# Reducing Carbon Footprint of Concrete – The Low-Hanging Fruit

Karthik Obla

June 14, 2023

NRMCA

## Net Zero efforts by Industry Stakeholders

- U.S. Green Building Council (USGBC)
- Green Globes Building Certification
- architecture 2030
- The American Institute of Architects
- 2012 International Green Construction Code (IgCC)
- Setting Standards for Sustainability – ASTM International Committee E60
- CLF Carbon Leadership Forum
- EC3
- SEI Structural Engineering Institute (ASCE)
- SE2050 Committing to Net Zero
- aci
- neu – An ACI Center of Excellence for Carbon Neutral Concrete
- NIST Projects/Programs – Low Carbon Cements and Concretes Consortium

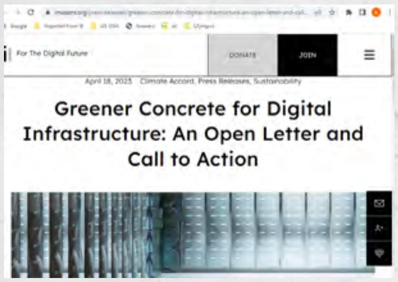
# Calls for net zero from Purchasers, Influencers

UN SBTI – 5000+ companies with targets

UN Net Zero Asset Owner Alliance

SCIENCE BASED TARGETS
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

WORLD ECONOMIC FORUM





The Economist | Menu | Weekly edition | The world in brief | Search

Science & technology | Tackling global warming

How to make low-carbon concrete from old cement

nature > editorials > article

EDITORIAL | 28 September 2021

**Concrete needs to lose its colossal carbon footprint**

# Federal Government - Inflation Reduction Act, 2022

- $5.8B for an advanced manufacturing fund intended to help speed decarbonization at industrial plants (SEC. 50161)
- $2.15 billion to GSA (SEC. 60503) and $2 billion to the FHWA (SEC. 60506) — to procure low-carbon materials for transportation and other projects
- $250M to EPA to help manufacturers develop EPDs (SEC. 60112)
- $100M for EPA, FHWA, and GSA to develop Ecolabel - identify lower levels of embodied greenhouse gas emissions (SEC. 60116)

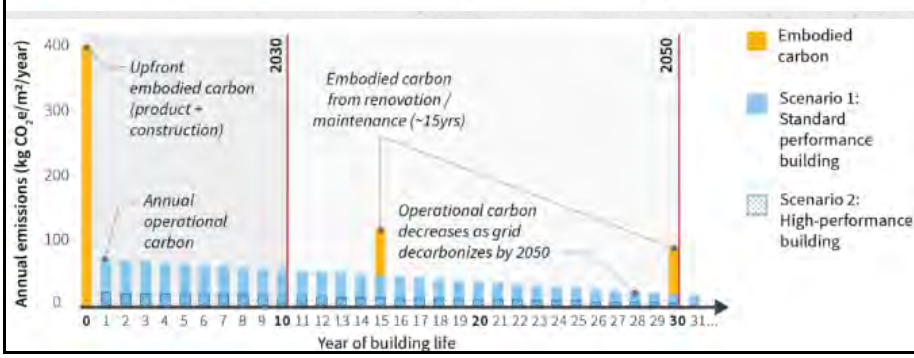
| | **GSA IRA Limits for Low Embodied Carbon Concrete - May 16, 2023** (EPD-Reported GWPs, in kilograms of carbon dioxide equivalent per cubic meter - $kgCO_2e/m^3$) | | |
|---|---|---|---|
| **Specified concrete strength class** (compressive strength [f'c] in pounds per square inch [PSI]) | **Top 20% Limit** | **Top 40% Limit** | **Better Than Average Limit** |
| ≤2499 | 228 | 261 | 277 |
| 3000 | 257 | 291 | 318 |
| 4000 | 284 | 326 | 352 |
| 5000 | 305 | 357 | 382 |
| 6000 | 319 | 374 | 407 |
| ≥7200 | 321 | 362 | 402 |

Add 30% to these numbers for GWP limits where high early strength[1] concrete mixes are required for technical reasons.

# State Buy Clean Legislation

- California (AB 262)
- Colorado (HB21-1303)
- Minnesota (Buy Clean Study & Buy Clean/Buy Fair Pilot Program)
- New Jersey – Low Embodied Carbon Concrete Leadership Act (signed into law)
- Oregon (HB 4139A)
- Washington (2021-23 Biennium Budgets & Buy Clean/Buy Fair Pilots)
- City of Austin, TX (Climate Equity Action Plan)
- City of Portland, OR (Procurement Services; Low Carbon Concrete)
- Other Buy Clean Initiatives and/or State & Local Climate Action Plans…

