Issues Arising from Using Supplementary Cementing Materials in Cement Based Foams

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INTRODUCTION

- Cement Based Foams
- Supplementary Cementing Materials
What are Cement Based Foams?

- Cement based foam is a light weight mixture of:
  - Cementitious material
  - Fine aggregate (for density higher than 800 kg/m³)
  - Water
  - Stable foam

- Applications typically include:
  - Engineered, non-structural fill
  - Precast panels
  - Thermal and acoustic insulation
  - Refractory materials
Cement Based Foams In Alberta

- Principal advantages:
  - High strength to weight ratio
  - Low demolition cost
  - Favourable thermal properties

- Properties of Interest
  - Rheology (must be self-levelling)
  - Thermal Conductivity
Mix Constituents & Supplementary Cementing Materials

- Portland cement (Type HE)
- Fly ash (class C)
- Foaming agent
- Polypropylene fibre
- Silica fume
- Metakaolin

Typical Mix Constituents
Alternate SCM
Fly ash (class C) was introduced at 20%, 25% and 50% of the binder.

Silica fume at 10% and 20%

Metakaolin at 10% and 20% of the binder.

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Fly Ash (Class C)</th>
<th>Silica Fume</th>
<th>Metakaolin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Dioxide (SiO₂)</td>
<td>35</td>
<td>90</td>
<td>51</td>
</tr>
<tr>
<td>Aluminum Oxide (Al₂O₃)</td>
<td>20</td>
<td>2</td>
<td>42</td>
</tr>
<tr>
<td>Ferric Oxide (Fe₂O₃)</td>
<td>5</td>
<td>2</td>
<td>0.50</td>
</tr>
<tr>
<td>Calcium Oxide (CaO)</td>
<td>20</td>
<td>0</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Production of Cement Based Foams

1. Foam Generation
   • Diluted surfactant is aerated using compressed air.
   • Liquid-air combine is then forced to pass through a nozzle.
2. Preparing the Slurry
3. Flow Check for Target Density
4. Adding the Foam to the Slurry

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Weight (%)</th>
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<tbody>
<tr>
<td>Fatty Alcohol</td>
<td>1-10</td>
</tr>
<tr>
<td>Alcohol</td>
<td>6.5-35</td>
</tr>
<tr>
<td>Fatty Acid</td>
<td>10-65</td>
</tr>
</tbody>
</table>

Composition of synthetic foaming agent

Schematic of a foam generator
Components of the Foam Generator

- Liquid to Intake
- Air to Nozzle
- Air Source
- 100 Psi
Sequence for Foam Generation

1. 3% foaming agent
2. Air
3. Foam

Nozzle
Step-1. Foam Production

Stable foam coming out from nozzle

Foam ready to be mixed with slurry
Step 2. Preparing the Slurry

• Dry Powder of Cement and SCM is Mixed with Water.

• Modified Drill (Paint Mixer) used for Mixing.
Step 3. Flow Check for Target Density

- Time taken for 350 ml of slurry to flow through the Marsh funnel relates to cast density.
- Besides density, this test also ensures flow-ability.

**Marsh Funnel**

**Marsh Funnel Test**
Step 4. Adding Foam to Slurry

- Gradual mixing of foam and slurry.
- Addition of fibre reinforcement, if any.
- Check for cast density of foam concrete intermittently.
  - Cast at 400, 600 and 800 kg/m³
## Polypropylene Fibres

<table>
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<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Fibre Length (mm)</td>
<td>20</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>910</td>
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<tr>
<td>Tensile Strength (MPa)</td>
<td>450</td>
</tr>
<tr>
<td>Modulus of Elasticity (MPa)</td>
<td>3450</td>
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<tr>
<td>Denier</td>
<td>3</td>
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</table>
## Composition of Mixes Examined

<table>
<thead>
<tr>
<th>SCM</th>
<th>Cast Density kg/m³</th>
<th>Cement kg/m³</th>
<th>Water kg/m³</th>
<th>SCM kg/m³</th>
<th>Foam kg/m³</th>
<th>Fibre (0.2% Vf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% Fly Ash</td>
<td>800</td>
<td>425</td>
<td>291</td>
<td>85</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>319</td>
<td>218</td>
<td>64</td>
<td>22</td>
<td>23</td>
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<td></td>
<td>400</td>
<td>213</td>
<td>146</td>
<td>43</td>
<td>28</td>
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<td>25% Fly Ash</td>
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<td>408</td>
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<tr>
<td>50% Fly Ash</td>
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<td>170</td>
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<td>170</td>
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<td>23</td>
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<tr>
<td>10% Silica Fume</td>
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<td>464</td>
<td>291</td>
<td>47</td>
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<td>23</td>
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<td>213</td>
<td>146</td>
<td>43</td>
<td>26</td>
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</tr>
<tr>
<td>10% Metakaolin</td>
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<td>47</td>
<td>17</td>
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</table>
Tests Conducted

1. Compressive Test
   (ASTM C 39)

2. Thermal Conductivity
   (ASTM D5334)
Foam Concrete Specimens

- Size of cylinders 3in x 6in (75 mm x 150 mm)
- Size of cube 50 mm x 50 mm x 50 mm

Thermal Test

Compressive Test
Experimental Set Up

Thermal Probe Needle Test ASTM D 5334 method is:

- A transient heat method.
- Capable of determining the thermal conductivity & diffusivity of soil and soft rock.
- Suitable only for isotropic materials.

- Applicable to dry materials over a wide temperature range from <0 to >100°C, depending on the suitability of the thermal needle probe construction to temperature extremes.

