Aggregate Morphology in Cement-Based Materials

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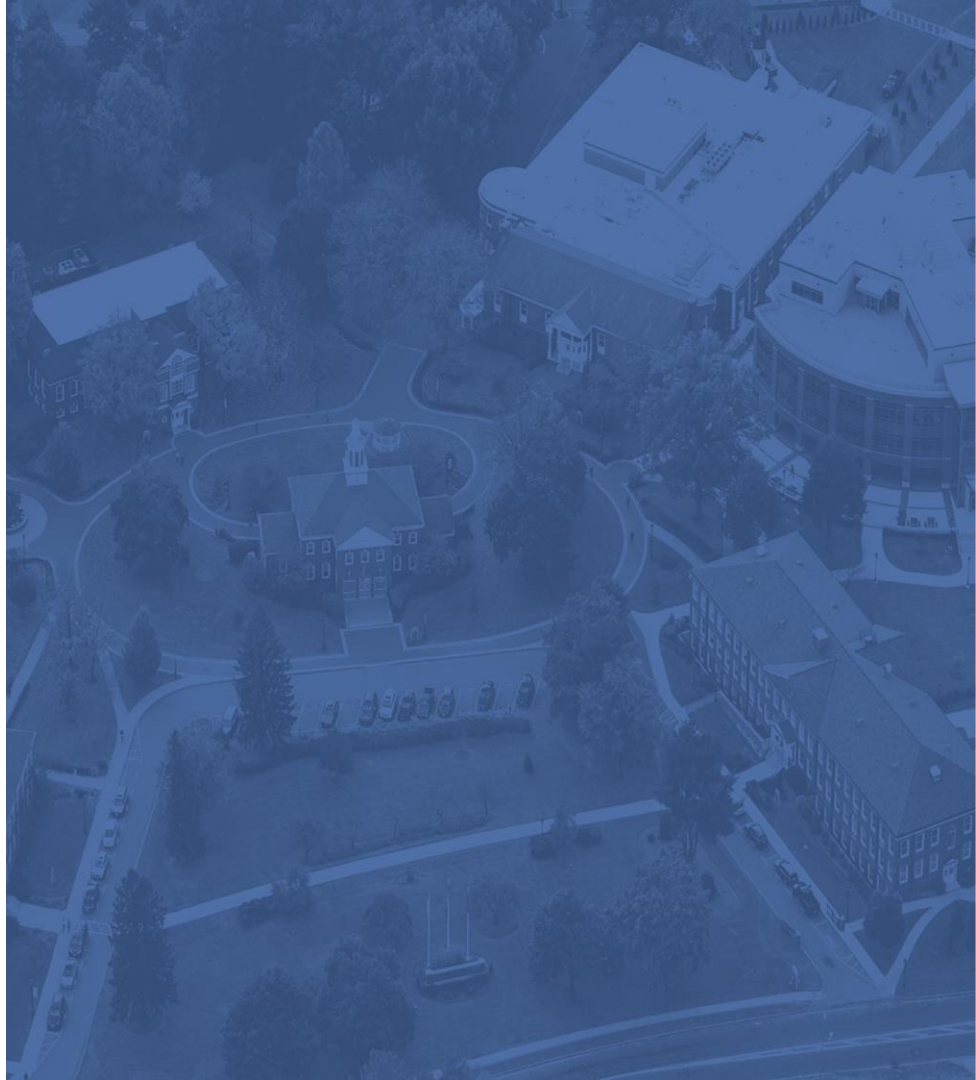
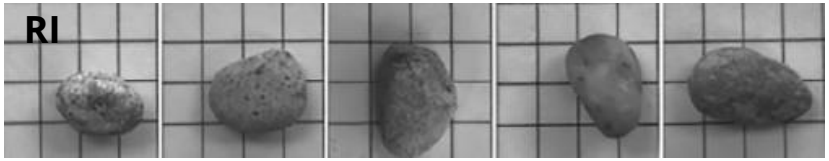
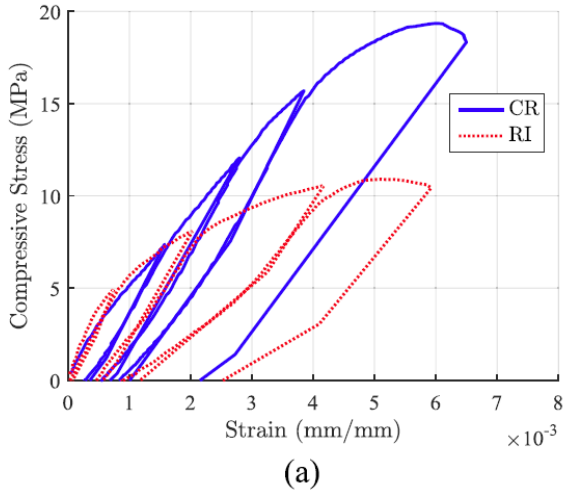


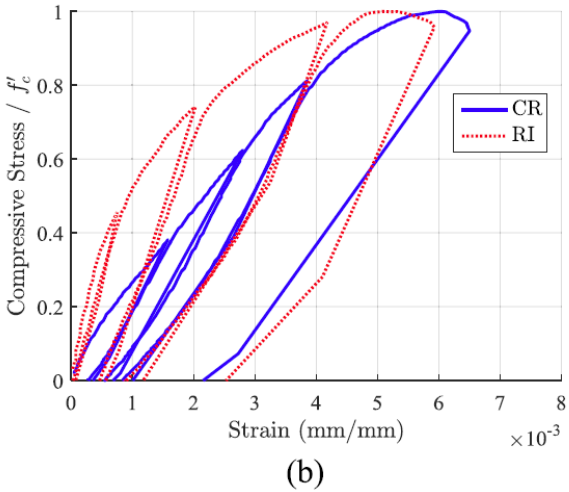
WHY?

