PCI's Precast Concrete Mix Design Training

PCI Precast/Prestressed Concrete Institute

Precast Concrete Mix Design Training

This course is intended to train someone with a basic understanding of concrete so that they can create a concrete mix design meeting their company's needs, or to evaluate the suitability of a mix for specific applications. This course is specific to needs of the Precast / Prestressed Concrete industry.

Developed by the PCI Quality Enhancement Committee

- Paul Ramsburg, Chair – Sika Corp
- Jason Blasé, Vice Chair – Conewago Precast
- Gary Wildung – FDG, Inc,
- Corey Greika – Coreslab Structures
- Brian Matthys – Mid-States Concrete
- Ed McDougle – Ross Bryan Assoc.
- Bill Ray – Precast Consulting Services
- George Savant – High Concrete Group
- Keith Wallis – Prestressed Casting Co.
- Chris Kelly – Gate Precast
- Brian Peterson – Coreslab Structures
- Steve Qualls – Ross Bryan Assoc.
- David Jabolnsky – A.L. Patterson
- Patrick Carlin – Rocky Mountain Prestress
- Dean Frank - PCI
- Jessica Burnett - PCI
- Dr. Wael Zatar – Marshall University
- Matt Gawelko – FDG, Inc.

In conjunction with:

Quality Activities Council, Technical Activities Council, Concrete Materials Committee

CONTENT

Learning Objectives:

- Select raw materials suitable for a specific application
- Complete the mathematics to proportion a basic absolute volume mix design, as per ACI 211
- Design both structural and architectural mixes
- Design and adjust Self-Consolidating Concrete (SCC) mixes
- Evaluate a mix using statistical analysis
- Troubleshoot plastic and hardened concrete issues

Sessions:

Materials – A discussion of various concrete constituent properties and how they affect the concrete's performance, and suggestions for selecting materials for different applications.

Proportioning – A walk through of the ACI-211 method of absolute volume mix design, and a session of designing concrete, using a provided worksheet, from historical data. A mix design Excel spreadsheet, designed for this course, will also be provided.

Durability / SCC – A discussion of materials and proportioning considerations for designing durable concrete. This session on Self-Consolidating Concrete moves past the basics and gives practical suggestions on making consistent SCC repeatedly..

Architectural / Statistics – We revisit both materials and proportioning, but this time with a view to concrete aesthetics. Best practices are presented for designing the mix and the sample approval process. Also, this session covers the basic statistical processes needed to evaluate the performance of concrete mixtures.

Trouble Shooting – The concrete we design may exhibit performance issues at times, this session teaches how to identify the cause of several common problems, and what the solutions are.

Precast Concrete Mix Design Training

Module 1
Materials

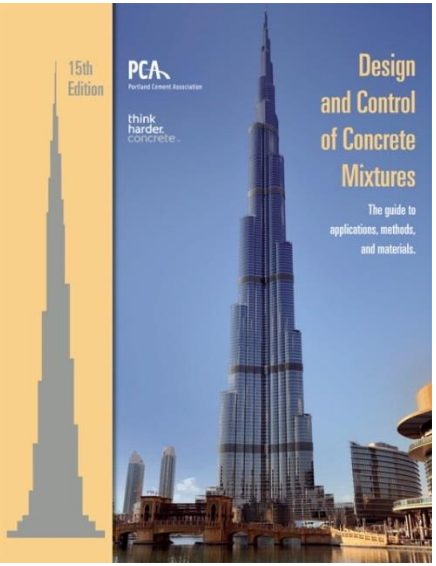
PCI Precast/Prestressed Concrete Institute

CONTENT

- Aggregates
- Cementitious
- Water
- Admixtures

Resources

- PCA Design and Control of Concrete Mixtures
- PCI TM-103 Quality Control Technician/Inspector Level III Training Manual
- PCI MNL-116 Manual for Quality Control for Plants and Production of Structural Precast Concrete Products
- ACI E4-12 Chemical Admixtures for Concrete



Aggregates

The importance of using the right type and quality of aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 80% by mass) and strongly influence the concrete’s plastic and hardened properties.

Fine aggregates consist of natural sand or crushed stone with most particles smaller than 0.2 in. (5 mm). Coarse aggregates consist of gravels or crushed stone with particles mostly larger than 0.2 in. (5 mm) and generally between 3/8” and 1 ½” (9.5 mm and 37.5 mm).

The aggregates are usually washed and graded at the plant or pit. Some variation in the type, quality, cleanliness, grading, moisture content, and other properties is expected.

Aggregates must conform to certain requirements and should consist of clean, hard, strong, and durable particles free of chemicals, coatings of clay, or other fine materials that may affect the hydration and bond of the cement paste. The characteristics of the aggregates influence the properties of the concrete.

Aggregates

Characteristics of Aggregates:

Resistance to Freeze/Thaw – The freeze/thaw resistance of an aggregate is related to its porosity, absorption, and pore structure. Specifications require the magnesium sulfate test.

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ve with cement alkalis. This
king in concrete.

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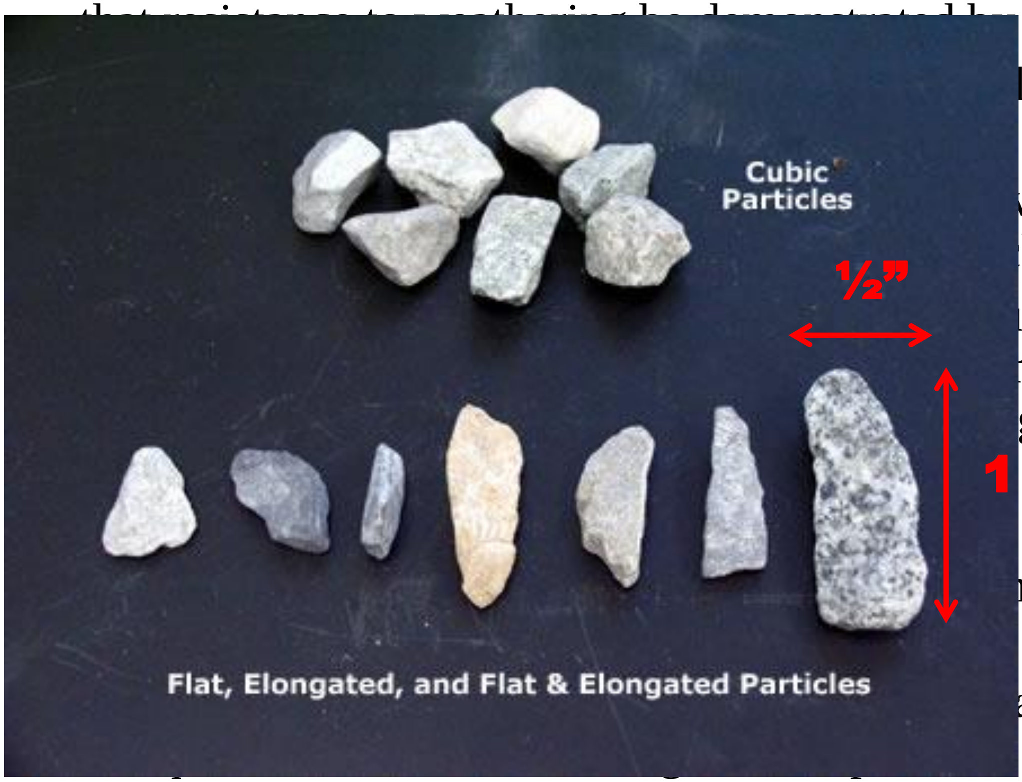
gregates. Sand has a bigger

of an aggregate is
ne workability of fresh

ate’s weight to the weight of
Most normal weight
aggregates have a specific gravity ranging from 2.4 to 2.9. It is not a measure of aggregate quality, it is used for certain computations in a mix design.



Aggregates

Characteristics of Aggregates:

Dry-rodded Unit Weight – The mass (weight) of one cubic foot of dry coarse aggregate that is compacted, by rodding in three equal layers, in a standard container. For any one aggregate the dry-rodded unit weight varies with the size and gradation.

Absorption and Surface Moisture – The moisture conditions of aggregates are designated as:

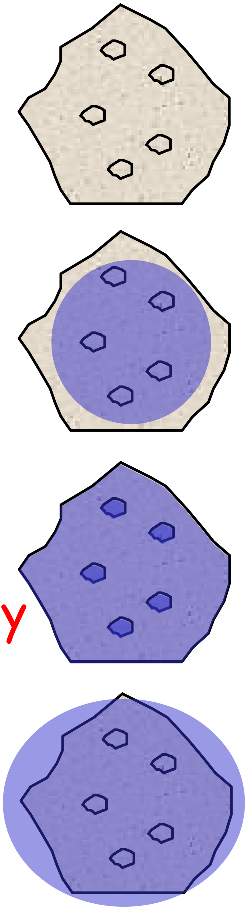
- **Oven-dry: fully absorbent**
- **Saturated Surface-Dry: neither absorbing water from, nor contributing water to, the concrete mix**
- **Wet with Free Moisture: containing an excess of moisture on the surface**

Aggregates

Deleterious Substances in Aggregates:

- Organic Impurities: affect setting time and hardening, and may cause deterioration
- Material finer than the #200 sieve: affect bond and increases water demand
- Lightweight Materials (coal, lignite): affect durability and wear resistance
- Friable Particles: affect workability and durability, break up in mixing, and increase water demand
- Clay Lumps: absorb mixing water or cause pop-outs.

Aggregate Moisture



Bone Dry
or
Oven Dry

Air Dry

Absorbed moisture
(absorption)

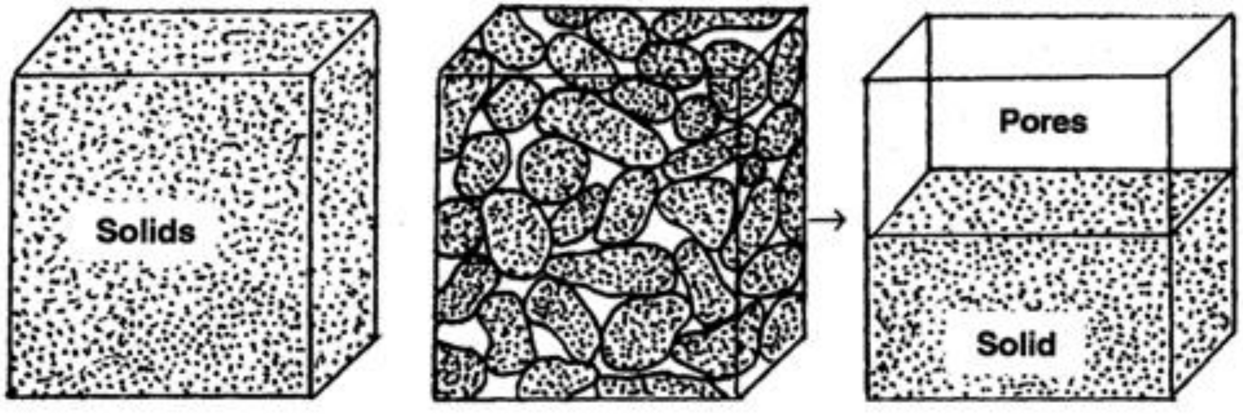
Saturated
and
Surface Dry

SSD (ideal)

Moist

Free moisture
(moisture content)

Dry Rodded Unit Weight



Particle Density

100% Solid

Weight = 169.7 lbs

Volume = 1 cuft

Specific Gravity = 2.72

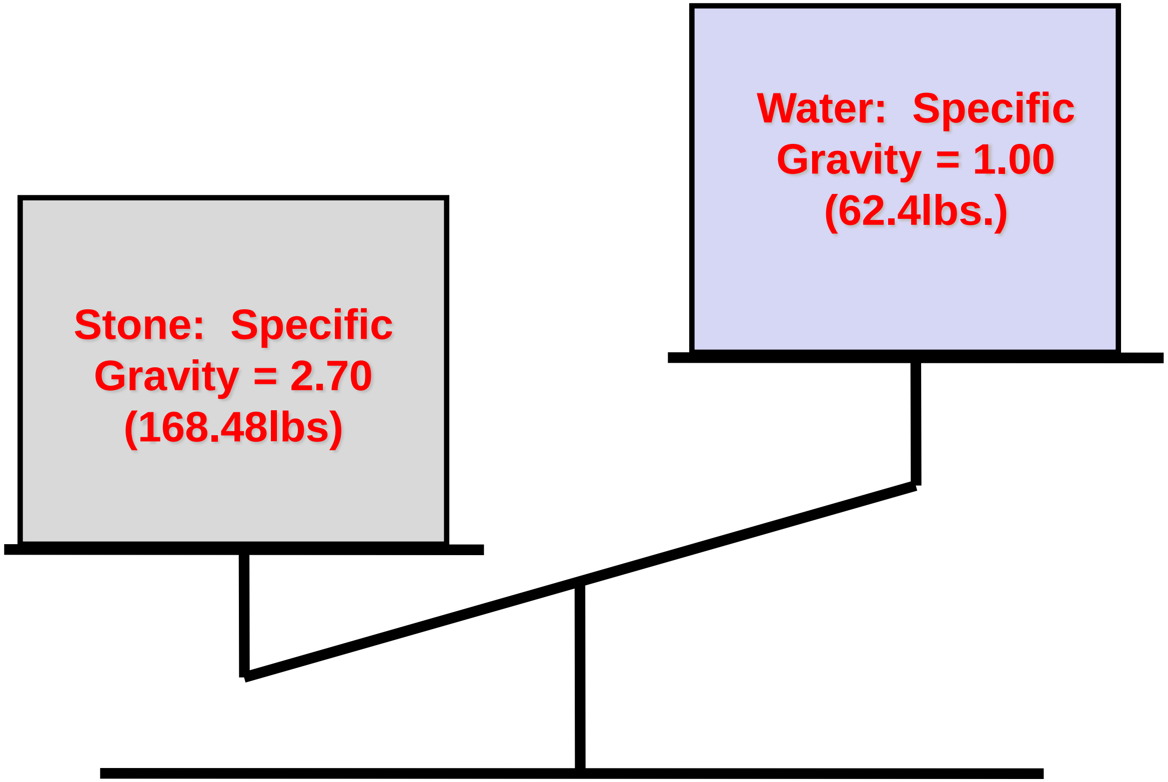
Bulk Density

65% Solid, 35% Void

Weight = 110.3 lbs

Volume = 1 cuft

Specific Gravity



Water: Specific Gravity = 1.00 (62.4lbs.)

Stone: Specific Gravity = 2.70 (168.48lbs)

Cement – 3.15
Steel – 7.85

Same Volume, but 2.70 Times More Mass

The specific gravity of any material is the weight of that material in air divided by the weight of an equal volume of water. An aggregate with a specific gravity of 2.50 would thus be two and one-half times as heavy as water for the same volume.

Choosing an Aggregate

- In precast concrete the most common coarse aggregate size is #67, this is a ¾” maximum nominal size.
- In architectural concrete sizes vary greatly due to appearance requirements. Aggregates are often gap graded. A typical size is ½” x ¼”.
- A fine sand will give a smoother formed surface but may lower compressive strength. Too much of a fine sand will make the mix difficult to finish (sticky).
- A well blended sand and stone will help SCC be stable and flow without as much admixture as may be typical.
- Manufactured sands can restrict flow/slump due to their angular shape, but they can have a lower water demand.
- Aggregates should meet the durability criteria set out in ASTM C-33.

Choosing an Aggregate

- The potential reactivity with cement alkalis should be considered when selecting an aggregate. Potential for ASR is measured with ASTM C-1260.
- An aggregate with higher potential for reactivity can still be used if a significant amount of pozzolan is also utilized.
- There are 12 standardized test methods for ASR, they can be found in PCA’s “Design” on page 96.
- More fines in a mix will lead to higher shrinkage levels.
- Aggregates that have organics should not be used in concrete – therefore there is an expiration date of aggregate at the production facility.
- Aggregates will segregate as they set at a production facility.
- In mixes that are expected to exceed 9000 psi a smaller aggregate should be utilized. ½” stone will give a higher compressive strength.

About Fineness Modulus

High FM

- Less cement necessary
- Harsher mix (hard to finish)
- Higher bleed
- Potential segregation

Low FM

- More cement necessary
- Higher water demand
- Stickiness
- Harder to air entrain
- Higher shrinkage and risk of cracking

Cementitious

Portland Cements are hydraulic since they set and harden by reacting with water. The raw materials used in manufacturing cement consist of combinations of limestone, marl, or oyster shells, shale, clay and iron ore. The raw materials must contain appropriate proportions of lime, silica, alumina, and iron components.

Basically, Hydraulic Cements may be considered as being composed of the following compounds:

- Tricalcium Silicate = C_3S
- Dicalcium Silicate = C_2S
- Tricalcium Aluminate = C_3A
- Tetracalcium Aluminoferrite = C_4AF

C_3S hydrates and hardens rapidly and is largely responsible for initial set and early strength

C_2S hydrates and hardens slowly and contributes to strength increases at ages beyond one week

C_3A causes the concrete to liberate heat during the first few days of hardening and contributes slightly to early strength

C_4AF reduces the clinkering temperature in the manufacture of cement. It hydrates rapidly but contributes very little to strength

Cementitious

Types of Portland Cement		Potential Compound Composition %				Blaine Fineness
ASTM C-150	Description	C3S	C2S	C3A	C4AF	
I	General	55	19	10	7	370
II	Sulfate-Resisting	51	24	6	11	370
III	High-Early Strength	56	19	10	7	540
IV	Low Heat of Hydration	28	49	4	12	380
V	High Sulfate-Resisting	38	43	4	9	380

Cementitious

Properties of Hydraulic Cement:

Fineness: Fineness of cement affects heat released and rate of hydration. Greater cement fineness increases the rate at which cement hydrates and thus accelerates strength development.

Setting Time: The setting times indicate that the paste is or is not undergoing normal hydration reactions. Setting time is affected by fineness, water cement ratio, admixtures and Gypsum. Setting times of concrete do not correlate directly to setting times of paste tested in a laboratory.

False Set: Evidenced by a significant loss of plasticity without the evolution of much heat shortly after mixing. Further mixing will restore plasticity.

Specific Gravity: The specific gravity of cement it generally 3.15. Its principal use is in mixture proportioning calculations.

Advanced Cement Properties

- In concrete the mixture of cement and water is referred to as paste, and it acts as an adhesive to bind the fine and coarse aggregates together.
- Hydration starts immediately upon contact between cement and mix water. During hydration, the calcium silicates form calcium hydroxide and a gel-like calcium silicate hydrate (C-S-H). Among the portland cement components, calcium aluminate is the most reactive with water.
- The calcium silicate hydrate gel is the most important cementing component of concrete. It is responsible for the engineering properties of concrete such as setting and hardening, and strength development.

Advanced Cement Properties

- As hydration proceeds, the cement particles and water react to form hydration products, primarily calcium silicate hydrate gel, which grows out from the particles into space originally occupied by the water. As these growing particles converge the paste solidifies. The concrete gradually stiffens, loses workability, sets, and develops mechanical strength concurrently with hydration.
- Concrete does not harden because of drying. The apparent drying is the result of consumption of water in the chemical reactions. A cement paste will set and harden even when submerged in water.
- If sufficient moisture is available hydration will continue indefinitely, although increasingly slowly.

Loss on Ignition

LOI

Maximum = 3 % (ASTM)

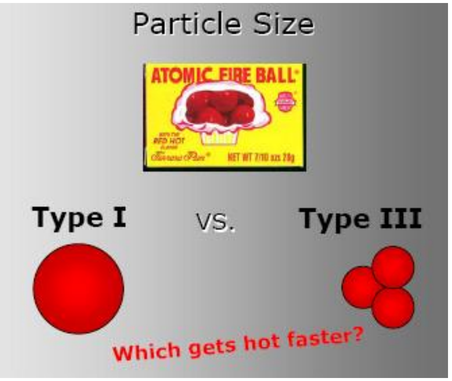
- Calculated by finding mass loss when cement is heated to a very high temperature, (900 F).
- Extent of the hydration and carbonation of free lime and magnesia due to exposure to cement to the atmosphere.

Blaine

FINENESS

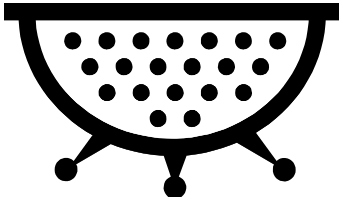
Measured in surface area per unit weight. (m^2/kg or cm^2/g)

Relates to reactivity (set time, early strength), ultimate strengths.



- 325 Mesh

Amount of material remaining on a 325 mesh (325 openings per 1 in^2).



- The coarse particles that remain play a small role in hydration and strength development.
- In conjunction with the **blaine** this value can give you a better indication of the particle size distribution.
- If blaine is very high (ie 4800) and 325 mesh is low (ie 82) it means that there is a large amount of “super” fines, (which have a tendency to a function of clinker that has already hydrated….since they have already reacted their presence is detrimental to concrete).

Time of Set

VICAT

Measure of set time of cement paste.

- Both initial and final set are measured by determining the length of time it takes the cement paste to resist the penetration of round needle of prescribed weight.
- Translates loosely to concrete.

