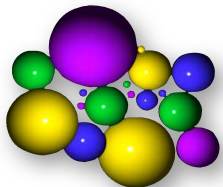




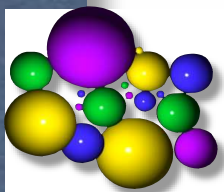
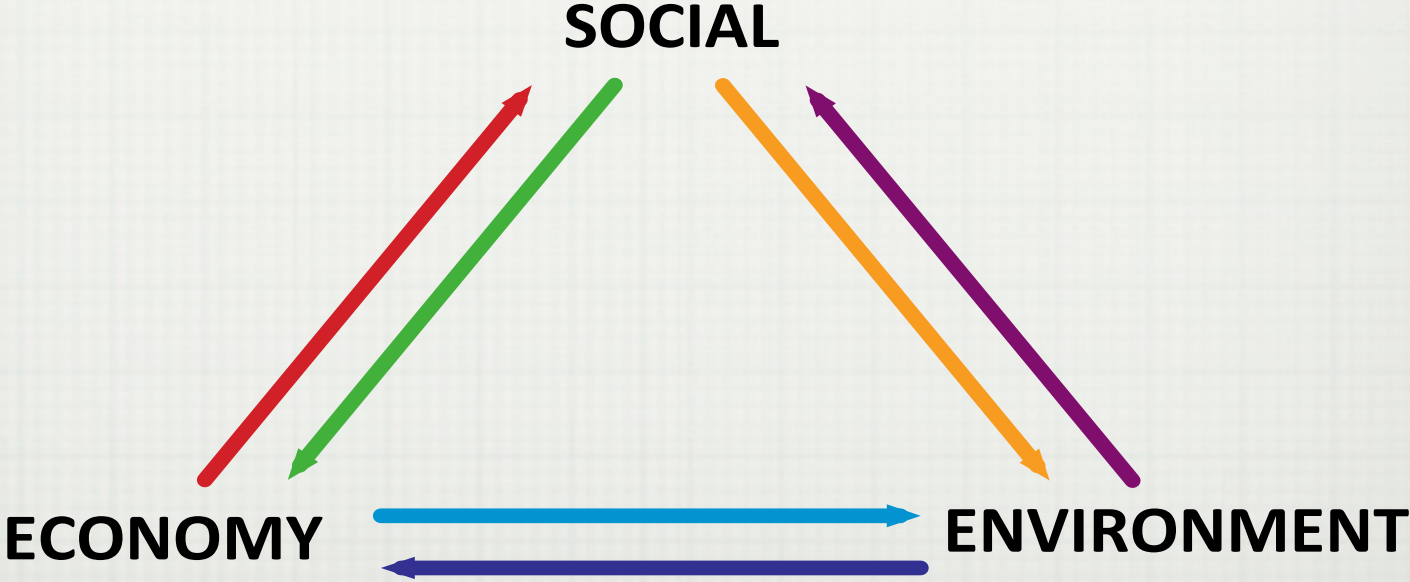
Design and Mix Proportioning of **Green Concrete** Using 100% Fly Ash Based Hydraulic Binder

Raj Patel, MS.; P.Eng.
Director of Engineering Research
&
Fred Kinney
Sr. VP of R&D



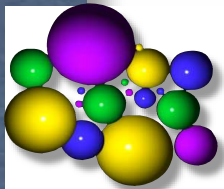
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CONCRETE SUSTAINABILITY



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

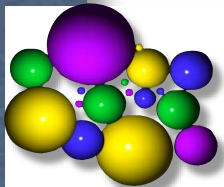


FLY ASH BASED HYDRAULIC BINDER (FAHB)

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%

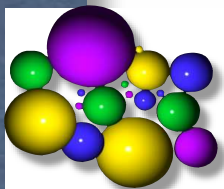


MIX PROPORTIONING OF eGC

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



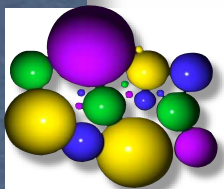
ESTIMATION OF MIXING WATER

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

$$W = 0.171 * \text{slump} - 0.977 * \text{NMSA} - 13.36 * (\ln f' \text{ cr})^2 + 81.69 * (\ln f' \text{ cr}) \quad (p < 0.005)$$