# Embodied and Operational Carbon


Embodied carbon – majority released upfront

*Source: Carbon Leadership Forum*

# Life Cycle Stage – Cradle to Gate

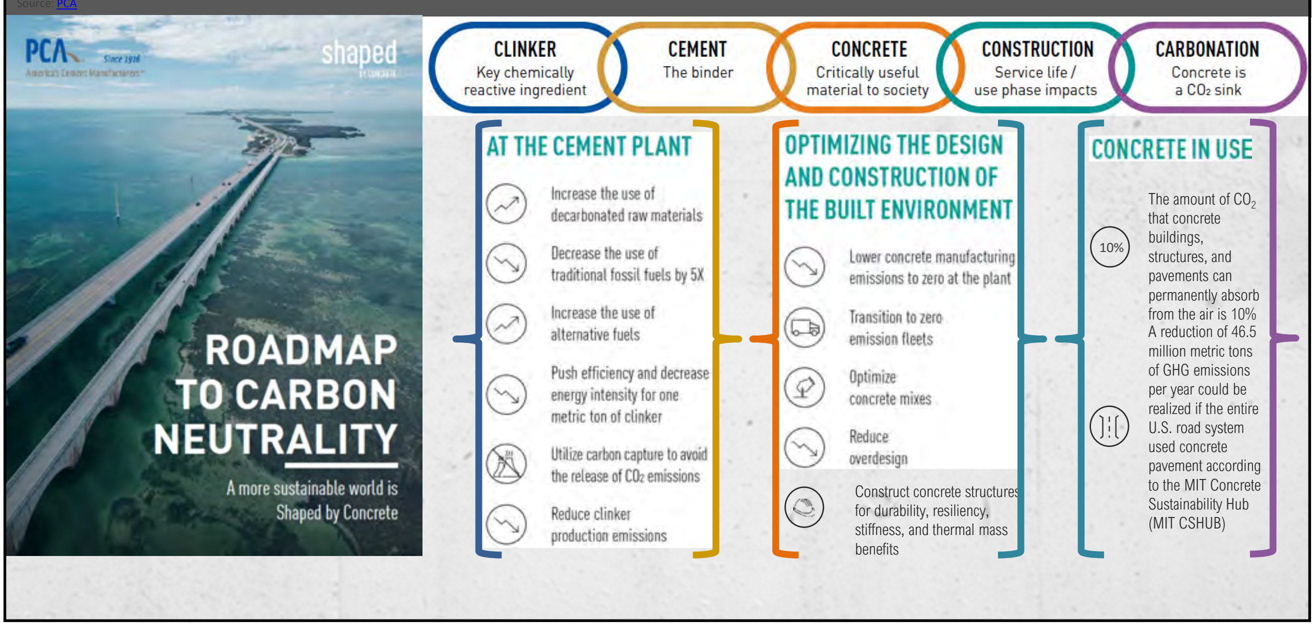
**Building Life Cycle Information Modules**

| Product stage | | | Construction Process stage | | Use stage | | | | | | | End-of-life stage | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw Material supply | Transport | Manufacturing | Transport | Construction/Installation | Use | Maintenance | Repair | Replacement | Refurbishment | Operational Energy Use | Operational Water Use | De-Construction/ Demolition | Transport | Waste processing | Disposal |
| A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 |

***Figure 1.*** Life cycle stage schematic – alpha-numeric designations as per NSF PCR (adapted from CEN 15978:2011)

# Roadmap to Carbon Neutrality: Cement & Concrete

Source: PCA



# NRMCA Sustainability Initiatives

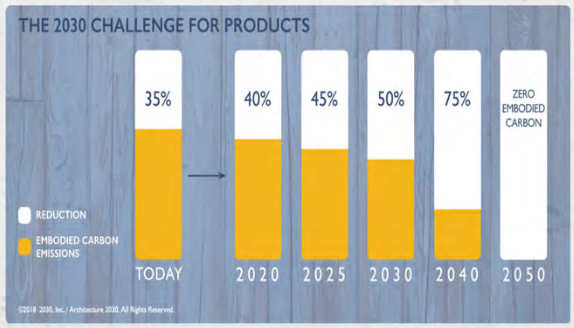
2009 | 2012 | 2014 | 2016 | 2021

ADOPTER architecture 2030 CHALLENGE

NRMCA CERTIFIED EPD

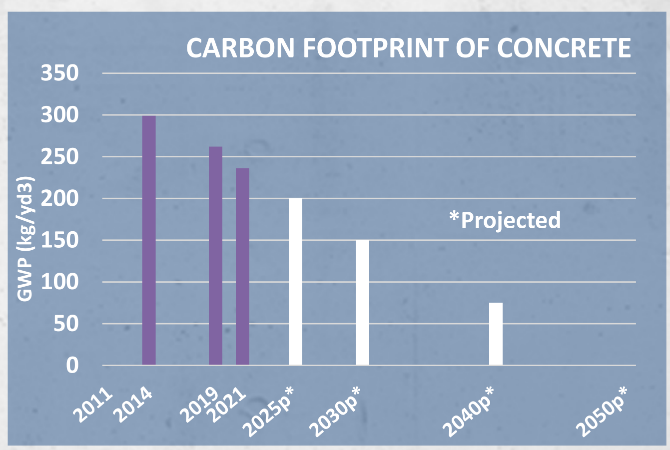
BUILD WITH STRENGTH

Roadmap to Carbon Neutrality
A more sustainable world is Shaped by Concrete




# EPD Program Progress

- 21% decrease in embodied $CO_2$
- 40,000+ concrete EPDs



## The Takeaway

- Lot of ongoing efforts to get to Net Zero by 2050
- Low-carbon concrete likely to become mainstream
- More regions and markets
- Companies need to plan

## Solutions for Low Carbon Concrete

- Performance-based Specifications
- Improved acceptance testing
- Improved product quality
- Rational Interpretation of Codes, Standards, and Specifications
- Lower over designs
- Optimized mixtures

# Performance-based Specifications

Architect/Engineer

# Prescriptive Specifications

2.1.2 Water-Cement Ratio

Maximum water-cement ratio (w/c) for concrete shall be 0.40 by weight, for all work.

segregation or bleeding. The cementitious materials content of concrete shall be at least 675 pounds per cubic yard. Except that concrete to be placed by tremie the cementitious materials content shall be at least 725 pounds per cubic yard.

c. Fly Ash: Fly Ash shall have a high fineness and low carbon content and shall exceed the requirements of ASTM-C-618, "Specification for Fly Ash and Raw or Calcined Natural for Use in Portland Cement Concretes" for Class F, except that the loss of ignition shall be less than 3% and all fly ash shall be a classified processed material. Fly ash shall be obtained from one source for the concrete delivered to the project. Complete chemical and physical analysis of the fly ash shall be submitted to the Architect prior to use. Concrete mixes proportioned with fly ash shall contain not less than 10% nor more than 20% by weight of cement to fly ash.

