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Effects of nanoclay addition on the permeability and mechanical properties of ultra high toughness cementitious composites

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Key words:
Nanoclay; Water permeability; Pore structure; Cementitious composites; Strain hardening

Introduction

In order to enhance the toughness and tensile strain capacity and to control the cracking behavior of concrete, ultra-high toughness cementitious composites containing different dosages of nanoclay (NC-UHTCCs) were designed and investigated, since nanoparticles can modify the microstructure and induce unique performance modifications of cementitious composites.

The nanoclay is comprised of thin flakes with a mean diameter within 1 to 10 μm and a mean thickness lower than 10 nm, as shown in Figure 1.

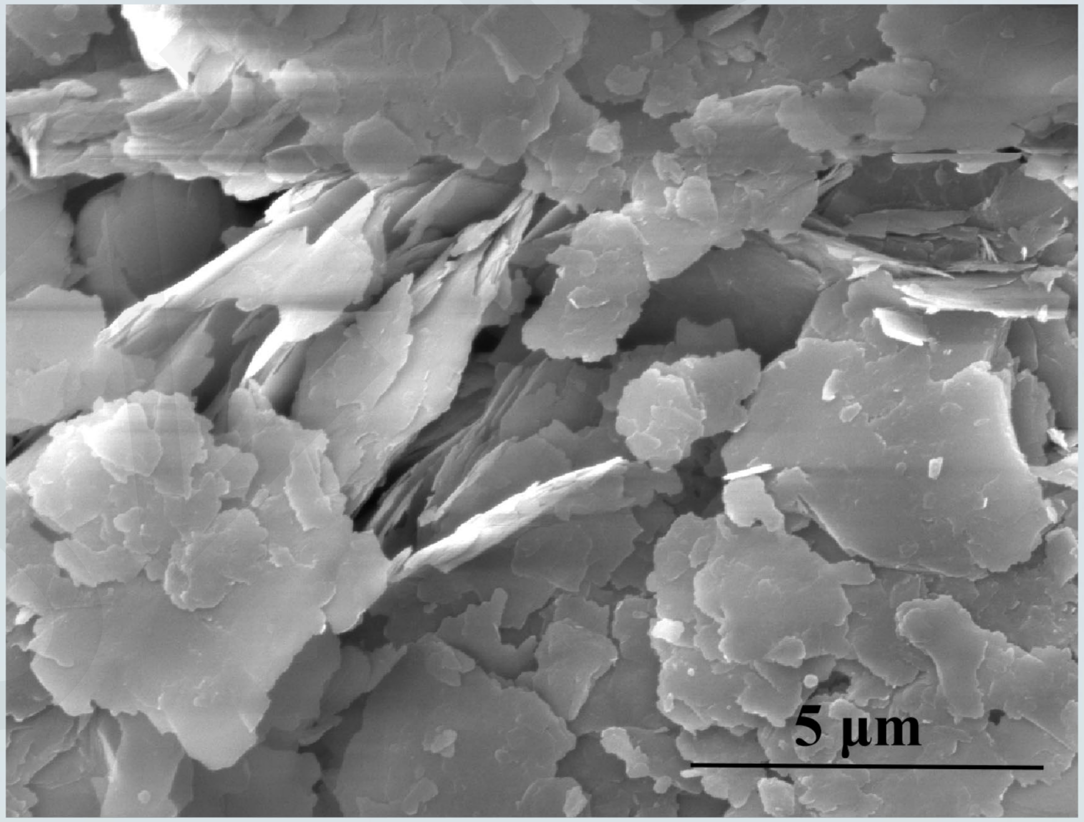


Figure 1 FSEM image of nanoclay

Experimental

- Preparation of NC-UHTCC specimens

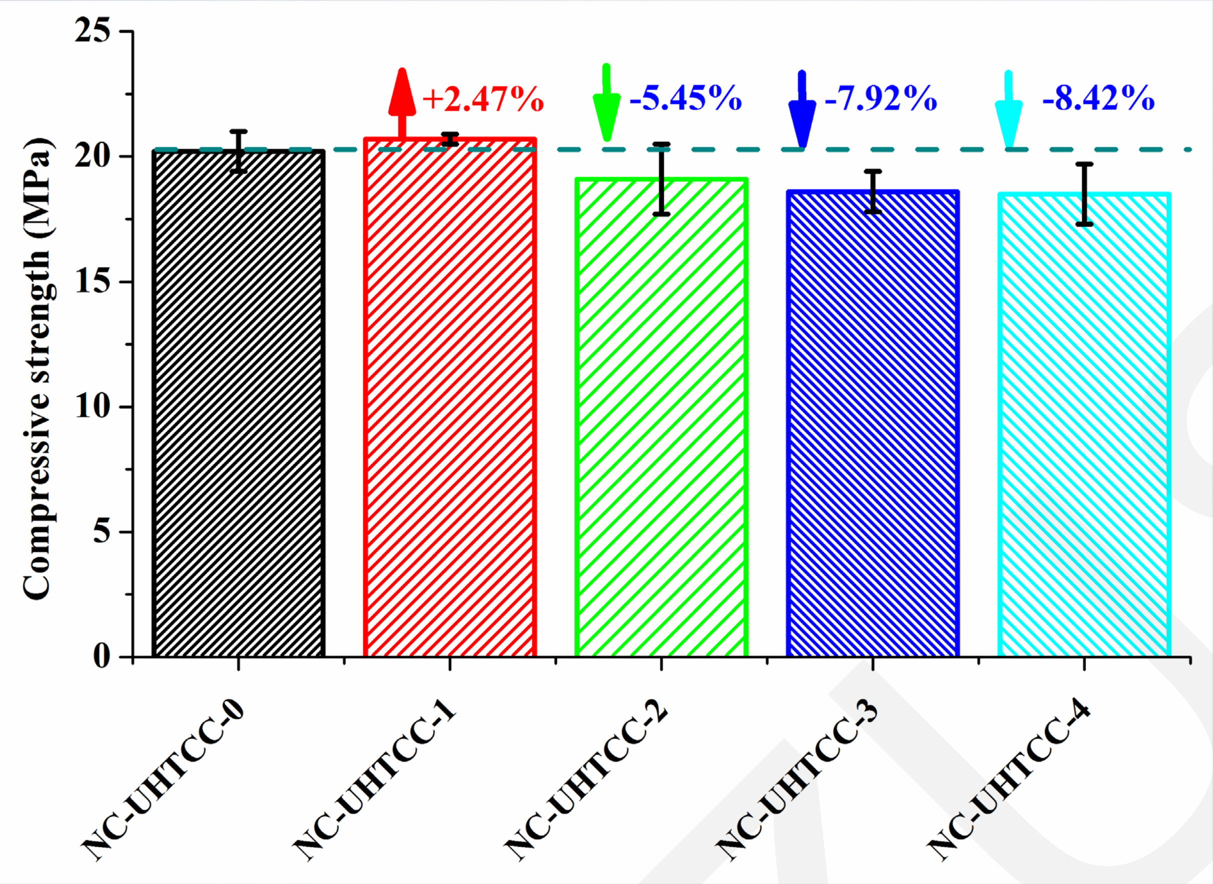
The materials including cement, fly ash, silica fume, silica sand, nanoclay, polycarbonate superplasticizer, polyvinyl alcohol fiber and water were first mixed in proportion. After molding and curing, various specimens were prepared.

- Materials characterization tests

Comprehensive experimental research and in-depth analysis were conducted to study the mechanical properties, mid-span deflection, waterproof performance, cracking patterns, mercury intrusion porosimeter and microstructure.

