Effects of Nanomaterials on Engineering Performance of a Siliconate-Based Sealer for Cementitious Composite

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Outline

1. Introduction
2. Experimental program
3. Results and Discussion
4. Conclusions and Future Work
5. Acknowledgments

Introduction

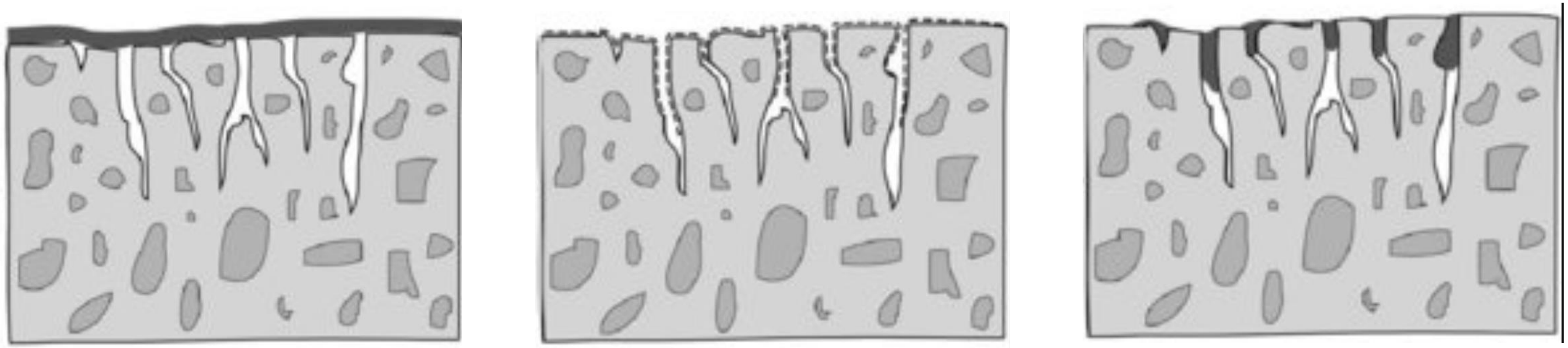
Surface treatments

Effectively protect concrete from salt scaling and extend the service life of concrete pavements, bridge decks, …

Barrier coatings: *epoxy, acrylics,…*

Hydrophobic impregnation: *silane, siloxane, … (3 to 4 years)*

Pore blocker: *soy methyl ester, sodium silicate, …*



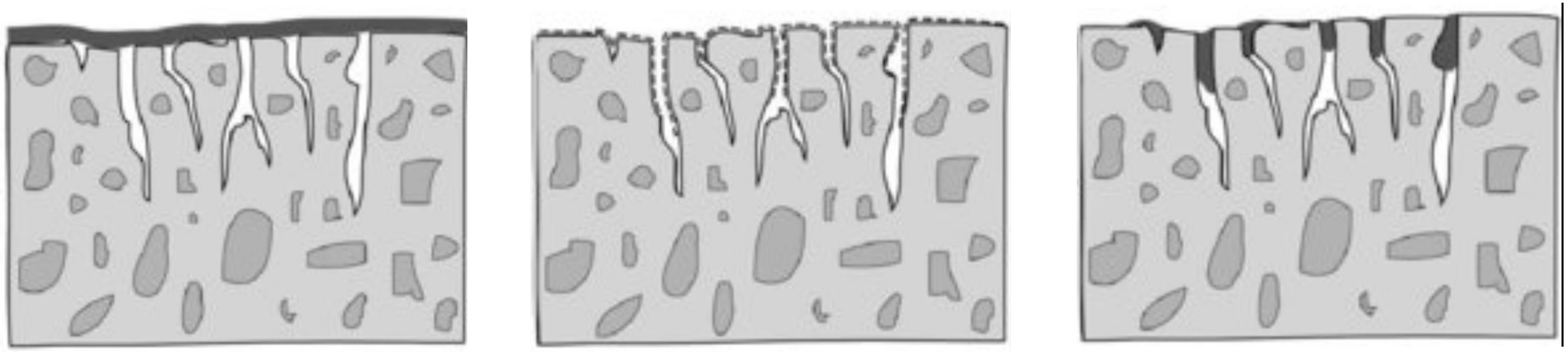
(Diamond S, Berke NS. 1997)

Introduction

Potassium methyl siliconate

as surficial hydrophobic treatment of wood, cellulose, etc.

- Reacts with airborne CO_2 and generates a compact, cross-linked, and insoluble methyl-silicone membrane
- Provides the substrate with a hydrophobic and denser surface
- Serves as a pore blocker: methyl-silicone membrane, potassium carbonate or bicarbonate



(Diamond S, Berke NS. 1997)

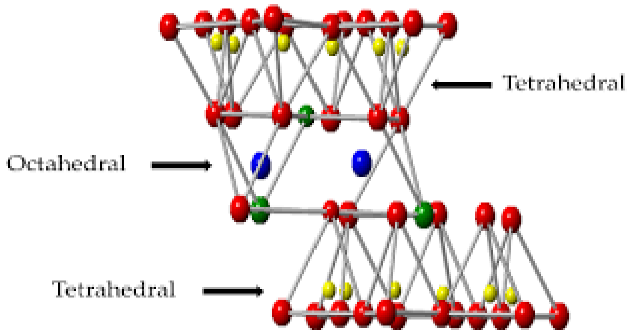
Introduction

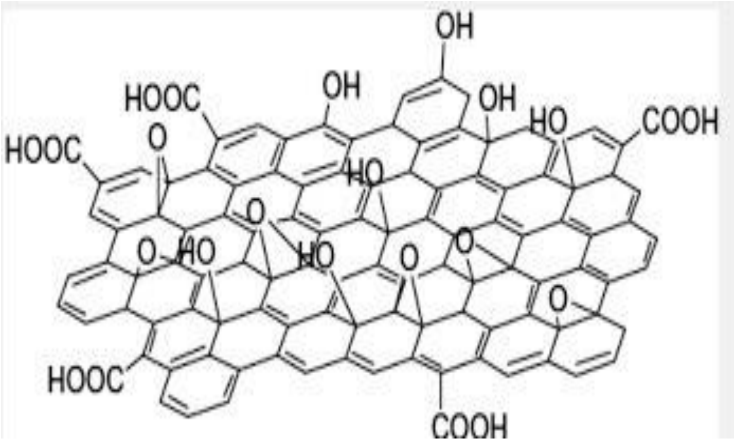
Nano-enhanced Sealer

as surficial hydrophobic treatment of wood, cellulose, etc.

