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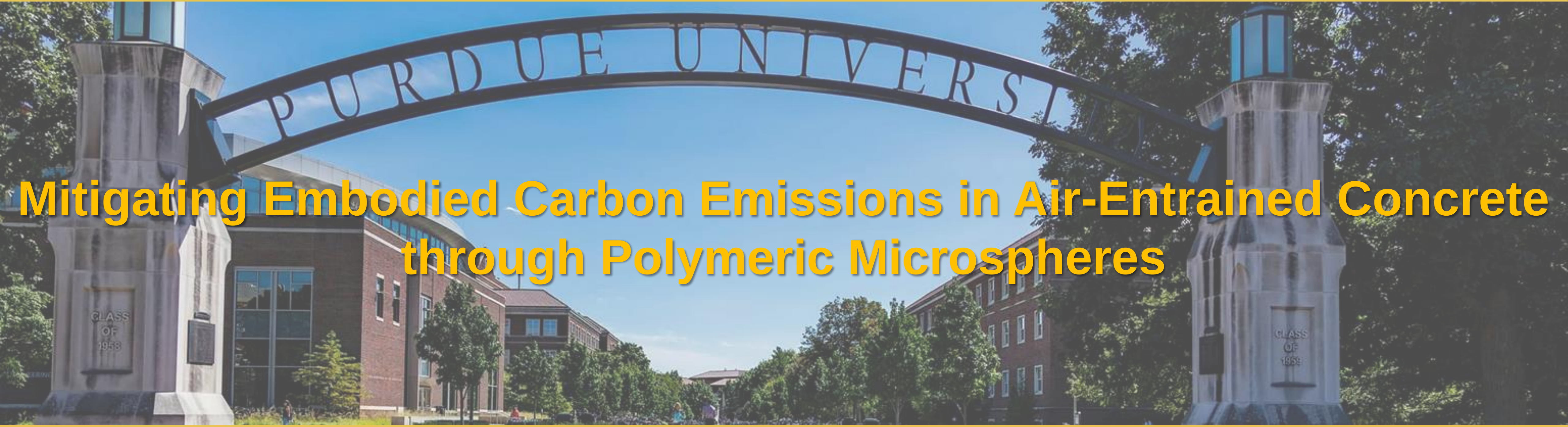
Mitigating Embodied Carbon Emissions in Air-Entrained Concrete through Polymeric Microspheres



Rui He

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11-06-2024

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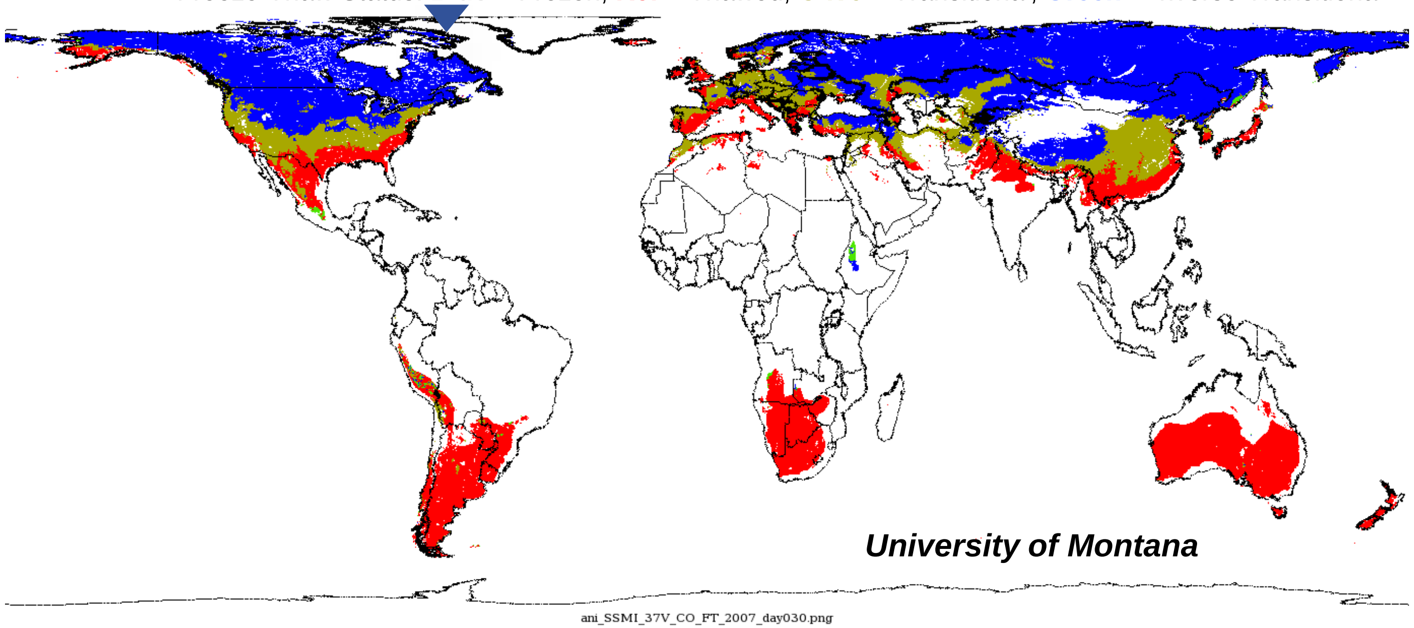
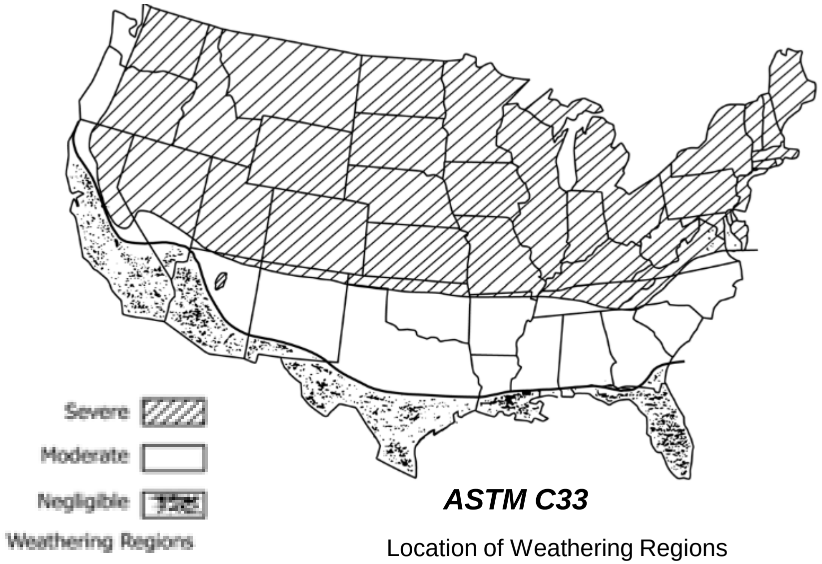
Problem Statement

Freeze-Thaw Status: Blue = Frozen, Ref = Thawed, Olive = Transitional, Green = Inverse Transitional



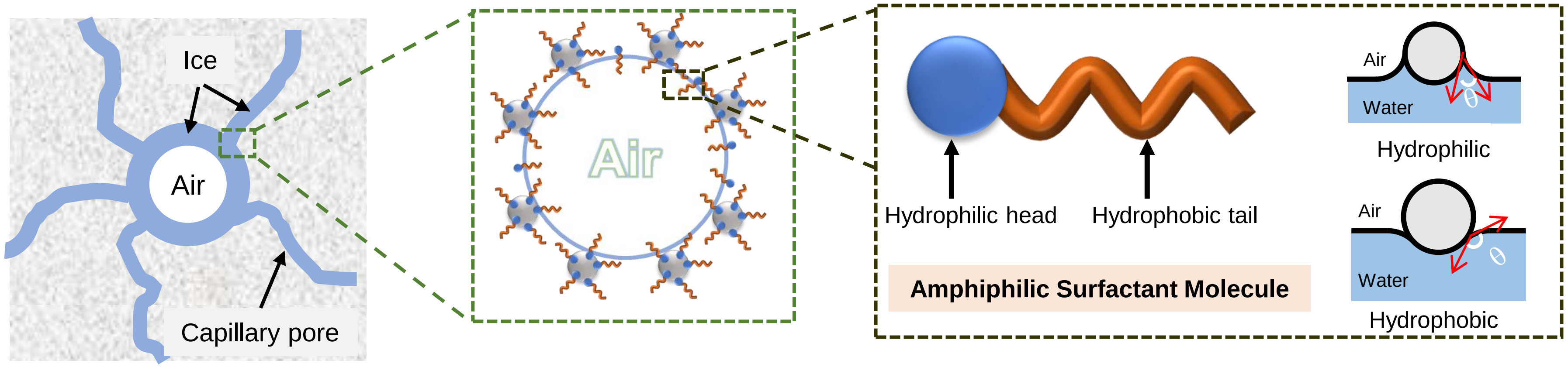
Global Monthly Freeze/Thaw Time Series Animation

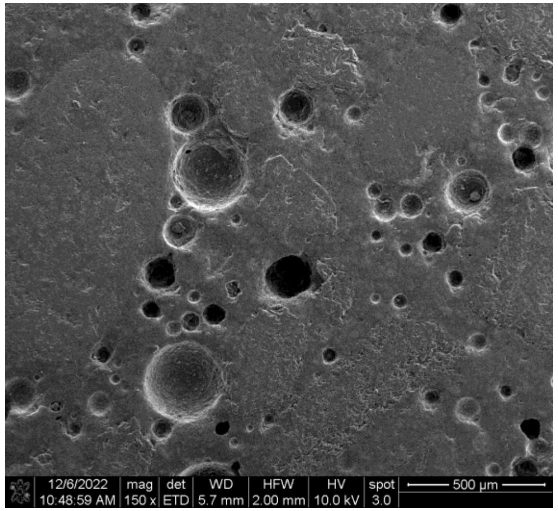


Location of Weathering Regions

- According to ASTM C33, **over 60% of the U.S.** is within *severe* weathering regions.
- Air-entraining agent is an effective admixture to improve the freeze-thaw resistance of concrete.