Influence of Aggregate Shapes

- No fine aggregate
- Maximum strength vs. Resilience from pseudo-cyclic loadings.
- CR: Crushed / RI: River (Round)







[Lee et al., 2019]

WHY?

2D Morphology Parameters:

- Sphericity
- Roundness
- Regularity

3D Morphology Parameters:

- Volume
- Surface area
- “True” Sphericity [Wadell, 1932]

2D Morphology Parameter

$$\text{Area sphericity} : S_A = \frac{A_s}{A_{cir}}$$

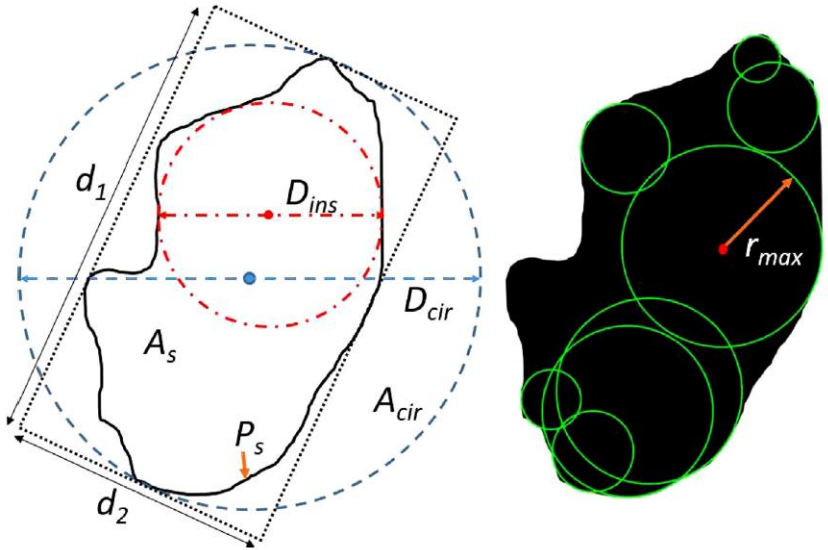
$$\text{Diameter sphericity} : S_D = \frac{D_c}{D_{cir}}$$

$$\text{Circle ratio sphericity} : S_C = \frac{D_{ins}}{D_{cir}}$$

$$\text{Perimeter sphericity} : S_P = \frac{P_c}{P_s}$$

$$\text{Width to length ratio sphericity} : S_{WL} = \frac{d_2}{d_1}$$

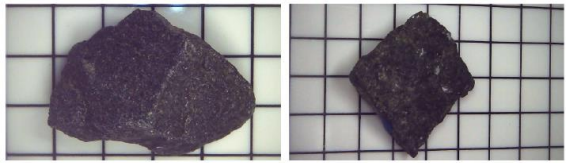
$$\text{Roundness} : RD = \frac{\sum_i (r_i / r_{max})}{N}$$



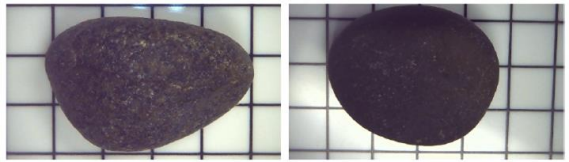
- **ASTM D4791: Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles**
- **Aggregate Image Measurement System (AIMS)**

2D Morphology Parameter - Issues

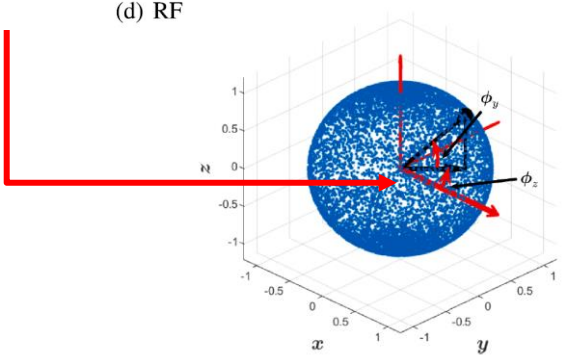
[Lee et al., 2022]