- Nano-SiO2/siloxane sealer/mortar: water absorption ↓ ~20%, gas permeability ↓ ~28% (Li et al. 2018)
- Nanoclay/silane sealer/concrete: water permeability ↓ ~39% (Woo et al. 2008)

Graphene oxide & montmorillonite nanoclay





Introduction

Hypothesis

The admixed GO and montmorillonite NC can provide the PMS sealer w/ better performance:

- GO/NC modify the PMS sealer and improve its hydrophobicity: via nano/micro-roughness.
- NC may react with alkaline PMS sealer to generate K-A-S-H gel to refine the microstructure of mortar matrix.
- GO may catalyze the process in hypothesis 2.

Experimental materials

Raw materials

NC

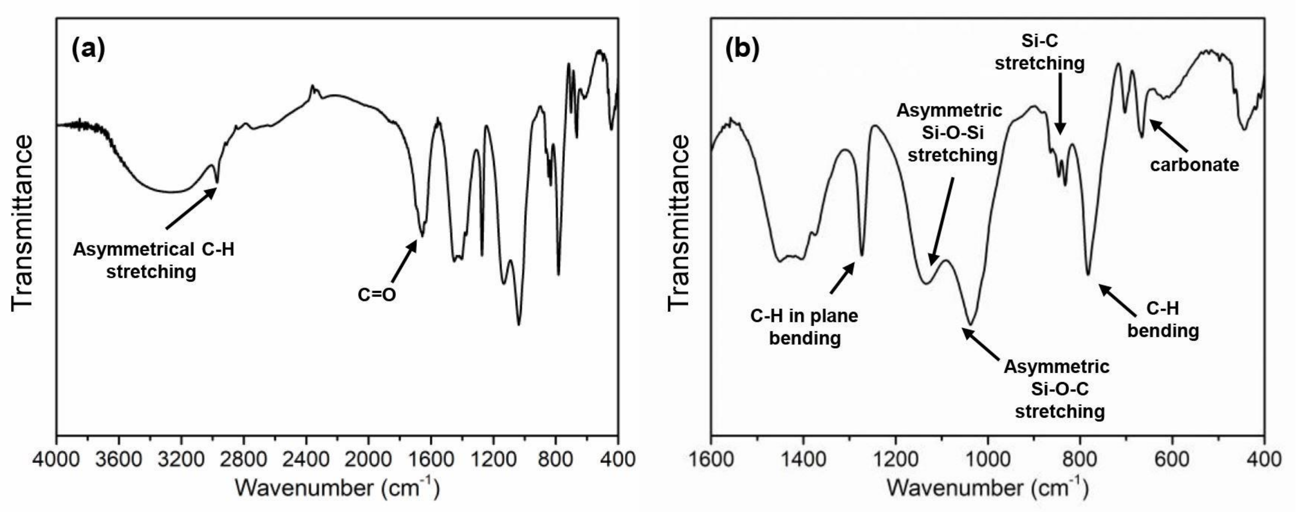
- bulk density: 0.678 g/cm^3
- aspect ratio: 200 to 400
- Lateral size: ~20 to 25 μm
- Si-O tetrahedron sandwiched by 2 layers of Al-O octahedron

GO: 71 wt.% C + 26 wt.% O

- lateral size: 4 to 20 μm
- zeta potential: -30 mV at pH 7.0

A penetrating PMS sealer:

PMS/siloxane resin hybrid



Experimental materials

Nano-sealer

Branson digital sonifier
(S-450D, 400W, and 60% amplitude)

To obtain a well-dispersed nano-modified PMS sealer suspension

- 30 min ultrasonic dispersion
- GO: 0.015%, 0.03%, 0.06%, 0.1%, 0.15%
- Based on water contact angle of GO-modified PMS sealer then introduce NC.

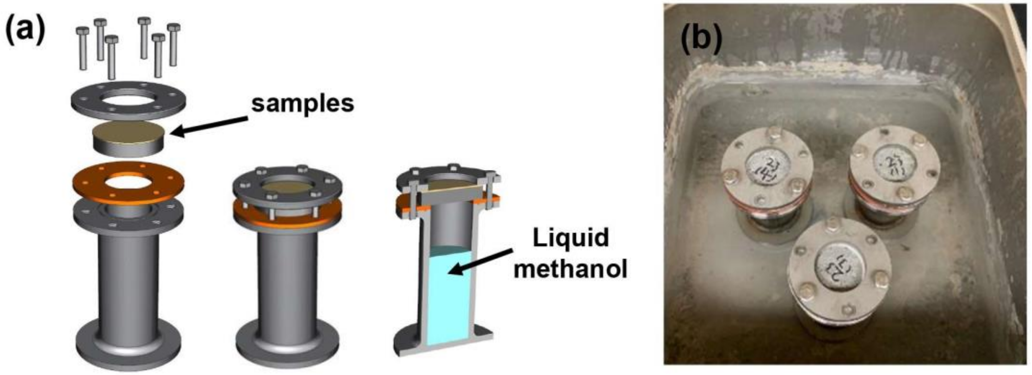
1.5N-6G-P, 3N-6G-P, 6N-6G-P, 10N-6G-P, 15N-6G-P