Air Entraining Agent





Material /Practice	Change	Effect	Material /Practice	Change	Effect
Cement	Increase in cement content	↑	Chemical admixture	Water reducers	↑
	Increase in fineness	↓		Retarders	↑
	Increase in alkaline content	↑		Accelerators	↔
SCMs	Fly ash	↓↓	Placing and finishing	Belt conveyors	↓
	Silica fume	↓↓		Pumping	↓↓
	slag	↓		Prolonged internal vibration	↓
Aggregate	Increase in max. size	↓		Excessive finishing	↓
	Sand content	↑	w/c ratio	Increase w/c ratio	↑

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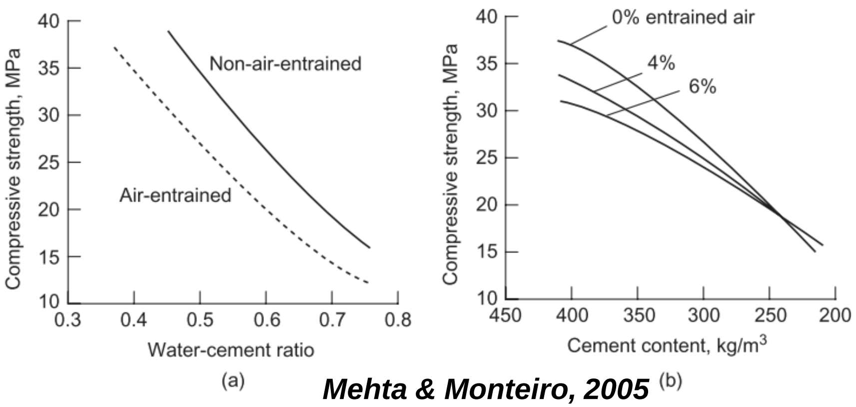
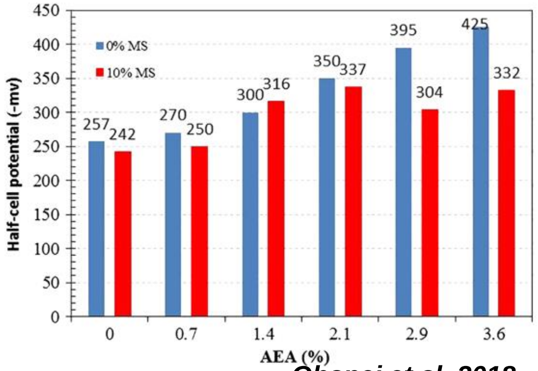
Sources of Embodied Carbon Emission

1. **Overdoes cement** to compensate for strength loss
2. Other potential long-term **durability issues** (Restoration and demolition)
3. Rejection in the field due to **specification non-compliance**



Mehta & Monteiro, 2005



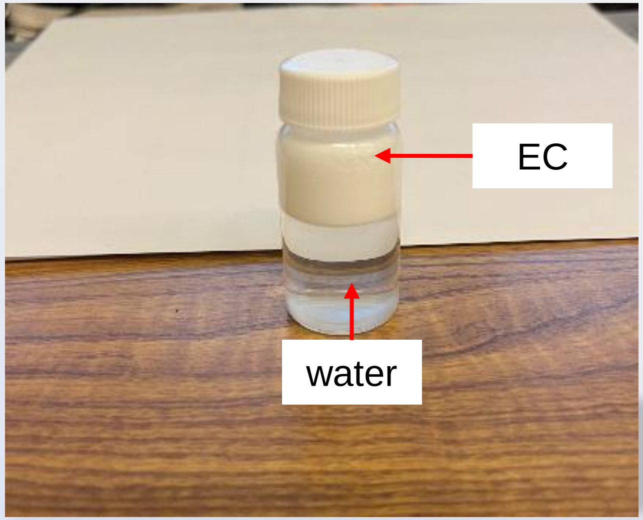
Ghanei et al. 2018

The same is true for air content. There are concretes that must be air entrained, but that is based on the exposure class of the concrete; mainly for concrete exposed to freezing and thawing. Calling out the exposure class for each concrete application or class of concrete on the project will invoke the necessary air content requirements. Air entraining decreases concrete strength, which means increased cement content to maintain the same strength level. For instance, a 10% increase in cementitious materials content for 4,000 psi air entrained concrete compared to non-air entrained concrete of the same strength would roughly translate to a 9% increase in carbon footprint for the concrete.

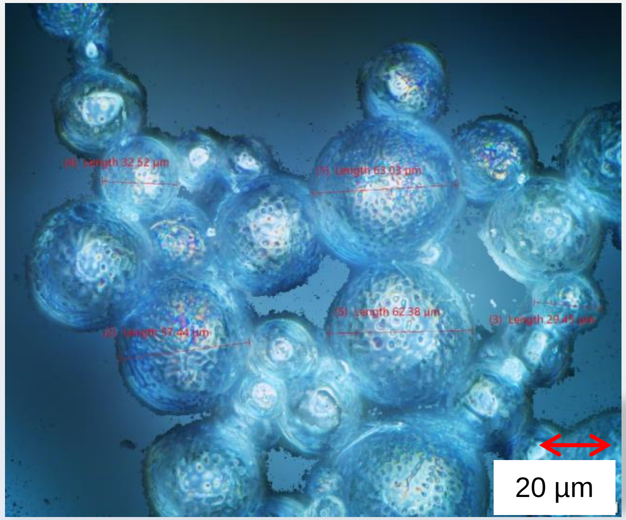
NRMCA

Microsphere AEA Characterization

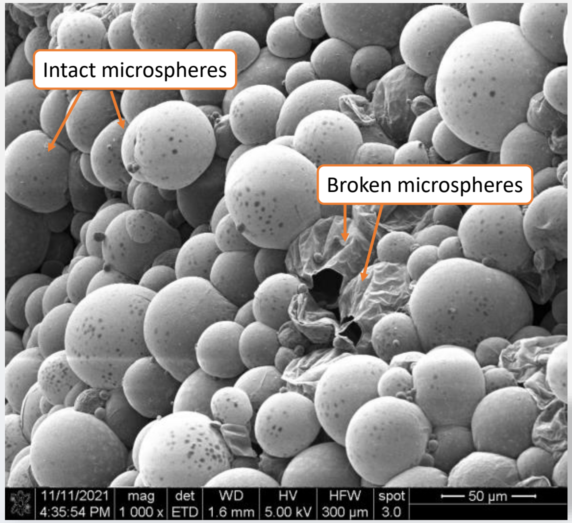
Characterization



Super lightweight microspheres (EC)



