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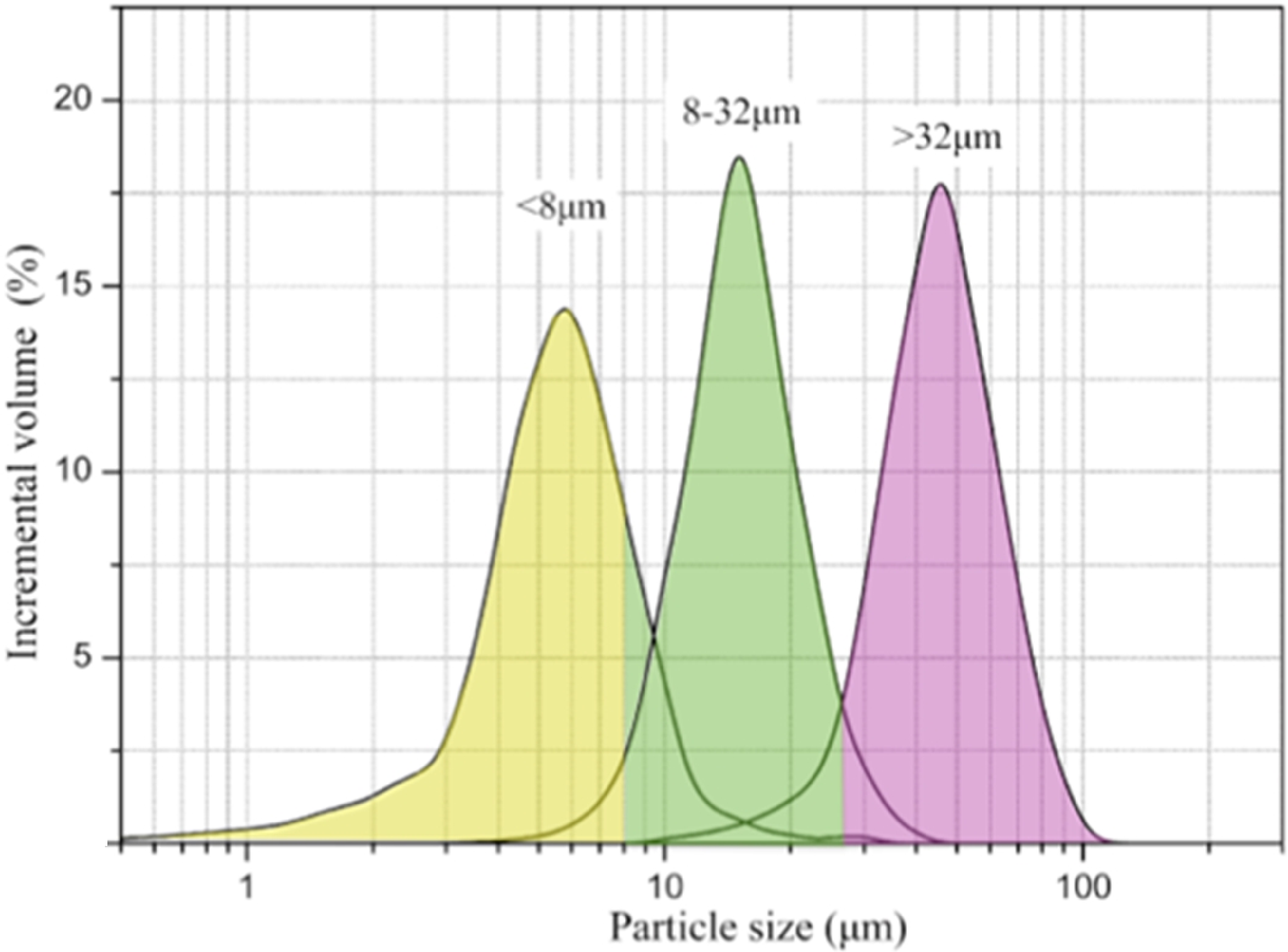
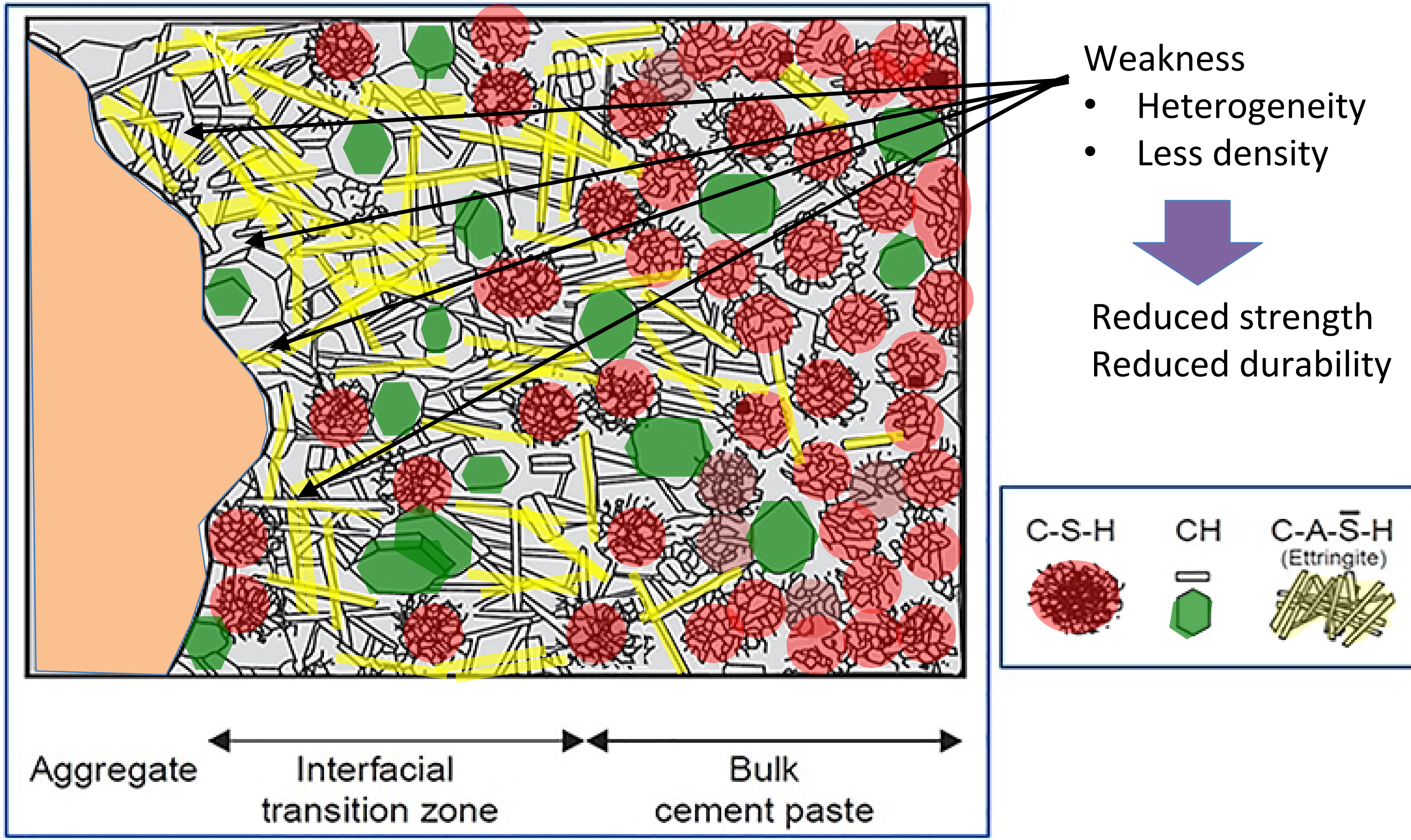
Can Improved Paste-Aggregate Interaction at the Interfacial Transition Zone Enhance Durability?

