Are AAB intermediate between cement and mineral suspensions?

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Regensburg, 11.03.2020

Alkali Activated Binder (AAB)

solid amorphous aluminosilicate

- slag
- fly ashes
- calcined clay

+

- Sodium hydroxide NaOH

alkali-activator solution

solid alkali activator

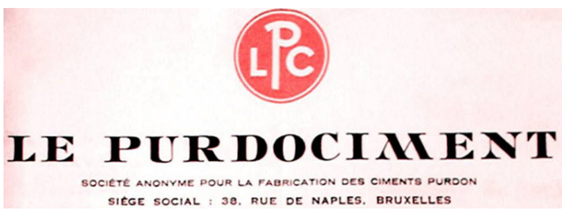
- Sodium carbonate: Na_2CO_3

→

Alkali-activated material

- Less cohesive than OPC
- Low superplasticizer compatibility

Alkali Activated Binder (AAB)



Buchwald et al. Material and Structures (2015)

σ_c (2015)= 50MPa

Motivation of the problem

Cement

AAB

- Control the fresh properties
- Measure the interaction forces
- Study polymers compatibility

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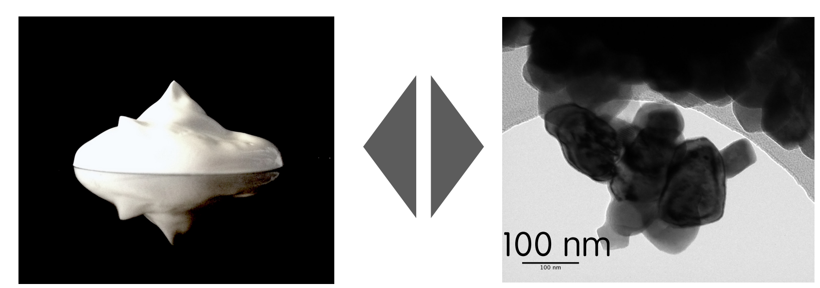


Calcite

Liberto et al. JCIS (2019)

Liberto et al. Soft Matter (2017)

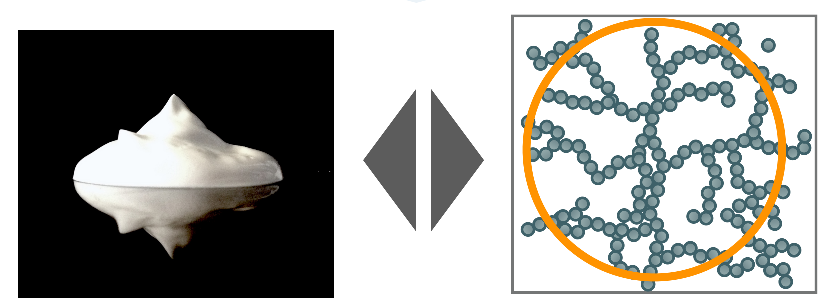
Motivation of the problem

Oscillatory Rheology

Cement

AAB

- **Control the fresh properties**
- Measure the interaction forces
- Study polymers compatibility



Calcite

Liberto et al. JCIS (2019)

Liberto et al. Soft Matter (2017)

Materials

Calcite

- $CaCO_3$
- 70 nm particles
- ϕ =5-30%

Weak long-range attraction

Liberto et al. JCIS (2019)
Liberto et al. Soft Matter (2017)

AAB

- 91.5% GGBS*, 5%$Ca(OH)_2$, 3.5% Na_2CO_3
- µm particles
- ϕ =41-53% (w/c 0.5-0.3)

?

Purdociment 1955
Buchwald et al. Material and Structures (2015)

Cement

- CEM I 52.5 R
- µm particles
- ϕ =39-51% (w/c 0.5-0.3)

Strong short-range attraction

Jönsson et al. Langmuir (2005)

* GGBS: Ground granulated blast-furnace slag: CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%)

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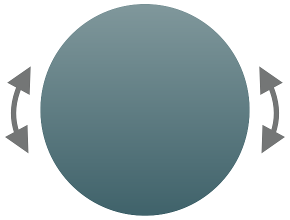
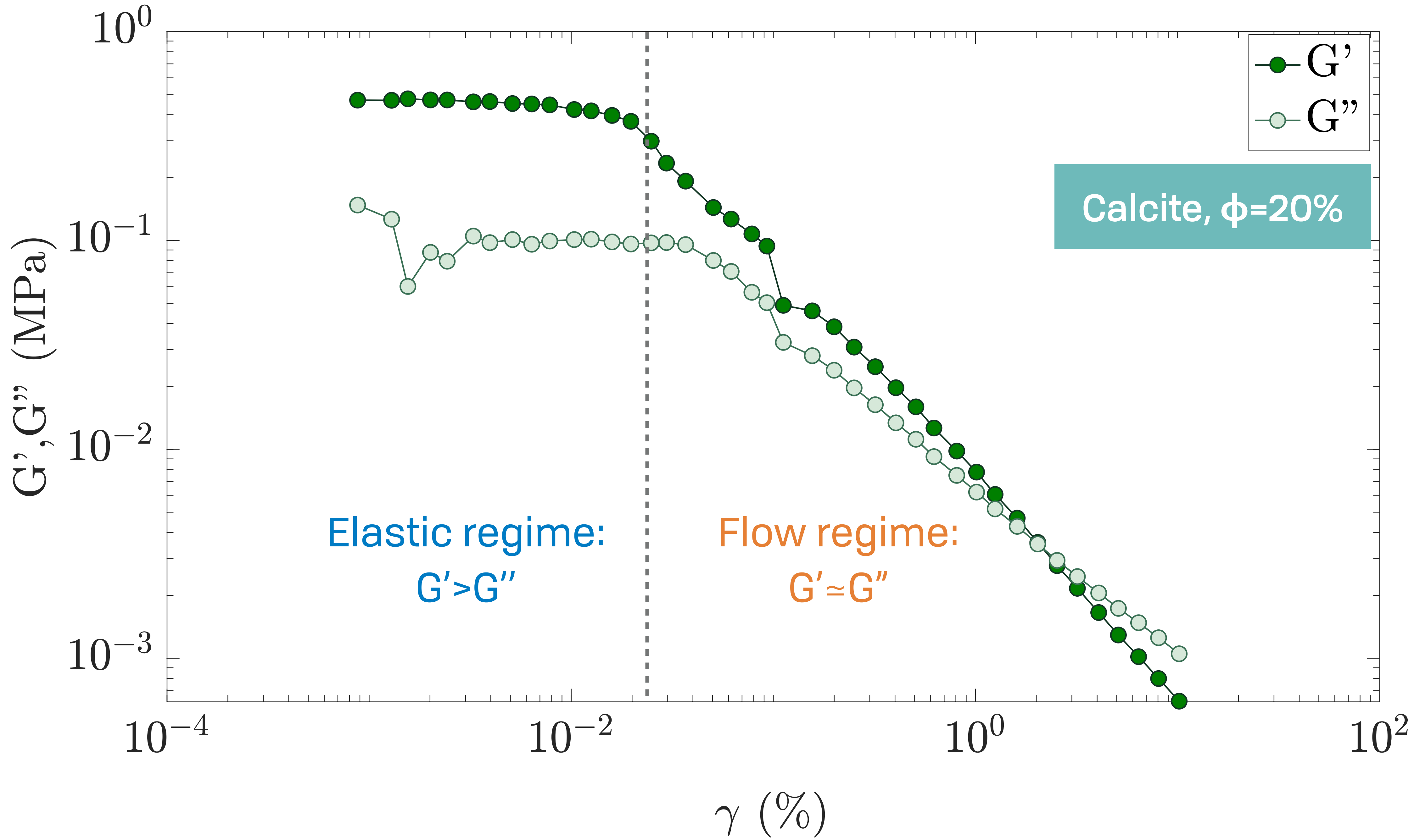
Take home message(s)

- Oscillatory rheometry can give hints on particle cohesiveness
- The deformation mechanism depends on both concentration and interaction
- AAB are intermediate between cement and calcite suspensions