Optical microscope image

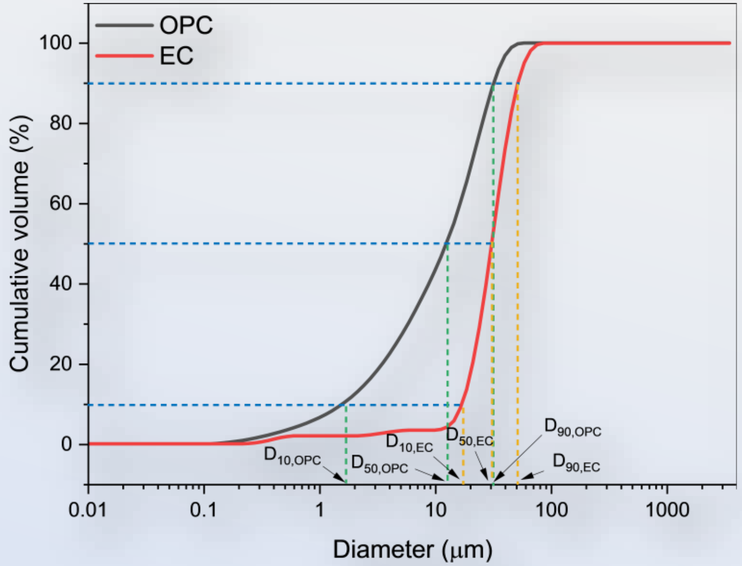


Scanning electronic microscope image

Polymeric microspheres used in this work are denoted as EC

Microsphere AEA Characterization

Characterization

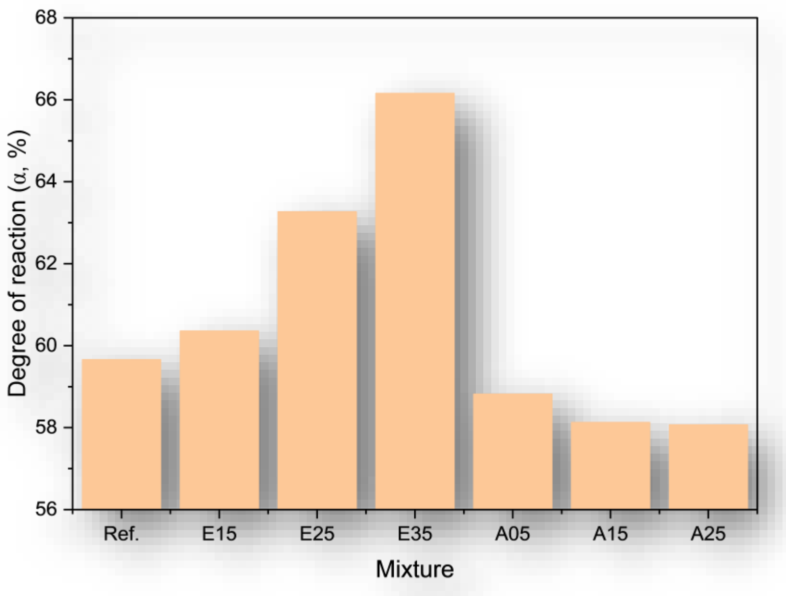


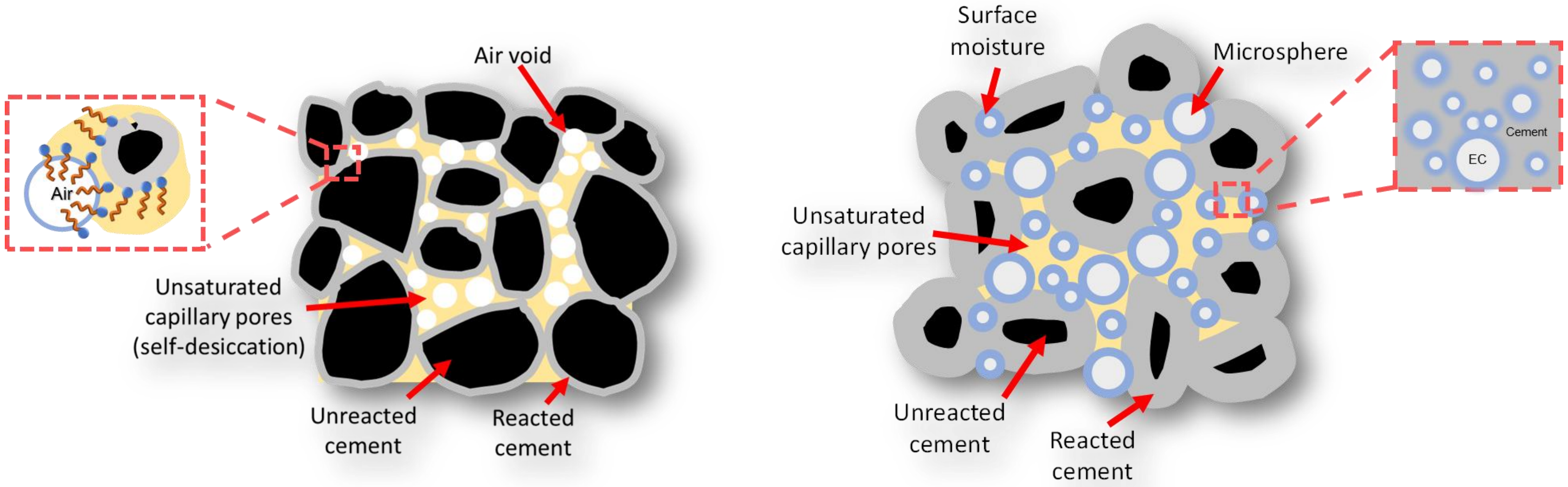
		Sample #1	Sample #2	Sample #3
Wet mass (g)		3.343	3.773	4.407
Dry mass (g)	24 h	0.148	0.166	0.399
	48 h	0.147	0.164	0.191
	72 h	0.147	0.164	0.191
Water content (%)	24 h	95.57	95.60	90.95
	48 h	95.60	95.65	95.67
	72 h	**95.60**	**95.65**	**95.67**

45 °C oven dry

- The as-received EC is wet, the average adsorbed moisture content is **95.64%**.
- The dosage of **EC** is presented as the mass ratio of cement. For example, EC1.5% (or E15) equals the mass of wet EC is 1.5% of the cement.
- The dosage of **AEA** is given as the fluid ounce per 100 lbs of cement. For example, AEA1.5 (or A15) equals 1.5 fl oz/100 lbs cement.

Hydration Properties

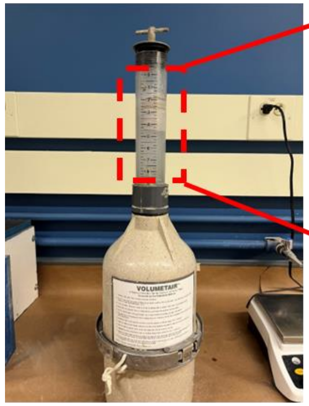




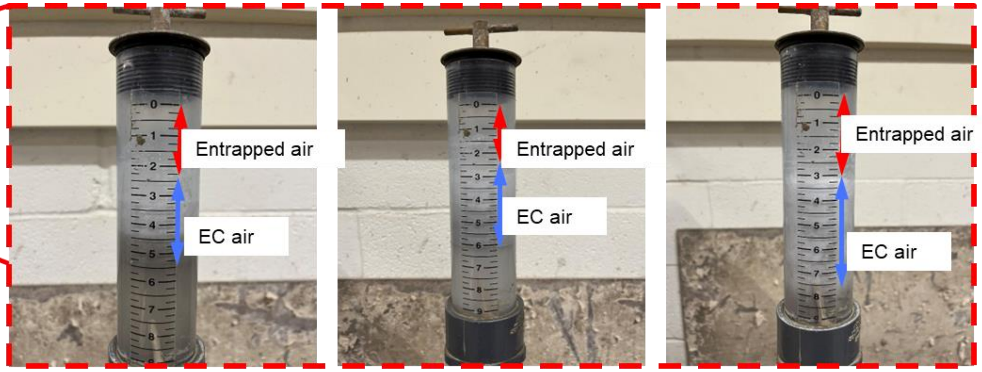
- Moisture releasing of EC particles results in an '*internal curing*' effect, leading to a higher hydration degree

Air Content Determination

ASTM C231



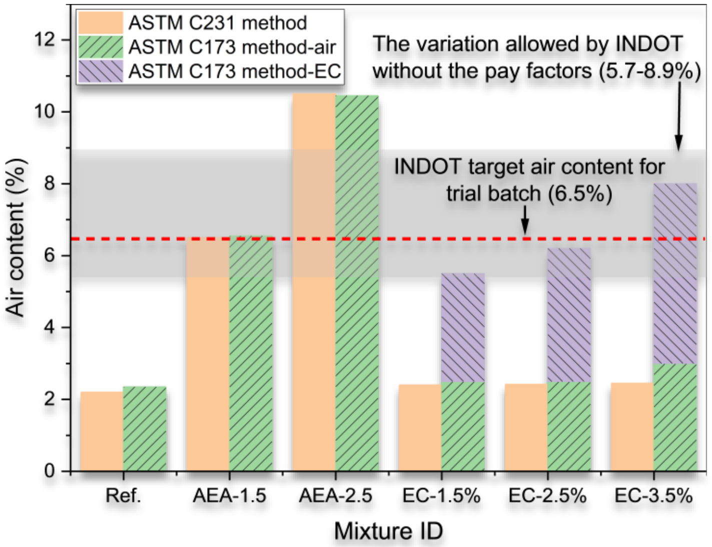
ASTM C173



EC 1.5%
Entrapped air: 2.5%
EC air: 3.0%
Design EC volume: 3.1%

EC 2.5%
Entrapped air: 2.5%
EC air: 3.7%
Design EC volume: 5.1%

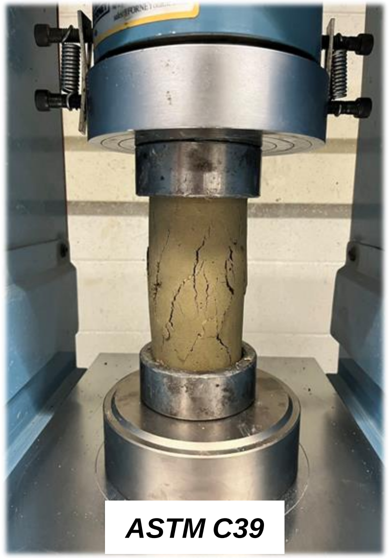
EC 3.5%
Entrapped air: 3.0%
EC air: 5.0%
Design EC volume: 7.2%

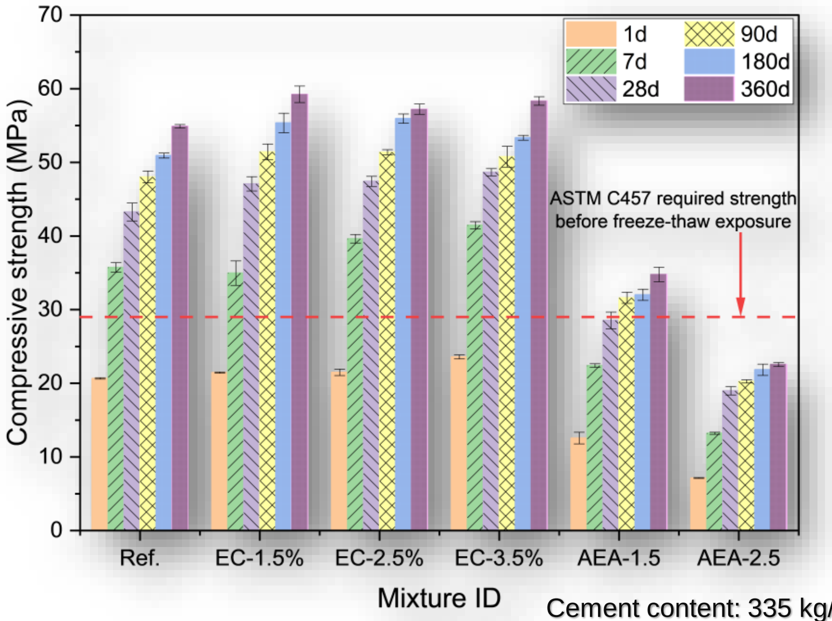


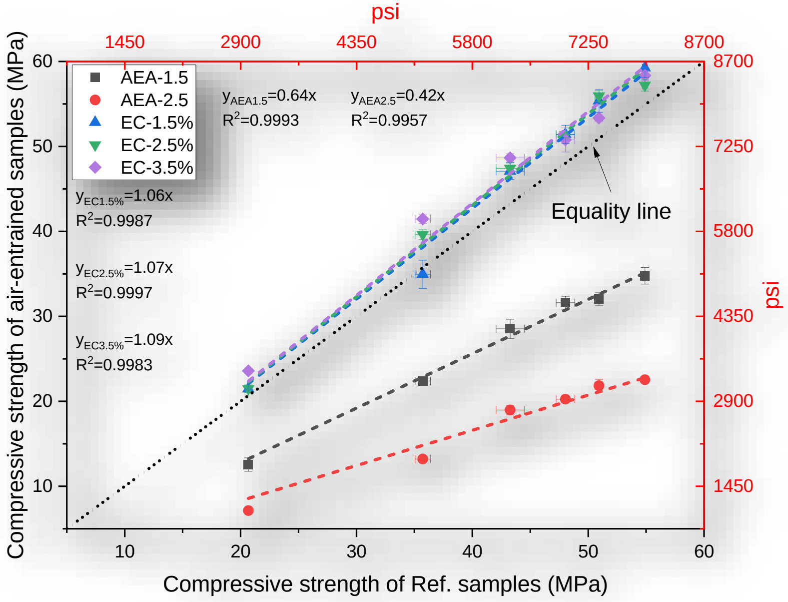
- **Pressure method** (*ASTM C231*) cannot reflect the entrained air contributed by EC particles
- **The volumetric method** (*ASTM C173*) can be used to determine the air content of concrete air-entrained by EC