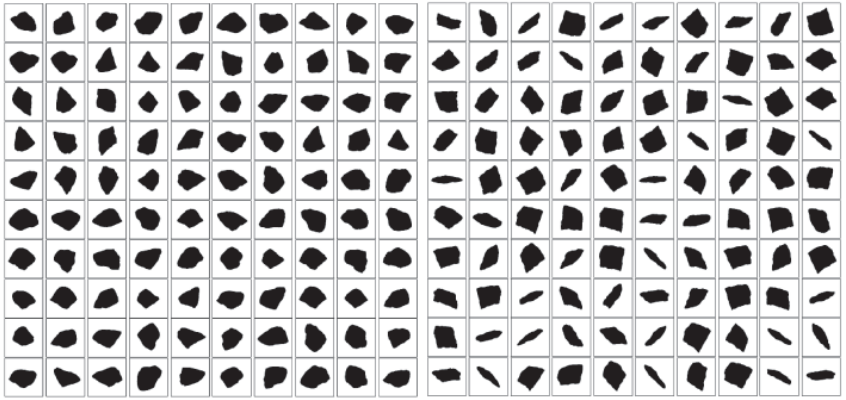


(a) CO (b) CF

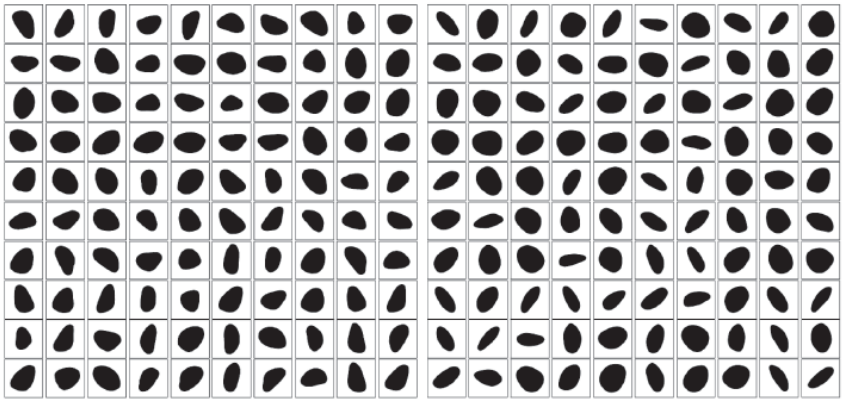


(c) RO (d) RF





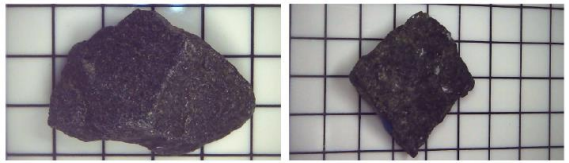
(a) Particle CO (b) Particle CF



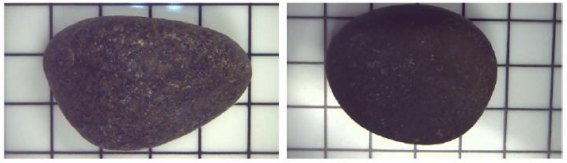
(c) Particle RO (d) Particle RF

2D Morphology Parameter - Issues

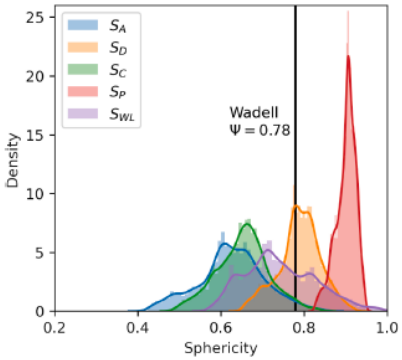
Variability according to projection angles



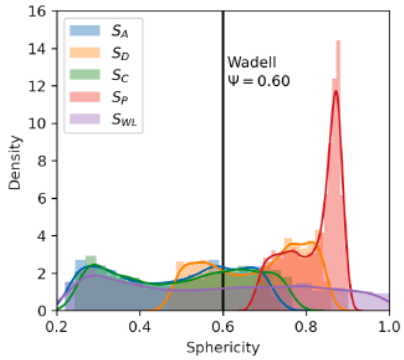
(a) CO (b) CF



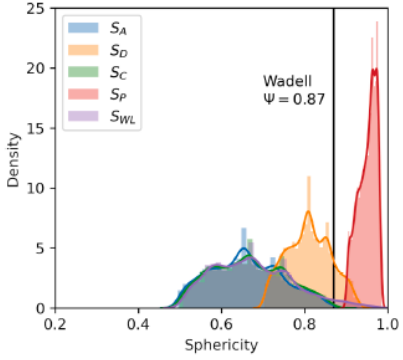
(c) RO (d) RF



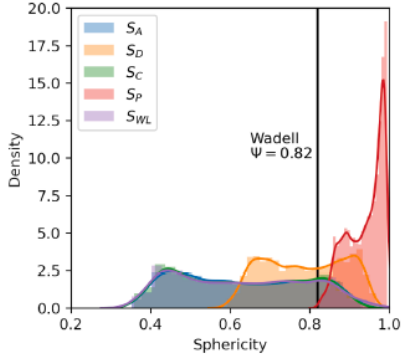
(a) Particle CO



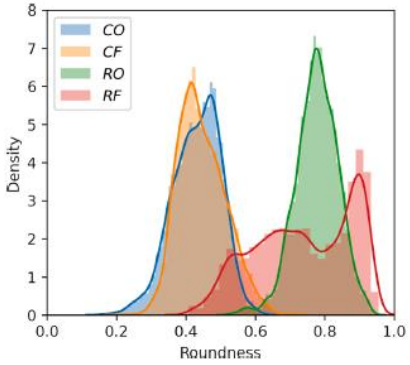
(b) Particle CF



(c) Particle RO



(d) Particle RF



3D Morphology Parameter

“True” Sphericity [Wadell, 1932]

$$\psi = \frac{A_{eq}}{A}$$

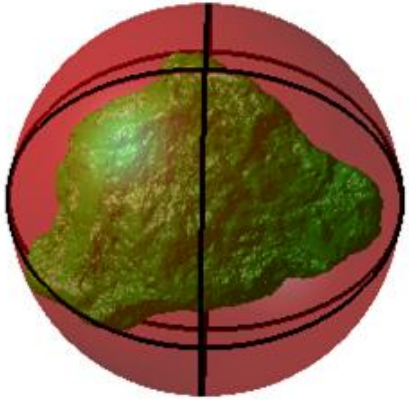
$$0 \leq \psi \leq 1$$

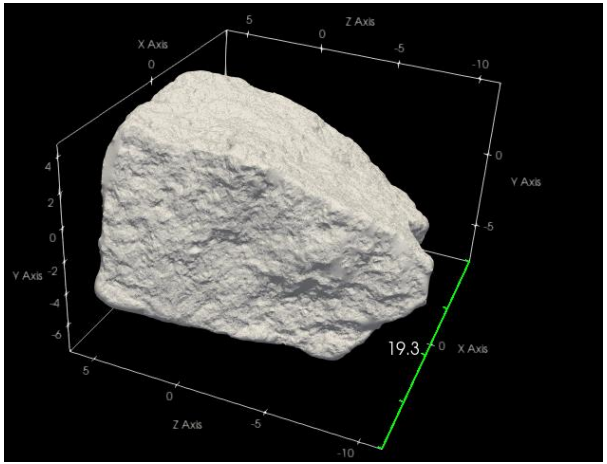
M-A-V-L [Su et al., 2020]

$$M = \frac{AL}{6V}$$

$$1 \leq M < \infty$$

$$M = \frac{1}{\psi} \cdot \frac{L}{D_{eq}}$$





3D Morphology Parameter - Measurement

Structured Light Scanning

Collect Point Clouds → Acquire point clouds from Multiple angles → Reconstruction of 3D model by photogrammetry

