Ultra-High Strength Concrete Mixtures Using Local Materials

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**Organization**

- **Ultra-High Strength Concrete (UHSC)**
  - Development
  - Advantages
  - Applications

- **Research Objectives**

- **Experimental Program**
  - Materials
  - Mixture Proportions
  - Specimen Preparation
  - Testing

- **Results**

- **Conclusions**

- **Recommendations for Future Work**
Development of UHSC

Recommended principles for developing UHSC:

- Removal of coarse aggregate to enhance homogeneity.
- Use of silica fume for pozzolanic reaction.
- Use of steel aggregate to increase density.
- Use of quartz powder to maximize pozzolanic reaction during heat treatment.
- Optimization of granular mixture to enhance compacted density.
- Application of presetting pressure for better compaction.
- Post-setting heat treatment to enhance the mechanical properties of the microstructure.
- Addition of steel fibers to achieve ductility.
Advantages of UHSC

• UHSC results in smaller sections and significant weight reductions.

• Reduced number of structural elements.

• Greater energy absorption during seismic events.

• Dense microstructure of UHSC provides excellent protection against corrosion.

• Excellent chloride penetration resistance and lower water absorption.

• Excellent freeze-thaw durability.
Applications of UHSC

- Precast concrete units
- High-pressure pipes
- Blast resistant structures
- Seismic resistant structures
- Security enclosures
- Walkways
- Long span bridges
- Nuclear waste containment structures
Sherbrooke Pedestrian Bridge, Quebec, Canada

- 197 ft (60 m) long.
- Post-tensioned.
- 6 in (150 mm) thick deck slab.
- No conventional reinforcement.
- UHSC with a compressive strength of 29 ksi (200 MPa) was used.
Sustainability

Pros:

• Reduced member sizes are possible with UHSC, which reduces the volume of concrete used to produce a given structural element.

• Reduced cement usage is possible.

• Increased service life.

Cons:

• High initial cost.

• Use of high cement content in UHSC mixtures may increase cement consumption.

• Prepackaged commercially available products are typically shipped to a local producer.
Research Objectives

• Develop UHSC mixtures that are cost effective.

• Use locally available materials to produce UHSC to improve sustainability.

• Investigate the effects of age, curing regimen, and fibers on compressive strength of concrete.
Experimental Program - Materials

Cement: Type I/II portland cement

Silica Fume: Rheomac SF 100 (BASF Chemicals), SiO$_2$ content is 96.9%.

Fine Sand:

Particle Size: 0.00295 - 0.0236 in (75-600 μm).

Steel Fibers:

Length: 0.5 in (13 mm)

HRWRA:

Glenium 3030 NS from BASF chemicals

<table>
<thead>
<tr>
<th>Grain Size Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve No.</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>
Experimental Program - Mixture Proportions

Mixture Designation:

- Mixture names were four digit symbols.
  
  First letter referenced the mixture category.
  
  Second letter referred to the source of the aggregate.
  
  Last two numbers referred to the percentage increase in water and cementitious materials content over the base mixture.

- BL20 was a mixture from category B that used aggregates from Las Cruces and had 20% more water, cement, and silica fume than the base mixture (BL00).
## Experimental Program - Mixture Proportions