Basic Philosophy of Particle Size Selection



What is the Interfacial Transition Zone (ITZ)



Weakness
- Heterogeneity
- Less density

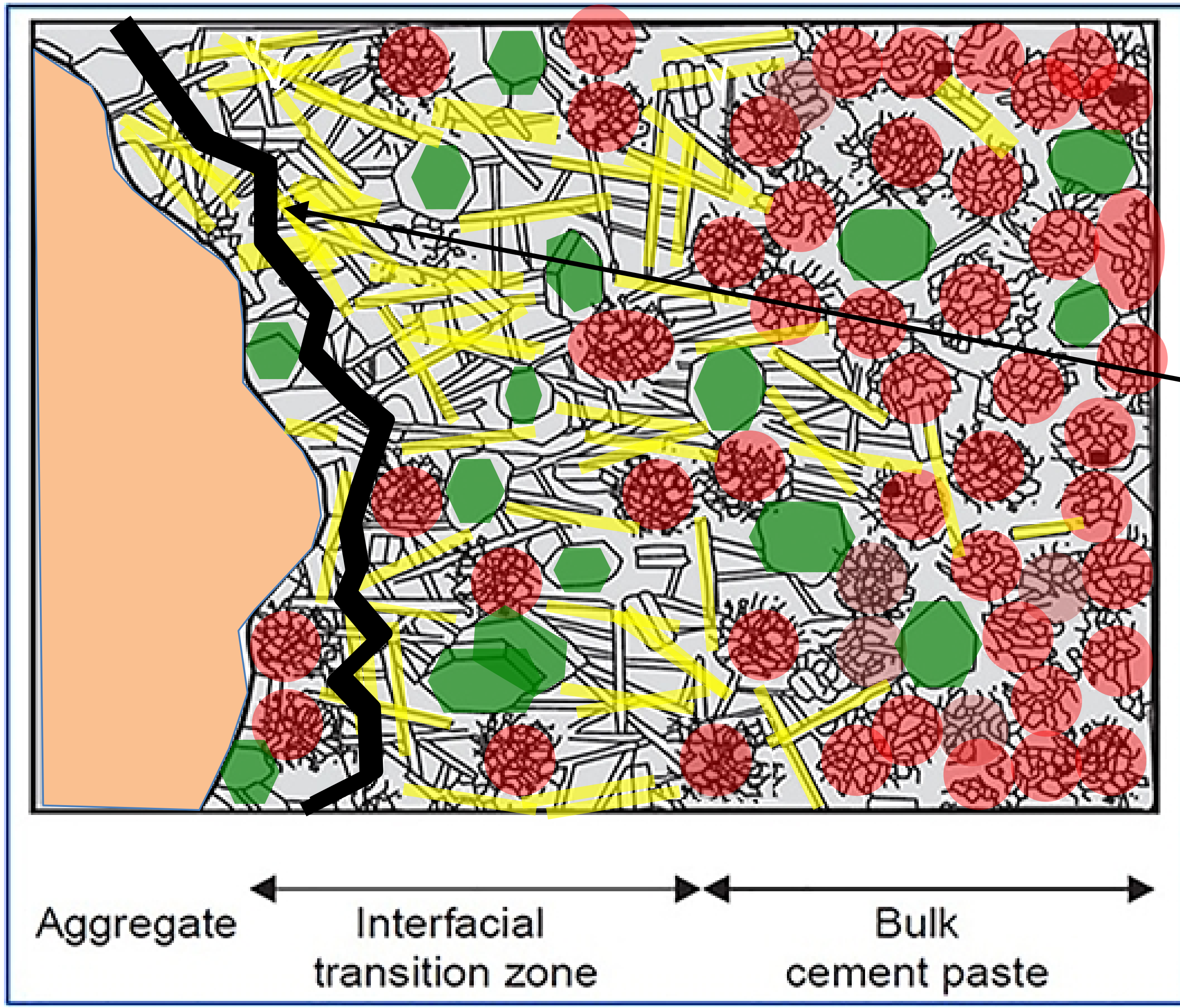
Reduced strength
Reduced durability

The problem with weakness in the ITZ

Issues with weak cement paste in the ITZ:

