Cementitious Materials and Concrete Design

Glenn Schaefer
March 9, 2021

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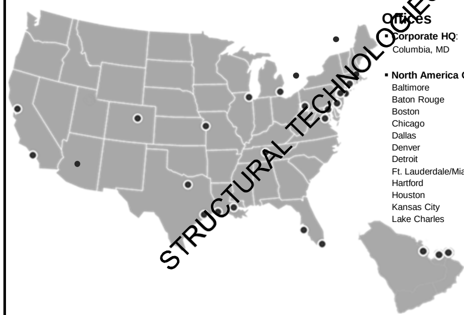

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Glenn Schaefer

- Joined STRUCTURAL TECHNOLOGIES 5+ years ago
  - Director of Concrete Durability & Concrete SME
- Prior Experience (25+ years cement & concrete)
  - W.R. Grace (Admixtures) – *Now GCP Applied Technologies*
    - R&D / Technology
    - Technical Service
    - Product Management
  - Consulting Engineering Firm - Concrete Durability and Materials / Assessments
  - CEMEX (US)

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Objectives

- Concrete is complex
- Materials that go into concrete influence performance
- Concepts related to materials selection and concrete design
  - Cement vs. Pozzolans – Why use SCM?
  - Admixtures – What do they do?
  - Cracking Potential Reduction – How to influence?

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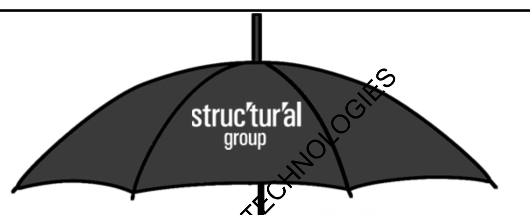

Investigation & Analysis	Engineering	Products / Systems
Offline Condition Assessment; Online Condition Assessment; Field / Lab Testing; Durability Modeling	Civil / Structural; Construction Engineering; Quality Control Design	Concrete Repair; Structural Strengthening; Seismic Upgrade; Hydrodemolition; Corrosion Control; Moisture Control

Specialty Contracting

- Repair, strengthening & protection of civil / structural infrastructure

Making Structures Stronger and Last Longer

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Concrete

- Relatively economic building material
- Raw materials are available locally
- Cast into any shape; texture; color
- Strong enough (at the right time)
- Durable enough (for service exposure)

Challenge: To make uniform, high quality, high performing concrete

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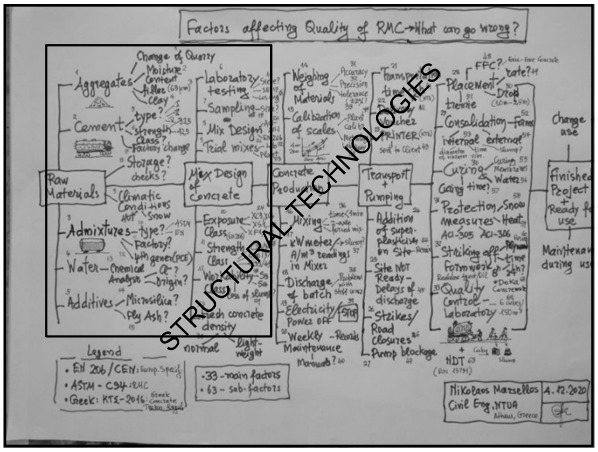

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Cement = Lime (60%) + Silica (20%) + Alumina (10%) + Iron (10%) melted in a kiln

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A “Typical” Cubic Yard of Concrete

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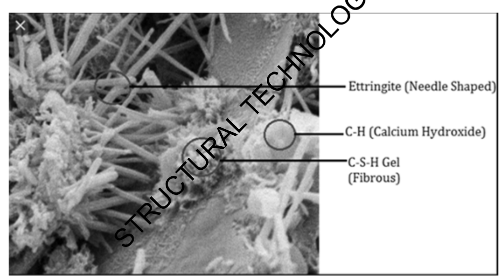
Cement Hydration

- Chemical Reaction



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Cement
vs
Pozzolans
Supplementary Cementitious Materials (SCM)

