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Relation between drying shrinkage behavior and the microstructure of metakaolin-based geopolymer

Key words:
Geopolymer; Drying shrinkage; Microstructure; Modeling

Introduction

- Geopolymer, as a newly developed binder system, has drawn attention from scientists and engineers for its eco-benefits and superior characteristics, such as low CO2 emission, high early strength, fire resistance, corrosion durability and etc..
- The unique gel structure of geopolymer which leads to good performance also causes severe drying shrinkage and potential risk of cracking. These drawbacks significantly constrain the practical application of geopolymers.
- Previous studies have revealed important features of drying shrinkage of geopolymers. This study further conducted both experimental and modeling investigations to reveal the underlying mechanism of drying shrinkage of MKG. It bridges the gap between drying shrinkage and microstructure of geopolymer and help to design for the long-term durability.

Experiments

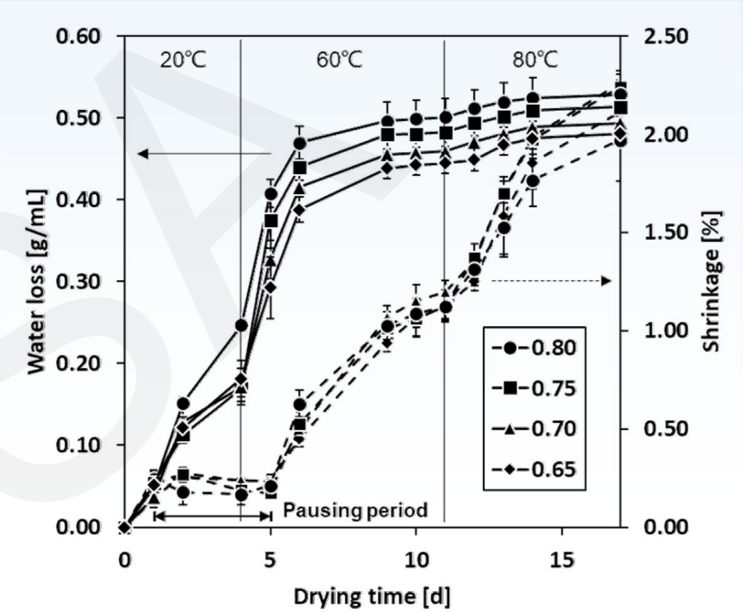
- A mini-bar drying shrinkage test is conducted referring to the test standard JC/T 603 and ASTM C490.
- The linear drying shrinkage and water loss are calculated as

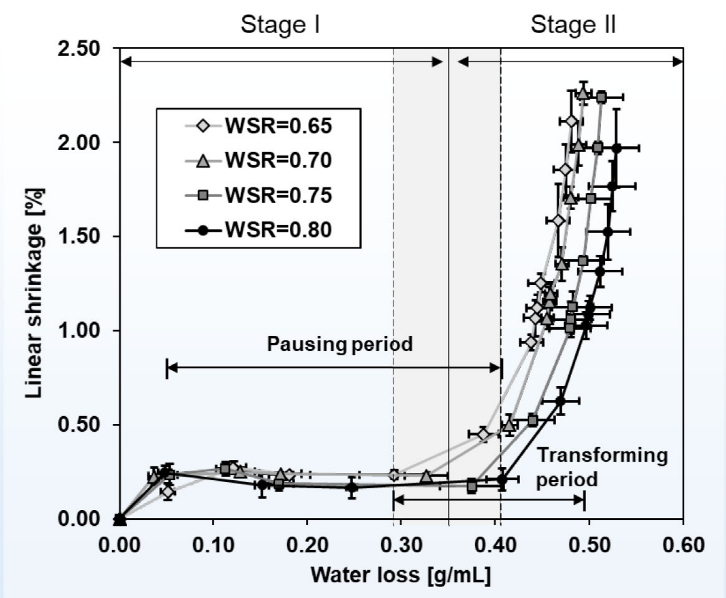
Drying shrinkage $$\varepsilon_L = \frac{L - L_0}{L_0}$$ Water loss $$w = \frac{M - M_0}{V_0}$$

- The drying shrinkage of MKG has a two-staged relation with the water loss:

(1) Stage 1: low shrinkage with a pausing period when water loss below the critical value;

(2) Stage 2: intensive shrinkage with loss of water beyond a critical water loss value.