- Lower compressive strength due to weaker bond
- Reduced durability because of increased porosity
- Shrinkage due to dissolution of cement particles
- Highly alkaline CH in ITZ can carbonate or form ettringite (expansion issues)

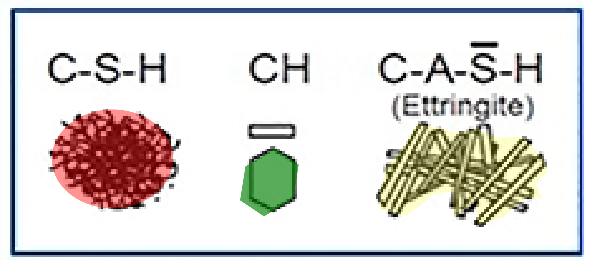
Shrinkage leads to cracks in the ITZ



Shrinkage from dissolving cement particles

Cracking

Opens doors to Chemical Attack



The benefits of a denser paste in the ITZ

Denser paste provides better protection against chemical attack

- less paste porosity reduces transport of ions from salts, including chlorides and alkali
- less fissuring in ITZ reduces channels for moisture and salt ingress

Evidence supports this: e.g. commonly used silica fume to fill voids between cement particles in bulk paste and in ITZ, but ...

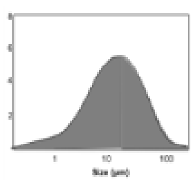
Possible downsides of silica fume: cost, scarcity of supply, poor rheology and finishability, high water demand, high level of superplasticizers, plastic shrinkage

UFFA - An alternative to silica fume

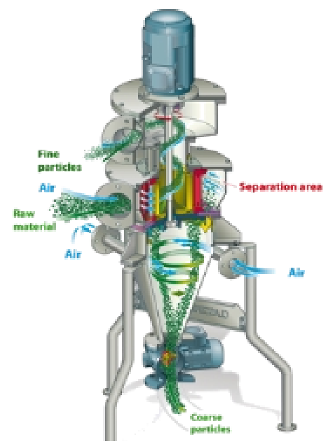
Ultrafine fly ash (UFFA) can provide many of the benefits of silica fume (e.g. Micron3 by Boral). Pros of UFFA vs. silica fume:

- lower cost & more availability
- better rheology/lower water demand & lower admixture requirement
- less shrinkage
- less sticky / better finishability

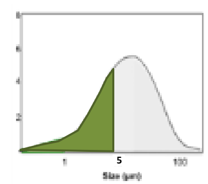
Huntington Plant



OFF SPEC FLY ASH



~20-25% of ash is high end product



MARKETABLE PRODUCT (high performance cement substitute)

Pacificorp recently issued in RFI/RFP for Hunter and Huntington fly ashes

Roman Cement is partnering with a company participating in RFI/RFP and will be providing test data

A field test of UFFA products

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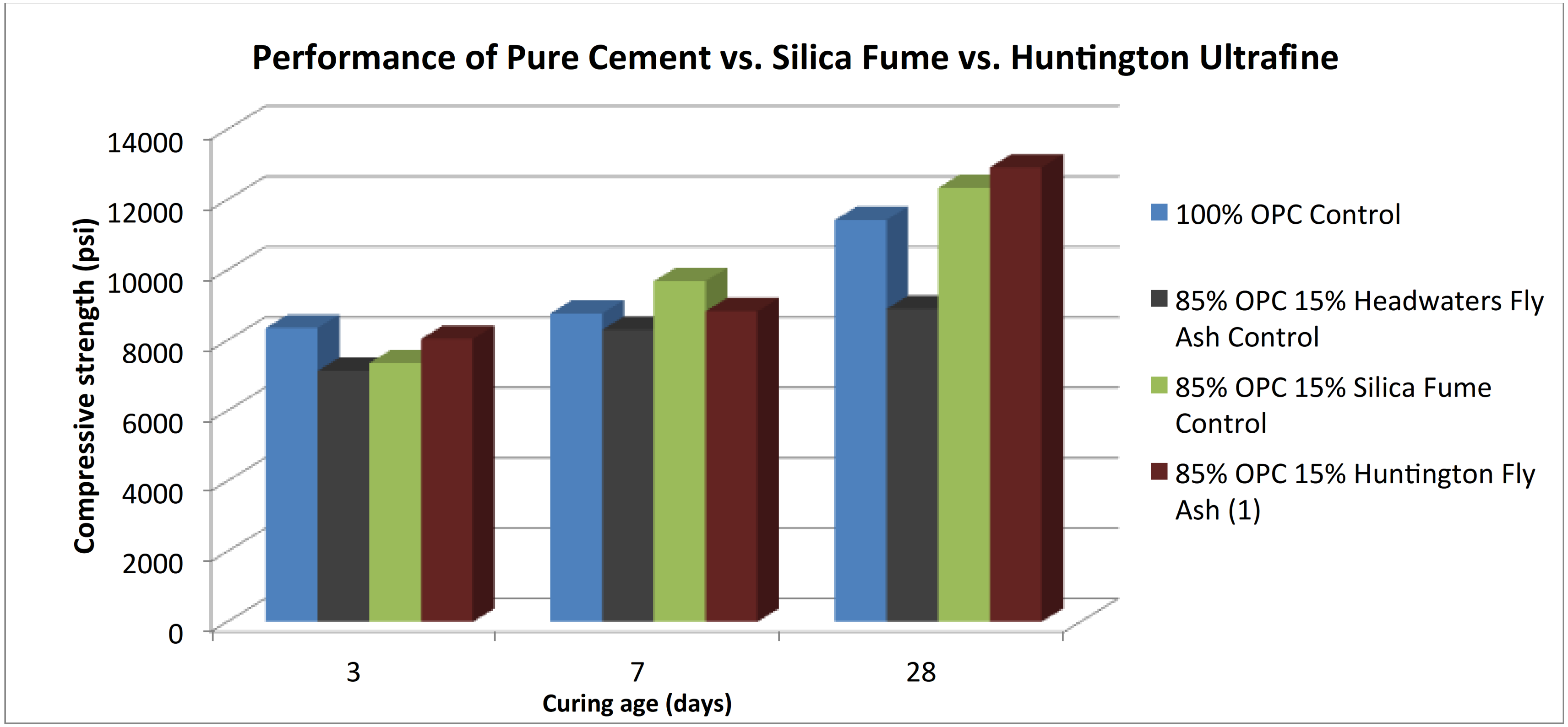
- Roman Cement has been working with Pacificorp (Berkshire Hathaway) to develop a UFFA product since 2016
- Hunter and Huntington power plants
  - poor quality fly ash, almost entirely landfilled, high carbon