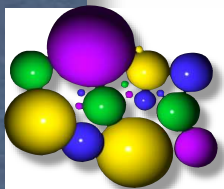
W = Estimated mixing water in kg/m³

Slump = Required slump in mm

f' cr = 28-d required compressive strength, MPa

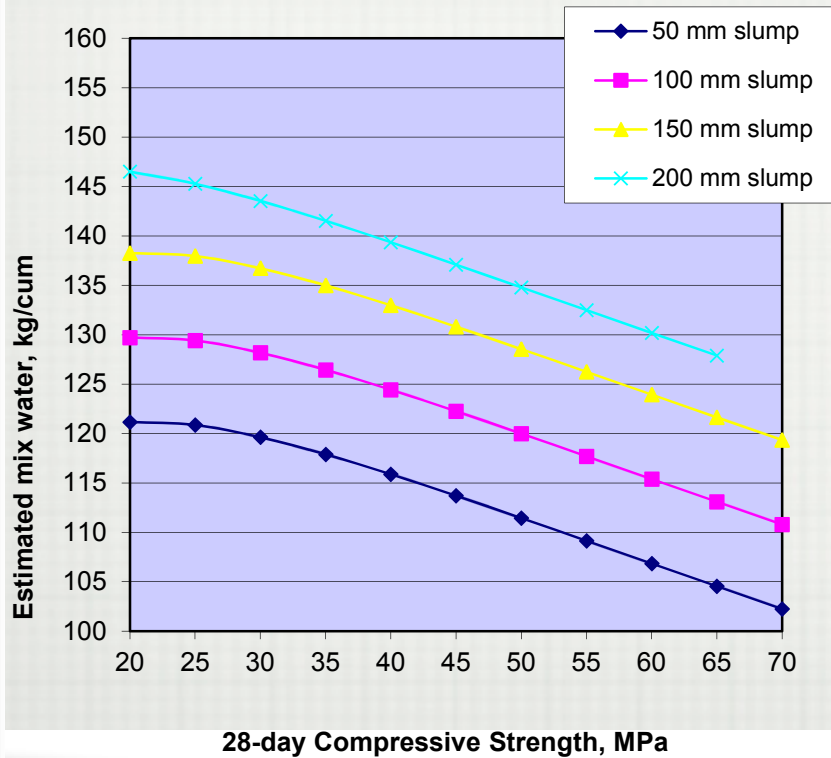
* For Air-entrained concrete use 10% less water

Note: 1 kg/m³ = 1.6855 lb/y³, 1 mm = 0.04 inch, 1 MPa = 145 Psi

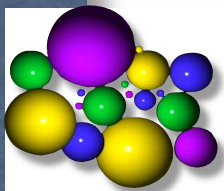
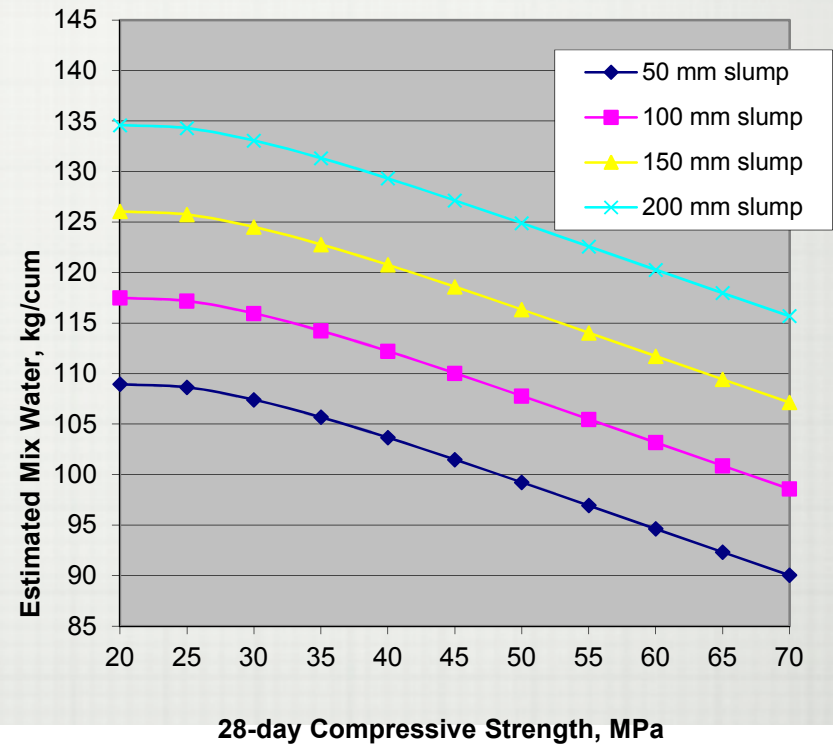