Microstructure characterization

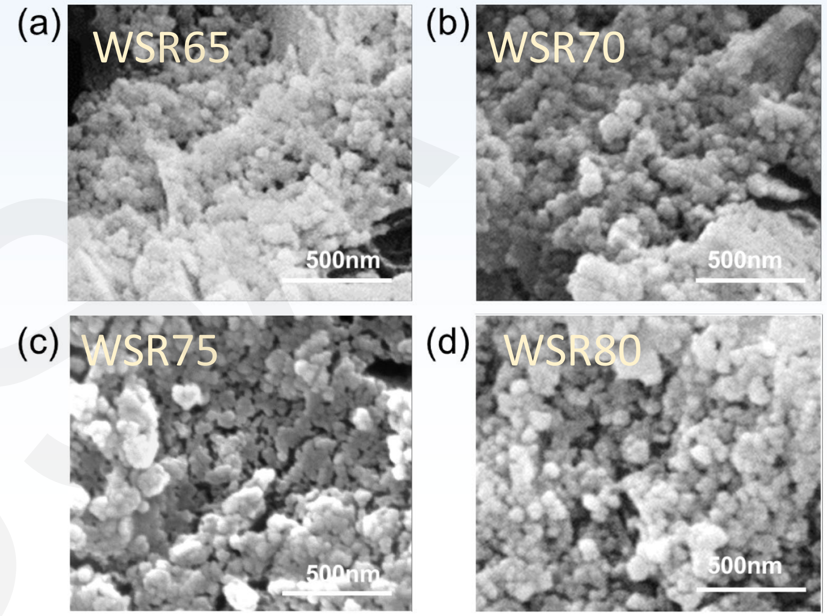
- As revealed by SEM, a three-leveled hierarchical pore system was identified in the binder:

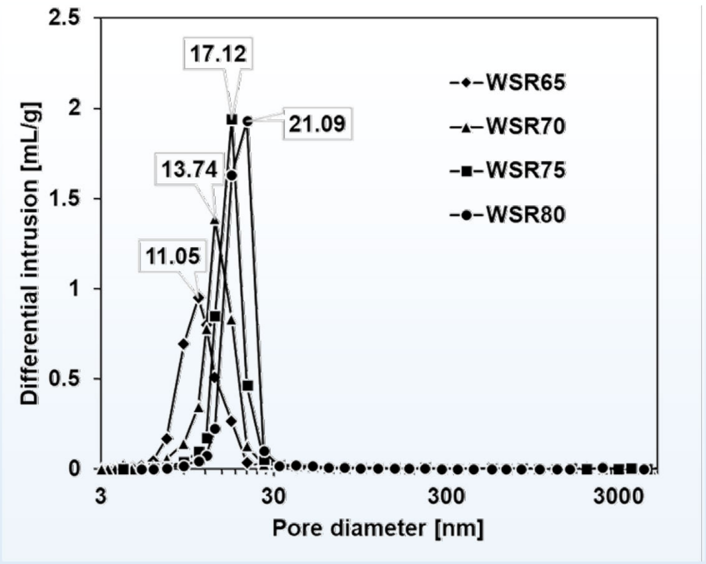
(1) Level I - mesopores (void size of >5 μm): some air bubbles and mesocracks occurred on this scale.

(2) Level II – micropores (void size within 5 nm to 5 μm): a large volume fraction of interstitial micropores and micro cracks formed among the clustered aluminosilicate gel.

(3) Level III – nanopores (void size of <5 nm): the gel clusters consist of nanoscale gel globules, which produce interconnected nanopores.

- As reveal by mercury intrusion porosimetry (MIP), the characteristic pore size and porosity of MKG are increase with the increase of the water/solid ratio (WSR).





Modeling

- The three main driving forces behind the shrinkage behavior were identified and are ex-plained below. Their relationship with the volu-metric shrinkage strain is also expressed quantita-tively.

