A Study of Aggregate Settlement in a Simulated Cement System

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Background

- Self consolidating concrete (SCC) must flow under own weight, resist segregation
- Admixtures, cm/w ratio, aggregate selection
Purpose

• Evaluate impact of aggregate size and gradation on segregation in SCC
• Examine models for segregation
Relationships

- Settling velocity indicates segregation resistance
- Relation between single particle velocity, average multiple particle velocity, and packing density
Affect of Multiple Particles

• As volume of particles approaches volume of container, group settling velocity approaches zero
• Gradation affects packing density
Mechanisms of Action

- Particles collide with each other slowing the velocity, different size particles settle at different speeds.
- Particle causes an upward movement of fluid surround particle slowing the velocity of other particles, slower average settling velocity.
Methodology

• 4 different glass marbles in 3 different fluids
• Varying volume fractions and particle sizes
• Measured average settling velocity
Analysis

• Measured multiple particle velocity and volume fraction, solved for single particle velocity and coefficient using regression analysis

\[ u_a = u_s \left(1 - \frac{\varphi}{\varphi_m}\right)^k \]  

(Shen, 2009)

• Where: 
  - \( u_s \) = single particle settling velocity
  - \( u_a \) = average group settling velocity
  - \( \frac{\varphi}{\varphi_m} \) = vol. fraction/max packing density
Analysis

- Regression analysis in form of:
  \[ u_\alpha = u_s \left( 1 - \frac{\varphi}{\varphi_m} \right)^k \]

- \( u_\alpha \) as dependent variable and \( 1 - \frac{\varphi}{\varphi_m} \) as the independent variable

- Values found for \( u_s \) and \( k \)

- Regression values for \( u_s \) strongly correlated with the experimental values

- Strong correlation for variables in proposed model

- **High Viscosity**
  - \( R^2 = 0.9976 \)
  - \( 0.6 \quad 0.7 \quad 0.8 \quad 0.9 \quad 1 \quad 1.1 \quad 1.2 \)
  - \( 0 \quad 0.05 \quad 0.1 \quad 0.15 \)
  - Log Group Velocity
  - Linear (25 mm) vs Linear (21 mm)

- **High Viscosity**
  - \( R^2 = 0.9894 \)
  - \( 0.6 \quad 0.7 \quad 0.8 \quad 0.9 \quad 1 \quad 1.1 \quad 1.2 \)
  - \( -0.15 \quad -0.1 \quad -0.05 \quad 0 \)
  - \( \log \left( 1 - \frac{\varphi}{\varphi_m} \right) \)
  - 25 mm vs 21 mm

- **High Viscosity**
  - \( R^2 = 0.9484 \)
  - \( -0.15 \quad -0.1 \quad -0.05 \quad 0 \)
  - Log Group Velocity
  - 25 mm vs 21 mm

- **High Viscosity**
  - \( R^2 = 0.9976 \)
  - \( 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad 14 \quad 16 \quad 18 \)
  - Single Particle Regression
  - Single Particle Experimental Velocity (mm/s)
  - 25 mm vs 21 mm

- **High Viscosity**
  - \( R^2 = 0.9484 \)
  - \( -0.15 \quad -0.1 \quad -0.05 \quad 0 \)
  - Log Group Velocity
  - 25 mm vs 21 mm
Analysis

- Values for single particle settling velocity from regression coefficients differ by ~20% from the measured single particle settling velocity.
- High $R^2$ values indicate correlation between group settling velocity the volume fraction/max packing density.
Additional Model

- Additional gradation term: $u_a = u_s \left(1 - \frac{\varphi}{\varphi_m}\right)^k (F.M. \times \varphi)^j$
- *F.M.* is modified fineness modulus used to assess coarseness of gradation
- Regression analysis found $j \sim$ zero, indicating this term is not necessary
- Packing density describes gradation adequately
Gradation

- Gradation with average diameter 20.5 mm was compared to model
- $k$ value used same as 21 mm
- $u_s$ of particle interpolated from data
- Discrepancy between experimental settling velocity and modeled velocity is in same range as single particle velocities described previously
Discussion and Conclusions

• Correlation between single particle settling velocity, group settling velocity, and packing density

• Fineness modulus term is irrelevant in model:  \( u_a = u_s \left(1 - \frac{\varphi}{\varphi_m}\right)^k (F.M. \times \varphi)^j \)

• Average aggregate size may be used in model when aggregate is graded
Future Study

- Particle shape
- Average diameter
- Components of constants