ESTIMATION OF MIXING WATER

12.5 mm NMSA

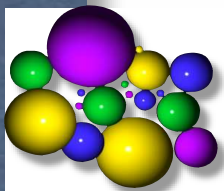
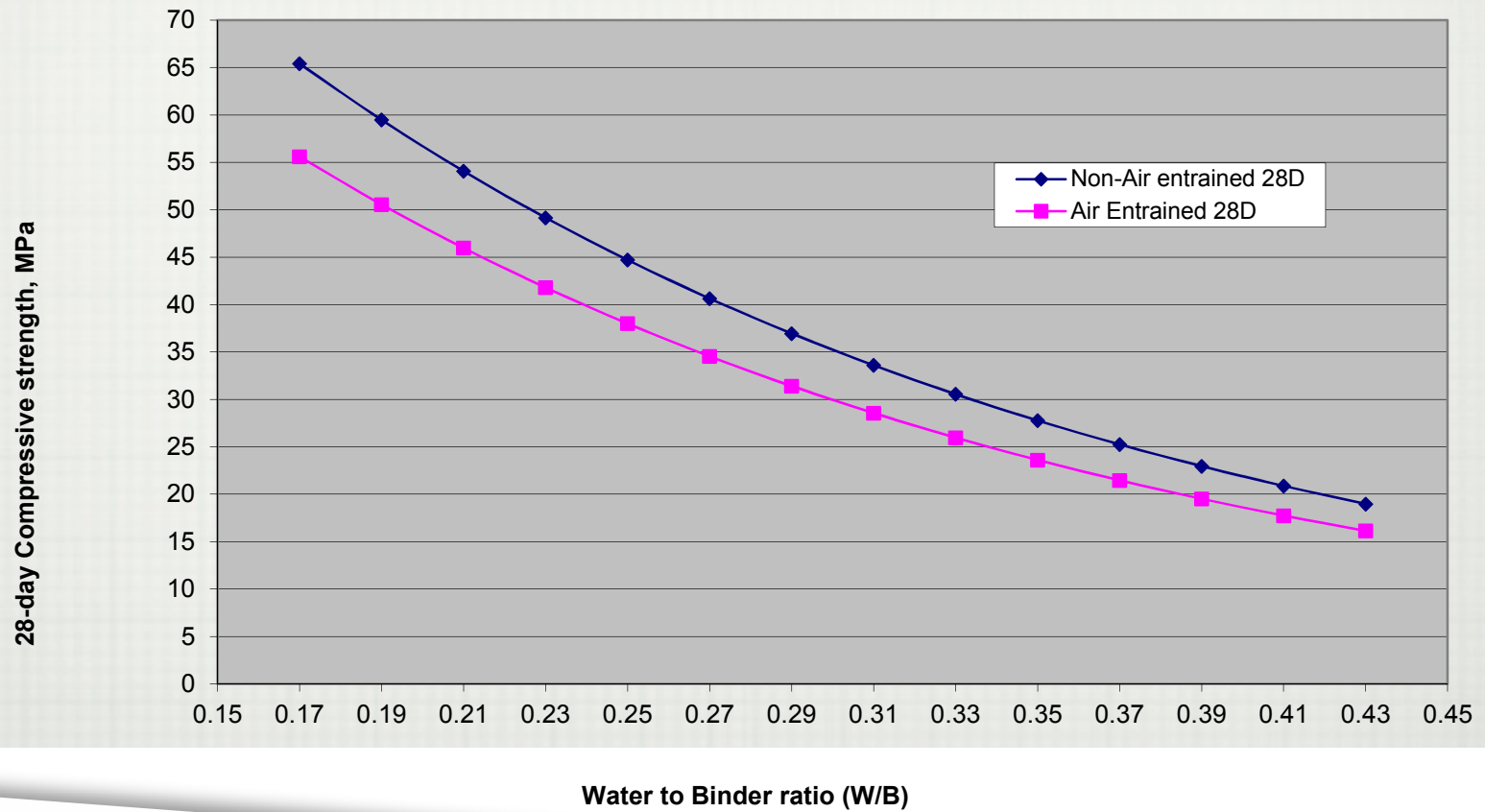