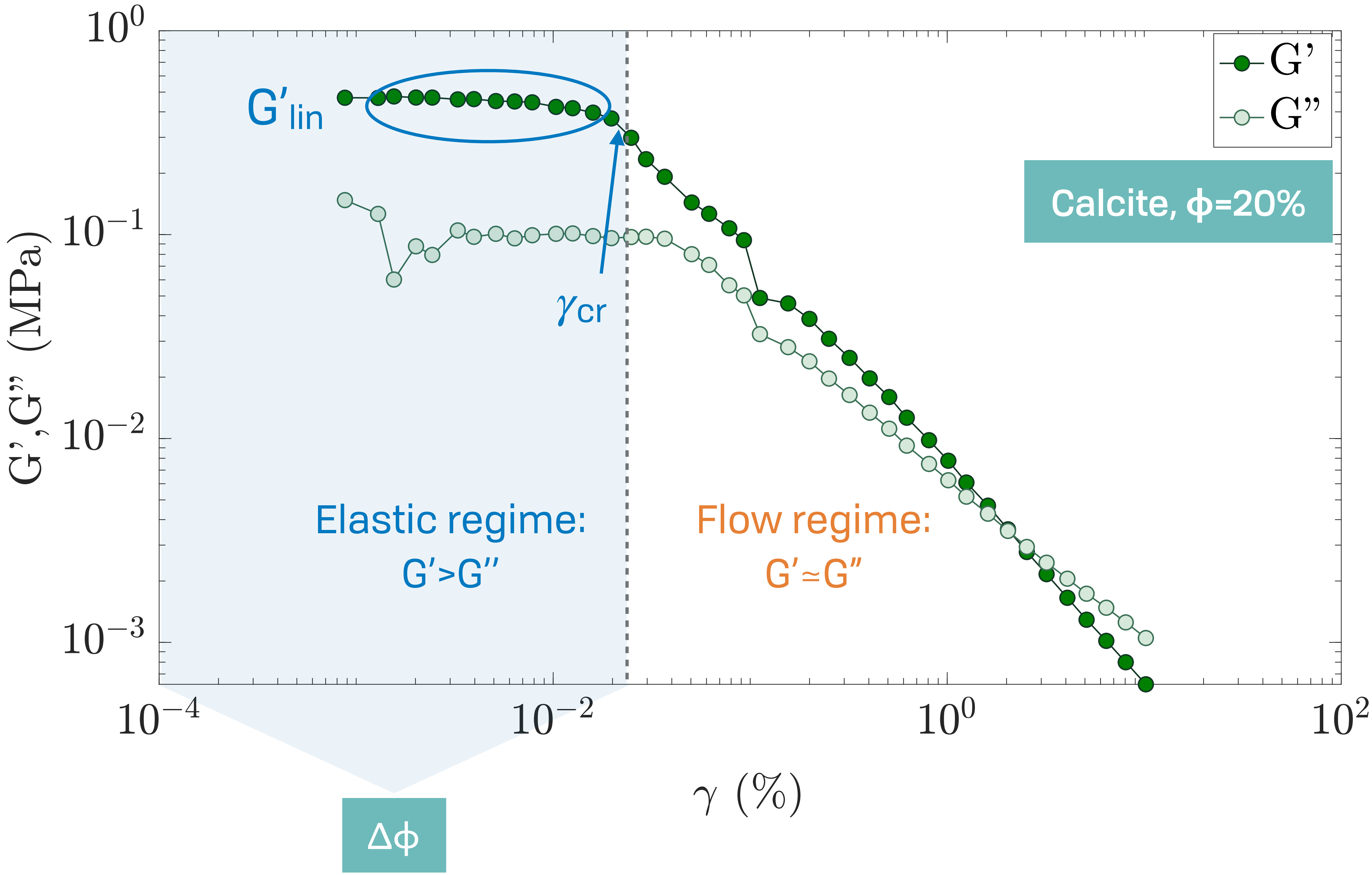
Oscillatory Rheology



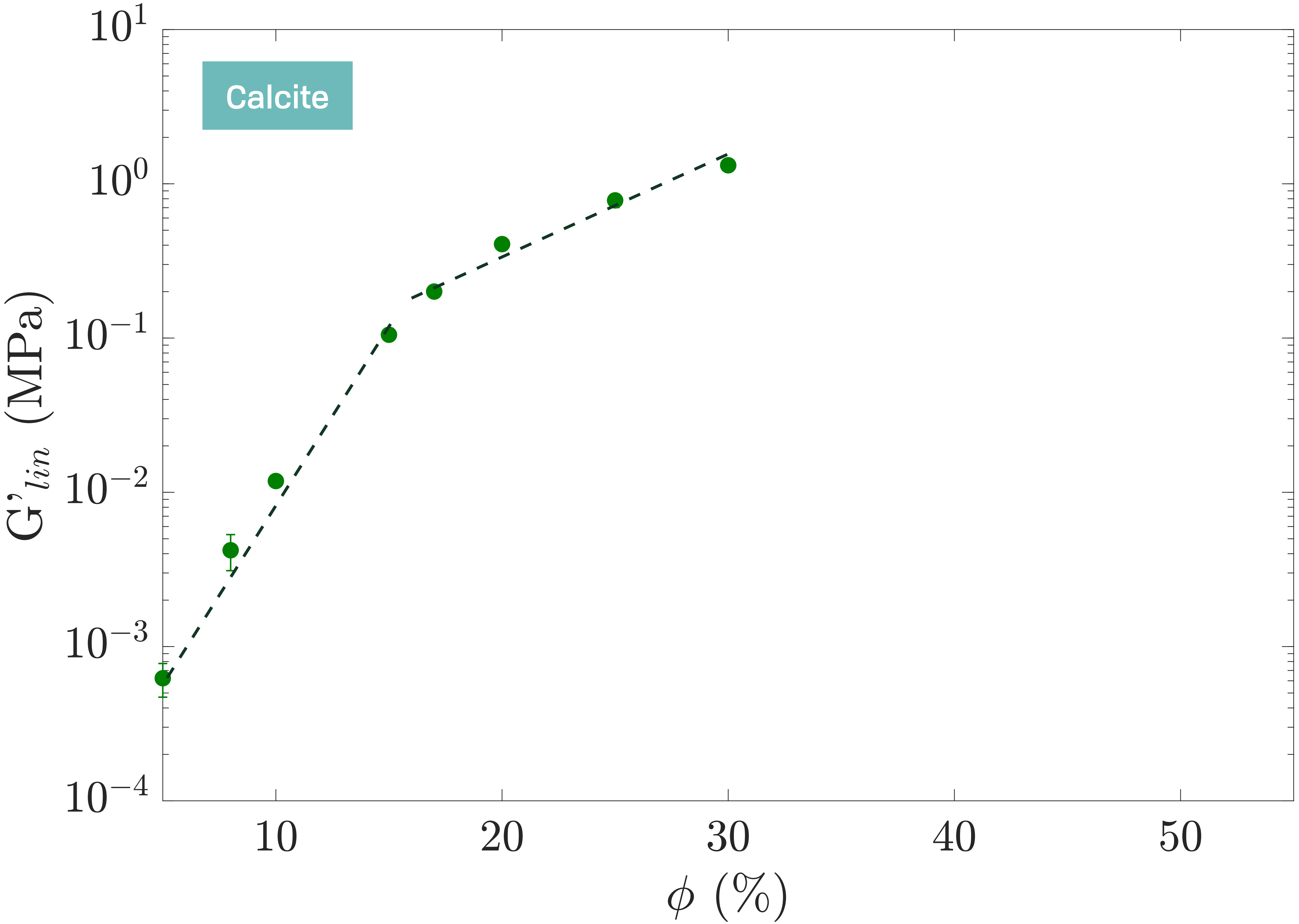


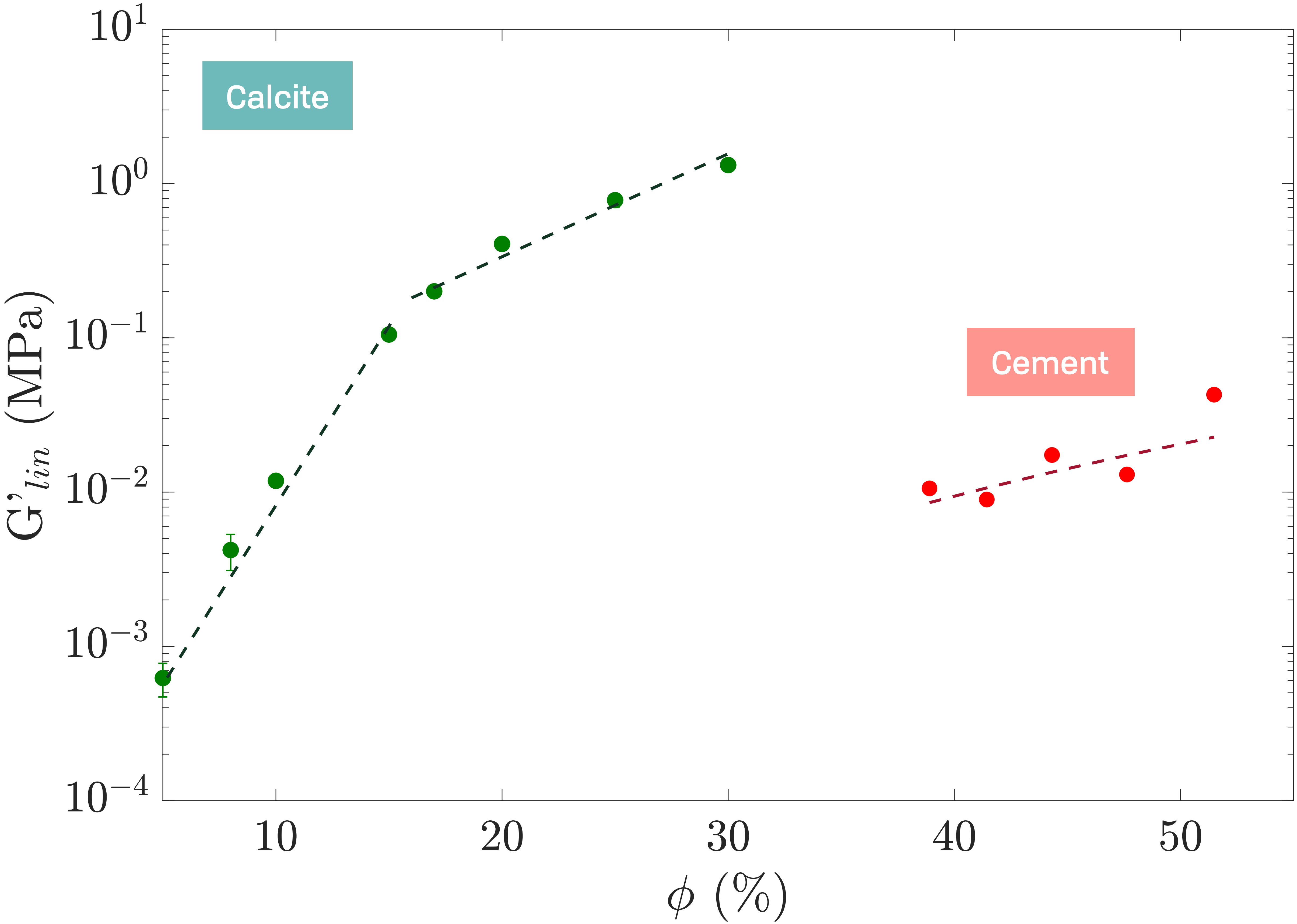
Liberto et al. Soft Matter (2017)

Oscillatory Rheology



Liberto et al. Soft Matter (2017)


Calcite
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
G'$_{lin}$ (MPa)
10
20
30
40
50
ϕ (%)


Calcite
Cement
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
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10
20
30
40
50
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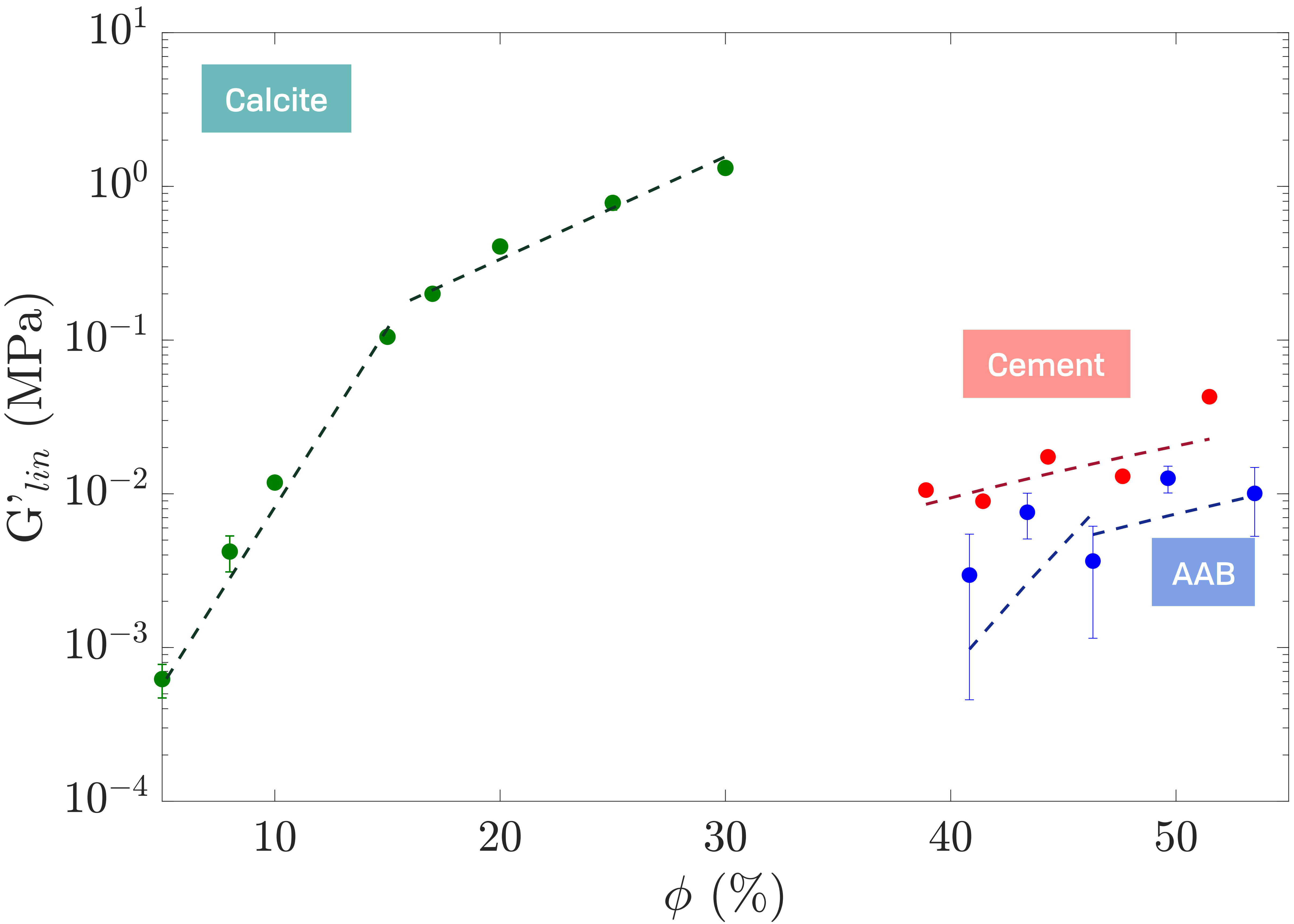

Calcite
Cement
AAB
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
G'_{lin} (MPa)
10
20
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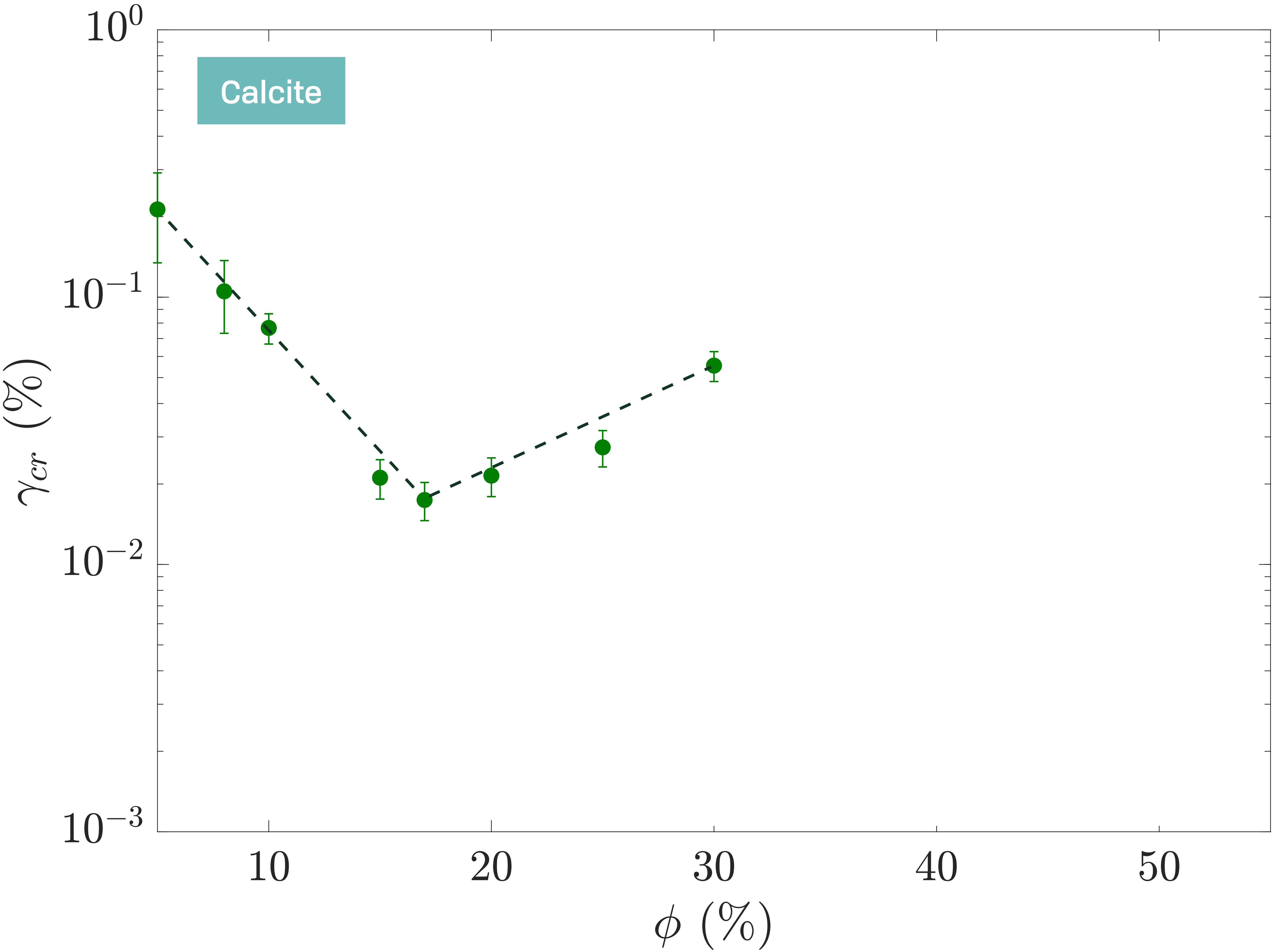
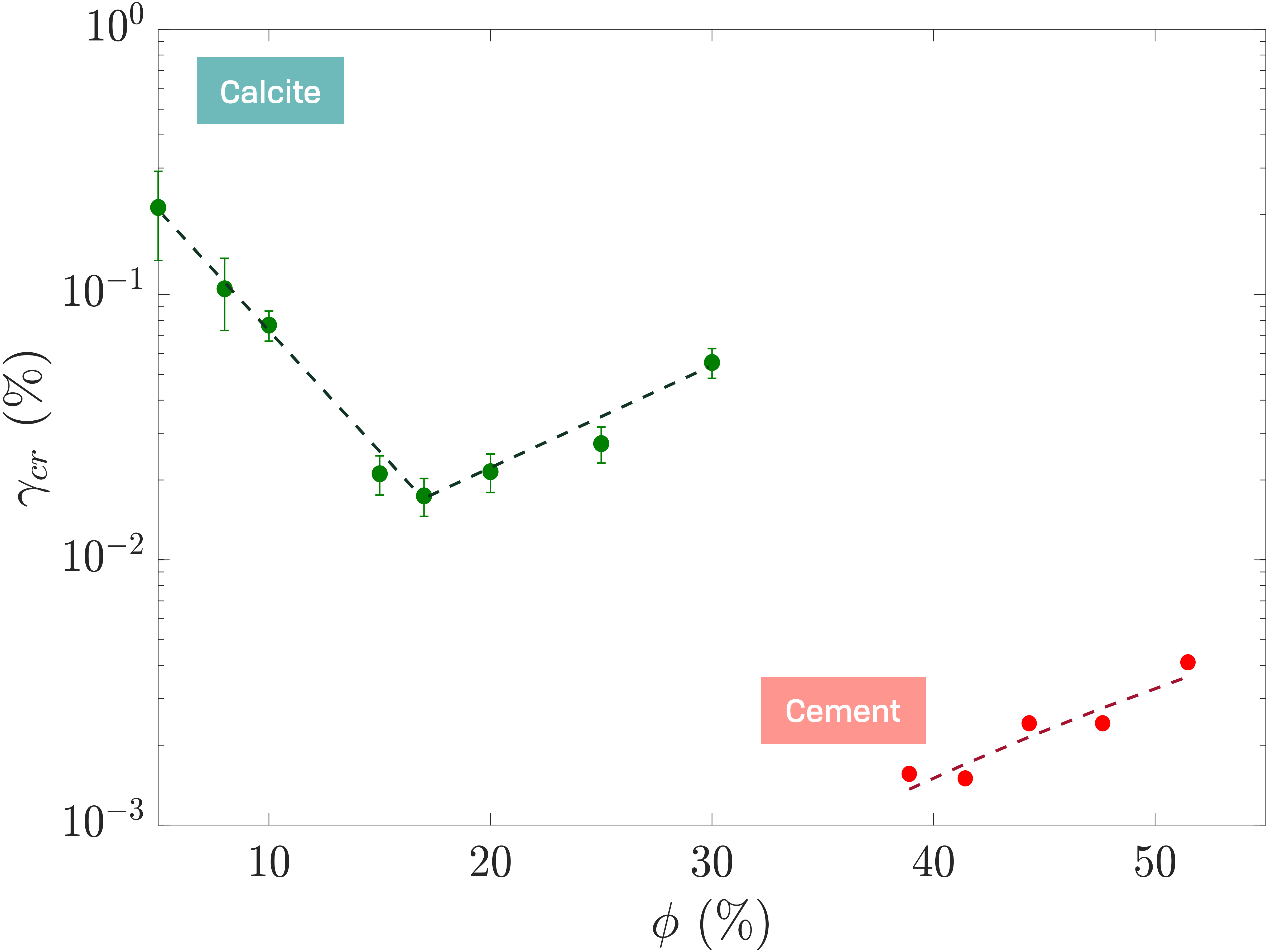
40
50
ϕ (%)


Calcite
10^{0}
10^{-1}
10^{-2}
10^{-3}
γ_{cr} (%)
10
20
30
40
50
ϕ (%)



10^0
10^{-1}
10^{-2}
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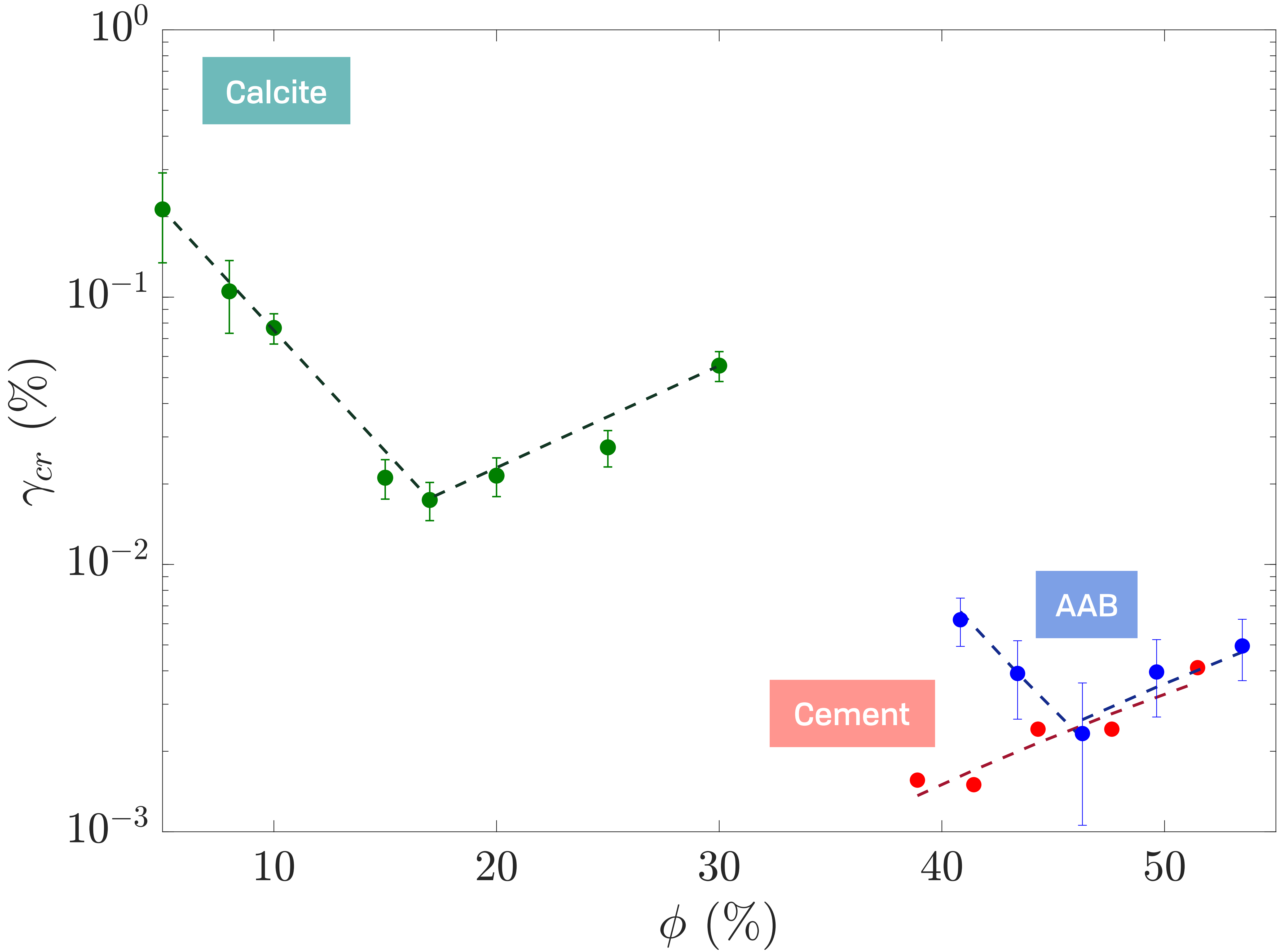
10
20
30
40
50
γ_{cr} (%)
ϕ (%)
Calcite
Cement


