Design and Mix Proportioning of Green Concrete Using 100% Fly Ash Based Hydraulic Binder

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CONCRETE SUSTAINABILITY

SOCIAL

ECONOMY

ENVIRONMENT
GREEN CONCRETE (eGC)

- 100% Fly Ash Based Hydraulic Binder (FAHB)
- Non-Portland, Non-Geopolymer Cement
- Non-Caustic Liquid Activators
- Does not need elevated curing temperature
FLY ASH BASED HYDRAULIC BINDER (FAHB)

Class C fly ash : 84.00%
Class F fly ash : 13.50%
Total activators liquid : 3.82%

Note:
Activator solid part : 65.5%
Activator water : 34.5%
Activator liquid : 100%
MIX PROPORTIONING OF eGC

Similar as of ACI 211 guidelines

Except

• Estimation of mixing water per unit volume of concrete
• Relationship between W/B and Compressive Strength (f’ cr) of concrete
ACI 211 recommends simplified tables for mixing water per unit volume of concrete (Air and non-air concrete) with two variables:

- Slump
- NMSA

ACI 211 also suggest correction in mixing water when using:

- Different shape of aggregates
- Water reducing chemical admixtures
ESTIMATION OF MIXING WATER

Model for eGC

\[ W = 0.171\times \text{slump} - 0.977\times \text{NMSA} - 13.36\times (\ln \text{f’ cr})^2 \\
+ 81.69\times (\ln \text{f’ cr}) \]  
(p < 0.005)

\( W \) = Estimated mixing water in kg/m³

\( \text{Slump} \) = Required slump in mm

\( \text{f’ cr} \) = 28-d required compressive strength, MPa

* For Air-entrained concrete use 10% less water

**Note:** 1 kg/m³ = 1.6855 lb/y³, 1 mm = 0.04 inch, 1 MPa = 145 Psi
ESTIMATION OF MIXING WATER

12.5 mm NMSA

28-day Compressive Strength, MPa

25 mm NMSA

28-day Compressive Strength, MPa
<table>
<thead>
<tr>
<th>Data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. f’ cr</td>
<td>35 MPa (5000 psi)</td>
</tr>
<tr>
<td>2. Targeted slump</td>
<td>100 mm (4 inch)</td>
</tr>
<tr>
<td>3. NMSA</td>
<td>25 mm (1 inch)</td>
</tr>
<tr>
<td>4. Class C (SG)</td>
<td>2.75</td>
</tr>
<tr>
<td>5. Class F (SG)</td>
<td>2.26</td>
</tr>
<tr>
<td>6. Activators (SG)</td>
<td>1.335</td>
</tr>
<tr>
<td>7. CA, crushed lime stone (SG)</td>
<td>2.788</td>
</tr>
<tr>
<td>8. FA, natural sand (SG)</td>
<td>2.624</td>
</tr>
<tr>
<td>9. DRBD of CA</td>
<td>1698 kg/m³ (2862 lb/y³)</td>
</tr>
</tbody>
</table>
Follow ACI 211 steps:

STEP 1
Desired Slump : 100 mm (4 inch)

STEP 2
NMSA : 25 mm (1 inch)

STEP 3
Required 28-d strength f’ cr : 35 MPa (5000 psi)
STEP 4

Estimated Total Mix Water

\[ W = 0.171 \times \text{slump} - 0.977 \times \text{NMSA} - 13.36 \times (\ln f' \text{ cr})^2 + 81.69 \times (\ln f' \text{ cr}) \]

\[ W = 0.171 \times 100 - 0.977 \times 25 - 13.36 \times (\ln 35)^2 + 81.69 \times (\ln 35) \]

\[ = 114 \text{ kg/m}^3 \ (192 \text{ lbs/y}^3) \]
eGC MIX PROPORTIONING
SAMPLE COMPUTATION

25 mm NMSA

Estimated Mix Water, kg/cum

28-day Compressive Strength, MPa

50 mm slump
100 mm slump
150 mm slump
200 mm slump

2" slump
4" slump
6" slump
8" slump

20 25 30 35 40 45 50 55 60 65 70
**eGC MIX PROPORTIONING**

**SAMPLE COMPUTATION**

**Step 5: Find W/B**

![Graph showing the relationship between W/B and 28-day Compressive strength (28D)](image)

- **Non-Air entrained 28D**
- **Air Entrained 28D**

**Water to Binder ratio (W/B)**

**28-day Compressive strength, MPa**

0.15 0.17 0.19 0.21 0.23 0.25 0.27 0.29 0.31 0.33 0.35 0.37 0.39 0.41 0.43 0.45
STEP 6

Find Binder Content

Binder = \( \frac{W \text{ (Mix water)}}{W/B} \)

= 114 \( \frac{0.30}{0.30} \)