American Concrete Institute
Always advancing

Compressive Strength



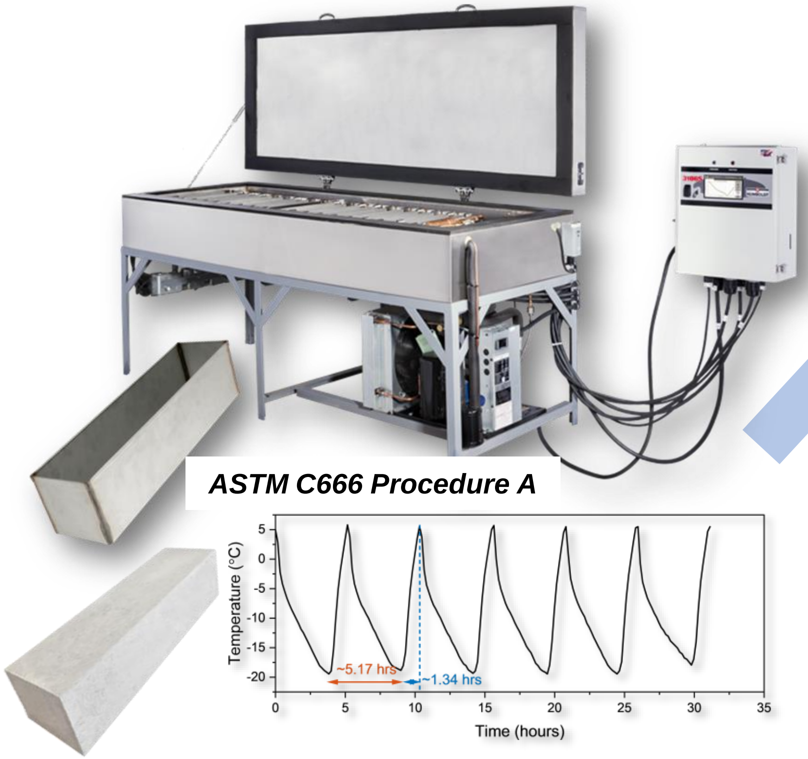


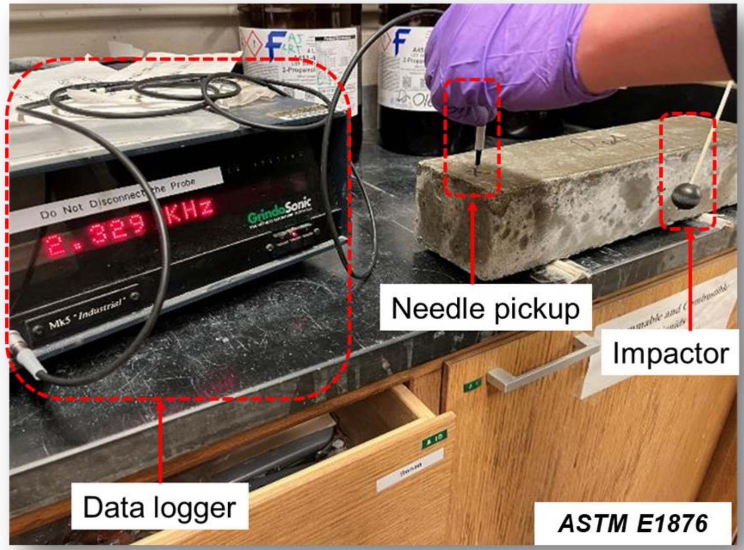


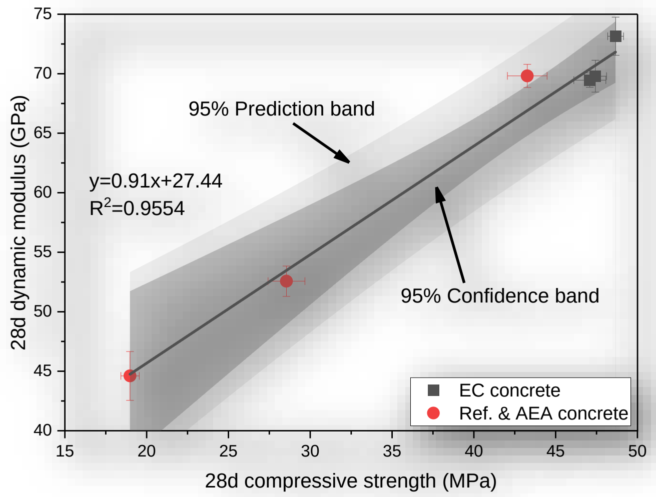
Cement content: 335 kg/m^3 = 565 lbs/yd^3

- The compressive strength of EC concrete is **6%-9% higher** than that of OPC
- 1% increase of entrained air by AEA results in **7%-8.4% compressive strength reduction**

Freeze-Thaw Resistance





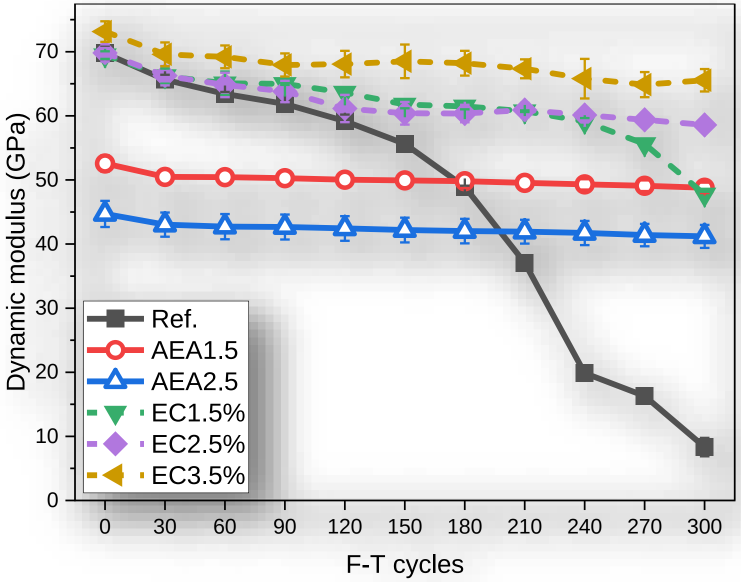


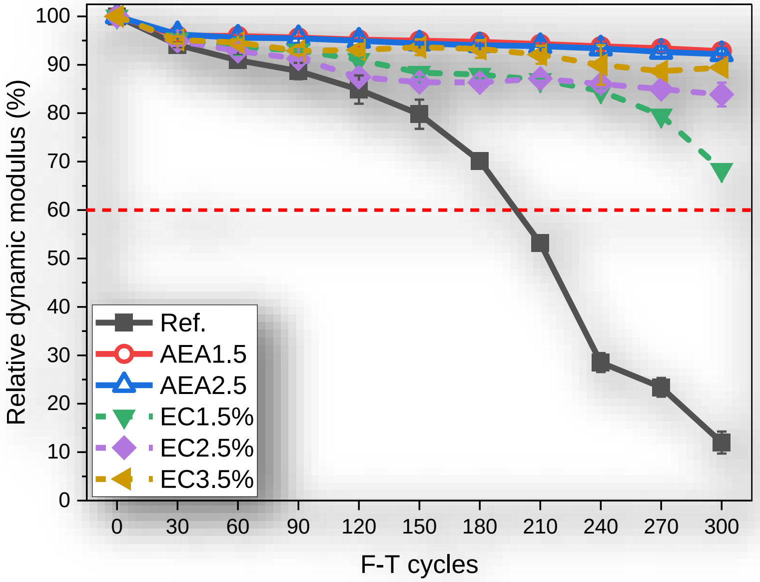
Sample tray: 90 mm × 110 mm ×415 mm

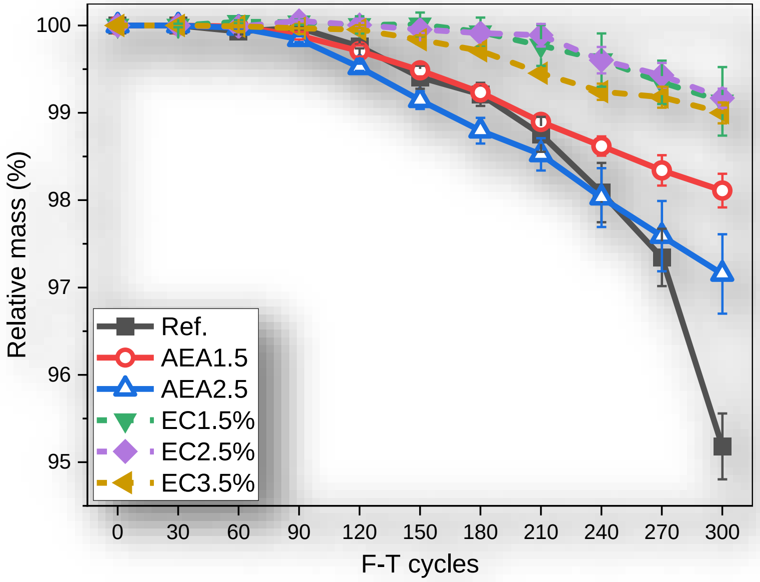
Concrete beam: 76 mm × 102 mm ×406 mm (3'' x 4'' x 16'')

