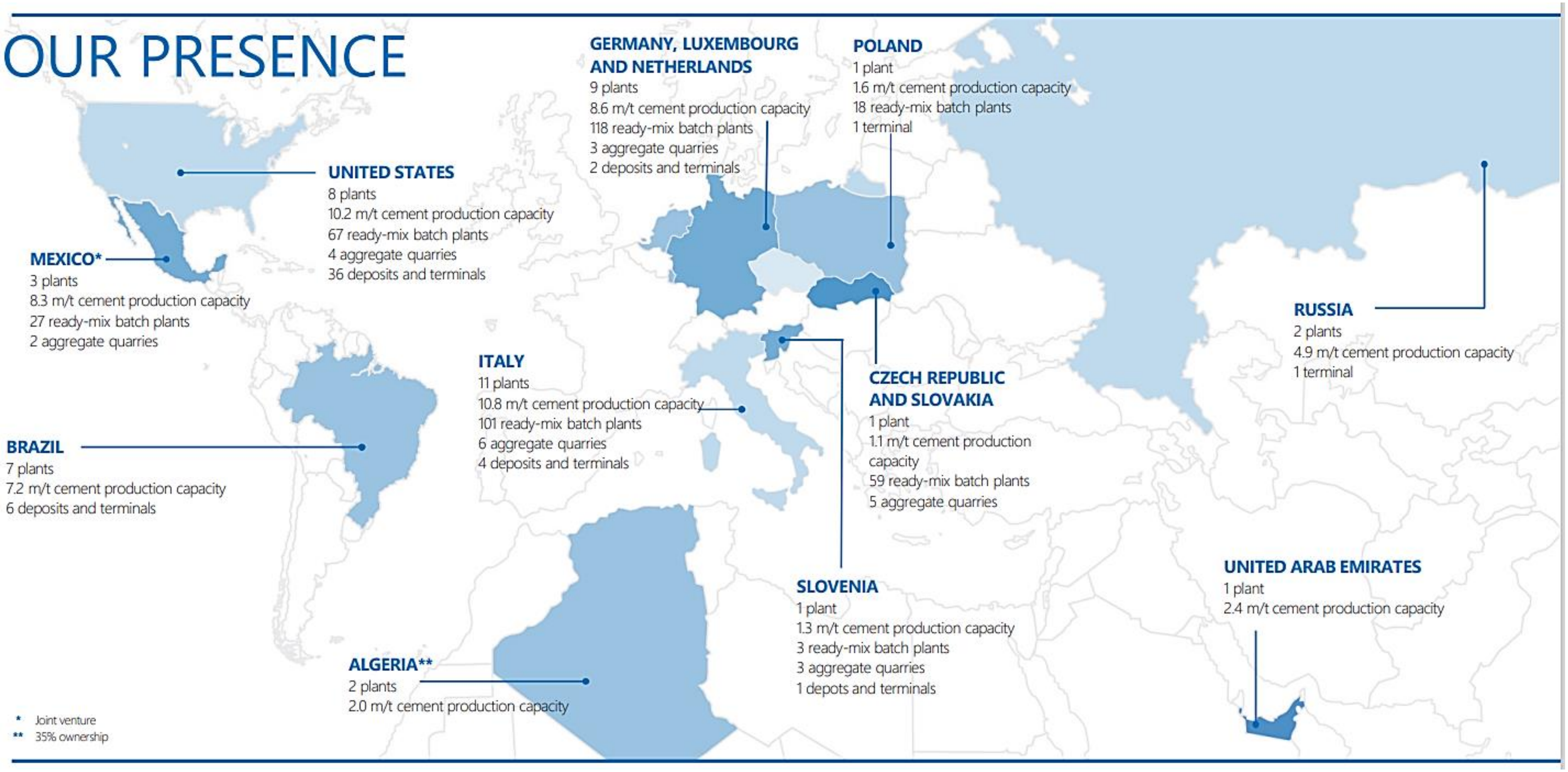
Rheology and performance of eco-friendly cements based on slag, limestone and calcined clay: a comparative study of superplasticizer interactions

Nisrine El Fami, Fulvio Canonico

Built - Buzzi Innovation Lab and Technology

Buzzi S.p.A.



WE ARE A MULTI-REGIONAL GROPU FOCUSED IN THE PRODUCTION OF CEMENT AND PRE-CAST CONCRETE

110 years of history

Ground in 1907 by Pietro and Antonio Buzzi in Italy

PLAN

- Environmental and scientific context
- Materials and experimental methodology
- Rheological results and discussion
- Key conclusions and perspectives

Sustainability in the Cement Industry

5C Framework for a Carbon Neutral Cement Industry

https://lowcarboneconomy.cembureau.eu/5-years-on/the-5c-approach/

Sustainability in the Cement Industry

- *SCMs partially replace clinker in composite cements offer promising solutions for low-carbon binders*
- *Common SCMs: limestone, slag, natural pozzolan, calcined clay…*
- *SCMs offer promising Lower CO_2 footprint and offer promising solutions for low-carbon binders*



Sustainability in the Cement Industry

- *SCMs significantly modifies the fresh-state behavior of cementitious systems*
- *Result in increased viscosity, yield stress, and structural build-up, requiring the use of chemical admixtures*
- *Superplasticizers are therefore essential to control particle dispersion and restore adequate workability*

Rheology becomes a key tool to link environmental strategies, material formulation, and fresh-state performance.