Total Alkalis

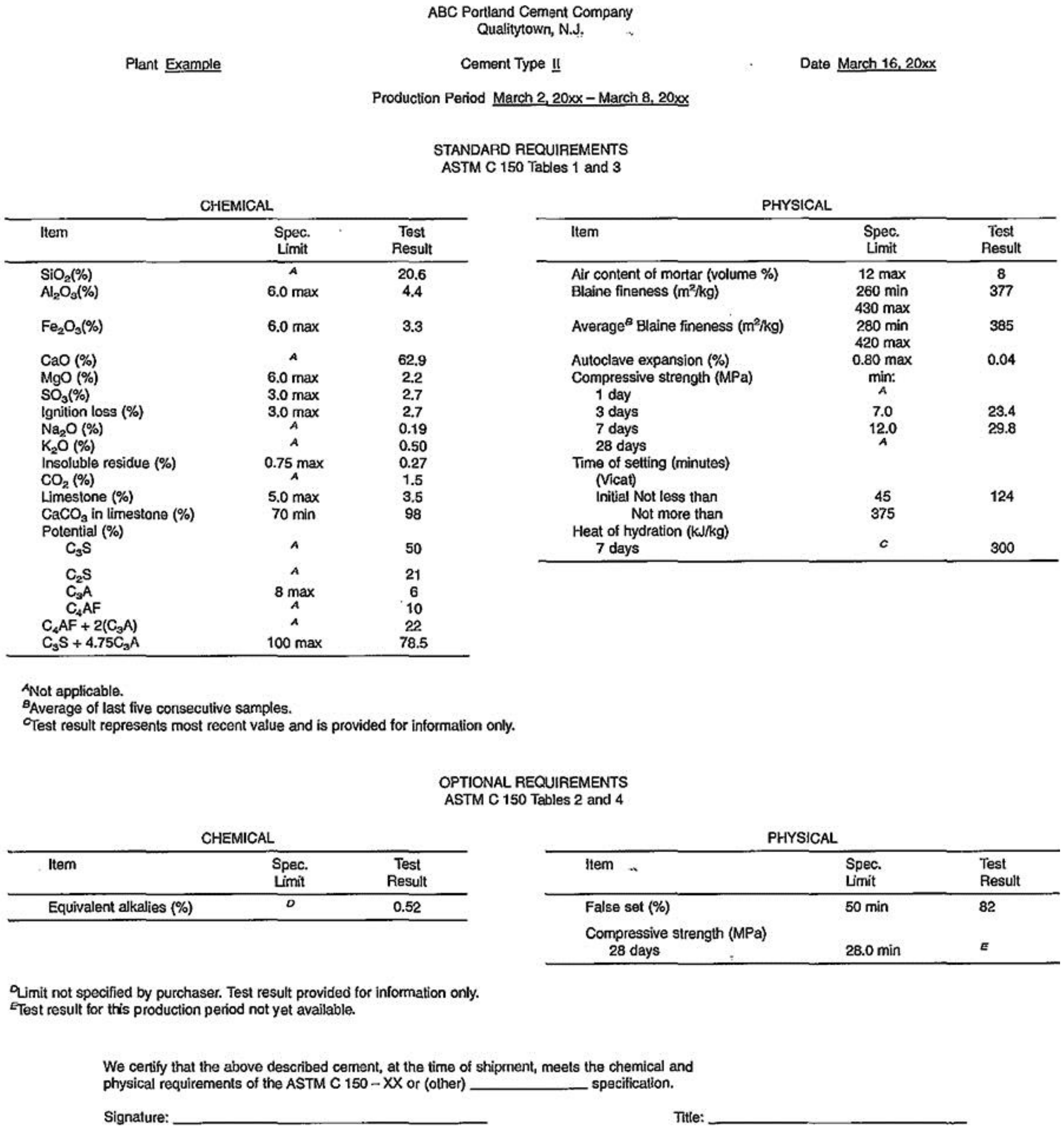
NaEq

Weighted average of alkalis in cement.

NaEq = Na_2O + .659 K_2O

- Low alkali cements < 0.60 NaEq
- Higher alkali cements typically have better early strengths but lower ultimate strengths.
- Higher alkali cements require less air-entrainment, and change the performance of HRWR's

Mill Certifications



ABC Portland Cement Company
Qualitytown, N.J.

Plant Example

Cement Type II

Date March 16, 20xx

Production Period March 2, 20xx – March 8, 20xx

STANDARD REQUIREMENTS
ASTM C 150 Tables 1 and 3

CHEMICAL

Item	Spec. Limit	Test Result
SiO_2(%)	[A]	20.6
Al_2O_3(%)	6.0 max	4.4
Fe_2O_3(%)	6.0 max	3.3
CaO (%)	[A]	62.9
MgO (%)	6.0 max	2.2
SO_3(%)	3.0 max	2.7
Ignition loss (%)	3.0 max	2.7
Na_2O (%)	[A]	0.19
K_2O (%)	[A]	0.50
Insoluble residue (%)	0.75 max	0.27
CO_2 (%)	[A]	1.5
Limestone (%)	5.0 max	3.5
$CaCO_3$ in limestone (%)	70 min	98
Potential (%)		
C_3S	[A]	50
C_2S	[A]	21
C_3A	8 max	6
C_4AF	[A]	10
$C_4AF + 2(C_3A)$	[A]	22
$C_3S + 4.75C_3A$	100 max	78.5

PHYSICAL

Item	Spec. Limit	Test Result
Air content of mortar (volume %)	12 max	8
Blaine fineness (m^2/kg)	260 min 430 max	377
Average[B] Blaine fineness (m^2/kg)	280 min 420 max	385
Autoclave expansion (%)	0.80 max	0.04
Compressive strength (MPa)	min:	
1 day	[A]	
3 days	7.0	23.4
7 days	12.0	29.8
28 days	[A]	
Time of setting (minutes)		
(Vicat)		
Initial Not less than	45	124
Not more than	375	
Heat of hydration (kJ/kg)		
7 days	[C]	300

[A] Not applicable.
[B] Average of last five consecutive samples.
[C] Test result represents most recent value and is provided for information only.

OPTIONAL REQUIREMENTS
ASTM C 150 Tables 2 and 4

CHEMICAL

Item	Spec. Limit	Test Result
Equivalent alkalies (%)	[D]	0.52

PHYSICAL

Item	Spec. Limit	Test Result
False set (%)	50 min	82
Compressive strength (MPa)		
28 days	28.0 min	[E]

[D] Limit not specified by purchaser. Test result provided for information only.
[E] Test result for this production period not yet available.

We certify that the above described cement, at the time of shipment, meets the chemical and physical requirements of the ASTM C 150 – XX or (other) ______________ specification.

Signature: ______________________________

Title: ______________________________

SCM's / Pozzolans

Supplementary Cementitious Materials

(Pozzolans / Mineral Admixtures)

SCM's are added to concrete as part of the total cementitious system. They may be used in addition to or as a partial replacement of portland cement. They are used to improve a particular property. The optimum amount should be established by testing. SCM's react differently with various cements.

Types:

- Ground Granulated Blast-furnace Slag (Slag)
- Fly Ash
- Silica Fume
- Metakaolin
- Natural Pozzolans

SCM's / Pozzolans

- Fly Ash
  - Ash is the most widely used SCM in concrete
  - It is the waste by-product of coal burning power plants
  - Ash will add to the rheological properties of concrete
  - Ash can contribute to instability in the air void matrix
  - Can protect a concrete from ASR with proper dosage
  - Dosage is 10% to 25% of total cementitious
  - Adds to the durability of concrete

- Slag
  - Waste by-product of the iron industry
  - Can protect a concrete from ASR with proper dosage
  - Recommended dosage is 20% to 50% for structural and 15% to 35% for architectural concrete
  - Adds to the durability of concrete

SCM's / Pozzolans

A Word About Slag:

Specification: ASTM C989 (Grade 80, 100, or 120)

Reaction: Cementitious and pozzolanic

Advantages:

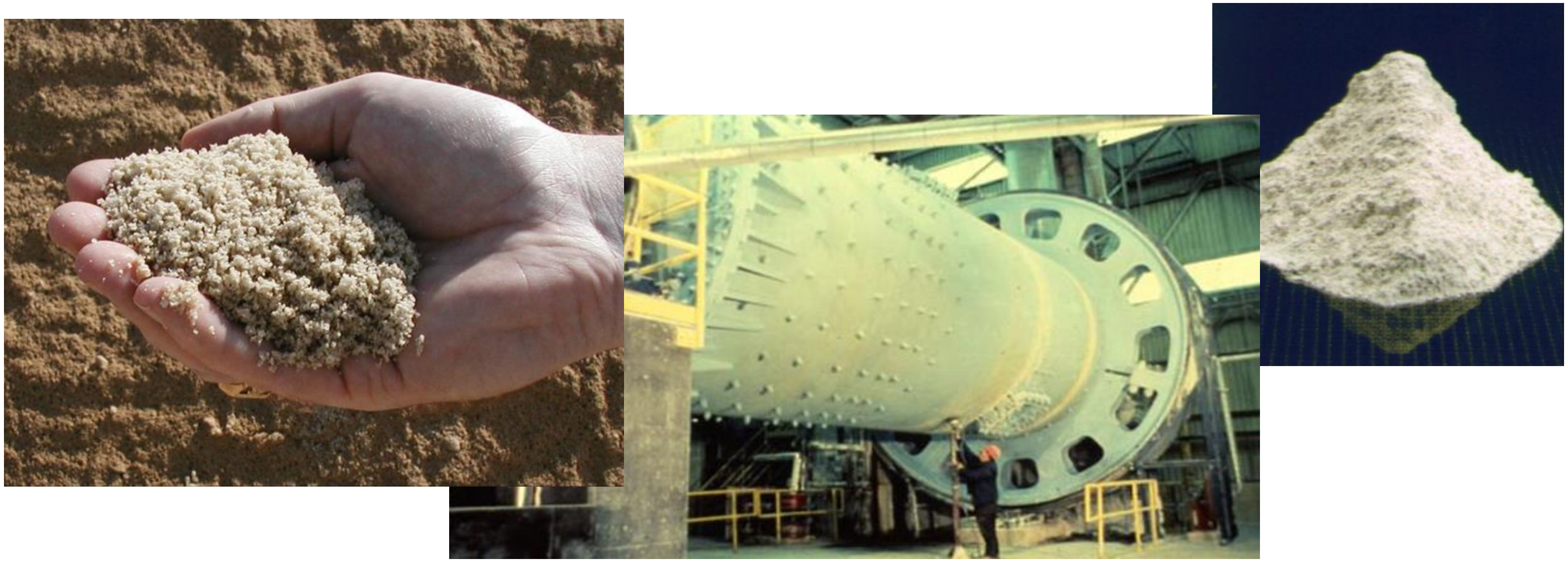
- May be cheaper than cement
- Reduces heat of hydration
- Improves Sulfate resistance
- Reduces ASR
- Higher strength at later ages

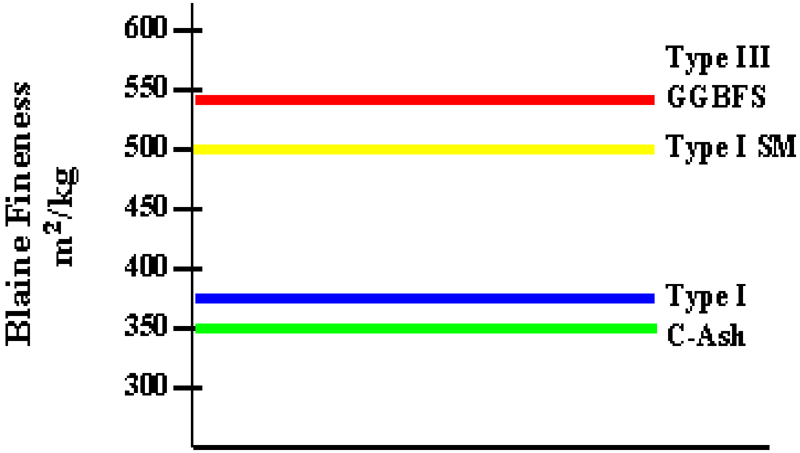
Disadvantages:

- Another variable
- Scaling and drying shrinkage may be increased
- Early strengths retarded in cooler weather

Note: When forms are stripped, the concrete will be discolored with greens, blues, and blacks like ink blots, but will bleach rapidly when exposed to sun light.

Grinding to Cement Fineness





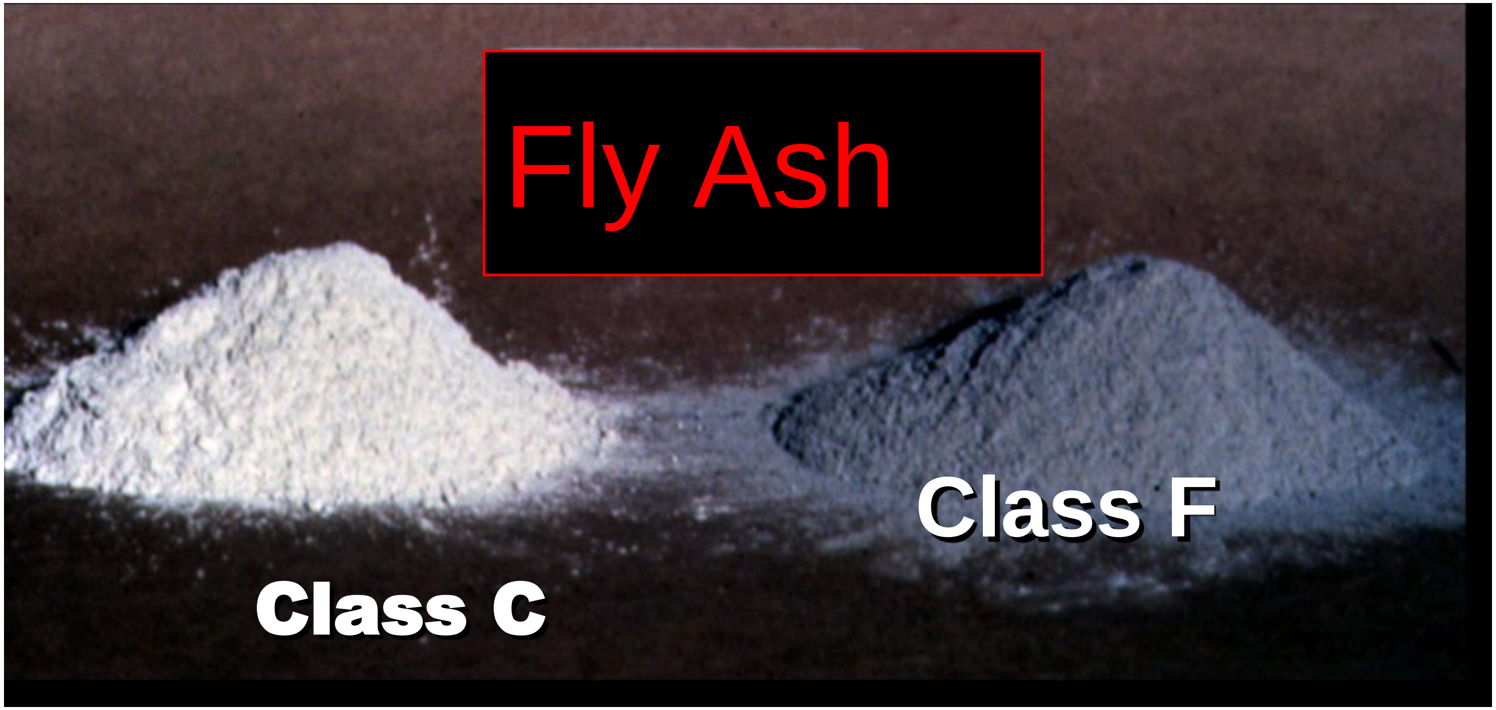
Thoughts to take away…

- Chemistry of slag cements from source to source can differ.
- Performance can vary greatly with different Cements
- Higher alkali cements generally perform better with slag
- The difference between a grade 100 v 120 (within a source) is fineness. This translates into difference in setting and early strength.
- Greening – (function of sulfates being exposed to oxygen) it goes away with time. The stronger and denser the concrete, the longer it takes.
- No incompatibilities with chemical admixtures – Sometimes less Water Reducer and more Air Entrainer

Fly ash….What is it?

Literally the ash flying through the air collected by electrostatic precipitators after the combustion of coal used to produce power.

Fly Ash



Pozzolan- Siliceous or aluminosiliceous material that **itself** possesses **little or no cementitious** value but will, in the presence of water, **chemically react** with the calcium hydroxide released in the hydration of **portland cement** to form compound possessing **cementitious properties**.

Class “C” Fly Ash

- Derived from Western Coals
  - Found from Mid-west to California
- Usually tan or buff in color
- May have high calcium content
- Have a low LOI (naturally without processing)
- Not as effective as F Ash in resistance to sulfate attack or ASR

Class “F” Fly Ash

- Derived from Eastern Coals
  - Found from Mid-west to the east coast
- Usually light to dark gray in color
- Have a low calcium content
- May have a high LOI
  - Processing technology is available to remove carbon
- Typically increases resistance to sulfate attack and ASR

Fly Ash in Concrete

- Replaces from 10 to 30 percent
- Specific Gravity 2.2 - 2.6
- Some specifications require 1.2 or 1.3 to one replacement
- Chemistry may vary from different sources
  - Testing is ALWAYS required

Available Forms of Fly Ash and Slag Cement

Separate Product in Bulk

- **ASTM C 989 (AASHTO M 302)** Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- **ASTM C 618** – Specification for Fly Ash in Concrete

Blended With Portland Cement

- **ASTM C 595 (AASHTO M 240)** Specification for Blended Hydraulic Cements
- **ASTM C 1157** Standard Performance Specification for Hydraulic Cement

SCM's / Pozzolans

- Silica Fume
  - When using silica fume a dosage of 3% to 5% (of total cementitious materials) can be used with ease. A dosage of up to 10% may be used if excess of 10,000 psi compressive strength is needed in 28 days.
  - Silica fume will make a mix very sticky and difficult to finish.
  - A significantly higher dosage of chemical admixtures will be necessary. Silica fume has a specific gravity of 2.20 to 2.50
  - 3% silica fume will add to the flow of a concrete mixture

Silca Fume

- By-product of producing silicon metal or ferrosilicon alloys
  - The “smoke” produced by the smelter is silica fume
- Ultra fine silca (85-96%) between 50 and 100 times finer then Portland Cement
- Black in color
- Good for high strength concrete
- Can make plastic concrete “sticky”

Water

Water that is safe to drink is safe to use in concrete. However some waters that are not fit to drink may be suitable for use in concrete.

Acceptance Criteria for Questionable Water Supplies (From ASTM C94)

	Limits	Test Method
Compressive strength, minimum % of control at 7 days	90	C109 or T131
Time of set, deviation from control, hr:min.	-1:00 +1:30	C191 or T131

Chemical Limits for Wash Water used as Mixing Water (From ASTM C94)

Chemical or type of construction	Max concentration, ppm	Test Method
Chloride	500	ASTM D512
Sulfate	3,000	ASTMD516
Alkalis ($Na_2o + k_20$)	600	
Total Solids	50,000	AASHTO T26

Water

Water Cement Ratio is the most significant factor to both early and late compressive strength, as well as long term durability

Weight (in pounds) of water per pound of cementitious material

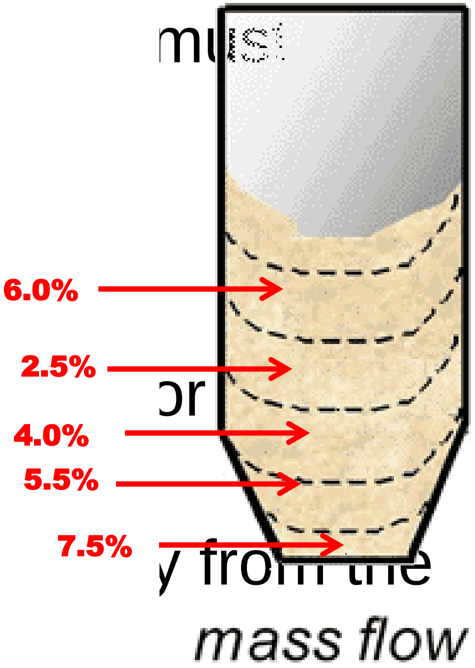
26 gal x 8.33 = 217 lbs   217 / 720 lbs. = 0.30 w/c ratio

The amount of water needed to fully hydrate a pound of cement is about 0.25lb

A typical w/c ratio for prestressed members is 0.38 to 0.43 (driven by release)

Moisture Control

- Aggregate moisture control can be one of the biggest issues in concrete production
- Absorbed vs. Free Moisture
- Drying aggregates can be an must take them below absorption
- Light Weight Aggregates
  - KEEP SATURATED
- Allow water on aggregate to or before loading into batchplai
- Exterior aggregate bins mus y from the aggregate stockpile



Admixtures

Admixtures are those ingredients in concrete other than portland cement, water and aggregates. Chemical admixtures can control any attribute of a mix. (see ASTM C260 & C494)

Chemical Admixtures Typically Used:

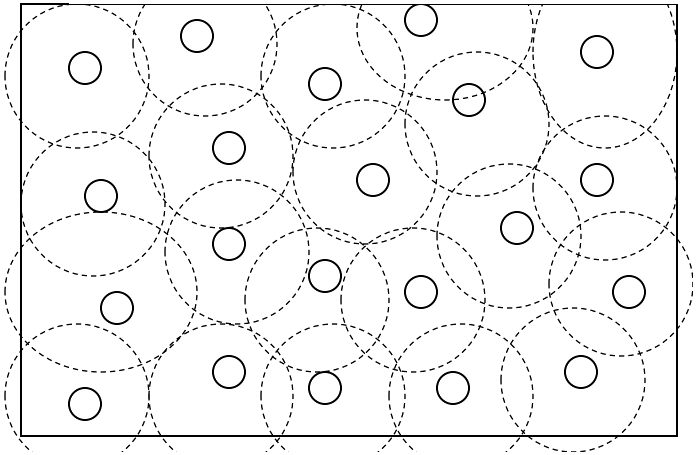
- Air entraining agent – retains proper air in a concrete mixture
- Retarder – slows down the setting of concrete and early strength gain
- Accelerator – speeds up early strength gain
- High Range Water Reducer (HRWR) – reduces water in a mix / increases workability at a given w/c R
- Stabilizer – increases viscosity / reduces segregation
- Corrosion Inhibitor – prevents / lessens steel corrosion, accelerating properties
- Pigment – colors concrete

Air In Concrete

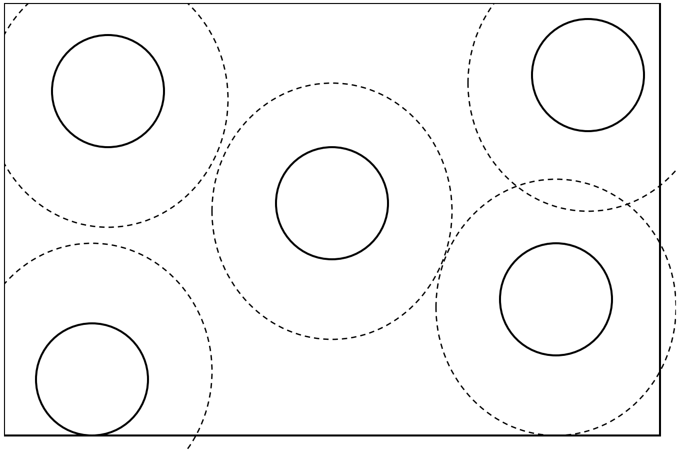
SIZE MATTERS – SMALLER IS BETTER!

