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Pore Structure and Mechanical Properties of FRCC in the Freeze–thaw Environment: A Review

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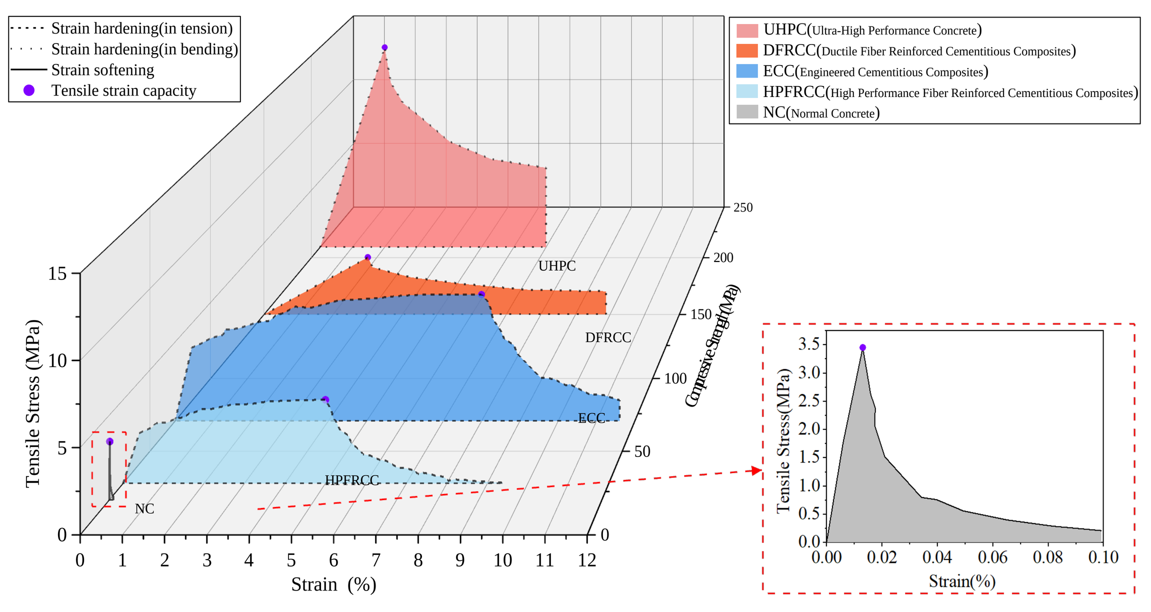
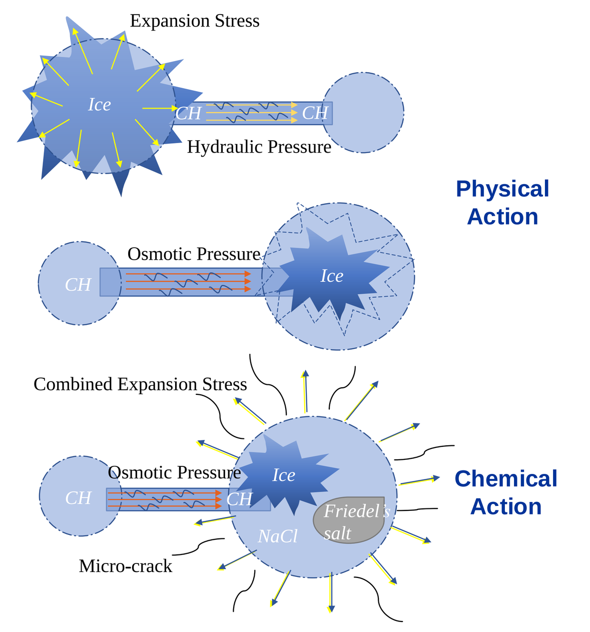
Weizhe Wu, Huaqiao University, 21014086094@stu.hqu.edu.cn
Yixin Zhang, Huaqiao University, zhangyixin@hqu.edu.cn
Yang Liu, Huaqiao University, lyliuyang@hqu.edu.cn

Introduction

- Fiber reinforced cement composites (***FRCC***) is a composite material formed by the homogeneous blending of non-continuous short fibers as reinforcement in a cement matrix.
- The fiber-bridging stress resists the crack opening and prevents the entry of harmful substances, which improves the ***tensile properties*** and ***durability*** of FRCC.
- ***Pore structure*** is the key to analyzing the frost resistance of FRCC.
- As a heterogeneous material, the cracking behavior of FRCC is highly dependent on different ***micromechanical*** constituent parameters, mainly including fiber, matrix, and fiber-matrix interfacial properties.