Materials and Experimental Program

Cement systems

CEM II/A-LL (EN 197-1) (limestone)

CEM III/A (EN 197-1) (slag)

CEM III/B (EN 197-1) (slag)

CEM II/C-M (Q-LL) (EN 197-5)

(limestone + calcined clay)

Chemical admixtures

Superplasticizer SP1

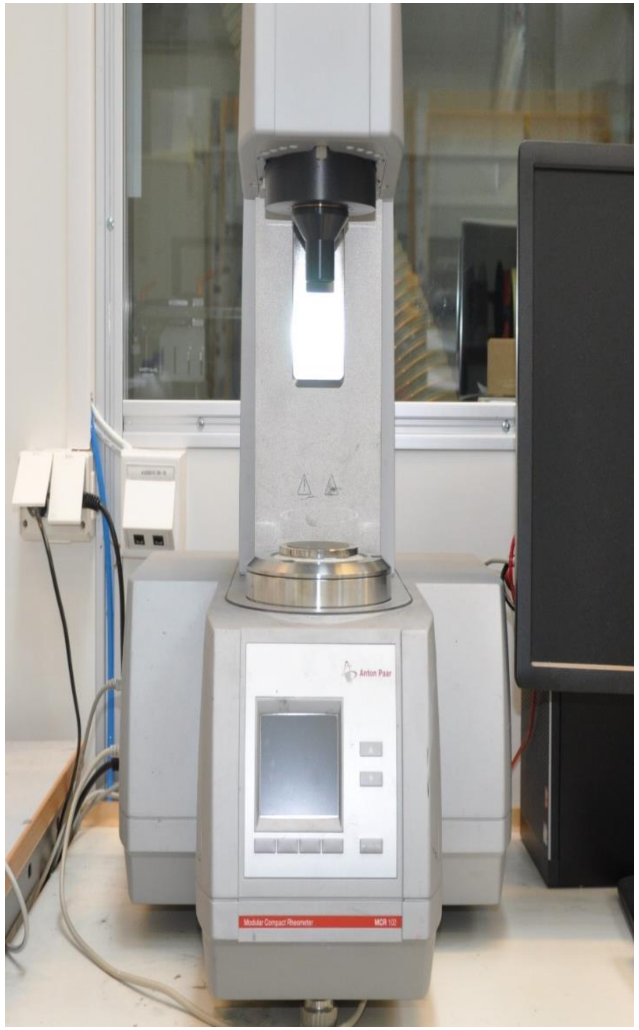
Superplasticizer SP2

Mix design parameters

Dosage : 0,6% - 0,8% -1%

w/c=0,45

Rheological Tests Performed

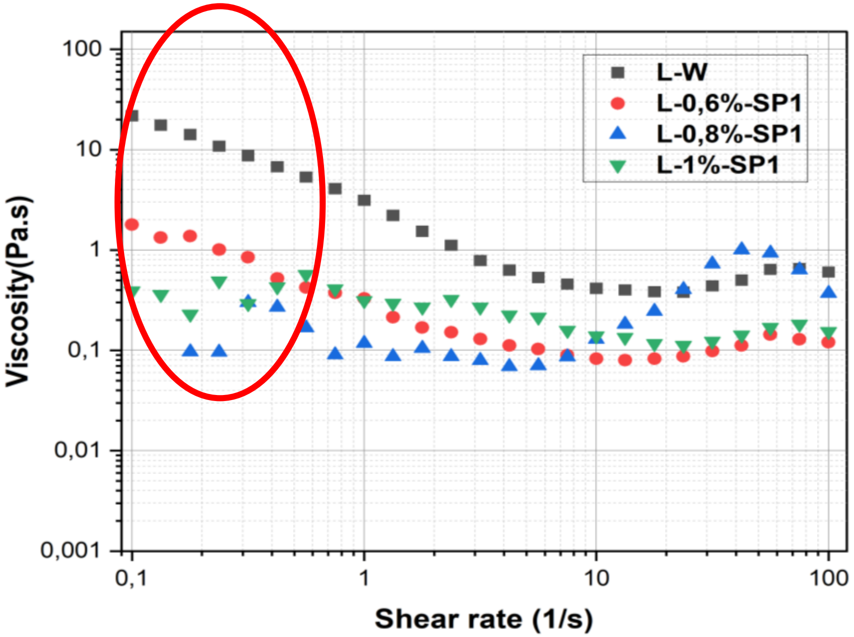


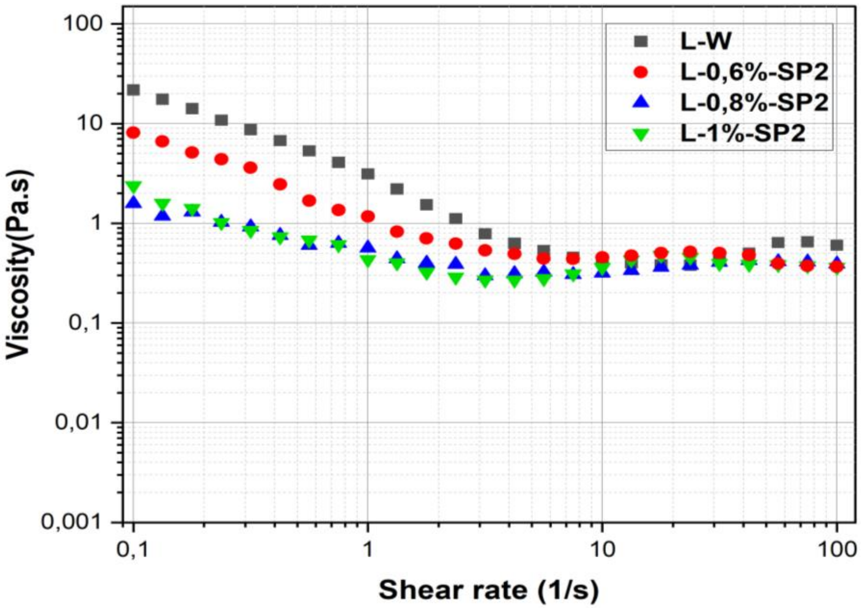
Antoon Paar MCR 102e

- Flow curves and apparent viscosity
- Static and dynamic yield stress
- Oscillatory tests for viscoelastic properties

