CONTRIBUTION OF THE COARSE AGGREGATE FRACTION TO RHEOLOGY –
EFFECTS OF FLOW COEFFICIENT, PARTICLE SIZE DISTRIBUTION, AND VOLUME FRACTION

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Introduction - Rheology influences in concrete

- Ion content and strength
- Surface chemistry and charges
- Polymer sizes and structure
- Selective adsorption
- Competitive adsorption
- Different particle charges
- Hydration phases
- Morphology
- Powder properties
- Different particle sizes
- Solid volume fraction
- Interaction of particle sizes
- PSD of finest particles
- PSD of coarser particles
Introduction – Relevance of coarse aggregates

• With increasing flowability and increasing strength, the relevance of the finer fractions increases.

• However, 96% of all ready mixed concrete types are normal strength and normal consistency. (BTB 2016)
We can effectively manipulate the rheology on nm to mm scale. We would not try to significantly control rheology based on mm scale. But effects on mm and cm scale overlap with paste effects.
Introduction – Challenges

Different ideas have been developed,

– Grading curves (e.g. Andreasen, Funk & Dinger)

– Modelling (e.g. De Larrard, Stroeven)

But grading curves cannot represent the complex reality,

And real aggregates seldomly behave like modellised (and mostly uni-sized, often round) particles.
Introduction - Motivation

Is there a simple experimental parameter that can predict the „rheology“ of aggregates?

Can the flow coefficient provide adequate information?

EXPERIMENTAL SETUP
Quartzitic aggregates

Three fractions: 2/4; 4/8; 8/16

Density ~ 2650 kg/m³
Experimental – investigated variations

<table>
<thead>
<tr>
<th></th>
<th>100:0</th>
<th>80:20</th>
<th>60:40</th>
<th>40:60</th>
<th>20:80</th>
<th>0:100</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/4 → 4/8</td>
<td><img src="2/4_4/8_100.png" alt="Image" /></td>
<td><img src="2/4_4/8_80.png" alt="Image" /></td>
<td><img src="2/4_4/8_60.png" alt="Image" /></td>
<td><img src="2/4_4/8_40.png" alt="Image" /></td>
<td><img src="2/4_4/8_20.png" alt="Image" /></td>
<td><img src="2/4_4/8_0.png" alt="Image" /></td>
</tr>
<tr>
<td>2/4 → 8/16</td>
<td><img src="2/4_8/16_100.png" alt="Image" /></td>
<td><img src="2/4_8/16_80.png" alt="Image" /></td>
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<tr>
<td>4/8 → 8/16</td>
<td><img src="4/8_8/16_100.png" alt="Image" /></td>
<td><img src="4/8_8/16_80.png" alt="Image" /></td>
<td><img src="4/8_8/16_60.png" alt="Image" /></td>
<td><img src="4/8_8/16_40.png" alt="Image" /></td>
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<td><img src="4/8_8/16_0.png" alt="Image" /></td>
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</tbody>
</table>
Experimental – investigated variations
Experimental – grading curves
Experimental – flow coefficient

1. Determine funnel opening
2. Place beaker and balance
3. Fill aggregates in plastic pipe
4. Start vibrating
5. Open funnel
6. At 1000 g, start stop watch
7. Take time, when balance shows
   \[ m = 1000 \cdot (1 + 7 \cdot \rho_p/2.70) \]
8. For standard aggregates, the flow coefficient is the time that
   \(~7 \text{ kg or } \sim 2.6 \text{ l}\) take to run out.
Each sample was tested three times from the same batch.