Results and discussion

Mechanical properties



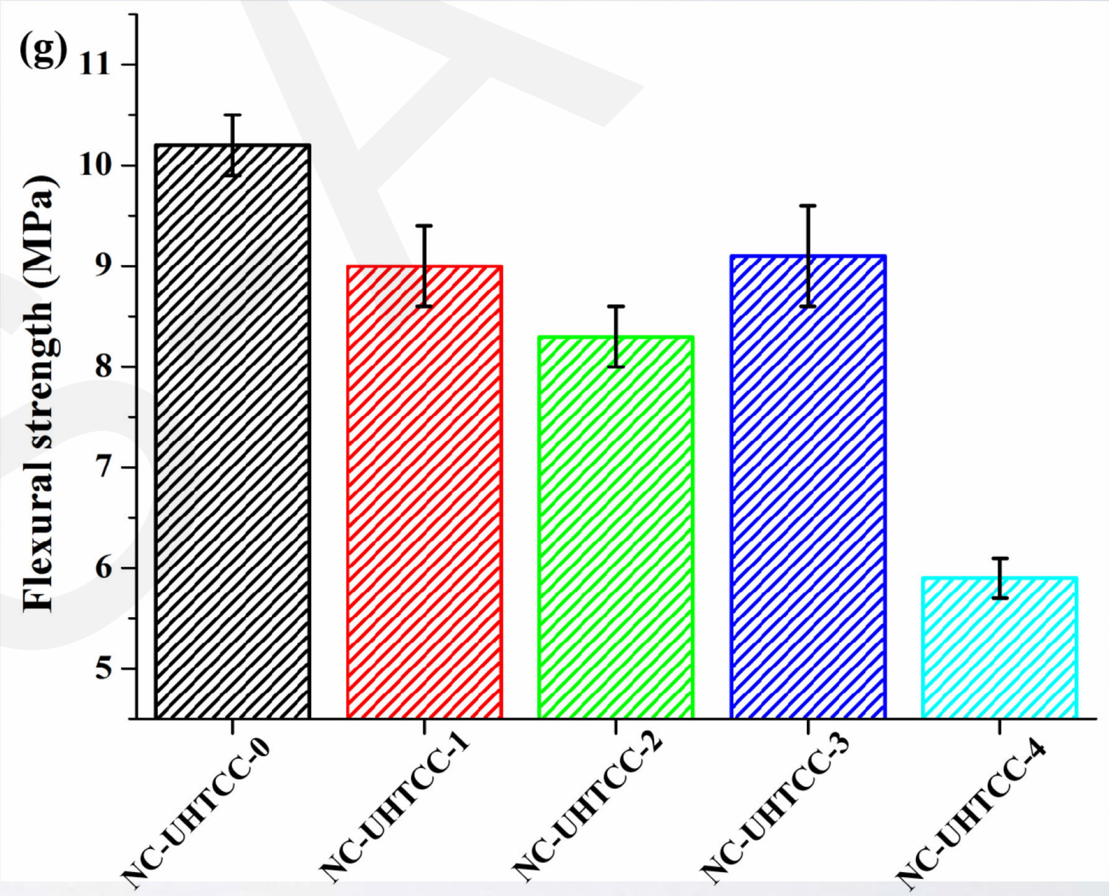


Figure 2 Compressive strength of NC-UHTCCs

Figure 3 Flexural stress versus mid-point deflection plots of NC-UHTCC: (a) NCUHTCC-0, (b) NC-UHTCC-1, (c) NC-UHTCC-2, (d) NC-UHTCC-3, (e) NC-UHTCC-4, and (f) comparison of the stress-deflection plots of all NC-UHTCC specimens

Addition of 1wt% nanoclay shows few effects to the compressive strength of UHTCCs and nanoclay addition does not reduce the toughness of UHTCCs..