Effect of SCMs and Superplasticizer Dosage on Flow Behavior

Limestone cement



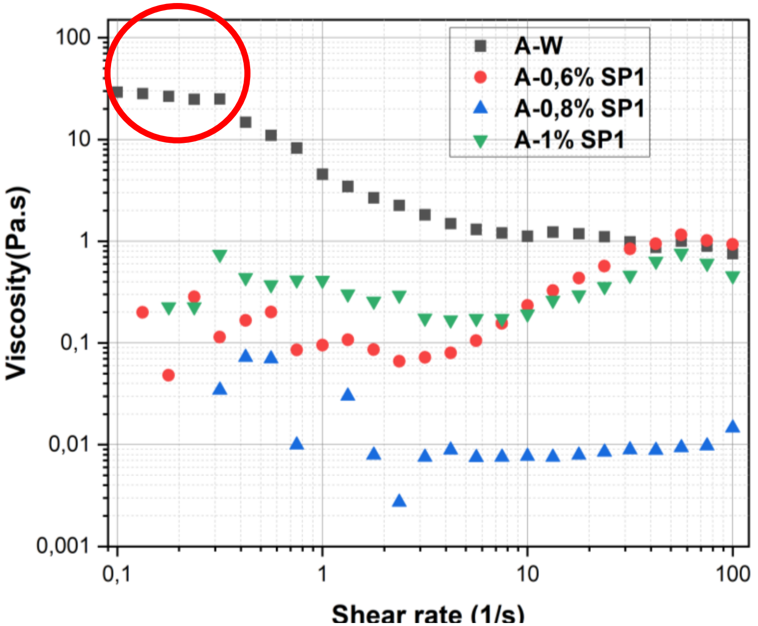


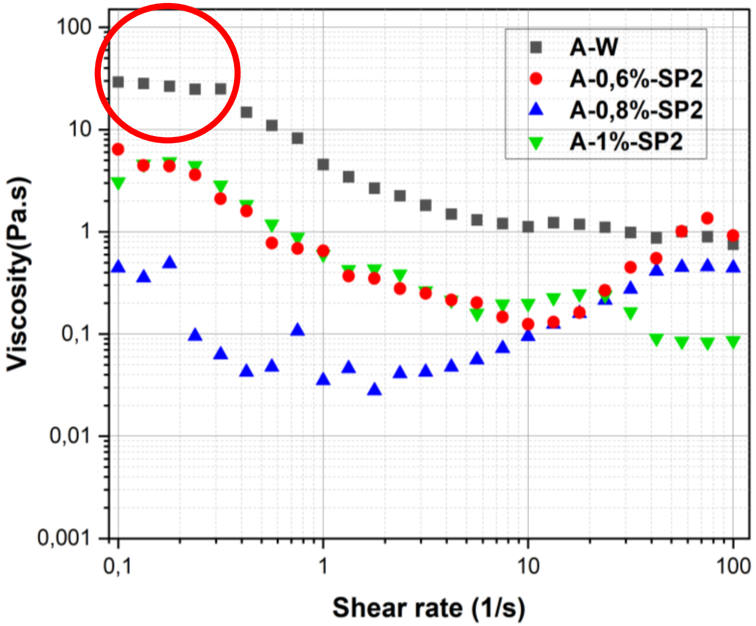
- *Limestone pastes show high viscosity at low shear rates due to strong interparticle interactions and filler-induced densification*

- *SP1 is more effective than SP2, particularly at 0.8%, leading to improved fluidity.*