25 mm NMSA



SELECTION OF W/B

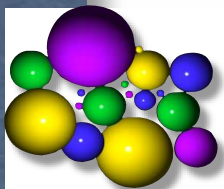
W/B to Compressive strength (28D)



eGC MIX PROPORTIONING SAMPLE COMPUTATION

Data

1. f'_{cr}	: 35 MPa (5000 psi)
2. Targeted slump	: 100 mm (4 inch)
3. NMSA	: 25 mm (1 inch)
4. Class C (SG)	: 2.75
5. Class F (SG)	: 2.26
6. Activators (SG)	: 1.335
7. CA, crushed lime stone (SG)	: 2.788
8. FA, natural sand (SG)	: 2.624
9. DRBD of CA	: 1698 kg/m ³ (2862 lb/y ³)



eGC MIX PROPORTIONING SAMPLE COMPUTATION

Follow ACI 211 steps:

STEP 1

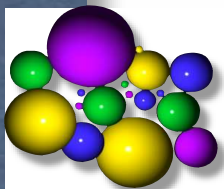
Desired Slump : 100 mm (4 inch)

STEP 2

NMSA : 25 mm (1 inch)

STEP 3

Required 28-d strength f'_{cr} : 35 MPa (5000 psi)



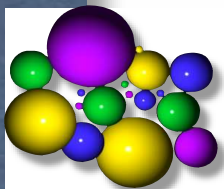
eGC MIX PROPORTIONING SAMPLE COMPUTATION