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Cement Hydration

- Chemical Reaction

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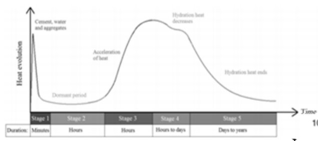
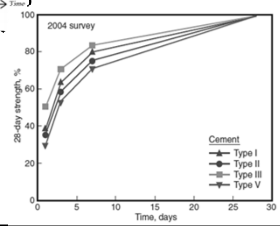
Cement





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Portland Cement Summary

- Understood but Generic – "Tried and True"
  - Hydration leaves inherent porosity
  - Under certain conditions (mass concrete) temperature rise can be an issue
  - ASR & Sulfate attack issue
  - Some environmental "baggage"


A.D. 1824 . . . . N° 5022.

Artificial Stone.

ASPDIN'S SPECIFICATION.

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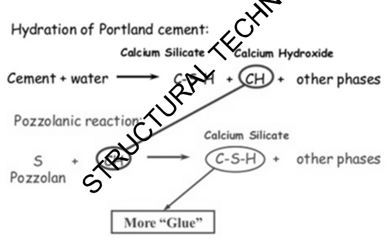
Pozzolans (aka **S**upplemental **C**ementitious **M**aterial)

Possess little or no cementitious value but which will, in finely divided form, react chemically with calcium hydroxide in the presence of water.



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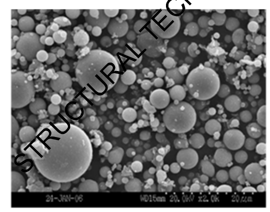
Common Pozzolans

Fly Ash

- Waste Product of Coal Fired Power Plant
- Spherical Particles / Same size range as cement
- 15-30% cement replacement



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Common Pozzolans

GGBFS / Ground Granulated Blast-Furnace Slag "Cement" = Slag

- By-Products of Iron Blast Furnace
- Angular Particles / similar particle size range as cement
- 35% cement replacement up to 80% in special applications
- Some cementitious properties

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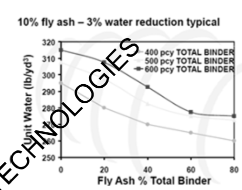
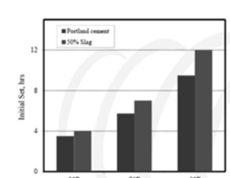
Fly Ash & Slag

Plastic Properties:

- Water Demand Reduction
  - Ball-bearing effect w/Fly Ash



- Reduction in bleeding
  - More pronounced with Fly Ash
- Retarding Effect on Set Time



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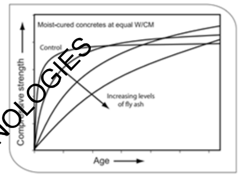
Fly Ash & Slag

Hardened Properties:
- Later Age Strength Enhancement
- Heat of Hydration Reduction
  - Peak temperatures reduced
- Improves Permeability – Durability
  - Pozzolanic Reaction
- Can help control ASR and Sulfate Resistance
  - "Prove" effectiveness of mitigation via testing



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Common Pozzolans

Microsilica = Silica Fume
- Byproduct of production of silicon metals – Electric arc furnaces
- 100x smaller than cement and round particles
- 5%-10% cement replacement

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Silica Fume

- Abrasion Resistance
- Chemical Attack Resistance
- **Water demand - significantly higher – Must have HRWR**
- "Sticky" finishing
- Significant reduction in bleeding
- **Dramatically decreases permeability / Densifier**
- Darkens Color of Concrete

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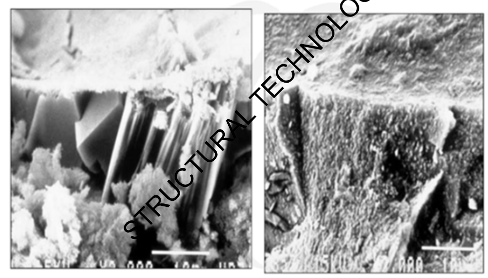
Silica Fume