## Performance Specifications

- Strength
- Modulus of Elasticity
- Durability - Resistivity
- Volume change – potential for cracking
- Hundreds of standardized tests are available to characterize concrete performance

## Most Common Prescriptive Requirements

| Prescriptive Requirement | Frequency Seen |
|---|---|
| Restriction on SCM quantity | 85% |
| Max *w/cm* | 73% |
| Minimum cementitious content | 46% |
| Restriction on SCM type, characteristics | 27% |
| Restriction on aggregate grading | 25% |

# Prescription detracts from Sustainability

| Specification Provision | Impact of provision | | |
|---|---|---|---|
| | Sustainability | Performance | Cost |
| Restriction on quantity of SCM | ↓ | ↓ | ↑ |
| Maximum *w/cm* | ↓ | ↔ | ↑ |
| Minimum cementitious content | ↓ | ↔ | ↑ |
| Restriction on SCM characteristics | ↓ | ↓ | ↑ |
| Restrictions on characteristics of aggregates | ↓ | ↔ | ↑ |

**Ref: Lemay, Lobo, Obla, Hanley Wood University, 2019**

# Exposure Categories Durability (ACI 318)

**Table 19.3.1.1—Exposure categories and classes**

| Category | Class | Condition | |
|---|---|---|---|
| Freezing and thawing (F) | F0 | Concrete not exposed to freezing-and-thawing cycles | |
| | F1 | Concrete exposed to freezing-and-thawing cycles with limited exposure to water | |
| | F2 | Concrete exposed to freezing-and-thawing cycles with frequent exposure to water | |
| | F3 | Concrete exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals | |
| Sulfate (S) | | Water-soluble sulfate ($SO_4^{2-}$) in soil, percent by mass[1] | Dissolved sulfate ($SO_4^{2-}$) in water, ppm[2] |
| | S0 | $SO_4^{2-} < 0.10$ | $SO_4^{2-} < 150$ |
| | S1 | $0.10 \le SO_4^{2-} < 0.20$ | $150 \le SO_4^{2-} < 1500$ or seawater |
| | S2 | $0.20 \le SO_4^{2-} \le 2.00$ | $1500 \le SO_4^{2-} \le 10{,}000$ |
| | S3 | $SO_4^{2-} > 2.00$ | $SO_4^{2-} > 10{,}000$ |
| In contact with water (W) | W0 | Concrete dry in service | |
| | W1 | Concrete in contact with water where low permeability is not required | |
| | W2 | Concrete in contact with water where low permeability is required | |
| Corrosion protection of reinforcement (C) | C0 | Concrete dry or protected from moisture | |
| | C1 | Concrete exposed to moisture but not to an external source of chlorides | |
| | C2 | Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources | |

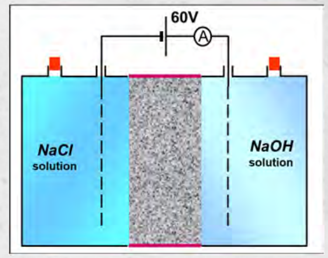
**Table 19.3.2.1—Requirements for concrete by exposure class**

| Exposure class | | Maximum *w/cm*[1,2] | Minimum $f_c'$, psi | Additional requirements: Air content | | | Limits on cementitious materials |
|---|---|---|---|---|---|---|---|
| F0 | | N/A | 2500 | N/A | | | N/A |
| F1 | | 0.55 | 3500 | Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete | | | N/A |
| F2 | | 0.45 | 4500 | Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete | | | N/A |
| F3 | | 0.40[3] | 5000[3] | Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete | | | 26.4.2.2(b) |
| | | | | Cementitious materials[4] — Types | | | Calcium chloride admixture |
| | | | | ASTM C150 | ASTM C595 | ASTM C1157 | |
| S0 | | N/A | 2500 | No type restriction | No type restriction | No type restriction | No restriction |
| S1 | | 0.50 | 4000 | II[5][6] | Types with (MS) designation | MS | No restriction |
| S2 | | 0.45 | 4500 | V[6] | Types with (HS) designation | HS | Not permitted |
| S3 | Option 1 | 0.45 | 4500 | V plus pozzolan or slag cement[7] | Types with (HS) designation plus pozzolan or slag cement[7] | HS plus pozzolan or slag cement[7] | Not permitted |
| | Option 2 | 0.40 | 5000 | V[8] | Types with (HS) designation | HS | Not permitted |
| W0 | | N/A | 2500 | None | | | |
| W1 | | N/A | 2500 | 26.4.2.2(d) | | | |
| W2 | | 0.50 | 4000 | 26.4.2.2(d) | | | |
| | | | | Maximum water-soluble chloride ion ($Cl^-$) content in concrete, percent by mass of cementitious materials[9,10] | | Additional provisions | |
| | | | | Nonprestressed concrete | Prestressed concrete | | |
| C0 | | N/A | 2500 | 1.00 | 0.06 | None | |
| C1 | | N/A | 2500 | 0.30 | 0.06 | | |
| C2 | | 0.40 | 5000 | 0.15 | 0.06 | Concrete cover[11] | |

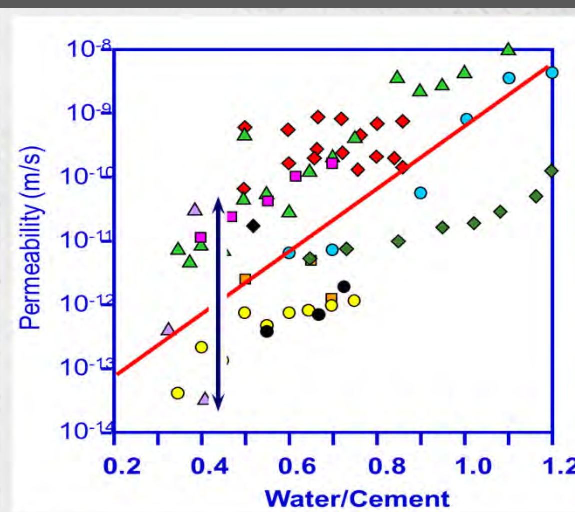
# Performance Alternative: Permeability

- For ASTM C1202 (accelerated curing for mixtures with SCM):
  - o *w/cm* = 0.55 → Maximum 3000 coulombs
  - o *w/cm* = 0.50 → Maximum 2500 coulombs
  - o *w/cm* = 0.45 → Maximum 2000 coulombs
  - o *w/cm* = 0.40 → Maximum 1500 coulombs
- For ASTM C1876 (resistivity) (56 day):
  - o *w/cm* = 0.55 → Minimum 60 Ω-m
  - o *w/cm* = 0.50 → Minimum 75 Ω-m
  - o *w/cm* = 0.45 → Minimum 90 Ω-m
  - o *w/cm* = 0.40 → Minimum 120 Ω-m