Effect of SCMs and Superplasticizer Dosage on Flow Behavior

CEM III/A



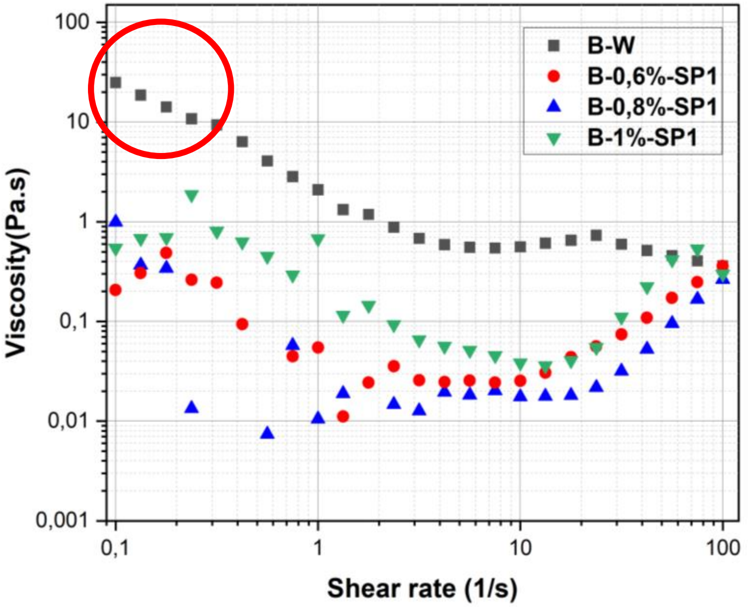


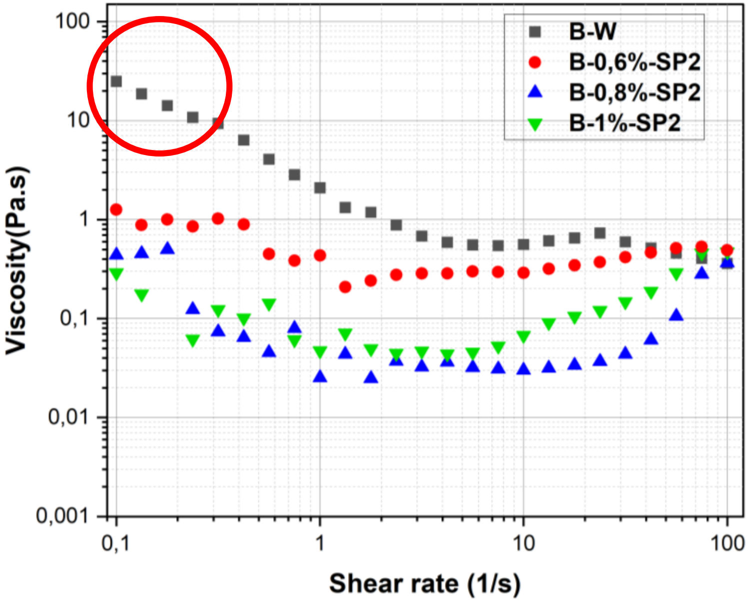
Slag-containing systems present higher viscosity in reference conditions.

SP1 increases fluidity but may induce destabilization at low shear rates, while SP2 provides better stability.

An overdosing at 1% leads to viscosity increase, likely due to flocculation caused by excessive adsorption.

