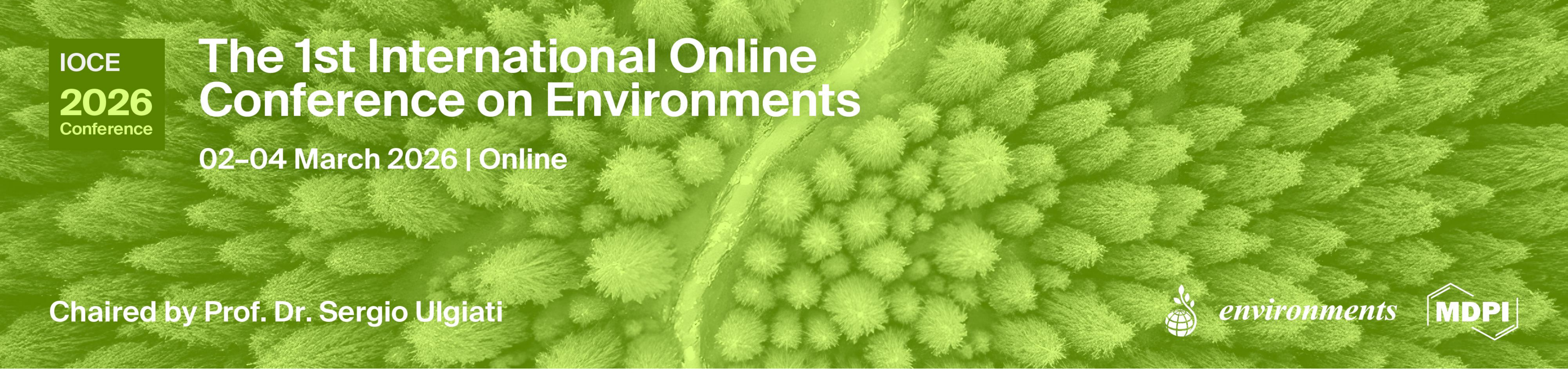

Valorization of lignin for the development of sustainable amphiphilic modifiers with high surface activity for environmentally responsible cement systems

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INTRODUCTION & AIM

Developing sustainable cement-based materials requires reducing the environmental impact associated with conventional petrochemical admixtures. Modern concrete technology relies heavily on surface-active agents that modify rheology, water demand, and microstructure development. The performance of cement composites is strongly influenced by interfacial phenomena occurring in aqueous systems. Surface-active molecules affect wetting, particle dispersion, and the formation of adsorption layers on cement grains. These mechanisms directly control workability, fluidity, and the development of the porous structure in hardened materials. Bio-inspired amphiphilic aromatic compounds derived from renewable resources represent a promising alternative to synthetic superplasticizers. Their molecular architecture—combining hydrophilic functional groups with hydrophobic aromatic segments—suggests the ability to reduce surface tension and interact with cement particles.

The aim of this study was to evaluate the surface activity and adsorption behavior of selected bio-inspired compounds and assess their potential application in cement and concrete technology.