### Mixture Proportions

<table>
<thead>
<tr>
<th>Mixture Details</th>
<th>Cement (lb/yd³, kg/m³)</th>
<th>Silica Fume (lb/yd³, kg/m³)</th>
<th>Fine Sand (lb/yd³, kg/m³)</th>
<th>Steel Fibers (lb/yd³, kg/m³)</th>
<th>Water (lb/yd³, kg/m³)</th>
<th>HRWRA (g/yd³, l/m³)</th>
<th>w/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Mixture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>AL00</td>
<td>1585 (940)</td>
<td>-</td>
<td>1558 (924)</td>
<td>321 (190)</td>
<td>444 (263)</td>
<td>4.75 (23.50) 0.28*</td>
</tr>
<tr>
<td>B</td>
<td>BL00</td>
<td>1197 (710)</td>
<td>388 (230)</td>
<td>1424 (844)</td>
<td>321 (190)</td>
<td>444 (263)</td>
<td>3.00 (14.80) 0.28</td>
</tr>
<tr>
<td></td>
<td>BL20</td>
<td>1436 (852)</td>
<td>466 (276)</td>
<td>903 (535)</td>
<td>319 (189)</td>
<td>532 (315)</td>
<td>3.25 (16.00) 0.28</td>
</tr>
<tr>
<td>C</td>
<td>CL00</td>
<td>1500 (890)</td>
<td>375 (222)</td>
<td>1338 (793)</td>
<td>-</td>
<td>413 (245)</td>
<td>5.00 (24.70) 0.22</td>
</tr>
<tr>
<td></td>
<td>CL20</td>
<td>1800 (1067)</td>
<td>450 (267)</td>
<td>840 (498)</td>
<td>-</td>
<td>495 (294)</td>
<td>3.0 (17.29) 0.22</td>
</tr>
<tr>
<td>D</td>
<td>DL00</td>
<td>1500 (890)</td>
<td>375 (222)</td>
<td>1411 (837)</td>
<td>-</td>
<td>375 (222)</td>
<td>6.00 (29.64) 0.20</td>
</tr>
<tr>
<td>E</td>
<td>EL00</td>
<td>1500 (890)</td>
<td>375 (222)</td>
<td>1347 (799)</td>
<td>200 (119)</td>
<td>375 (222)</td>
<td>6.00 (29.64) 0.20</td>
</tr>
</tbody>
</table>

* Water-to-Cement Ratio

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Experimental Program - Curing

Three curing regimens were investigated:

MC: Cured at a temperature of 73.4°F (23°C) and a RH of 100% until the day of testing.

WB: Heat cured in a water bath at 122°F (50°C) until the time of testing.

OV: Heat cured in a water bath at 122°F (50°C). Then, dry cured at 392°F (200°C) for two days prior to testing.
Experimental Program - Testing

Compressive Strength:

- 2 in (50 mm) cubes and 4 by 8 in (100 by 200 mm) cylinders.
- About 400 cylinders and cubes were tested for compressive strength.

Modulus of Rupture:

- Prismatic specimens with dimensions of 3 x 4 x 16 in (75 x 100 x 400 mm).
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### Results: Compressive Strength of UHSC

#### Compressive Strengths, psi (MPa)

<table>
<thead>
<tr>
<th>Mixture</th>
<th>W/CM</th>
<th>7 days</th>
<th>28days</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL00 (MC)</td>
<td>0.28</td>
<td>6940 (47.9)</td>
<td>-</td>
</tr>
<tr>
<td>BL00 (MC)</td>
<td>0.28</td>
<td>6880 (47.4)</td>
<td>-</td>
</tr>
<tr>
<td>BL20 (MC)</td>
<td>0.28</td>
<td>7080 (48.8)</td>
<td>9210 (63.5)</td>
</tr>
<tr>
<td>BL20 (WB)</td>
<td>0.28</td>
<td>8430 (58.1)</td>
<td>(9650) (66.5)</td>
</tr>
</tbody>
</table>
## Results: Compressive Strength of UHSC

### Compressive Strengths, psi (MPa)

<table>
<thead>
<tr>
<th>Mixture</th>
<th>W/CM</th>
<th>7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2 in (50 mm) cube</td>
<td>2 in (50 mm) cube</td>
</tr>
<tr>
<td><strong>CL00 (WB)</strong></td>
<td>0.22</td>
<td>14,080 (97.1)</td>
<td>16,250 (112.1)</td>
</tr>
<tr>
<td><strong>CL20 (WB)</strong></td>
<td>0.22</td>
<td>13,560 (93.5)</td>
<td>15,200 (104.8)</td>
</tr>
<tr>
<td><strong>CL00 (OV)</strong></td>
<td>0.22</td>
<td>14,380 (97.1)</td>
<td>17,120 (118.0)</td>
</tr>
<tr>
<td><strong>DL00 (WB)</strong></td>
<td>0.20</td>
<td>13,030 (89.9)</td>
<td>17,750 (122.4)</td>
</tr>
<tr>
<td><strong>DL00 (OV)</strong></td>
<td>0.20</td>
<td>20,010 (138.5)</td>
<td>23,480 (161.9)</td>
</tr>
<tr>
<td><strong>EL00 (OV)</strong></td>
<td>0.20</td>
<td>21,180 (146.1)</td>
<td>24,010 (165.6)</td>
</tr>
</tbody>
</table>
Results: Compressive Strength of UHSC

- Compressive strength development with age was observed in UHSC specimens even though they were heat treated.