Calcite
AAB
Cement
10^0
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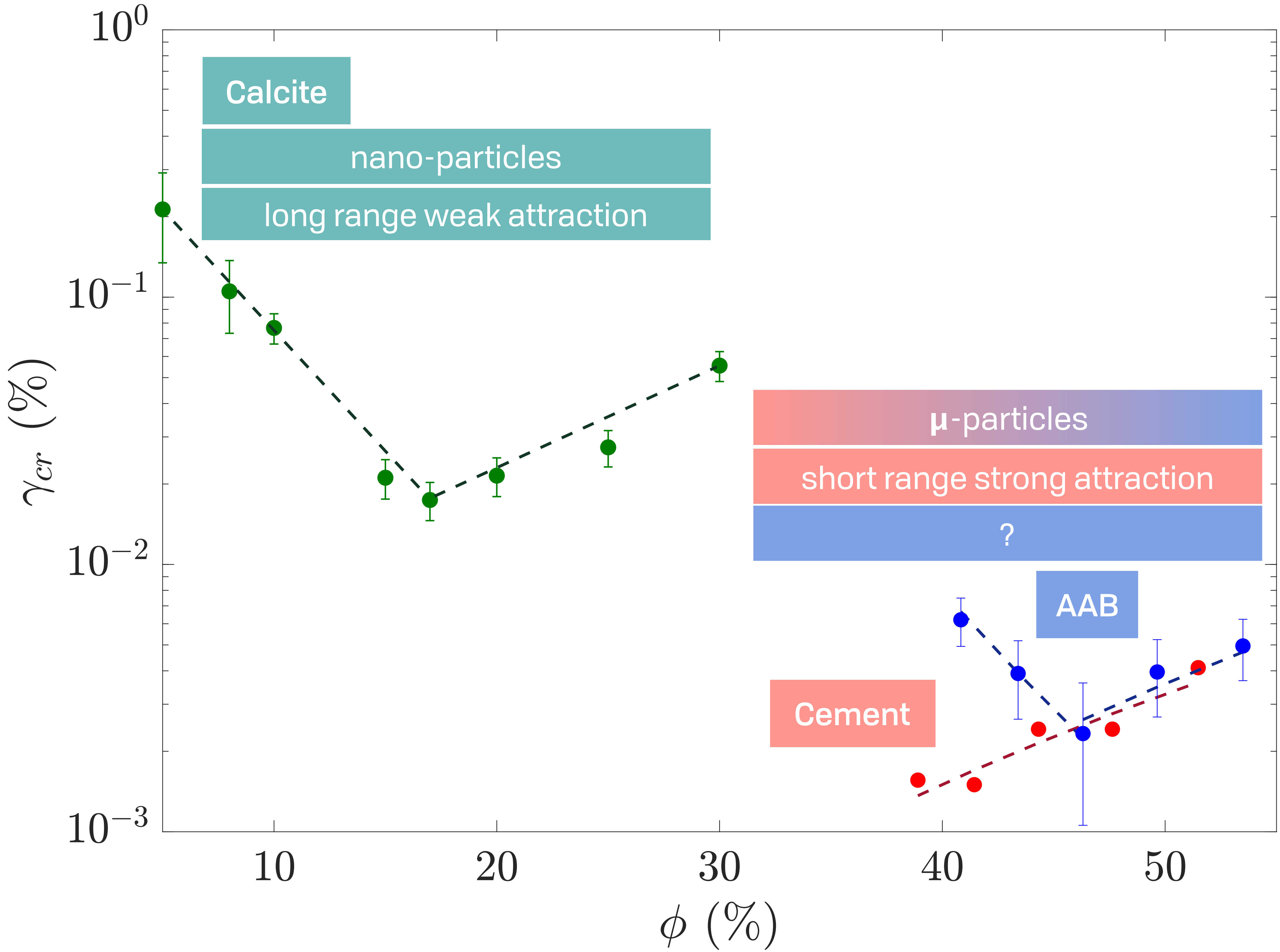
Calcite
nano-particles
long range weak attraction
μ-particles
short range strong attraction
?
AAB
Cement
10^{0}
10^{-1}
10^{-2}
10^{-3}
γ_{cr} (%)
10
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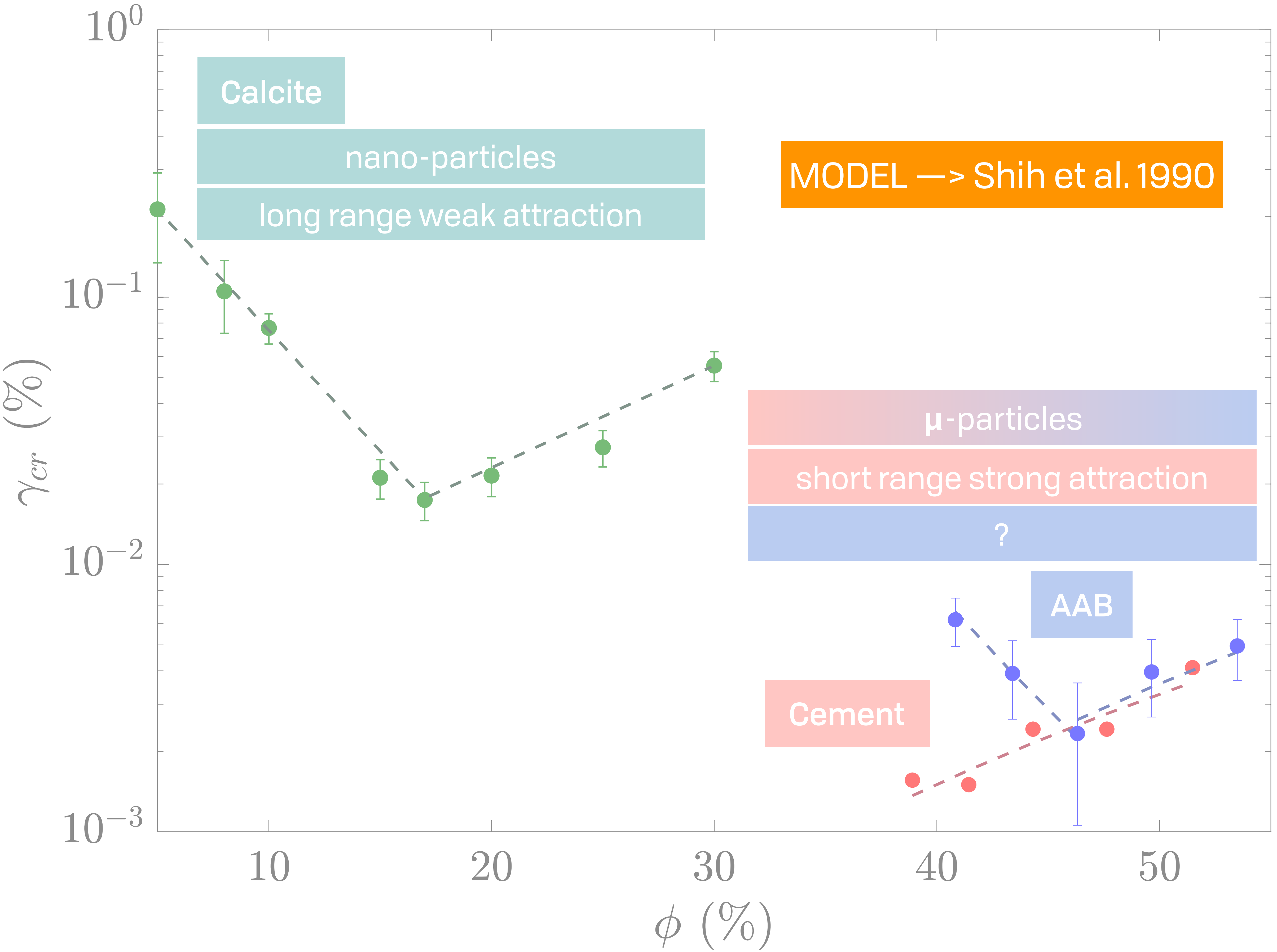
Calcite
nano-particles
long range weak attraction
MODEL —> Shih et al. 1990
μ-particles
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AAB
Cement
10^0
10^{-1}
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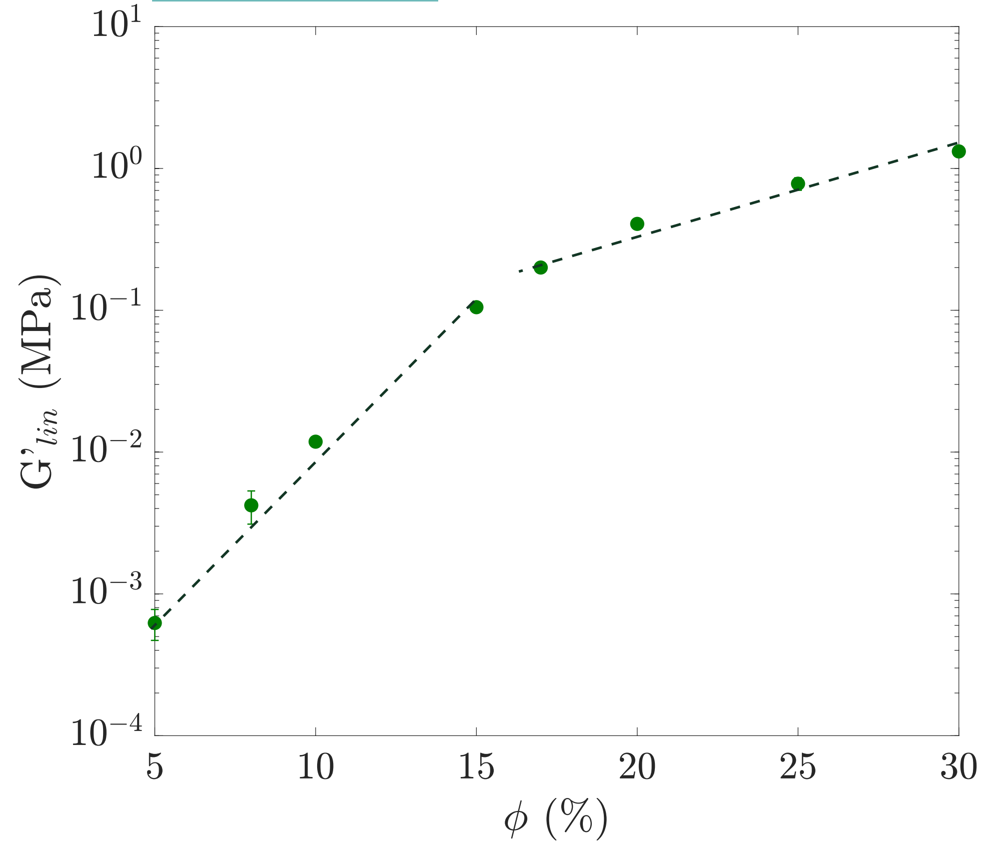
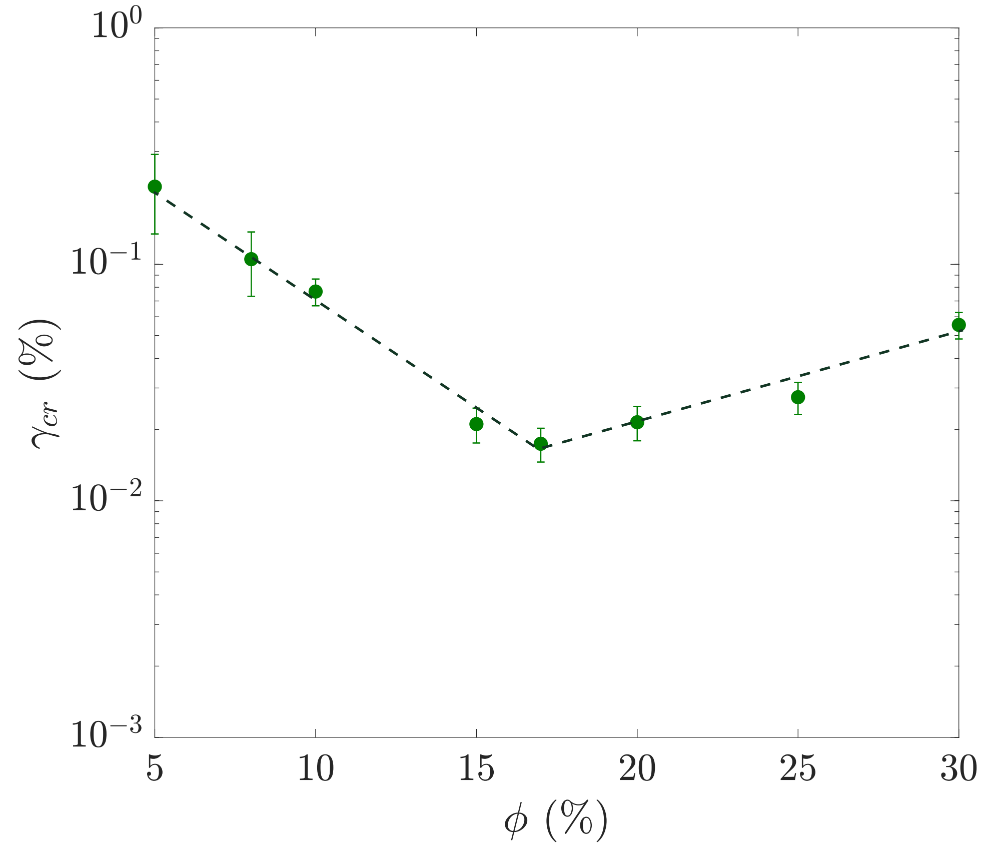
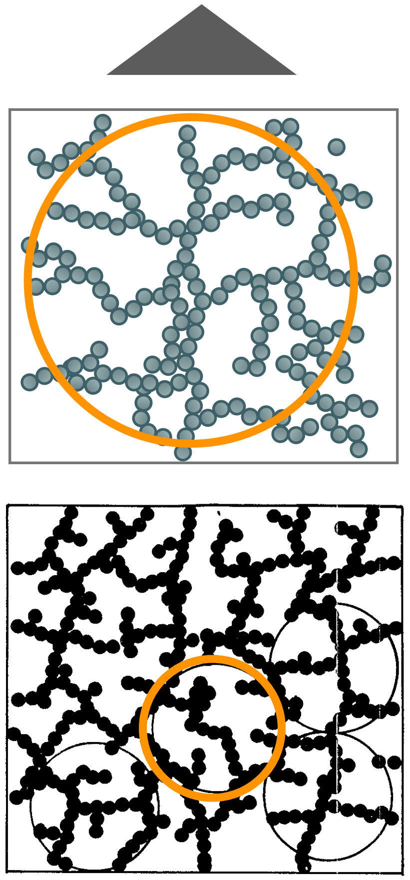
Calcite