Typical classification of fiber reinforced cement composites



Freeze-thaw damage mechanisms

Objectives

- Investigate the effects of fiber inherent properties on the ***pore characteristics*** of FRCC under different freeze-thaw cycles.
- Investigate the correlation between the inherent properties of fiber, fiber-matrix interface bonding property, and the ***mechanical properties*** of FRCC in the freeze-thaw environment.
- Summarize the existing freeze-thaw damage models of FRCC based on pore structure and propose the prospect of establishing ***multi-scale freeze-thaw damage models.***

Pore Structure Characteristics

➢ **Spacing Factor(L)**

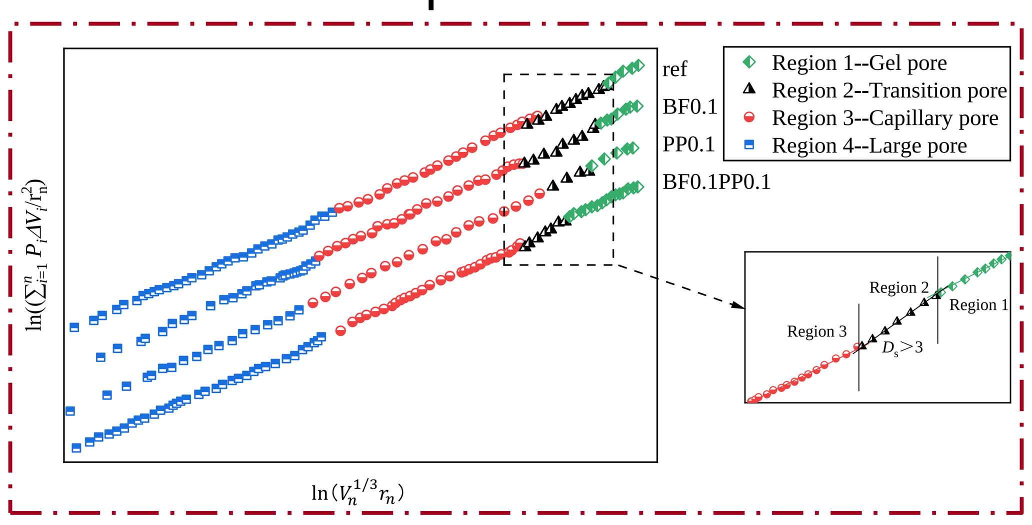
- *Theoretically*, the lower the L, the lower the hydrostatic pressure and the better the frost resistance of FRCC;
- Established *experimental studies* have found that changes in L do not affect the frost resistance.

➢ **Cumulative Pore Volume Distribution(CPVD)**

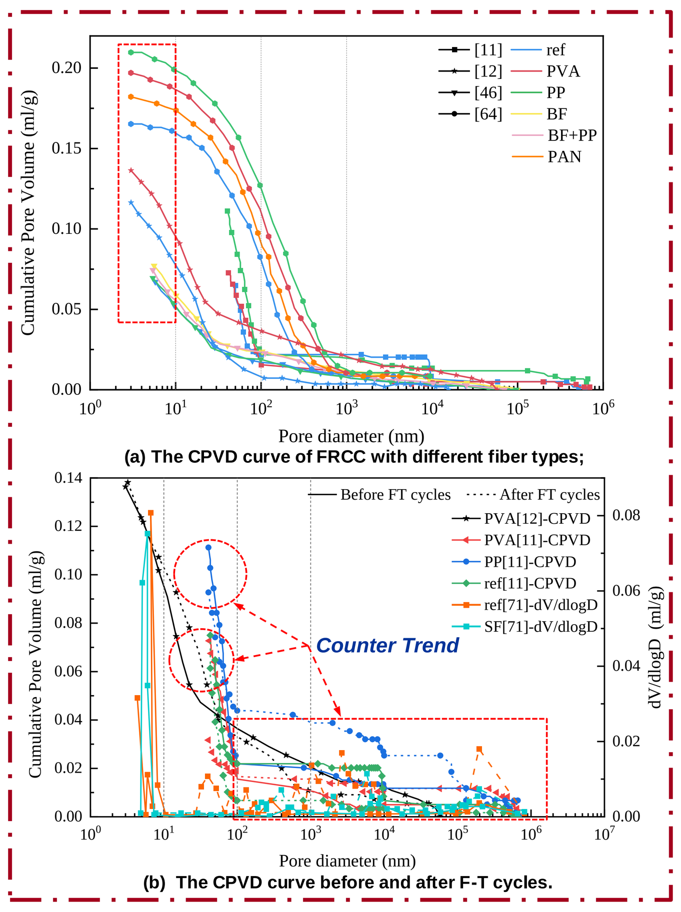
- The incorporated fibers increase the air content of matrix and produce fiber-matrix ITZ, which has a certain effect on the large and capillary pores.
- The fibers effectively *resists the tendency* of pore changes caused by freeze-thaw cycles and inhibits freeze-thaw damage.

