CO$_2$ SEQUESTRATION IN NON-AIR ENTRAINED CONCRETE

By

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UWM Center for By-Products Utilization

Reduce, reuse, recycle, and repair for sustainable developments.

Minimize use of manufactured materials.

Maximize environmental benefits: resource conservation, clean water, and clean air.
Basic Approach

WA$T€ is wasted if you waste it, otherwise it is a resource. Resource is wasted if you ignore it and do not conserve it with holistic best practices and reduce societal costs. Resource is for the transformation of people and society.

Focus on turning brown fields into green fields – Opportunities are here, now!!
Basic Approach

Recycle. Recycle as is.

Recycle without additional processing, (i.e., without adding any cost to it).

Avoided disposal leads to reduced GHGs.
Progression: 21\textsuperscript{st} Century Solid Waste Management

Recycling, sustainable infrastructures, sustainable management of resources (SMR), durable construction materials, global climate change, reduced GHGs, improved air quality, CO2 reduction & sequestration, and carbon offsets.
ABSTRACT

• This study deals with an investigation conducted for the development of a technology for the carbon dioxide (CO\textsubscript{2}) sequestration in non-air entrained concrete (including no-fines concrete and CLSM).

• Several experimental factors such as replacement of cement with ASTM Class C fly ash, different replacement levels of cement with fly ash, and different environmental exposures (i.e., relative humidity and carbon dioxide concentration) were studied in this project.
INTRODUCTION

Global warming has attracted increasingly serious interest among scientists, policy makers, politicians, journalists, and the general public around the world. Popular and academic articles, books, web sites, and television news and documentaries all provide dramatic and detailed examples of the serious consequences of ignoring the issue of global warming. One of the most prevalent greenhouse gases responsible for the global warming is the carbon dioxide (CO$_2$).
EXPERIMENTAL STUDY

Materials

• ASTM Type I portland cement and one ASTM Class C fly ash fly were used in this study.

• The cement and Class C fly ash met the requirements of ASTM standard C 150 and ASTM C 618, respectively.

• Natural sand and crushed quartzite stone of maximum size of ¾ inches (19 mm) were used as a fine aggregate and coarse aggregate.
RESULTS AND DISCUSSION

Fig. 1. 28-Day Depth of Carbonation of Series 1 Mixtures
CONCLUSIONS

• The relative humidity and carbon dioxide concentration are two key factors governing CO\(_2\) sequestration in concrete.

• Concrete with or without Class C fly ash (Mixtures F1, F4, and F7), cured in 100\% relative humidity and 0.15\% CO\(_2\) concentration, did not show any depth of carbonation.

• A reduction of relative humidity from 100\% to 50\% at 0.15\% CO\(_2\) concentration increased the carbon dioxide sequestration potential of concrete.
The earth, the sea (water), and the air are the concern of every nation.” President John F. Kennedy, fall 1963, in a speech to the U.N. General Assembly.
Spaceship Earth – La Bella Terra

Center for By-Products Utilization
Thank you very much for your interest.
Aabhar Tamaro, Afcharisto Poly, Arigatou Gozaimasu, Dziekuje, Maraming Salamat, Merci Beaucoup, Muchas Gracias, Grazie Molte, Muito Obrigado, Salamat, Shukriya, Spasibo, Thank you, Toda Raba.
• Carbonation test was performed to determine the depth of carbonation indicating potential of CO$_2$ sequestration in non-air entrained concrete.

• The study revealed an increase in CO$_2$ sequestration potential with increase in the replacement level of cement by Class C fly ash.

