Concretes for pavements and bridge decks: A Primer

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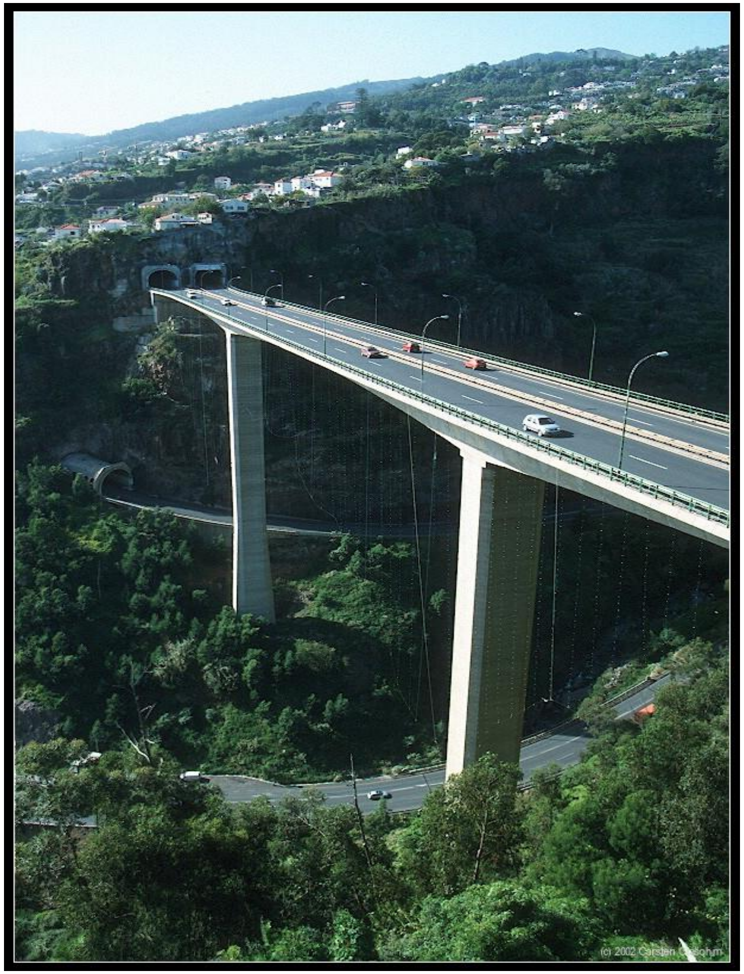
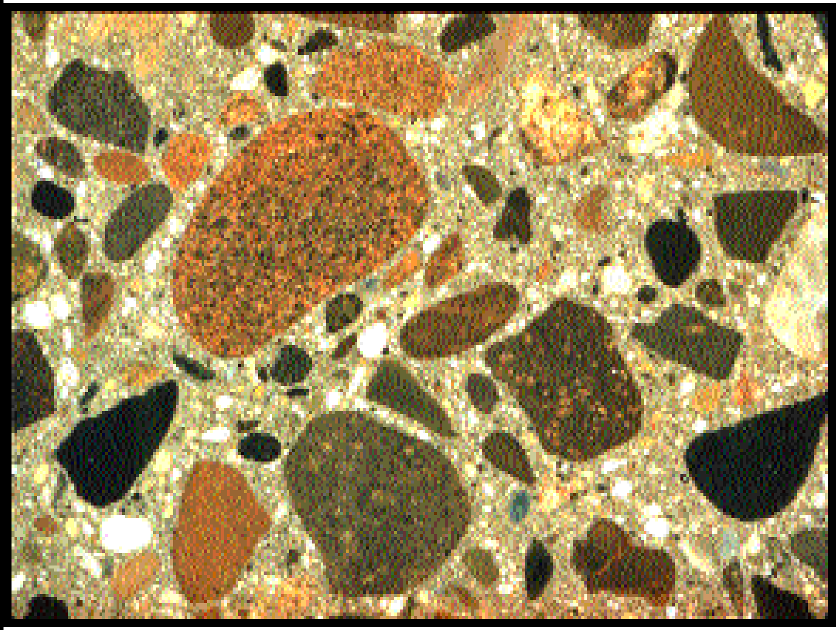
Structural Concretes



What is CONCRETE ?

- From the Latin word “Concretus”
- Means : To hold together or grow together
- It is a “Formable Rock”
- A composite material – Binder(s) + Filler (s)