Fly ash was classified to D90 of about 8-10 microns (D50 of about 3.5 microns)

Mortar and concrete test results:

- high strength, comparable to silica fume
- lower admixture requirement
- much less sticky, better workability/finishability
- excellent strength performance when used in amounts of 5-20% by weight of cementitious binder

Results of Huntington UFFA



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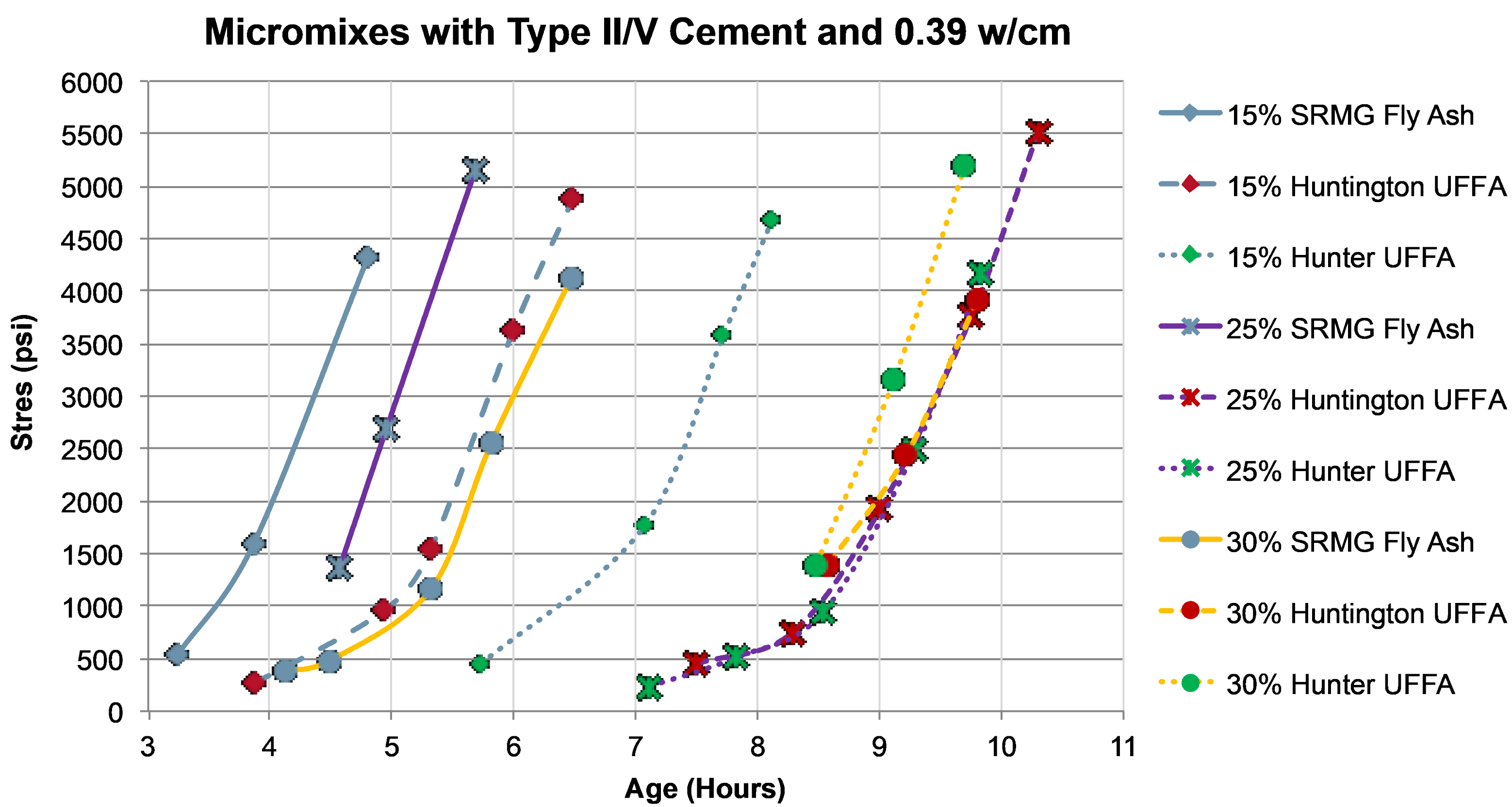
Known issues with UFFA - retardation