= 380 \text{ kg/m}^3 \ (640.5 \text{ lb/y}^3)
### BINDER CONTENT
**BREAK OUT**

<table>
<thead>
<tr>
<th>FAHB</th>
<th>Class C: $0.84 \times 380 = 319$ kg/m$^3$ = (538 lb/y$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class F: $0.135 \times 380 = 51$ kg/m$^3$ = (86 lb/y$^3$)</td>
</tr>
<tr>
<td></td>
<td><strong>Total Activator</strong> = $0.0382 \times 380 = 14.52$ kg/m$^3$ = (24.47 lb/y$^3$)</td>
</tr>
<tr>
<td>Class C</td>
<td>84.0%</td>
</tr>
<tr>
<td>Class F</td>
<td>13.5%</td>
</tr>
<tr>
<td>Activator (liq)</td>
<td>3.82%</td>
</tr>
<tr>
<td>Activator (S)</td>
<td>2.5%</td>
</tr>
<tr>
<td>Activator (w)</td>
<td>1.32%</td>
</tr>
</tbody>
</table>
Activation (liquid) : 65.5% solid
: 34.5% water

Water Available from Activator
0.345*14.52 = 5.0 kg/m³ (8.5 lb/y³)

Net Mixing Water
114 - 5 = 109 kg/m³ (183.7 lb/y³)
STEP 7

Quantity of Coarse Aggregate
Follow ACI 211.91 Table 6.3.6
FM of Fine Aggregate : 2.62
NMSA : 1 inch (25 mm)
DRBD of CA : 1698 kg/m$^3$ (2862 lb/y$^3$)

ACI 211 Table 6.3.6 recommends 0.69 m$^3$ (or y$^3$) Coarse Aggregate

Weight of CA = 0.69*1698 = 1172 kg/m$^3$ (1975 lb/y$^3$)
Absolute Volume Basis

Step 8

Volume of net Mixing water: $\frac{183.7}{62.4} = 2.94 \text{ ft}^3$
Solid volume of Class C: $\frac{538}{(2.75 \times 62.4)} = 3.14 \text{ ft}^3$
Solid volume of Class F: $\frac{86}{(2.26 \times 62.4)} = 0.61 \text{ ft}^3$
Volume of total Activator: $\frac{24.47}{(1.355 \times 62.4)} = 0.29 \text{ ft}^3$
Solid volume of CA: $\frac{1975}{(2.785 \times 62.4)} = 11.77 \text{ ft}^3$
Volume of entrapped air: $0.015 \times 27 = 0.40 \text{ ft}^3$
Total volume except FA: $= 18.75 \text{ ft}^3$
Solid volume of FA: $27 - 18.75 = 8.25 \text{ ft}^3$
Required Weight of FA: $8.25 \times 2.624 \times 62.4 = 1352 \text{ lb (802 kg)}$
**BATCH WEIGHT PER UNIT VOLUME OF eGC**

**Step 9**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Mixing Water</td>
<td>184 lb/y³</td>
<td>109 kg/m³</td>
</tr>
<tr>
<td>Class C ash</td>
<td>538 lb/y³</td>
<td>319 kg/m³</td>
</tr>
<tr>
<td>Class F ash</td>
<td>87 lb/y³</td>
<td>51 kg/m³</td>
</tr>
<tr>
<td>Activator NBA 100</td>
<td>15.16 lb/y³</td>
<td>9 kg/m³</td>
</tr>
<tr>
<td>Activator NM 300</td>
<td>9.31 lb/y³</td>
<td>5.52 kg/m³</td>
</tr>
<tr>
<td>Coarse Aggregate, SSD</td>
<td>1975 lb/y³</td>
<td>1172 kg/m³</td>
</tr>
<tr>
<td>Fine Aggregate, SSD</td>
<td>1352 lb/y³</td>
<td>802 kg/m³</td>
</tr>
</tbody>
</table>
## Mix Proportioning Data

<table>
<thead>
<tr>
<th>Mix #</th>
<th>Req. 28D strength (f’cr), MPa</th>
<th>Targeted slump, mm</th>
<th>NMSA, mm</th>
<th>Targeted air, %</th>
<th>Esti. total mix water, kg/m³</th>
<th>W/B</th>
<th>Actual slump, mm</th>
<th>Air %</th>
<th>Final set, Min</th>
<th>1D strength, MPa</th>
<th>7D strength, MPa</th>
<th>28D strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>100</td>
<td>25</td>
<td>NAE</td>
<td>114</td>
<td>0.3</td>
<td>106</td>
<td>1.4</td>
<td>250</td>
<td>14</td>
<td>25</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>100</td>
<td>25</td>
<td>NAE</td>
<td>111</td>
<td>0.27</td>
<td>90</td>
<td>1.5</td>
<td>267</td>
<td>19</td>
<td>31</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>100</td>
<td>25</td>
<td>5 to 6%</td>
<td>103</td>
<td>0.26</td>
<td>100</td>
<td>5</td>
<td>315</td>
<td>20</td>
<td>30</td>
<td>37</td>
</tr>
</tbody>
</table>

Note: 1 Mpa = 145 Psi  
1mm = 0.04 inch  
1 kb/m³ = 1.6855 lb/y³
CONCLUSION

- eGC has different mix water requirement compared to traditional PCC
- The relationship of W/B to $f'_c$ indicates any required strength is achievable without additional chemical and mineral admixtures
- eGC mix proportioning method follows the similar steps of ACI 211 guidelines
- This mix proportioning method would help producing green and sustainable concrete using 100% FAHB
Thank You!

Questions?

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