Insulating Lightweight Cementitious Materials

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Our Activities to Produce Lightweight Cementitious Materials

- **Find a total or partial substitute for lightweight aggregates**
  - Reduced density using conventional aggregates
    - Eliminate energy costs to produce aggregates
    - Reduce need to ship aggregates from distant locations
    - Improve thermal resistance
    - Lower costs
  - Systems without any aggregates
    - High insulation value products
- **Low shrinkage and good dimensional stability**
- **Equal to better strength than existing materials at same unit weight**
- **Lower permeability and enhanced durability**
Applications in Today’s Presentation

- Lightweight concretes using normal weight aggregates
- Lightweight coarse aggregate free systems
- Alternative to aerated autoclave concrete

Note that the data in this presentation are based upon preliminary laboratory and field testing and results would be expected to vary based upon available materials and production parameters.
Structural Lightweight Concretes

- Typically have strengths in 30 to 40 MPa range depending on the application
- Use lightweight coarse aggregates to achieve 1750-2000 kg/m$^3$
  - Usually manufactured
  - Need to be kept saturated for best performance
    - Difficult in dry or freezing environments
- Applications
  - Lighter slabs reduce deadload allowing for taller buildings, or smaller columns increasing usable space
  - Better fire resistance and noise reduction
  - Longer spans and reduced deadloads in bridges
Sustainable Alternative to Conventional Structural Lightweight

- Reduce the need for lightweight aggregates
  - Reduce production and shipping costs
  - Easier handling in winter and dry months
  - Improved resistance to spalling in fires
  - Reduced long-term drying shrinkage
- Reduced concrete permeability
- Higher workability
- Improved thermal resistance (lower thermal conductivity, $k$; higher $R$ value)
Typical Mixture Design Guidelines

- $w/cm \leq 0.28$
- Normal Weight Gravel 9-12 mm
- Silica Fume 5-10%
- Fly ash or ground granulated blast furnace slag optional
- Foaming Admixture
- Superplasticizer as needed

Typical Plastic Properties

- SCC type performance
- Air 12-35%

*Increased air improves yield to lower content of cementitious materials and aggregates used!*
Enhanced Properties

- Lower thermal conductivity
- Improved drying shrinkage due to low w/cm matrix
- Significantly reduced permeability (enhanced durability)
- Good fire resistance comparable to cementitious fireproofing
- Excellent freezing and thawing resistance
Thermal Conductivity

- Thermal Conductivity ($k$) significantly lower at same density
- Large range of essentially constant low k
- Increase in k with density is linear versus exponential

Improved thermal performance at lower weight vs. other cement/gypsum products
Shrinkage for a w/c=0.25 mix will mainly be of autogeneous, not drying.
Highly water impermeable concrete --- for bridge decks/parking garages?
Probably need SRA for early age autogeneous shrinkage control.
Fire Test

Temperature evolution of 4"x4"x4" cubes of LW concrete (02264-3P, BSG Field Samples, Dry UW107.4pcf)

![Graph showing temperature evolution over time for different samples in a fire test.](image-url)
ASTM C666 - 97
Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

Approx. 1760 kg/m³
The message for structural lightweight:

1. Preliminary work has a product that meets lower range of LW concrete specification (21 MPa at 1840 kg/m$^3$).

2. A strong matrix is needed for this LW concrete (w/c=0.3 or lower).

3. Matrix still has room to be optimized.

4. Cementitious is the strength contributor—maximizing cement content while cost permits. Concrete can be stronger if more cementitious is used. (Increased air and reduced energy in aggregate production offsets this.)

5. Coarse aggregate specific gravity in our lab was high; not representative of typical aggregate (2.9 vs. 2.6) increasing unit weights.

6. Drying only lowers ~1% of our UW, so we get desired UW almost instantly, while normal LW aggregate takes longer to get to the target UW.

7. Improved durability properties at equivalent cost due to low permeability of matrix and quality of the air system.

8. Lower thermal conductivity than normal weight/conventional lightweight concrete.
Benefits

To Concrete Producer: Save space that is needed for stockpiling, equipment to handle, and moisture/freezing control of LW aggregates.

To Contractors:

1) Easy placement (SCC workability),
2) High 1-day strength (17 MPa) can speed up construction.
3) Fast drying of floor (MVER), faster tile/carpet installation.

To Owner: Our technology enables the making of LW concrete available at any place where regular concrete is produced, which means saving money for the building being constructed. Reduced long-term energy use in the building with enhanced fire protection and sound reduction.
Challenges

1) Control of air within a very narrow window (+/-2% of target)?

2) Are other physical properties (MOE, creep) affecting building design?

3) Introduction of new technology
**No Coarse Aggregate Light Weight Cementitous**

*Cementitious technology* that provides *air, fire, moisture & thermal protection* in a user and environmentally *safe material*. This material can be sprayed, pumped, poured, troweled or made into forms (boards, molding, etc.)