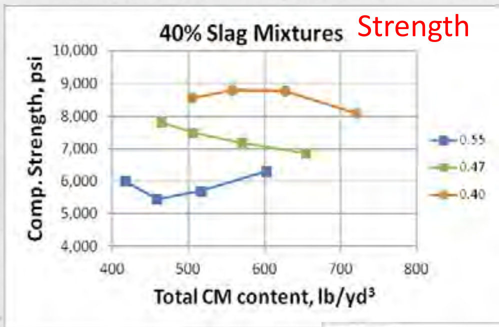

# Specifying *w/cm*

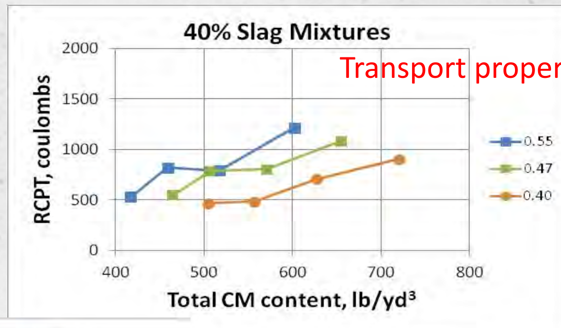
- Wide range of permeability
- SCMs, paste volumes
- Lower is not always better
  - – Impacts sustainability, constructability



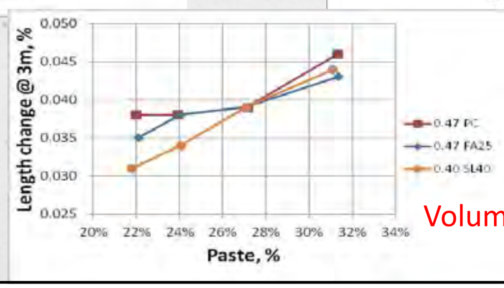

*(Adapted from Hearn et al, 1996)*

# Specifying Minimum CM content




Strength/Workability
Higher Cementitious




Volume Change

Durability / Cracking
Lower Cementitious

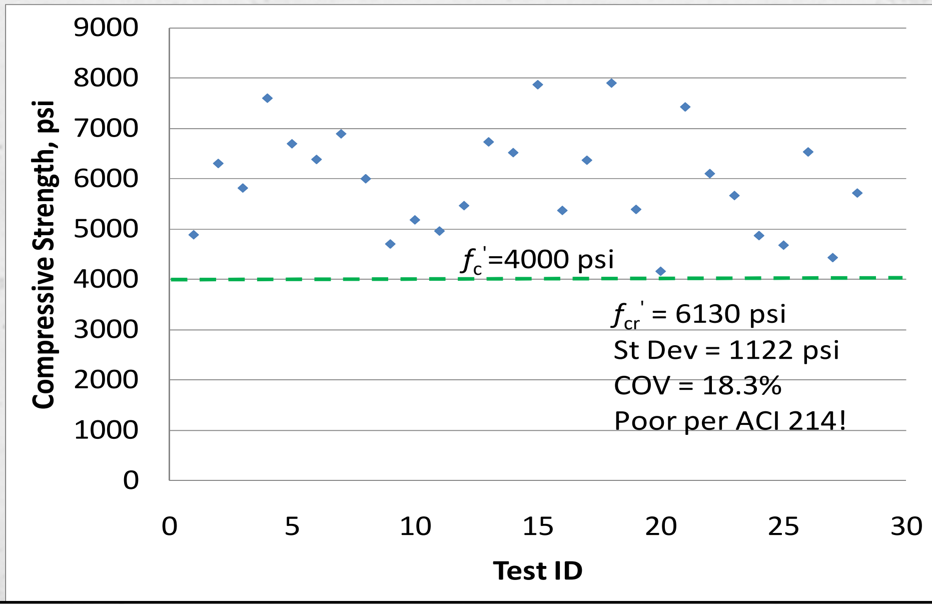
# Example – Specification

- Prescriptive mixture, *w/cm*=0.40, No SCM, 3500 psi, non-air-entrained
  - Water content = 300 lb/yd$^3$
  - Cement = 750 lb/yd$^3$
  - Average strength = 7500 psi (10 psi/lb)

**Table 5.3.3—Approximate mixing water and air content for different slumps for concrete without water-reducing admixtures and nominal maximum sizes of aggregates**

| | Water of concrete for indicated nominal maximum sizes of aggregates, lb/yd$^3$ | | | | | | |
|---|---|---|---|---|---|---|---|
| Slump, in.* | 3/8 | 1/2 | 3/4 | 1 | 1-1/2 | 2† | 3† |
| Non-air-entrained concrete | | | | | | | |
| 1 to 2 | 350 | 335 | 315 | 300 | 275 | 260 | 220 |
| 3 to 4 | 385 | 365 | 340 | 325 | 300 | 285 | 245 |

# Impact of Maximum *w/cm* or Minimum CM content




Try to avoid prescription that increases overdesign


www.nrmca.org/P2P

# Improved Acceptance Testing

Owner / Contractor / Lab

## Acceptance Testing (defined)

- Architect/Engineer specifies 4000 psi
- Concrete truck arrives at jobsite, specimens made
- Specimens initially cured
- Transported, cured and tested at lab
- Specimens need to meet acceptance criteria
- **Testing need to comply with standards**