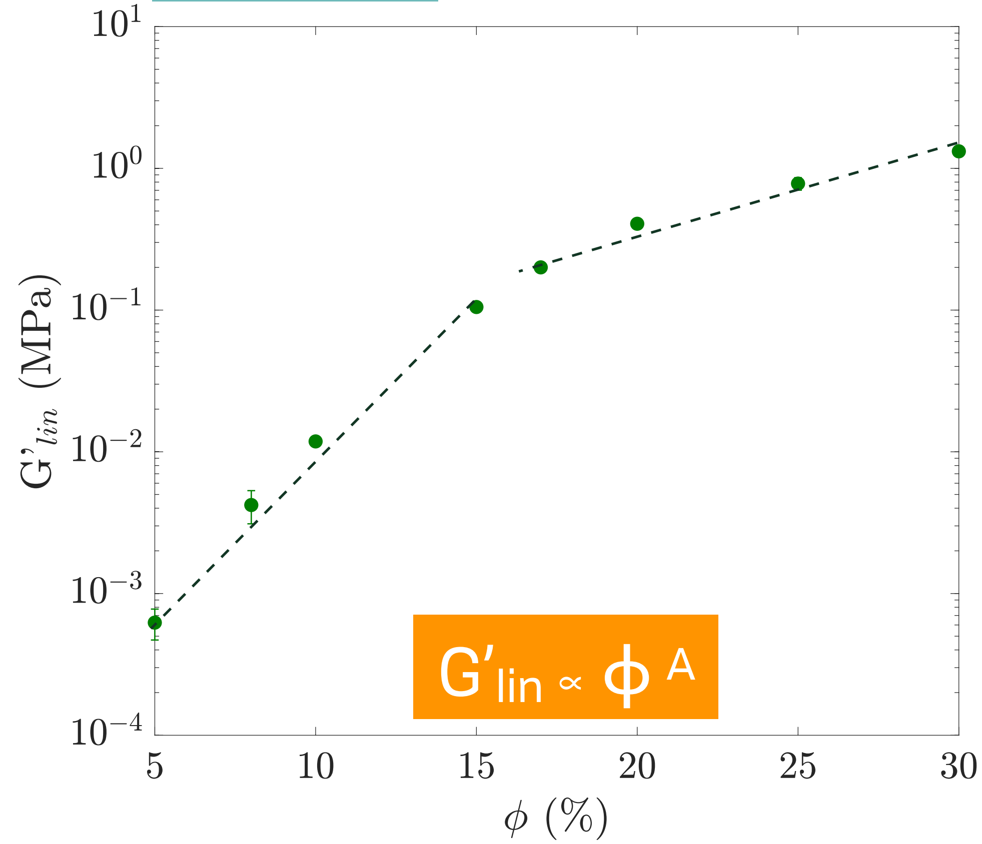
Liberto et al. Soft Matter (2017)

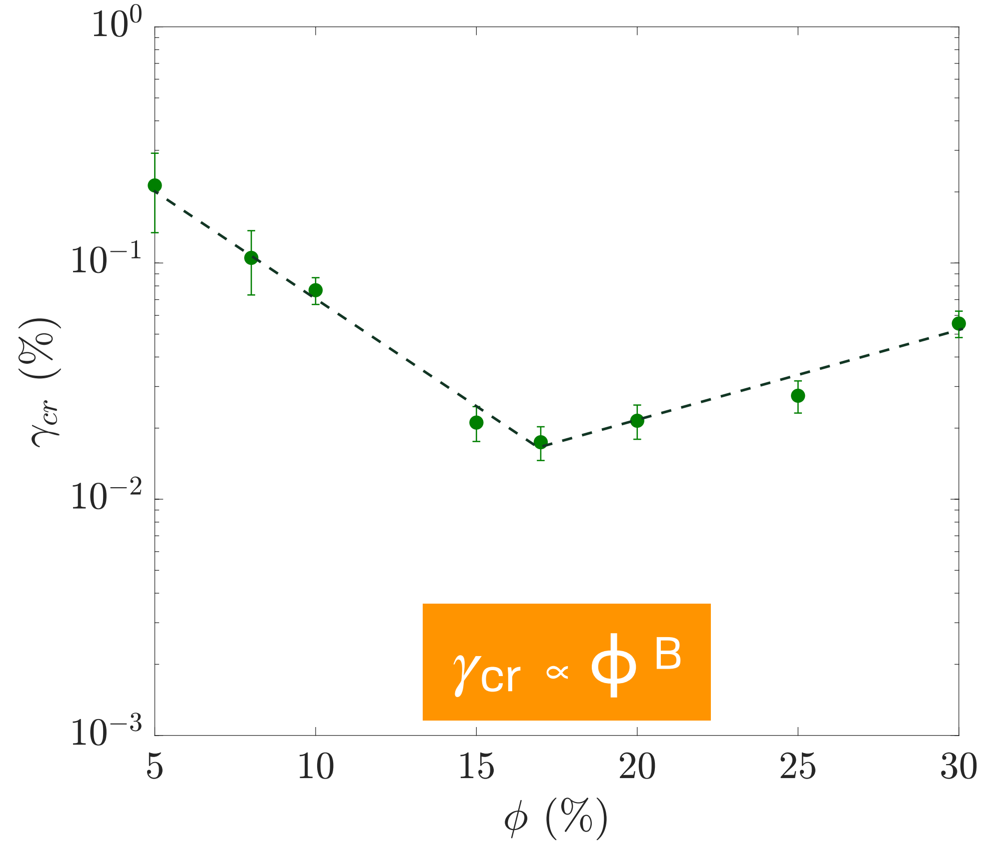
Fractal structure at rest



Shih et al. PRA (1990)

Calcite

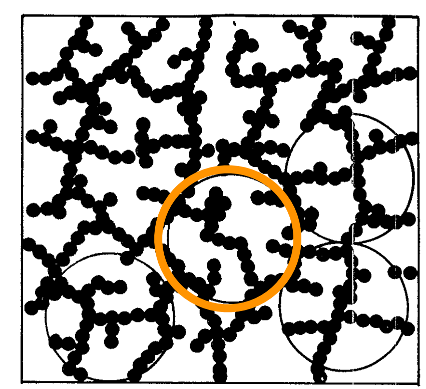




Liberto et al. Soft Matter (2017)

Fractal structure at rest

- Interfloc links
- Floc rigidity
- Concentration



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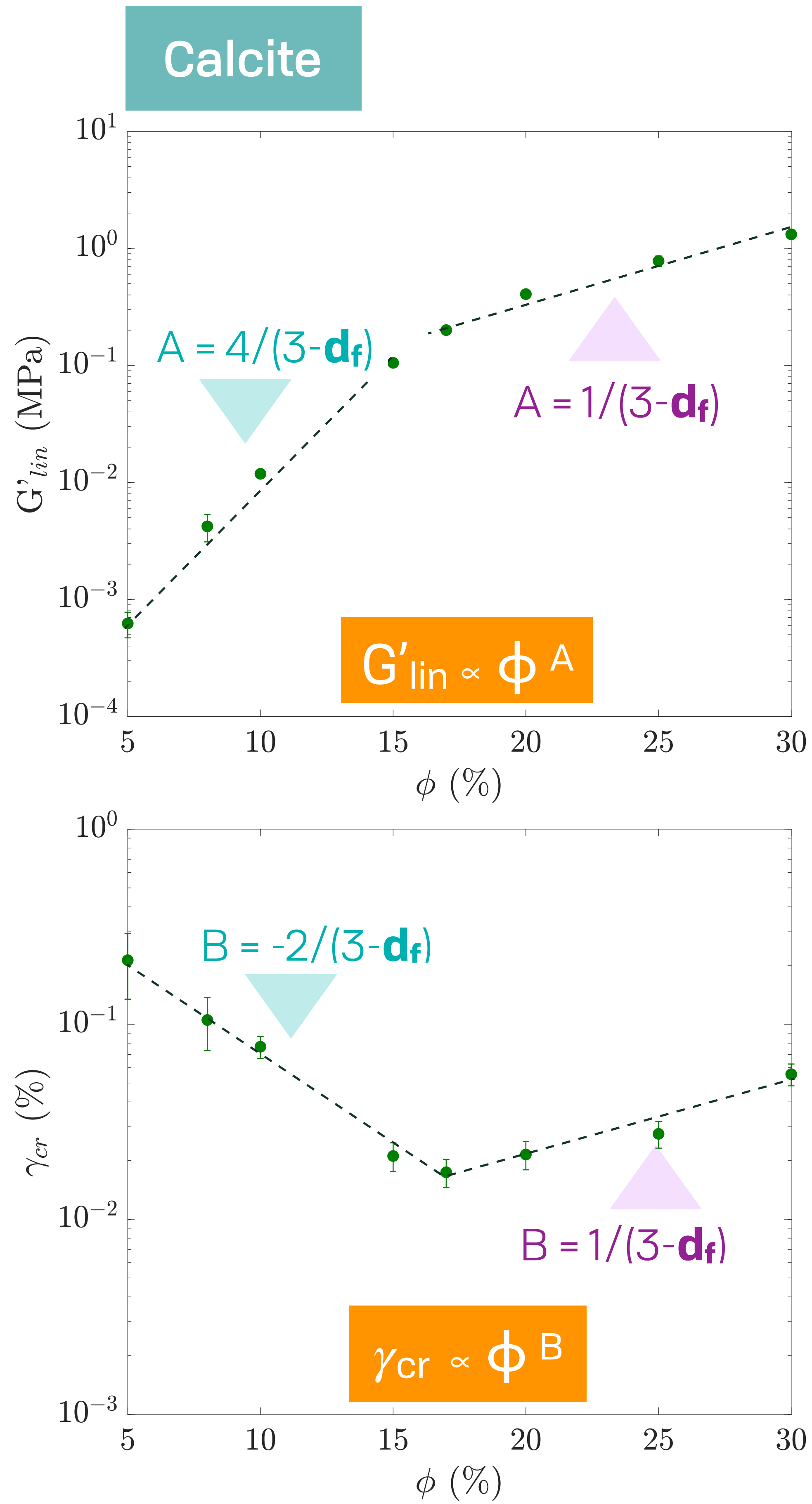


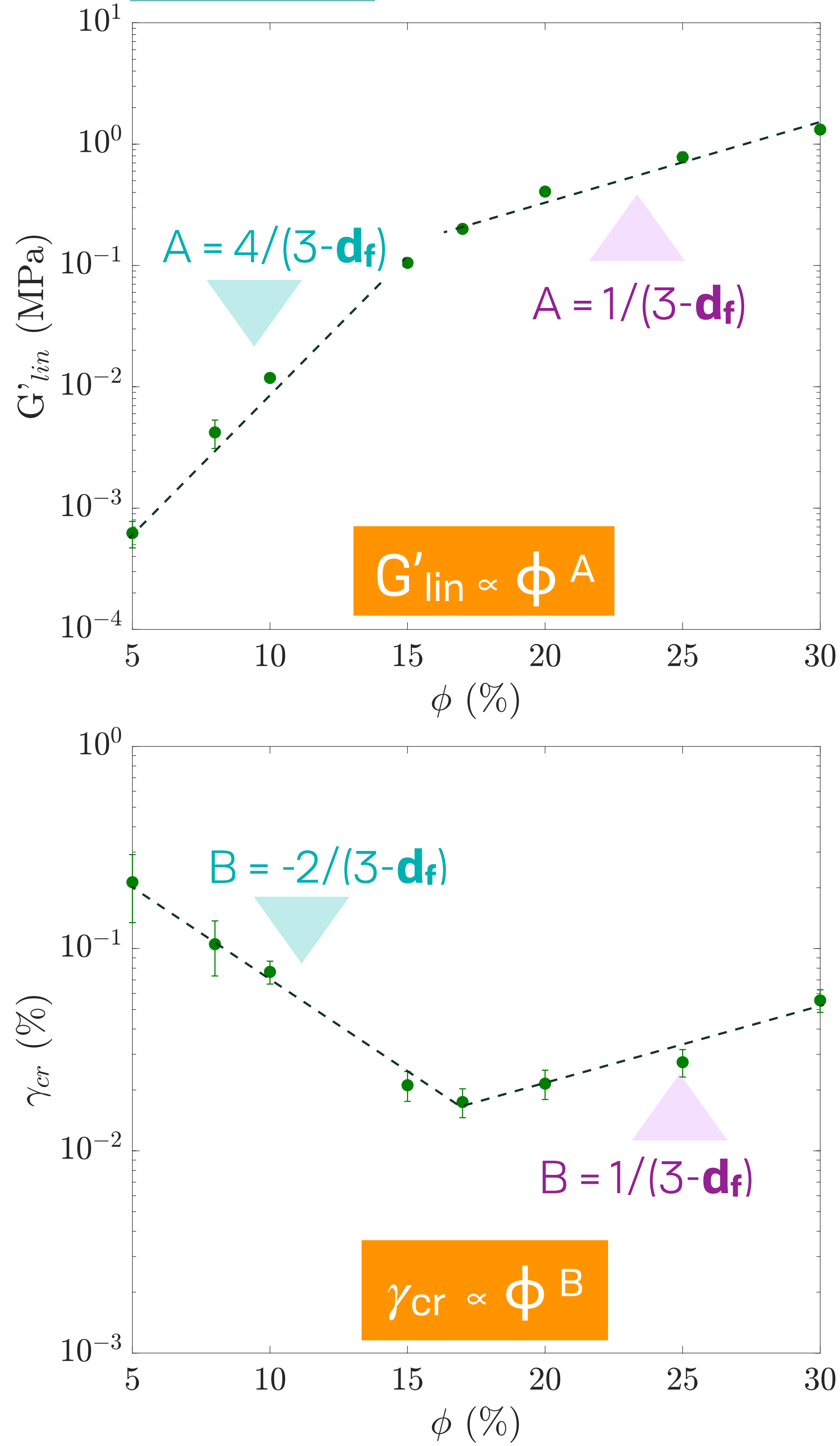
Fractal structure at rest

Deformable floc → Rigid floc

ϕ

Liberto et al. Soft Matter (2017)