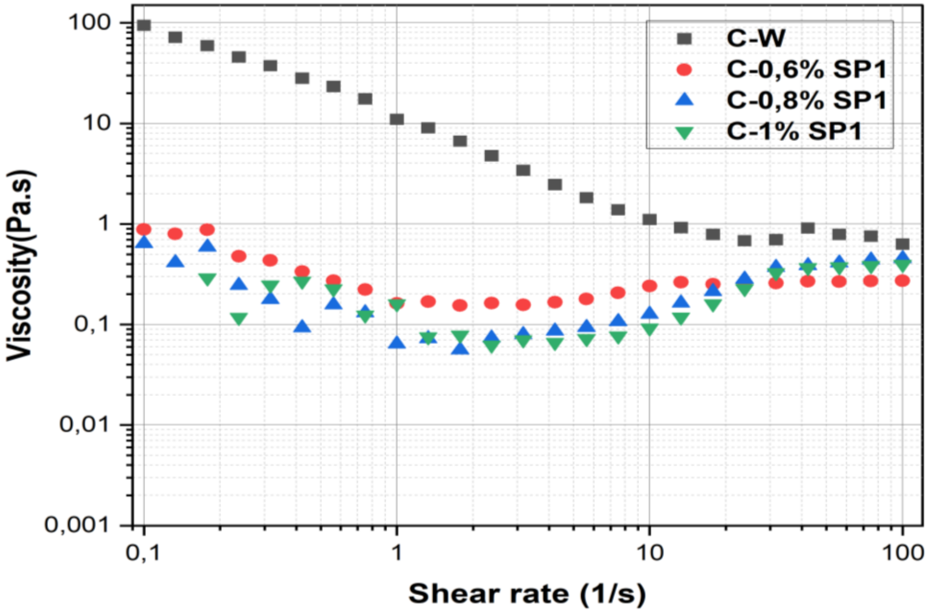
CEM III/B

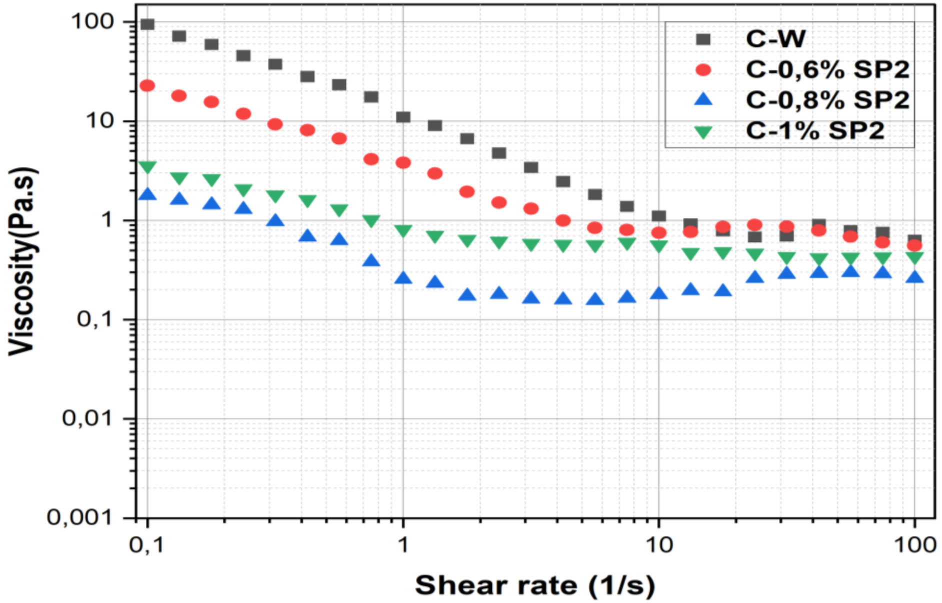




Effect of SCMs and Superplasticizer Dosage on Flow Behavior

Limestone calcined clay cement



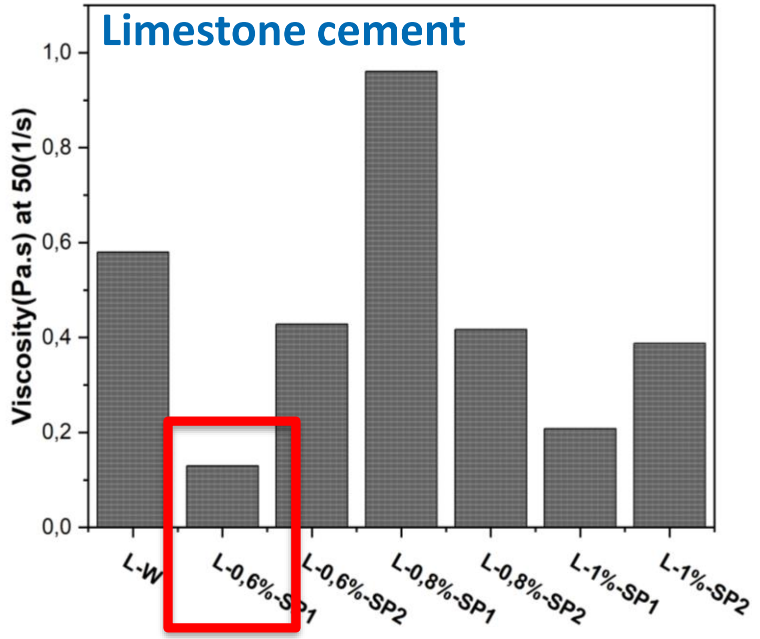


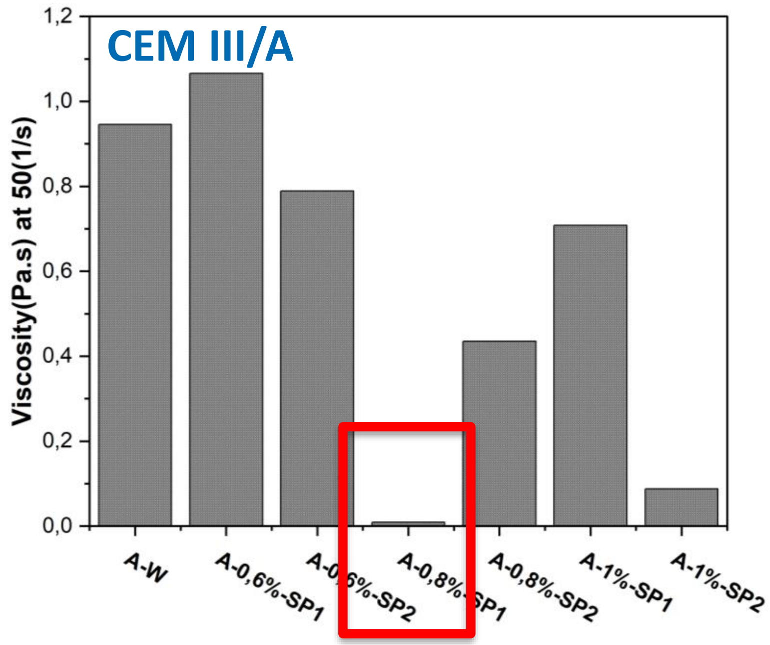
Calcined clay cement pastes exhibit significantly higher viscosity over the entire shear rate range.

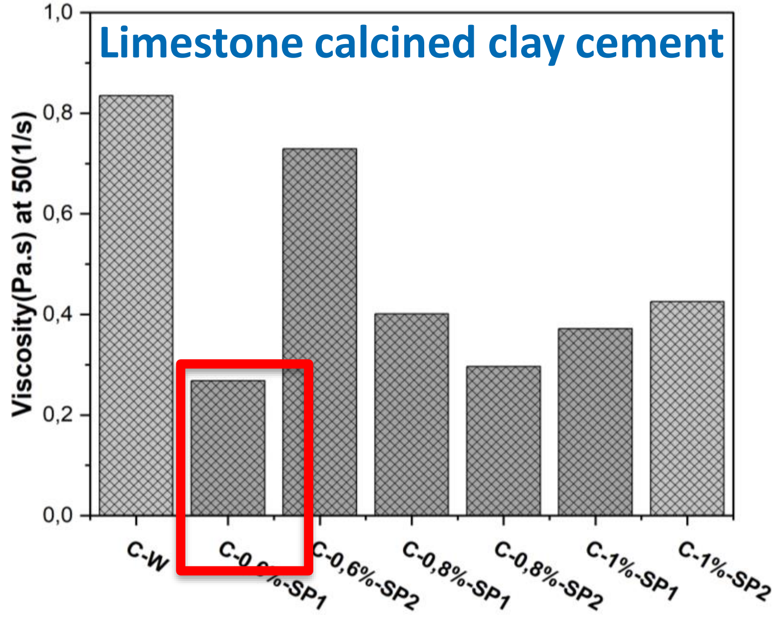
The high viscosity is attributed to strong water adsorption and enhanced interparticle interactions induced by calcined clay.