Results and discussion

Cracking patterns

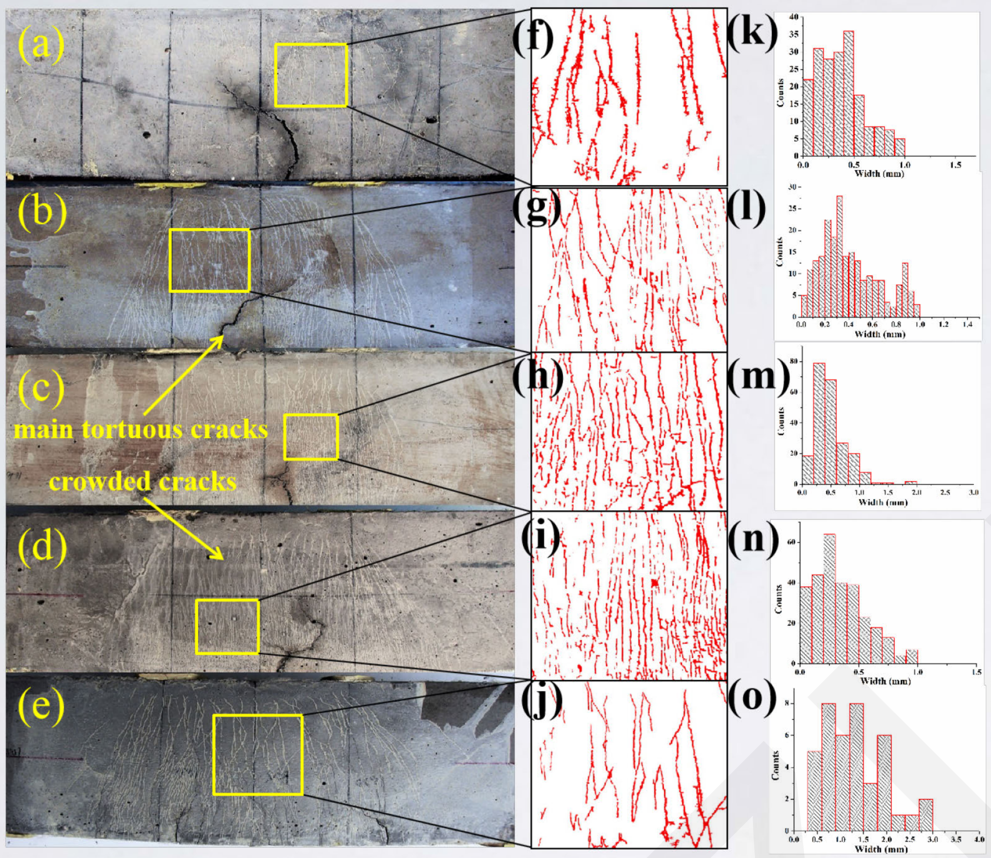


Figure 4 Micro cracks and the results of imaging analysis: (a) NC-UNTCC-0, (b) NCUHTCC-1, (c) NC-UHTCC-2, (d) NC-UHTCC-3, (e) NC-UHTCC-4. Left: the original pictures of NC-UHTCC specimens after FPB tests, middle: the figures of the areas with crowded cracks after imaging analysis, and right: the statistic results of crack width for the areas with crowded cracks.