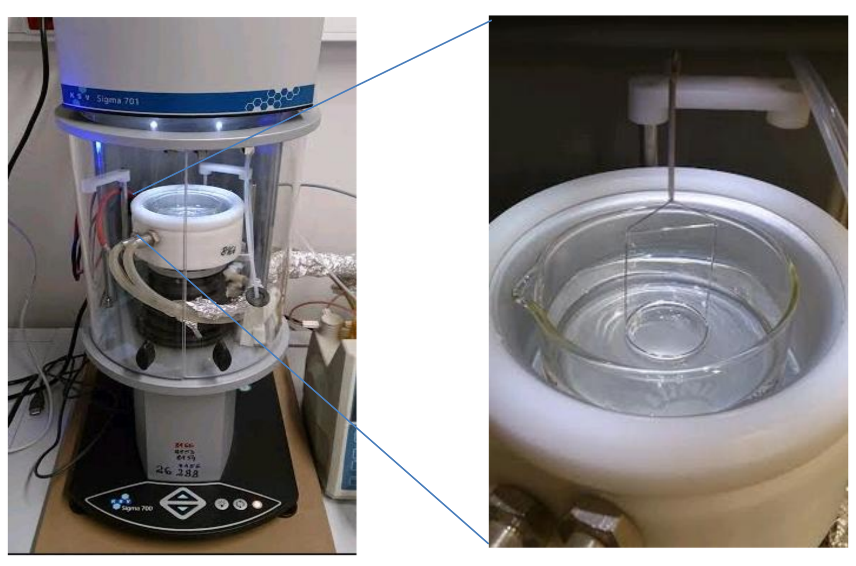
METHOD

Aqueous solutions of bioinspired compounds with different molecular weights and chemical modifications were prepared. For comparison, synthetic additives were analyzed, including sulfonated melamine–formaldehyde condensate (SMF) and sulfonated naphthalene–formaldehyde condensate (SNF) Surface tension was measured using the Du Noüy ring method with a KSV Sigma 701 tensiometer. Adsorption parameters—surface excess (Γ), molecular area (A_min), and Gibbs free energy (ΔG_ads) were calculated using the Szyszkowski equation.

$$\gamma_i = \gamma_0\left[1 - B_{SZ}\ln\left(\frac{c}{A_{SZ}}+1\right)\right]$$

$$\Delta G_{ads} = -RT\ln A_{SZ}$$

$$A_{\min} = \frac{1}{\Gamma_\infty N_A} \qquad \Gamma_\infty = \frac{\gamma_0 B_{SZ}}{RT}$$



LS1 – soft wood sodium lignosulfonate,
LS2 – soft wood sodium lignosulfonate, ultrafiltrated