STEP 4

Estimated Total Mix Water

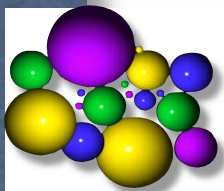
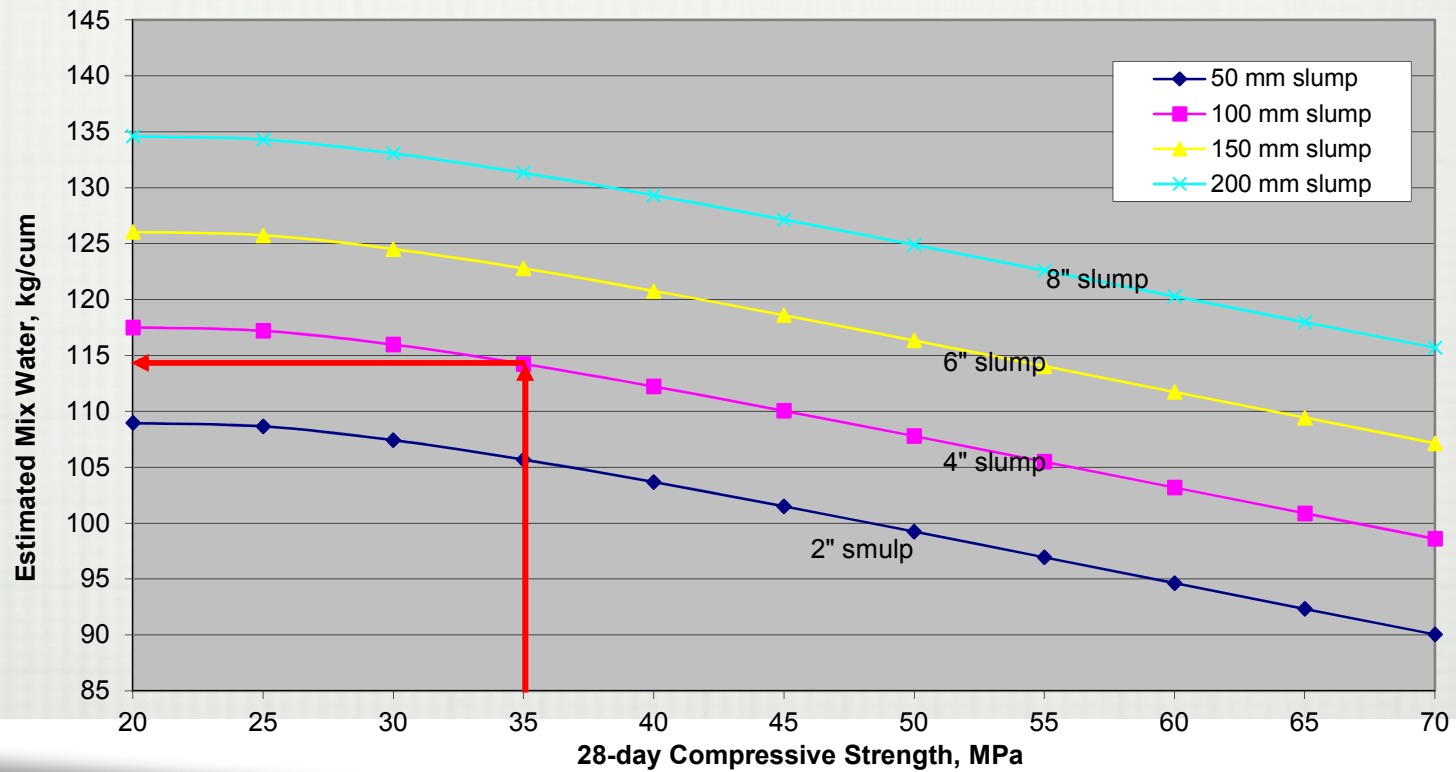
$$W = 0.171 * \text{slump} - 0.977 * \text{NMSA} - 13.36 * (\ln f' cr)^2 + 81.69 * (\ln f' cr)$$

$$W = 0.171 * 100 - 0.977 * 25 - 13.36 * (\ln 35)^2 + 81.69 * (\ln 35) \\ = 114 \text{ kg/m}^3 \text{ (192 lbs/y}^3\text{)}$$