# Standard Curing (ASTM C31) Strength

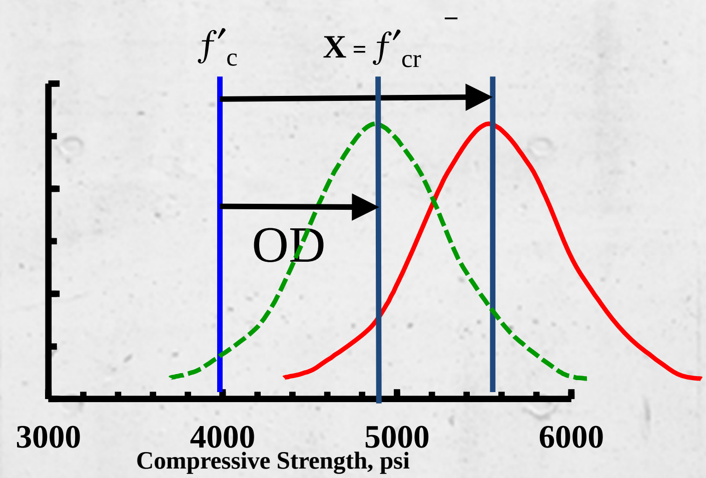
- Maintain moisture
- Initial temperature in field
  - 60°F to 80°F
  - $f'_c$ > 6000 psi - 68°F to 78°F
- Transport to lab within 48 hrs or 8h after final set
- Transportation time 4 hrs or less
  - Proper Cushioning, Protect from Freezing, Moisture Loss
- Lab curing 73.5±3.5°F and moist

# Who is Watching Out for the Cylinders? CI, August 2018
by K. Obla, O. Werner, J. Hausfeld, K. MacDonald, G. Moody, N. Carino

*If initial curing is not in accordance with ASTM C31/C31M, there may be up to a 20% reduction in the 28-day compressive strength*

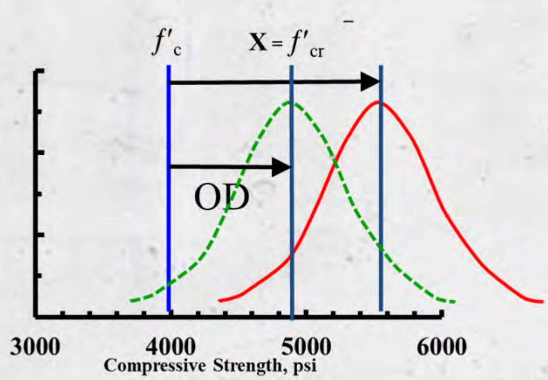

 

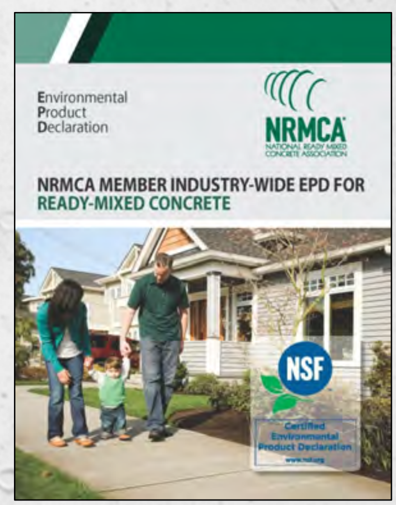
# Impact of non-standard testing




1MPa = 145 psi

# Concrete Strength and Embodied Carbon (GWP)




Average Strength ▲ Embodied Carbon ▲

Strength ▲ 100 psi (0.7 MPa) GWP ▲ 2.3%

## ACI Requirements on Initial Curing

Standard cured in accordance with ASTM C31

Legally binding….not optional or good to have

- Contractor
  - Shall provide space and electrical power for initial curing
- Testing agency
  - Shall verify standard curing is according to ASTM C31
  - Shall ensure test report includes max/min temps of the initial curing period
- Who is responsible for supplying the curing container on site?
  - ACI 301 - Testing agency
  - ACI 311.6 - Owner or Owner's representative shall provide this
  - ACI 132 TN - A/E defines responsibilities in contract docs. Testing agency includes cost of curing container in their bid (if needed)

How to change?

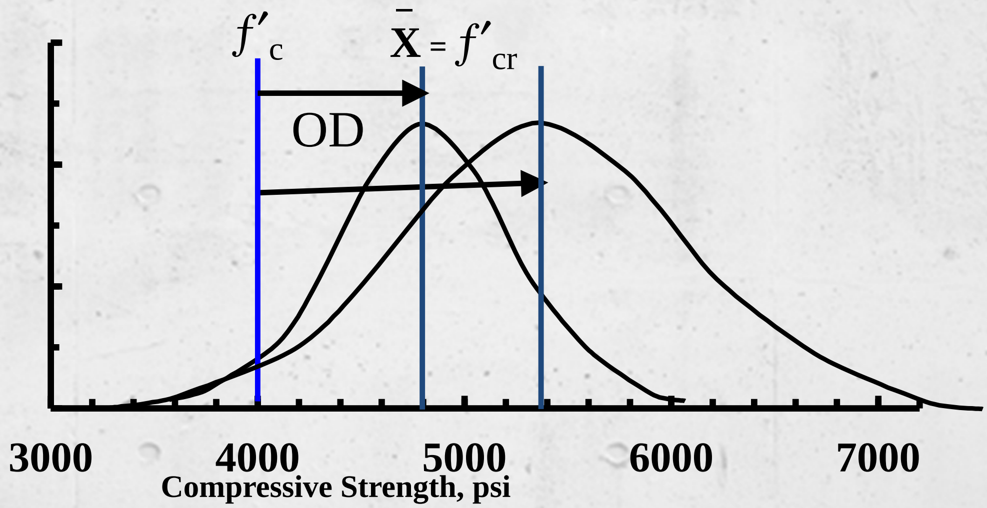
Educate purchasers of testing services

Accountability of non-standard testing

## Improved Product Quality

Concrete Producer / Ingredient material supplier / Lab

## Improved Quality Lowers Over Design




## How to Improve Concrete Quality

- Try to lower variability

| | |
|---|---|
| Material | Cement, SCMs – new / changed materials<br>average 1000 $yd^3$/week plant receives 12 CM shipments and 60 aggregate shipments<br>Rely on supplier quality |
| Manufacturing | Batching, mixing, delivery time, temperature |
| Testing | Sampling, specimen preparation, initial/final curing, transporting, test procedures and equipment |