PREVENTS FREEZE/THAW DAMAGE

IMPROVES WORKABILITY



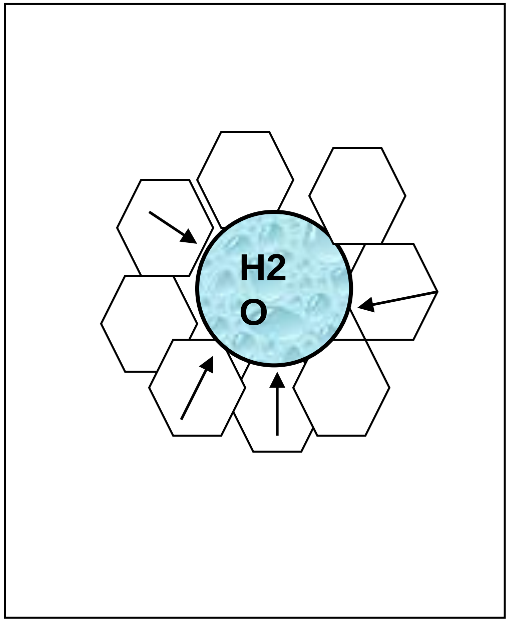
5% AIR

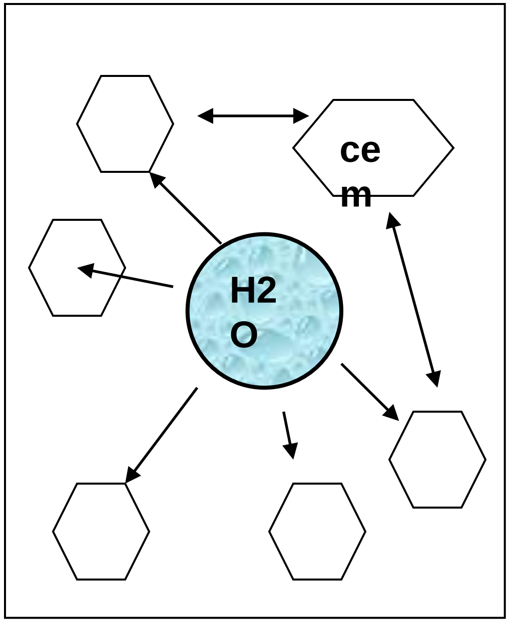


5% AIR

HRWR (super)

- REDUCE WATER CONTENT BY 12% TO 30%
- EFFECTS LAST 30 TO 120 MINUTES, FOLLOWED BY A RAPID SLUMP LOSS (DEPENDING ON BRAND AND DOSAGE RATE)
- REDUCED W/C-RATIO = HIGH COMPRESSIVE STRENGTHS, INCREASED EARLY STRENGTH, INCREASED DURABILITY
- PRODUCES FLOWING CONCRETE (ASTM C1017 - >7.5” SLUMP)
- NEGATIVELY CHARGES ALL CEMENT PARTICLES IN A MIX SO THEY WILL REPEL EACH OTHER





What Makes SCC possible?

A Polycarboxylate based Ultra High Range Water Reducer
That has several very important properties.

1. **Electrostatic dispersion**, a state created by the admixture which allows it to attach to the cement grains electrically and repel other admixture molecules and cement grains.

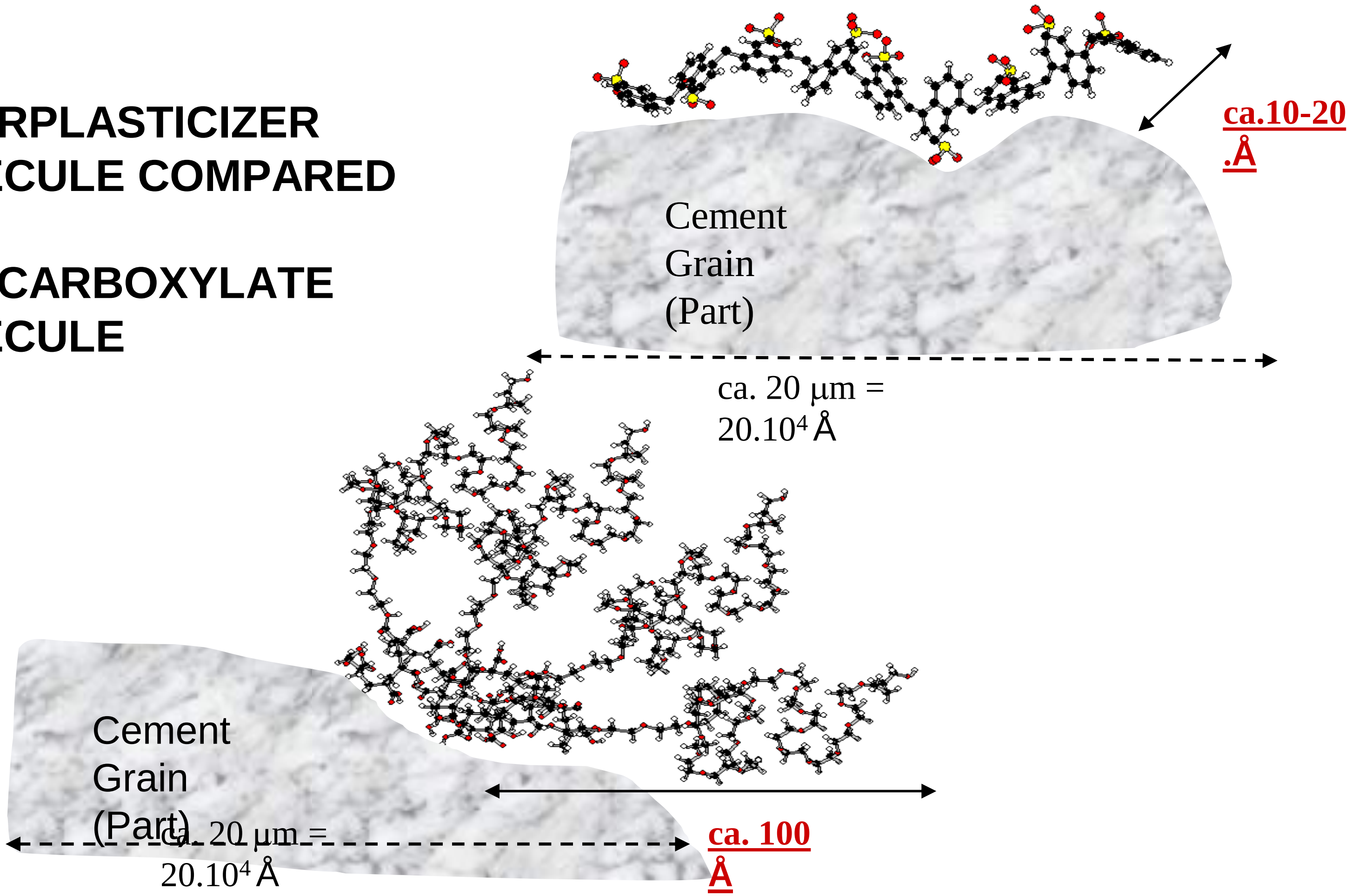
2. A much larger than normal **molecular weight** (size).

3. **Steric Hindrance**, a state created by the massive size of the admix molecules attached to the cement grains that prevents contact of the grains and promotes fluidity of the cement paste. It also takes longer for the admixture to be overtaken by the gel formation around the cement grain caused by the hydration reaction.

4. **Up to 40 percent** water reduction capabilities.

Admixtures

SUPERPLASTICIZER MOLECULE COMPARED TO A POLYCARBOXYLATE MOLECULE



Cement Grain (Part)

ca.10-20 .Å

ca. 20 µm = 20.10^4 Å

Cement Grain (Part)

ca. 20 µm = 20.10^4 Å

ca. 100 Å

Advanced Admixtures

- Dosages depend on a number of variables that are specific to each mix design and production facility.
- Can specify in oz / 100wt or oz per yard.
- Most mixes will have air entrainer and HRWR.
- Retarder when needed in summer, and commonly, always in high strength mixes.
- Hardening accelerators vs. set accelerators
- ASTM C494 “Standard Specification for Chemical Admixtures for Concrete”
    - Type A Water-reducing admixtures
    - Type B Retarding admixtures
    - Type C Accelerating admixtures
    - Type D Water-reducing and accelerating admixtures
    - Type F Water-reducing, high-range, admixtures
    - Type G Water-reducing, high-range, and retarding admixtures
    - Type S Specific performance admixtures

Advanced Admixtures

- Admixture effectiveness varies depending on its concentration in the concrete and the effect of the various other materials.
- Adequate testing should be performed to determine the effects of an admixture on the plastic and hardened properties of concrete
  - Slump
  - Slump Loss
  - Air
  - Set Time
  - Strength
  - Shrinkage
  - Permeability

- A rule of thumb is for all admixtures to be added seperately.
- ACI Education Bulletin E4-12 “Chemical Admixtures For Concrete” – Free Resource

Advanced Admixtures

- Water-reducing admixtures are based on a variety of materials
  - Lignosulfonic acids and their salts
  - Hydroxylated polymers
  - Hydroxylated carboxylic acids and their salts
  - Sulfonatedmelamine or napthalene formaldehyde condensates
  - Polyether-polycarboxylates

- HRWR or “Superplasticizers” are used to achieve low w/c ratios and highly flowable mixes.
- Effects last for a discrete period of time, this varies for each product.
- Slump extenders are available

Advanced Admixtures

- Never use Calcium Chloride Accelerators in prestressed concrete members (or steel reinforced).

- Accelerators can be used to achieve high early strength but may result in lower 28 day strength.

- Corrosion Inhibitors, like Calcium Nitrite, can be used to reduce or delay the onset of reinforcing steel corrosion in concrete. Calcium Nitrite acts as a Non-Chloride Accelerator.

- Hydration Stabilization Admixtures: These “super retarders” essentially stop the hydration of most of the primary phases in portland cement. They are used to achieve very long slump life and delayed set times.

Advanced Admixtures

- Shrinkage Reducing Admixtures can reduce drying shrinkage of concrete. These work by reducing the surface tension in the water in the pours of the cement paste in the concrete. This tension force is responsible for most of concrete's drying shrinkage.

- Viscosity Modifiers / Stabilizers (VMA) make the fresh concrete more cohesive and less susceptible to segregation and bleeding.

Thank you for your time!

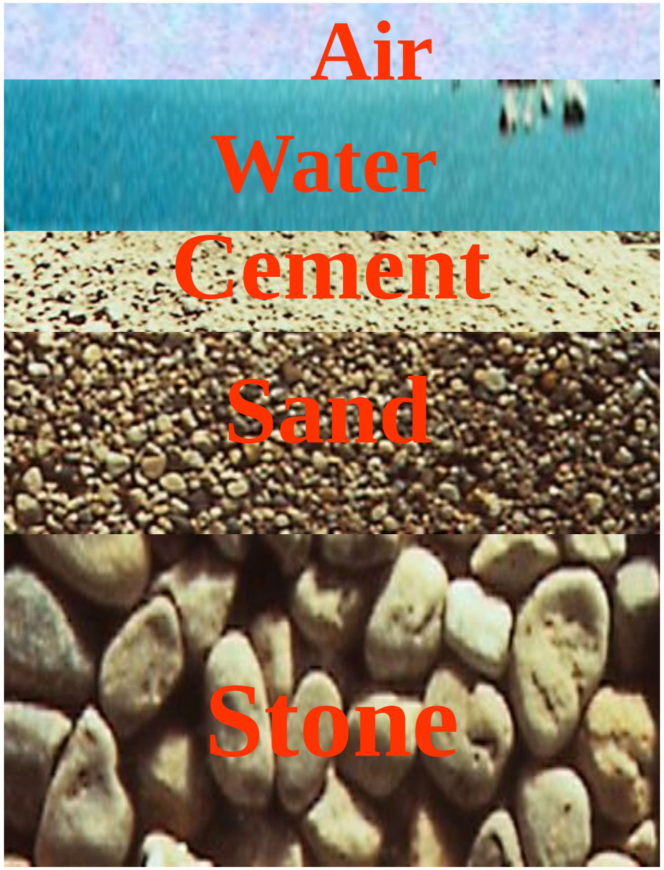
Questions?

Precast Concrete Mix Design Training

Module 2
Proportioning

PCI Precast/Prestressed Concrete Institute

A Typical Cubic Yard of Concrete



Volume	Weight (lb)
6%	-
18%	300
10%	500
25%	1250
40%	1800
27 cu.ft	~4000 lb

Steps:

1. Slump and Nominal Max. Agg. Size
2. Mixing Water Requirement
3. Air Content
4. Cement Content
5. Coarse Aggregate
    5.1. Nominal Max. Aggregate Size
    5.2. DRUW
    5.3. Weight of Coarse Aggregate
6. Calculate Absolute Volume (except sand)
7. Fine Aggregate (sand)
    7.1 Determine volume of Fine Aggregate
    7.2 Convert volume of fine agg. to Weight
8. Tabulate weights and Volumes of basic ingredients

Step 1

Slump definition (ACI 116):

> A measure of consistency of freshly mixed concrete, mortar, or stucco equal to the subsidence measured to the nearest ¼ in. (6 mm) of the molded specimen immediately after removal of the slump cone.

How to measure slump (ASTM C143)

*Select a Slump value…

Step 1… continue

Nominal Max. Aggregate Size:

Is the sieve size next larger than the largest sieve on which at least 15% of the coarse aggregate is retained

Standard Specification for Concrete Aggregates (ASTM C33 Table 2)

*Select an aggregate size

Step 1… continue

Specification for Concrete Aggregates
(ASTM C33 Table 2)

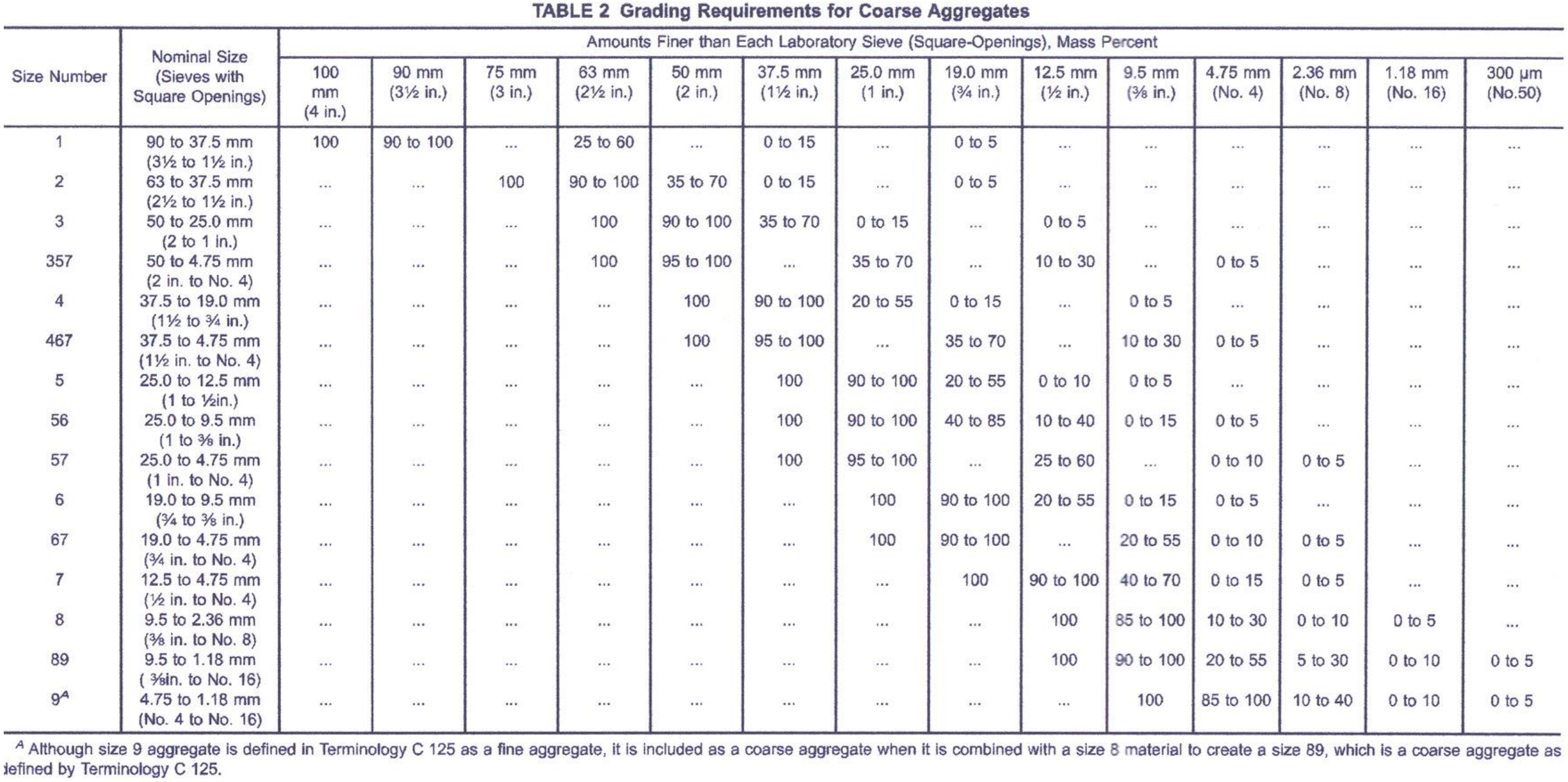


TABLE 2 Grading Requirements for Coarse Aggregates

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Mass Percent													
		100 mm (4 in.)	90 mm (3½ in.)	75 mm (3 in.)	63 mm (2½ in.)	50 mm (2 in.)	37.5 mm (1½ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	12.5 mm (½ in.)	9.5 mm (⅜ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No.50)
1	90 to 37.5 mm (3½ to 1½ in.)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...	...
2	63 to 37.5 mm (2½ to 1½ in.)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...	...
3	50 to 25.0 mm (2 to 1 in.)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
357	50 to 4.75 mm (2 in. to No. 4)	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...	...
4	37.5 to 19.0 mm (1½ to ¾ in.)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...	...
467	37.5 to 4.75 mm (1½ in. to No. 4)	...	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...	...
5	25.0 to 12.5 mm (1 to ½in.)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...	...
56	25.0 to 9.5 mm (1 to ⅜ in.)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...	...
57	25.0 to 4.75 mm (1 in. to No. 4)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...	...
6	19.0 to 9.5 mm (¾ to ⅜ in.)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...	...
67	19.0 to 4.75 mm (¾ in. to No. 4)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...	...
7	12.5 to 4.75 mm (½ in. to No. 4)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...	...
8	9.5 to 2.36 mm (⅜ in. to No. 8)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5	...
89	9.5 to 1.18 mm (⅜in. to No. 16)	...	...	...	...	...	...	...	...	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5
9[A]	4.75 to 1.18 mm (No. 4 to No. 16)	...	...	...	...	...	...	...	...	...	100	85 to 100	10 to 40	0 to 10	0 to 5

[A] Although size 9 aggregate is defined in Terminology C 125 as a fine aggregate, it is included as a coarse aggregate when it is combined with a size 8 material to create a size 89, which is a coarse aggregate as defined by Terminology C 125.

Step 2: Mixing Water & B3: Air Content

Slump, inches.	**Mixing Water, lb./cu. yd.**							
	No. 4 Mortar	**3/8 in.**	**1/2 in.**	**3/4 in.**	**1 in.**	**1½ in.**	**2 in.**	**3 in.**
Non-Air Entrained Concrete								
1 – 2	420	310	295	280	265	250	240	230
3 – 4		335	325	310	295	280	270	260
6 – 7		375	355	335	320	305	295	280
Air, %	4.0	3.0	2.5	2.0	1.5	1.0	0.5	0.3
Air-Entrained Concrete								
1 – 2	380	280	270	260	245	235	230	220
3 – 4		305	300	290	275	265	260	250
6 – 7		345	330	315	300	290	285	270
Exposure	**Recommended Air Content, %**							
Moderate	7.5	6.0	5.5	5.0	5.0	4.5	4.0	3.5
Severe	9.0	7.5	7.0	6.5	6.5	6.0	5.5	5.0

Maximum W/C Ratio for Concrete in Severe exposure (From ACI 211.1)

Type of Structure	Structure wet continuously or frequently and exposed to freezing and thawing*	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1” cover over steel	0.45	0.40**
All other structures	0.50	0.45**

*Concrete should also be air entrained.

** If sulfate resisting cement (type II or type V) is used, permissible water-cement ratio May be increased by 0.05

Water / Cement Ratio

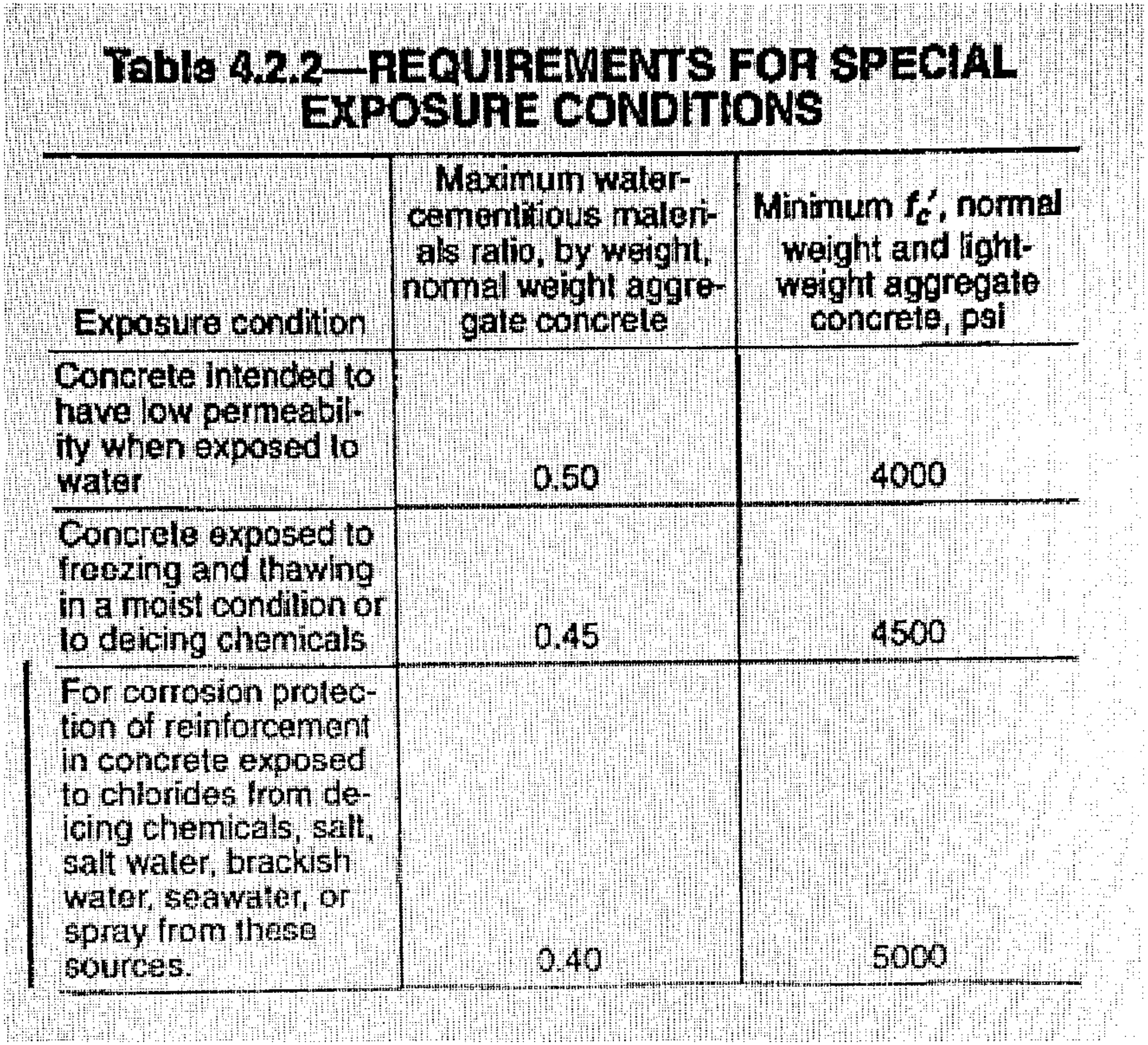


Table 4.2.2—REQUIREMENTS FOR SPECIAL EXPOSURE CONDITIONS

Exposure condition	Maximum water-cementitious materials ratio, by weight, normal weight aggregate concrete	Minimum f_c', normal weight and lightweight aggregate concrete, psi
Concrete intended to have low permeability when exposed to water	0.50	4000
Concrete exposed to freezing and thawing in a moist condition or to deicing chemicals	0.45	4500
For corrosion protection of reinforcement in concrete exposed to chlorides from deicing chemicals, salt, salt water, brackish water, seawater, or spray from these sources.	0.40	5000

ACI 318

Step 3: Air Content

Entrapped Air (ACI 116):

Air voids in concrete that are not purposely entrained and that are larger, mainly irregular in shape, and less useful than those of entrained air, and 1 mm or larger in size.