- Rapid strength development of UHSC mixtures is mainly attributed to the high cementitious content and increased rate of hydration caused by post-setting heat treatment.
Results: Effect of Age

- The ratio of 7-day to 28-day compressive strength of the fiber reinforced UHSC mixture (EL00) was 0.88 while it was 0.84 and 0.85, respectively, for the plain concretes CL00 and DL00.

Reasons:

Accelerated hydration and pozzolanic reactions.
Results: Effects of Curing Regimen

- Specimens cured according to curing regimen OV exhibited the greatest strengths.

- Specimens cured according to curing regimen WB showed better strengths than those cured according to MC.

<table>
<thead>
<tr>
<th>Mixture category</th>
<th>7 days</th>
<th>28 days</th>
<th>Curing regimens considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL20</td>
<td>19.1</td>
<td>4.77</td>
<td>MC, WB</td>
</tr>
<tr>
<td>CL00</td>
<td>21.3</td>
<td>9.23</td>
<td>WB, OV</td>
</tr>
<tr>
<td>DL00</td>
<td>53.6</td>
<td>32.3</td>
<td>WB, OV</td>
</tr>
</tbody>
</table>
Results: Effects of Fibers

- The percentage increase in compressive strength due to steel fibers at 7, 14, and 28 days were 5.43, 5.45, and 2.25 percent, respectively.

- The increase in compressive strength was consistent with the literature.
# Results: Modulus of Rupture of UHSC

<table>
<thead>
<tr>
<th>Category</th>
<th>Mixture</th>
<th>w/c</th>
<th>w/(c+sf)</th>
<th>7 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AL00 (MC)</td>
<td>0.28</td>
<td>0.28</td>
<td>1675 (11.55)</td>
</tr>
<tr>
<td>B</td>
<td>BL00 (MC)</td>
<td>0.37</td>
<td>0.28</td>
<td>1450 (10.00)</td>
</tr>
<tr>
<td>D</td>
<td>DL00 (OV)</td>
<td>0.25</td>
<td>0.20</td>
<td>1585 (10.93)</td>
</tr>
<tr>
<td>E</td>
<td>EL00 (OV)</td>
<td>0.25</td>
<td>0.20</td>
<td>2650 (18.30)</td>
</tr>
</tbody>
</table>
Results: Modulus of Rupture of UHSC

- Greatest flexural strengths were obtained with mixture EL00 (2650 psi [18.3 MPa]).
- Flexural strength of fiber reinforced UHSC was greater than that of plain UHSC by 68.3%.
Conclusions

- UHSC was developed with materials locally available in Las Cruces, New Mexico that produced a compressive strength of 24,010 psi (165.6 MPa) and a flexural strength of 2655 psi (18.3 MPa).
- The strength properties of UHSC produced with local materials were similar to those provided by prepackaged, commercially available products such as Ductal.
- Prolonging the mixing period increased the workability of the mixtures.
- Specimens cured with oven drying attained greater strengths than specimens cured according to MC and WB.
- Age, curing regimen, and fibers influence the compressive strength of concrete.
- Steel fibers increased flexural strength by about 68% and compressive strength by 2 to 5%.
Recommendations for Future Work

• To improve sustainability, fly ash should be considered as a partial replacement for silica fume and cement.

• Efforts should be made to reduce the temperature of 392°F (200°C) that was used in the present work for the OV curing regimen. This would reduce energy costs.

• Polypropylene fibers should be investigated as a replacement for steel fibers.

• Mechanical and physical properties such as modulus of elasticity, split tensile strength, and shrinkage of UHSC should be investigated.

• Durability issues such as DEF, ASR, freeze-thaw durability, and corrosion resistance of UHSC should be investigated.
Thank You