Calcite



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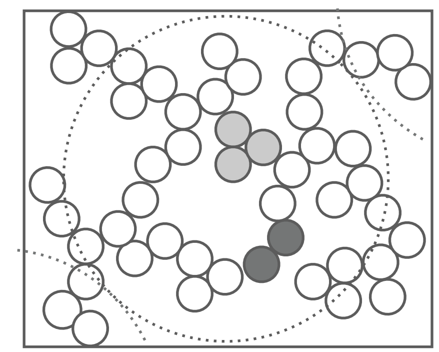
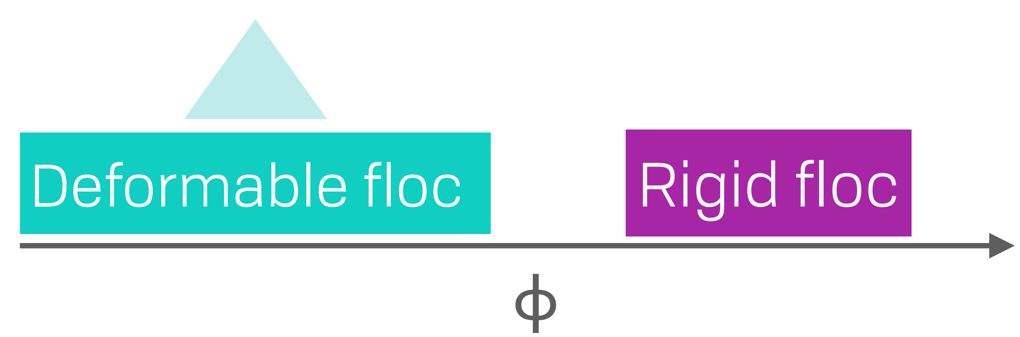
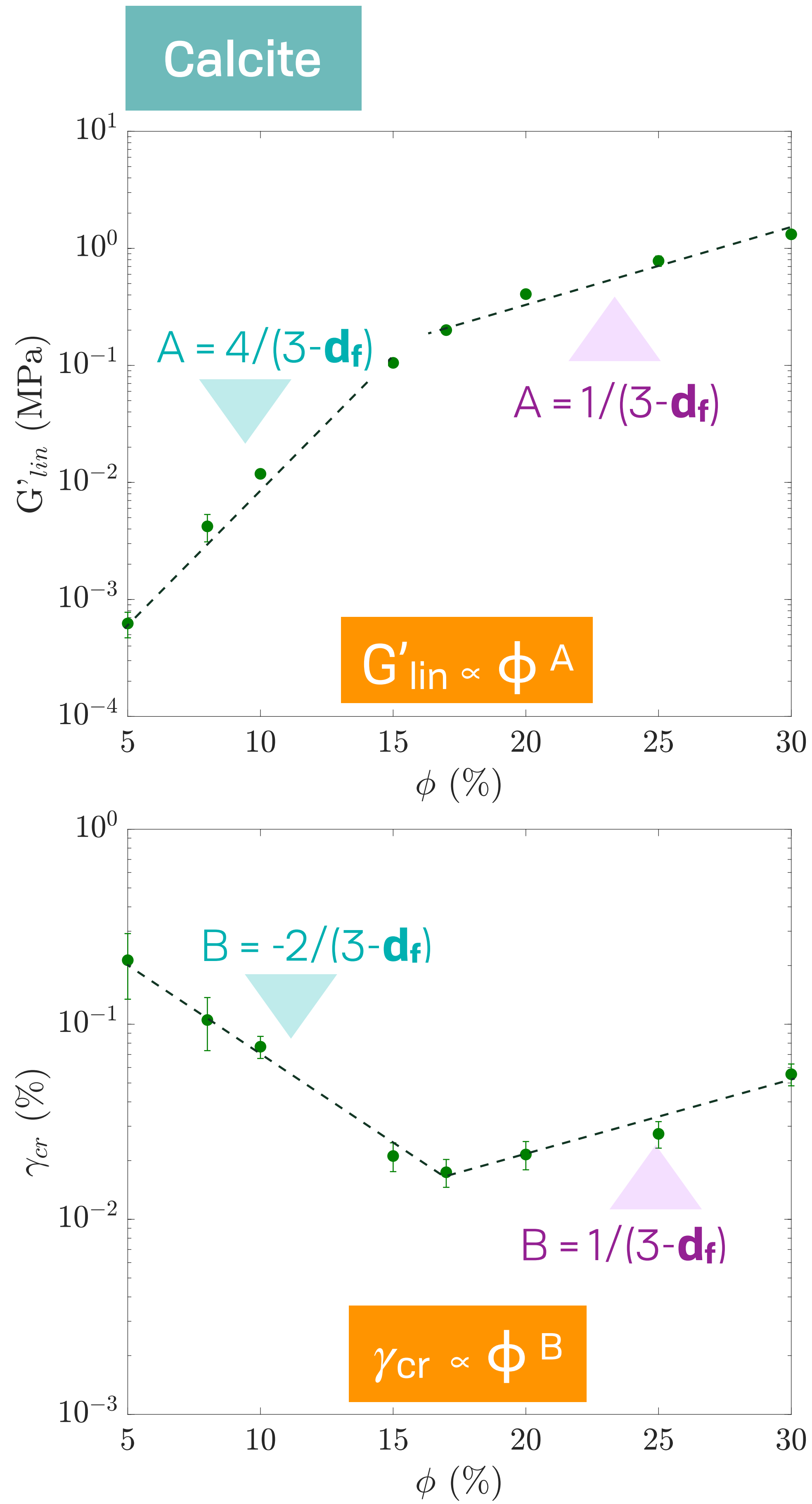
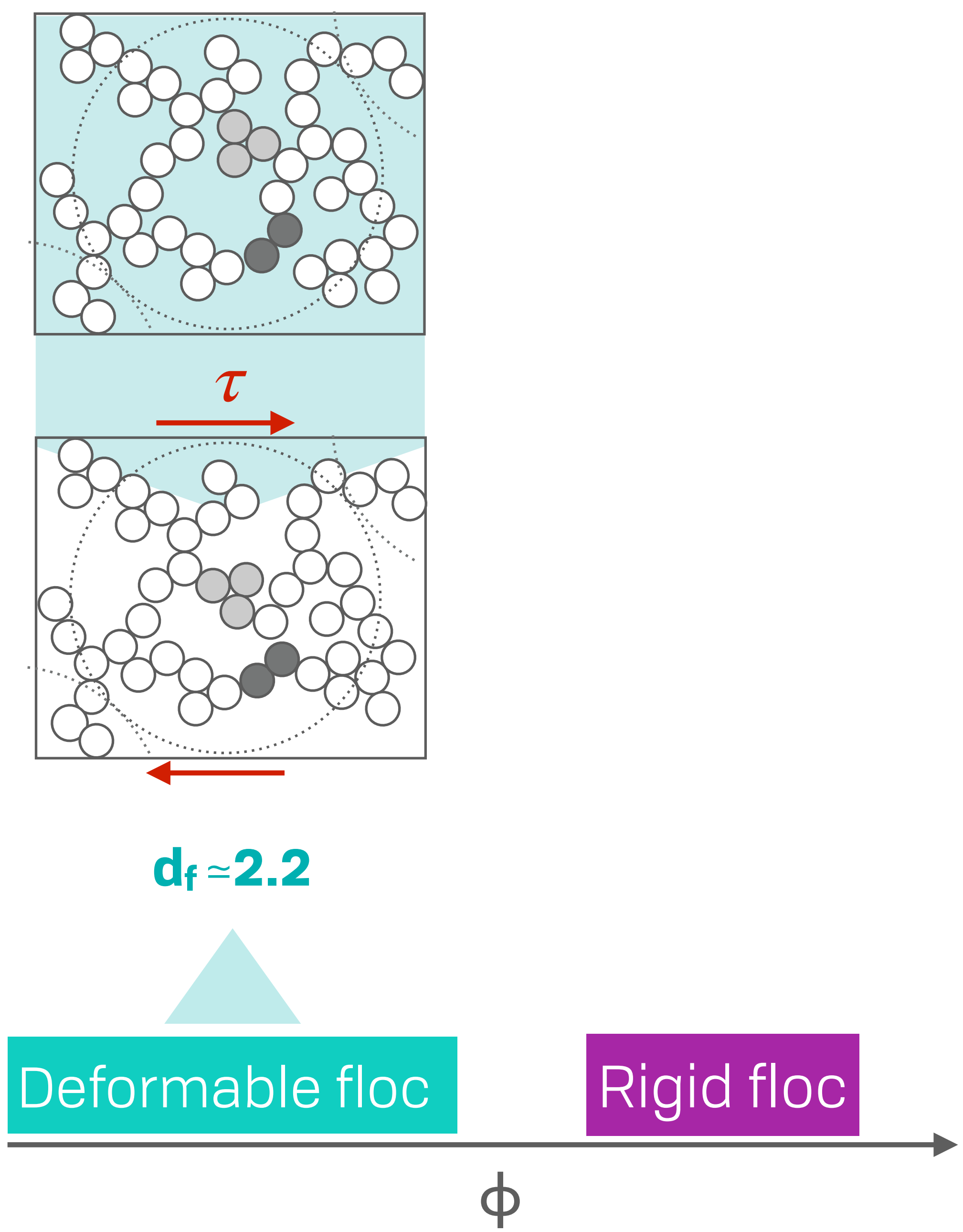