Entrained Air (ACI 116)

Microscopic air bubbles intentionally incorporated in mortar or concrete during mixing, usually by use of a surface-active agent; typically between 10 and 1000 μm (1 mm) in diameter and spherical or nearly so.

Moderate Exposures

Where freezing temperature are expected, but concrete will not be saturated for extended periods prior to freezing, and will not be exposed to deicing salts.

Examples: Exterior beams
Columns
Walls
Abutments
Exterior slabs under roofs

Severe Exposure

Where concrete will be exposed to deicing salts, or where concrete will be in contact with water and will potentially be saturated prior to freezing

Examples: Pavements
Bridge decks
Curbs
Gutters
Sidewalks
Canal and pond linings
Tanks

Step 4: Cement Content

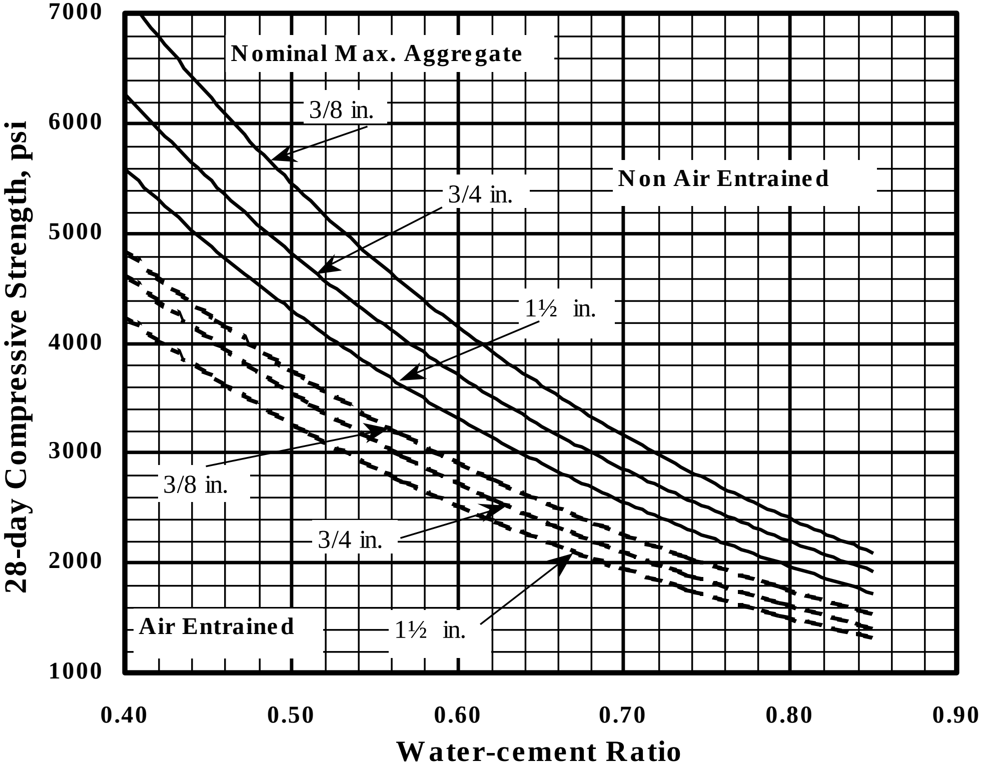
Water Cement Ratio, by weight		
Compressive strength, psi*	Non-air entrained concrete	Air-entrained Concrete
At 28 days, moist cured		
7000	0.34	--
6000	0.41	--
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
At release with accelerated curing**		
5000	0.33	--
4500	0.39	0.33
4000	0.45	0.37
3500	0.50	0.42
3000	0.56	0.46

*Values are estimated strength for concrete with no more than 2% air for non-air-entrained concrete and less Than 6% air in air-entrained concrete.

**With type III cement, release at 16 hours after casting

Step 4: Cement Content

$$\text{Cement} = \frac{\text{Mixing water}}{\text{w/c ratio}}$$



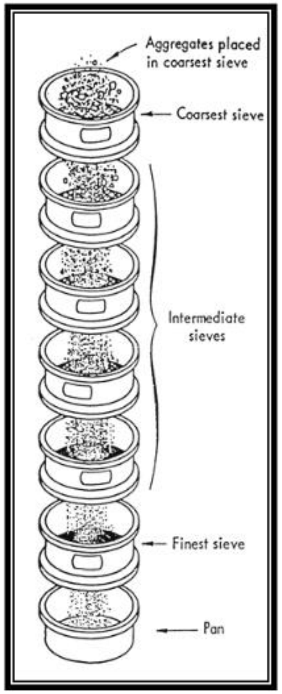
Step 5.1:Fineness Modulus (FM)

Fineness Modulus (ASTM C125):

- A factor obtained by adding the percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: 150μm (No.100), 300μm (No.50), 600μm (No.30), 1.18 mm (No.16), 2.36 mm (No.8), 4.75 mm (No.4), 9.5 mm (3/8 in), 19.0 mm (3/4 in), 37.5 mm(1 ½ in), 75 mm(3 in), 150 mm(6 in)

Step 5.1:Fineness Modulus (FM) of Sand

Example: FM of sand



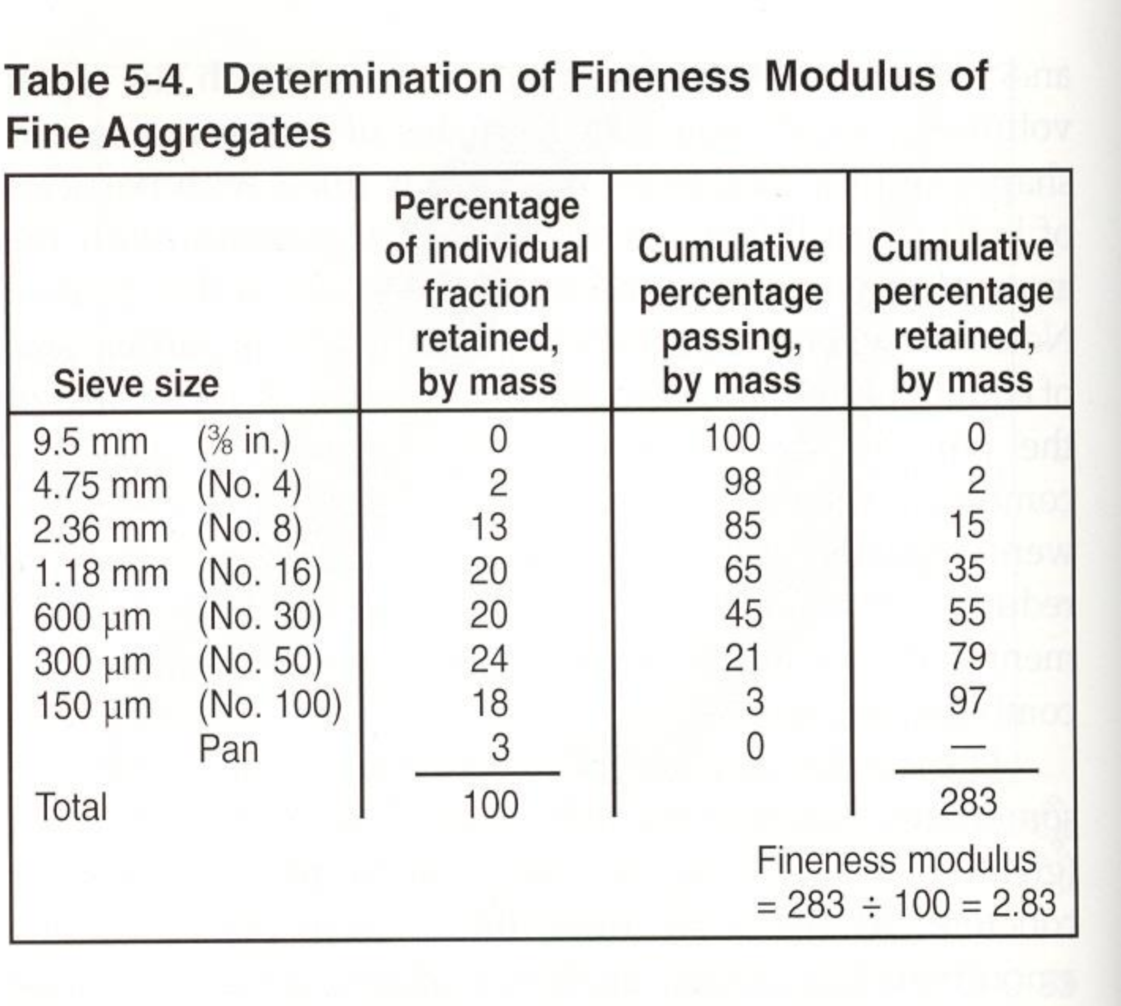


Table 5-4. Determination of Fineness Modulus of Fine Aggregates

Sieve size		Percentage of individual fraction retained, by mass	Cumulative percentage passing, by mass	Cumulative percentage retained, by mass
9.5 mm	(⅜ in.)	0	100	0
4.75 mm	(No. 4)	2	98	2
2.36 mm	(No. 8)	13	85	15
1.18 mm	(No. 16)	20	65	35
600 µm	(No. 30)	20	45	55
300 µm	(No. 50)	24	21	79
150 µm	(No. 100)	18	3	97
	Pan	3	0	—
Total		100		283

Fineness modulus = 283 ÷ 100 = 2.83

Step 5.1: Coarse Aggregate Content

Nominal Maximum Size Coarse Aggregate	b/b_o[*] for different Fineness Modulus of Fine Aggregate (Sand)				
	2.20	2.40	2.60	2.80	3.00
3/8 in.	0.52	0.50	0.48	0.46	0.44
1/2 in.	0.61	0.59	0.57	0.55	0.53
3/4 in.	0.68	0.66	0.64	0.62	0.60
1 in.	0.73	0.71	0.69	0.67	0.65
1 ½ in.	0.77	0.75	0.73	0.71	0.69
2 in.	0.80	0.78	0.76	0.74	0.72
3 in.	0.84	0.82	0.80	0.78	0.76

[*] b/bo is the volume of dry-rodded coarse aggregate in a unit volume of concrete

Step 5.2: DRUW (Dry Rodded Unit Weight)

The maximum weight of coarse aggregate that can be consolidated into a 1 cubic foot bucket.

The "DRUW" of a coarse aggregate is determined by ASTM C29

The max. weight of coarse aggregate in a volume of 1 cu.yd = DRUW, lb/cu.ft. x 27

Step 5.3: Weight of dry Coarse Aggregate

Wt. of dry CA = b/bo x DRUW, lb/cu.ft. x 27

Step 6: Absolute Volume of Ingredients

$$\text{Absolute vol., cu.ft.} = \frac{\text{Wt. of ingredient, lb}}{\text{SG x Unit Wt of water, lb/cu.ft}}$$

Step 6.1: Cement, cu.ft.
Step 6.2: Water, cu.ft.
Step 6.3: Coarse Aggregate, cu.ft
Step 6.4: Air ➔ air content x 27 cu.ft.

Step 6.5: Sum up the absolute volumes of cement, water, air, and coarse aggregate

6.1: CEMENT

CONDITIONS:

650lbs Type 3 Portland Cement

SP.GR. = 3.15

$$\text{Vol} = \frac{\text{Wt of material}}{\text{S.G. of material x ut.wt. of } H_2O}$$

$$\text{Vol} = \frac{650}{3.15 \text{ x } 62.4}$$

6.2 WATER

CONDITIONS:

w/c R = .38

Weight = 8.33lbs/gal.

$$\text{Weight } H_2O = \text{lbs cem} \times \text{w/c R}$$

$$\text{Weight } H_2O = 650 \times .38$$

$$\text{Vol.} = \frac{\text{Weight}}{1 \times 62.4}$$

6.3 Coarse Aggregate

CONDITIONS:

Volume of dry-rodded coarse aggregate = 0.62

(From volume of CA chart, slide 14)

Dry-rodded unit weight = 98.6

Cubic feet in a cubic yard = 27

Specific Gravity = 2.73

$$\text{Weight} = 0.62 \times 98.6 \times 27$$

$$\text{Vol} = \frac{\text{Weight}}{2.73 \times 62.4}$$

6.4 Air

CONDITIONS:

Air specification = 6.0%

Vol. = Air % x 27 cubic ft.

Vol. = 0.06 x 27

Step 7: Fine Aggregate

Step 7.1:

Abs. Vol. of Fine Agg. = 27 – Abs. Vol. of
(Cement + Water + Coarse
Aggregate + Air)

Step 7.2:

Wt. of Fine Agg. = Abs. Vol. of Fine Agg.
x SG x 62.4

Step 8: Tabulate Weights & Volume

Material	Weight, lb.		Absolute volume, cu.ft.
Cement Fly Ash	550 130		2.80 0.95
Mixing Water	285		4.57
Coarse Aggregate 1 Coarse Aggregate 2	1000 720		5.83 4.31
Fine Aggregate	1180		7.19
Air, ________5__%	--		1.35
Total			27.00

Changing Aggregate

CEMENT 520 lb./c.y. / (**3.15** S.G. x 62.4) = 2.65 cu.ft.

FLY ASH 110 lb./c.y. / (**2.20** S.G. x 62.4) = 0.80 cu.ft.

SILICA FUME **0** lb./c.y. / (**2.25** S.G. x 62.4) = **0** cu.ft.

WATER **285** lb./c.y. / (**1** S.G. x 62.4) = **4.57** cu.ft.

COARSE AGGREGATE #1 1600 lb./c.y. / (**2.75** S.G. x 62.4) = 9.68 cu.ft.

COARSE AGGREGATE #2 0 lb./c.y. / (**2.68** S.G. x 62.4) = 0 cu.ft.

AIR **0.05** **5** % x 27 = **1.35** cu.ft.

VOLUME FILLED = 19.05 cu.ft.

FINE AGGREGATE 27.00 - 19.05 = 7.95 cu.ft.

cu.ft. 7.95 x (**2.63** S.G. x 62.4) = 1305 lb./c.y.

DETERMINATION OF ABSOLUTE VOLUME
METRIC

CEMENT ________kg/m^3 / (________S.G. x 1000) = ________m^3

FLY ASH ________kg/m^3 / (________S.G. x 1000) = ________m^3

WATER ________kg/m^3 / (____1___S.G. x 1000) = ________m^3

COARSE AGGREGATE ________kg/m^3 / (________S.G. x 1000) = ________m^3

AIR .... ________% / 100 = ________m^3

VOLUME FILLED .... = ________m^3

FINE AGGREGATE .... 1 - ________ = ________m^3

m^3 ____________ x (_________ S.G. x 1000) = ___________kg

Proportioning from Field Data

Required Strength When Data is Available, to Establish a Standard Deviation

Specified compressive strength, f'_c, psi	Required average compressive strength, f'_{cr}, psi
≤ 5000	$f'_{cr} = f'_c + 1.34s$ $f'_{cr} = f'_c + 2.33s - 500$ Use larger value
Over 5000	$f'_{cr} = f'_c + 1.34s$ $f'_{cr} = 0.90f'_c + 2.33s$ Use larger value

Proportioning from Field Data

Required Strength When Data is not Available, to Establish a Standard Deviation

Specified compressive strength, f'_c, psi	Required average compressive strength, f'_{cr}, psi
Less than 3000	$f'_c + 1000$
3000 to 5000	$f'_c + 1200$
Over 5000	$1.10f'_c + 700$

Thank you for your time!

Questions?

QUALITY ENHANCEMENT COMMITTEE


50LB BLACK KOW MANURE
$5.17 ea
AISLE BAY
OG 128
60LB QUIKRETE CONCRETE MIX
$2.97 ea
0000-929-514
AISLE BAY
BW 067
BLACK KOW
Cow
0.5-
BLACK GOLD
DON'T FOR
QUIKRETE
Ready-To-Use
CONCRETE MIX

Precast Concrete Mix Design Training

Module 3
Durability

PCI Precast/Prestressed Concrete Institute

What is durable concrete?

- "The durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties."

- Different concretes require different degrees of durability depending on the exposure environment and the properties desired.
- The concrete ingredients, proportioning of those ingredients, interactions between the ingredients, and placing and curing practices determine the ultimate durability and life of the concrete.

PCA – Design and Control of Concrete Mixtures, 14th edition

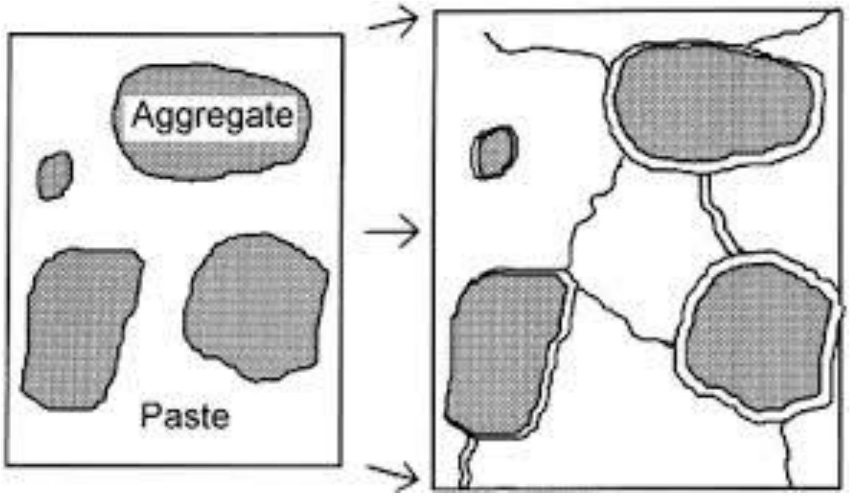
Basic Concerns of Concrete Service Life

- Alkali Silica Reaction (ASR)
  - A type of concrete deterioration that occurs when the active mineral constituents of some aggregates react with the alkali hydroxides in the concrete.
  - Needed in order for ASR to occur:
    - Cement alkali (>0.60)
    - Aggregate containing reactive silica minerals (ASTM- C295 / C1260)
    - Presence of moisture in the concrete
  - Prevention:
    - Total cementitious alkalis below 0.60
    - The addition of supplementary cementitious materials
    - Non-reactive aggregates

PCI requirements – Aggregate testing ASTM C1260

Basic Concerns of Concrete Service Life

- Delayed Ettringite Formation (DEF)
  - Sulfate compounds react with calcium aluminate in cement to form ettringite within the first few hours after mixing with water. If concrete is exposed to high temperatures during curing the ettringite can dissolve and when exposed to moisture later reform, creating expansive forces within concrete.
  - Expansion and cracking can occur in concretes of particular chemical makeup when they have achieved high temperatures soon after placement (~160 to 210 F)
  - Prevention:
    - Use sound (proven) materials
    - Cure below 158° F, after initial set
    - Use SCM's to mitigate the re-formation of ettringite



This delayed expansion is characterized by expanding paste that becomes detached from various components of the mix, creating gaps at the paste-aggregate interface. The gap can then be filled with larger ettringite crystals.