Portland Cement Concrete With Silica Fume



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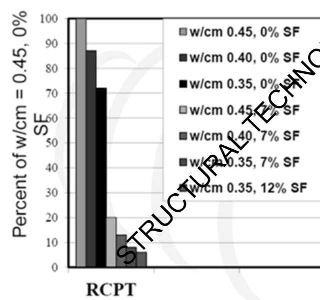
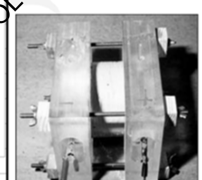
Silica Fume – Low Permeability





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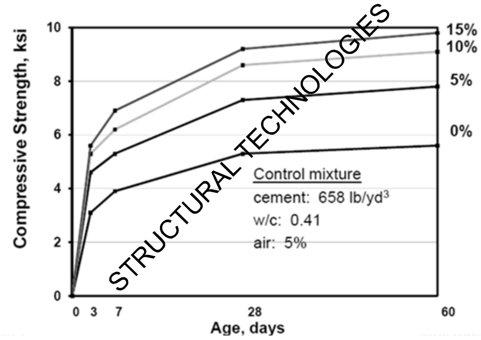
Silica Fume – Compressive Strength



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Cement vs Pozzolan Summary

- SCMs are used in at least the majority of Concrete today
- Pozzolans enhance hardened concrete performance
  - Some accompany changes to Plastic Properties
- Enhanced strengths (particularly later ages)
- Reductions in Permeability
  - Corrosion resistance improvement
  - Enhanced Durability
  - Sulfate & Chemical Attack Resistance
- Control of ASR

Higher Performance Concretes used regularly (non-sidewalks/driveways) impossible without Pozzolans

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Concrete Admixtures

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Admixture Definition

- A material other than water, aggregates, cementitious materials, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing.
- Chemicals react with cementitious materials or paste during hydration
- Highly Technical Products
  - ≈ $18 Billion Market (Globally)
- Dominated by Grace (GCP), Sika, BASF (MasterBuilders)
  - RPM International (Euclid), Fosroc, Mapei, Chryso, and others

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Why Use Admixtures

- Enhance plastic and hardened concrete properties
  - Increase Strength
  - Improve Mix Workability
  - Improve Early Strengths
  - Control Set Time
  - Reduce Permeability
  - Control Efflorescence
  - Improve Color Vibrancy
  - Meet Durability Requirements
  - Control Shrinkage
  - Improve mix economics

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Admixture Types by ASTM Specification

- ASTM C260 - Air Entraining Admixtures
- ASTM C494 - Chemical Admixtures
  - Type A: Water Reducing Admixtures
  - Type B: Retarding Admixtures
  - Type C: Accelerating Admixtures
  - Type D: Water Reducing, Retarding Admixtures
  - Type E: Water Reducing, Accelerating Admixtures
  - Type F: High Range Water Reducing Admixtures, Normal Set
  - Type G: High Range Water Reducing Admixtures, Retarded Set
  - Type S: Specific Performance
    - Corrosion Inhibitors, Shrinkage reducers, Alkali-silica reactivity inhibitors, color, AWA, etc.

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ASTM C494 Admixtures

- Type A: Water Reducing Admixtures
- Type B: Retarding Admixtures
- Type C: Accelerating Admixtures
- Type D: Water Reducing, Retarding Admixtures
- Type E: Water Reducing, Accelerating Admixtures
- Type F: High Range Water Reducing Admixtures, Normal Set
- Type G: High Range Water Reducing Admixtures, Retarded Set
- Type S: Specific Performance

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Groups

- Set Time Modification
  - Retard/Slow Down in hot weather
  - Accelerate/Speed Up in cold weather
- Water Reducing = Slump Enhancing
  - Normal ≈5%
  - High Range / Superplastizer: 12% - 25%
- "Other" category

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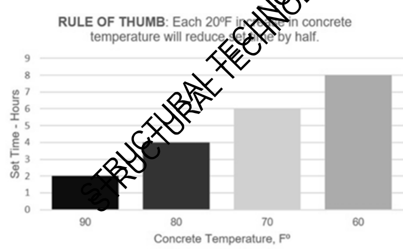
Set Time Modifiers