(1) Capillary pressure-induced shrinkage

$$\varepsilon_{V,c} = \frac{S_c p_c}{K_b}$$

(2) Surface energy change-induced shrinkage

$$\varepsilon_{V,s} = -\frac{\Delta \Pi}{K_b(1-2\mu)}$$

(3) Gel densification-induced shrinkage

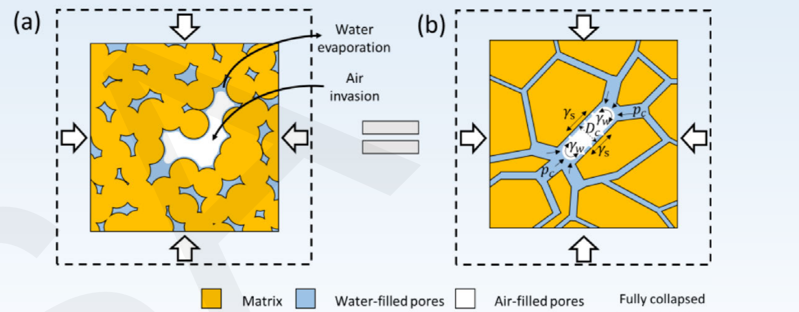
$$\varepsilon_{V,g} = \frac{w_s}{\rho_w} - \frac{w^*}{\rho_w}\operatorname{atan}\left(\frac{w_s}{w^*}\right)$$

Total drying shrinkage

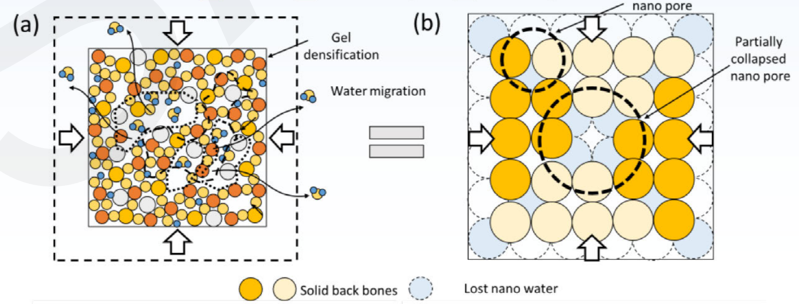
$$\varepsilon_V = \varepsilon_{V,c} + \varepsilon_{V,g} + \varepsilon_{V,s}$$

$$\varepsilon_L = \frac{\varepsilon_V}{3}$$

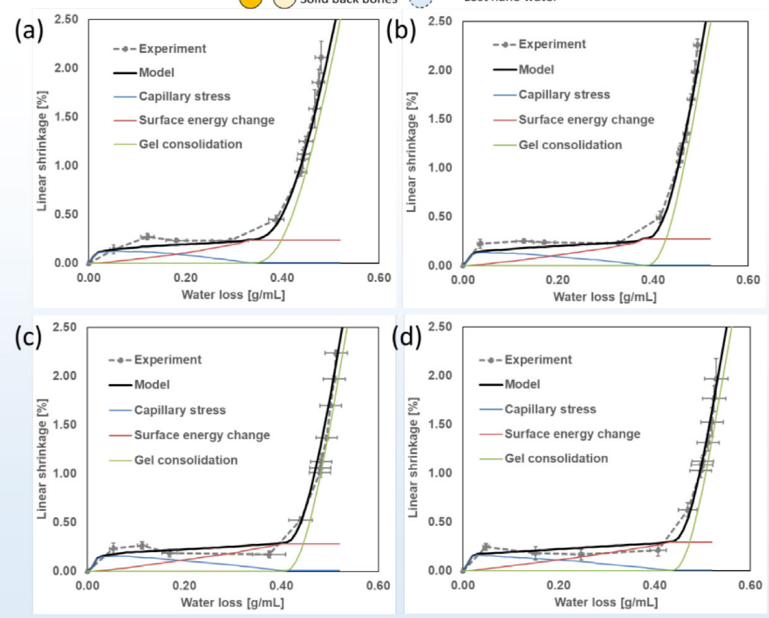
Stage I



Stage II



Model vs. Exp.



Discussion and conclusion

- The three-leveled pore system of the MKG binder resulted in two-stage drying shrinkage behavior. The initial WSR indirectly influenced the shrinkage behavior of MKG owing to its effect on the pore structures.
- During the early drying stage (stage I), the loss of micropore water controlled the shrinkage. The dominant driving force of the drying shrinkage transformed from capillary stress to surface energy change during this stage. The porosity and pore size distribution both controlled the drying shrinkage during this transformation.
- During the later drying stage (stage II), the loss of nanopore water and gel densification became the dominant factors. At this point, the volume of MKG drastically reduced (by as much as 7–10 times the shrinkage during stage I). Thus, this must be avoided in applications by keeping the water loss lower than the critical value, which is also dependent on the micro porosity and initial WSR.

Beyond these conclusions, the drying shrinkage problem of geopolymers is complex and multi-scale in nature. Many shrinkage mechanisms, especially those on the nanoscale, need to be further elucidated. More studies are needed to completely uncover these basic mechanisms.

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