Basic Concerns of Concrete Service Life

- Sulfate Attack
  - Excessive amounts of sulfates in soil or water can attack and destroy a concrete that is not properly designed
  - Prevention:
    - Design with a low water cement ratio
    - Use type 2 cement
    - Use SCM’s

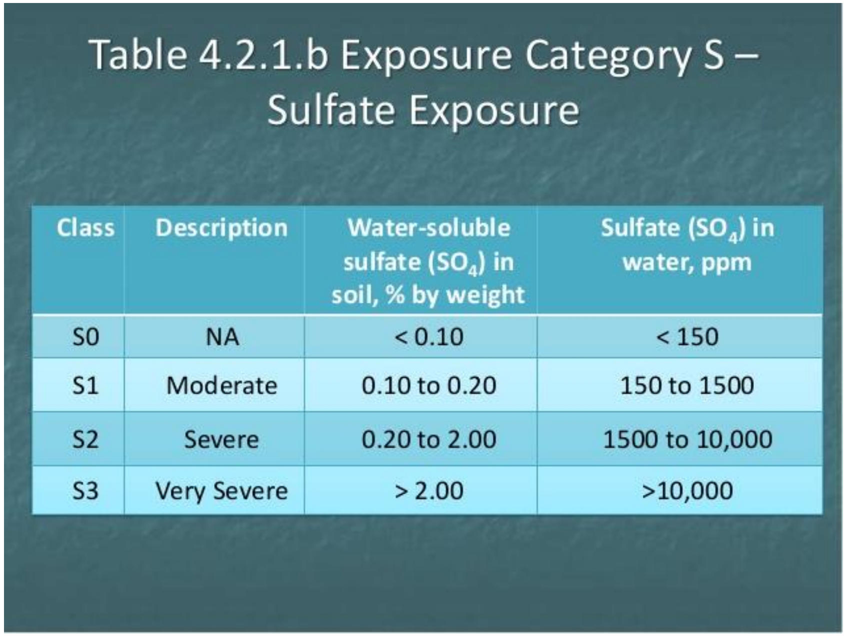


Table 4.2.1.b Exposure Category S – Sulfate Exposure

Class	Description	Water-soluble sulfate (SO_4) in soil, % by weight	Sulfate (SO_4) in water, ppm
S0	NA	< 0.10	< 150
S1	Moderate	0.10 to 0.20	150 to 1500
S2	Severe	0.20 to 2.00	1500 to 10,000
S3	Very Severe	> 2.00	>10,000

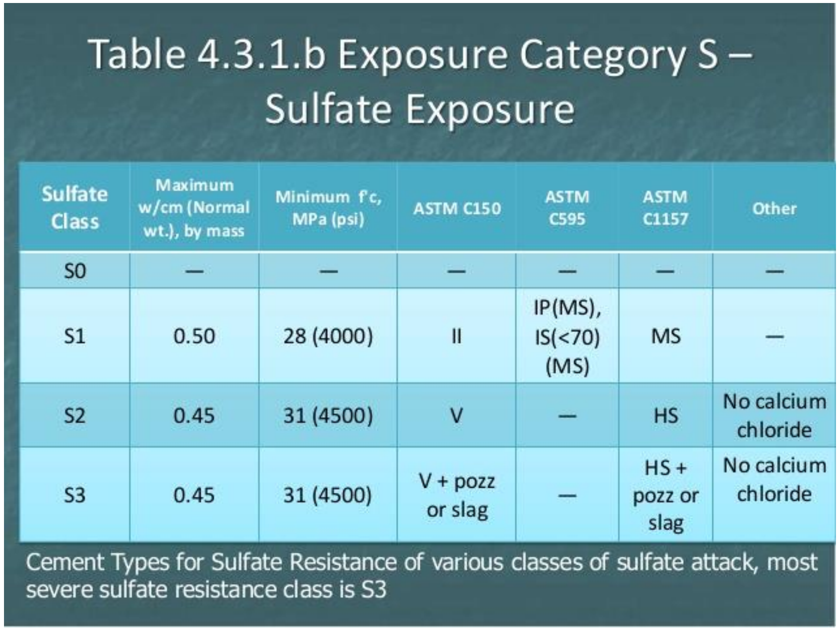


Table 4.3.1.b Exposure Category S – Sulfate Exposure

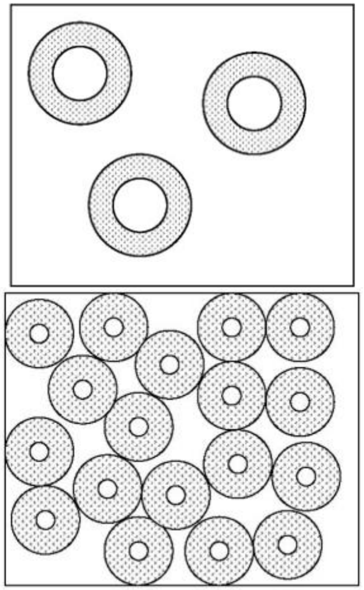
Sulfate Class	Maximum w/cm (Normal wt.), by mass	Minimum f'c, MPa (psi)	ASTM C150	ASTM C595	ASTM C1157	Other
S0	—	—	—	—	—	—
S1	0.50	28 (4000)	II	IP(MS), IS(<70) (MS)	MS	—
S2	0.45	31 (4500)	V	—	HS	No calcium chloride
S3	0.45	31 (4500)	V + pozz or slag	—	HS + pozz or slag	No calcium chloride

Cement Types for Sulfate Resistance of various classes of sulfate attack, most severe sulfate resistance class is S3

Basic Concerns of Concrete Service Life

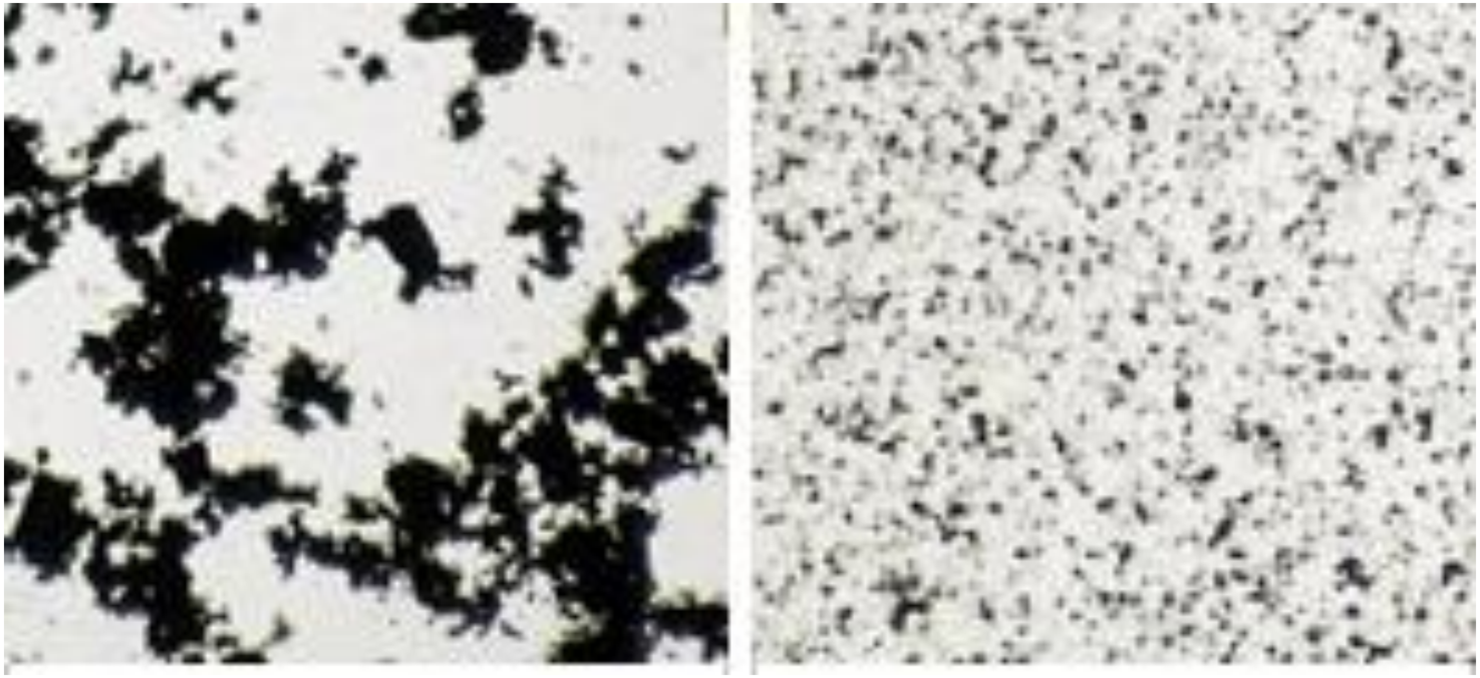
- Freeze / Thaw
  - The freezing of concrete results in the formation of ice inside the concrete. When frozen water expands by 9%, this volume expansion generates significant tensile stress in the concrete. Cycles of freezing and thawing leads to distress.
  - If the freezing water does not have microscopic air bubbles to expand within, then cracking and scaling can occur.

Prevention:



- – Air Content – 5%-8% for ¾” agg, Spacing factor <0.008 in, Specific surface area of 600in^2/in^3
- – W/C R <0.45
- – Min. 4500 psi
- – Fly ash, slag, silica fume not to exceed 25%, 50%, 10% respectively
- – Proper finishing after bleed water has evaporated

Basic Concerns of Concrete Service Life

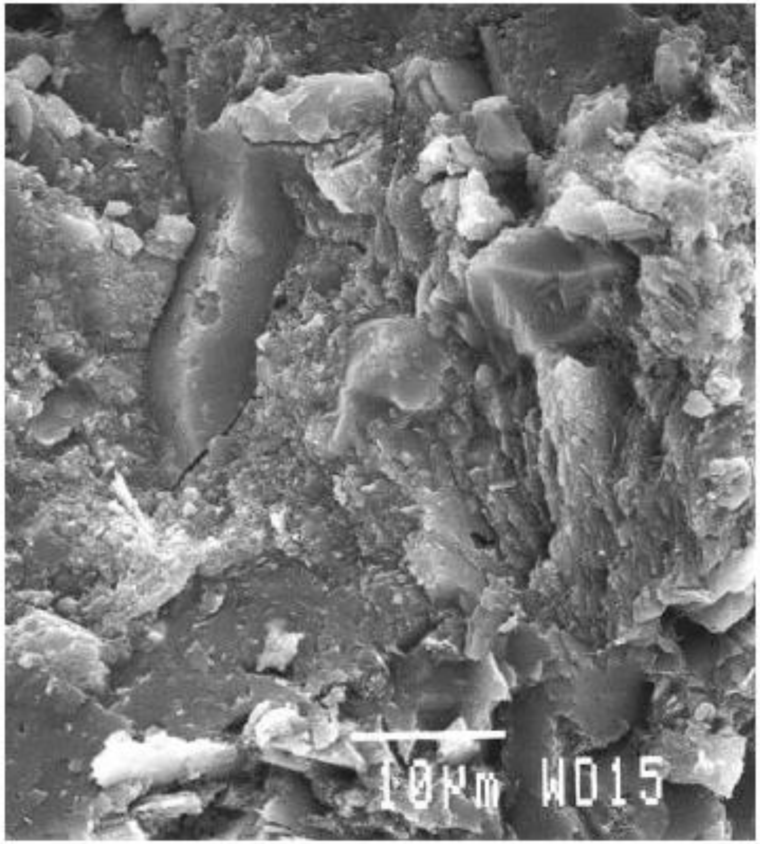


Basic Concerns of Concrete Service Life

- Permeability
  - The amount of water migration through concrete when the water is under pressure or to the ability of concrete to resist penetration by water or other substances.
  - The overall permeability of concrete is a function of:
    - Permeability of the paste
    - Permeability and gradation of the aggregate
    - Quality of the paste and the aggregate transition zone
    - Relative proportion of paste to aggregate

  - Decreased permeability improves concrete's resistance to freezing and thawing, sulfate, chloride-ion penetration, and other chemical attack.
  - Decrease permeability by:
    - Lowering the water cement ratio
    - Using an aggregate with a more uniform gradation
    - Use a SCM (i.e. Slag, Fly Ash, Silica Fume…)
  - Tests:
    - AASHTO T 259 – ponding chloride solution
    - ASTM C 1556 -
    - ASTM C 1202 – rapid chloride permeability test (Coulomb)

w/c ratio – 0.50



w/c ratio – 0.36

*Both specimens shown at same magnification

Testing

- ASTM C:
  - 39 – Compressive strength of cylindrical concrete specimens
  - 157 – Length change of hardened hydraulic-cement mortar and concrete
  - 295 – Petrographic examination of aggregates for concrete
  - 457 – Microscopical determination of parameters of the air-void system in hardened concrete
  - 642 – Density, absorption, and voids in hardened concrete
  - 666 – Resistance of concrete to freezing and thawing
  - 672 – Scaling resistance of concrete surfaces exposed to deicing chemicals
  - 1138 – Abrasion resistance of concrete
  - 1202 – Electrical indication of concrete's ability to resist chloride ion penetration
  - 1218 – Water-soluble chloride in mortar and concrete
  - 1260 – Potential alkali reactivity of aggregates
  - 1543 – Penetration of chloride ion into concrete by ponding
  - 1556 – Apparent chloride diffusion coefficient of cementitious mixtures by bulk diffusion
  - 1567 - Potential Alkali-Silica Reactivity of combinations of cementitious materials and aggregate (accelerated mortar-bar method)

Thank you for your time!

Questions?

QUALITY ENHANCEMENT COMMITTEE

Precast Concrete Mix Design Training

Module 3
Self-Consolidating Concrete

PCI Precast/Prestressed Concrete Institute

Self-Consolidating Concrete Defined

"A highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing significant separation."

Khayat, Hu and Monty

CONTENT

- Polycarboxylate
- Designing SCC
- Performance Requirements

The Polycarboxylate

Superplasticized	Self consolidating
measured by slump	measured by spread
• 6” to 10-1/2”	• 20” to 30”
cohesive and non-segregating	cohesive and non-segregating
requires vibration for proper consolidation during placement	requires no vibration during placement

The Polycarboxylate

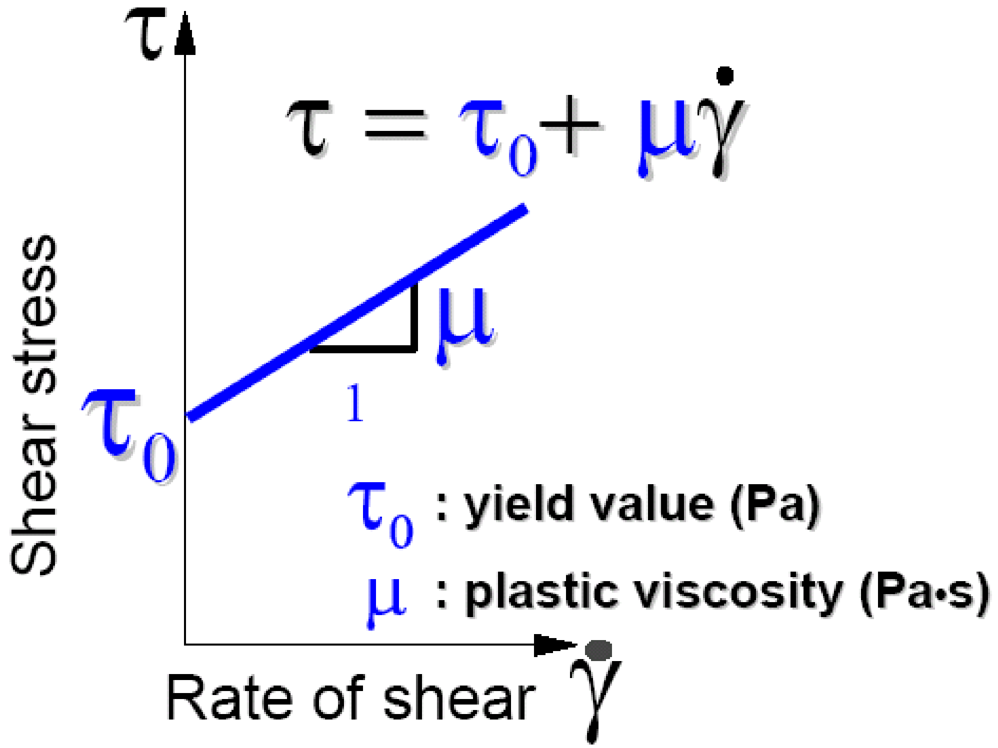
What Makes SCC possible?

A Polycarboxylate based High Range Water Reducer

1. **Electrostatic dispersion**, a state created by the admixture which allows it to attach to the cement grains electrically and repel other admixture molecules and cement grains.
2. A much larger than normal **molecular weight** (size).
3. **Steric Hindrance**, a state created by the massive size of the admix molecules attached to the cement grains that prevents contact of the grains and promotes fluidity of the cement paste. It also takes longer for the admixture to be overtaken by the gel formation around the cement grain caused by the hydration reaction.
4. **Up to 40 percent** water reduction capabilities.

Rheology and SCC

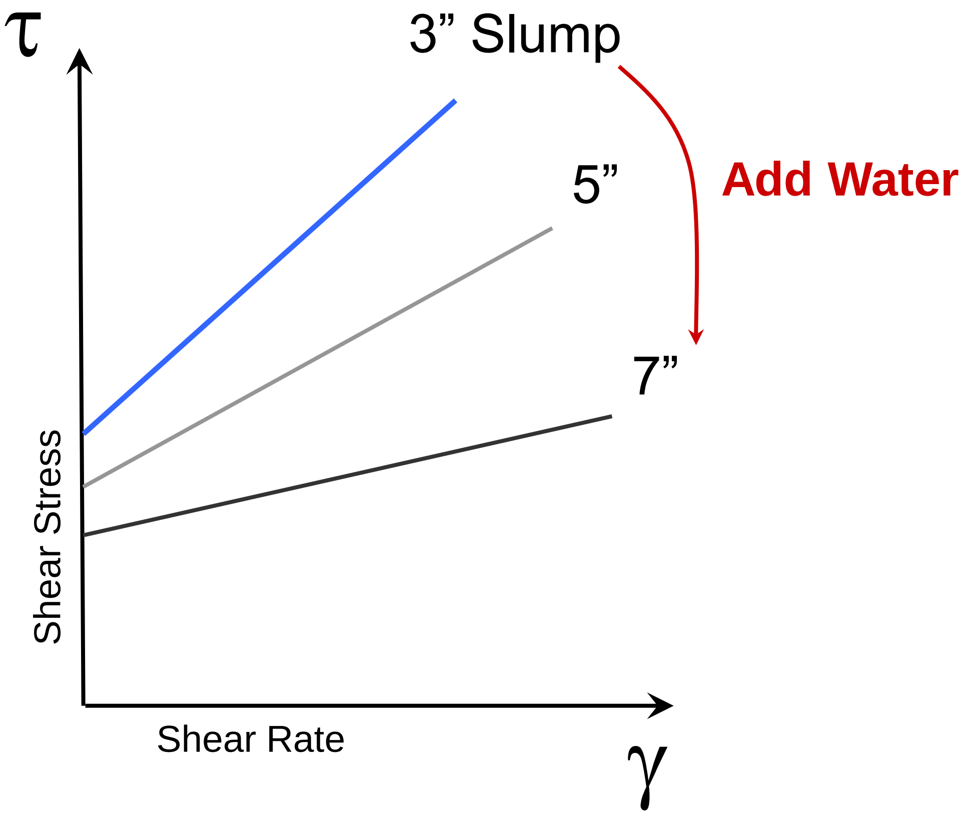
Rheology: The science of the deformation and flow of materials



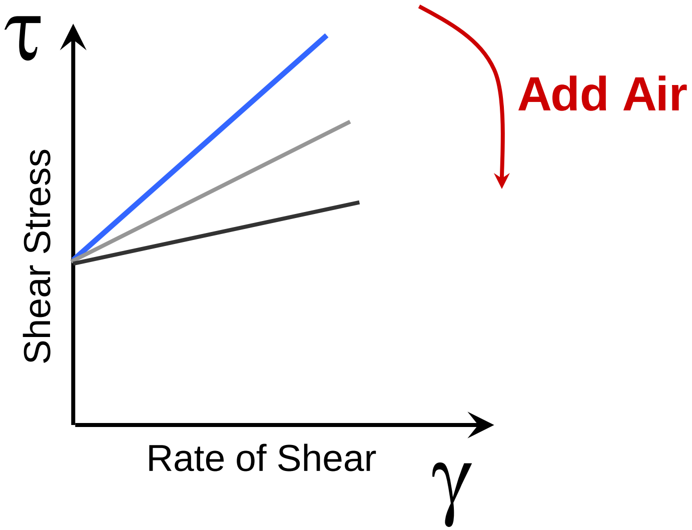
Yield value (τ_0) **must be low to promote flow without applied energy**

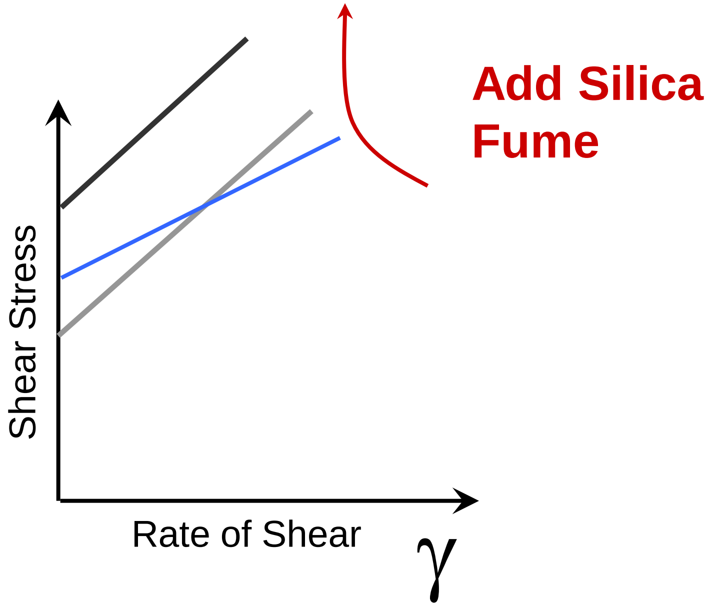
Plastic viscosity (μ) **must be low enough to promote rapid flow, BUT high enough to prevent segregation**

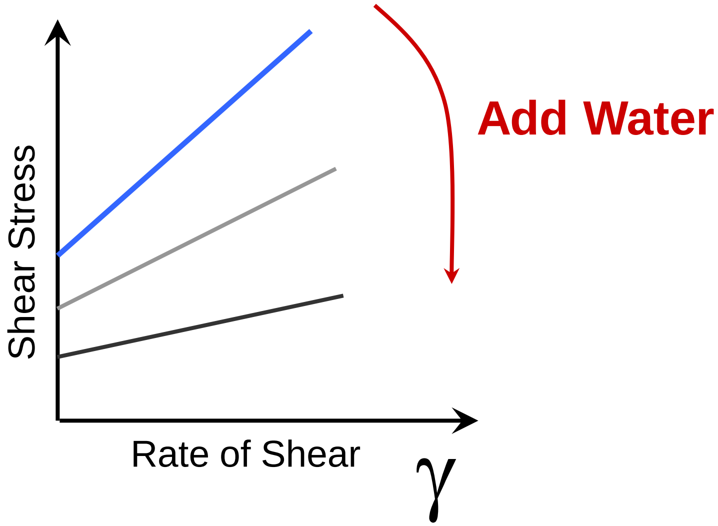
Rheology and SCC

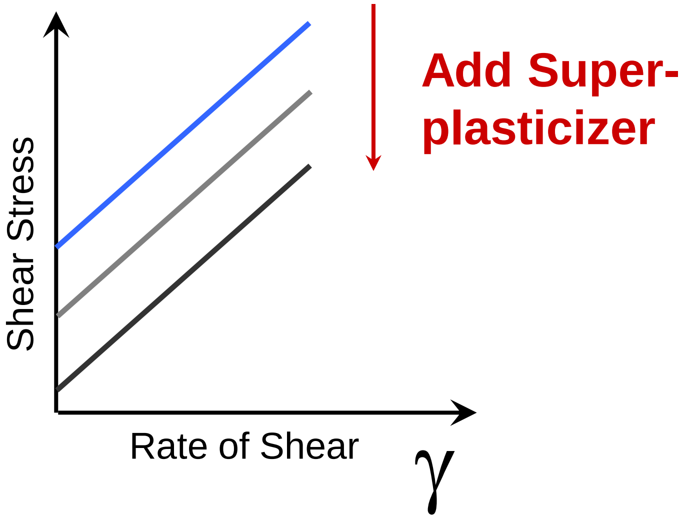


Effects of Mix Design on Rheology









Dr. Olafur Wallevik, Rheology of Cement Suspension, Icelandic Building Research Institute, 2002

Three Key Properties of SCC

Resistance to Segregation

During placement and while flowing, the concrete should retain its homogeneity. There should be no separation of aggregate from paste or water from solids and no tendency for coarse aggregate to sink downwards through the fresh concrete mass under gravity

Passing Ability

The ability of concrete to flow freely in and around dense reinforcement without blocking

Filling ability

The ability of the concrete to flow freely under its own weight, both horizontally and vertically upwards, if necessary, and to completely fill formwork of any dimension and shape without leaving voids

Mix Design

Coarse aggregate – can be made from most normal aggregates, but grading requirements are tighter than normal concrete

Fine Aggregate – Helpful to use finer (well graded) material than normal to help the cohesion necessary to resist segregation.