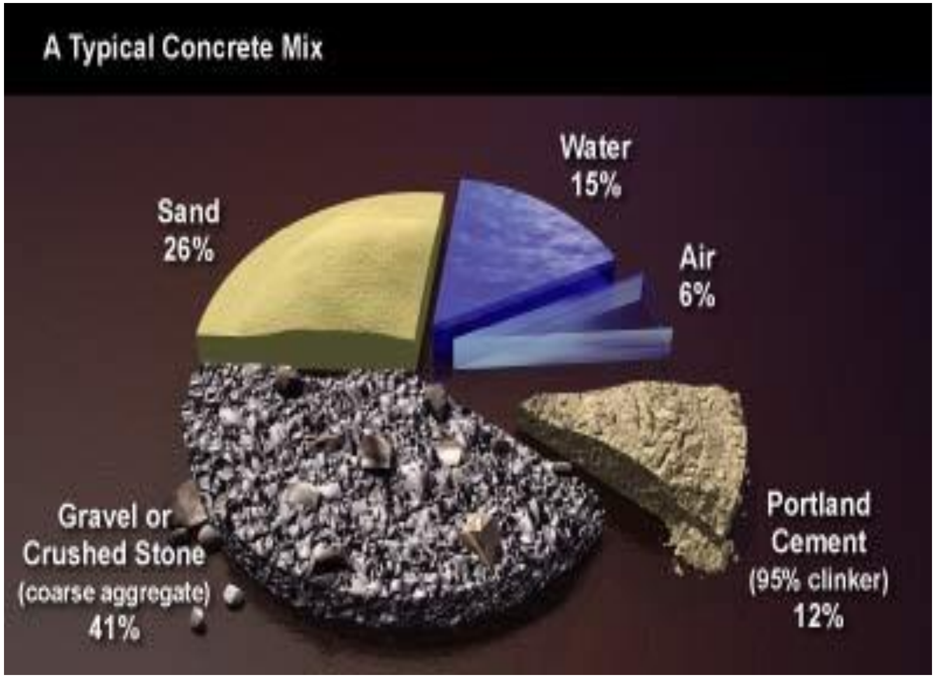


Scale of concrete use

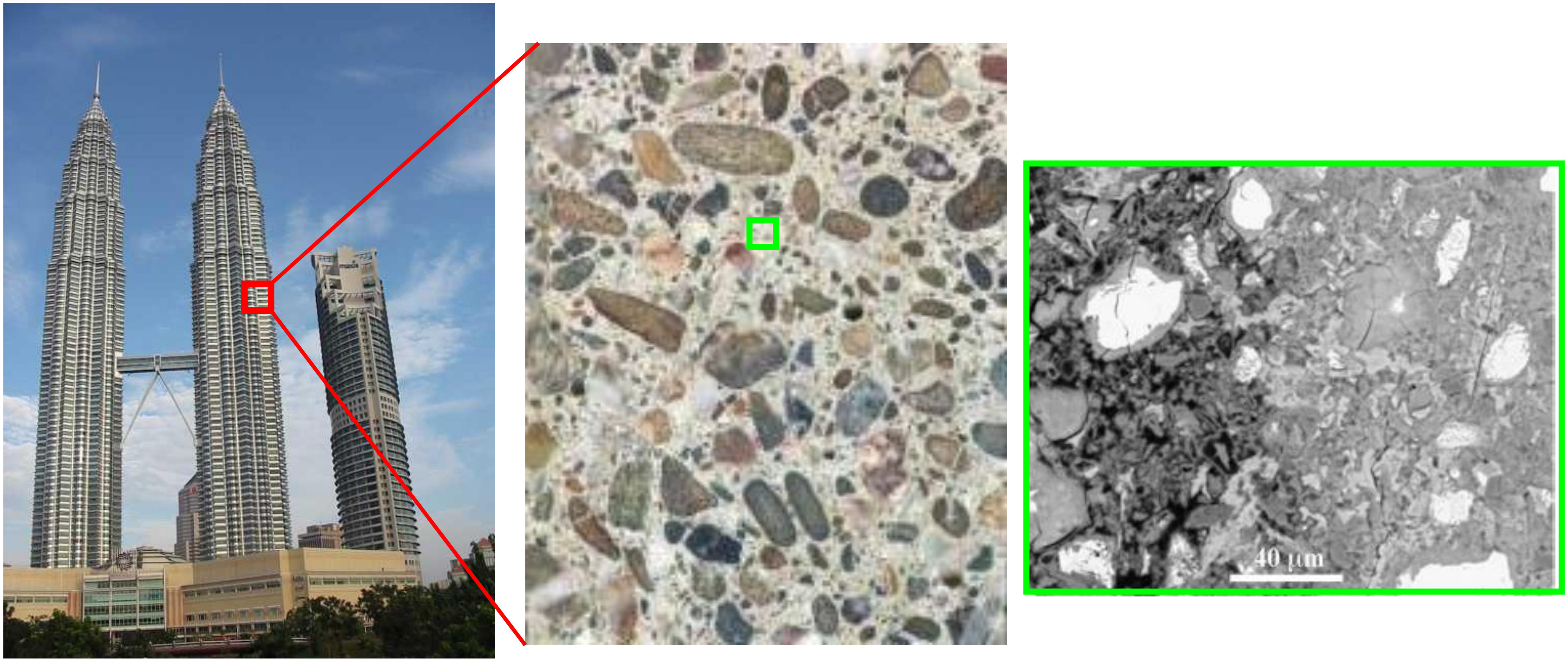
- Present consumption of concrete of the order of 12 billion tons every year
- Humans consume no material except water in such tremendous quantities

Raw material usage in concrete

- Normal concrete: 12-15 percent cement, 8-10 percent mixing water, 70-80 percent aggregate by mass.
  - 1.5-2 billion tonnes of cement, 9-12 billion tonnes of sand and rock together with one billion tonne of mixing water
- 12 billion tonne concrete industry is the largest user of natural resources

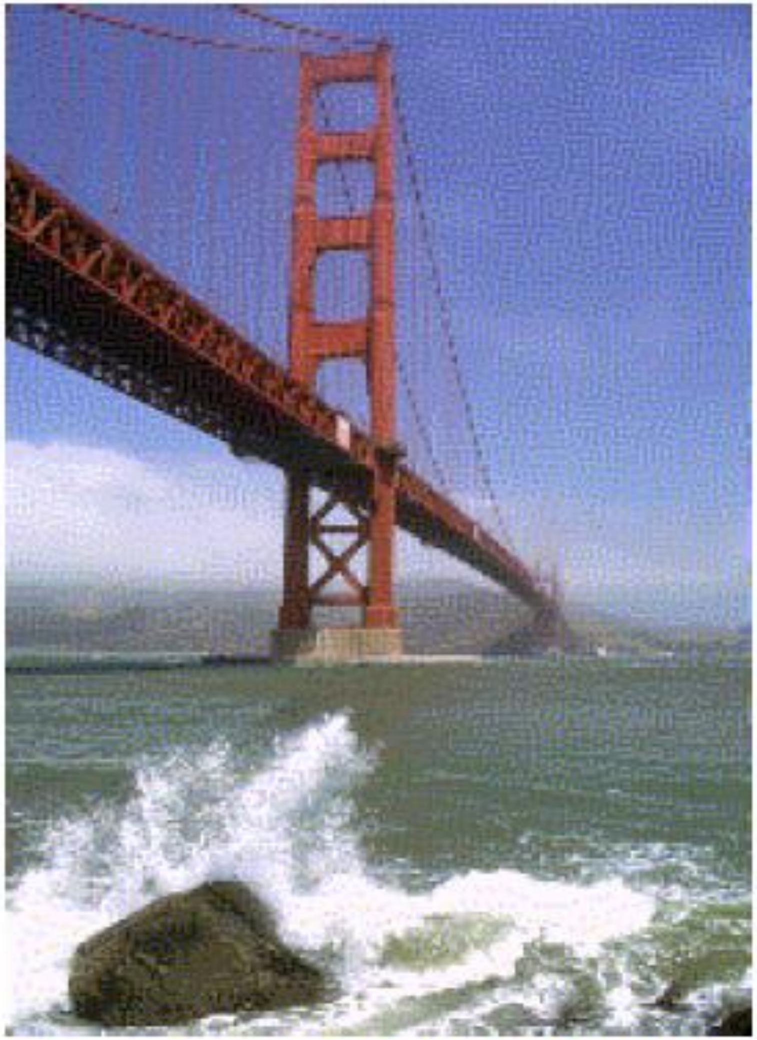


Size scales in concrete



Macroscale **Mesoscale** **Microscale**

Bridges – Large concrete consumers



Concrete Pavements

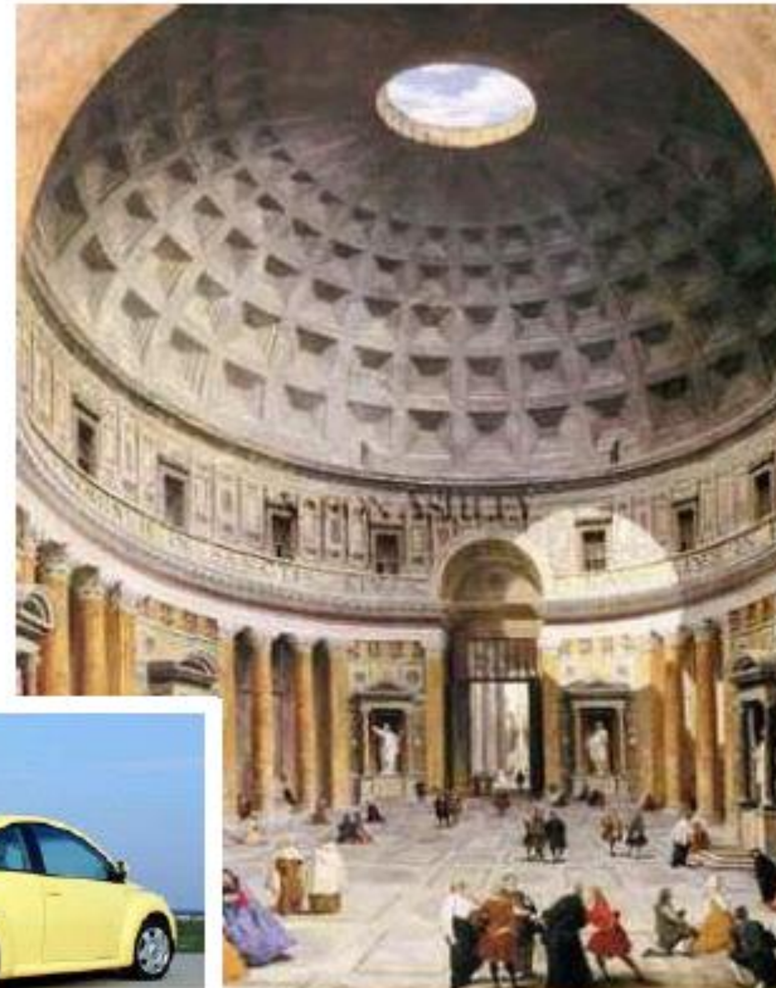
Early Concrete Uses

- 1 mile long Michigan rural concrete road - 1909

Roman Use of Concrete

- Romans - arches

Designs placed 'Concrete' Mainly in Compression (Coliseum, Pantheon)