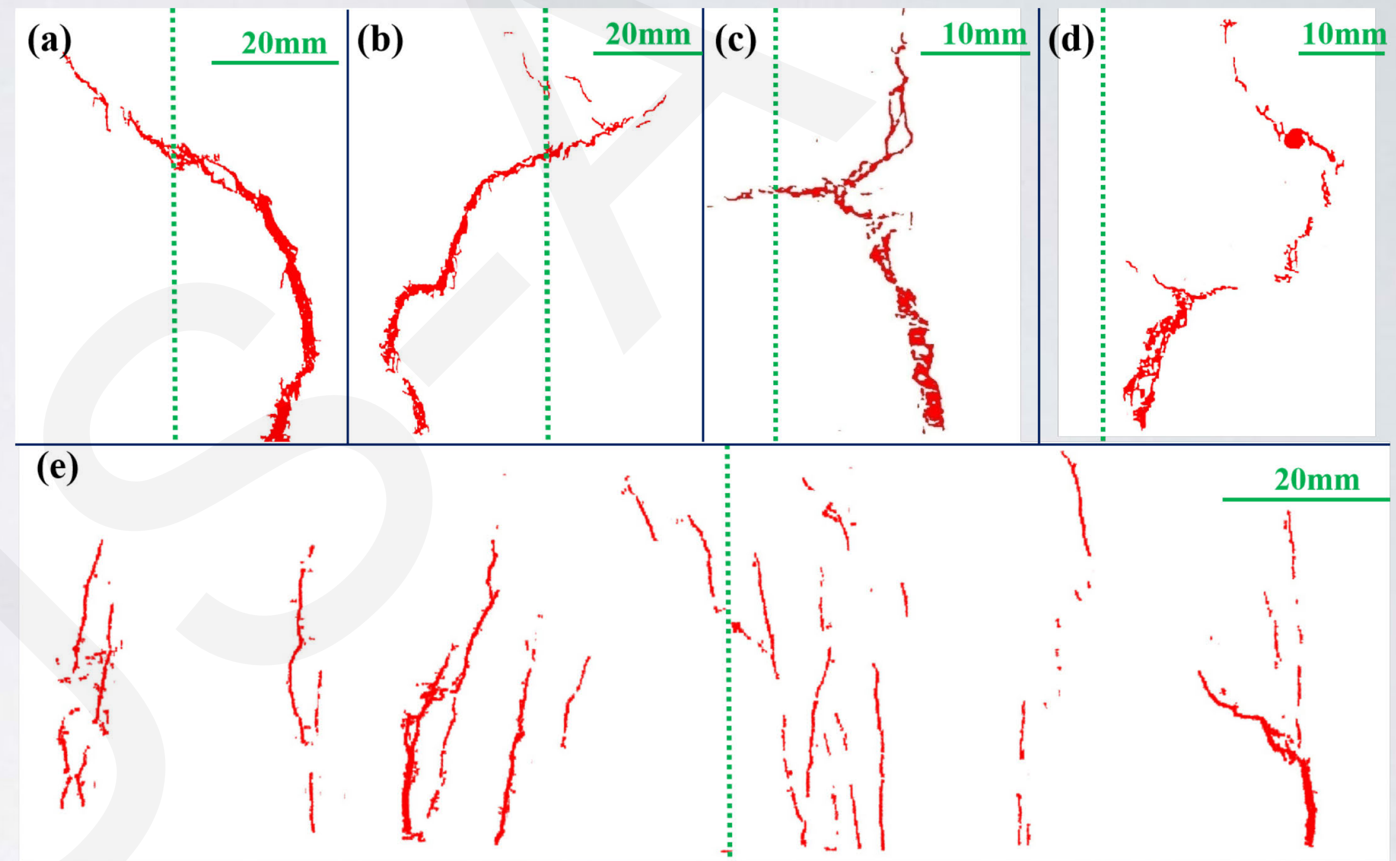


Figure 5 Macro cracks in different specimens: (a) NC-UNTCC-0, (b) NC-UHTCC-1, (c) NCUHTCC-2, (d) NC-UHTCC-3, (e) NC-UHTCC-4. Here the vertical dashed lines represent the middle lines of NC-UHTCC specimens

All the specimens show two types of cracks: main tortuous cracks and crowded cracks.