➢ **Fractal Dimension(D_s)**

- The fractal of pores is *scale-dependent*; The D_s of large pores is significantly reduced;
- A ***D_s**-based freeze-thaw damage model* has been developed.



Bi-logarithmic curve in the four fractal regions



The CPVD curves of FRCC

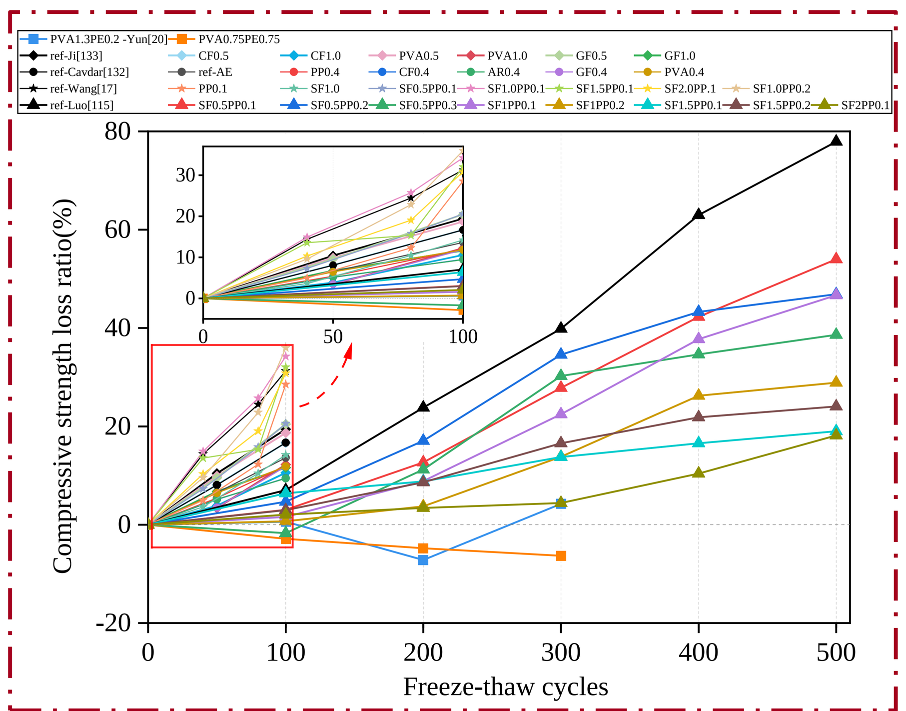
Mechanical Properties

➢ **Tensile Strength**

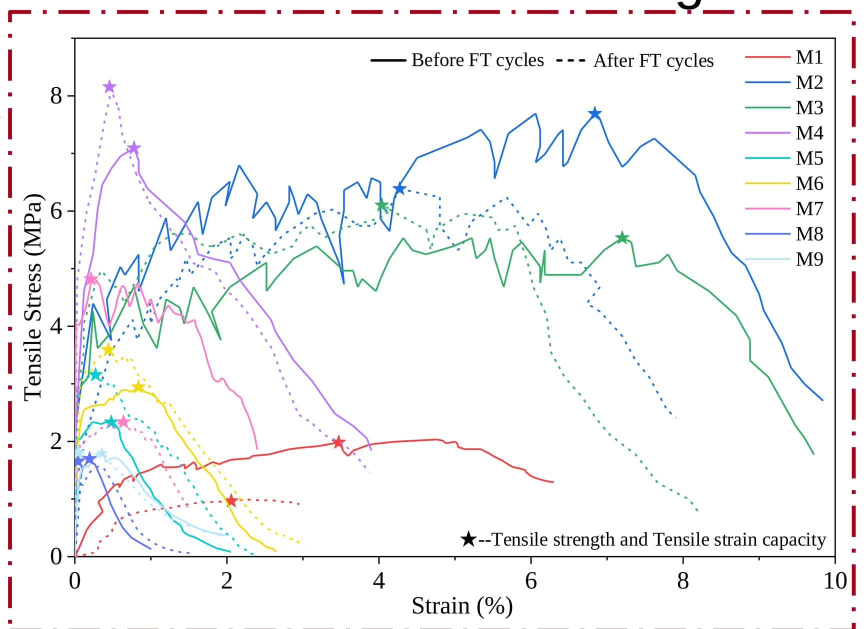
- Fibers: 1. Air content of matrix(⬆); 2.Bridging effect to restrain matrix.
- Hydration Degree: Continued hydration causes increased strength.

➢ **Tensile Strain Capacity**

- Mainly related to the *degree of fiber maintenance bridging*:
  1. Fiber modulus of elasticity;
  2. *Interfacial bonding strength;*
  3. Matrix toughness.



Compressive strength loss ratio of FRCC after F-T cycles



Axial tensile stress-strain curve of FRCC before and after F-T cycles

➢ **Compressive Strength**

- Freezing-thaw cycles: compressive strength (⬆⬇).
- Fibers:

1. *Rigid fibers* are most effective;
2. Fiber *volume content*: appropriate;
3. “Positive *mixing effect*”.

Relationship between Pore Structure and Mechanical Properties

Mechanical Properties	*Pore Characteristics*	*Existing Model*
Compressive Strength	Porosity	$$\sigma = \sigma_0(1-p)^n$$ σ - Compressive strength; σ_0 -Theoretical compressive strength at zero porosity; p - ***porosity***; n - empirical power index.
	Pore Distribution Fractal Dimension	$$R_c = 4.7375 \cdot (\frac{D_s}{V_c})^{0.3995}$$ R_c - Compressive strength; D_s - ***Fractal dimension*** of the pore surface; V_c - Volume of the ***capillary pore***.