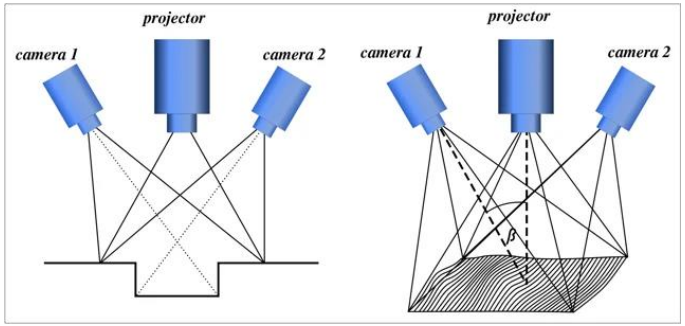
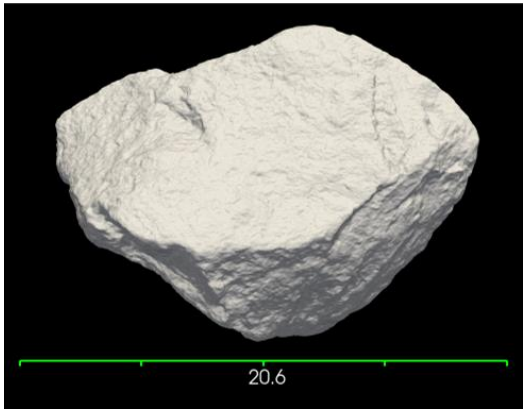


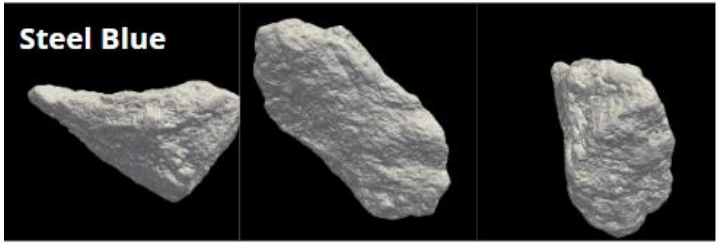
Figure by https://blog.medit.com/medit/what-is-structured-light-scanning



- **Polyga FlexScan3D C504**
- **Resolution: 6 microns (i.e., distance between a point-to-point)**

3D Models from SLS

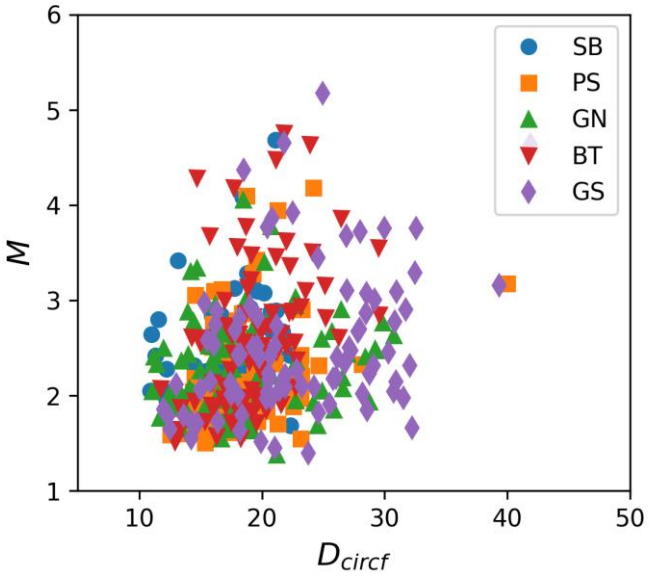
- 3D Models obtained from Structured Light Scanning
- 5 different coarse aggregates from a local quarry (Chicopee, MA)



3D Parameters from SLS - Individual Particles

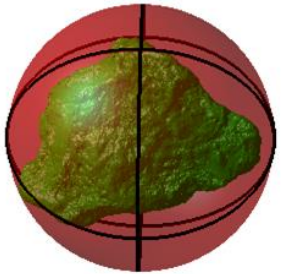
- **Different Morphology Parameters**

$$M = \frac{AL}{6V}$$

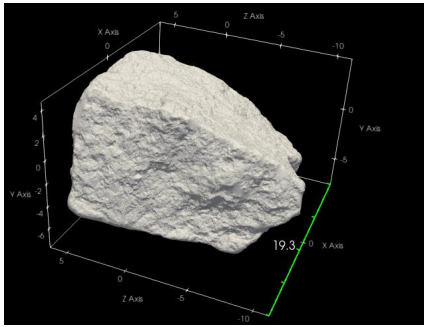


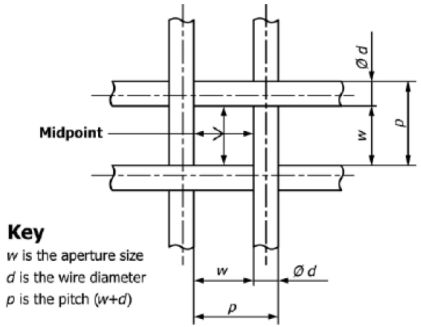
Which "L" must be used?