Precast, Prestressed Concrete

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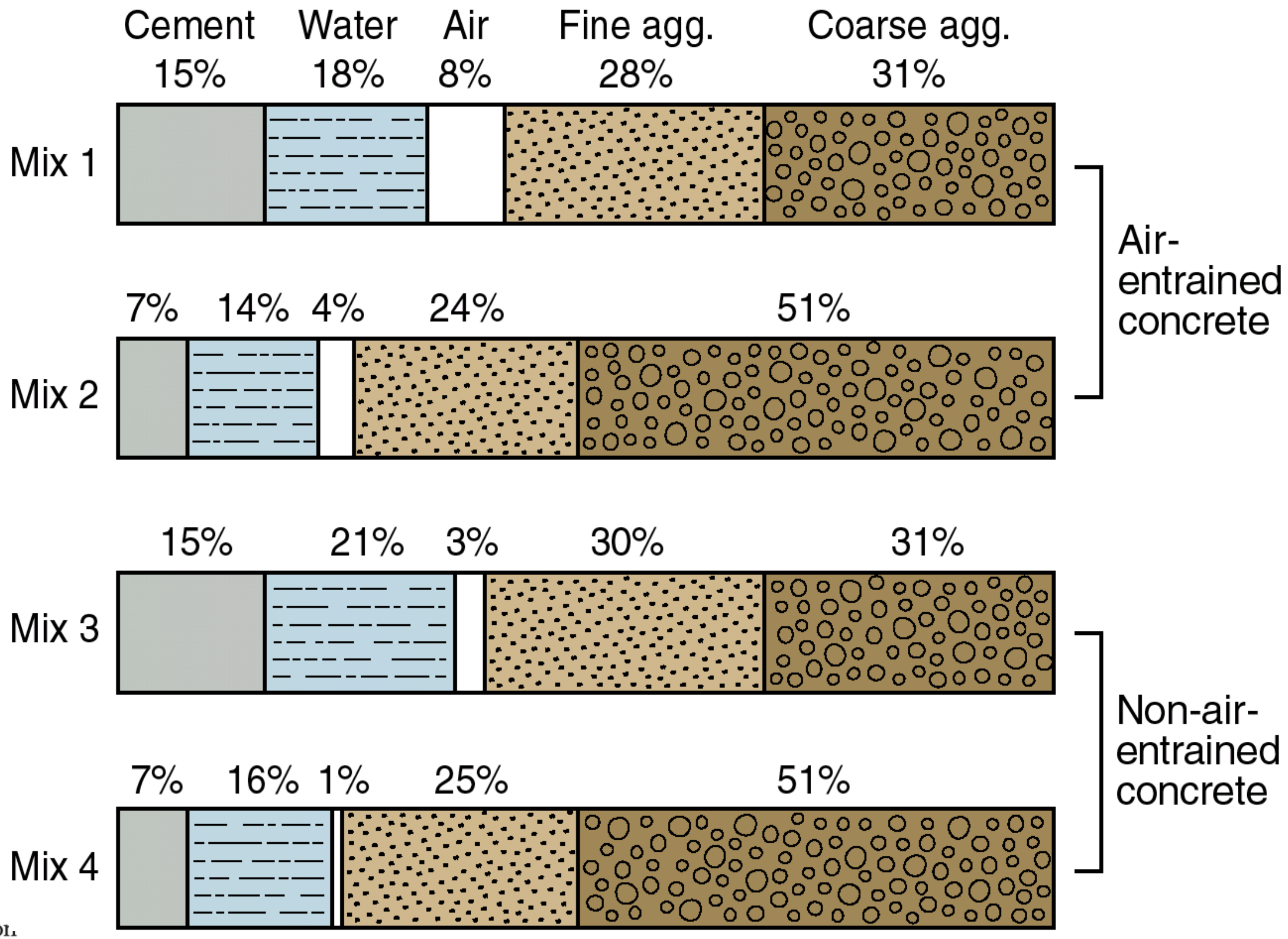
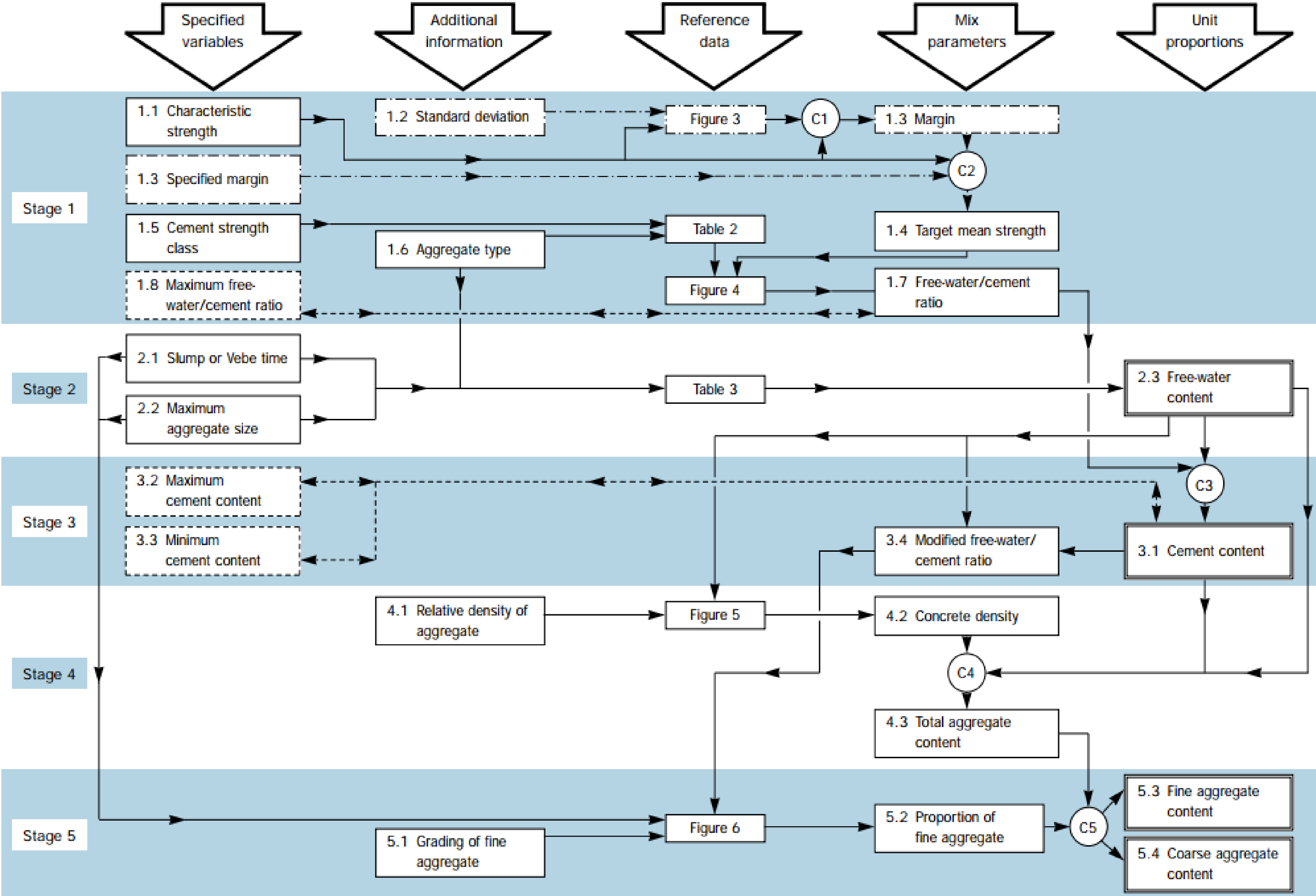
Mehta and Monteiro 2005