- NC: 0.015%, 0.03%, 0.06%, 0.1%, 0.15% by the mass of PMS sealer

15N-6G-P: 0.15% NC+0.06%GO+PMS

Experimental test

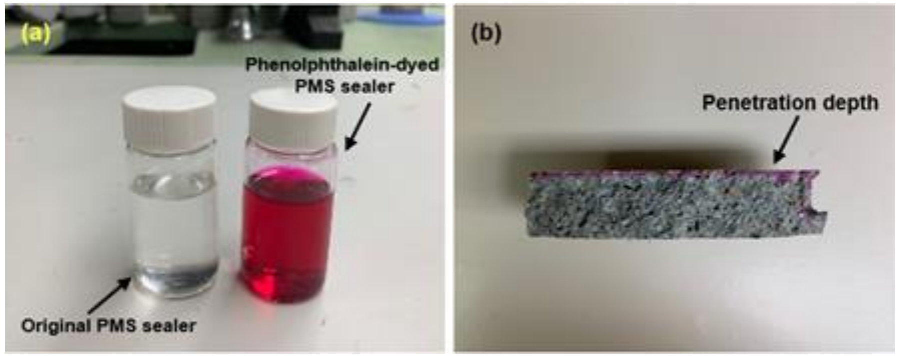
- **Water absorption test:** 5 cm (D) × 2 cm (H) **(**ASTM C1585-20)
- **Gas permeability test:**



- **Water contact angle** (ASTM D7334)
- **<u>Penetration depth</u> vs. Viscosity**
- **Salt scaling test:**