UFFA from Pacificorp Hunter and Huntington plants induced significant retardation



Use of Limestone to offset UFFA retardation

Roman Cement worked with a precast manufacturer and a concrete company to find a solution to retardation

Several blends containing Mine Rock Dust and other limestone powders were tested:

- Concrete with OPC, UFFA, Rock Dust
- Concrete with OPC, GGBFS, Rock Dust
- Concrete with OPC, Fly Ash, Rock Dust
- Concrete with OPC, GGBFS, (optionally UFFA or fly ash) Limestone “Flour” (Blue Mountain Minerals)
- Decorative precast with white cement, GGBFS, Marble White 80 (Specialty Minerals)
- GFRC with white cement, GGBFS, Marble White 80 (or Rock Dust)

Tested Limestone Powders – Particle Size Distributions

These limestone materials are all coarser than OPC

- OPC -> 1-45 microns
- Rock Dust -> 1-110 microns / D50 ~ 17 microns
- Blue Mountain Flour -> 5-150 microns / D50 ~ 45 microns
- Marble White 80 -> 10-200 microns / D50 ~ 75 microns

Question: When designing a concrete or precast concrete mix, how should we classify the Rock Dust, Flour, Marble White 80?

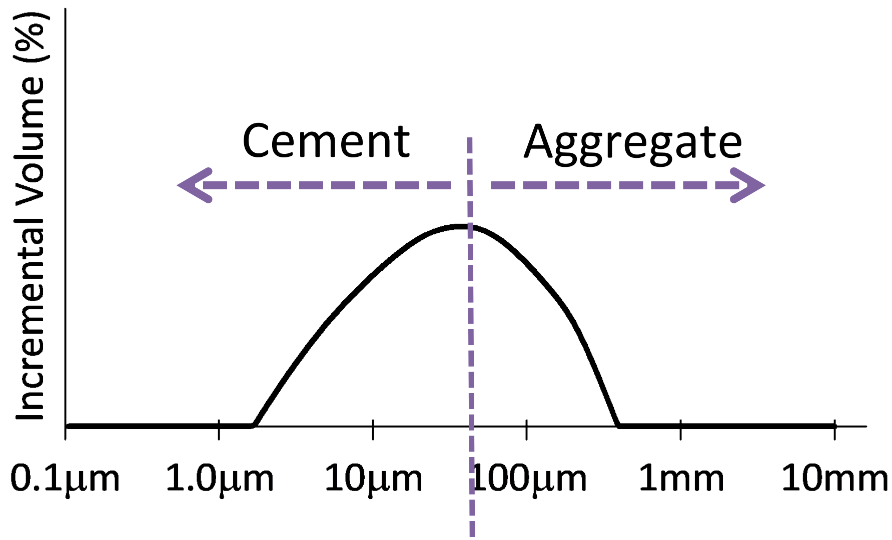
- Is it aggregate?
- Is it cement?
- Does it matter? → **Yes it does!**

From a design and proportioning standpoint it matters a lot

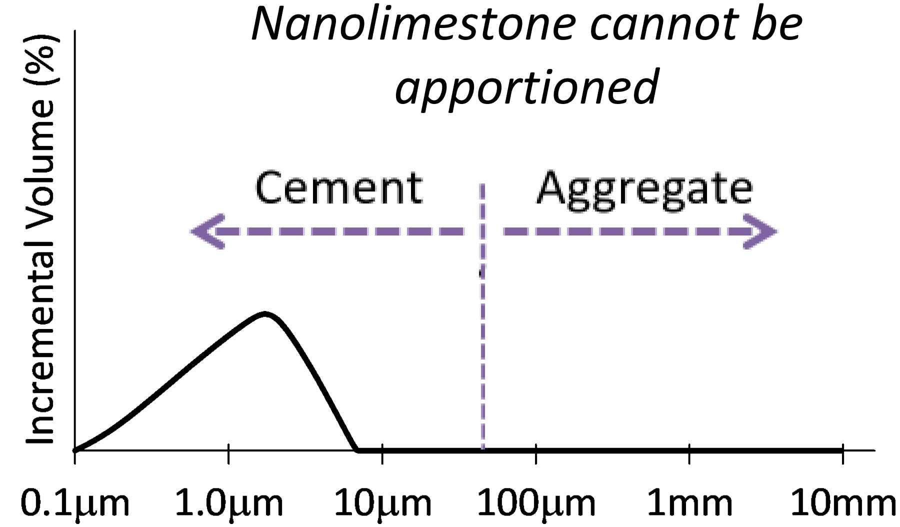
Apportionment - where do we draw the line?

Apportion coarse limestone between cement and aggregate depending on particle size and the effect on water demand, e.g.:

- Rock Dust (60% cement, 40% aggregate)
- Blue Mountain (45% cement, 55% aggregate)
- Marble White 80 (25% cement, 75% aggregate)
- Note – dividing line not fixed but empirically determined