Cement – In most cases, all types may be used, but sometimes larger quantities must be used for cohesion.

Fly-Ash & Slag Cement – Very useful as filler material for cohesion and helps increase overall concrete strength & density.

Mix Design

Design Methods – 2 different approaches:

Powder Method

Increased cement, pozzolons, and inert filler (limestone fines) used to optimize packing density and maintain mix cohesion, typically 700 to 900 lbs/yd^3

Admixture Method

Polycarboxylate-based supers made for SCC enhance paste viscosity

Viscosity Modifying Admixtures (VMA) (specialty carbohydrates, synthetic viscosifiers) increase paste viscosity and yield stress

Mix Design Volumes

Typical Precast / Prestress Concrete		**Self-Consolidating**
Cementitious	11-22%	13-22%
Coarse Aggregate	35-45%	30-45%
Fine Aggregate	25-35%	30-42%
Water	12-20%	14-22%
Air	Up to 8%	Up to 8%

SCC Mix Design

- What’s typical for you?
  - 53% CA to Fine Agg ratio
  - Max .38 w/cR
  - ½” to ¾” stone size
  - Well graded aggregate
  - 680 to 750 pounds cementitious

SCC Performance Requirements

- Required Mix Qualification (PCI)
  - Slump Flow range
  - J-ring value
  - VSI rating
  - Column Segregation
  - Strand bond
  - Air range
  - Strength average

Update on Industry Acceptance

ACI

- ACI 237R-07 – Self Consolidating Concrete
- ACI 211 - Proportioning Concrete Mixtures : *Proportioning SCC*

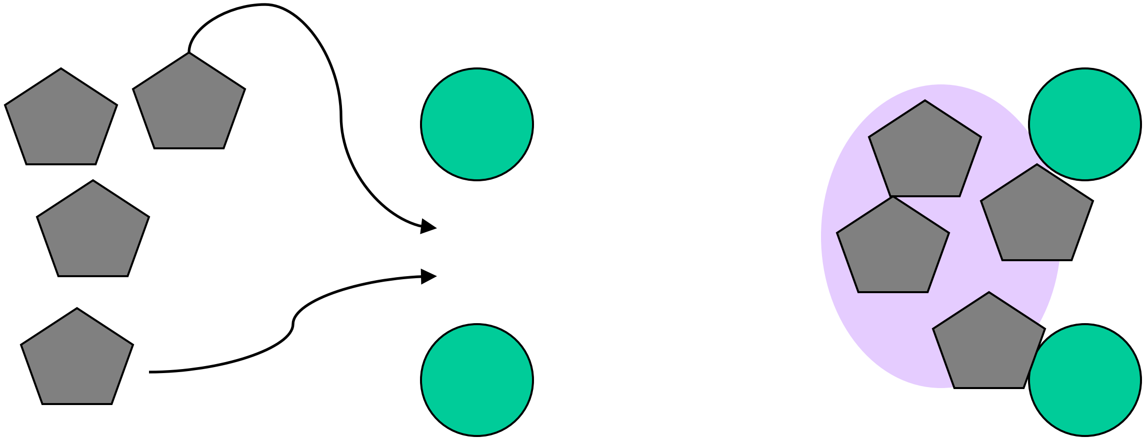
PCI

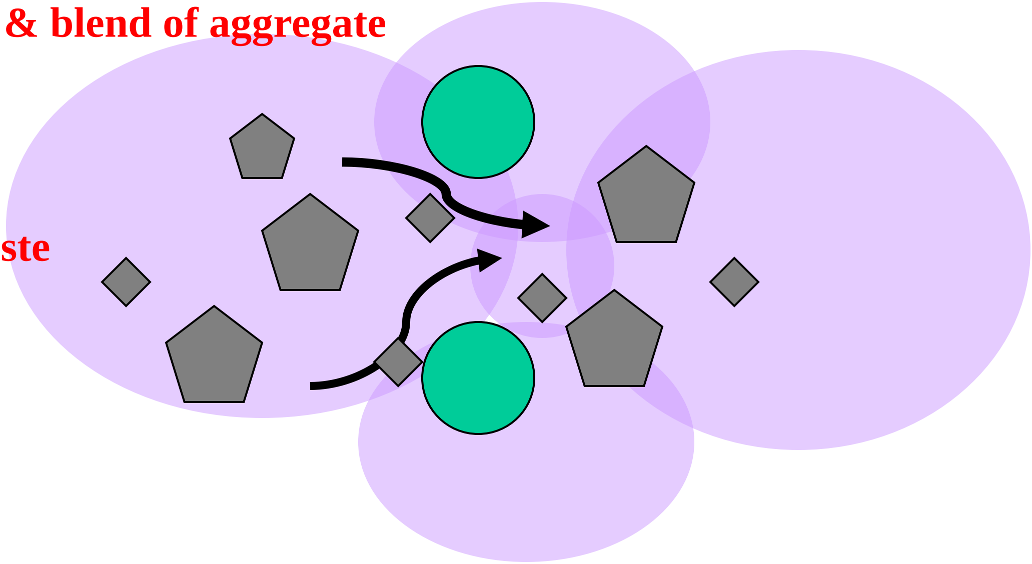
- Guidelines for SCC

ASTM

- Test methods – Slump Flow (C 1611), Column Segregation (C1610), J-Ring (C1621)

What is blocking or passing ability?





Size, volume, & blend of aggregate

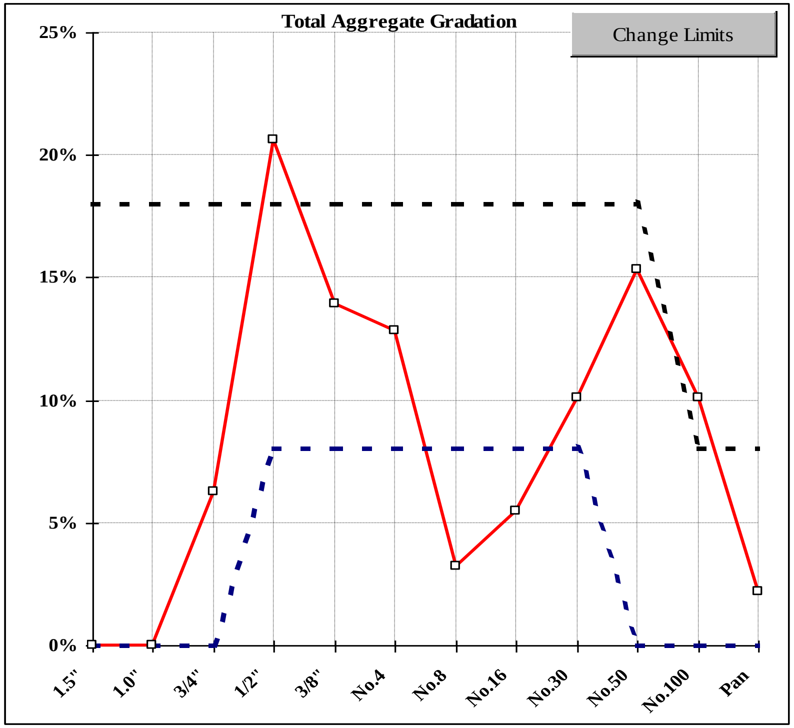
Sufficient volume of paste

Suggested Powder Content

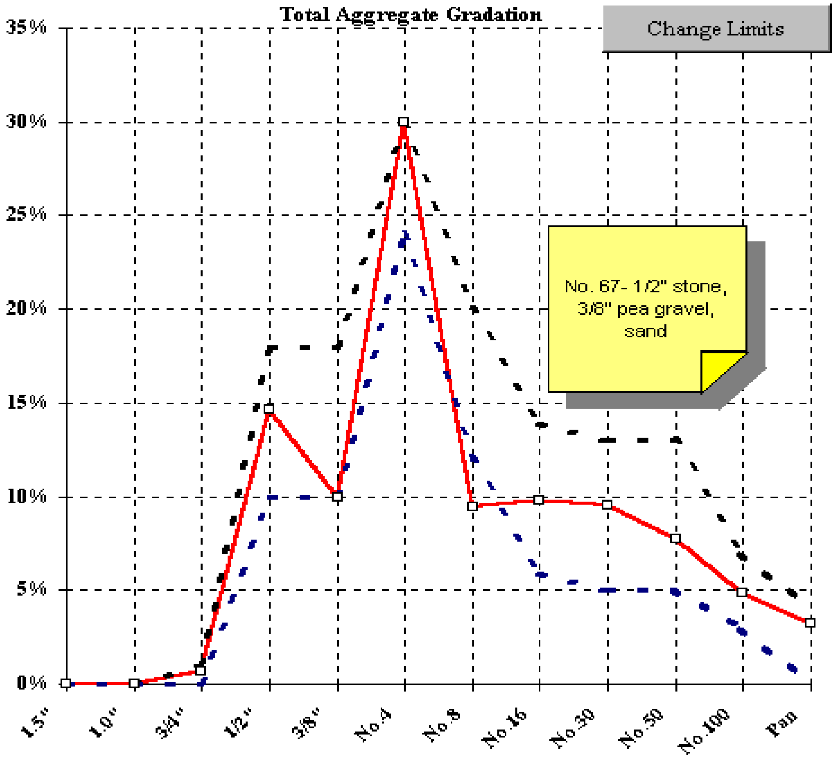
	Slump Flow, in. <22	Slump 22-26, in 22-26	Slump Flow, in. >26
Powder Content Lb/yd^3	< 650	650 - 750	750 +

Absolute volume of coarse aggregate	28-32% (total mix volume)
Paste Fraction (calculated on volume)	34-40% (total mix volume)
Mortar Fraction (calculated on volume)	60-70% (total mix volume)
Volume of water to powder ratio	0.8-1.0 (0.8-1.15 optional*****) *****with VMA
Typical w/cm	0.32 – 0.45
Typical cement (powder content)	750-900 pounds

Aggregate Grading

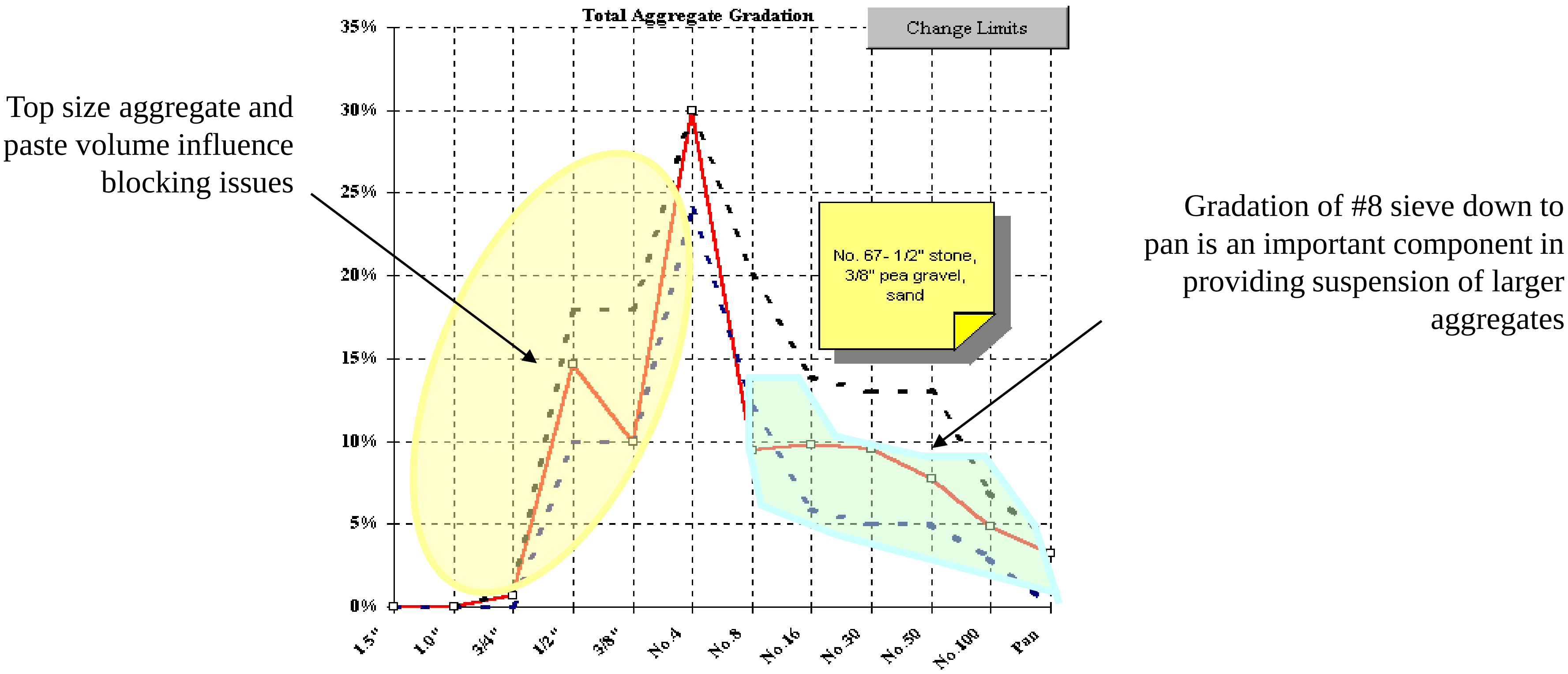


An example of a typical # 57 blend, indicating a Gap Graded Aggregate



- **An optimized SCC aggregate grading with blended aggregates**

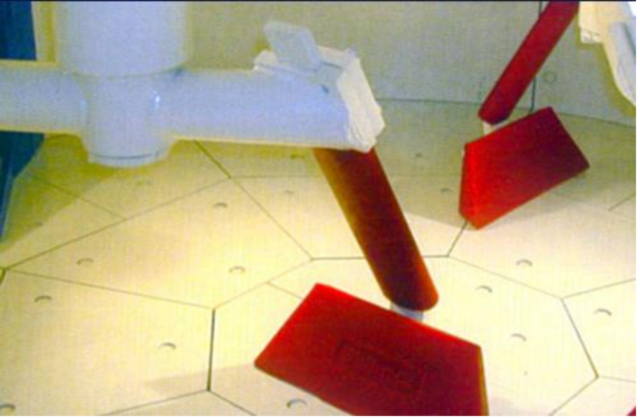
SCC Mix Design



Top size aggregate and paste volume influence blocking issues

Gradation of #8 sieve down to pan is an important component in providing suspension of larger aggregates

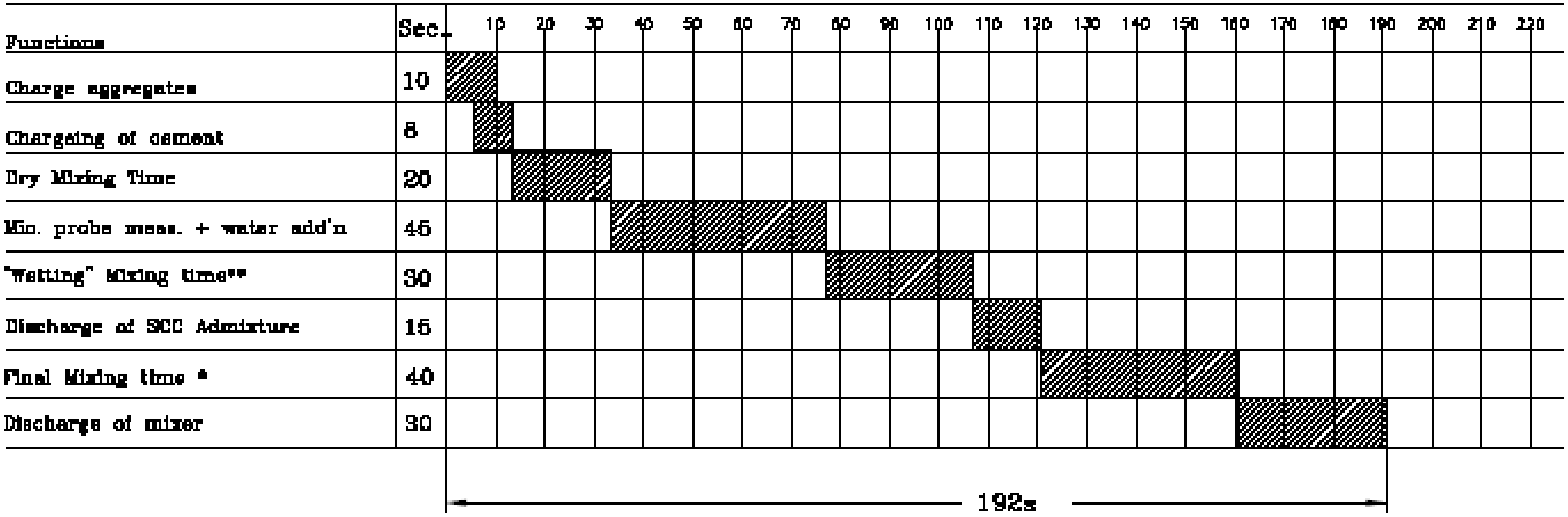
What's important when looking at gradation and aggregate size.



Type of mixer, makes a difference

Planetary / Twin Shaft / Spiral Blade

Typical SCC Time Cycle Diagram with microwave probe in mixer



Functions	Sec.
Charge aggregates	10
Chargeing of cement	8
Dry Mixing Time	20
Mic. probe meas. + water add'n	46
"Wetting" Mixing time**	30
Discharge of SCC Admixture	16
Final Mixing time *	40
Discharge of mixer	30

Typical SCC Mixing Cycle *

Adjustments to mix

Property	Powder Content	Water Content	Maximum Coarse Aggregate Size	Sand-to-Aggregate Ratio	VMA Dosage	HRWRA Dosage
Fluidity						
Too Low		↑			↓	↑
Too High		↓			↑	↓
Viscosity						
Too Low	↑	↓			↑	
Too High		↑			↓	
Insufficient Passing Ability	↑	↓	↓	↑	↑	
Stability						
Excessive Segregation	↑				↑	
Aggregate Pile			↓	↑		
Mortar Halo	↑	↓			↑	↓

Thank you for your time!

Questions?

QUALITY ENHANCEMENT COMMITTEE

Precast Concrete Mix Design Training

Module 4
Architectural Concrete

PCI Precast/Prestressed Concrete Institute

CONTENT

- Materials
    - White Cement
    - Pigment
    - Aggregates
- Architectural Mix Design
    - Acid etch/Sand Blast recommendations
    - Exposed aggregate recommendations
- Sample Generation

White Cement

White cement is made of selected raw materials containing negligible amounts of iron and manganese oxides, as those materials are what produce the gray color. White cements all have inherent color differences depending on their source.

White cement conforms to ASTM C-150 and is produced as a type 1 or type 3.

Slag may be used as a white cement filler to lessen the cost of the mix. Though it should be understood that the slag will discolor the concrete until it bleaches out, usually within 7 days. Slag is not true white, and it varies in color, so it should be used in limited dosages in light colored mixes.

White Cement Requires Special Manufacturing Techniques

Select Raw Materials that are Low in Iron

Limestone

Sand

Clay

Gypsum

Clinker

- **Carefully Selected Raw Materials**
- **Specialized Manufacturing Techniques**
- **Quality Control of Whiteness**

Manufacturing White Cement

Additional Quality Control Measures Ensure:

Uniform Color

Consistent Performance

Reliable Strength

Using White Cement

Mixes & Batching

Dedicated Equipment

- Batching
- Delivery

Specify Light Colored Aggregates (or match the colored matrix?)

- Fine Aggregate Most Important
- Coarse More Critical in Polished or Deep Grind

Pigment Basics

Tinting Strength

- The ability of a pigment to change the color of a given mix - ie. If a pigment changes the color of a mix substantially with a small addition of color, that pigment is said to have a high tinting strength. The tinting strength of a pigment depends on the iron content and the fineness of that particular pigment.

Saturation Point

- The point at which color intensity stops rising proportionally to the rate of addition of the pigment.