D_{circf}



L_{max}

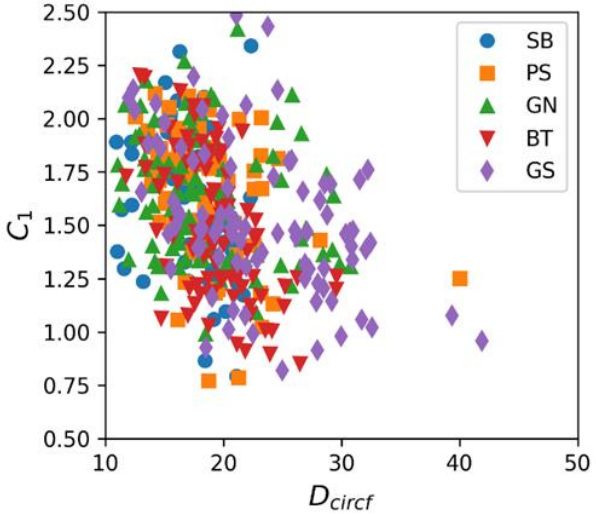




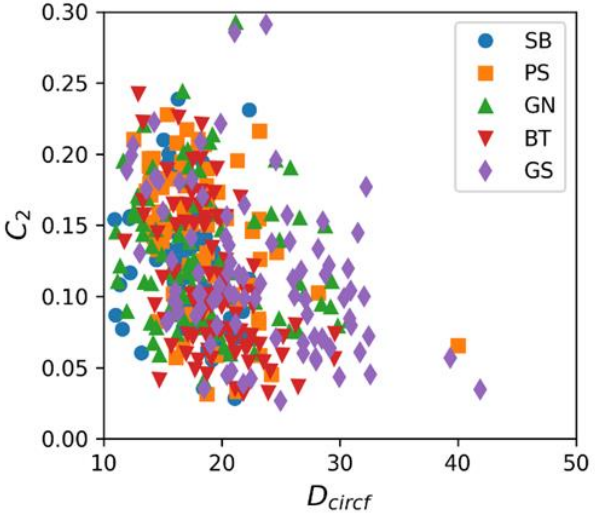
ASTM E11: Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves