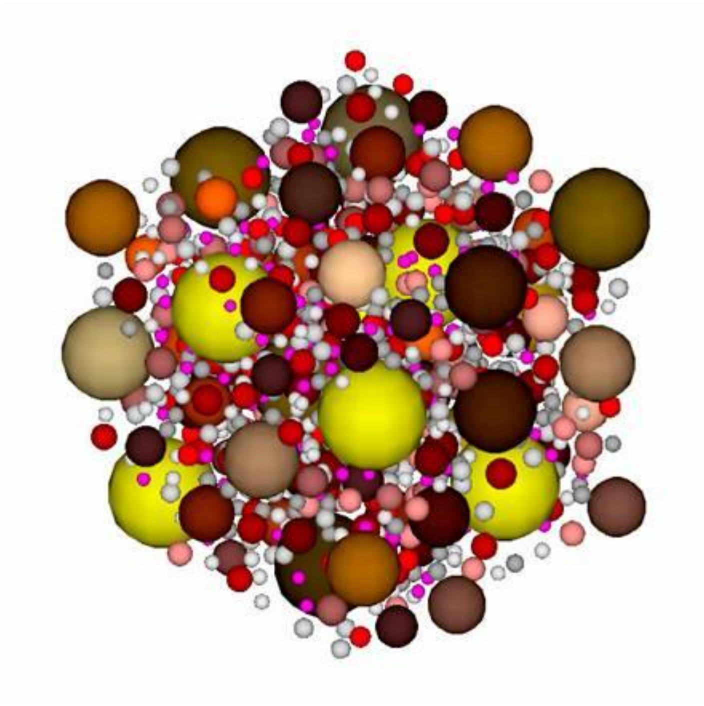
Proportions - Range

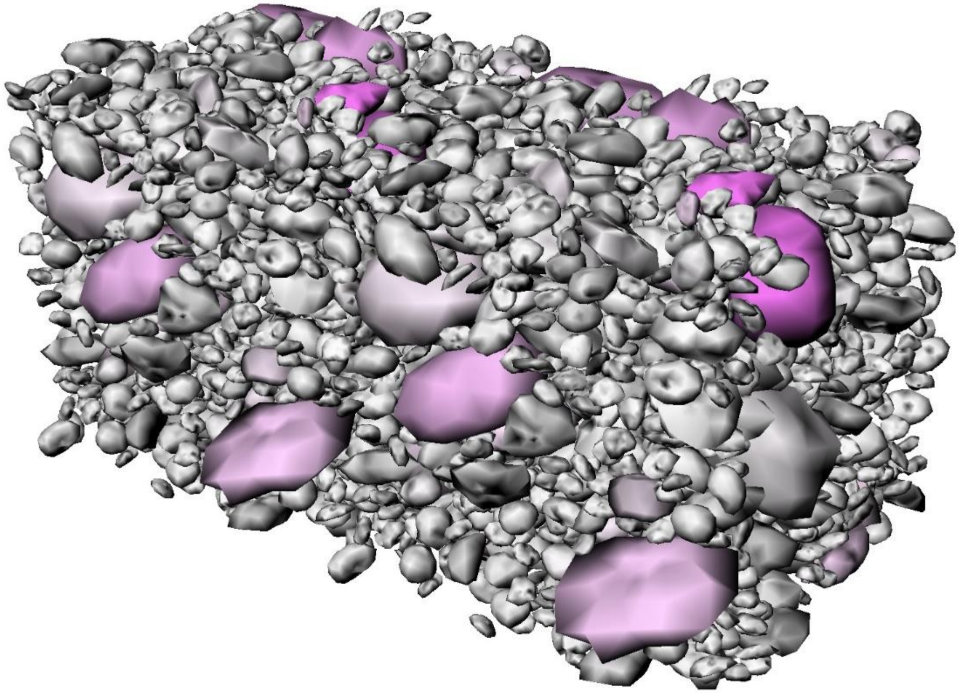


N.Neithalath; Presented at the AZ Pavement Conference, ASU, November 2013


Specified variables
Additional information
Reference data
Mix parameters
Unit proportions
Stage 1
1.1 Characteristic strength
1.2 Standard deviation
Figure 3
C1
1.3 Margin
1.3 Specified margin
C2
1.5 Cement strength class
Table 2
1.4 Target mean strength
1.6 Aggregate type
1.8 Maximum free-water/cement ratio
Figure 4
1.7 Free-water/cement ratio
Stage 2
2.1 Slump or Vebe time
Table 3
2.3 Free-water content
2.2 Maximum aggregate size
Stage 3
3.2 Maximum cement content
C3
3.3 Minimum cement content
3.4 Modified free-water/cement ratio
3.1 Cement content
Stage 4
4.1 Relative density of aggregate
Figure 5
4.2 Concrete density
C4
4.3 Total aggregate content
Stage 5
Figure 6
5.2 Proportion of fine aggregate
C5
5.3 Fine aggregate content
5.1 Grading of fine aggregate
5.4 Coarse aggregate content