- Also used for specimens containing moisture.
Thermal Conductivity

- Coefficient of thermal expansion for cellular concrete varies directly with density

- Typically 5.0 to 7.0 x 10⁻⁶ per °F (9.0 to 12.6 x 10⁻⁶ per °C)

<table>
<thead>
<tr>
<th>Oven Dry Density</th>
<th>Thermal Conductivity, K</th>
</tr>
</thead>
<tbody>
<tr>
<td>lb/ft³</td>
<td>kg/m³</td>
</tr>
<tr>
<td>20</td>
<td>320</td>
</tr>
<tr>
<td>30</td>
<td>480</td>
</tr>
<tr>
<td>40</td>
<td>640</td>
</tr>
<tr>
<td>50</td>
<td>800</td>
</tr>
</tbody>
</table>

*Typical thermal conductivity values for oven dry cellular concrete*
Transient Line Source Thermal Test (ASTM D 5334)

Schematic of electrical circuit and data acquisition system at the University of Alberta
Components of the Thermal Probe Needle

- Power Supply
- Base platform with axial heating source
- Computerized data-acquisition
Sample Preparation

Foam concrete cylinders

Drilling the sample to accommodate the thermal probe
Testing of Specimens

Base platform with axial heating source

Sample mounted and ready for testing
Calculation of Thermal Conductivity

- Temperature of needle and time-history are recorded
- Power supply values were recorded
- Graph plotted between needle temperature and time (ln) in seconds
  - Slope of the plot is calculated
- Thermal conductivity $K$ was calculated from the above
Results & Discussion

- Effects of SCM on:
  a) Fresh Properties
  b) Compressive Strength of Hardened Samples

- Effects of Thermal Conductivity on:
  a) 20 to 50% of Fly Ash
  b) 10 to 20% of Silica Fume
  c) 10 to 20% of Metakaolin
Effects of Supplementary Cementing Materials

Fresh Properties

- Time taken by slurry to flow through the funnel decreases with an increase in Fly Ash.
- Silica Fume and Metakaolin registered higher time-to-flow for the same cast density.

- In particular, Metakoalin showed a significant increase in time-to-flow compared with Silica Fume for identical dosage and density.
- Uneven fibre dispersion was observed with reduced flowability at higher dosage of SCM, in all cases.

<table>
<thead>
<tr>
<th>SMC</th>
<th>% of Replacement Materials</th>
<th>Marsh Funnel Reading (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly Ash</td>
<td>20%</td>
<td>35-40</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>34-39</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>33-37</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>10%</td>
<td>40-49</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>60-64</td>
</tr>
<tr>
<td>Metakoalin</td>
<td>10%</td>
<td>60-70</td>
</tr>
<tr>
<td></td>
<td>20% (7 ml HRWRA)</td>
<td>90-120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>54-60</td>
</tr>
</tbody>
</table>
Increased amount of Fly Ash reduces the compressive strength.

Difficult to minimize the difference between cast and dry density specially for < 600 kg/m³.
Increased amount of Silica Fume increases the compressive strength.
Compressive Strength (3)

- Higher Dosage of Metakoalin increases the compressive strength.

- Significant drop was noticed in the dry density specially for cast density less than 600 kg/m$^3$.

- Small sizes of samples should be avoided specially for lower density as it led to inconsistent dry density.

![Graph showing Compressive Strength vs Relative Density for MK 10% and MK 20%](image)
1. Fly Ash

- The thermal conductivity decreased with an increase in the fly ash fraction in the binder.

- A linear relationship was obtained between thermal conductivity and dry-density as noted by other researchers.
2. Silica Fume

- An increase in the Silica Fume fraction of the binder led to a drop in the thermal conductivity.
3. Metakoalin

- Thermal conductivity **increased** with an increase in Metakoalin dosage in the binder. (Could this be due to the $Al_2O_3$ component?)

There was a linear relationship between thermal conductivity and dry density in all cases.
Concluding Remarks

- It is difficult to achieve desired dry density for cast density less than 600 kg/m$^3$
  - This was further compounded for smaller specimens

- Fly ash with 50% mix in general and 400 kg/m$^3$ in particular was difficult to cast.

- Where as the compressive strength decreased with an increase in the dosage of fly ash, silica fume and metakoalin led to an increase in the compressive strength, for the levels examined.

- For Fly-Ash and Silica Fume, the thermal conductivity decreased with an increase in dosage. On the other hand, metakoalin when used as an SCM led to an increase in the thermal conductivity of the foamed composite.
Exposure to Sulphates
Sulphate Exposed (no fibre)

- Sulphate exposed samples exhibit a decrease in thermal conductivity immediately upon exposure due to onset of cracking. Sustained exposure to sulphates beyond 30 days led to an increase in the thermal conductivity. This is likely due to self-healing.

Thermal conductivity of plain (0.0% fibre) cement-based foams after immersion to sulphate bath and water bath for various duration of exposure (457 kg/m³).
Sulphate exposed samples with fibre reinforcement exhibit an increase in the thermal conductivity upon immediate exposure. This was attributed to crack arrest mechanisms effected through the presence of micro-fibres.

Thermal conductivity of fibre reinforced (0.2%) cement-based foams after immersion to sulphate bath and water bath for various durations of exposure. (cast density = 475 kg/m³).
Effect of Sulphates

When exposed to a sulphate solution, specimens with fibres have higher flexural toughness factor and thermal conductivity compared to an unexposed sample. These parameters drop only after 30 days of sustained exposure.

This may have a bearing on the choice of SCM, since that will lead to improved fibre-matrix bond.
Acknowledgements

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THANK YOU!