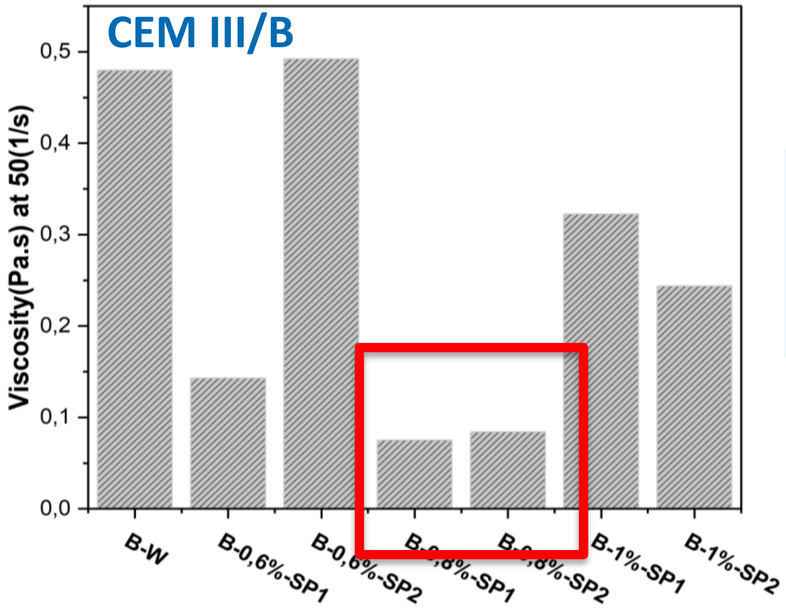
Superplasticizers reduce viscosity, with SP1 showing a more pronounced dispersing effect than SP2.

Effect of SCMs and Superplasticizer Dosage on Flow Behavior







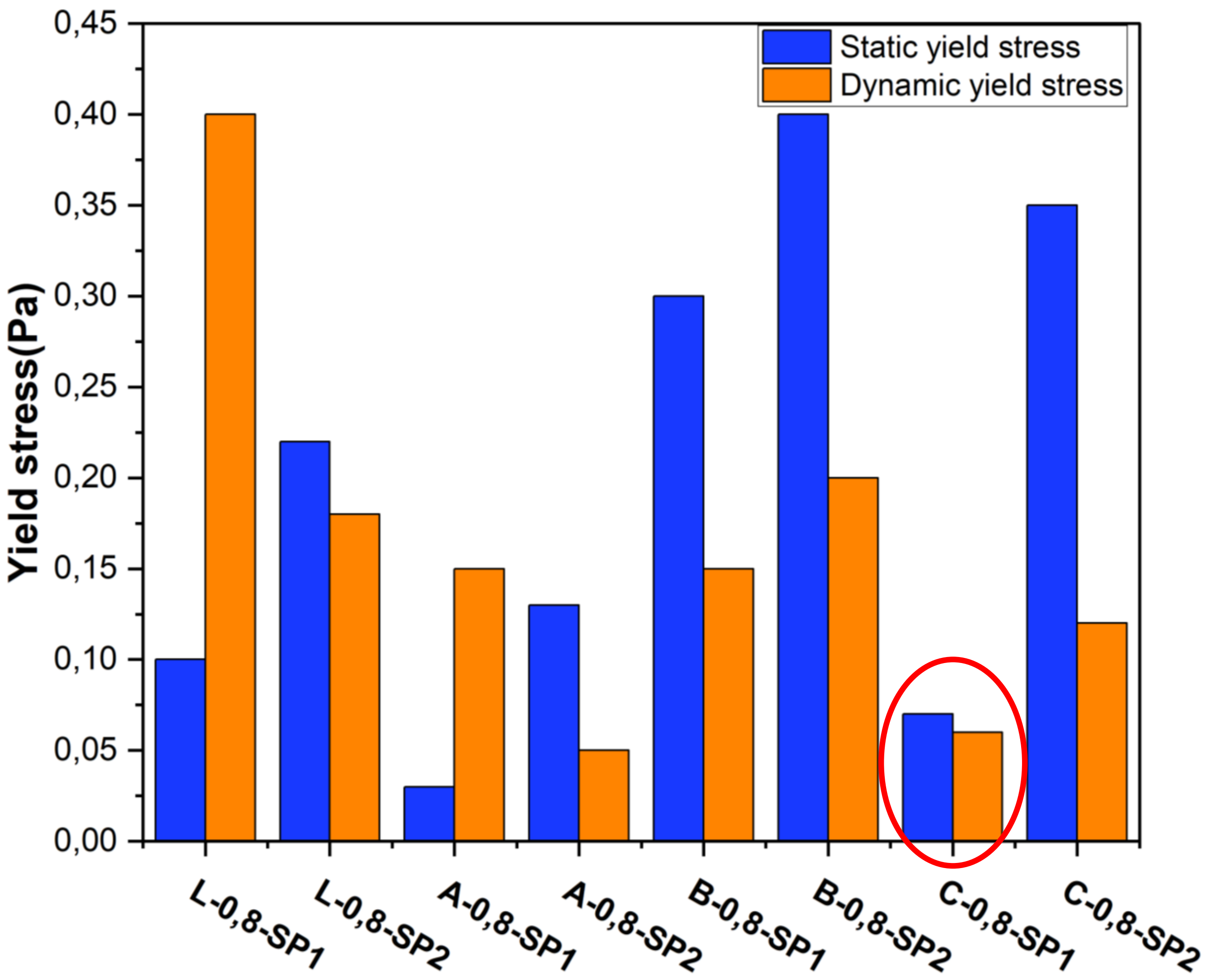


Apparent viscosity at 50 s^{-1} reflects the residual structure after floc breakdown.

Limestone systems show the lowest viscosity due to dilution.

Superplasticizers are most effective in calcined clay systems.