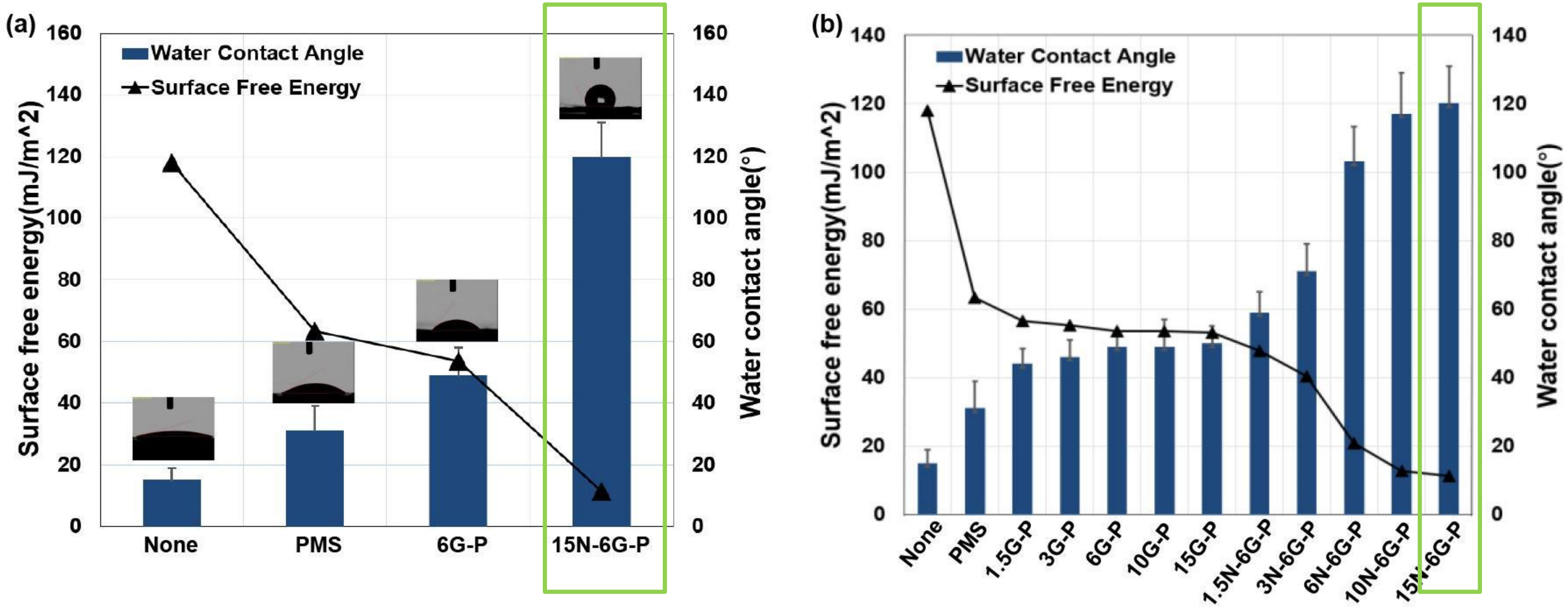
  F/T+W/D cycles in 3.5 wt% NaCl

- **High-resolution optical microscope**
- **TGA/DTG:** 50°C to 500°C, 10°C/min



Results & Discussion

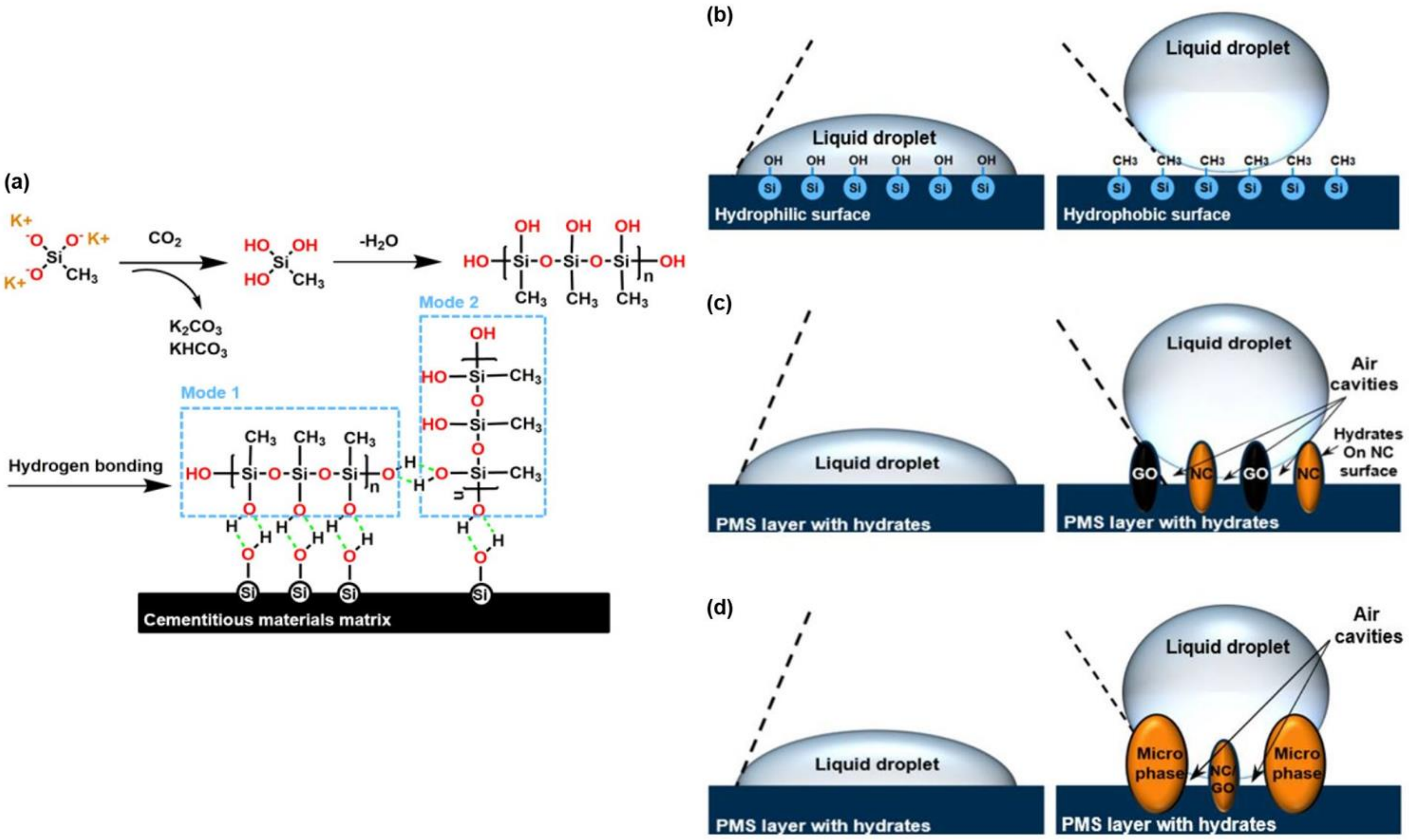
Water contact angle and surface free energy



GO and NC reduced the hydrophilicity and decreased the surface free energy of PMS sealer membranes

Results & Discussion

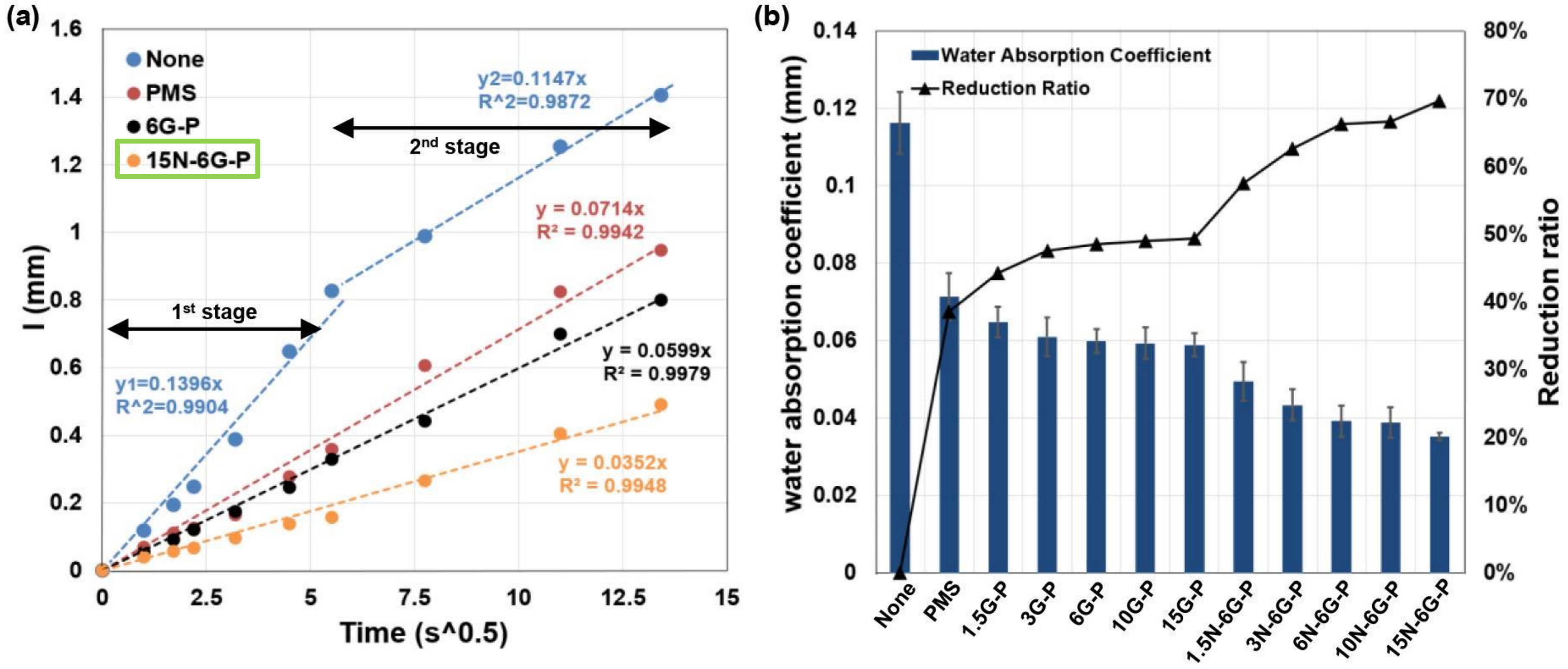
Water contact angle and surface free energy



a rough nano-/micro-scale hierarchical structure due to agglomeration of nanomaterials