Frost Resistance (Relative Dynamic Modulus of Elasticity, etc)	Fractal Dimension	$$\omega = 1 - \frac{D_{s,FT} - D_{s,min}}{D_{s0} - D_{s,min}}$$ $D_{s,FT}$ - fractal dimension under the damage status subject to the FT cycles; D_{s0} - initial fractal dimension before the FT cycles; $D_{s,min}$ - minimum value of fractal dimension, constant; ω - damage parameter. Freeze-thaw durability coefficient ***K_n**(RDME)* with the damage parameters ***ω*** revealed a significant ***negative correlation***.
Tensile Strength	Micromechanical Parameters (Pore size\Porosity)	$$\sigma_c(c,c_p) = g\sigma_0\left[\frac{\sqrt{\pi}}{2}\frac{\bar{K}}{\tilde{\delta}^{*-1}\sqrt{(c+c_p)/c_p}} + (\frac{4}{3}\sqrt{\bar{C}} - \frac{1}{2}\bar{C})\right]$$ A quantitative relationship is established between micromechanical parameters (***pore size, porosity***) and ***cracking strength***.

Prospects for the modified model:

Combining the *quantitative relationship* between *pore characteristics* parameters and *mechanical properties* as well as *freeze-thaw damage parameters*, a freeze-thaw damage model based on the macro mechanical index of pore structure parameters can be established.

Conclusions

- The association between pore characteristics and freeze-thaw damage is mostly characterized qualitatively or semi-quantitatively, and there is ***no quantitative general model***.
- The ***appropriate*** amount of fiber incorporation can effectively reduce the mechanical property damage of FRCC caused by freeze-thaw cycles; Changes in microscopic parameters that occur during freeze-thaw cycles need to be ***consistently quantified.***
- Investigate the effect of fibers on ***the evolutionary process*** inside the material under freeze-thaw cycles from the micro-scale is the basis for the establishment of a freeze-thaw damage model for macroscopic mechanical indicators.