- Cement Hydration is a chemical reaction
  - Speeds up with heat / slows down in cold



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Set Time Modifiers

- Correct for temperature difference
  - Accelerators used in cold weather to get "neutral" set
  - Retarders used in hot weather to get "neutral" set
- Fine Tune Set Time
  - Accelerators to speed up set times (and strength gain)
    - Application of loads (shoring removal)
    - Form work stripping
  - Retarders for slump retention
    - Difficult placement conditions
    - Cold Joint Elimination

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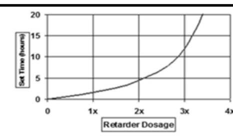
Cautions



Retardation is not linear

- Overdose
- Longer set times provide more opportunity for moisture loss in the plastic state - higher potential for plastic shrinkage cracking.
  - Increased need for protection against moisture loss.
  - fog misting
  - evaporation retarders
  - plastic sheeting
  - shades and wind breaks

Accelerators

- Early age strength gain can impact later age strengths
- With Acceleration comes slump loss/workability issues
- Not an "anti-freeze"

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Water Reducers

- Two "classes"/types
  - Standard – 5% - 10% water reduction
  - High-Range (Superplasticizer) – 12% -25%
  - Both have neutral set and retarding variation
- Allow for "reduction" in water (lower w/c ratio) while maintaining workability.
  - w/c ratio specifications
  - Compressive strength
- Allow for increase in workability at a given water (w/c ratio) content
  - Placeability

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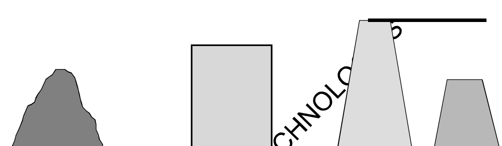

Cement = 500 lbs. Water = 300 lbs. Slump = 5 in.

$$\frac{\text{Water}}{\text{Cement}} \quad \frac{300 \text{ lbs.}}{500 \text{ lbs.}} = 0.60$$

Strength = 3500 psi

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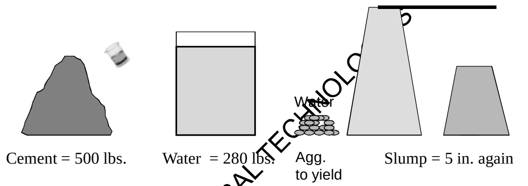

$$\frac{\text{Water}}{\text{Cement}} \quad \frac{280 \text{ lbs.}}{500 \text{ lbs.}} = 0.56$$

Strength = 4000+ psi

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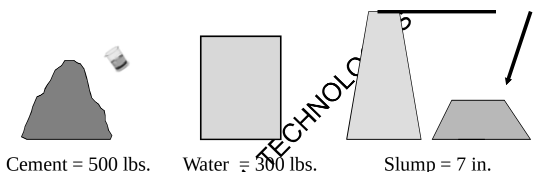

$$\frac{\text{Water}}{\text{Cement}} \quad \frac{300 \text{ lbs.}}{500 \text{ lbs.}} = 0.60$$

Strength = 3500 psi +

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Components of Water Reducers

- Dispersants for water reduction/workability
- Accelerators to keep setting time within limits
  - some don't accelerate, but reduce retardation
- Retarders for slump loss control
- Strength enhancers for early strength
- Viscosity Modifier for stability
- Air Management Package
- Other Chemical for specific attributes
- Many components have multiple effects
- All may act differently as cement, temperatures vary

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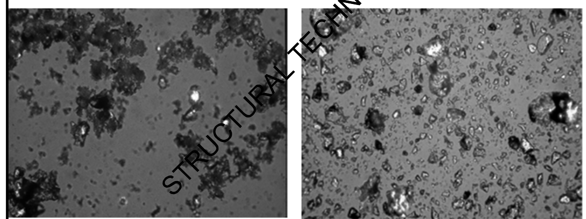
How do water reducers work