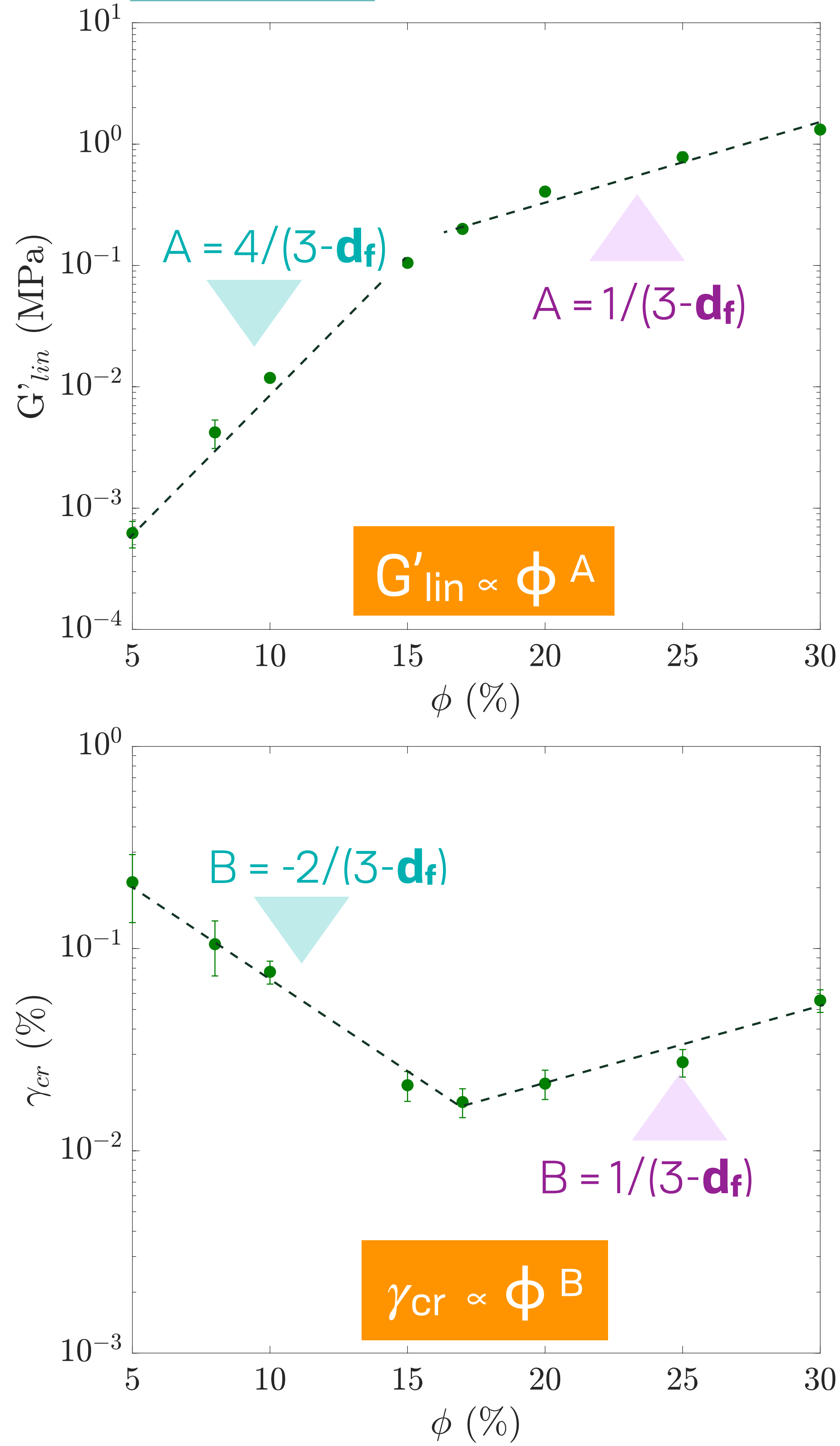




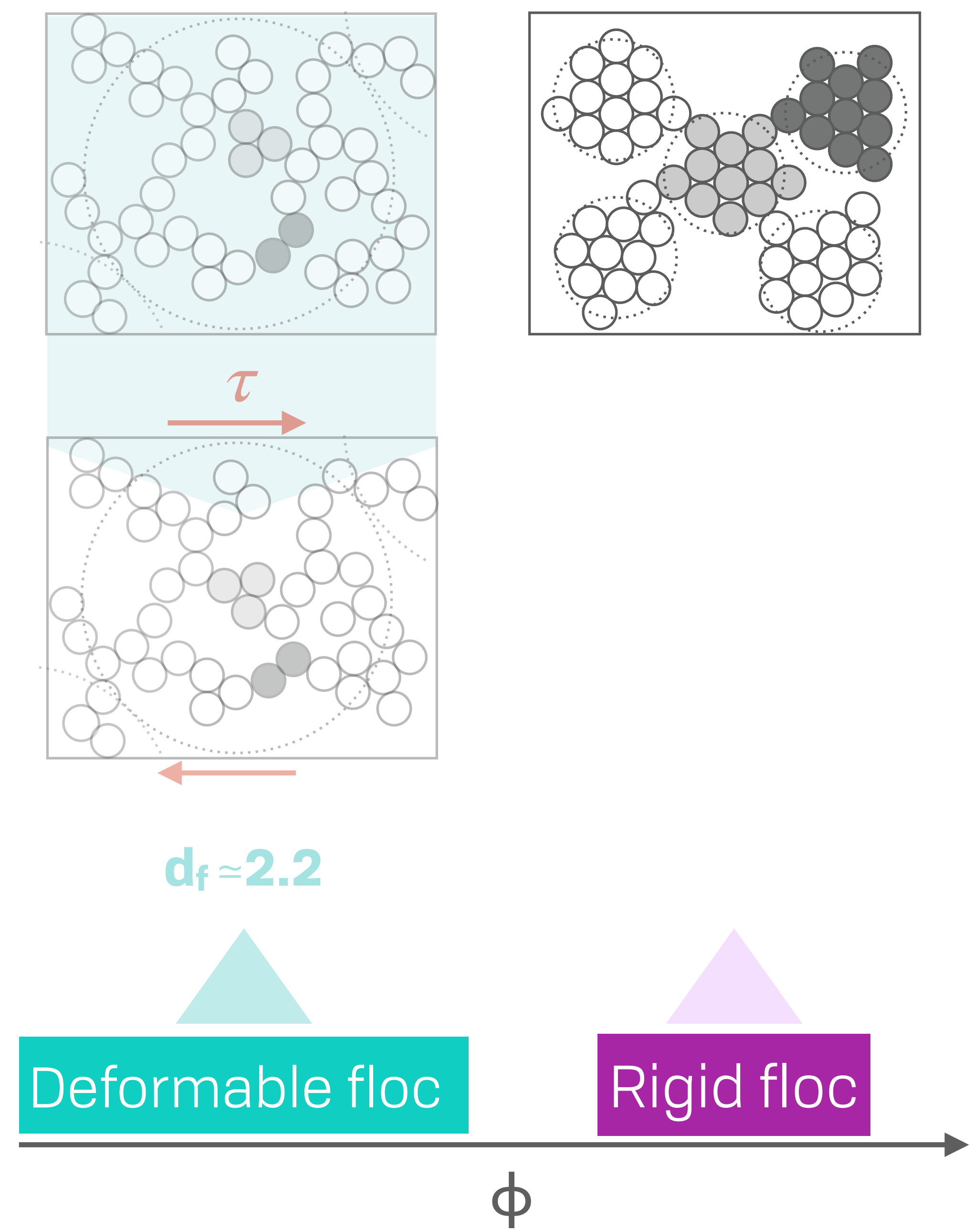
Fractal structure under shear

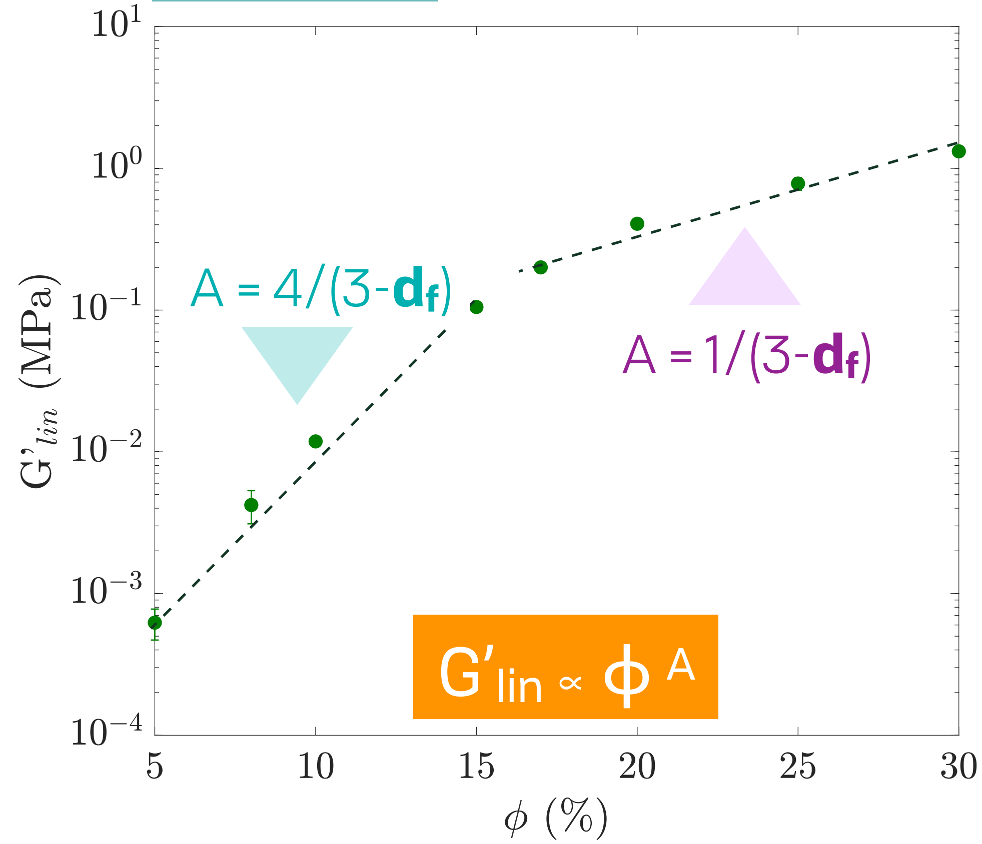


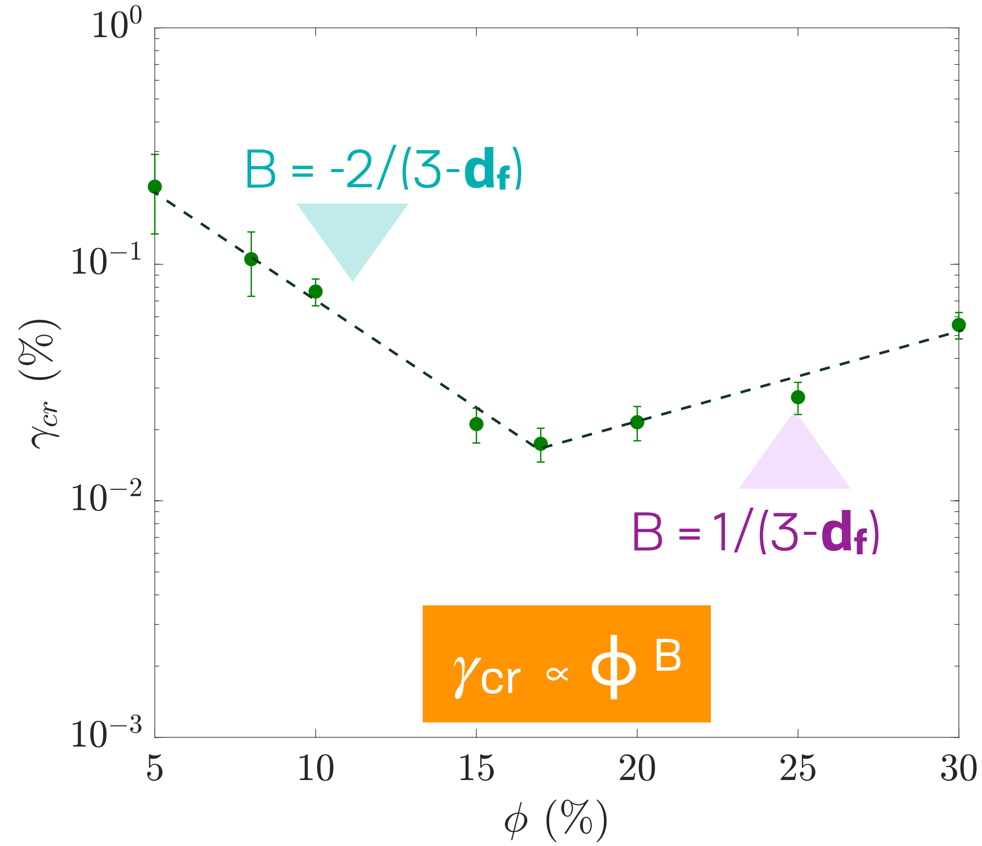
Calcite



Fractal structure at rest







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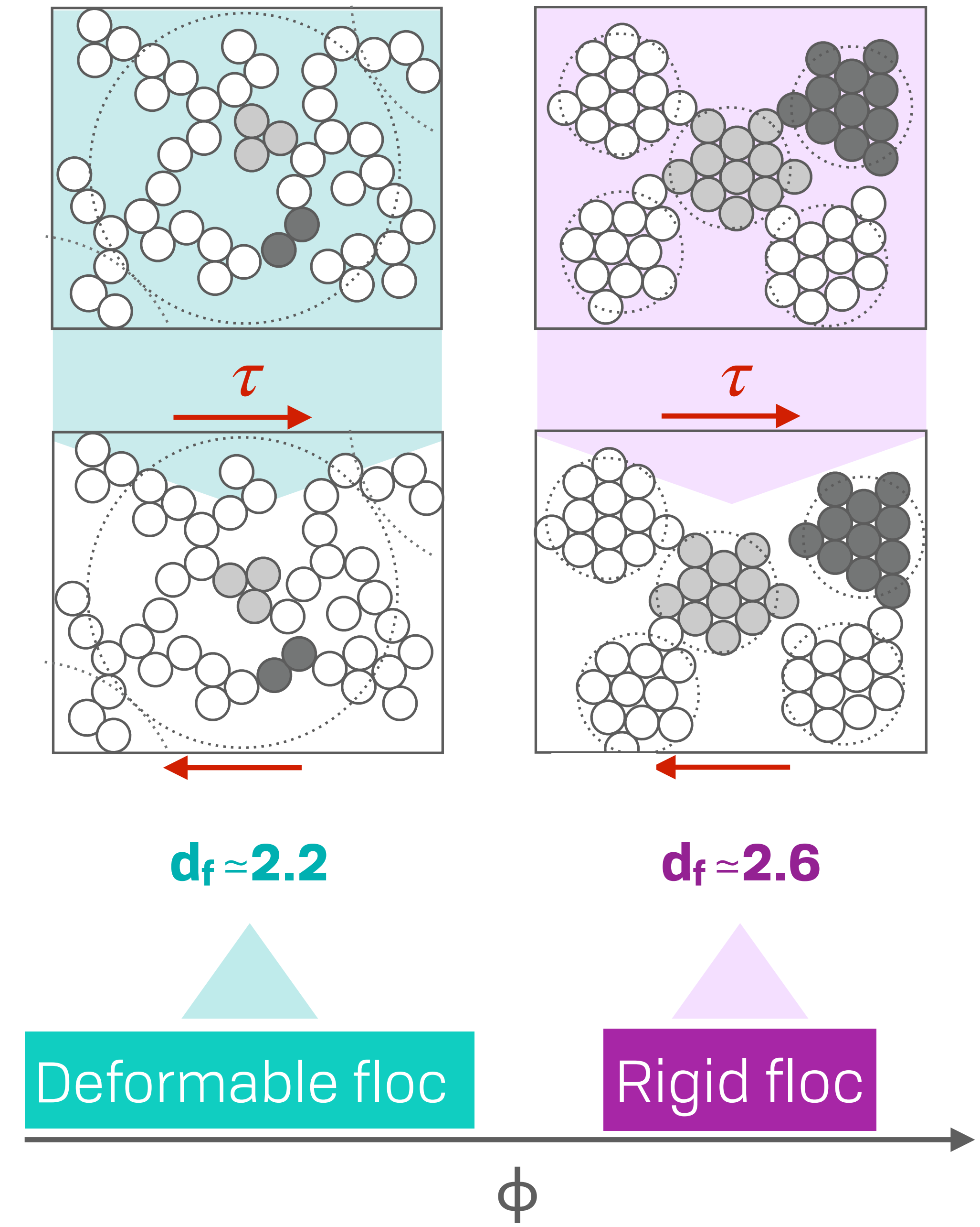
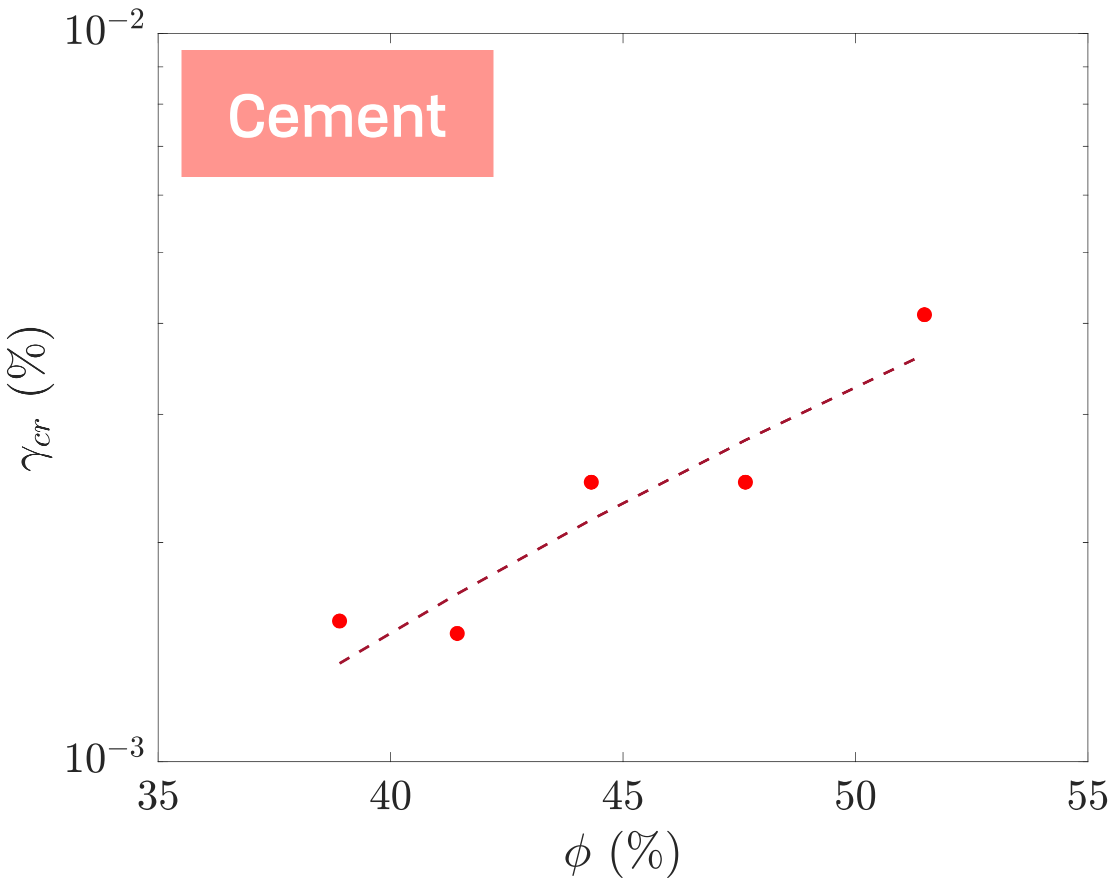
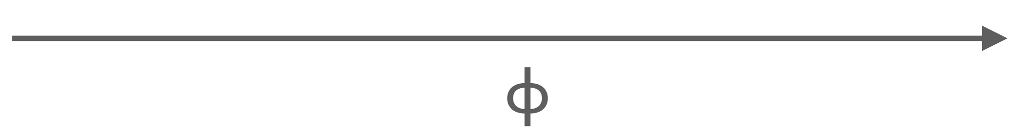
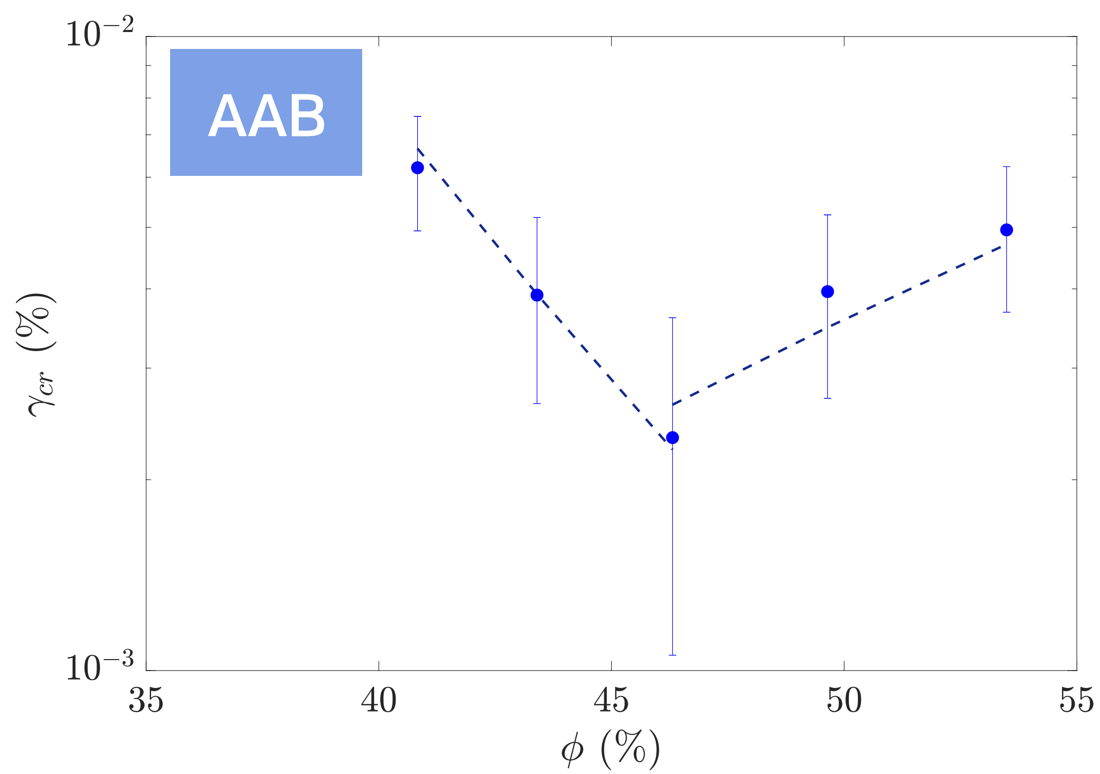



Cement
10^{-2}
10^{-3}
γ_{cr} (%)
35
40
45
50
55
ϕ (%)


ϕ


AAB
10^{-2}
10^{-3}
γ_{cr} (%)
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40
45
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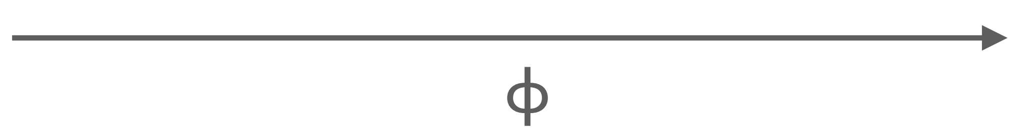
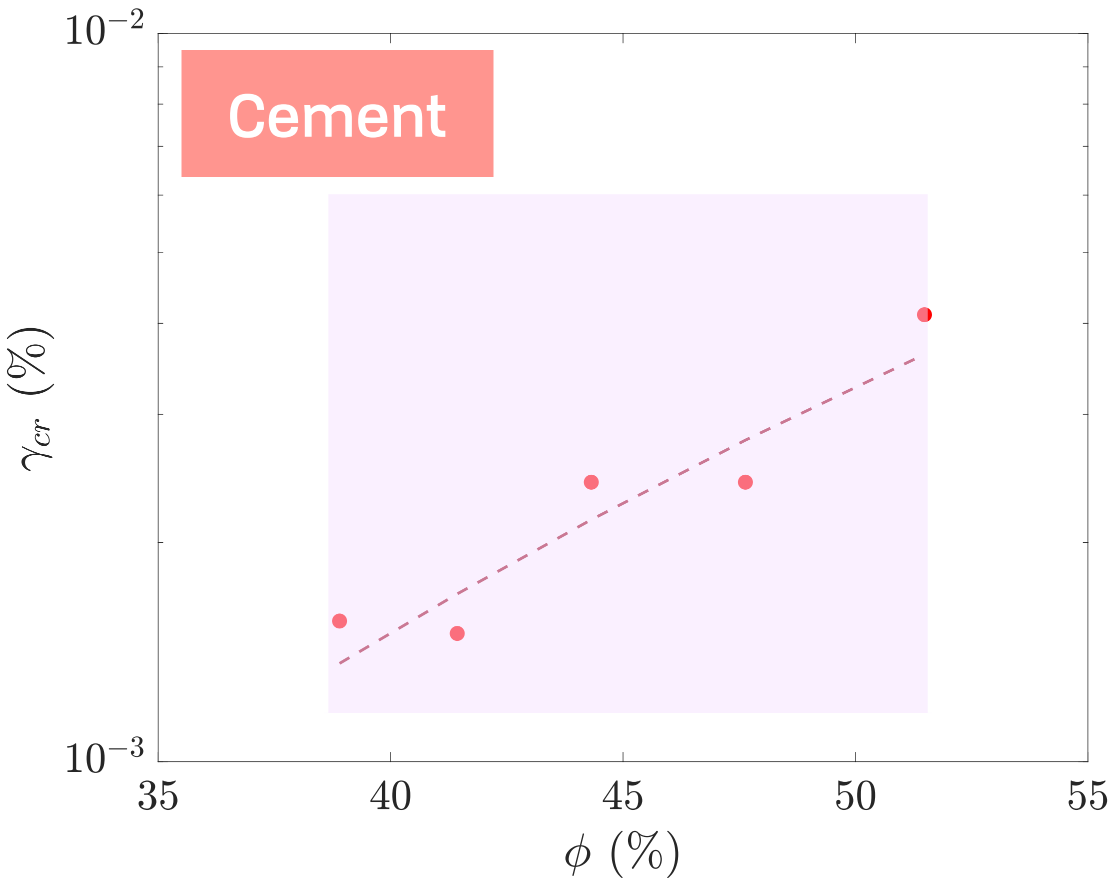
55
ϕ (%)