- Resonant frequency was determined every **30 cycles**
- The **mass** of the concrete beam was recorded simultaneously

Freeze-Thaw Resistance

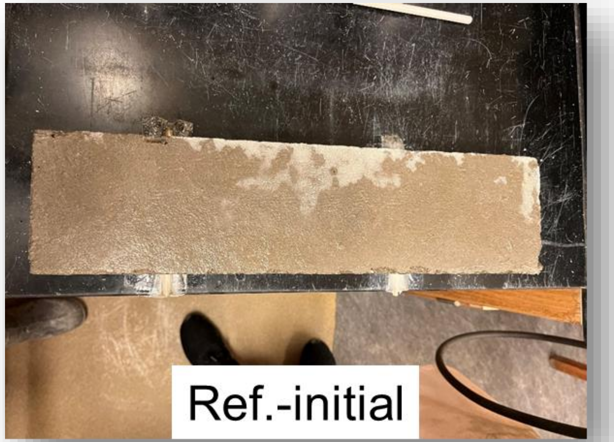


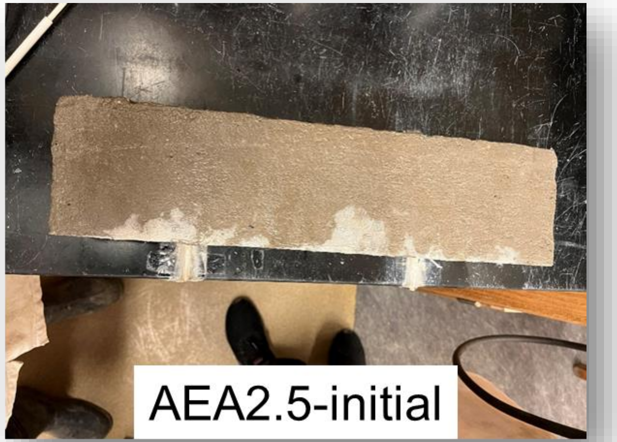


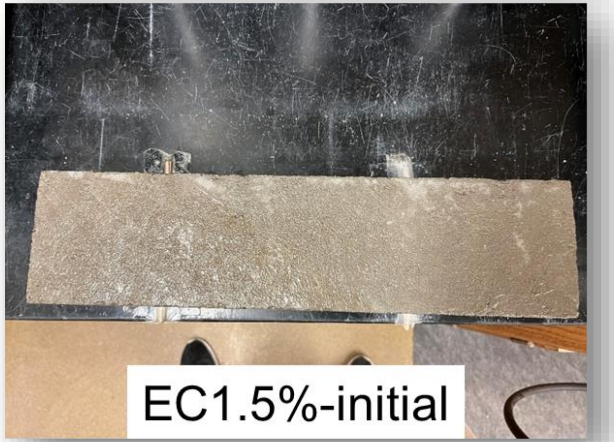


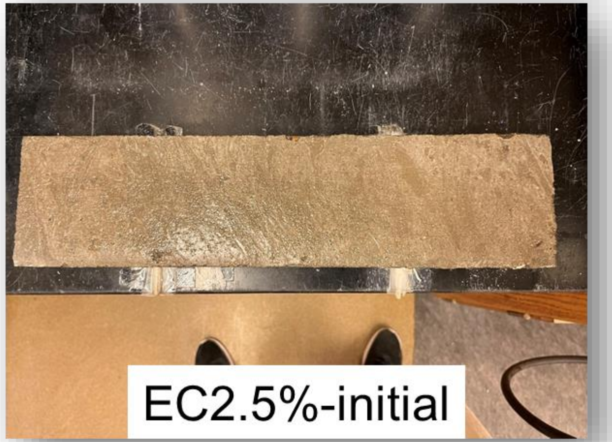
- ASTM C666 specifies terminating the test after **300 cycles** or after the relative dynamic modulus reaches **60%**
- AEA concrete maintained the highest relative dynamic modulus, but the **modulus value was low**.
- EC concrete showed a *comparative relative dynamic modulus* to that of AEA concrete, but a **higher modulus value**
- EC concrete showed **less mass loss** than EC and Ref. concrete

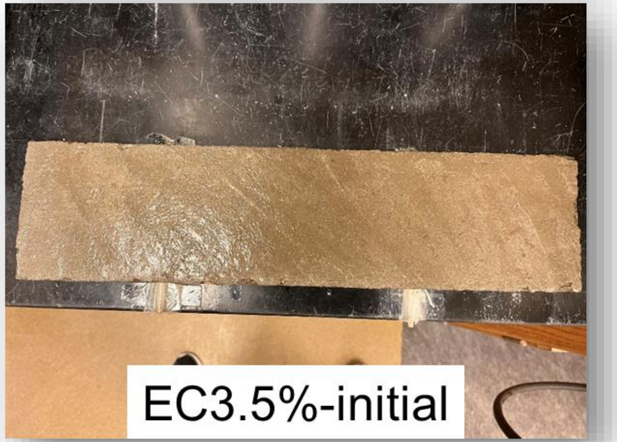
Freeze-Thaw Resistance











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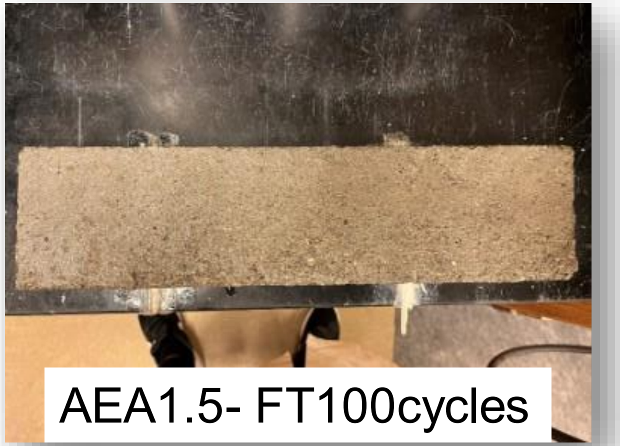
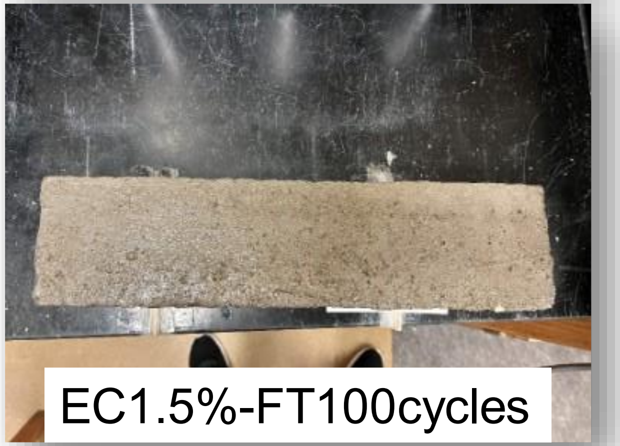
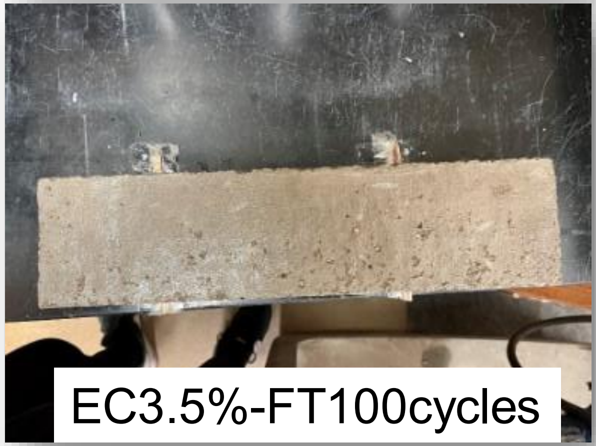
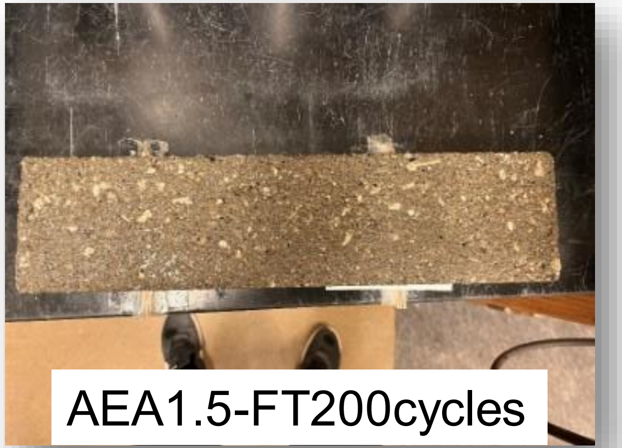
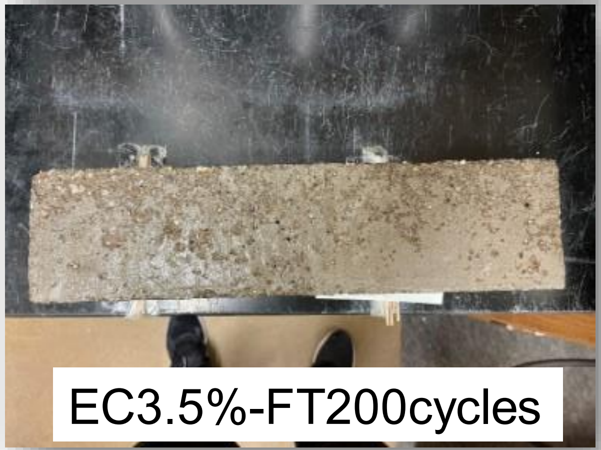