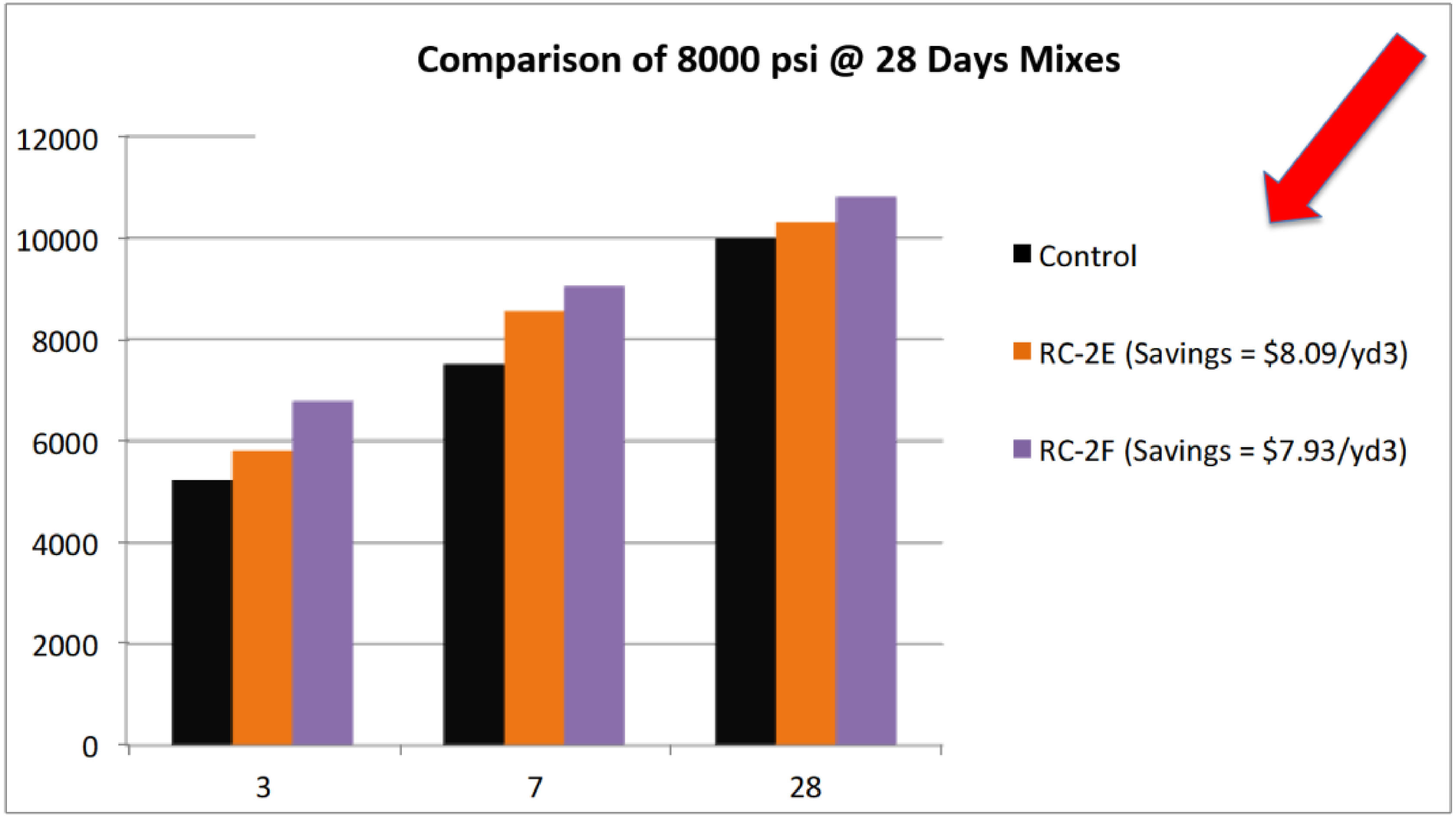


Nanolimestone cannot be apportioned



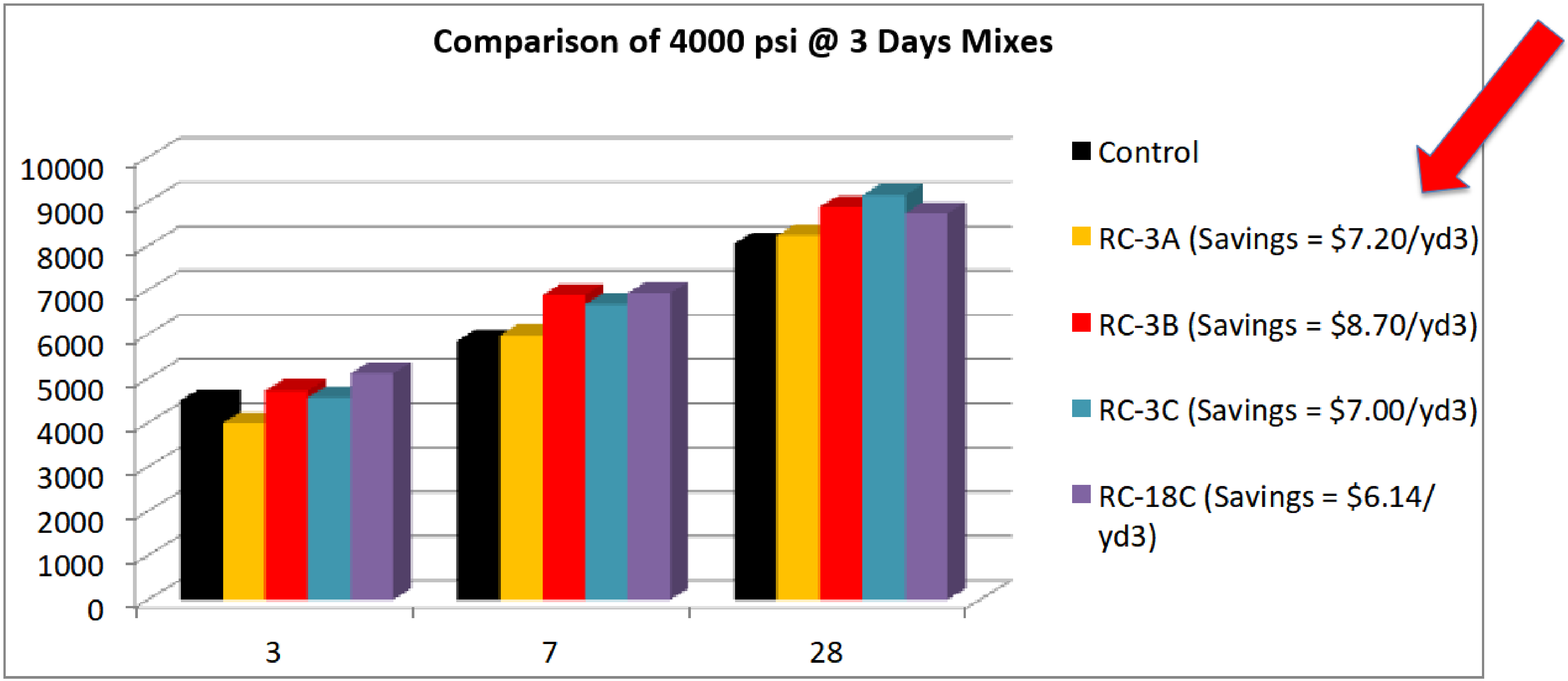
Test Results – 8000 psi mix

Testing of commercial concrete mix designed for 8000 psi @ 28 days



Test Results – 4000 psi mix

Testing of commercial concrete mix designed for 4000 psi @ 3 days