ϕ


Cement
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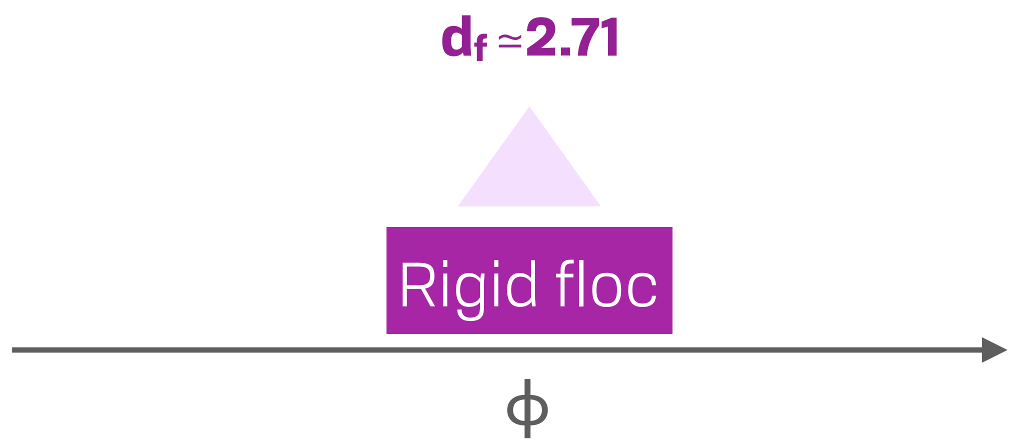
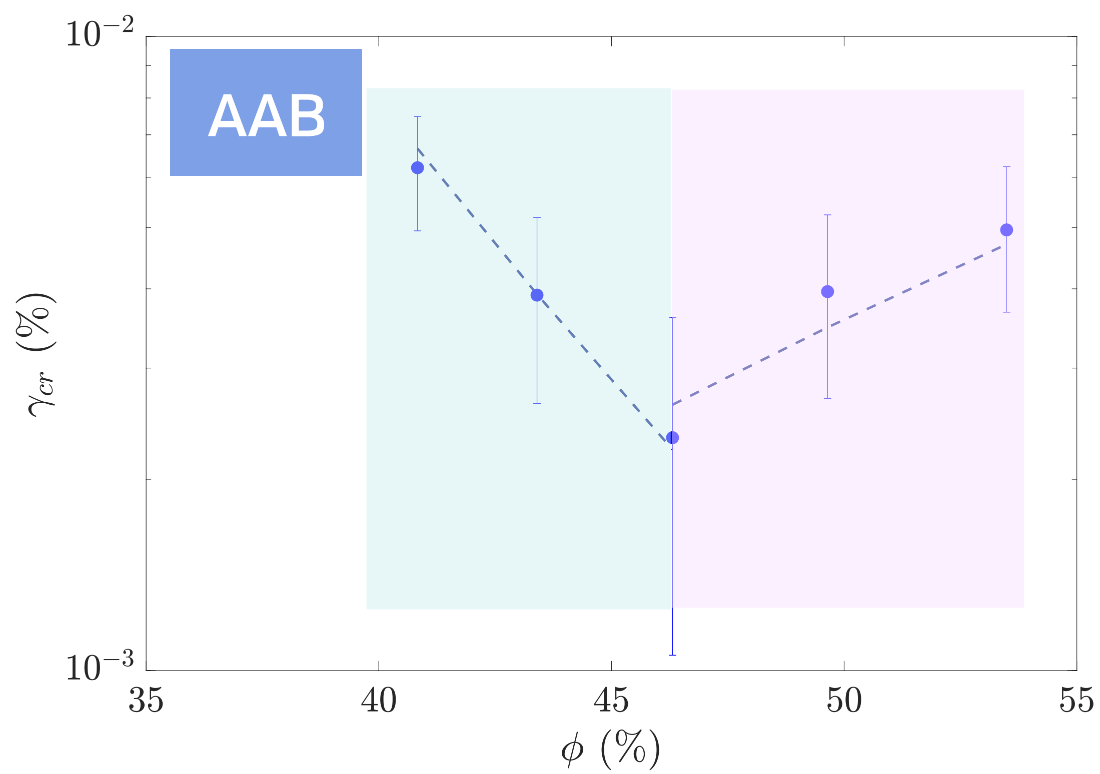

$d_f \simeq 2.71$
Rigid floc
ϕ


AAB
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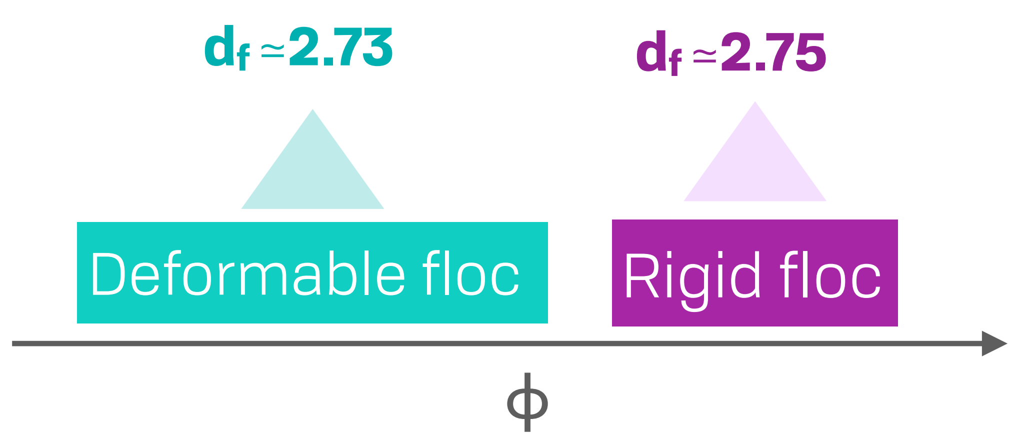
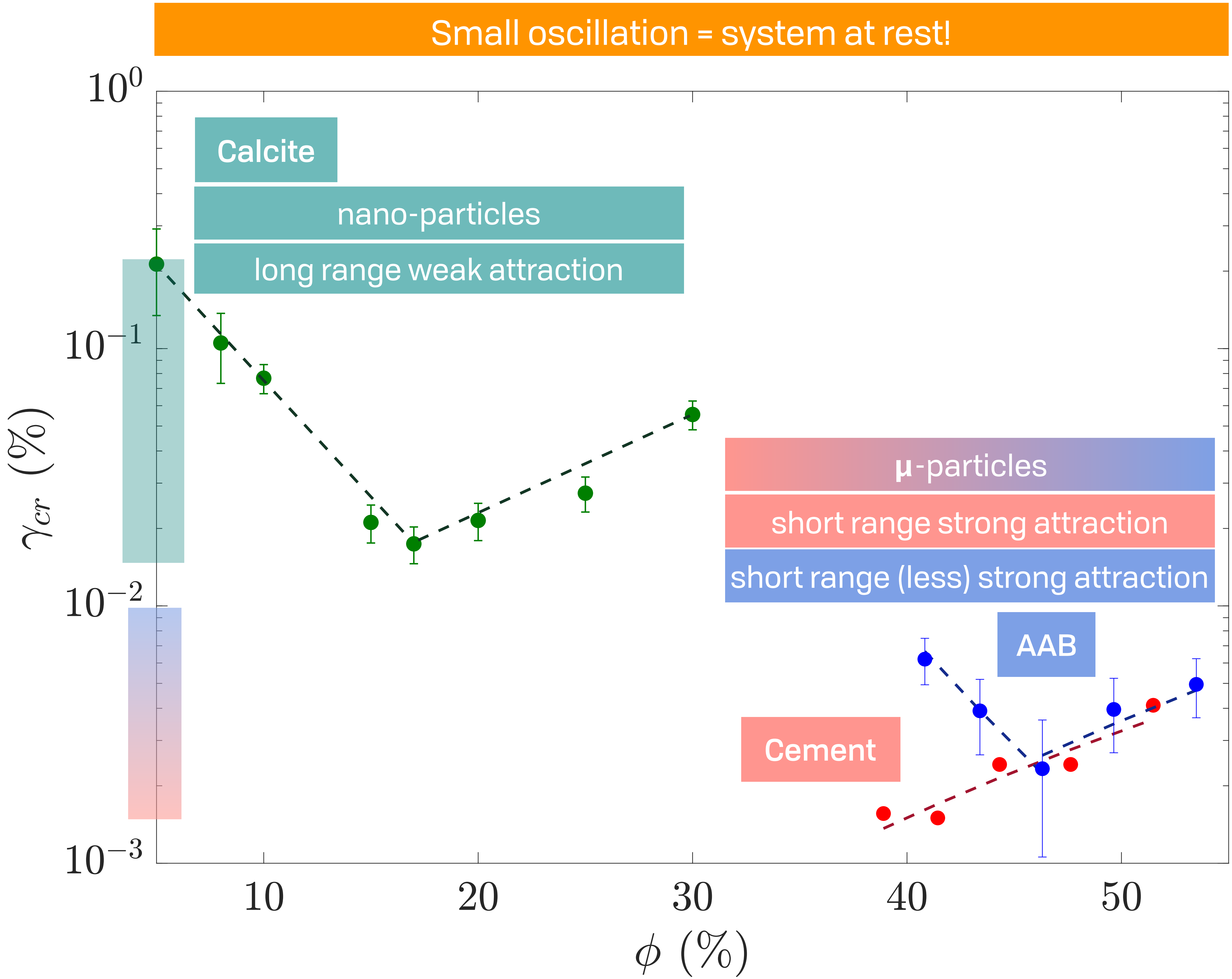
ϕ (%)


$d_f \simeq 2.73$
$d_f \simeq 2.75$
Deformable floc
Rigid floc
ϕ



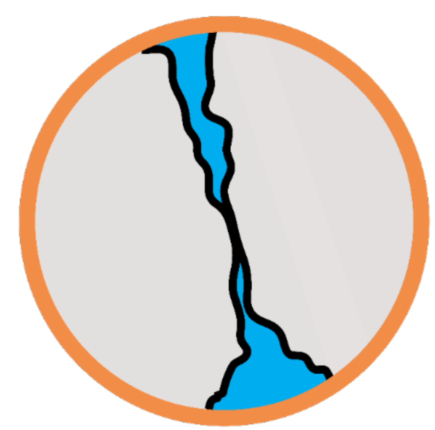
Small oscillation = system at rest!
Calcite
nano-particles
long range weak attraction
µ-particles
short range strong attraction
short range (less) strong attraction
AAB
Cement
10^0
10^{-1}
10^{-2}
10^{-3}
10
20
30
40
50
γ_{cr} (%)
ϕ (%)

Take home message(s)

- ☑ Oscillatory rheometry can give hints on particle cohesiveness
- ☑ The deformation mechanism depends on both concentration and interaction
- ☑ AAB are intermediate between cement and calcite suspensions

Perspectives

- Flow rheological measurements
- Chemical analysis
- Microscopical measurements (i.e. AFM)



Thank you!

LE PURDOCIMENT

SOCIÉTÉ ANONYME POUR LA FABRICATION DES CIMENTS PURDON

SIÈGE SOCIAL : 38, RUE DE NAPLES, BRUXELLES

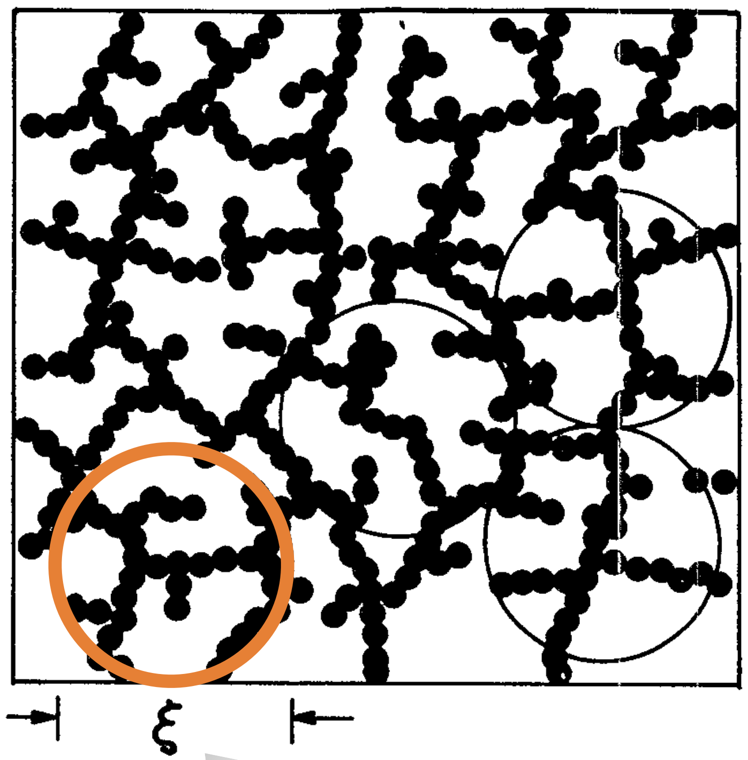
Buchwald et al. Material and Structures (2015)

teresa.liberto@tuwien.ac.at

Backup slides

Elasticity of fractal gels

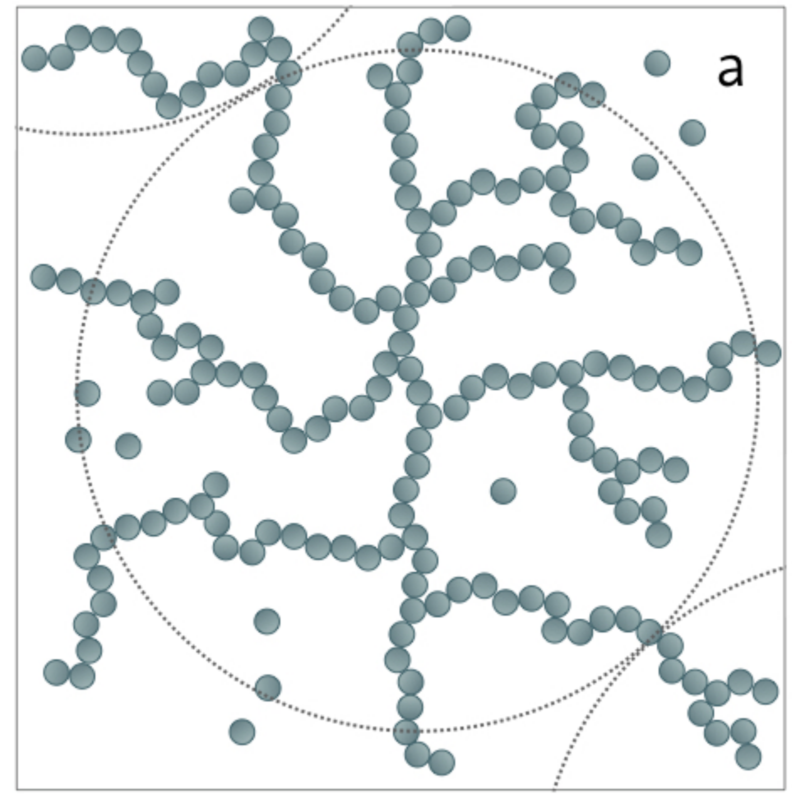
Shih et al. PRA (1990)