Freeze-Thaw Resistance





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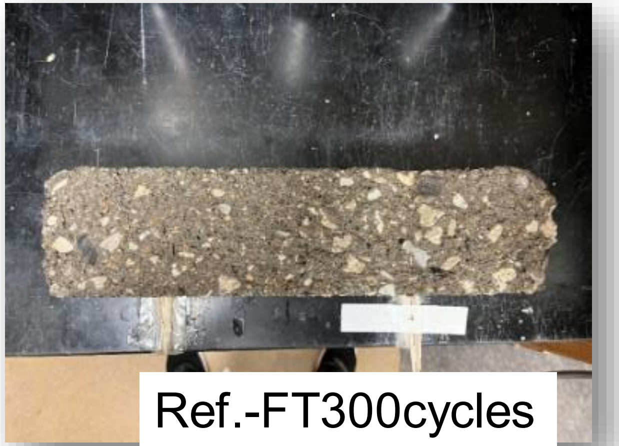
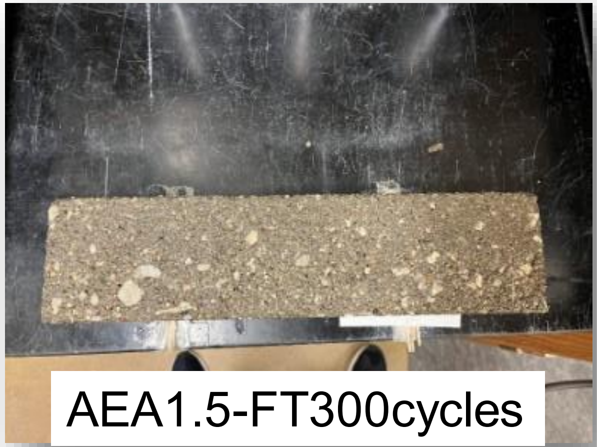
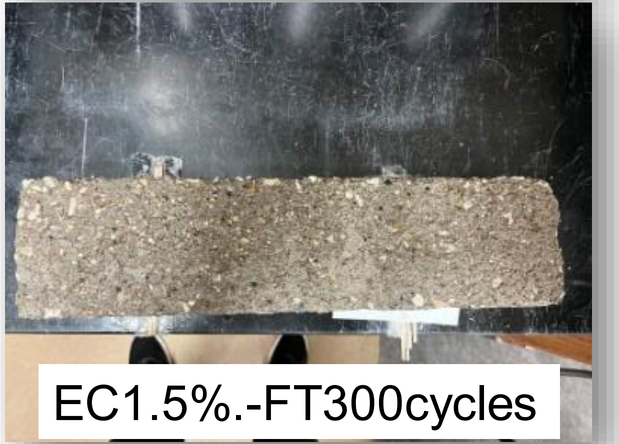
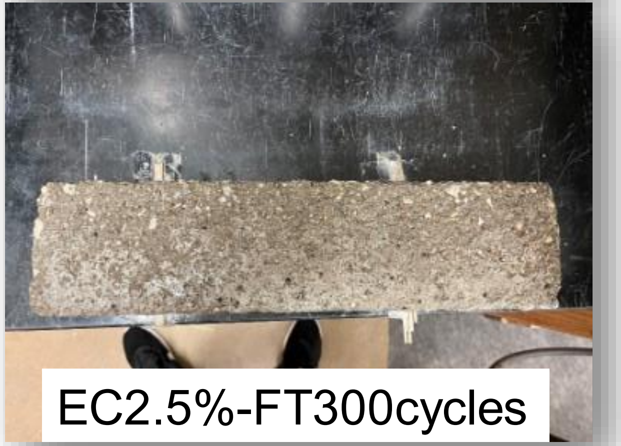
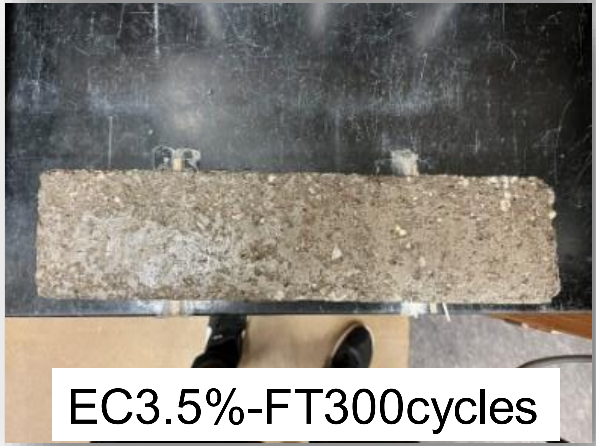


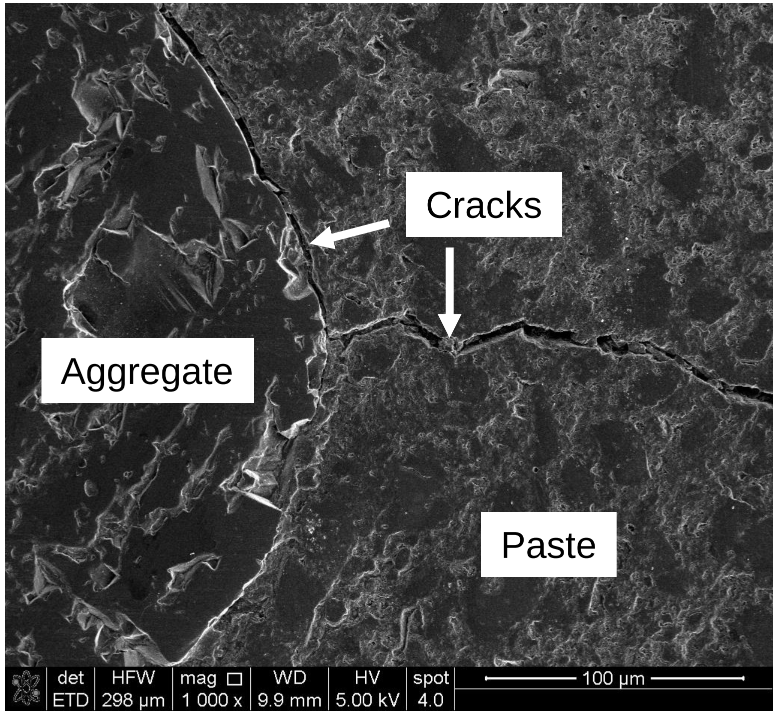




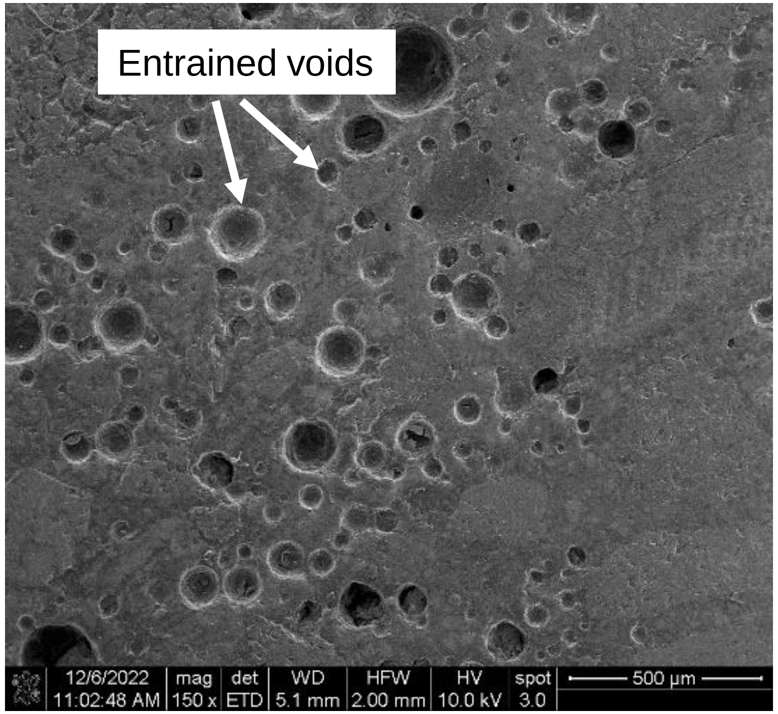




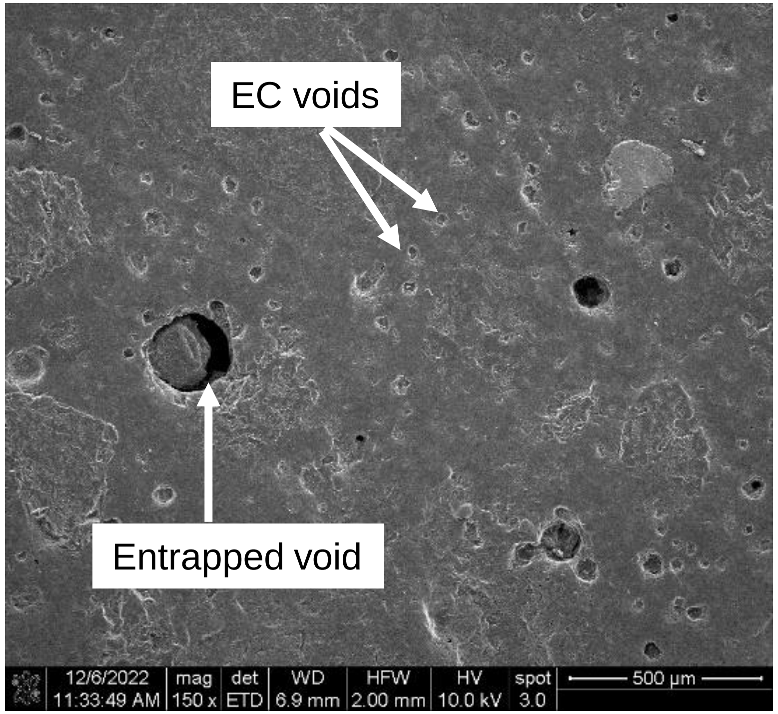
Microstructure Characterization



Ref.