Static and dynamic yield stress at 0.8% superplasticizer dosage



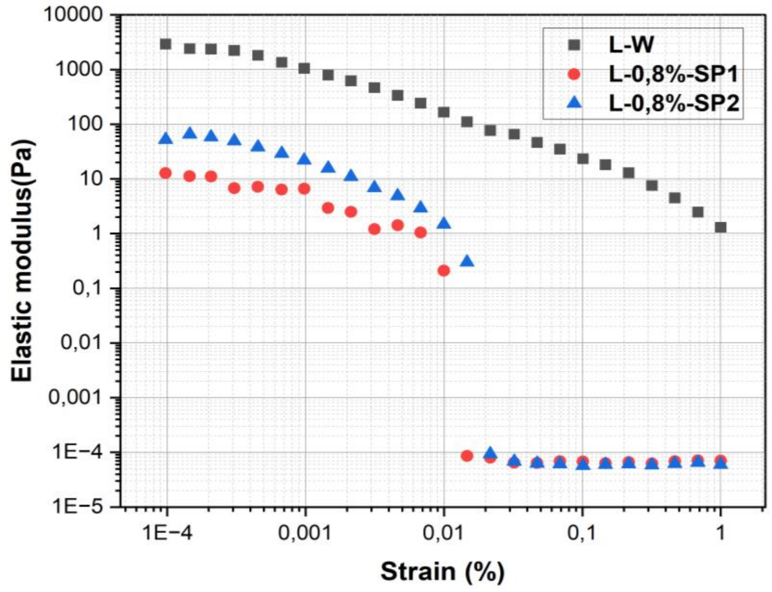
Static yield stress controls flow initiation, while dynamic yield stress reflects flow persistence under shear.

Depending on the dosage and adsorption kinetics, DYS can approach or even exceed SYS.

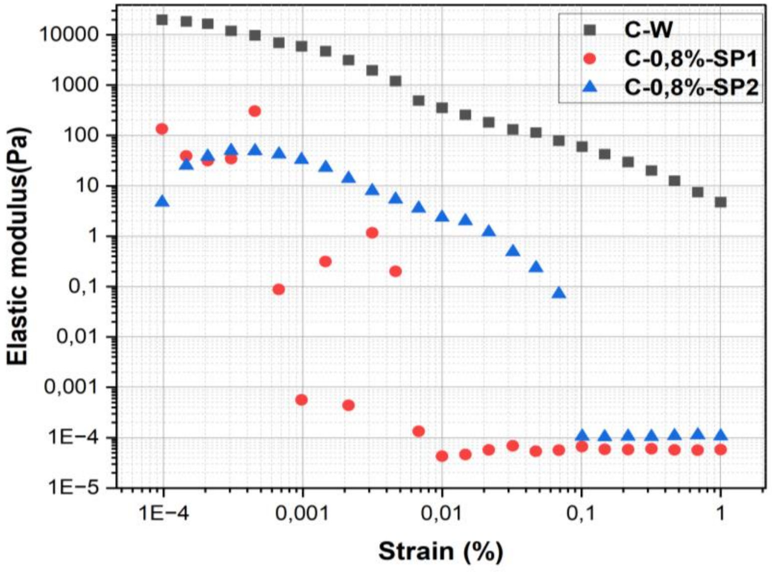
SP1 generally provides lower yield stress than SP2, especially for calcined clay cements.