• The study further suggested no adverse effect of CO$_2$ sequestration on the measured mechanical properties of concrete.
## Mixture Designations

<table>
<thead>
<tr>
<th>Series number</th>
<th>% Cement replacement</th>
<th>Curing Type</th>
<th>Mixture designation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100 % RH &amp; 0.15 % CO₂ concentration</td>
<td></td>
</tr>
<tr>
<td>Series 1</td>
<td>0</td>
<td>F1</td>
<td>F2</td>
</tr>
<tr>
<td>Series 2</td>
<td>15</td>
<td>F4</td>
<td>F5</td>
</tr>
<tr>
<td>Series 3</td>
<td>30</td>
<td>F7</td>
<td>F8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 % RH &amp; 0.15 % CO₂ concentration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>F2</td>
<td>F3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F5</td>
<td>F6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F8</td>
<td>F9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 % RH &amp; 5 % CO₂ concentration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>F3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>F6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>F9</td>
<td></td>
</tr>
</tbody>
</table>
## Mixture Proportions and Fresh Concrete Properties of Series 1 Concrete Mixtures (0% Cement Replacement)

<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Curing environment</strong></td>
<td>100 % RH &amp; 0.15 % CO₂ concentration</td>
<td>50 % RH &amp; 0.15 % CO₂ concentration</td>
<td>50 % RH &amp; 5 % CO₂ concentration</td>
</tr>
<tr>
<td>Cement, lbs/yd³</td>
<td>501</td>
<td>508</td>
<td>503</td>
</tr>
<tr>
<td>Fly ash, lbs/yd³</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>% Cement replacement</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sand, SSD, lbs/yd³</td>
<td>1490</td>
<td>1515</td>
<td>1505</td>
</tr>
<tr>
<td>3/4&quot; Aggregates, SSD, lbs/yd³</td>
<td>1755</td>
<td>1785</td>
<td>1775</td>
</tr>
<tr>
<td>Water, lbs/yd³</td>
<td>265</td>
<td>265</td>
<td>260</td>
</tr>
</tbody>
</table>

Note: 1 pound/cubic yard = 0.593kg/cubic meter, 1 inch =25.4 mm
<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to cementitious material ratio, W/Cm</td>
<td>0.53</td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td>Slump, inch</td>
<td>3</td>
<td>2-3/4</td>
<td>2</td>
</tr>
<tr>
<td>Air content, %</td>
<td>2.2</td>
<td>2.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Air temperature, F</td>
<td>70</td>
<td>70</td>
<td>69</td>
</tr>
<tr>
<td>Concrete temperature, F</td>
<td>71</td>
<td>72</td>
<td>70</td>
</tr>
<tr>
<td>Concrete density, lb/ft³</td>
<td>148.6</td>
<td>150.7</td>
<td>149.8</td>
</tr>
</tbody>
</table>

Note: 1 pound/cubic yard = 0.593kg/cubic meter, 1 inch = 25.4 mm
# Mixture Proportions of Series 2 Concrete Mixtures (15% Cement Replacement)

<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curing environment</td>
<td>100 % RH &amp; 0.15 % CO₂ concentration</td>
<td>50 % RH &amp; 0.15 % CO₂ concentration</td>
<td>50 % RH &amp; 5 % CO₂ concentration</td>
</tr>
<tr>
<td>Cement, lbs/yd³</td>
<td>426</td>
<td>426</td>
<td>425</td>
</tr>
<tr>
<td>Fly ash, lbs/yd³</td>
<td>94</td>
<td>94</td>
<td>94</td>
</tr>
<tr>
<td>% Cement replacement</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Sand, SSD, lbs/yd³</td>
<td>1520</td>
<td>1520</td>
<td>1515</td>
</tr>
<tr>
<td>3/4&quot; Aggregates, SSD, lbs/yd³</td>
<td>1765</td>
<td>1765</td>
<td>1760</td>
</tr>
<tr>
<td>Water, lbs/yd³</td>
<td>270</td>
<td>270</td>
<td>269</td>
</tr>
</tbody>
</table>