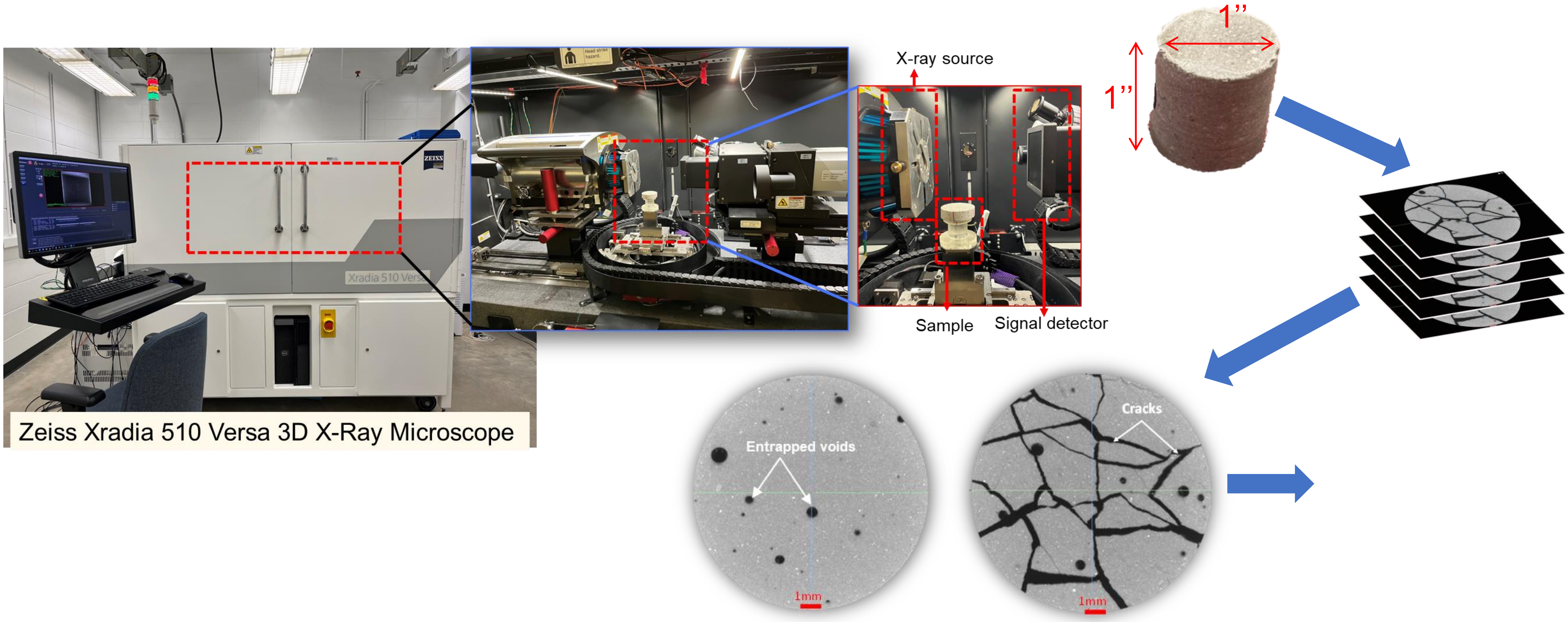


AEA-1.25



EC-1.0%

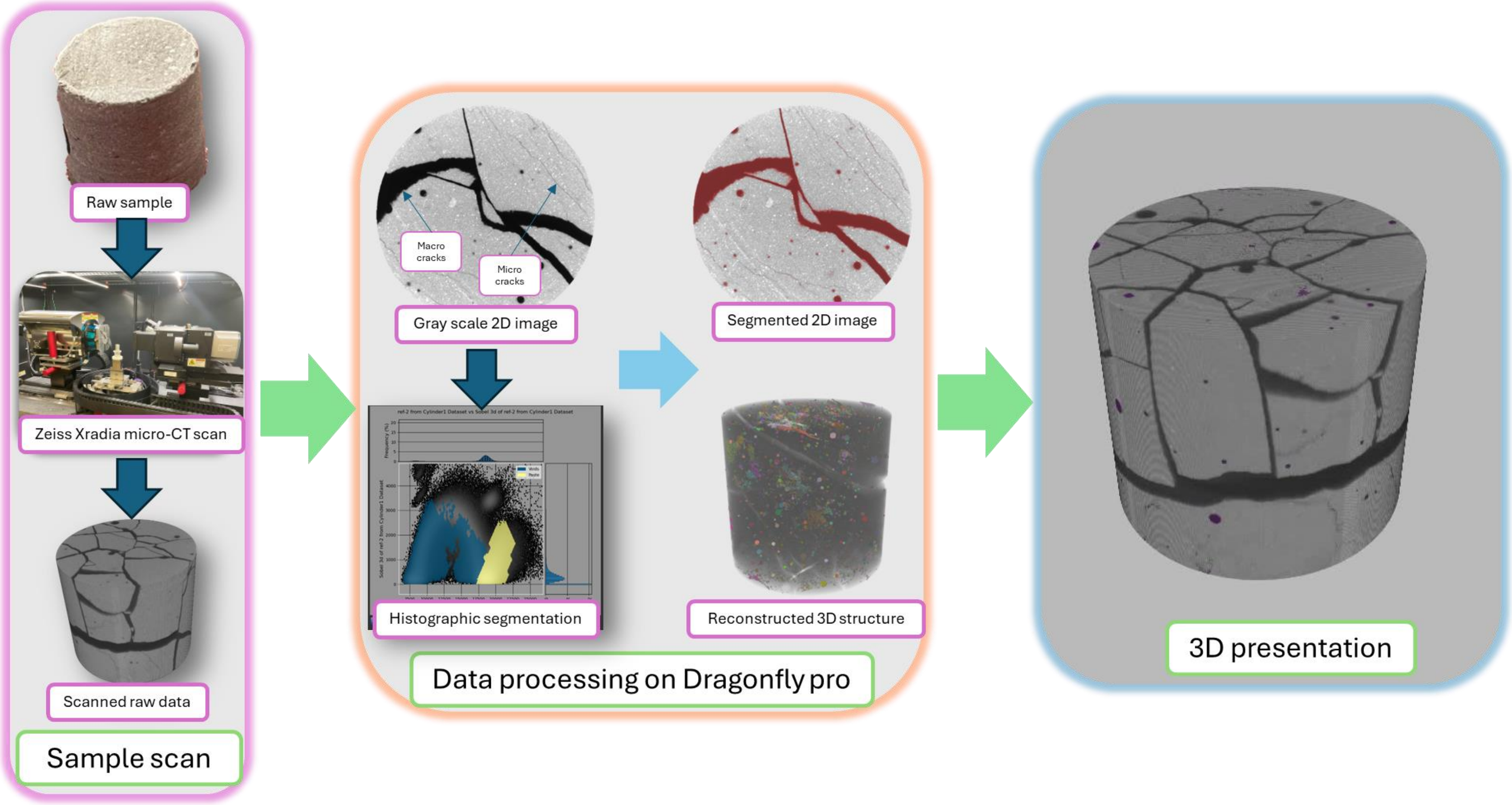
Micro-CT Characterization

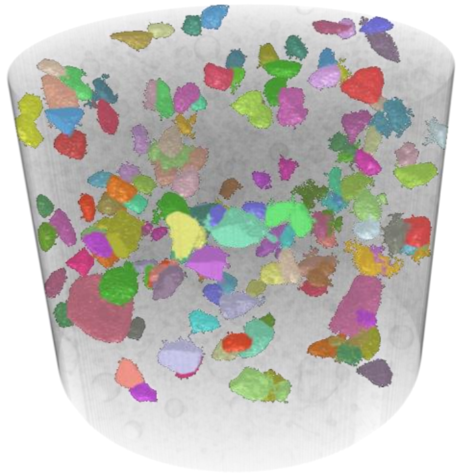


Before FT exposure (Ref.)

After FT exposure (Ref.)