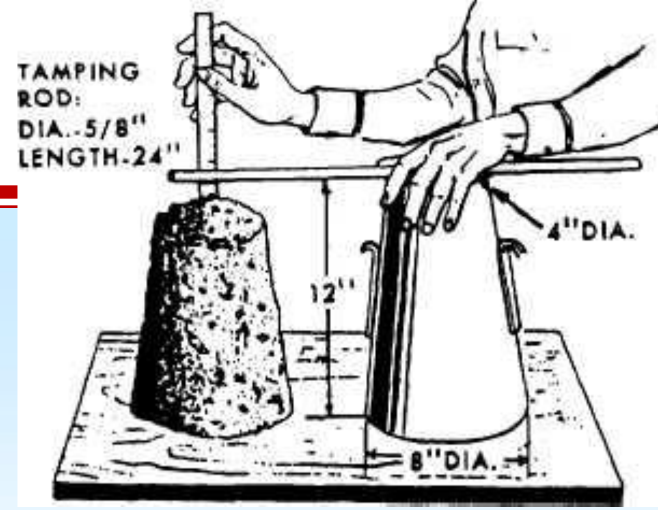
Particle Packing

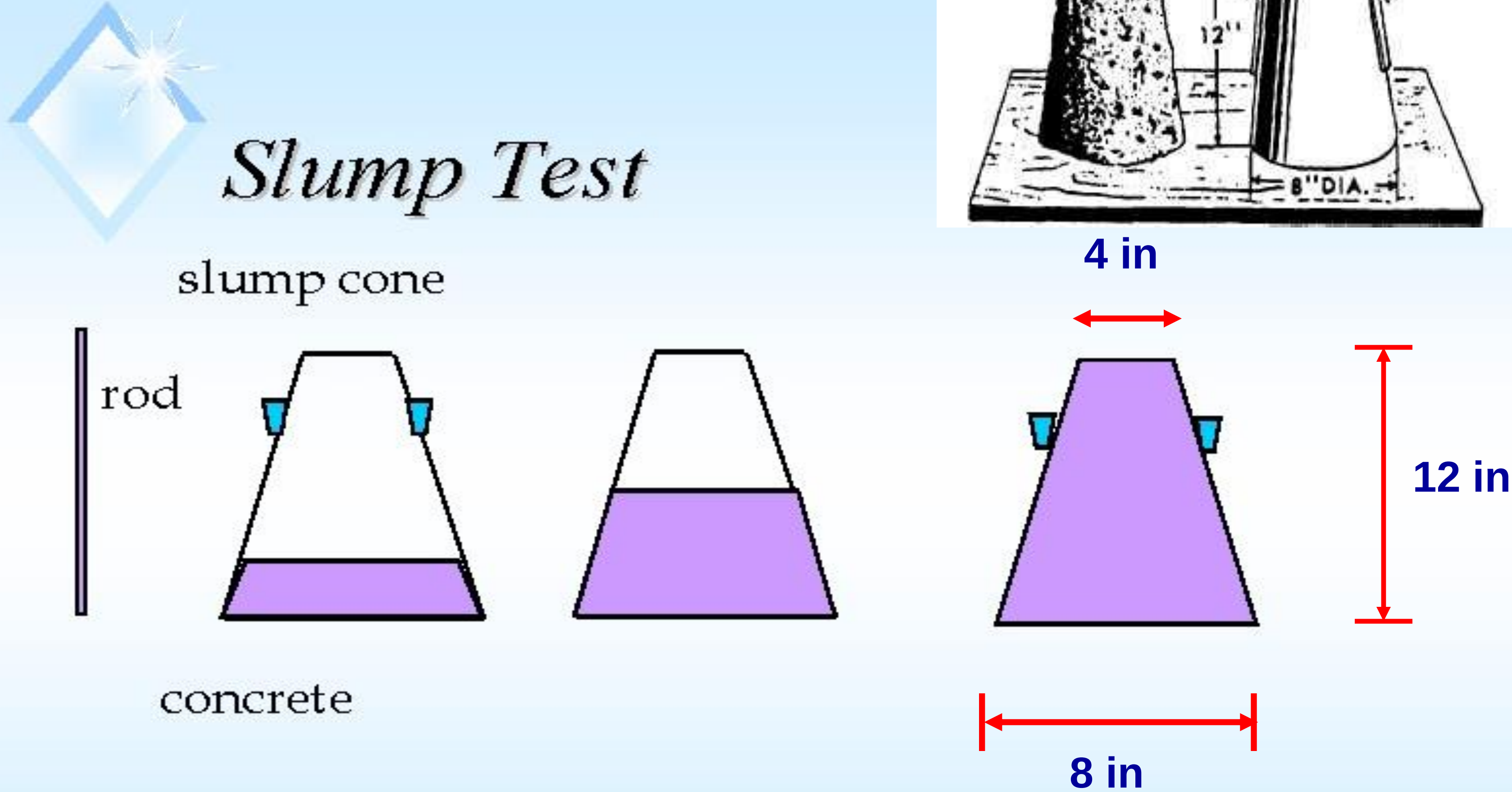




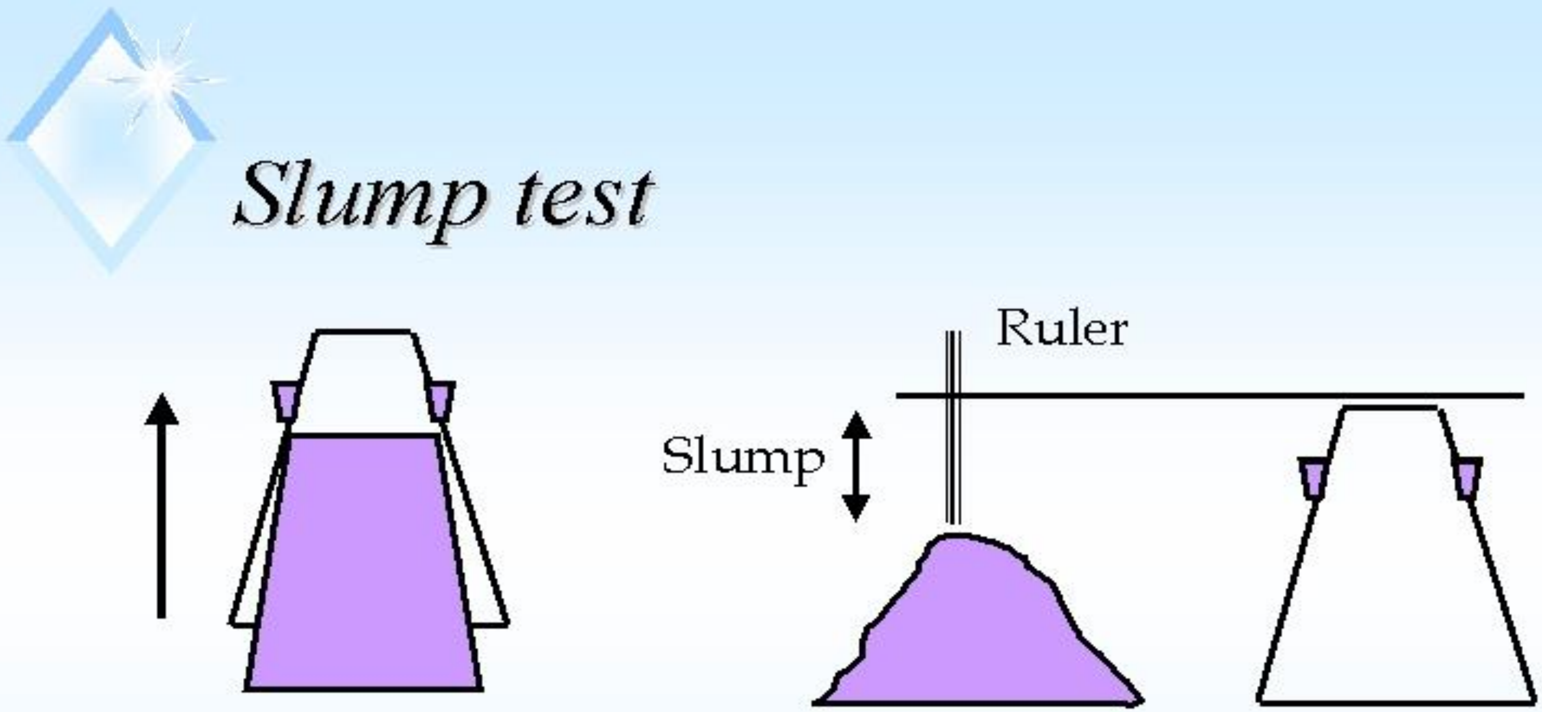
Significance of the material on performance?