Results & Discussion

Water absorption behavior

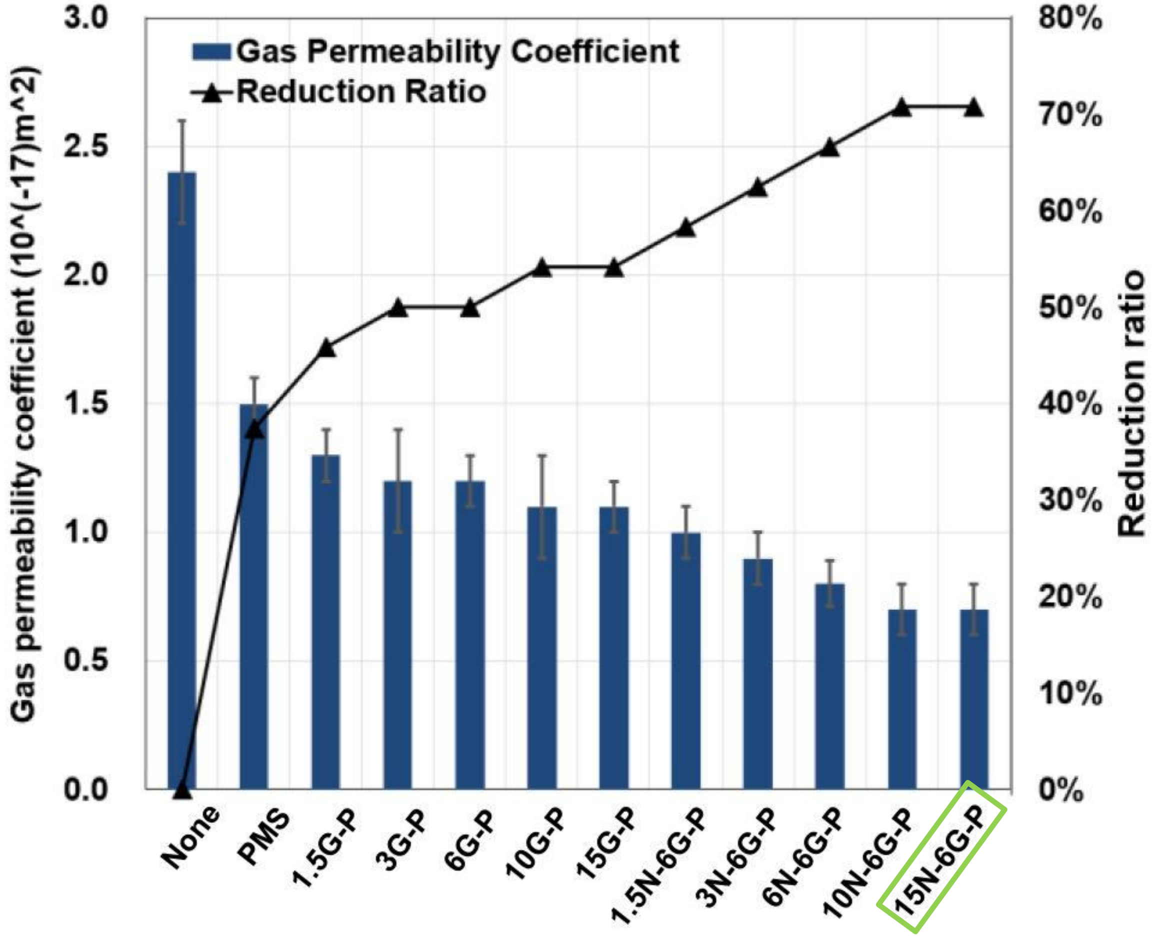


The application of original PMS-based sealer, 6G-P, and 15N-6G-P decreased the *k* of mortar surface by 39%, 48%, and **70%,** resp.

- ✓ The denser microstructure of mortar substrate induced by NC/GO
- ✓ The increased hydrophobicity of nano-modified sealer treated surface

Results & Discussion

Gas permeability



The application of original PMS-based sealer, 6G-P, and 15N-6G-P decreased the *G* of mortar surface by 38%, 54%, and **71%,** resp.