Results and discussion

Water permeability

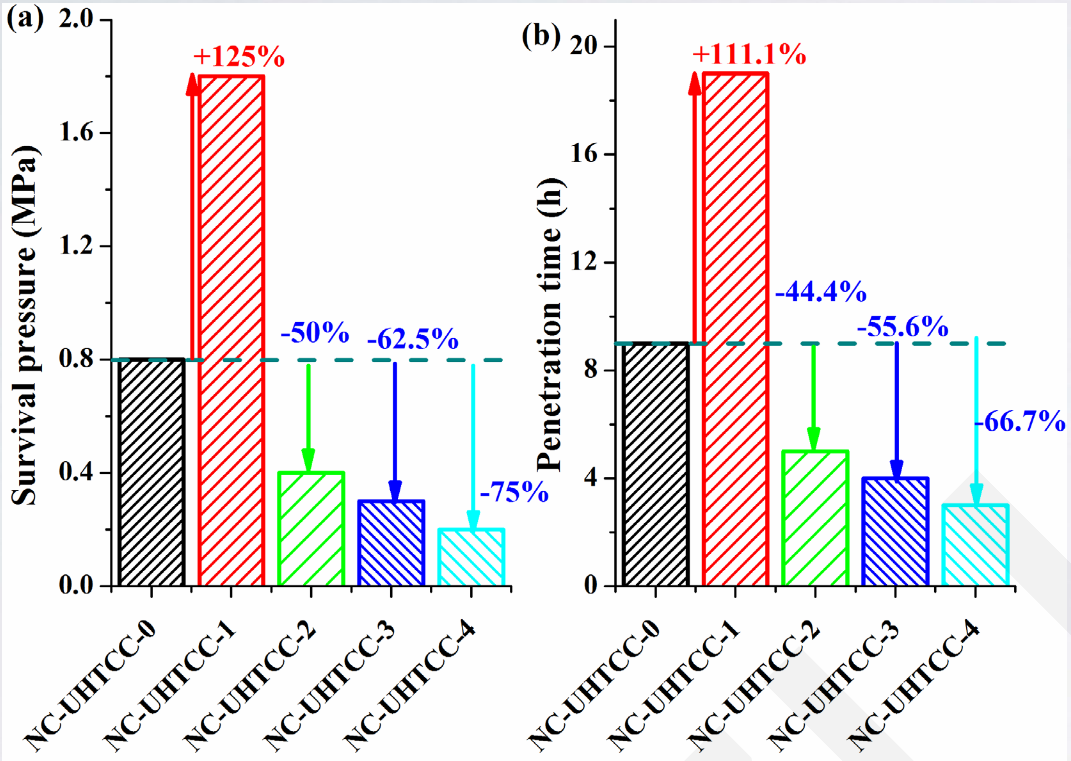


Figure 6 Water permeability properties of NC-UHTCC: (a) the survival pressure and (b) the time required for water penetrating through the NC-UHTCC specimens

The UHTCC containing 1wt% nanoclay has excellent water permeation resistance , which can be attributed to the refined microstructure due to the filling and heterogeneous nuclei effects of nanoclay and the tortuous penetration path of water molecules caused by the monodispersed nanoclay flakes.