Pigment Basics

Synthetic Iron Oxides

- High tinting strength
- Intense Colors
- Relatively Expensive
- Low Addition Rates - 1/4 to 3/4%

Natural Iron Oxides

- Lower tinting strength
- Earthtone Colors
- Relatively Inexpensive
- Higher Addition Rates - 1 to 3%

Blends

Iron Oxide Pigments

Synthetic Red

Natural Red

Synthetic Yellow

Natural Ochre

Synthetic Black Iron Oxide

Samples at 5%, 3%, 1% made with white cement

Pigment Basics

White – Titanium Dioxide

Green

- **Chromium Oxide**

Blue

- **Cobalt Oxide**

Carbon Black

Forms of Pigment

Powder

- Used by most architectural precast concrete plants

Liquid

- Used in concrete block plants
- Used in architectural/structural precast plants

Granular

- Used mostly in concrete paver plants
- Only Synthetic Iron Oxides available

Testing Requirements

ASTM C-979 Standard Specification for Integrally Colored Concrete

- Water Wettability
- Alkali Resistance
- Total Sulfates
- Water Solubility
- Atmospheric Curing Stability
- Light Resistance
- Effect on Setting of Concrete
- Air Content
- Effect on Compressive Strength of Concrete

Specifying Pigments for Architectural Precast Concrete

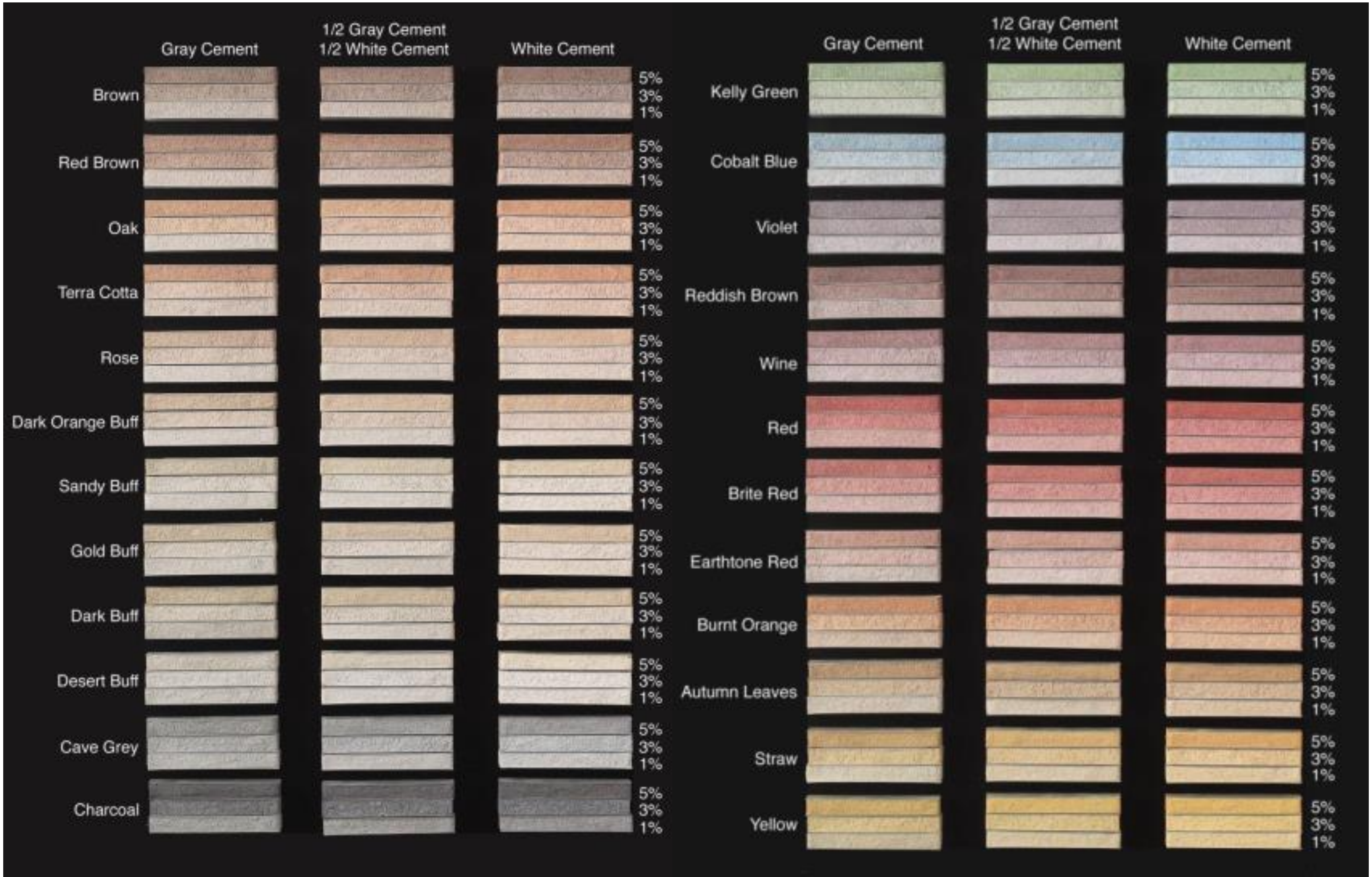
Color Samples

- PCI Color & Texture Guide, 2nd Edition

Color Additions

- No less than 1%
- No more than 5%

Specifying Pigments for Architectural Precast Concrete



Specific Issues for Producers

Don’t evaluate color in the dry state

QC issues

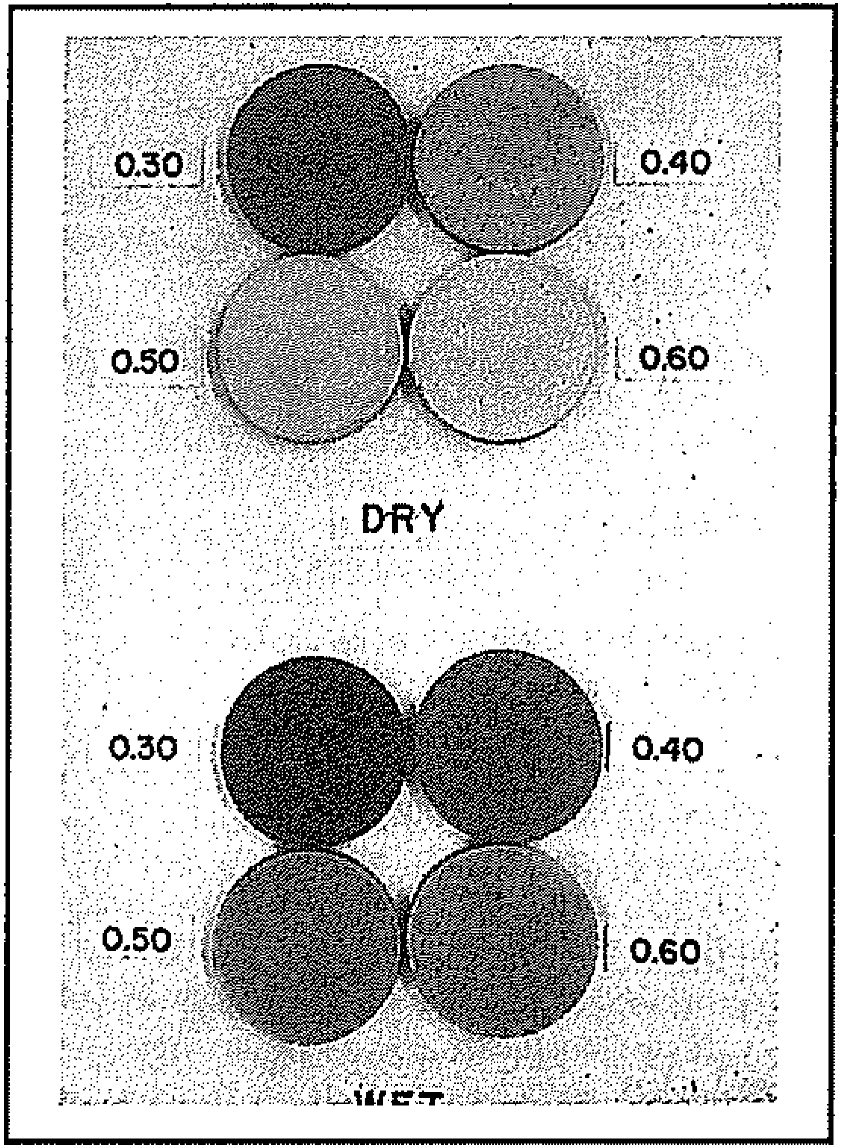
- include color number and lot number in mix design
- replace 12”x12’ samples every two years
- let samples cure at least one week
  - particularly with gray cement
  - particularly with pigments containing synthetic yellow iron oxide

Architectural Aggregate

- Gap graded aggregate is best for exposed agg finish
- Sands can be used to color a mix, but should match the colored matrix as closely as possible. This will help mask pour and mesh lines, material segregation, etc.
- Light acid wash mixes should have more sand than typical
- Aggregates need to be washed!
- Durability and Reactivity are a concern when selecting agg
- Excessive quantities of minus #200 material can affect the color of the concrete

Water Cement Ratio and Color

Comparison of the color of mature gray cement pastes both wet and dry at various water cement ratios



Architectural Mix Design

- Cement content varies with compressive strength requirement. Typically 635 to 750 pounds.
- Pigment counts as cementitious while proportioning
- Face mixes should be as impermeable as possible, max 6% absorption in 24 hours
- The cement to FA ratio should be between 1:1 and 1:3 if the mix will be exposed aggregate, so that aggregates do not dislodge.
- Heavy stone mixes should be designed with a lower slump (or VMA?)
- The optimum temperature for color consistency is 65°F to 85°F

Architectural Mix Design

Acid Etch/Sand Blast Guidelines

- CA/FA ratios should be around 60/40
- Max 3/8” coarse agg size is recommended for geometry considerations and fine form work
- Match the color of the sand to the matrix as closely as possible to hide blemishes
- Batch to batch w/c fluctuations should be minimized for color consistency
- Confirm aggregates are resistant to acid before developing mix
- Sands with close to 60% passing #30 sieve may have increased water demand and cement content

Architectural Mix Design

Exposed Aggregate Guidelines

- CA/FA ratios should be 65/35 or higher
- Washing retarder off panels at consistent maturity from panel to panel will help provide a more consistent product
- A gap graded CA provides a more consistent look
- Rounded river gravel or cubical crushed aggregates provide a more consistent exposed aggregate look than flat/elongated materials
- Masonry sands may be helpful in some cases (most particles passing No. 8 sieve) – FM of 2.4 or less.

Sample Generation

- Replace aggregate samples frequently
- Have a broad range of samples on hand to make the architect's selection process more efficient
- Replace concrete samples every few years to account for material changes
- Generate samples with architectural details if the job entails as these can change the perceived color

Sample Generation

- When making small batches for samples, ensure all of the color is thoroughly mixed into the batch. Your recipe has to be accurate for duplication purposes.
- The sample generation procedure should match the batch plant process as closely as possible to eliminate variables that can cause color differences.

Production Samples

- For acid etched or sand blasted samples, a range of varying depths should be provided for the architect to approve.
- Sample patch repairs should be provided and approved

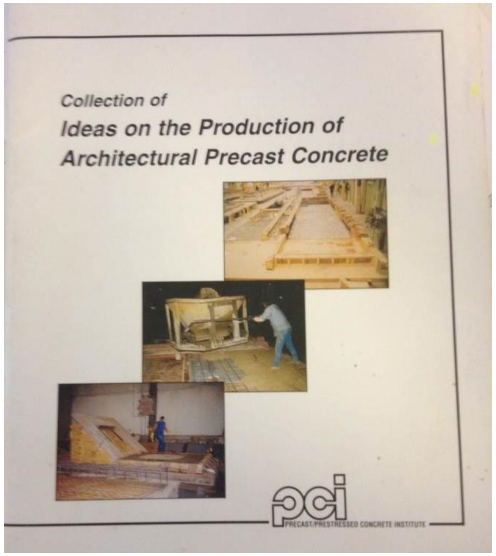
Production Samples

- Provide a top finish to the production sample to show what will be provided on the project.
- Have the architect sign the approved range for reference for the workers

References

- Collection of Ideas on the Production of Architectural Precast Concrete

  (Purchase at PCI.ORG)

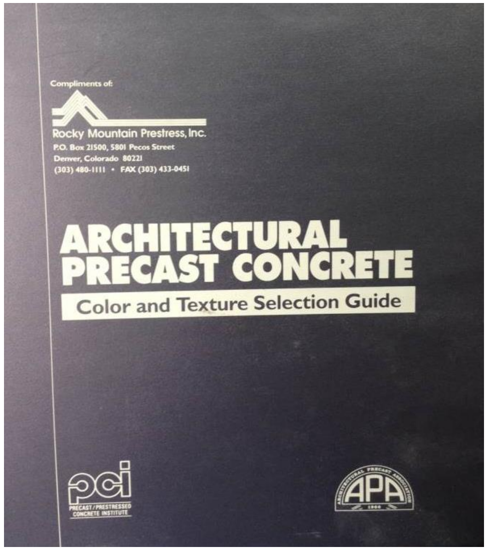


Collection of
Ideas on the Production of
Architectural Precast Concrete

pci
PRECAST/PRESTRESSED CONCRETE INSTITUTE

- Architectural Precast Concrete Color and Texture Selection Guide

www.pci.org/design_resources/color_and_texture_guide/



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P.O. Box 21500, 5801 Pecos Street
Denver, Colorado 80221
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ARCHITECTURAL PRECAST CONCRETE
Color and Texture Selection Guide

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Thank you for your time!

Questions?

QUALITY ENHANCEMENT COMMITTEE

Precast Concrete Mix Design Training

Module 4
Basic Statistics

PCI Precast/Prestressed Concrete Institute

The basic statistical methods discussed here are valuable tools for evaluating the test results of a concrete mix design. It is important that those who design precast/prestress mixes have a basic understanding of statistics and how they are used to evaluate test results.

CONTENT

Average

- The average, or Mean, is calculated by adding up all the test results and dividing that by the total number of test results.

$$\bar{X} = \Sigma X_i / n$$

where Σ is “Sum”

X_i is each individual test result

n is the total number of test results

$\bar{X}$ is Average

Average

Example:

These compressive strength results were acquired

X1 – 7200 psi
X2 – 6900 psi
X3 – 7500 psi
X4 – 7800 psi
X5 – 6850 psi
X6 – 7400 psi
X7 – 7200 psi

In this case n = 7

$\bar{X}$ = 7200+6900+7500+7800+6850+7400+7200 / 7 = 7264 psi

Range

- Range (R) is a simple measure of variability. It’s the difference between the maximum and minimum values of the results. It’s useful when a limited number of test results are available.

- From the previous results:

  Max = 7800 psi

  Min = 6850 psi

  Range = (7800 – 6850) = 950 psi

Standard Deviation

- The deviations (difference) from the average of each result are squared and summed.
- The sum is divided by one less the total number of results (n-1)
- The square root of that quantity gives the standard deviation

S = Standard Deviation

Σ = Sum

Xi = Individual Results

$\bar{X}$ = Average

n = Number of Tests

$$s = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

Standard Deviation

- Example:

Deviations $(X_i – X)$		**Deviations Squared** $(X_i – X)^2$
8350 – 8677 =	-327	106,929
8900 – 8677 =	+223	49,729
8140 – 8677 =	-537	288,369
9120 – 8677 =	+443	196,249
8850 – 8677 =	+173	29,929
8700 – 8677 =	+23	529
TOTAL		671,734

Standard Deviation

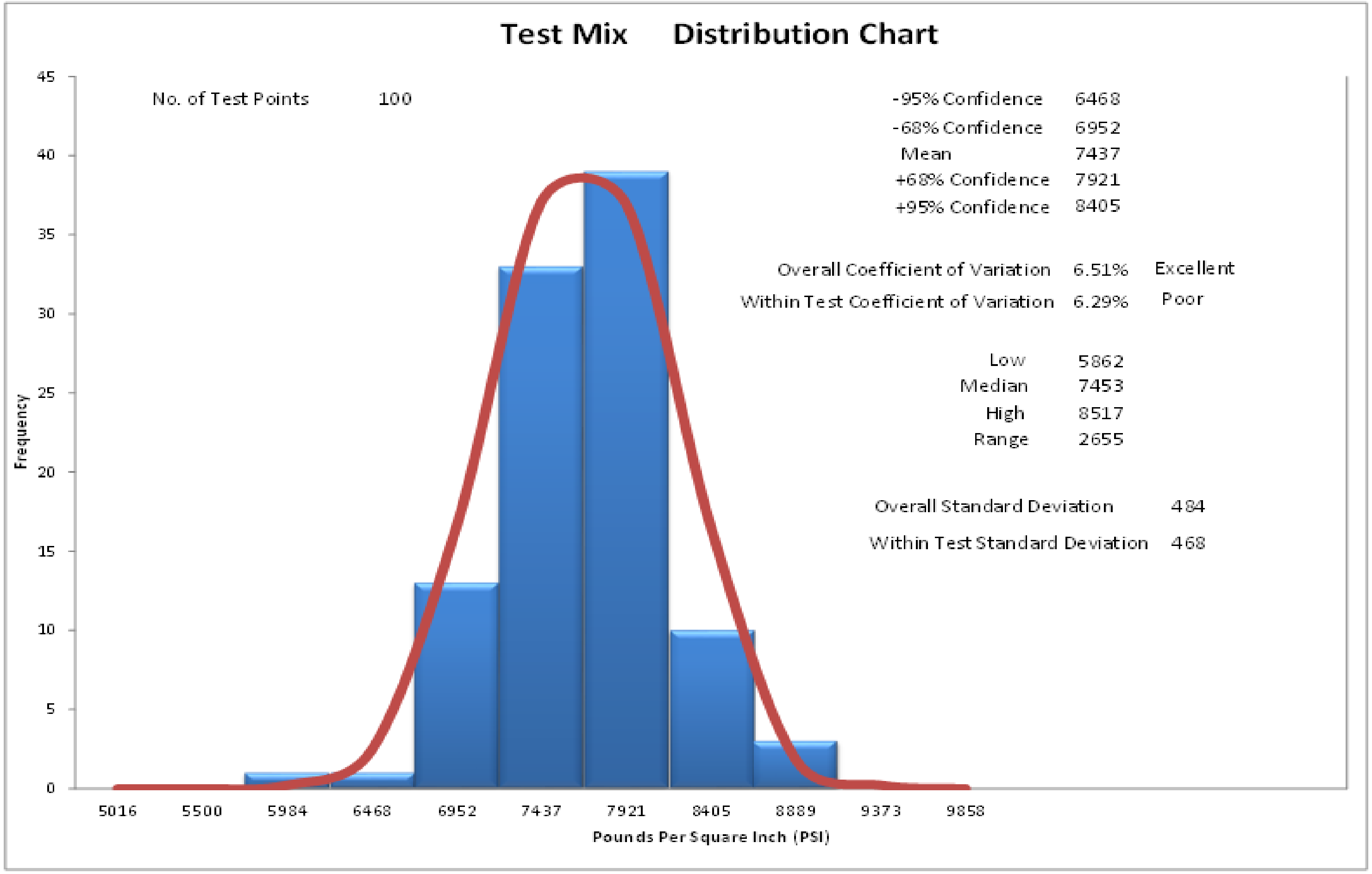
$$s = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$$

- $S = \sqrt{\frac{671{,}734}{(6 - 1)}} = \sqrt{134{,}346} = 367$

Frequency Distribution

- Frequency distribution is a helpful way to view test data to show statistical reasoning and predictions for a mix design
- It forms what is called a “Normal Distribution” curve. This curve is developed by grouping and counting concrete compressive strength data for a particular mix design
- The curve is symmetrical about the average (50% of the tests will be on either side of the average)
- The peak of the curve occurs at the average (mean) of the data
- The curve is generated from the Standard Deviation
  - The greater the spread of the curve the higher the deviation for the mix
- The area under the bell curve equals:
  - 1 standard deviation = 68.27% of the break data
  - 2 standard deviation = 95.45% of the break data

Frequency Distribution



No. of Test Points 100

-95% Confidence	6468	
-68% Confidence	6952	
Mean	7437	
+68% Confidence	7921	
+95% Confidence	8405	
Overall Coefficient of Variation	6.51%	Excellent
Within Test Coefficient of Variation	6.29%	Poor
Low	5862	
Median	7453	
High	8517	
Range	2655	
Overall Standard Deviation	484	
Within Test Standard Deviation	468	

Mix Design Approval

- The Concrete Producer as part of the submittal process must establish data to demonstrate that the mix being proposed will produce the required strength for a given project. This can be completed by the following methods:
  - Strength data from between 10-30 consecutive test points
  - Laboratory Trial batches in accordance with guidelines in ASTM C192
    - Three Point Curve Trial testing
      - Range of W/C ratio
      - Slump ± 0.75 in.
      - Air Content ± 0.5 Percent

Control of Strength per ACI 318

- ACI 318 allows revision of a concrete mix which is producing consistently overstrength tests. A sufficient number of tests to provide statistically significant data are required and as the number and reliability of the tests improve, the required safety factor or overstrength decreases. At least 15 tests (three 4x8 cylinders per test) are required and 30 is considered a standard minimum. The Standard Deviation of the results is computed. The required strength must equal the average, plus a safety factor, times the standard deviation:

Control of Strength per ACI 318

- Required Average Compressive Strength When Data are available to establish a Standard Deviation
  - $f'_c \leq 5000$
    - $f'_{cr} = f'_c + 1.34\sigma$
    - $f'_{cr} = f'_c + 2.33\sigma – 500$
  - *Use the larger value computed*

  - $f'_c > 5000$
    - $f'_{cr} = f'_c + 1.34\sigma$
    - $f'_{cr} = 0.90f'_c + 2.33\sigma$
  - *Use the larger value computed*

Control of Strength per ACI 318

Less than 15 tests available:

Specified Comp Strength f'c (psi)	Required Avg Comp Strength f'cr (psi)
Less than 3000	$f'_c + 1000$
3000 to 5000	$f'_c + 1200$
Over 5000	$1.10f'_c + 700$

For 15 or more tests available:

Number of tests	Modified Standard Deviation
15	1.16σ
20	1.08σ
25	1.03σ
30 or more	1.00σ

Evaluation and Acceptance

- When the Mix Design for a given project is approved for use and the Job has started test specimens shall be made in accordance with PCI MNL-116 guidelines
- The strengths for the mixture shall be reported and must satisfy the following two criteria before the concrete will be considered acceptable for the Project:

1. The Average of all sets of three consecutive strength tests equal or exceed the specified strength (f'_c)
2. No single strength test (average of 2 cylinders) falls below the specified strength (f'_c) by more than 500 psi if f'_c is 5000 psi or lower, or falls below f'_c by more than 10% if f'_c is greater than 5000 psi

Thank you for your time!

Questions?

QUALITY ENHANCEMENT COMMITTEE

Precast Concrete Mix Design Training

Module 5
Trouble Shooting

PCI Precast/Prestressed Concrete Institute

Common Problems

- Material Issues
- Plastic mix issues
- Strength & Strength Gain
- Cracking
- Finishing/Surface Defects
- Corrosion
- ASR
- Discoloration
- Efflorscence

A few comments on Cement…

- Cement performance is a balancing act of chemistry and physical properties – changes are made to maintain consistent setting and strength characteristics
- Even within a single source cement properties can differ
- Mill certifications represent a months average (C917 is a better indicator, may need to request that producer add this to provided data)

Cement cont.

- Blaine + 325 mesh is an important indicator of performance
- Alkali content has a big impact on early setting/strength as well as air entrainment
- Burning of waste materials in the manufacturing process can have an effect on the cement chemistry/performance – if done consistently will go un-noticed.

A few comments on SCM's…

- Chemistry of slag cements and fly ash from source to source can differ greatly.
- Greening – (function of sulfates being exposed to oxygen) it goes away with time. The stronger and denser the concrete, the longer it takes.
- Fly ash can have a impact on air entrainment.
- Silica fume will affect finishability, water demand and admixture dosages

A few thoughts on Aggregates…

- Overall play a huge role in both the plastic and hardened properties of your concrete product.
- They make up 60-80% of the volume and 70-85% of the weight.
- The use of dirty aggregates can reduce strength by 20-30%
- Watch out for materials finer then the 200 mesh – these cause the most problems (mostly water demand, strength, and air entrainment)
- Clays, pyrites, and coal can cause major problems
- Salt contamination can lead to efflorescence

Concrete Admixtures

Admixtures are the most precise part of the mix design.