✓ The denser microstructure of mortar substrate induced by NC/GO

CO_2

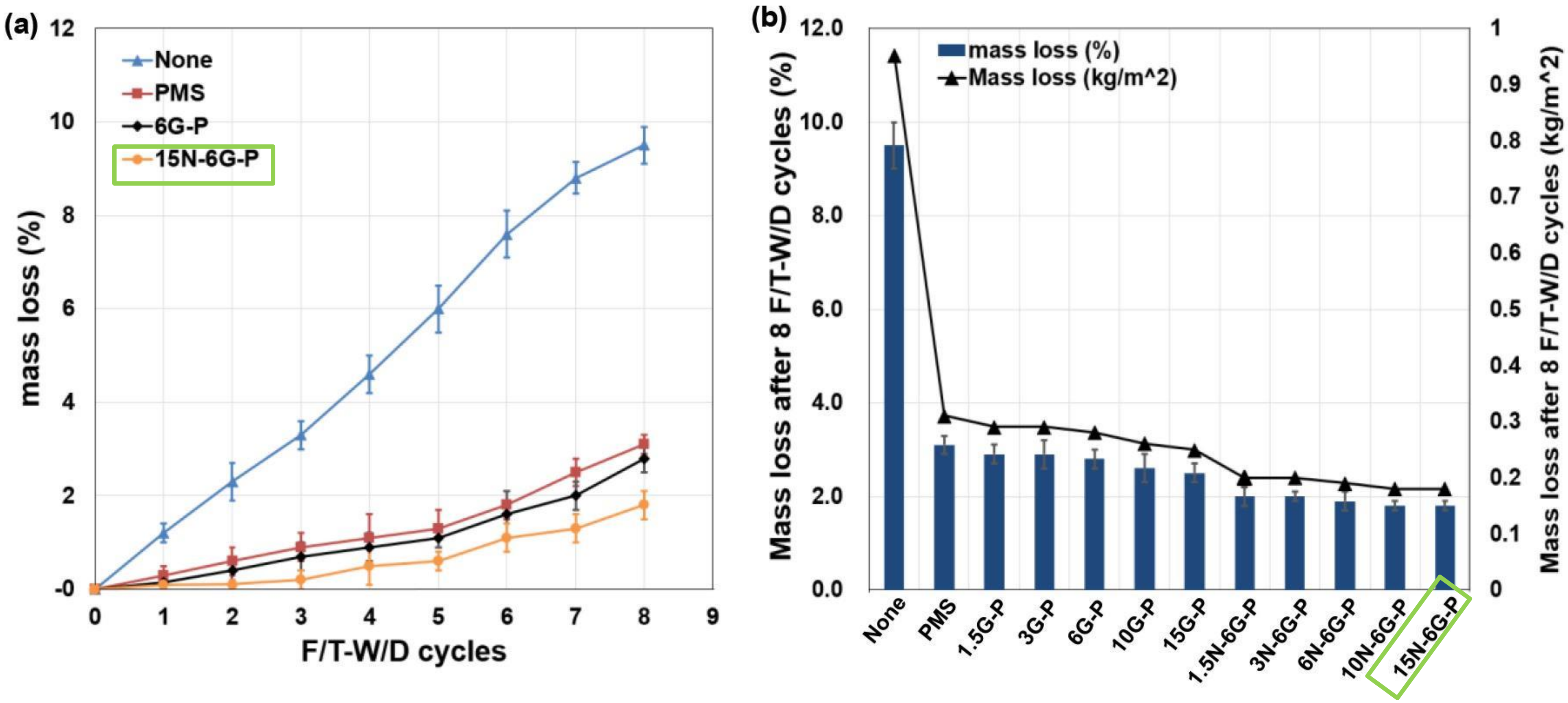
O_2

moisture vapor

→ Rebar corrosion risk

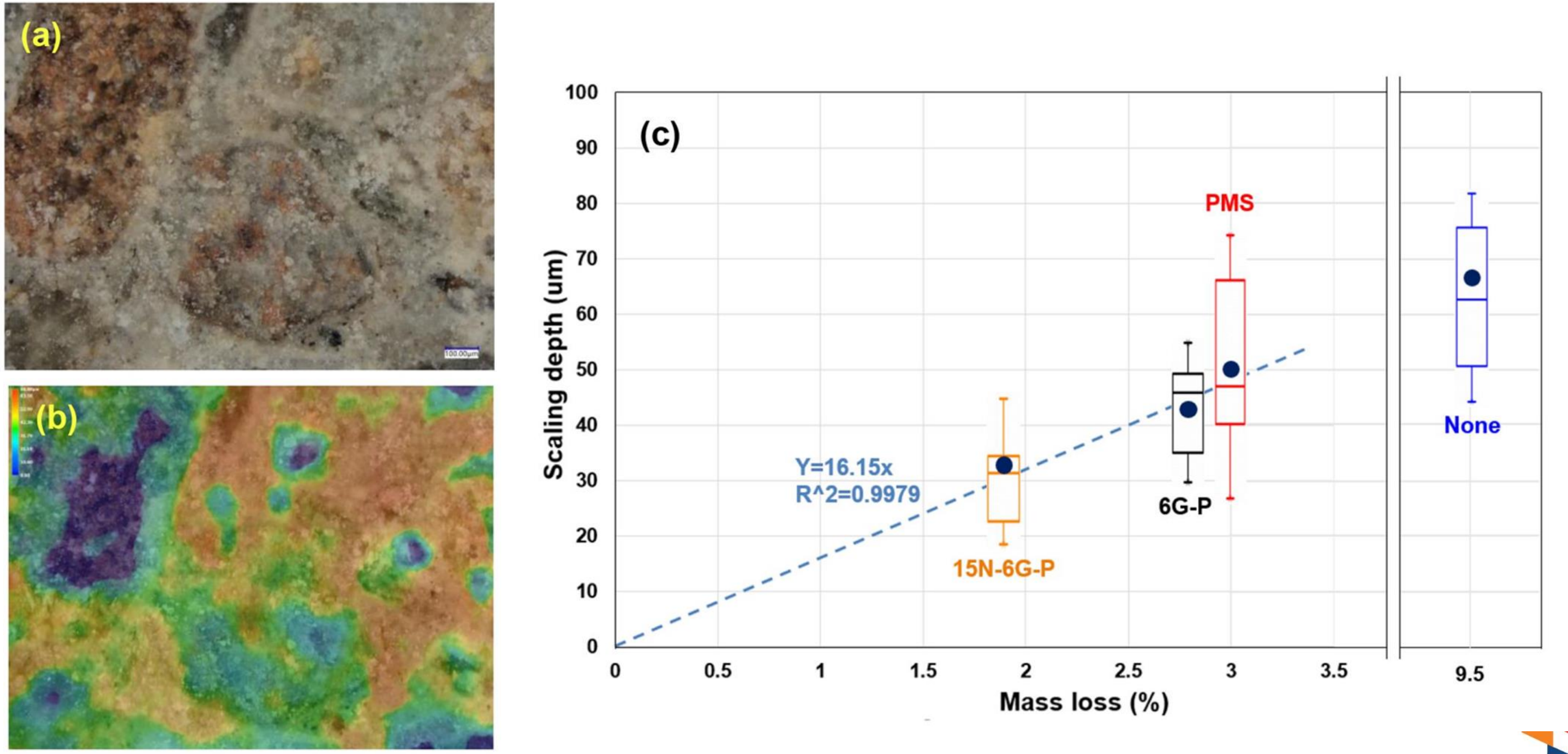
Results & Discussion

Salt-scaling resistance



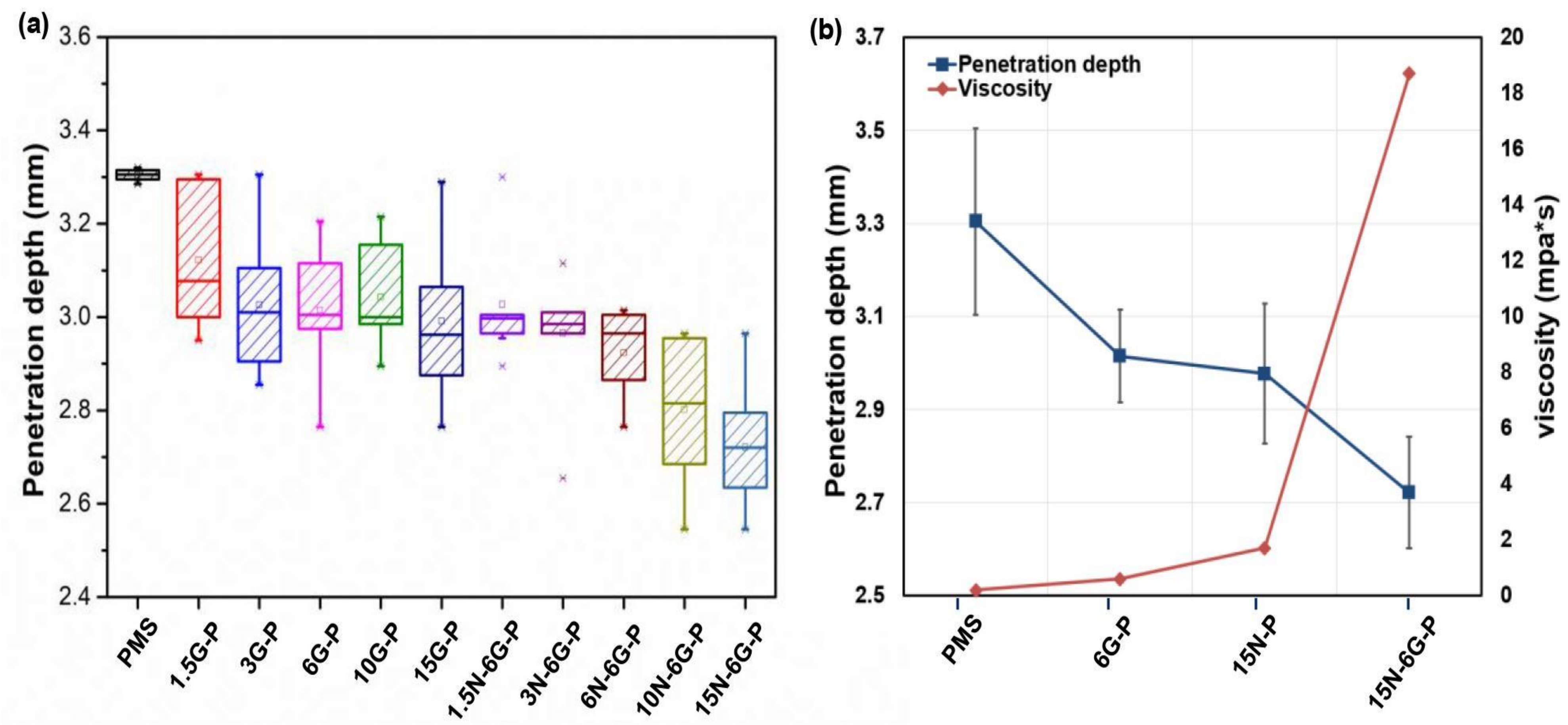
Results & Discussion

Salt-scaling resistance



Results & Discussion

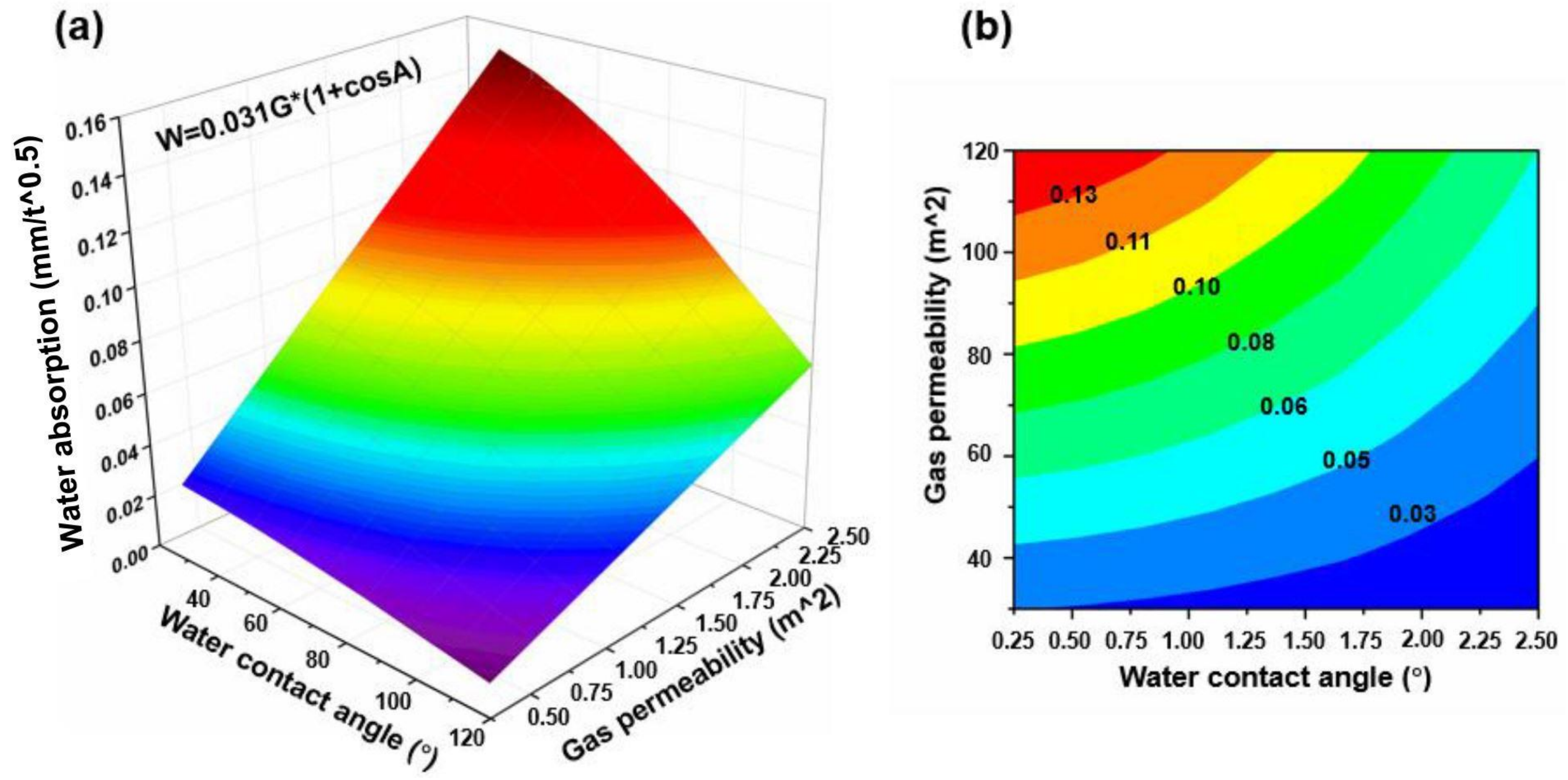
Penetration depth vs. viscosity



sealer application rate of 0.136 L/m^2

Results & Discussion

Relationship between parameters

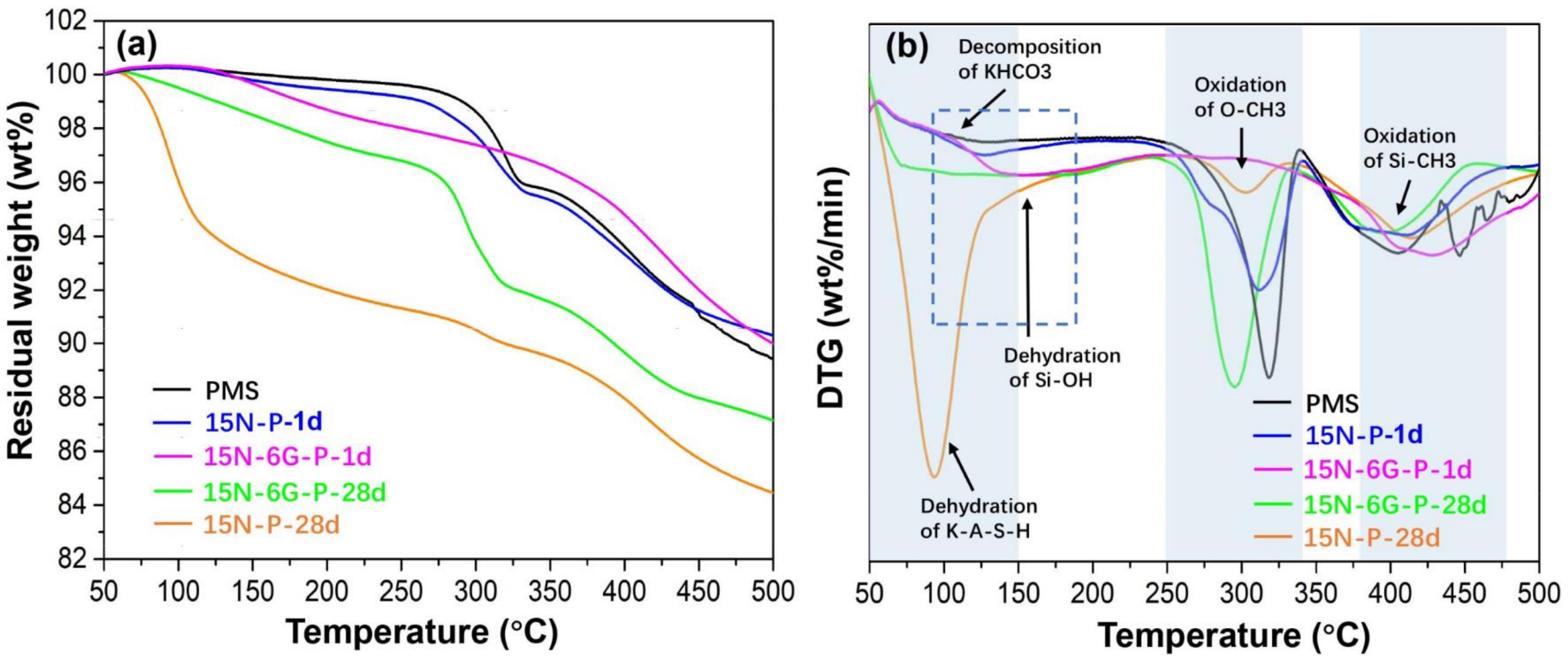


A decreased gas permeability & an increased water contact angle, together, would correspond to a lower water absorption coefficient.

A more diverse and comprehensive experimental dataset is needed to develop more reliable and more accurate models.

Results & Discussion

Thermogravimetric analyses of various sealers