3D Parameters from SLS - Individual Particles

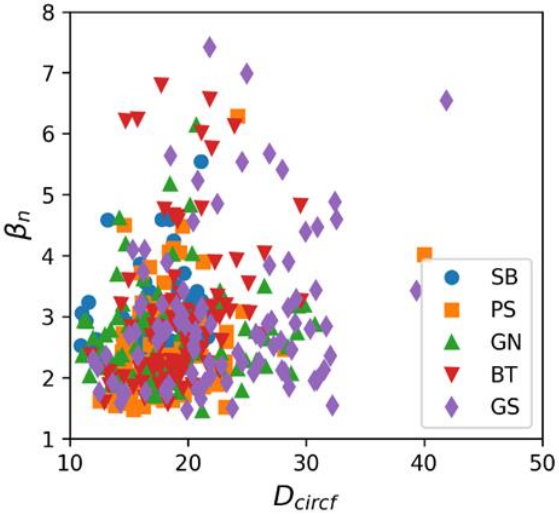
- **Different Morphology Parameters**



$$A = C_1 D_{circf}^2$$



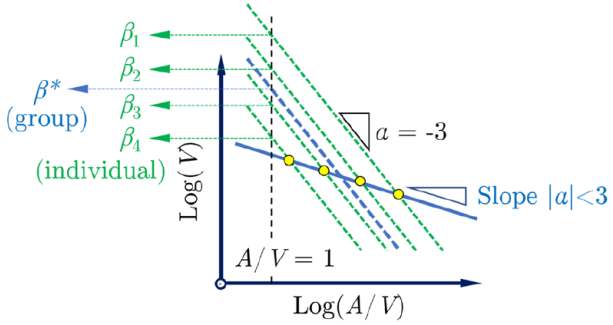
$$V = C_2 D_{circf}^3$$



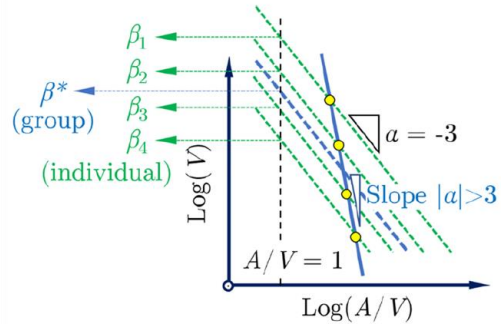
$$A^3 = \exp(\beta_n) \cdot V^2$$

Group Particle Morphology

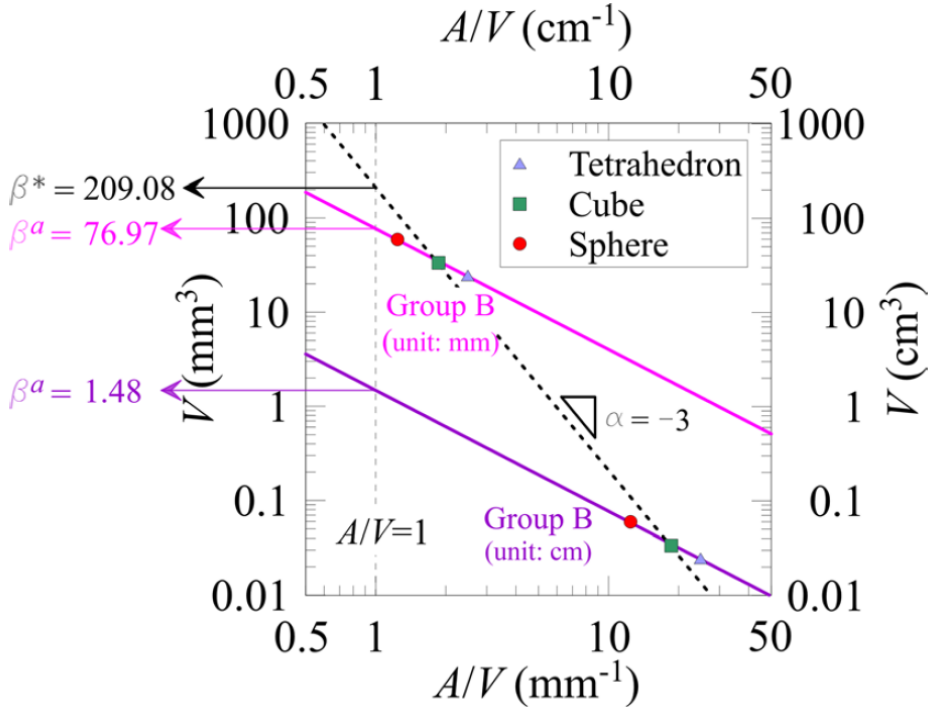
- **Power Law** to obtain the group 3D morphology parameter [Lee et al., 2022]



|a|<3 : Smaller particle → More angular

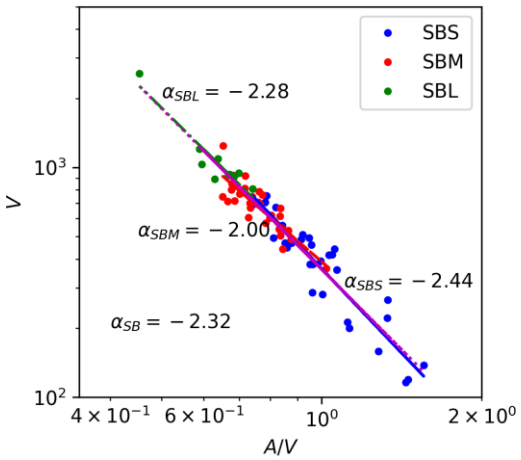


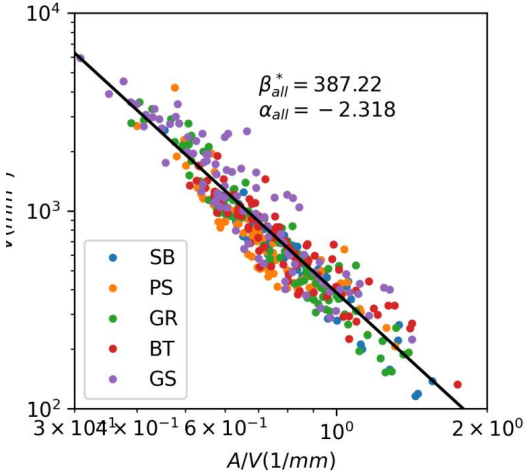
|a|>3 : Larger particle → More angular



Group Particle Morphology

- **Results from 500+ samples**
- **5 different groups of coarse aggregates available in Western MA**





Type	α	β*
SB	-2.324	360.32
PS	-2.130	350.72
GR	-2.473	345.50
BT	-1.888	424.53
GS	-2.266	427.09

- **α : Degree of Morphology Uniformity in Group**
- **β*: Group Morphology Parameter**