Note: 1 pound/cubic yard = 0.593kg/cubic meter, 1 inch =25.4 mm
<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to cementitious material ratio, W/Cm</td>
<td>0.52</td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td>Slump, inch</td>
<td>2³⁄₄</td>
<td>2½</td>
<td>3</td>
</tr>
<tr>
<td>Air content, %</td>
<td>1.5</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Air temperature, F</td>
<td>69</td>
<td>69</td>
<td>70</td>
</tr>
<tr>
<td>Concrete temperature, F</td>
<td>71</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Concrete density, lb/ft³</td>
<td>151.0</td>
<td>150.9</td>
<td>150.4</td>
</tr>
</tbody>
</table>

Note: 1 pound/cubic yard = 0.593 kg/cubic meter, 1 inch = 25.4 mm
## Mixture Proportions of Series 3 Concrete Mixtures (30% Cement Replacement)

<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>F7</th>
<th>F8</th>
<th>F9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curing environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% RH &amp; 0.15% CO₂ concentration</td>
<td>355</td>
<td>354</td>
<td>353</td>
</tr>
<tr>
<td>50% RH &amp; 0.15% CO₂ concentration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% RH &amp; 5% CO₂ concentration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement, lbs/yd³</td>
<td>191</td>
<td>190</td>
<td>189</td>
</tr>
<tr>
<td>Fly ash, lbs/yd³</td>
<td>1523</td>
<td>1520</td>
<td>1515</td>
</tr>
<tr>
<td>% Cement replacement</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Sand, SSD, lbs/yd³</td>
<td>1770</td>
<td>1765</td>
<td>1760</td>
</tr>
<tr>
<td>3/4” Aggregates, SSD, lbs/yd³</td>
<td>258</td>
<td>257</td>
<td>256</td>
</tr>
<tr>
<td>Water, lbs/yd³</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** 1 pound/cubic yard = 0.593kg/cubic meter, 1 inch = 25.4 mm
<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>F7</th>
<th>F8</th>
<th>F9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to cementitious material ratio, W/Cm</td>
<td>0.47</td>
<td>0.47</td>
<td>0.47</td>
</tr>
<tr>
<td>Slump, inch</td>
<td>3</td>
<td>3½</td>
<td>3¾</td>
</tr>
<tr>
<td>Air content, %</td>
<td>1.2</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Air temperature, F</td>
<td>70</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>Concrete temperature, F</td>
<td>71</td>
<td>70</td>
<td>71</td>
</tr>
<tr>
<td>Concrete density, lb/ft³</td>
<td>151.7</td>
<td>151.4</td>
<td>150.8</td>
</tr>
</tbody>
</table>

Note: 1 pound/cubic yard = 0.593 kg/cubic meter, 1 inch = 25.4 mm
Fig. 2. Depth of Carbonation of Concrete Mixtures
Fig. 3. Compressive Strength of Concrete Mixtures
Fig. 4. Splitting Tensile Strength of Concrete Mixtures
Fig. 5. Flexural Strength of Concrete Mixtures
Fig. 6. Abrasion Resistance of Concrete Mixtures
• Replacement of cement with Class C fly ash enhanced the carbon dioxide sequestration potential of concrete when exposed to an environment of 50% relative humidity and 0.15% CO₂ concentration.

• At 50% relative humidity, an increase of CO₂ concentration from 0.15% to 5% in the curing environment of concrete, enhanced carbon dioxide sequestration potential of concrete considerably irrespective of the replacement level of cement with fly ash.
• All concrete (Mixtures F3, F6, and F9) cured at 50% relative humidity and 5% CO₂ concentration developed similar potential for CO₂ sequestration irrespective of the cement content.

• Concrete with Class C fly ash, when cured at lower relative humidity of 50 %, exhibited lower strength levels than concrete without fly ash.
• Replacement of cement with Class C fly ash in concrete by 15 and 30 % showed lower compressive and splitting tensile strength of concrete at three-day age and but showed higher compressive strength at 7, 28, and 91-day ages compared concrete without fly ash.

• Curing of concrete at 50 % relative humidity resulted in poor strength development and reduced resistance to abrasion.