<table>
<thead>
<tr>
<th>Lightweight</th>
<th>Sound Absorbent</th>
<th>Dimensionally Stable</th>
<th>High R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire, UV &amp; Temperature Resistant</td>
<td>Air &amp; Moisture Resistant</td>
<td>EHS Benefits – Safer</td>
<td>Forms to Any Shape</td>
</tr>
</tbody>
</table>

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Dimensional Stability

Dimensionally stable at lower density
Thermal Conductivity

K-Value Comparison to Published Values

- Thermal Conductivity (k) significantly lower at same density
- Large range of essentially constant low k
- Increase in k with density is linear versus exponential

Improved thermal performance at lower weight vs. other cement/gypsum products

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Strength as a Function of Density
Forney Compression Strength Machine
(5.08 cm and 10.16 cm cubes)

- Higher strength at equivalent density
- Coupled with improved insulation properties

Enhanced performance at lower density while still meeting strength requirements
Air Flow

Air permeance is low at relatively low density 0.18 g/cm³ (11.2 pcy)
Equivalent to other board materials at much higher density and weight

- Combined with low thermal conductivity (k), and fire resistance
- Potential for multifunctional products
- Easier handling for boards
Vapor Permeance

- Increasing thickness lowers permeance as does increasing density

Water vapor permeability can be tailored
Cementitious Flowable Fill

- Low strength material that can replace soils
- Sand and cement without coarse aggregates
- High amount of air
- Unit weight under 100 pcf
- Relatively good thermal resistance, but high permeability
Flowable Fill Examples

- **Standard Mix Design**
  - 150 pcy cement
  - 312 pcy water
  - 2377 pcy sand
  - 25% air using DaraFill®
- **Mix 2 replace**
  - Replace DaraFill with new air system
- **Mix 3**
  - Cementitious foam system without sand
- **Mix 4**
  - Cementitious foam system with same sand as Standard Mix
Comparison of standard flowable to ones with new air system.

**Compressive Strength**

- **Standard CLSM Design (98.5 pcf)**
- **CLSM Using New Air System (85 pcf)**
- **No Sand Cementitious (22 pcf)**
- **Sand Addition to Cementitious (85 pcf)**

Comparison is made at 3 day, 7 day, and 28 day intervals.
Comparison of standard flowable to ones with new air system

R-Value vs. Compressive Strength

- CLSM Design:
  - 150 pcy Cement
  - 2377 pcy Sand
  - 312 pcy Water

- CLSM Using New Air System (85 pcf)

- No Sand Cementitious (22 pcf)

- Sand Addition to Cementitious (85 pcf)

Exceeds requirements for Roof-Deck Insulation
Background

- Novel foaming and cementitious compositions have been developed that significantly reduce thermal conductivity relative to other materials at the same density.
- These materials have equal to higher strength to corresponding materials at the same density.
- These materials can be pumped or poured into molds to form blocks, boards, decorative trim, etc.
- **Possible applications for precast customers**
  - Replace Autoclave Products
    - Doesn’t require aluminum flakes and powders to produce air that is interconnected (higher thermal conductivity)
    - Reduced capital demands, simple oven versus autoclave
  - Reduced weight for septic tanks and other manufactured products dependent upon strength needs.
  - Sound barriers and other manufactured products that will benefit from lower density and better properties.
- **Cellular Concrete**
  - Much lower k value at same density
  - Used in buildings where low weight more important than strength
  - Used in fills where low strength is desired (Flowable Fill)
### COMPARISON TO AUTOCLAVE AERATED CONCRETE

#### Current Comparison

Formulations beat k significantly
Strength comparable

<table>
<thead>
<tr>
<th>Strength Class</th>
<th>AC-2</th>
<th>AC-4</th>
<th>AC-6</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Compressive Strength $f_{k, AAC}$</td>
<td>290 (2.0)</td>
<td>580 (4.0)</td>
<td>870 (6.0)</td>
<td>psi (MPa)</td>
</tr>
<tr>
<td>Modulus of Elasticity $E_{AAC}$</td>
<td>190x10^3 (1343)</td>
<td>296x10^3 (2046)</td>
<td>377x10^3 (2611)</td>
<td>psi (MPa)</td>
</tr>
<tr>
<td>Thermal Conductivity $k$</td>
<td>0.80 (0.11)</td>
<td>0.97 (0.14)</td>
<td>1.25 (0.18)</td>
<td>BTU in / ft² h °F (W/mK)</td>
</tr>
<tr>
<td>Thermal Resistance $R$</td>
<td>1.25 (9.09)</td>
<td>1.03 (7.14)</td>
<td>0.80 (5.56)</td>
<td>ft²°F/BTU-in (m²K/W)</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>4.4x10⁻⁶ (8x10⁻⁶)</td>
<td>4.4x10⁻⁶ (8x10⁻⁶)</td>
<td>4.4x10⁻⁶ (8x10⁻⁶)</td>
<td>1/°F (1/K)</td>
</tr>
<tr>
<td>Dry Density</td>
<td>31 ± 1.6 (500 ± 25)</td>
<td>37 ± 1.6 (600 ± 25)</td>
<td>41 ± 1.6 (650 ± 25)</td>
<td>lb/ft³ (kg/m³)</td>
</tr>
<tr>
<td>Design Density</td>
<td>38 (520)</td>
<td>44 (715)</td>
<td>48 (765)</td>
<td>lb/ft³ (kg/m³)</td>
</tr>
</tbody>
</table>

Strength classes are defined for AAC block products in ASTM C 1386. Updated 12/19/07.
Status

- Novel new technologies can be used to make cementitious materials with specific gravities from 0.05 to 2.
- These materials have equivalent to higher strengths than other cement or gypsum based materials at the same density.
- Additional improvements include:
  - Significantly lower k values
  - Reduced need to store and transport special aggregates
  - For autoclave operations
    - Lower processing temperatures
    - No aluminum powders
  - For lightweight concretes
    - Significantly lower permeability and shrinkage
    - Good freezing and thawing resistance

Note that the data in this presentation are based upon preliminary laboratory and field testing and results would be expected to vary based upon available materials and production parameters.
Thank you!