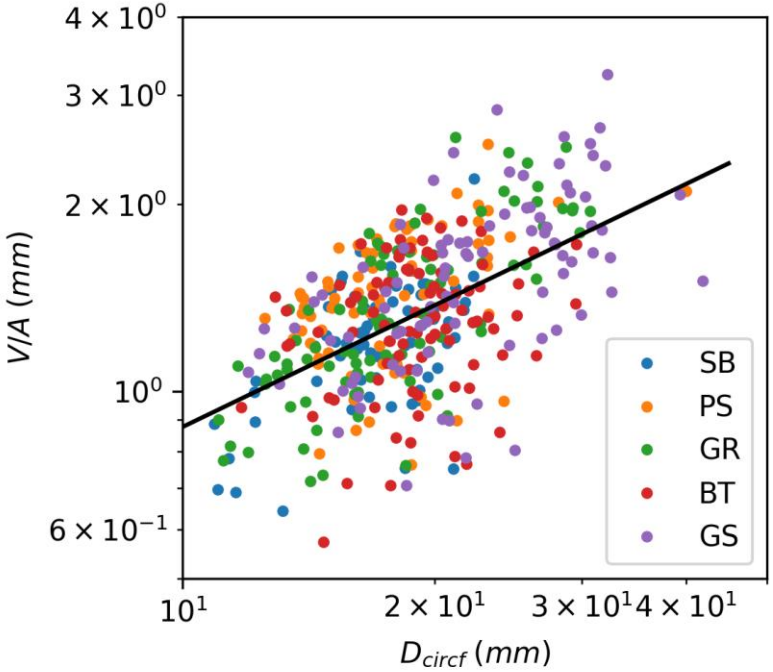
Current Practice of Mixture Design

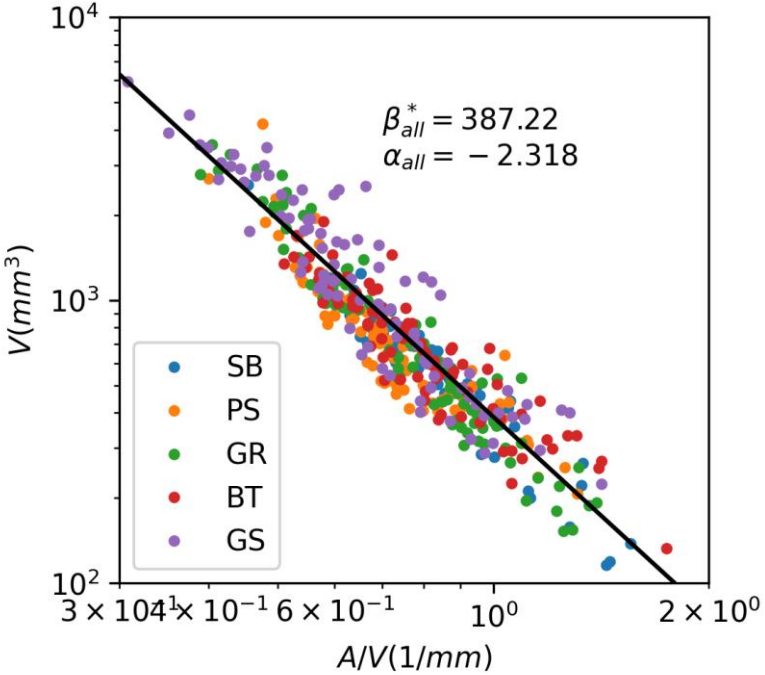
- **ACI 211.1**
  - Maximum (coarse) aggregate size: Water Content, Bulk Volume of Coarse Aggregate, Required air content for Freeze-and-Thaw.
  - Fineness Modulus: Bulk Volume of Coarse Aggregate.
  - Use of round aggregate: Reduce water contents by 8%.
- **ACI 302.1R**
  - Guidelines for the gradings of fine, coarse, and the combined aggregates for floor and slab construction
- **ACI 325.14**
  - Guideline for the grading of the combined aggregates for pavement.
  - Shilstone Coarseness Factor Chart, 0.45 power plot,
  - Limit the maximum flat/elongated aggregate (15 to 20%)

1D Morphology (i.e., Size) has been used for the references.