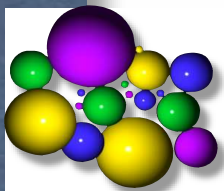
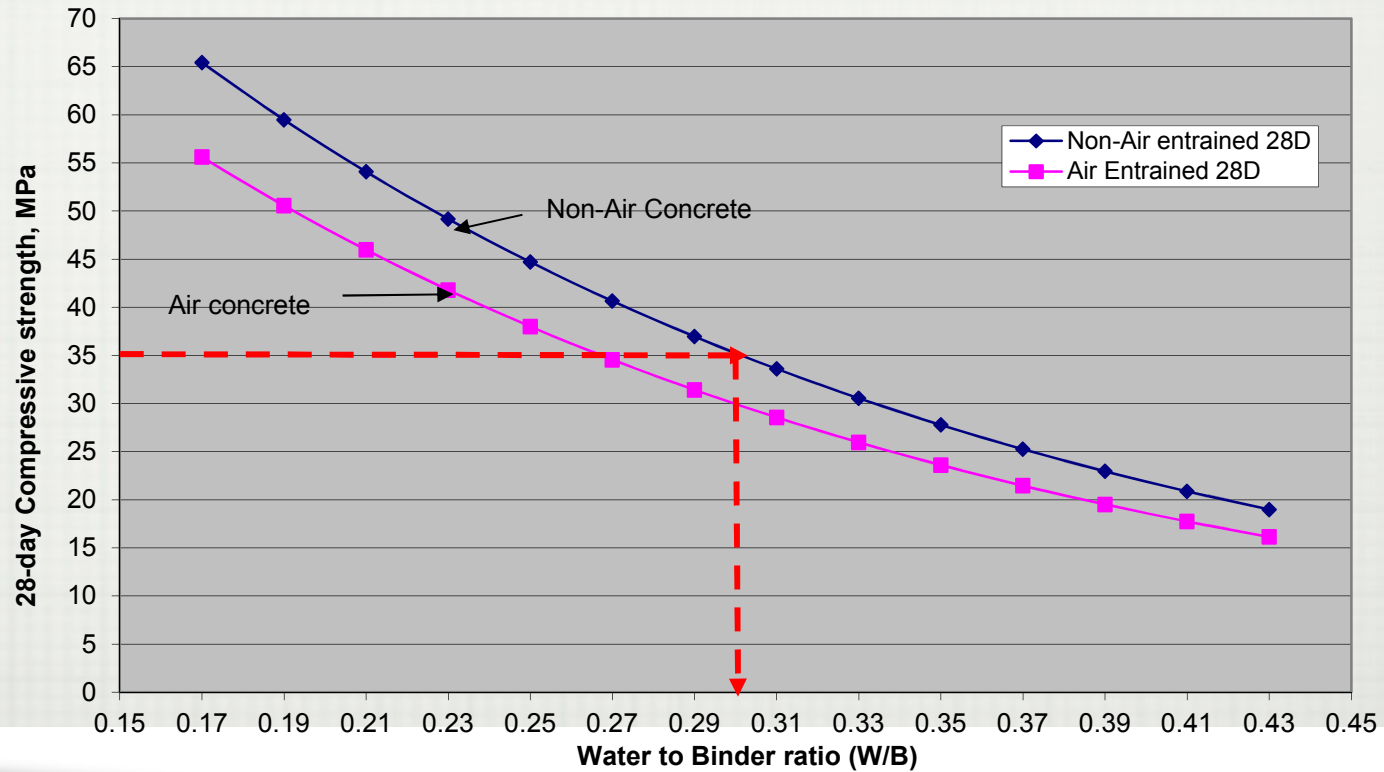
eGC MIX PROPORTIONING SAMPLE COMPUTATION

25 mm NMSA



eGC MIX PROPORTIONING SAMPLE COMPUTATION Step 5: Find W/B

W/B to Compressive strength (28D)



eGC MIX PROPORTIONING SAMPLE COMPUTATION

STEP 6

Find Binder Content

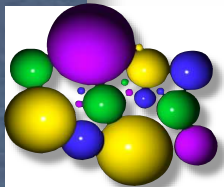
Binder = W (Mix water)

$\frac{\quad}{W/B}$

= $\frac{114}{\quad}$

0.30

= 380 kg/m³ (640.5 lb/y³)



BINDER CONTENT BREAK OUT

FAHB

Class C	:84.0%
Class F	:13.5%
Activator (liq)	:3.82%
Activator (S)	:2.5%
Activator (w)	:1.32%

$$\text{Class C: } 0.84 * 380 = 319 \text{ kg/m}^3 \\ = (538 \text{ lb/y}^3)$$

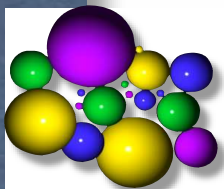
$$\text{Class F: } 0.135 * 380 = 51 \text{ kg/m}^3 \\ = (86 \text{ lb/y}^3)$$

$$\text{Total Activator} = 0.0382 * 380 = 14.52 \text{ kg/m}^3 \\ = (24.47 \text{ lb/y}^3)$$

Default Blend = 62%/38%

$$\text{NBA 100} = 0.62 * 14.52 = 9.0 \text{ kg/m}^3 \\ = (15.16 \text{ lb/y}^3)$$

$$\text{NM 300} = 0.38 * 14.52 = 5.52 \text{ kg/m}^3 \\ = (9.31 \text{ lb/y}^3)$$