Viscoelastic Response of Cement Pastes at Low Strain

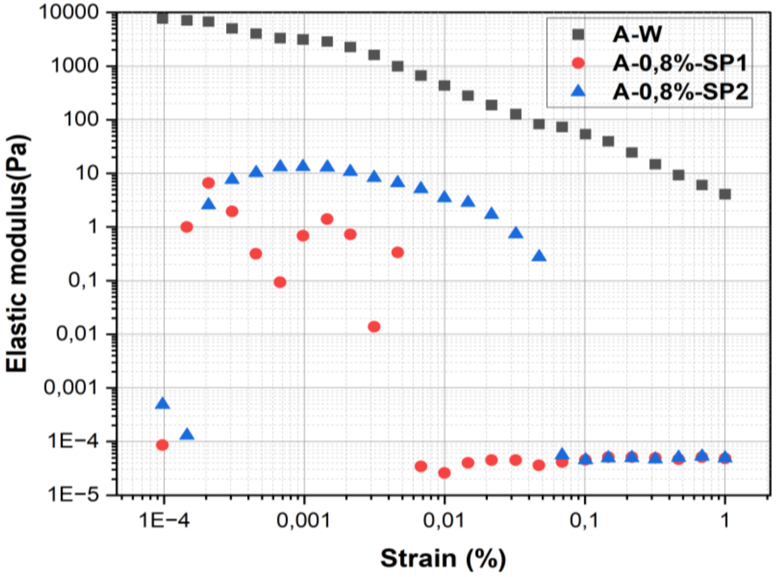
Limestone cement



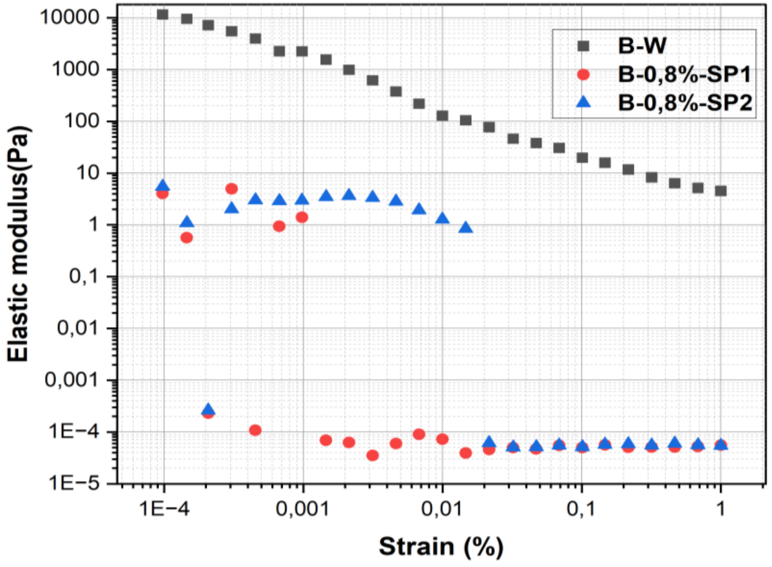
Limestone calcined clay cement



CEM III/A



CEM III/B

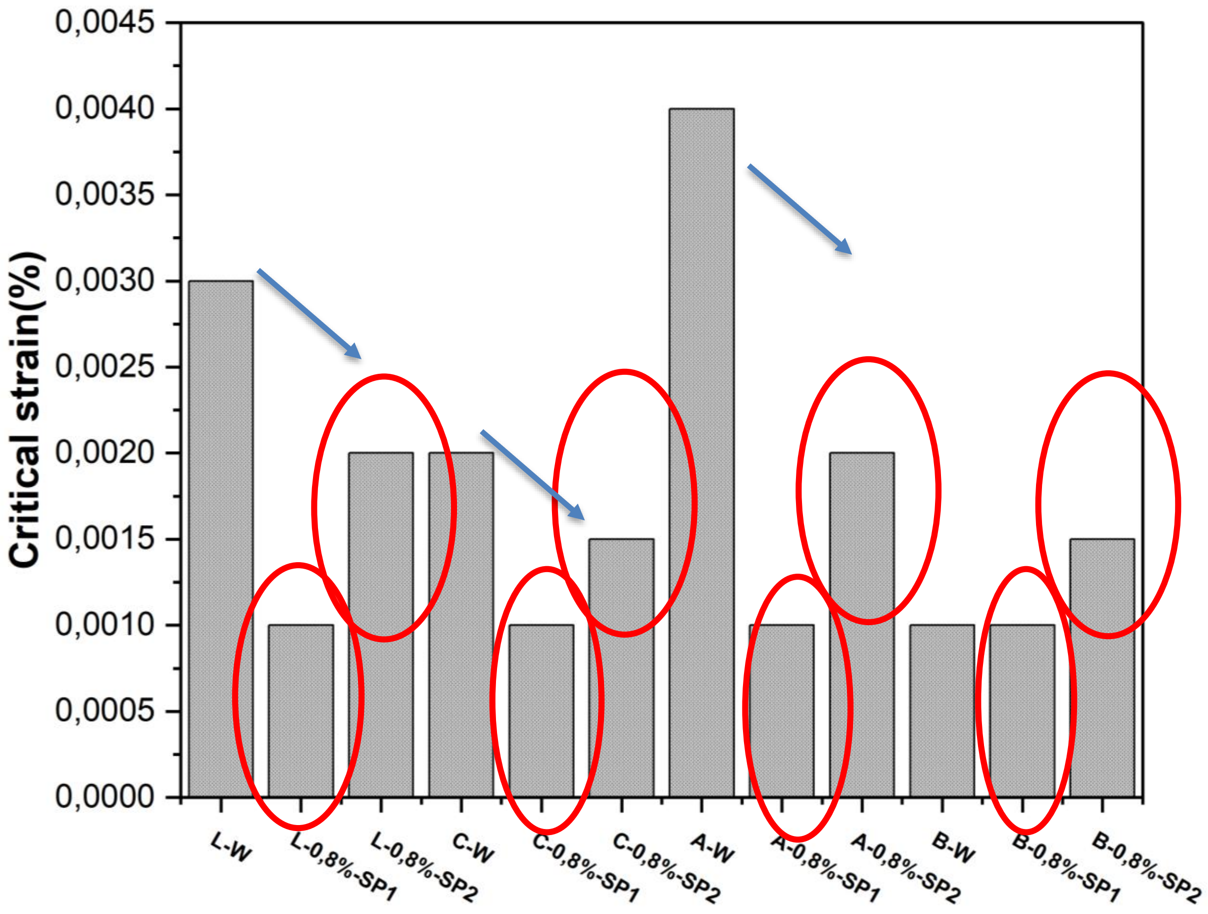


All systems exhibit a linear viscoelastic region at low strain.

Superplasticizers reduce stiffness by weakening interparticle connections

Calcined clay systems show the highest elastic modulus.

Effect of Superplasticizers on Critical Strain (γcr)



Critical strain $\gamma_{(cr)}$ reflects the resistance of the interparticle network to deformation.

Reference pastes exhibit **higher critical strain**, indicating stronger particle networks.

Superplasticizers significantly **reduce $\gamma_{(cr)}$**, reflecting enhanced dispersion.

SP1 leads to **lower and more uniform $\gamma_{(cr)}$** across all systems.

SP2 systems maintain **higher $\gamma_{(cr)}$** than SP1, suggesting partial adsorption.

Key conclusions and perspectives

Flow behavior

All systems show **shear-thinning (pseudoplastic) behavior**.

Reference pastes exhibit the **highest viscosity**, especially at low shear rates.

Superplasticizers significantly reduce viscosity by enhancing particle dispersion.

0.8% dosage provides the best compromise between fluidity and stability.

Elastic modulus **G’** reflects the stiffness of the particle network at rest.

Viscoelastic Response

The combined analysis of **elastic modulus and critical strain** provides complementary insight into microstructural stability.

Superplasticizer chemistry plays a key role in tailoring the viscoelastic stability of low-clinker composite cements.

Critical strain $\boldsymbol{\gamma_{(cr)}}$ indicates the resistance of the structure to deformation.

Key conclusions and perspectives

- Investigate the **time-dependent evolution** of rheological properties during early hydration.
- Correlate fresh-state rheology with **hardened-state mechanical properties**.
- Extend the analysis to **other dosage ranges** and alternative superplasticizer chemistries.

Thank you for your attention