The proper use of the chemical admixtures is critical for best results

Admixtures should be…

- Properly stored
- Properly combined
- Properly sequenced

Concrete Admixtures - Storage

- Exposure to external environment
  - Low / high temperatures
  - Exposure to light
- Shelf life
- Agitation
- Prevention of Contamination

Concrete Admixtures - Compatibility

Any known potential incompatibilities are spelled out on technical data sheets

- Always try to optimize your product mix to achieve desired performance
- Consult the proper type and use with your local sales representative
- **Sequencing of addition can be very important to concrete performance**

Concrete Admixtures – Sequencing/Performance

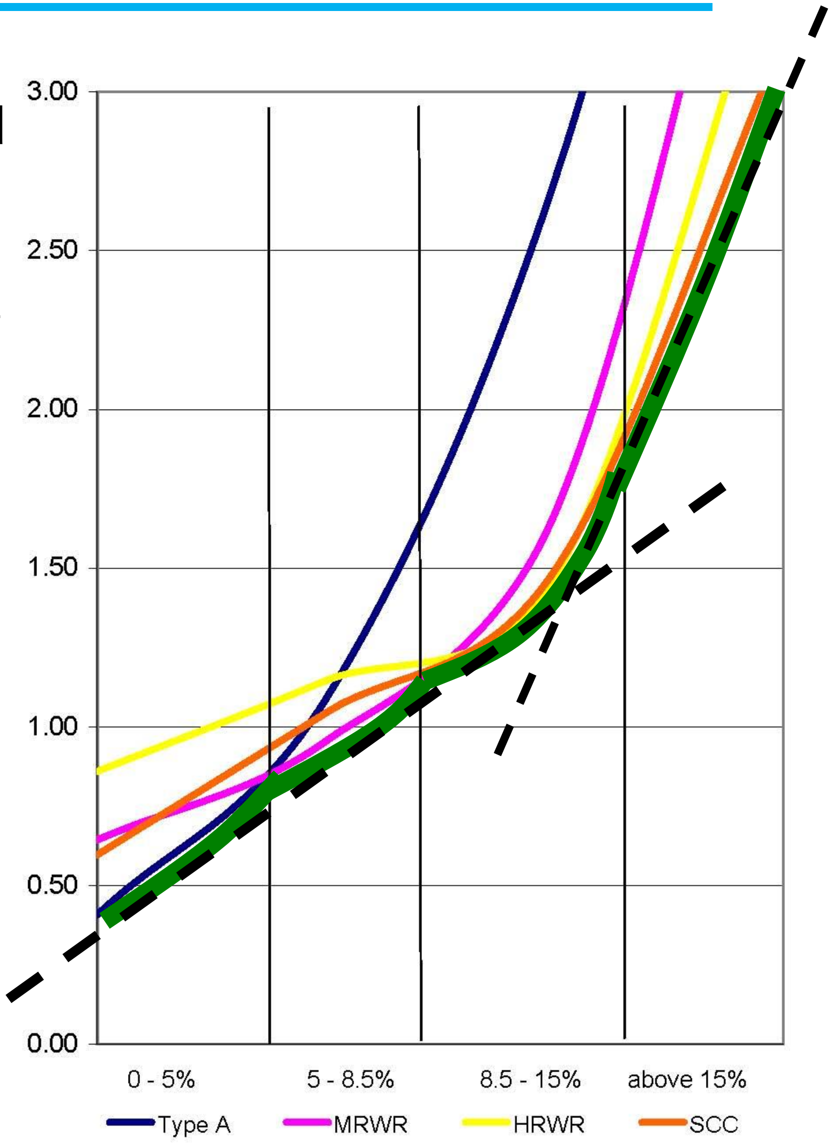
- Air entrainers – Discharge on sand stream or into water line. Should be added and mixed with fine and coarse aggregate before cementitious products are added into mixer
  - Later addition results in lower performance
- Air entrainers are highly reactive admixtures and will react with other products instantly resulting in lower performance or erratic behavior.
- Air entrainers are effected by temperatures in colder weather AEA’s are more efficient so the adjustments are needed (spring / fall)
- First batch of the day should not be considered as a bench mark and lead to immediate adjustments
- Use of hot water can effect performance and higher dosages can be necessary
- Moisture control is critical to provide consistent performance

Concrete Admixtures – Sequencing/Performance

- Water reducing admixtures should not be allowed to come into contact with dry cement
  - Typically added after cement is wet out but can also be added up front with aggregates

- Proper product selection depends on targeted application – cost / performance

- Performance is not linear



Concrete Admixtures – Sequencing/Performance

Water reducing admixtures

Up front addition vs. delayed addition

Up front

- Easier distribution throughout concrete mix
- Faster wetting
- Higher dosage
- Longer slump life

Delayed

- Lower dosage
- Higher water reduction per unit

Common Plastic Concrete Problems

- Bleeding
- Segregation
- Air Fluctuation
- Retardation
- Slump loss/fast set

Bleeding

Bleeding is the tendency for water to appear on the surface of fresh concrete and is caused by the settlement of heavier ingredients such as aggregates and cement

Slow bleed can lead to premature finishing

Excessive bleeding can reduce the quality and durability of concrete

- Poor Finish
- Low Strength
- Dusting
- Cracking

Bleeding

Causes	**Prevention**
•Coarse Sand	•Finer Sand
•Poorly Graded Sand	•Increase % Sand
•Low Air	•Air Entrainment
•Retardation	•Increase cement content
	•Flyash To Supplement Sand Fines
	•Decrease Setting Time

Segregation

- Segregation is the tendency for the coarse aggregate to separate from the mortar and is a measure of how cohesive the concrete mixture is
- Segregation can lead to non-uniform zones in the concrete, such as rock pockets or honeycombs

Segregation

Causes

Excessively Wet Mix

Over Vibration

Excessive Drop In Placing

Poor Gap Grading

Prevention

Lower Slump

Reduce Vibration

Reduce Free Drop

Increase smaller aggregate sizes

Increase fines content

Utilize a VMA

Air Fluctuations in Concrete

Causes	**Prevention**
•Cement Content/fineness/alkali	•Adjust Cement Content / Fineness/ Alkali
•Coarse Sand	•Finer Sand
•High % Coarse Aggregate	•Increase % Sand
•Flyash (LOI)	•Reduce Flyash Content
•Temperature	•Increase/decrease Conc. Temp.
•Slump	•Increase/decrease Slump
•Improper Mixing	•Check Mixer; Mix Time
•Chemical Admix	•Check For Admix Int.
•Improper Testing	•Follow ASTM Procedures
•Excessive Vibration	•Reduce Vibration

Key to controlling air is **CONSISTENCY!!!**

Materials

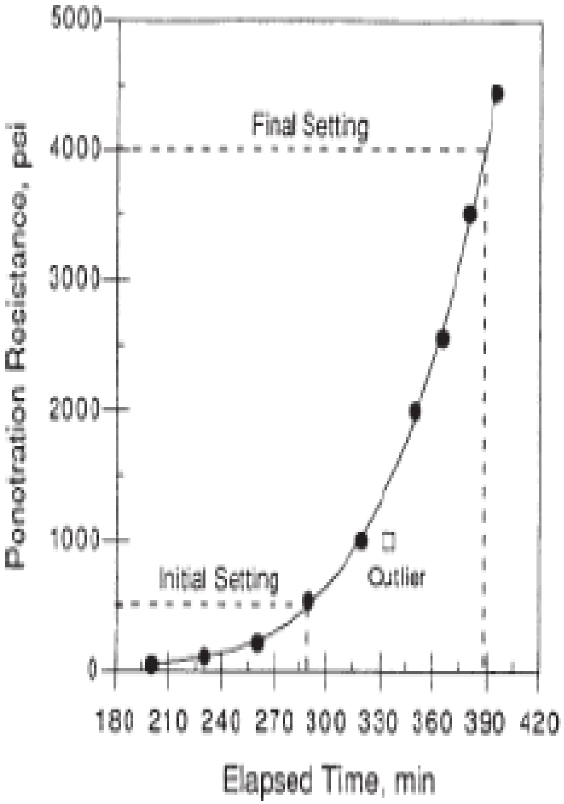
Batching

Transport

Placement & Finishing

Setting Characteristics

- Setting refers to how quickly a concrete mixture loses its fluidity and begins to stiffen from the results of hydration, the reaction between cement and water
- Gradual progression as the concrete loses slump, begins to stiffen and then begins to set
- Set control allows for transport, placement and finishing of the concrete



Retardation

Causes	**Prevention**
•Low Temperature	•Increase Concrete Temp.
•Excessive Mix Water	•Reduce Water in Concrete
•Cement Content/type	•Adjust Cement Content or Type
•Flyash	•Reduce SCM Content
•Cold Formwork	•Heat/thaw Forms
•Admix Type And Amount	•Use Additional Accelerator

Accelerated Set

Causes

- High Temperature
- Lack of Mix Water
- Cement Content/type
- Hot forms
- Admix Type And Amount

Prevention

- Decrease Concrete Temp.
- Increase Water Concrete
- Adjust Cement Content or Type
- Increase SCM Content
- Use Additional Retarder

Slump Loss

- Different from setting but can happen as a result of setting concrete
- True slump loss occurs as a function of the water reducer no longer holding cement particles apart, “wears off”.
- Slump keeping water reducer technology is now available

Hardened Concrete Problems

- Strength & Strength Gain
- Cracking
- Finishing/Surface Defects
  - Scaling
  - Delamination
  - Bug Holes
  - Blistering
  - Freezing
  - ASR
- Discoloration
- Efflorescence

Strength & Strength Gain

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Things to consider…

Only a problem for ACI if…

- Average of three cylinders falls more then 500 below f_c **AND**
- Average of three sets of consecutive cylinders falls below f_c

Testing

- Certified tester, curing method, temp of concrete
- Look at unit weight

Non/less destructive testing

- Swiss Hammer, Windsor probe

Coring

- Test for strength and look at petrographically
- Average strength of three cores need be $0.85f_c$ with no core falling below 0.75 fc for acceptance (many state DOT's do not recognize this, and require 100%)

Accepting

- Is the in place concrete structurally adequate for intended use

Cracking in the Absence of Loading

- Drying Shrinkage Cracking
- Plastic Shrinkage Cracking
- Thermal Cracking
- Crazing
- Steel Corrosion Cracks
- Alkali-Silica Reactivity

Concrete Cracks

Concrete is typically “restrained” so changes in volume result in cracks because concrete is weak in tensile

Volume changes occur due to chemical and autogenous shrinkage – both a result of hydration

- Chemical – absolute reduction in volume of solids & liquids
- Autogenous – Macroscopic volume reduction of cement paste

Drying Shrinkage Cracking

Cracking Of A Structure Due To Failure In Tension Caused By External Or Internal Restraints As Reduction In Moisture Content Develops, Or As Carbonation Occurs Or Both

Reduction in “paste” volume

CONCRETE SHRINKS 1/8” IN 20 FT

Drying Shrinkage Cracking

Causes

- Inadequate Curing
- Improper Jointing
- Form Temperature
- Reinforcing Steel Temperature

Prevention

- Protect Concrete
- Moist Cure 5-7 Days
- Joint Spacing & Depth
- Dampen/Cool Forms
- Reduce Temperature
- Fibers

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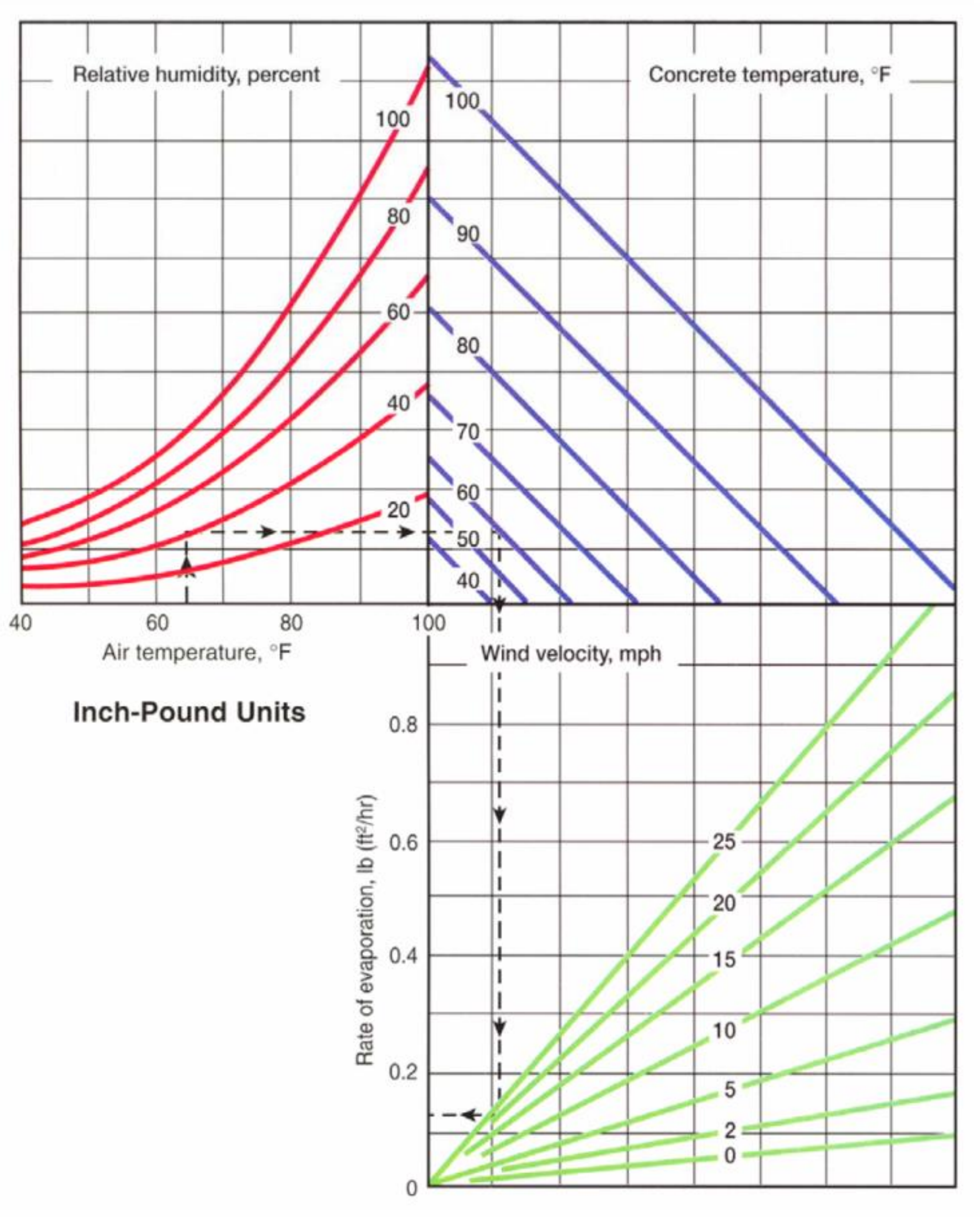
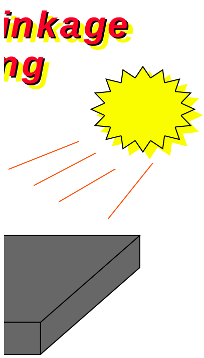


Source : Design and Control of Concrete Mixtures, 14th edition , PCA, Skokie Illinois



or formwork

Plastic Shrinkage Cracking

Causes

- Rapid Drying
- Excessive Rate Of Hydration
- High Slump/bleeding
- Wind
- Low Humidity
- Dry Subgrade
- Premature Finishing

Prevention

- Protect Concrete/moist Cure
- Lower Conc. Temp/Dampen Agg.
- Reduce Slump
- Erect Wind Shades
- Misting/fogging
- Dampen Forms
- Proper Finishing Techniques
- Fibers

Thermal Cracking

Cracking due to temperature differences within a concrete structure resulting in differential volume changes. As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. This causes tensile stresses that may result in thermal cracks at the surface if the temperature differential between the surface and center is too great.

Thermal Cracking

Causes

- Temperature Differentials
- Excessive Heat Of Hydration
- Ambient Temperature Variations

Prevention

- Reduce Concrete Temperature
- Delay Cooling
- Control Cooling/ Heating Rate
- Utilize SCM's
- Increase Tensile PSI

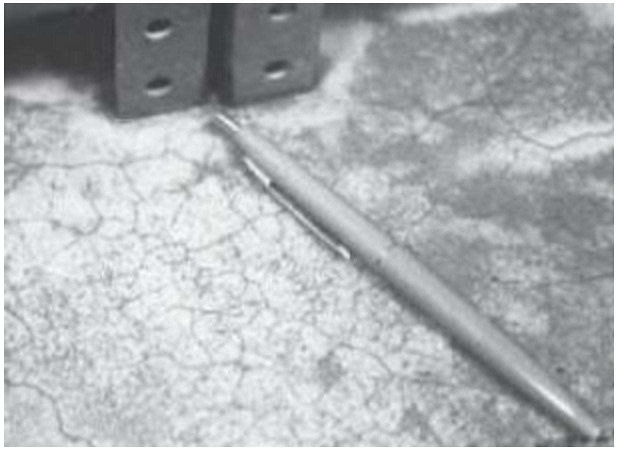
Crazing

The development of a network of fine random cracks on the surface of concrete (no deeper then 1/8”)

Typically irregular hexagonal areas

Appear at a very early age

Cosmetic Only



Crazing

Causes

- Excessive Finishing
- Finishing with bleed water
- Sprinkling cement on surface to control bleed
- Overly Wet Mixes
- Weather Conditions
- **Improper Curing**

Prevention

- Finish at the proper time
- Cure Concrete
- Use moderate w/c to reduce bleed
- Use wind barriers or evaporation reducers

Alkali Silica Reaction (ASR)

- As good aggregates become more and more scarce ASR is going to become a bigger issue.
- Many areas of the US currently have major issues with ASR.

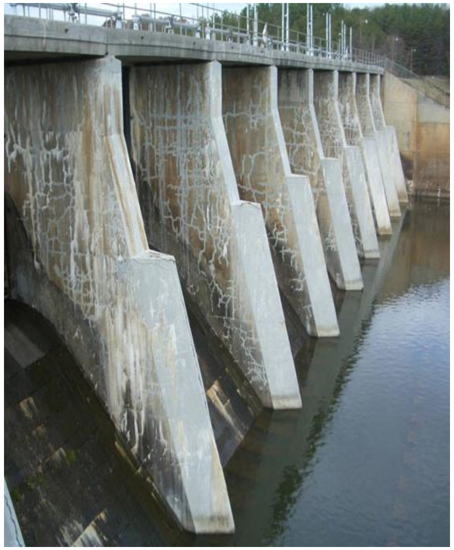
Alkali’s (Na, K from Cement) + Reactive Silica (Aggregates) → ASR Gel

ASR Gel + Moisture → Expansive ASR Gel

↓

Cracks Concrete

Prevention of ASR



Use low alkali cement

Use of low w/c, impermeable concrete

Use supplementary cementitious materials

  - Slag
  - Fly Ash
  - Silica Fume

Use a Lithium Nitrate

  - Dosage varies based on other mix materials

Steel Corrosion Cracks

Cause

Disruptive expansion caused by rusting of steel reinforcement, (rust expands up to 4 times its original volume)

Prevention

- Reduce concrete permeability
  - Low w/c
  - SCM
- Use of corrosion inhibiting admixture
- Surface treatments
- Cathodic Protection
- Epoxy Coded Rebar

Surface Defects

- Delamination
- Freezing
- Bug Holes
- Discoloration

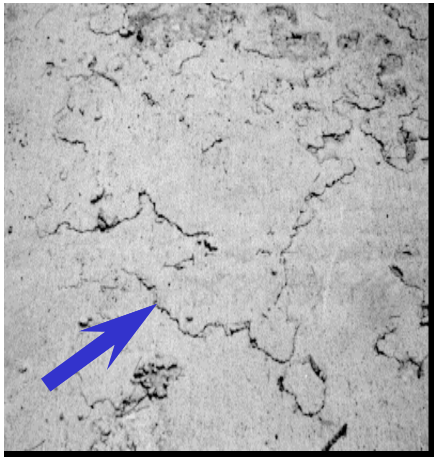
Delamination

Causes

- Premature Sealing of the Concrete Surface
- Rapid Evaporation of Bleed Water
- High Percentage of Entrained Air

Prevention

- Insure proper air content
- Accelerator or heated concrete
- Delay finishing



Bug Holes

Causes

- Mix proportioning
- Stiff mix
- Improper/lack of vibration
- Over application of form release
- High Air
- Sand with low fines

Prevention

- Redesign mix (increase fines)
- Use SCC
- Apply form release properly
- Use a VMA
- Insure proper vibration

Bugholes

For high cement content concretes, coarsely graded sands may be satisfactory because the cement helps provide the needed fines for workability, but with low cement content concretes, the fine aggregate particles are necessary for good workable mixtures.

Best FM for SCC? - 2.50 – 2.70?

Bugholes can be decreased by providing a sufficient quantity of fine aggregate with high surface area (minus No.8 sieve). Larger amounts of sand are not as effective as finer sand.

In richer mixes, coarsely graded sands provide a void-filling effect while minimizing the water demand.

Changing the cement content of a mixture by 94lbs. Generally has the same effect on workability as changing the minus No.8 fraction of the combined aggregate by 2.5%

Discoloration

Factors that affect color

- Cementitious materials
- Aggregates
- Admixtures
- Water content
- Batching
- Curing
- Finish/Surface texture
- Efflorescence

Every mix component as well as other outside influences!!

Discoloration

- Variation in materials, dosing, finishing and curing are the main causes for discoloration
- Key to uniform color is consistency in the entire process….materials → plastic concrete transport

Efflorescence

A deposit of salts, usually white, formed on a surface, the substance having emerged in solution from within either concrete or masonry and subsequently been precipitated by reaction, such as carbonation, or evaporation." ACI 116R

Conditions for Efflorescence

- There must be soluble salts available.
- There must be a source of water that is in contact with the salts, forming a salt solution.
- There must be a pathway for the salt solution to migrate to the surface and evaporate.

All three of these conditions must exist for efflorescence to occur.

Prevention of Efflorescence

Mix Design

- Low alkali cement, use SCM, low(er) w/c, well graded aggregate, use efflorescence controlling admixture

Curing

- Insure strength and density before subject to weathering

Storage

- Protect from extraneous water for as long as possible
- Good air circulation around pieces

Post applied sealer

Questions?

What's next for the
QUALITY ENHANCEMENT COMMITTEE

Exceptional Precast Practices
Continuous improvement in best practices

"Quality Summit"

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