- Dispersants – break up particles agglomerates



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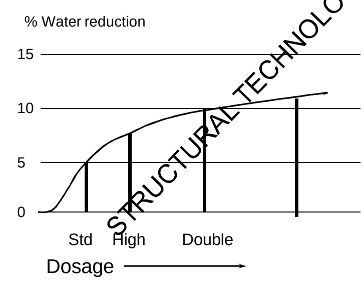
Water Reducer Addition Rates



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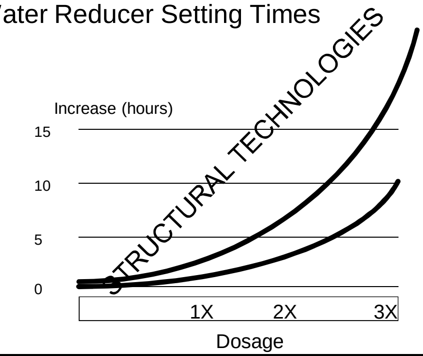
Water Reducer Setting Times



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Other "admixture" products

- Corrosion Inhibition
  - Inhibits the corrosive action of chlorides on reinforcing steel (passive film) - increases the corrosion threshold.
- Viscosity Modification
  - Thicken concrete paste (thixotropy) for SCC or Underwater concreting
- Shrinkage Reducing
  - Change surface tension of water as concrete dries

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Other "admixture" products

- Shrinkage Compensating
  - Expansion to offset shrinkage (net zero).
- ASR Mitigating
  - When pozzolans aren't available, Lithium Nitrate minimizes the expansion associated with ASR reaction
- Permeability Reducing
  - Clogs inherent porosity of paste – chemical compounds or crystallize
- Fibers – Low dosage of synthetic fiber to minimize early age shrinkage cracking by providing tensile strength

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Admixture Summary

- Many Chemistries all generally trying to accomplish dispersion or hydration rate modification
- Product Selection and Dosage Rates depend on many factors
  - Near impossible to "guess" an appropriate product/dosage for a given concrete
- "Side effects" to the intended purpose must be considered
  - Water Reduction usually has a retarding effect
  - Acceleration has slump and strength impacts
- Nearly all higher performance concretes can't be produced without admixtures (usually in combination)

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Cracking Potential Reduction

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Cracking

- Concrete is simply synthetic sedimentary rock. Just as rocks crack in nature, concrete (synthetic rock) will crack as well."
  Bryant Mather
- "What [concrete]....is free of cracks or micro-cracks? I have not seen any in 65 years of concrete work in all kinds of structures. Cracking seems to be a universal characteristic of concrete."
  Ed Abdun-Nur
- ACI 224R-01 notes in its opening section "Cracking due to drying shrinkage can never be eliminated in most structures."

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Fundamental Challenge

- Concrete is very strong in compression
  - 28-day compressive strength can range from about 3000 psi to over 10,000 psi
- Weak in tension
  - Tensile capacity is about 10% of its compressive strength
- When Tensile Stresses exceed Tensile Strength
  - Cracks

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Sources of Tension in Concrete

- External or "Structural" Sources
  - Gravity loads: dead and live loads
  - Lateral loads: wind and seismic
  - Loads from subgrade settlement or swelling
- "Internal" Mechanisms
  - Volume change restraint due to temperature changes or moisture related shrinkage
  - Expansion due to corrosion of reinforcing steel or deleterious chemical reactions

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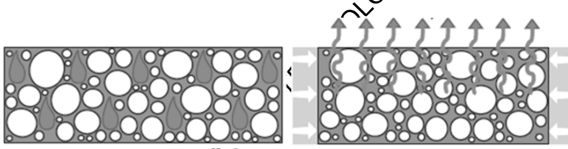
Shrinkage = Moisture Loss



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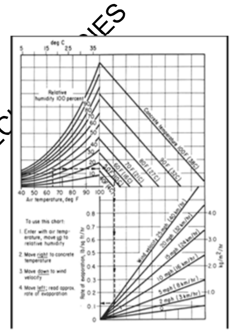
Control of Moisture Loss

- Concrete and air temperature
- Relative humidity
- Wind velocity



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Curing

- Wet Curing (adds water to system)
  - Ponding
  - Fogging Misting
  - Wet Coverings
    - Burlap
- Impermeable Membrane Curing (prevents water from leaving system)
  - Plastic
  - Formwork
  - "Curing Compound"