Slump Testing





Slump Testing

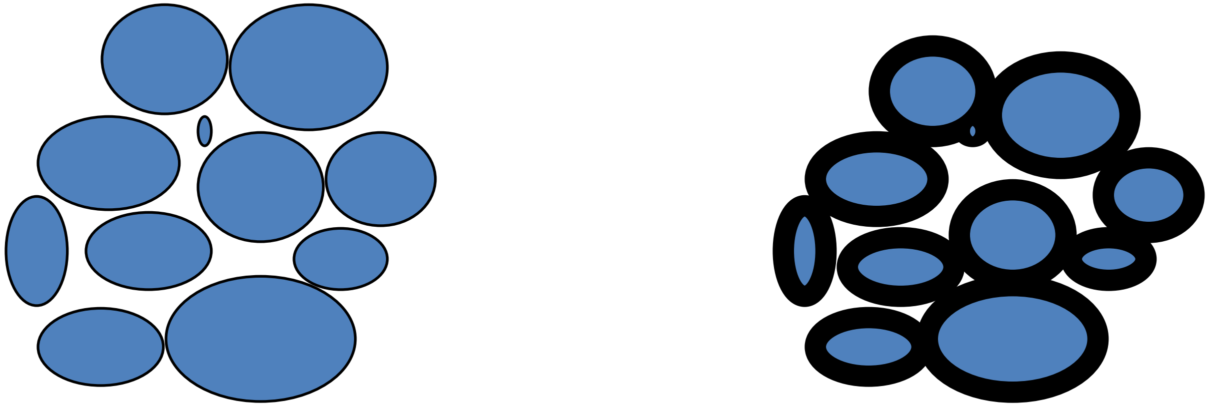


Measured to the nearest ¼ in (5 mm)

Uses of slump test

- Check on the day to day or hour to hour variation in materials
- Increased slump may indicate increased moisture states of aggregates
- Changes in slump indicate changes in aggregate gradation
- Indicates the relative amount of coarse to fine aggregates