Micro-CT Characterization





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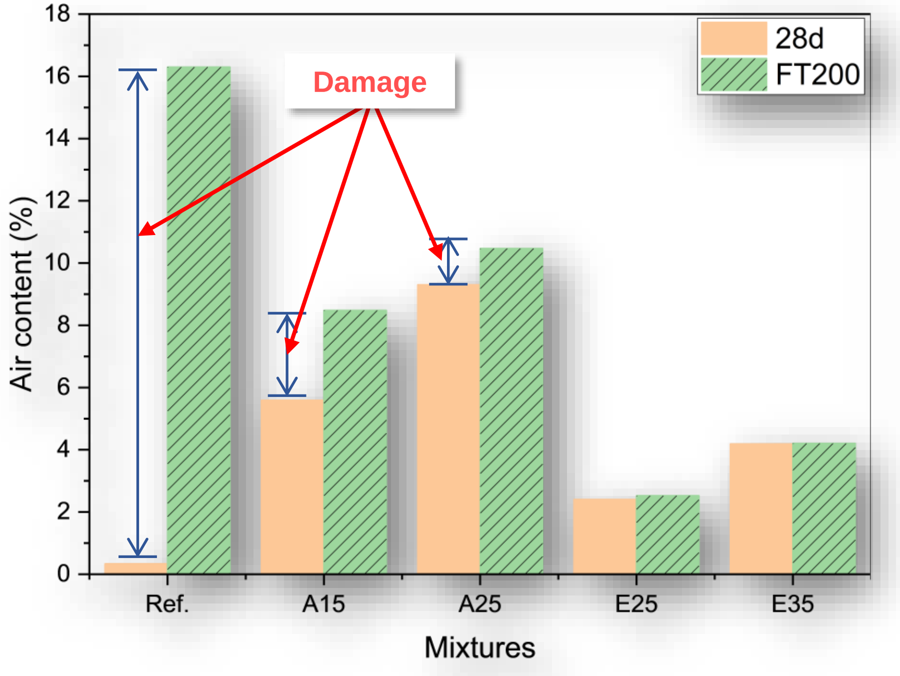
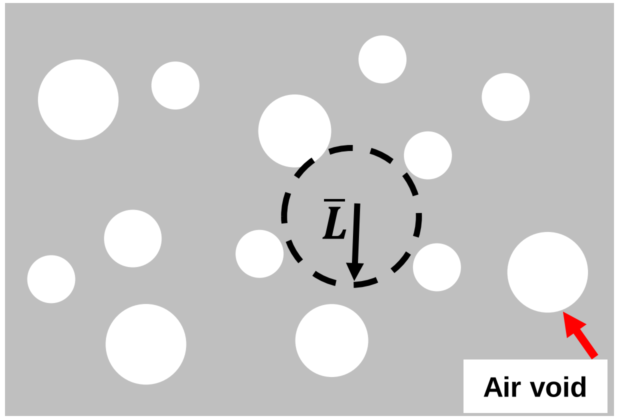
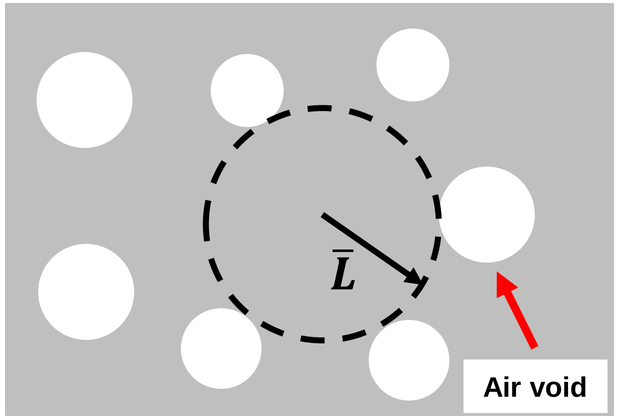


Mixture	Number of voids/pores	
	At 28d age	After 200 FT cycles
Ref.	869	78794
A15	107175	147247
A25	208764	211057
E25	**310563**	**300662**
E35	**600817**	**581977**





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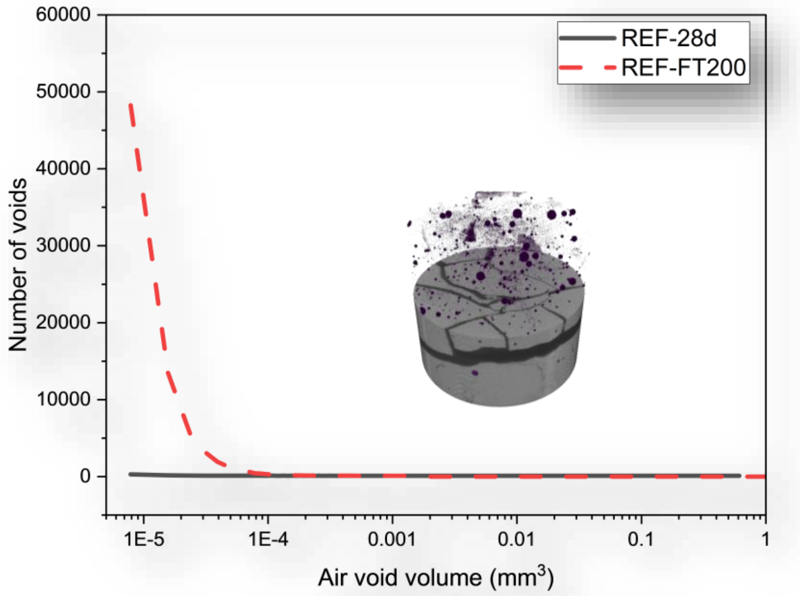
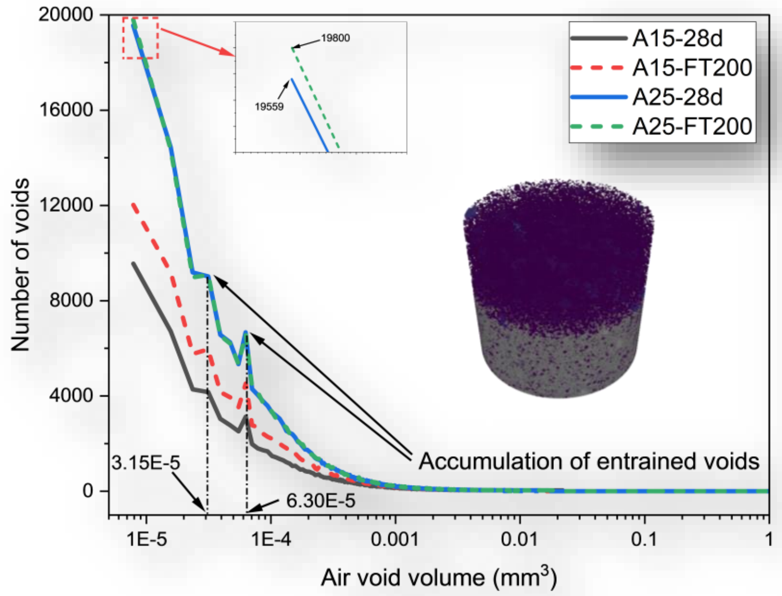
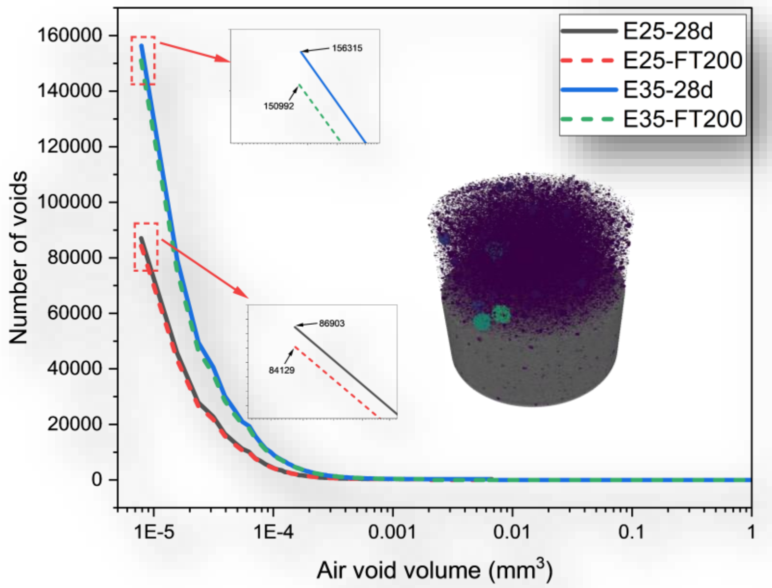


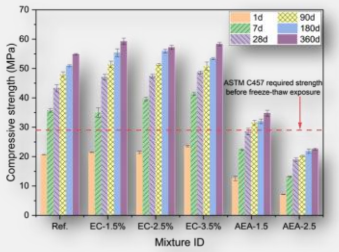


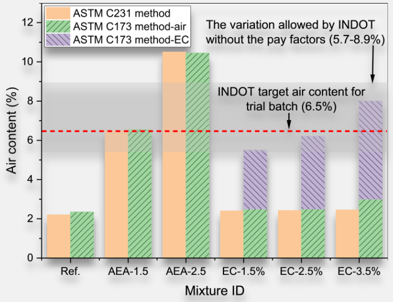


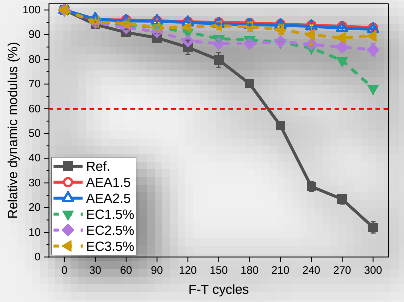
- Without air entraining, the Ref. specimen showed a significant void number increase after freeze-thaw exposure
- AEA specimens showed void number increase after freeze-thaw exposure and **unevenly distributed void size**
- EC specimens showed **fine and evenly distributed void**, which is favorable for freeze-thaw resistance

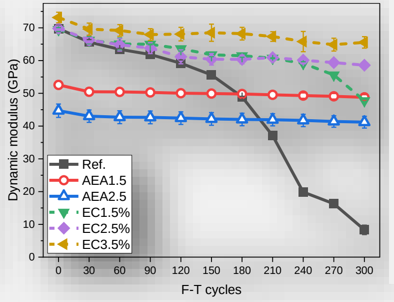
Conclusions

- For air-entrained concrete with similar freeze-thaw resistance, achieving the same target strength using microspheres can reduce the amount of cement required.
- The **compression method** (ASTM C231) does not accurately reflect the entrained air from EC. However, the **volumetric method** (ASTM C173) effectively measures the entrained air by EC
- With 2.5% and 3.5% EC additions, after 300 freeze-thaw cycles, the **relative dynamic modulus remains comparable** to that of concrete with 6.5% and 10% entrained air through traditional AEA.
- After 300 freeze-thaw cycles, EC-entrained concrete maintains **a higher dynamic modulus value** and experiences **less mass loss** than traditional AEA-entrained concrete.
- EC-entrained air concrete demonstrates **a more uniform air void distribution** compared to traditional AEA-prepared concrete.









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THANKS

Any Questions?

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