# NRMCA Quality Resources

www.nrmca.org/quality

- Cost of Poor Quality
- Improving Quality of Acceptance Testing
- Educational Resources for Improving Quality
- Quality Award
- Quality Survey
- Quality Certification Program
- Plant and Truck Certification Program
- Quality Guide
- Quality Management System



NRMCA Quality Certification


A NEW NRMCA COURSE
Improving Concrete Quality

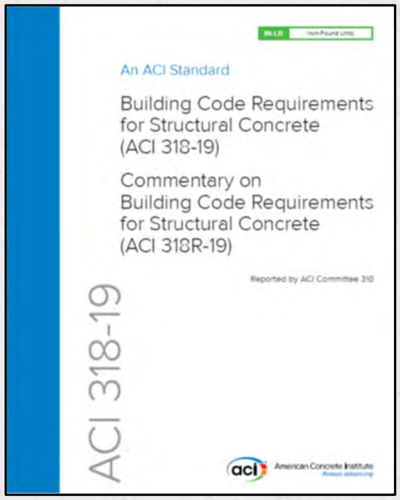
# Rational Interpretation of Codes, Standards, Specifications

Architect/Engineer

# Rational Interpretation of Codes

Minimum requirements for materials, design, and detailing

Covers strength, serviceability, durability





# Exposure Categories Durability (ACI 318)

**Table 19.3.1.1—Exposure categories and classes**

| Category | Class | Condition | |
|---|---|---|---|
| Freezing and thawing (F) | F0 | Concrete not exposed to freezing-and-thawing cycles | |
| | F1 | Concrete exposed to freezing-and-thawing cycles with limited exposure to water | |
| | F2 | Concrete exposed to freezing-and-thawing cycles with frequent exposure to water | |
| | F3 | Concrete exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals | |
| Sulfate (S) | | Water-soluble sulfate ($SO_4^{2-}$) in soil, percent by mass[1] | Dissolved sulfate ($SO_4^{2-}$) in water, ppm[2] |
| | S0 | $SO_4^{2-} < 0.10$ | $SO_4^{2-} < 150$ |
| | S1 | $0.10 \le SO_4^{2-} < 0.20$ | $150 \le SO_4^{2-} < 1500$ or seawater |
| | S2 | $0.20 \le SO_4^{2-} \le 2.00$ | $1500 \le SO_4^{2-} \le 10{,}000$ |
| | S3 | $SO_4^{2-} > 2.00$ | $SO_4^{2-} > 10{,}000$ |
| In contact with water (W) | W0 | Concrete dry in service | |
| | W1 | Concrete in contact with water where low permeability is not required | |
| | W2 | Concrete in contact with water where low permeability is required | |
| Corrosion protection of reinforcement (C) | C0 | Concrete dry or protected from moisture | |
| | C1 | Concrete exposed to moisture but not to an external source of chlorides | |
| | C2 | Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources | |

**Table 19.3.2.1—Requirements for concrete by exposure class**

| Exposure class | Maximum $w/cm$[1,2] | Minimum $f_c'$, psi | Additional requirements | | | Limits on cementitious materials |
|---|---|---|---|---|---|---|
| | | | Air content | | | |
| F0 | N/A | 2500 | N/A | | | N/A |
| F1 | 0.55 | 3500 | Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete | | | N/A |
| F2 | 0.45 | 4500 | Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete | | | N/A |
| F3 | 0.40[3] | 5000[3] | Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete | | | 26.4.2.2(b) |
| | | | Cementitious materials[4] — Types | | | Calcium chloride admixture |
| | | | ASTM C150 | ASTM C595 | ASTM C1157 | |
| S0 | N/A | 2500 | No type restriction | No type restriction | No type restriction | No restriction |
| S1 | 0.50 | 4000 | II[5][6] | Types with (MS) designation | MS | No restriction |
| S2 | 0.45 | 4500 | V[6] | Types with (HS) designation | HS | Not permitted |
| S3 Option 1 | 0.45 | 4500 | V plus pozzolan or slag cement[7] | Types with (HS) designation plus pozzolan or slag cement[7] | HS plus pozzolan or slag cement[7] | Not permitted |
| S3 Option 2 | 0.40 | 5000 | V[8] | Types with (HS) designation | HS | Not permitted |
| | | | | | | |
| W0 | N/A | 2500 | None | | | |
| W1 | N/A | 2500 | 26.4.2.2(d) | | | |
| W2 | 0.50 | 4000 | 26.4.2.2(d) | | | |
| | | | Maximum water-soluble chloride ion ($Cl^-$) content in concrete, percent by mass of cementitious materials[9,10] | | | |
| | | | Nonprestressed concrete | Prestressed concrete | Additional provisions | |
| C0 | N/A | 2500 | 1.00 | 0.06 | None | |
| C1 | N/A | 2500 | 0.30 | 0.06 | | |
| C2 | 0.40 | 5000 | 0.15 | 0.06 | Concrete cover[11] | |