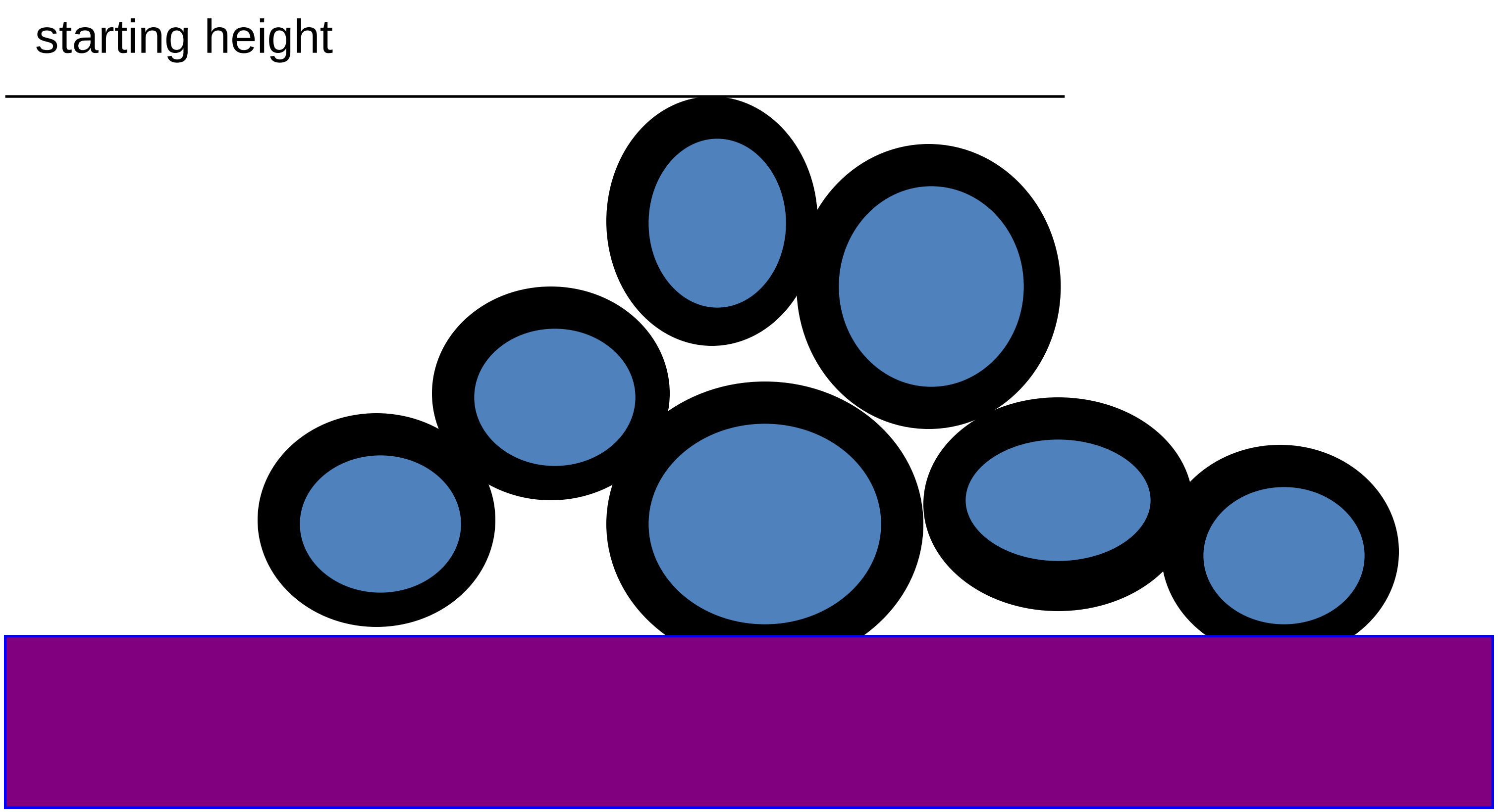
Factors affecting slump-paste content



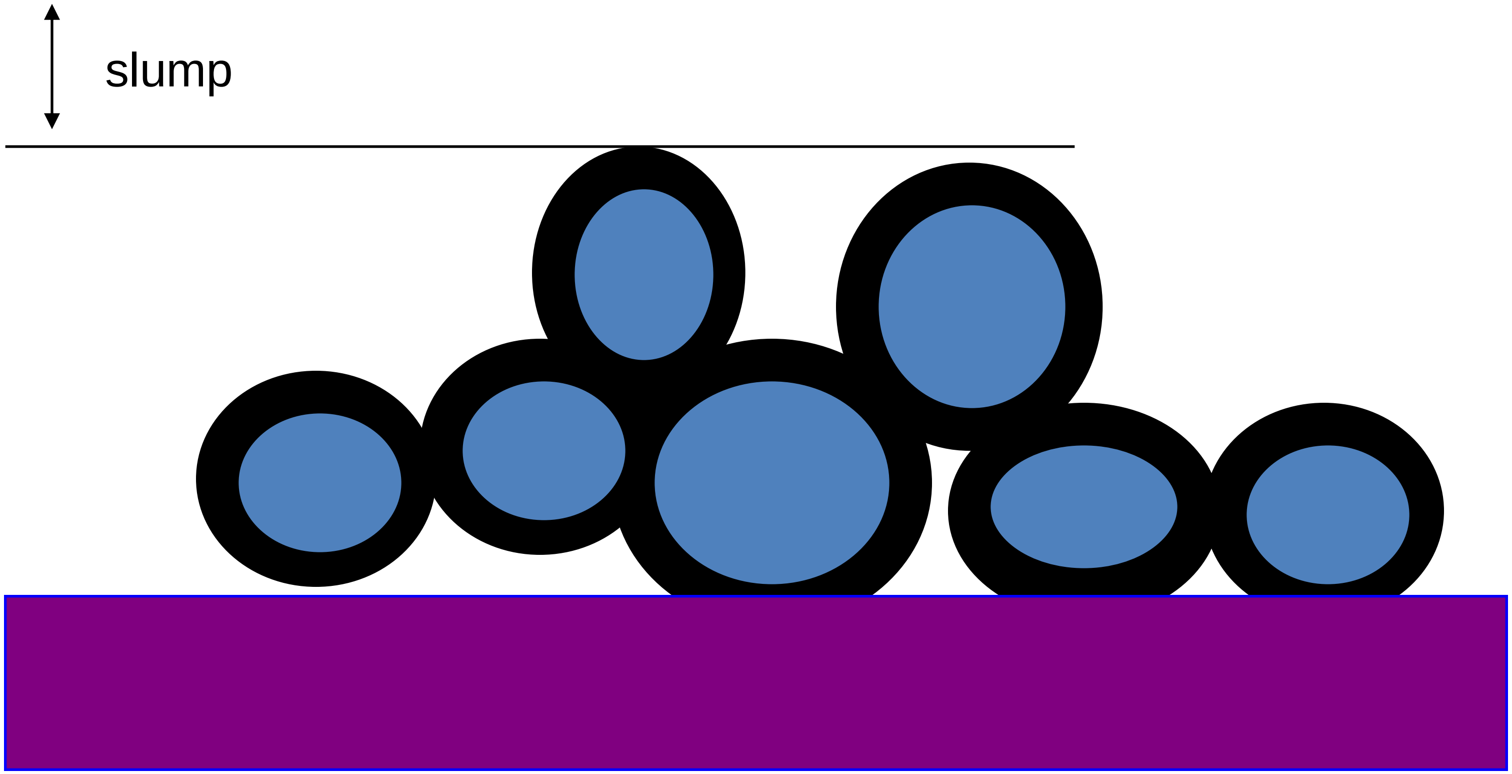
Low paste content
Harsh mix

High paste content
Rich mix

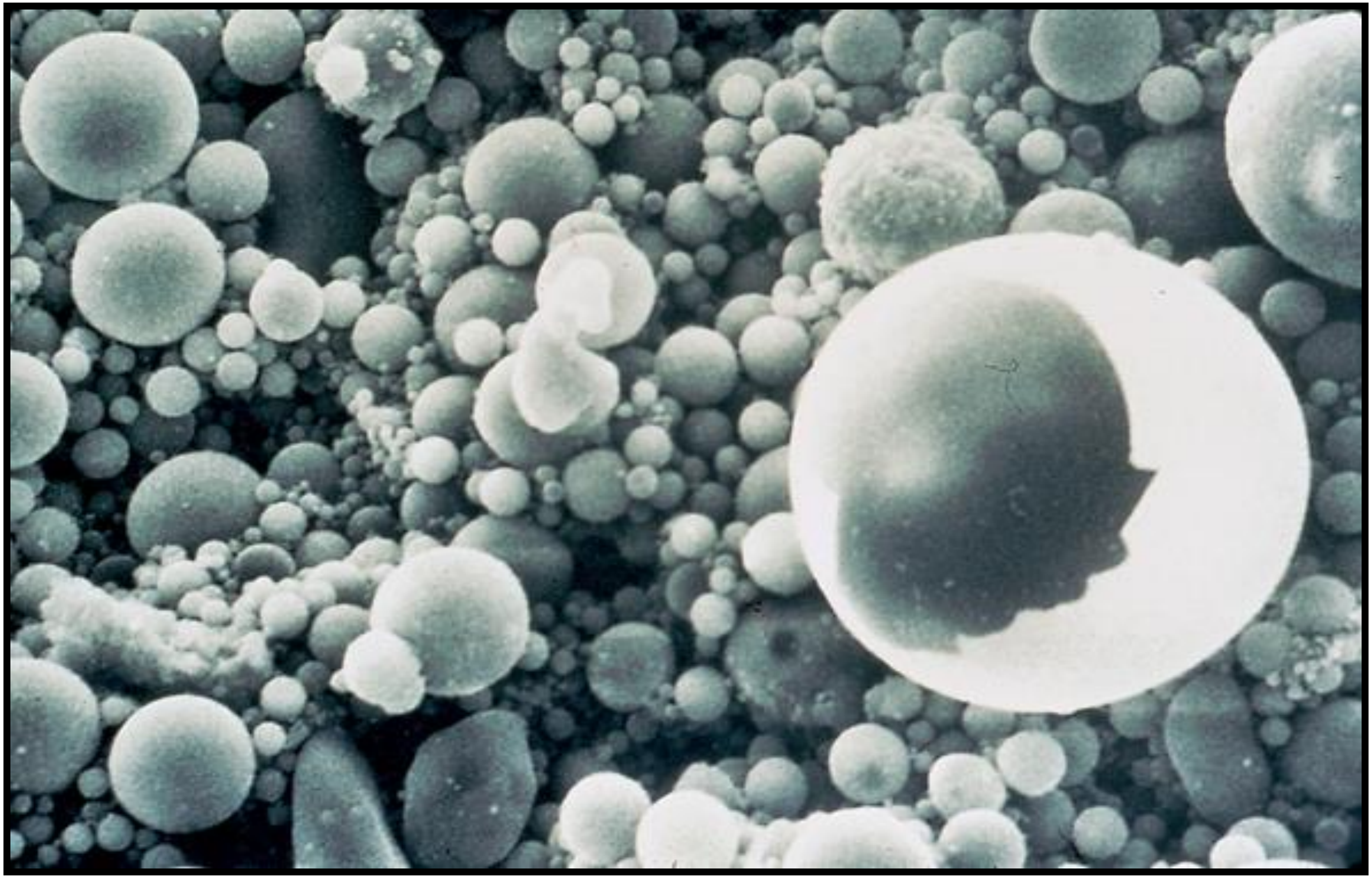
Ball bearing effect-start



Ball bearing effect-end

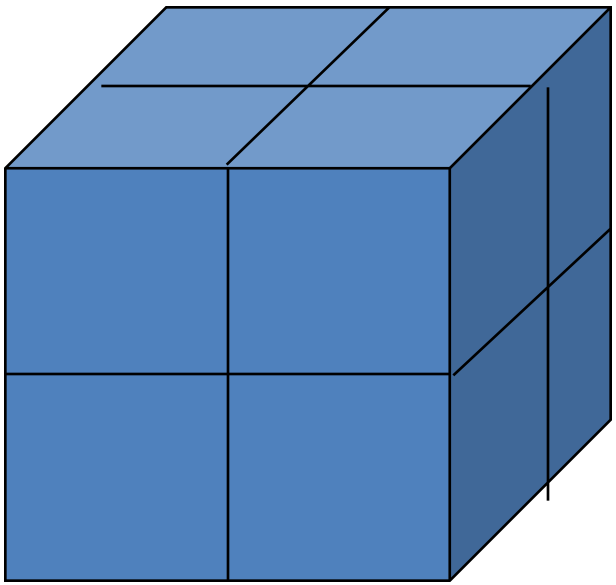


Fly ash benefit



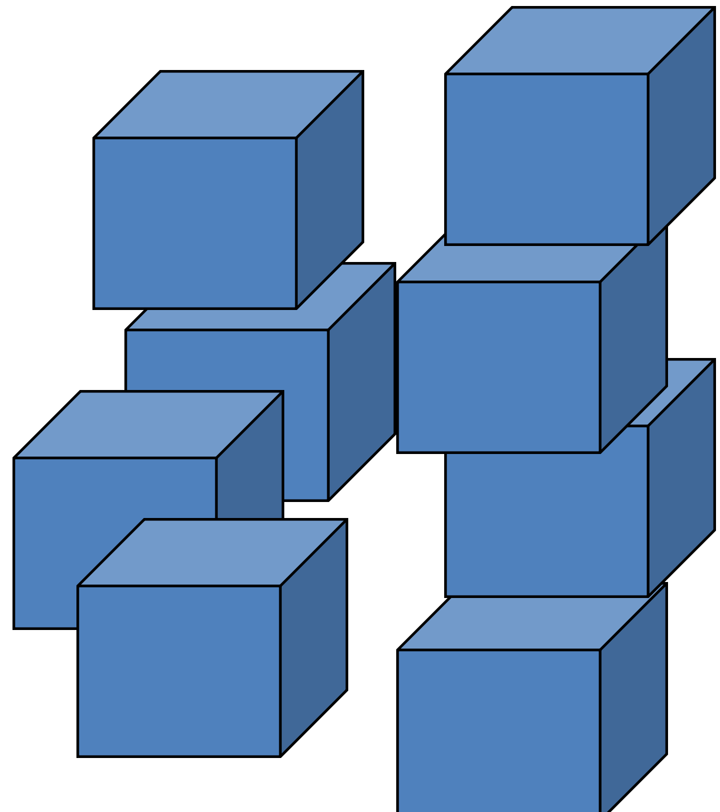
Aggregate size / surface area

block surface area = 1*1*6= 6



volume = 1 cubic in
surface area = 6 square inches

block surface area = 0.5*0.5*6=1.5



volume = 1 cubic in
surface area = 1.5*8= 12 square inches

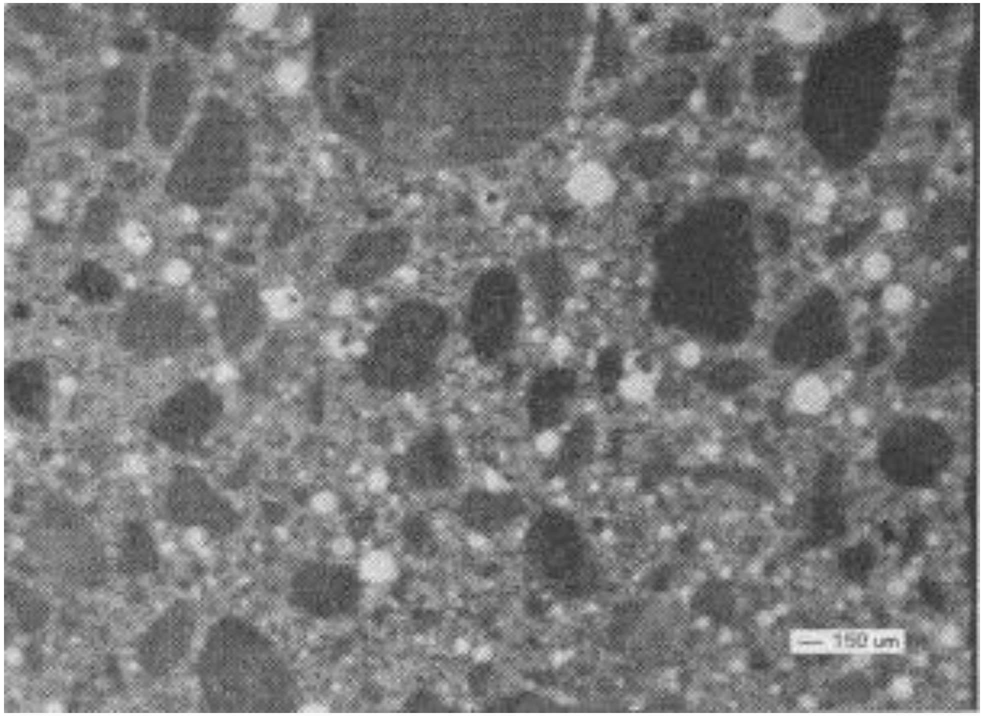