250°C - 340°C: volatile CH_3OH from the oxidation of -O-CH_3

370°C - 470°C: CO_2 from the oxidation of Si-CH_3

15N-6G-P-1d: The admixed GO prevented the oxidation of O-CH_3, likely due to the strong hydrogen bonding btwn the hydrophilic GO and -O-CH_3

The PMS sealer preferentially reacted with the admixed NC to produce K-A-S-H gel, ↓↓ its availability to react with CO_2 to produce $KHCO_3$.

Conclusion & summary

This study demonstrated synergistic benefits of modification by nanoclay and GO to the PMS-based sealer

- ✓ The mortar coated with the 0.15wt% NC+0.06wt.% GO+PMS hybrid (15N-6G-P) sealer represented the best performances, featuring its water contact angle of 120° (vs. 32°)
- ✓ A reduction of ~70% in both the water absorption coefficient and gas permeability coefficient of the mortar, vs. ~38% induced by the original sealer
- ✓ After 8 F/T+W/D cycles in 3.5 wt.% NaCl, the 15N-6G-P sealed mortar saw a 1.9% mass loss (vs. 3.0% for the original PMS sealed mortar and 9.5% for the unsealed mortar) and greatly reduced scaling depth

Conclusion & summary

- ✓ Hydrophobicity: -OH replacement by $-CH_3$; and micro-/nano-roughness induced by the admixed nanomaterials
- ✓ Refined the pores （film /pore blocker） of the mortar; NC reacted with the alkaline PMS sealer to produce more hydrates (K-A-S-H gel)
- ✓ A decreased gas permeability and an increased water contact angle, together, would correspond to a lower water absorption coefficient
- ✓ The lower the water absorption coefficient, the better resistance to salt scaling

Future work: concrete; long-term performance; optimization; life-cycle assessment in typical service environments

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Questions?

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