## ACI 318 and 301 Requirements for Strength

Test results - Should meet both criteria

$f'_{cr} = f'_c + 1.34S$

1. Average of 3 consecutive $\geq f'_c$

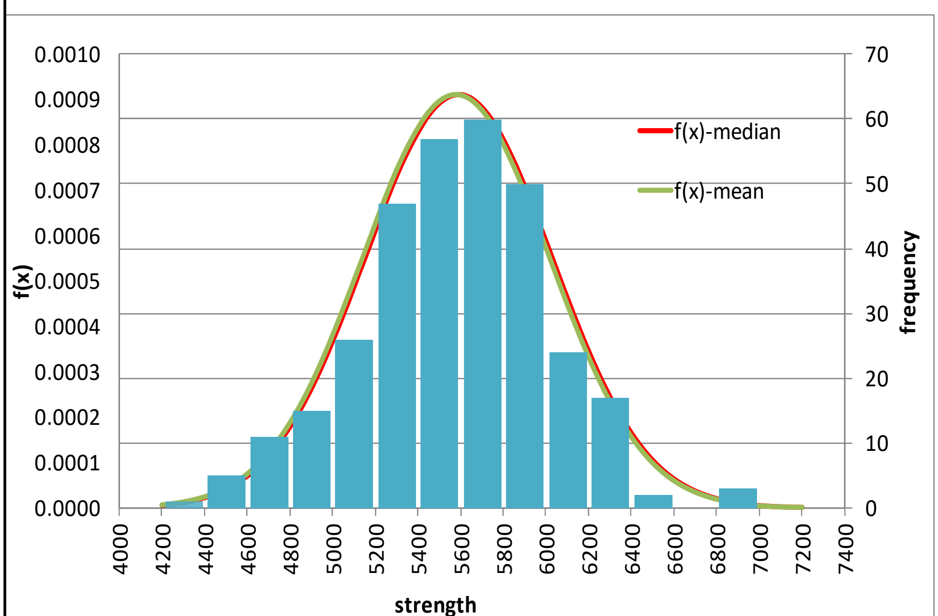
$2.33/\sqrt{3} = 1.34$

2. Single test $\geq (f'_c - 500)$
   For $f'_c > 5000$ psi – Single test $\geq 0.9f'_c$

$f'_{cr} = (f'_c - 500) + 2.33S$

Probability of failure < 1 in 100 (1%)

### Project data, Columbus, Air-entrained (7 months – 300 tests)




- X = 5580 psi
- S = 438 psi (very good per ACI 214)
- Estimated $f'_c$ (ACI 301) = 5580–1.34x438 = 4990 psi
- Data shows 2 instances where test result is <4490 and 9 instances where Running avg. of 3 <4990
- People design more conservatively than 1-in-100

# Investigating Low Strength Tests

- Verify testing accuracy
- Compare with design requirements
- NDT or In-place tests
- Cores

NRMCA PUBLICATION NO. 133 - 11

IN-PLACE CONCRETE STRENGTH EVALUATION – A RECOMMENDED PRACTICE

Research, Engineering and Standards Committee

© 2011

# Factors that can lead to higher GWP

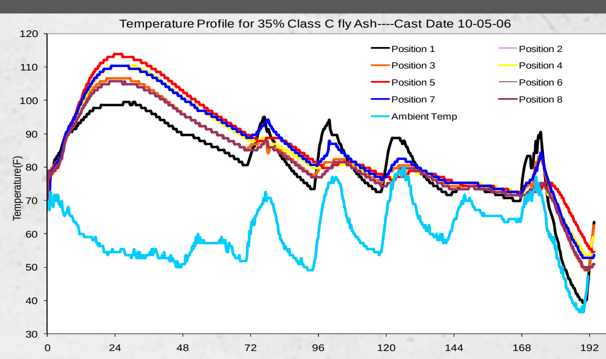
- Requiring each core test to come up to 100% of specified strength
  - ACI 318's requirement is 75%
- Penalty/incentives that apply to in-place price of concrete
- Not specifying later age strengths (>28 day)
- Requiring early-age strengths (4 day or less)
  - If not possible to avoid use the resulting higher 28-day strengths
- Requiring smaller aggregate size
- Trowel-finished slabs, super-flat floors
- Highly variable acceptance tests/over ordering lead to high returned concrete – can be 2-5%
- Not allowing reuse of returned fresh concrete (ASTM C1798), non potable water, recycled aggregate

# Optimized Mixtures

Concrete Producer

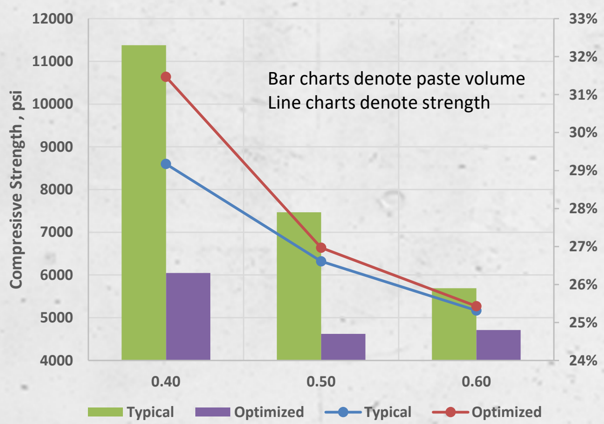
## Options

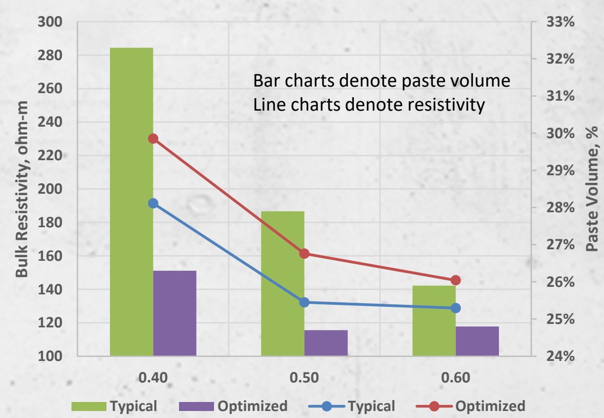
- Lower paste volume
- Higher SCM %
- Adjust for set retardation and early-age strength
  - Mix modification (accelerators, low *w/cm*)
  - Maturity