MIX WATER

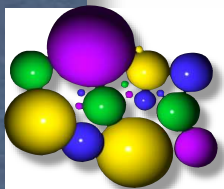
Activator (liquid) : 65.5% solid
: 34.5% water

Water Available from Activator

$$0.345 * 14.52 = 5.0 \text{ kg/m}^3 \text{ (8.5 lb/y}^3\text{)}$$

Net Mixing Water

$$114 - 5 = 109 \text{ kg/m}^3 \text{ (183.7 lb/y}^3\text{)}$$



eGC MIX PROPORTIONING SAMPLE COMPUTATION

STEP 7

Quantity of Coarse Aggregate

Follow ACI 211.91 Table 6.3.6

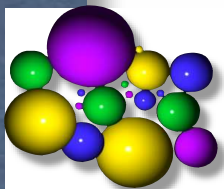
FM of Fine Aggregate : 2.62

NMSA : 1 inch (25 mm)

DRBD of CA : 1698 kg/m³ (2862 lb/y³)

ACI 211 Table 6.3.6 recommends 0.69 m³ (or y³) Coarse Aggregate

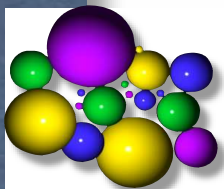
Weight of CA = 0.69*1698 = 1172 kg/m³ (1975 lb/y³)



Absolute Volume Basis

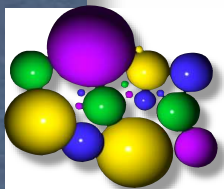
Step 8

Volume of net Mixing water	: 183.7/62.4	= 2.94 ft ³
Solid volume of Class C	: 538/(2.75*62.4)	= 3.14 ft ³
Solid volume of Class F	: 86/(2.26*62.4)	= 0.61 ft ³
Volume of total Activator	: 24.47/(1.355*62.4)	= 0.29 ft ³
Solid volume of C A	: 1975/(2.785*62.4)	= 11.77 ft ³
Volume of entrapped air	: 0.015*27	= 0.40 ft ³
Total volume except F A		= 18.75 ft³
Solid volume of F A	: 27 – 18.75	= 8.25 ft ³
Required Weight of F A	: 8.25*2.624*62.4=1352 lb (802 kg)	



BATCH WEIGHT PER UNIT VOLUME OF eGC Step 9

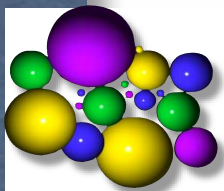
Net Mixing Water	: 184 lb/y ³ (109 kg/m ³)
Class C ash	: 538 lb/y ³ (319 kg/m ³)
Class F ash	: 87 lb/y ³ (51 kg/m ³)
Activator NBA 100	: 15.16 lb/y ³ (9 kg/m ³)
Activator NM 300	: 9.31 lb/y ³ (5.52 kg/m ³)
Coarse Aggregate, SSD	: 1975 lb/y ³ (1172 kg/m ³)
Fine Aggregate, SSD	: 1352 lb/y ³ (802 kg/m ³)



VALIDATION

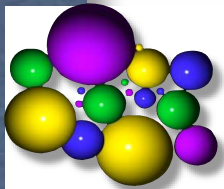
Mix Proportioning Data							Actual eGC Results					
Mix #	Req. 28D strength (f'cr), MPa	Targeted slump, mm	NMSA, mm	Targeted air, %	Esti. total mix water, kg/m ³	W/B	Actual slump, mm	Air %	Final set, Min	1D strength, MPa	7D strength, MPa	28D strength, MPa
1	35	100	25	NAE	114	0.3	106	1.4	250	14	25	34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

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



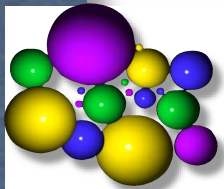
CONCLUSION

- eGC has different mix water requirement compared to traditional PCC
- The relationship of W/B to f' or 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?

Raj Patel
raj.patel@ceratechinc.com



3501 Brehms Lane, Suite D • Baltimore, MD. 21213