floc size $\xi \sim \dfrac{1}{\phi^{\frac{1}{(3-d_f)}}}$

fractal dimension

floc rigidity $K_\xi \propto \dfrac{1}{\xi}$

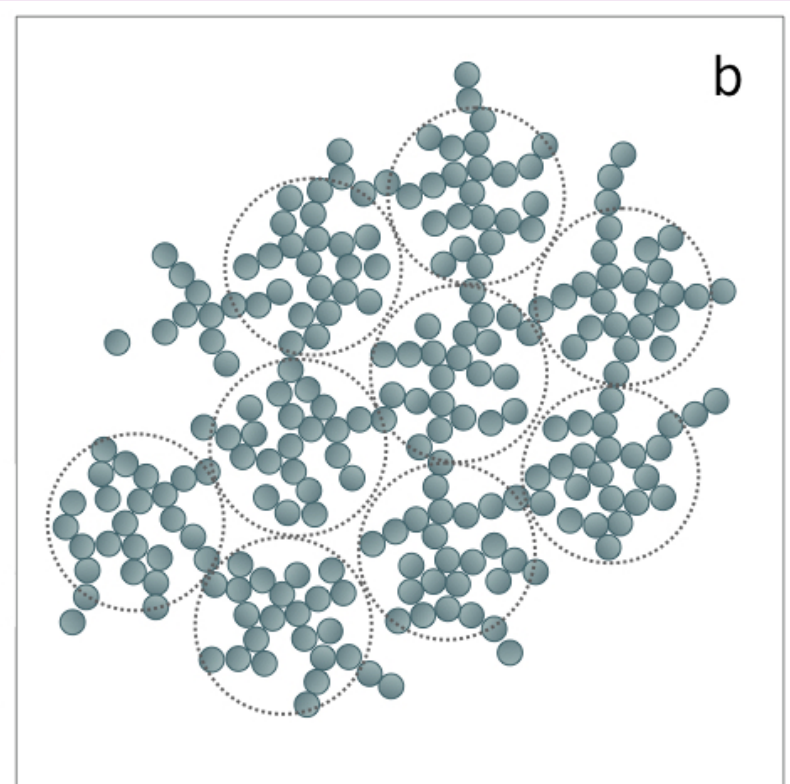


Low ϕ

$\uparrow \xi$

$\downarrow K_\xi$

STRONG LINK



High ϕ

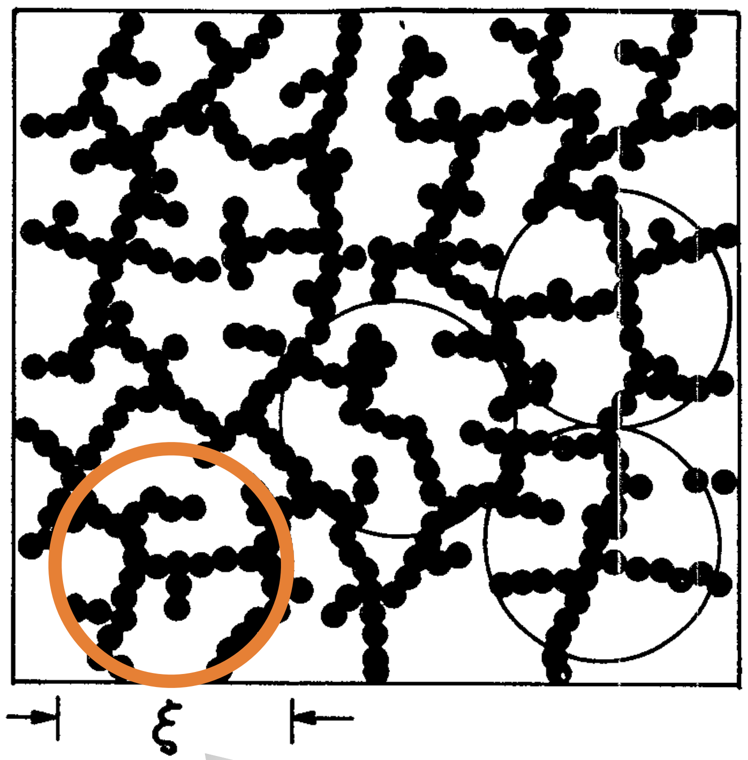
$\downarrow \xi$

$\uparrow K_\xi$

WEAK LINK

Elasticity of fractal gels

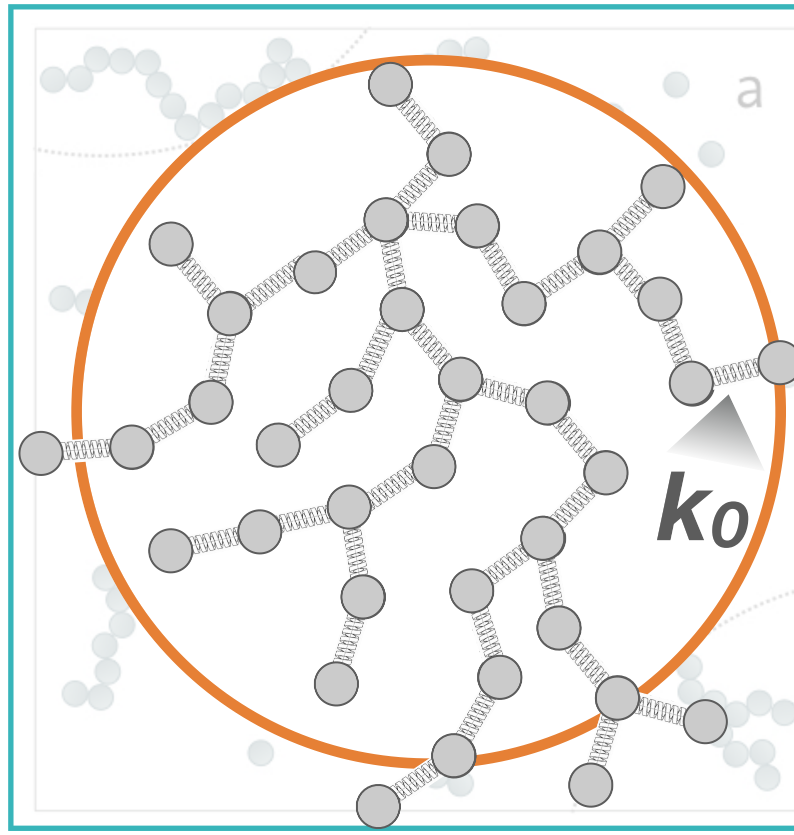
Shih et al. PRA (1990)



$K_\xi(\xi)$

floc size $\xi \sim \frac{1}{\phi^{\frac{1}{(3-d_f)}}}$

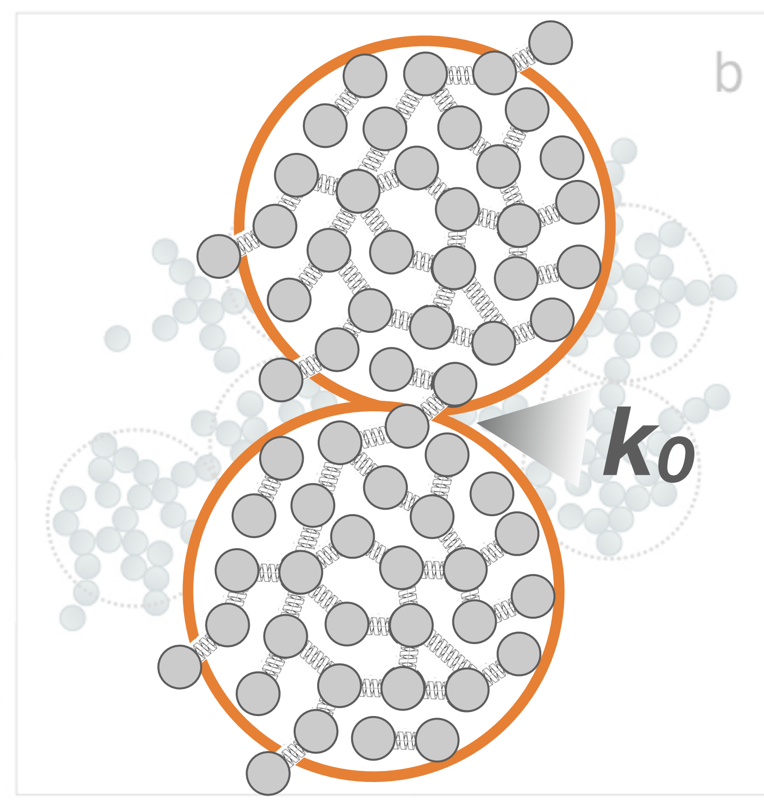
floc rigidity $K_\xi \propto \frac{1}{\xi}$



Low ϕ

G', γ_{cr} → $K_\xi(\xi)$

STRONG LINK



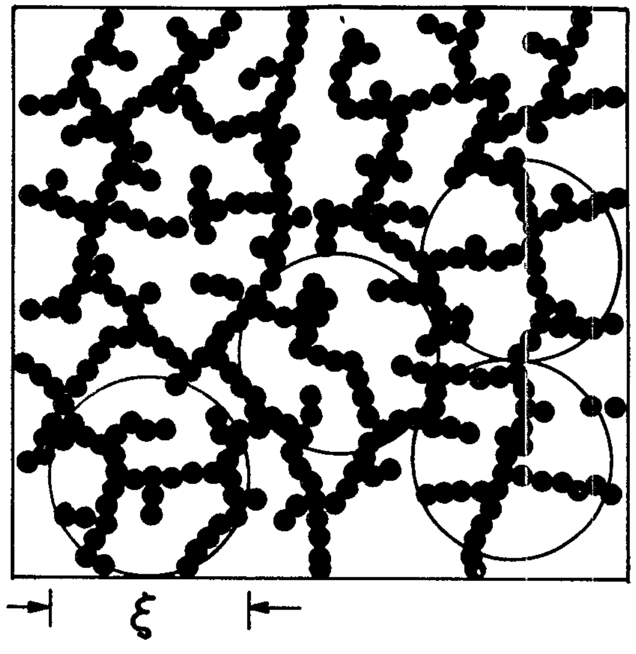
High ϕ

G', γ_{cr} → k_0

WEAK LINK

Shih 1990

x backbone fractal dimension



floc size $\xi \sim \dfrac{1}{\phi^{\frac{1}{(3-d_f)}}}$

floc rigidity $K_\xi \sim \dfrac{k_0}{\xi^{2+x}}$

system rigidity $K \sim K_\xi \left(\dfrac{L}{\xi}\right)$

strong link: low ϕ

$$K \sim K_\xi \left(\frac{L}{\xi}\right) \approx \frac{1}{\xi^{2+x}} \cdot \frac{1}{\xi} \approx \phi^{\frac{3-x}{3-d_f}}$$

$$F_\xi \sim K_\xi (\Delta L)_\xi \approx \frac{k_0}{\xi^{2+x}} \cdot \frac{\Delta L}{L/\xi}$$ force on a floc

$$\gamma_{cr} \sim \left(\frac{\Delta L}{L}\right) \approx \frac{\xi^{1+x}}{k_0} \approx \xi^{1+x} \approx \phi^{\frac{-(1+x)}{3-d_f}} \quad (F_\xi = 1)$$

bonds breakage

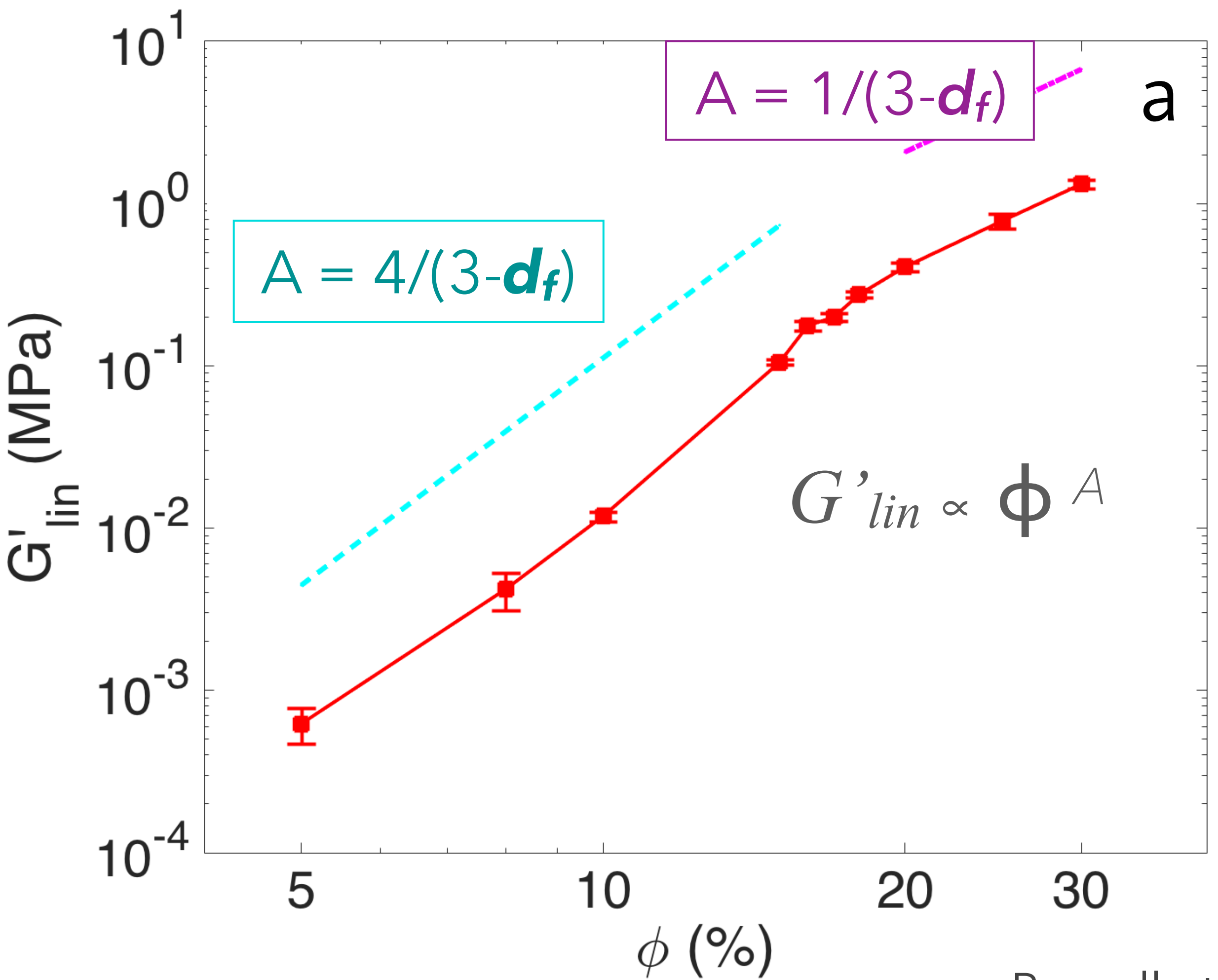
weak link: high ϕ

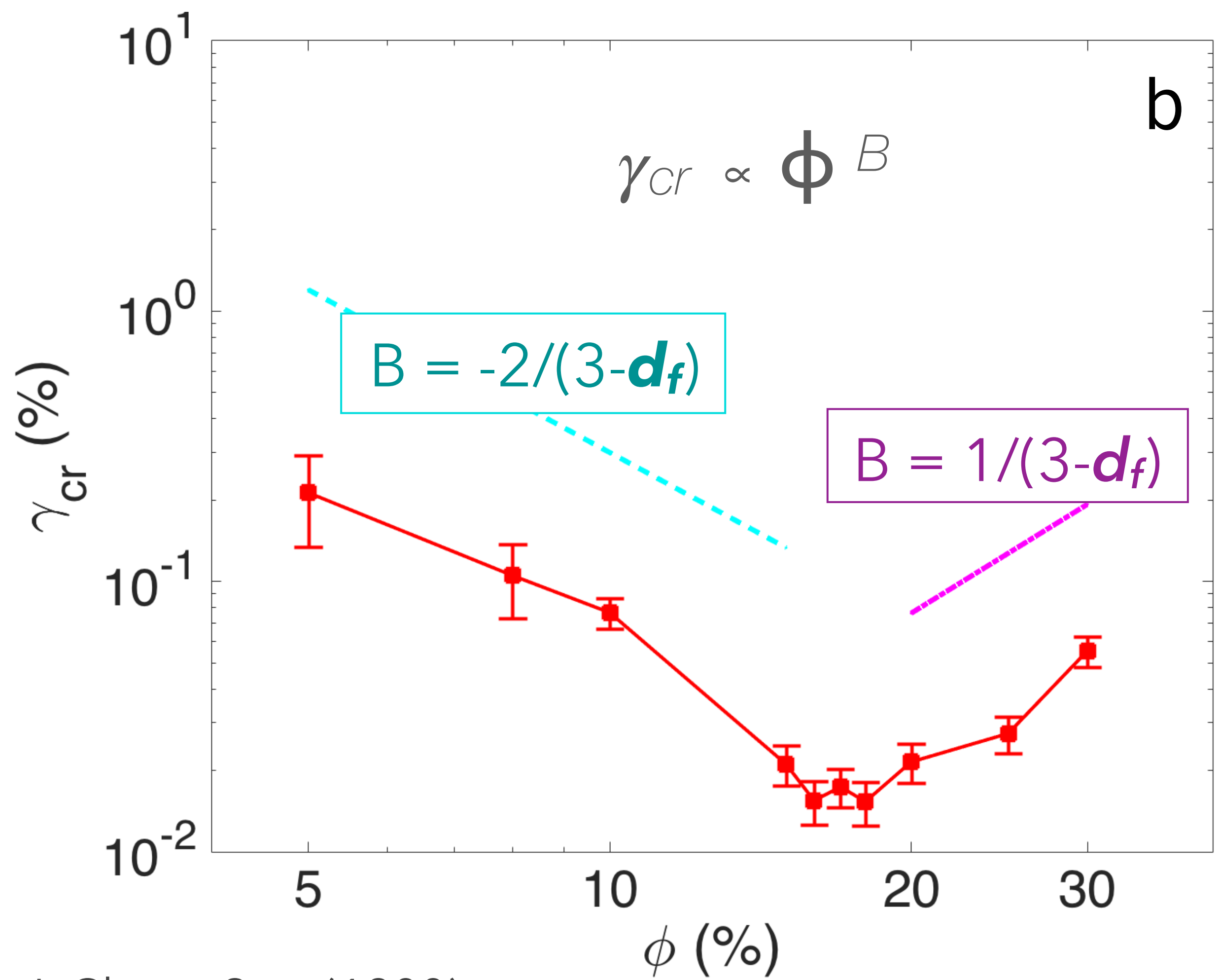
$$K \sim k_0 \left(\frac{L}{\xi}\right) \approx \frac{1}{\xi} \approx \phi^{\frac{1}{3-d_f}}$$

$$\gamma_{cr} \approx \frac{1}{\xi} \approx \phi^{\frac{1}{3-d_f}}$$

Shih et al., PRA (1990)

d_f = fractal dimension





Buscall et al., J. Chem. Soc. (1988)

$$\phi \sim \phi_0 (\xi / a)^{-(3-d_f)}$$

STRONG LINK	WEAK LINK
$d_f \simeq 2.2$	$d_f \simeq 2.6$
$\xi \sim 2$ µm	$\xi \sim 0.5$ µm

ϕ →