# Three Point Curve




- Typical curve water contents = 281 – 297 lb/yd$^3$
- Optimized curve water contents = 243 – 269 lb/yd$^3$

# High SCM mixtures possible

- I-35W bridge, MN – Concrete International, Feb 09

| Member | $f'_c$, psi | w/cm | CM, lb/yd$^3$ | PC, % | FA, % | SL, % | SF, % |
|---|---|---|---|---|---|---|---|
| Super structure | 6500 | 0.35 | 700 | 71 | 25 | - | 4 |
| Piers | 4000 | 0.45 | 575 | 15 | 18 | 67 | - |
| Footings | 5500 | 0.45 | <600 | 40 | 18 | 42 | - |
| Drilled Shafts | 5000 | 0.38 | <600 | 40 | 18 | 42 | - |

# While ensuring Excellent Performance

| Member | Performance Achieved |
|---|---|
| Super structure | Air entrained; PT; Strength > 8000 psi; RCP <250 Coulombs (90 d); shrinkage <0.04% (56d drying) |
| Piers | Conventional slump; thermal control for 3 d; strength > specified; RCP 500 coulombs (90 d) |
| Footings | Similar to drilled shaft mix; conventional slump; shrinkage = 0.04% (28d drying) |
| Drilled Shafts | Strength > 10,000 psi (cores); RCP 750 coulombs (28d) Low heat considerations (mass concrete); SCC mix |

# High SCM mixtures with demanding Performance Requirements

| | |
|---|---|
| Cement | 300 |
| Fly ash | 65 |
| Slag | 483 |
| Silica fume | 25 |
| w/cm | 0.25 |
| Slump flow | 25 in. |
| Strength | 16,160 psi |
| MOE | 7.5 M psi |

} 66% (Fly ash, Slag, Silica fume)

# Putting it all together

All Stakeholders

## Solutions for Low Carbon Concrete

### Performance-based Specifications

- Improved acceptance testing
- Improved product quality
- Rational Interpretation of Codes, Standards, and Specifications

} Lower over designs

- Optimized mixtures

# Example – Current State

- Prescriptive mixture, *w/cm*=0.40, No SCM, 3500 psi, non-air-entrained
  - Cement = 750 lb/yd$^3$
  - Average strength = 7500 psi (10 psi/lb)
  - Non-standard acceptance testing = need extra 500 psi
  - No incentive for good quality - Standard deviation = 1000 psi
  - Irrational interpretation of codes = 1 in 1000
  - Required average strength = 6600 psi (3500+3.1x1000-500+500) < 7500 psi
  - GWP = 321 kg CO2e/yd$^3$ Source: https://www.slagcement.org/lca-calculator

# Example – Using Principles discussed

- Performance mixture 3500 psi, No durability exposure, SCM allowed
  - Standardized acceptance testing = No need for extra strength
  - Incentive for good quality - Standard deviation = 450 psi
  - Rational interpretation of codes = 1 in 300
  - Required average strength = 4224 psi (3500+2.72x450-500)
  - Cementitious = 422 lb/yd$^3$ (10 psi/lb)
  - Cement = 211 lb/yd$^3$ (50% SCM mix)
  - GWP = 132 kg CO2e/yd$^3$ (59% reduction)

# Low Carbon Mixtures

| Mix | 2021 Avg. | Current | Lower (paste+OD) | Lower (paste+OD) + Higher SCM |
|---|---|---|---|---|
| Cement, lb/yd³ | 476 | - | - | - |
| Type IL Cement, lb/yd³ | 0 | 476 | 393 | 288 |
| Fly ash, lb/yd³ | 70 | 70 | 58 | 123 |
| Slag Cement, lb/yd³ | 35 | 35 | 29 | 61 |
| *w/cm* | 0.50 | 0.50 | 0.55 | 0.53 |
| Type A or F WR, oz/cwt. | 3.0 | 3.0 | 2.9 | 3.5 |
| Paste volume, % | 28.6 | 28.6 | 25.0 | 24.5 |
| GWP, kg $CO_2e/yd^3$ | 241 | 219 (-9%) | 188 (-22%) | 150 (-38%) |

# Low Carbon Mixtures

| Properties | Current | Lower (paste+OD) | Lower (paste+OD) + Higher SCM |
|---|---|---|---|
| Slump, in | 51/4 | 5 | 51/2 |
| Initial Set time, H:Min | 6:03 | 5:46 | 6:12 |
| 3-day strength, psi | 3230 | 2530 | 2510 |
| 7-day strength, psi | 4090 | 3200 | 2960 |
| 28-day strength, psi | 5810 | 4660 | 4840 |
| 28-day BR, Ω-m | 89 | 115 | 165 |

We can get to 2030 GWP goals with lower OD, and optimized mixtures while maintaining specified strength, durability and other performance

We can also use the lower OD to increase the specified strength and optimize section sizes

# Summary

| Action | Stakeholder |
|---|---|
| Performance-based Specifications | Architect/Engineer |
| Improved acceptance testing | Owner, Contractor, Test lab |
| Improved product quality | Producer, Ingredient material supplier, Test lab |
| Rational Interpretation of Codes, and Specs | Architect/Engineer |
| Lower overdesigns | Concrete Producer |
| Optimized mixtures | Concrete Producer |
| Demystify low-carbon concrete | Trade groups, technical institutes |
| Rational Codes/Standards (existing / new) | ACI, ASTM, AASHTO etc. |

All stakeholders need to be on the same page

Opportunity to raise the concrete industry (better quality, performance, innovation)

# Questions?

## Reducing Carbon Footprint of Concrete – The Low-Hanging Fruit

Karthik Obla
kobla@nrmca.org

NRMCA

BUILD WITH STRENGTH