Estimation of 3D Parameters from 1D Information

- **D_{circf} : More conservative than the sieve size.**



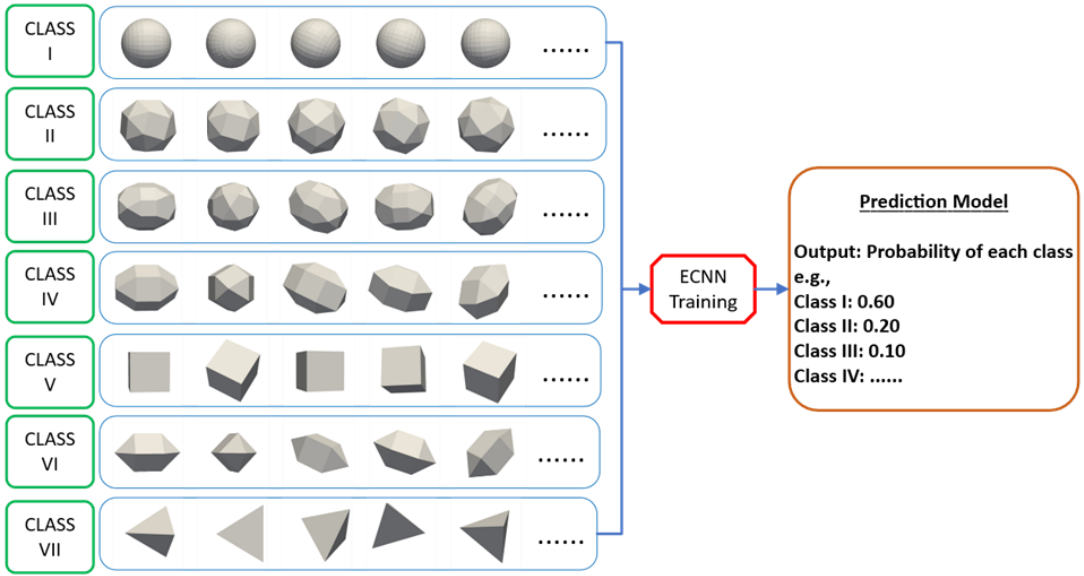


$$\frac{V}{A} = f(D_{circf})$$

$$\ln V = \beta^* + \alpha \ln\left(\frac{A}{V}\right)$$

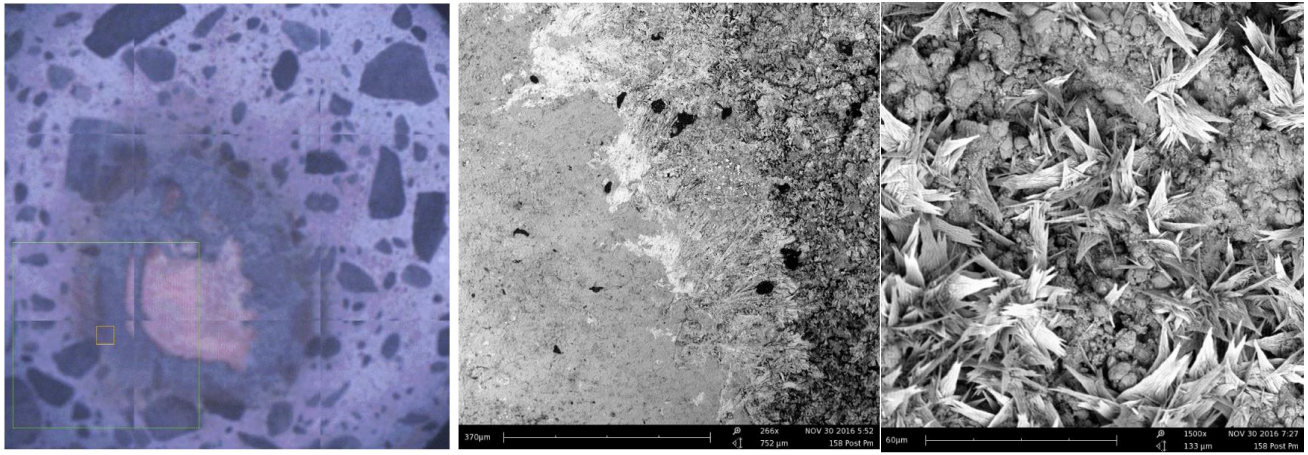
Research in Progress

- **Possible to reduce the time for measuring 3D morphology parameters?**
  - Efficient Convolutional Neural Network (ECNN)
    - Take 2D images by Mobile platform (Pad, Phone)
    - ECNN algorithm will estimate 3D morphology parameters. (e.g., β)
    - Collected 3D morphology parameters used for build V and A/V



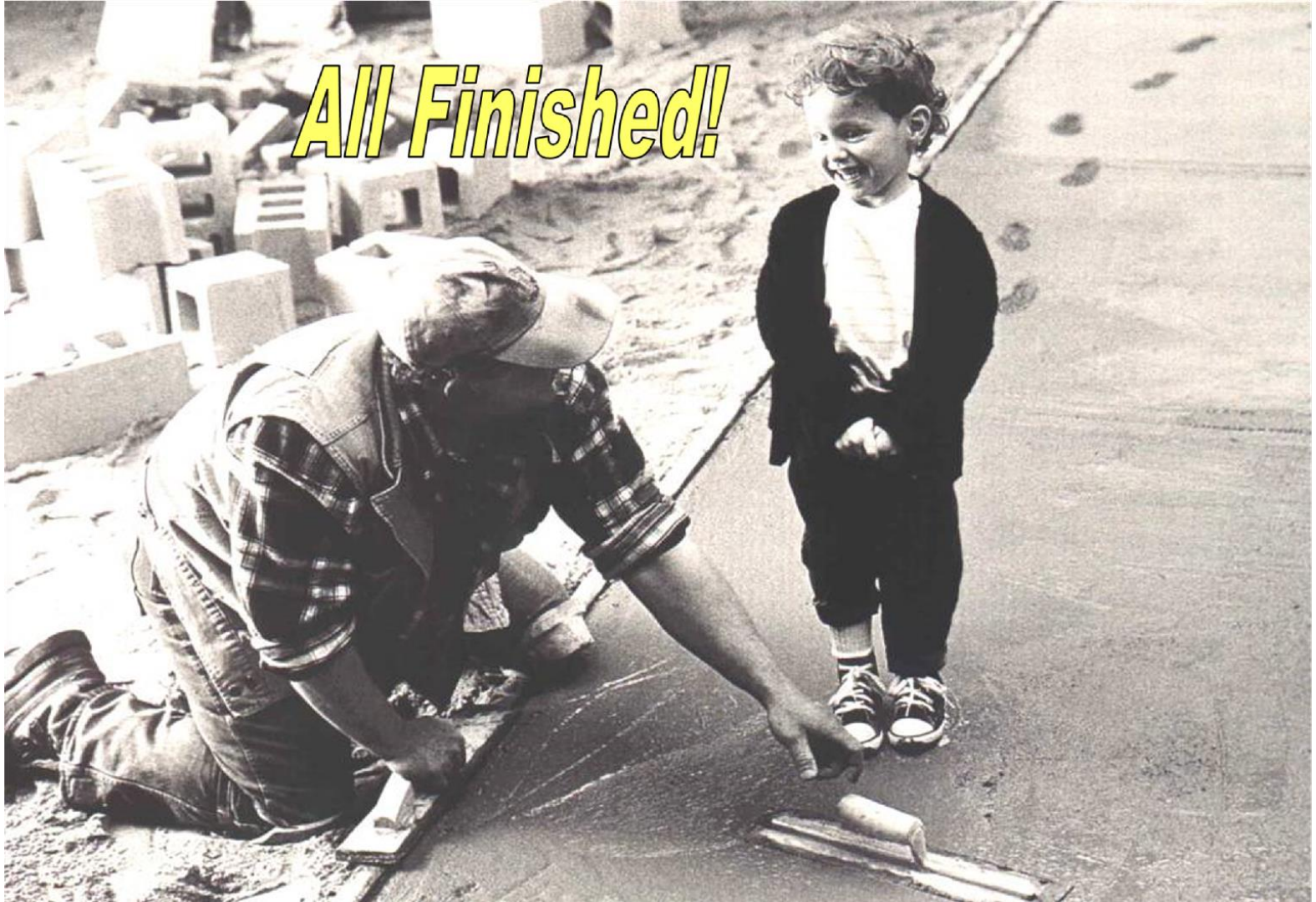
Research in Progress

- Influence of Aggregate Morphology on Mechanical/Rheological Properties of Cement-Based Materials
  - 3D Printing Particles
  - Selecting the particle out of database according to the controlled morphology parameter.
  - Require No supports in printing / No chemical reaction with paste matrix.



3D Printed Particles (Gypsum)

3D Printed Particles (Resin)


All Finished!

Research in Progress

- **Measurement of volume and surface area of Fine Aggregates**
  - Surface area produced by fine aggregates greater than that by the coarse.
  - Correlation to Fineness Modulus (i.e., average size of fine aggregate)
    - Standard Method: ASTM C136
    - Functional type: $D = 2^{FM} \bar{D}_{N+1}$ where D_{N+1} = the average sieve size of #100 and #200.
  - Maybe possible to use a Micro computerized tomography (Micro CT)
  - Morphology change tracking in comminution process. (Abrasion vs. Breakage)