Conclusion: benefits of apportioned limestone addition

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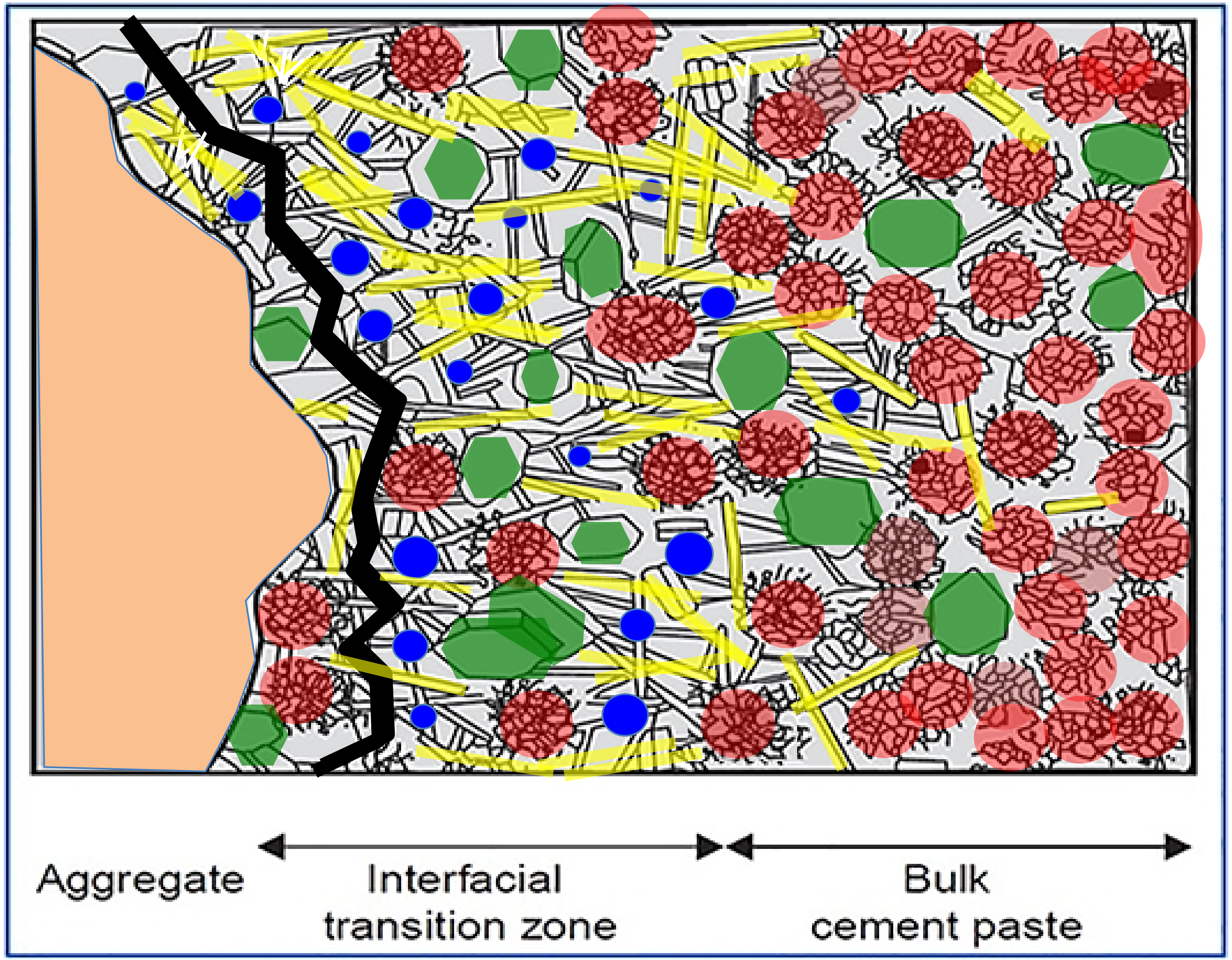
Conclusion:

Apportionment of coarse limestone yields consistent and high performance results:

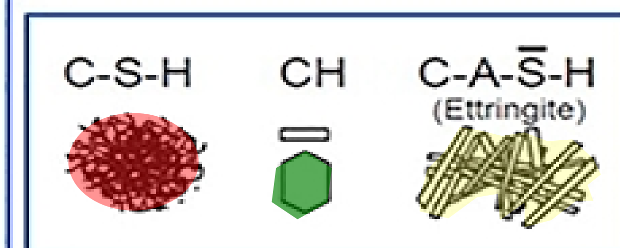
- Highly predictable rheology
- Highly predictable strength
- Substantial cost savings