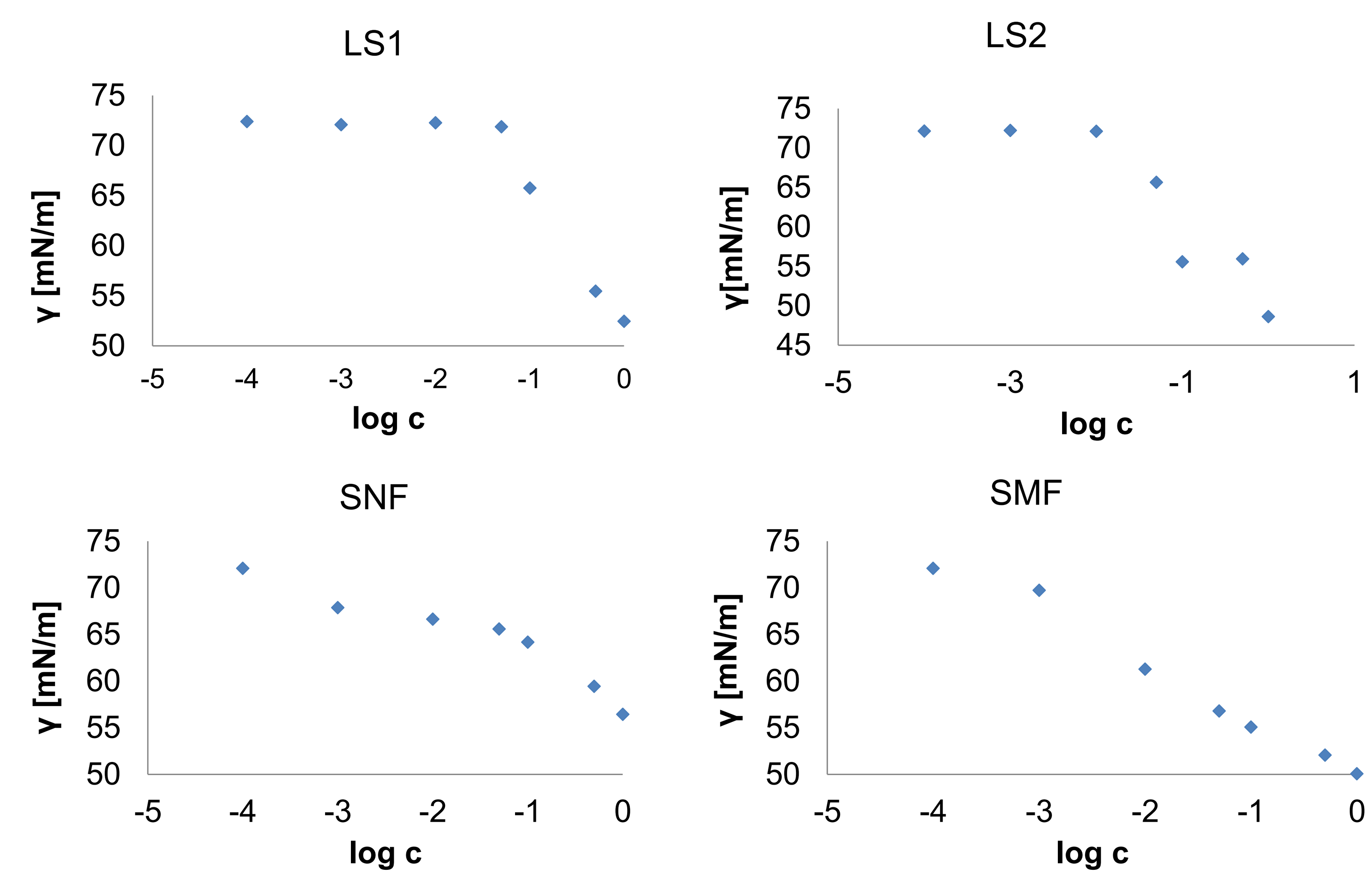
FUTURE WORK

Future work will explore hybrid systems combining bio-based surfactants with silver and copper nanoparticles to design sustainable multifunctional cement composites.

RESULTS & DISCUSSION

All compounds exhibited surface activity and reduced surface tension. Bio-based aromatic compounds showed higher surface excess (Γ up to 4.01 μmol/m²) than synthetic references, indicating more compact adsorption layers. Differences in A_min and ΔG_ads confirm distinct molecular packing. These results support the proposed interfacial adsorption mechanism in cement systems.

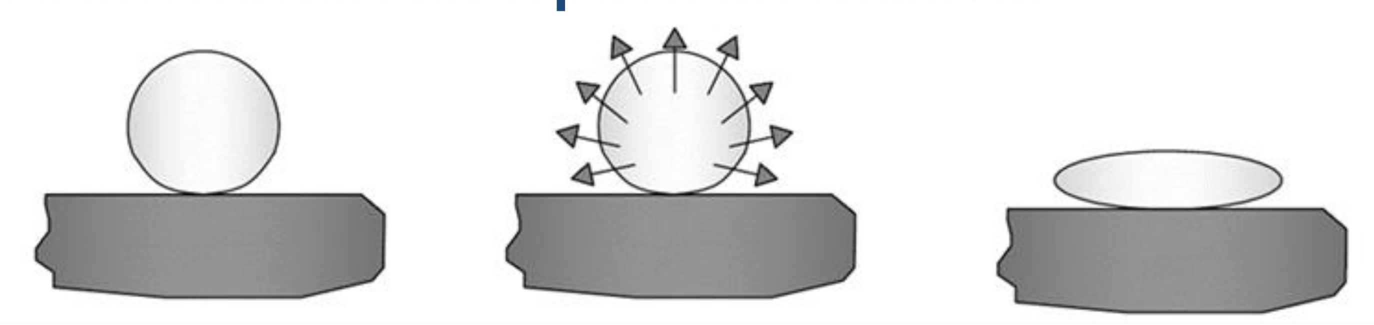
Surface Tension Measurements



Adsorption Parameters

Parameter	Unit	SNF	SMF	LS1	LS2
Γ	μmol/m²	1,16	0,78	4,01	2,13
A_{min} * 10^{18}	nm²	1,43	2,13	0,41	0,78
$-\Delta G_{ads}$	kJ/mol	26,46	2,61	11,73	17,46

Proposed Interfacial Adsorption Mechanism



high surface tension of water - cement grains poorly wetted | the surfactant forms an adsorption layer on the water surface - reducing the surface tension | well moistened cement grains

CONCLUSION

All investigated compounds exhibited surface activity and reduced surface tension at the air–water interface. Bio-based aromatic compounds formed more compact adsorption layers than synthetic references, indicating different molecular packing. The adsorption behavior confirms their potential as sustainable surface-active admixtures in cement and concrete technology.

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