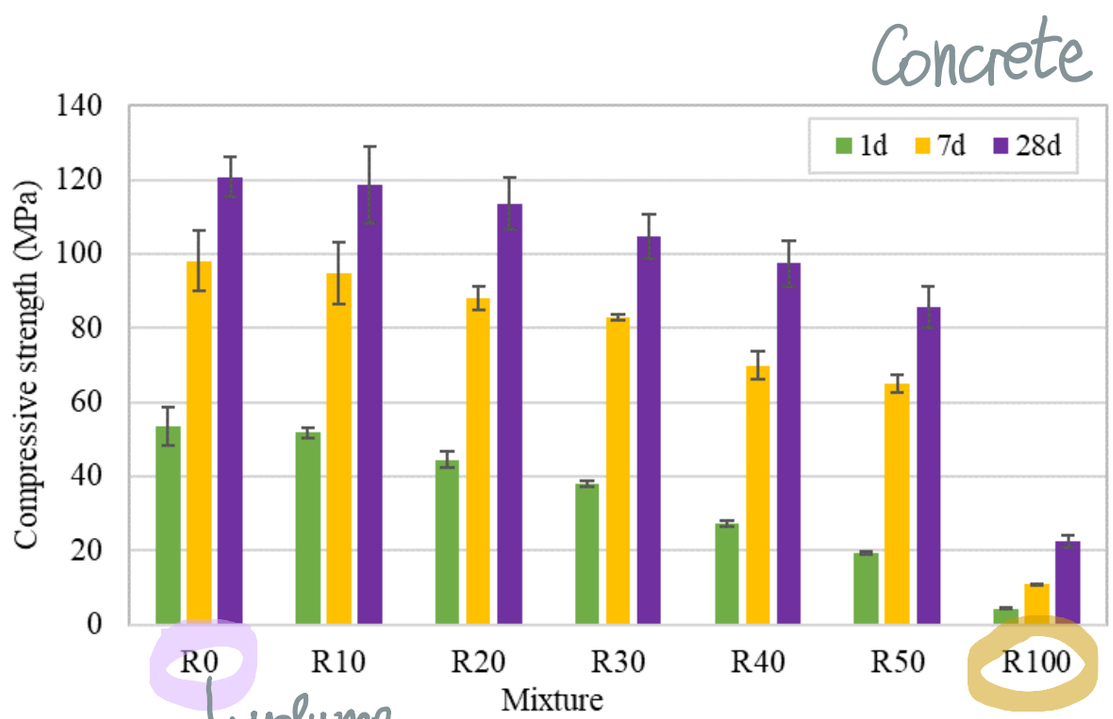


Daneshvar et al. *Case Studies in Construction Materials* (2022)

Recycled Concrete

The residual reactivity detected by SAOS is confirmed by mechanical testing





….after 28 days!

Daneshvar et al. *Case Studies in Construction Materials* (2022)

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https://www.bs.tuwien.ac.at

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