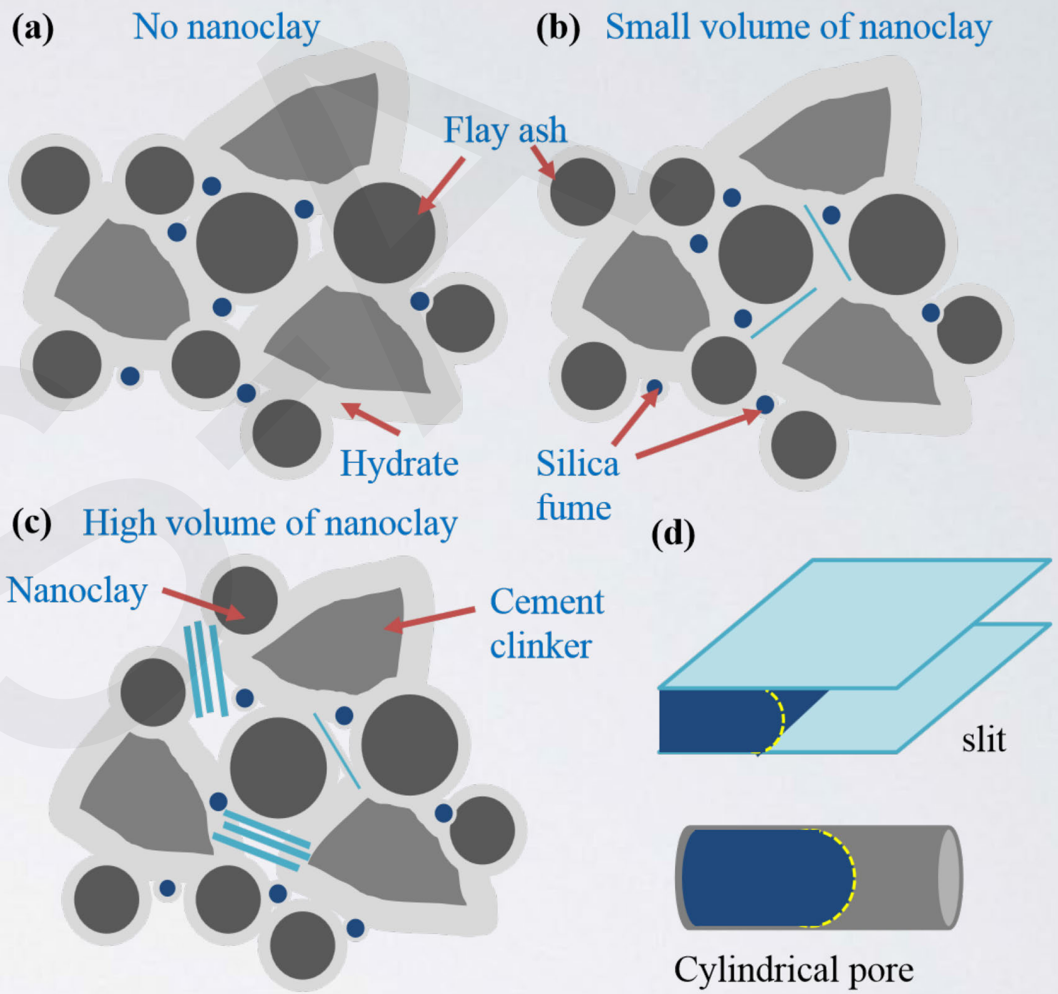


Figure 7 Effects of nanoclay on the pore structure and water permeability of NC-UHTCCs: (a) UHTCC without nanoclay showing relatively high dense packed microstructure, (b) UHTCC with a low volume of nanoclay showing denser microstructure, (c) UHTCC with a high dosage of nanoclay having porous microstructure, and (d) schematic illustration of water permeability trough slits and cylindrical pores. Here fibers were not demonstrated in this schematic diagram

Conclusions

1) Addition of 1wt% nanoclay shows few effects to the compressive strength of UHTCCs, while a further increase of nanoclay dosage results in a continuous decrease of compressive strength. The flexural strength of NC-UHTCCs decreases from approximately 10 MPa to approximately 6 MPa with the dosage of nanoclay increasing from 0wt% to 6wt%. The maximum mid-span deflections of all UHTCC were almost the same, approximately 5 mm, indicating that the introduction of a proper dosage of nanoclay would not degrade the flexural deformation capacity of UHTCCs.

2) Compared with other samples, a UHTCC containing 1wt% nanoclay has the smallest porosity of 31.75% and a threshold pore size of 183.13 nm, but the highest survival pressure Ps of 1.8 MPa and the largest penetration time tp of 19 hours. The excellent water permeation resistance of a UHTCC containing 1wt% nanoclay can be attributed to the refined microstructure due to the filling and heterogeneous nuclei effects of nanoclay and the tortuous penetration path of water molecules caused by the monodispersed nanoclay flakes. However, excessive nanoclay (>2%) addition would induce the agglomeration of nanoclay and the formation of nanoclay clusters which act as flaws in the cementitious matrix, leading to a decrease in the water permeation resistance of UHTCCs.