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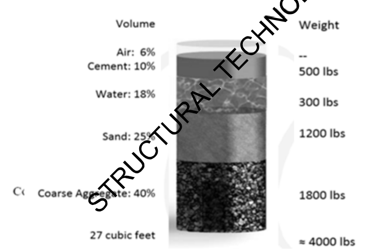
Control of Shrinkage

- Material selection and Mix design plays a role



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Minimizing Portions that Shrink

- Rocks volumetrically stable (**do not** shrink)
- Paste (water + cementitious) **does** shrink

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Paste Optimization

- Inevitably involves trade-offs
- Minimize Paste (Glue = Cement + Water)
- Maximize aggregate content (sand and stone)
- Optimize Aggregate "packing“

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Paste Optimization

- Inevitably involves trade-offs
- Minimize Paste (Glue = Cement + Water)
  - >28% paste is more prone to cracking
  - Low water content (≈decreased w/c ratio)
  - Use of Pozzolans
- Maximize aggregate content (sand and stone)
  - Workability/placeability (texture, roundness)
  - Aggregate size limits (form spacing, rebar)
  - Aggregate availability
- Optimize Aggregate "packing“
  - Minimizing the void space that must be filled

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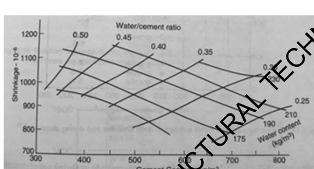
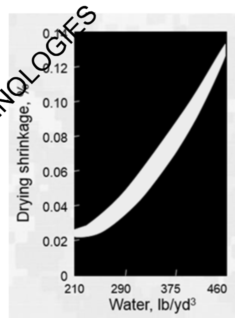
Minimizing Paste





After PCA (2002)

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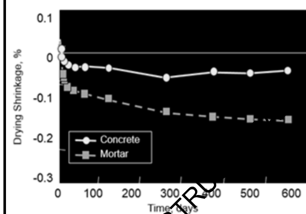
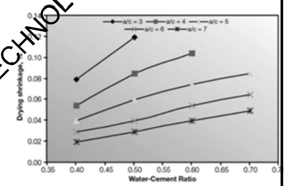
Aggregate Addition





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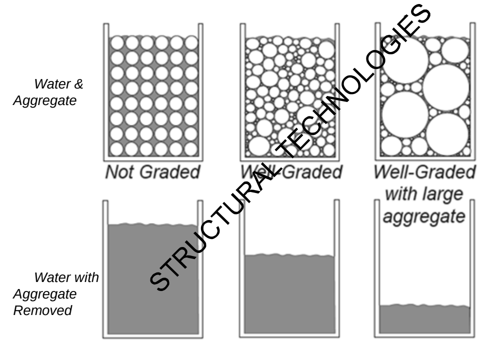
Aggregates



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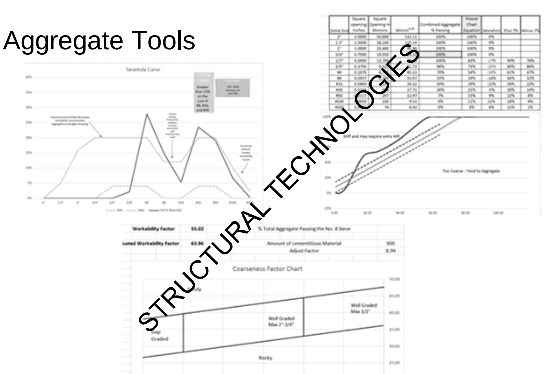
Aggregate Tools



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Cracking Potential Reduction Summary

- Many factors beyond direct control (i.e humidity)
- Minimize Paste / Maximize Aggregates but need to balance against
  - Workability/placeability (texture, roundness)
  - Aggregate size limits (form spacing, rebar) and availability
  - Gradation is key to minimizing void space that must be filled with paste
- Shrinkage is rarely reported in a mix design supporting data
- Admixture options and fibers

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Questions / Comments

Thank You

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