Effect of limestone addition on the ITZ

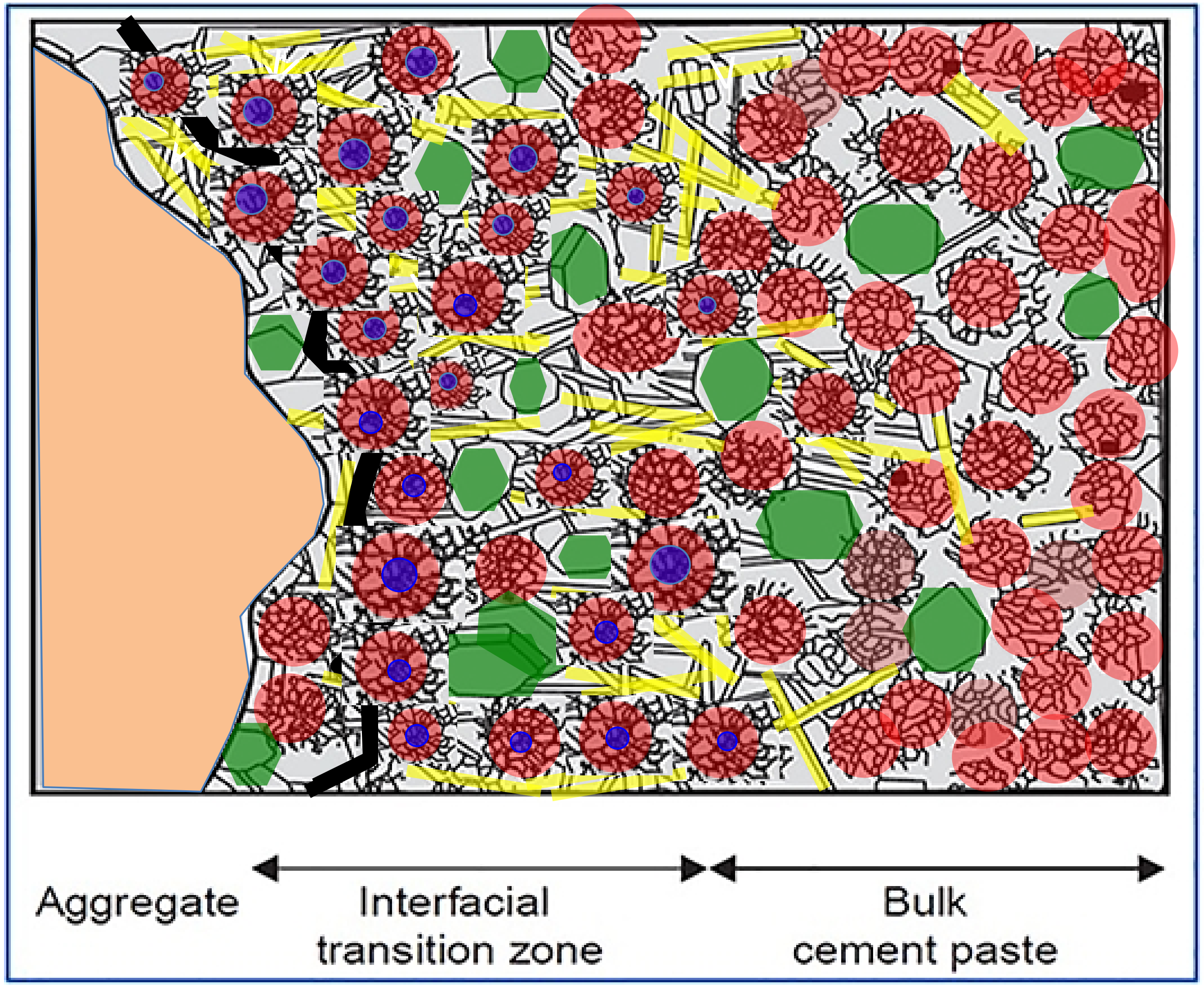


Limestone particles

Coarse and fine Limestone particles fill the ITZ

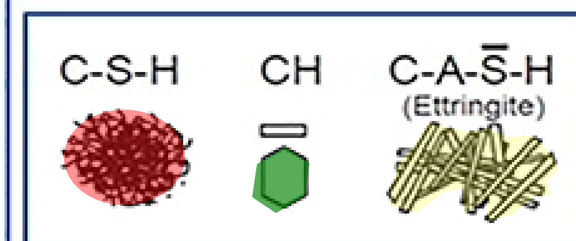


Strengthening of the ITZ by nucleation sites



Limestone particles / nucleation sites

C-S-H forms around the limestone particles that act as nucleation sites.



Fine tuning of limestone-apportioned mixes

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Effect on ITZ: Higher bond strength between paste and coarse aggregate

Other ways to further increase strength:

- Addition of supplemental lime (0.5-1.5%)

  Note: Literature shows lime being tested at 5%, 10%, 15%, and 20%, which never works -- effectiveness of lime is limited by low solubility of calcium hydroxide ***[Do not use more than will dissolve in mix water and be consumed early on!]***
- Supplemental calcium sulfate (0.5-1.5%), again, limited by solubility of calcium sulfate dihydrate ***[Do not use more than will dissolve in mix water and be consumed early on!]***

Purpose of lime-sulfate addition: correct aqueous chemistry during early stages of mixing and initial hydrate

- raise pH to activate fly ash and slag
- provide sulfate to react with aluminates in fly ash and slag