Each batch was repeated individually for three times. → 3 x 3 x 15 = 135 repetitions

The flow coefficient was determined as the arithmetic mean of 9 measurements.
Experimental – loose bulk density

EN 1097-3:199 Tests for mechanical properties of aggregates. Part 3: Determination of loose bulk density and voids
Experimental – limestone filler paste

<table>
<thead>
<tr>
<th>Reference SCC</th>
<th>Reference mortar mix</th>
<th>Limestone filler based paste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Cement</td>
<td>LS Filler</td>
</tr>
<tr>
<td>LS Filler</td>
<td>LS Filler</td>
<td>Water</td>
</tr>
<tr>
<td>Water</td>
<td>Water</td>
<td>LS Filler</td>
</tr>
<tr>
<td>Fine sand</td>
<td>Fine sand</td>
<td></td>
</tr>
<tr>
<td>Coarse sand &amp; aggregates</td>
<td>Coarse sand &amp; aggregates</td>
<td>Water</td>
</tr>
</tbody>
</table>

Similar rheology! No fine sand in the paste to avoid any interactions!

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Similar rheology
Experimental – limestone filler paste

Influence of the admixture combination:
Experimental – limestone filler paste

Pl. viscosity / pl. viscosity_{ref} [-] vs. yield stress_{L_{SF}} / yield stress_{L_{ref}} [-] for different mixes.

- Plastic viscosity ratio
- Reference cementitious mortar
- Yield stress ratio

Mixes: Mix 1, Mix 2, Mix 3, Mix 4, Mix 5, Mix 6, Mix 7, Mix 8, Mix 9, Mix 10, Mix 11, Mix 12, Mix 13, Mix 14, Mix 15, Mix 16, Mix 17
Experimental – limestone filler paste

Influence of the admixture combination:

- Experimental – limestone filler paste
Experimental – limestone filler “concrete”

100% LS paste

88% LS paste
12% coarse

78% LS paste
22% coarse

70% LS paste
30% coarse

64% LS paste
36% coarse

59% LS paste
41% coarse
Experimental – rheometric investigations

Rheometer 4-SCC

Bingham evaluation of measurement data

Only qualitative results possible:
• Yield stress related value: [A]
• Plastic viscosity related value: [A·s]
RESULTS
Results – flow coefficient

- Finer aggregates cause higher flow coefficients.

Flow coefficient [s]

Flow coefficient:
- Increasing content of coarser fraction
- 2/4-4/8
- 4/8-8/16

100/0 80/20 60/40 40/60 20/80 0/100

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Results – flow coefficient

The variation ranges are similar for:

- fine → medium
- medium → coarse

Range = 7.2 s
Range = 8.1 s
The variation ranges are similar for:

- fine → medium
- medium → coarse

but significantly wider for:

- fine → coarse
Increasing coarse aggregate contents decrease the flow coefficient.

A minimum can be found between the two fractions.
Ideal packing was achieved for 40:60 and 60:40 of two fractions.

Better packing density when the smaller fraction is finer sand.

Best packing possible with largest gap between coarse and fine aggregate.
Results – loose bulk density

Loose bulk density [kg/m³]

Flow coefficient [s]

Correlation?

No correlation!
Results – yield stress

No similarity between the blends.

Minimum always between the single fractions.

Minimum always with higher coarse volume.

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Results – viscosity

Lowest viscosity always with smallest aggregate fraction.

No big effect from small to medium.

Significant effect with coarsest fraction.

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Regardless of the volume fraction, the influence of the aggregates was always particular.

This means:
Already at smallest volume fractions, the aggregates affect the rheology.

And:
The aggregate volume fraction is a multiplier of the particular effect.
Results – yield stress vs. flow coefficient

Yield stress

Flow coefficient

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Results – viscosity vs. flow coefficient

Plastic viscosity

Flow coefficient

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Results – lowest yield stress PSD

Mesh minus [%] vs. Sieve diameter [mm]

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Results – highest viscosity PSD

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CONCLUSIONS
Conclusions

**Flow coefficient assessment:**
- The flow coefficient does not correlate with loose bulk density.
- The flow coefficient is also not an adequate tool to predict the rheology influence of the coarse particle.

**Grading:**
- Best yield stress reduction with coarse fractions > 50%
- Hardly effects of sand fractions on viscosity. Strong effect of coarse fraction.

**Volume fraction:**
- Blends of different aggregate fractions have particular influence of rheology.
- Volume fraction does not change particular effects, only the order of magnitude.
Conclusions

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THANK YOU VERY MUCH FOR YOUR KIND ATTENTION

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