Admixtures

- set retarding admixtures
- set accelerating admixtures
- water reducing admixtures
- superplasticizers
- air entraining admixtures

Unit Weight and Yield (ASTM C 138)

- Unit weight or fresh density
- **Yield** – volumetric quantity of concrete produced per batch
- Proper consolidation needed before determining yield and density
- Expressed in kg/m^3 or lb/ft^3

Air Content

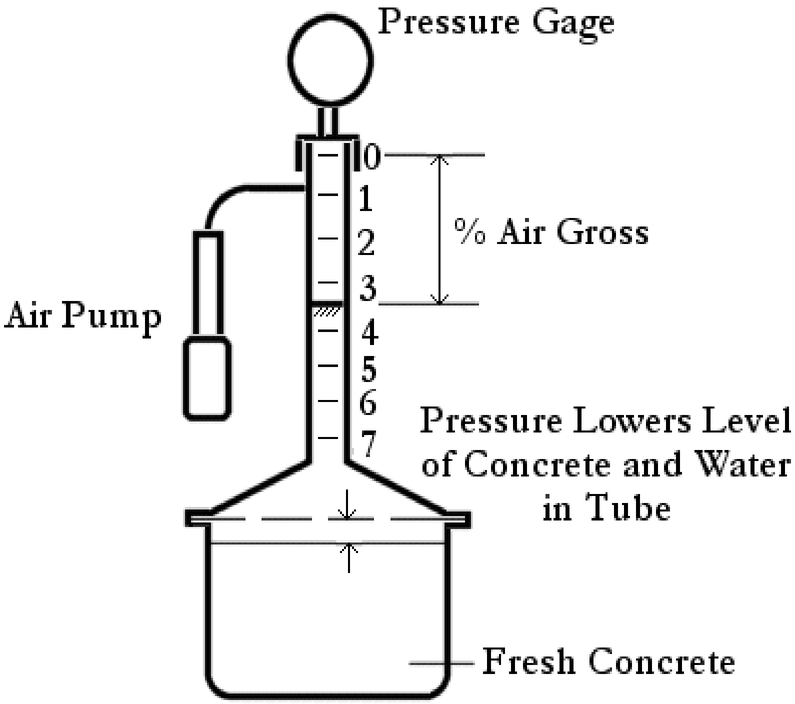


- To ensure sufficient freezing and thawing resistance
- Pressure Method
  - ASTM C 231
- Volume method
  - ASTM C 173
- Gravimetric Method
  - ASTM C 173
- Air Indicator Method
  - AASHTO T 199

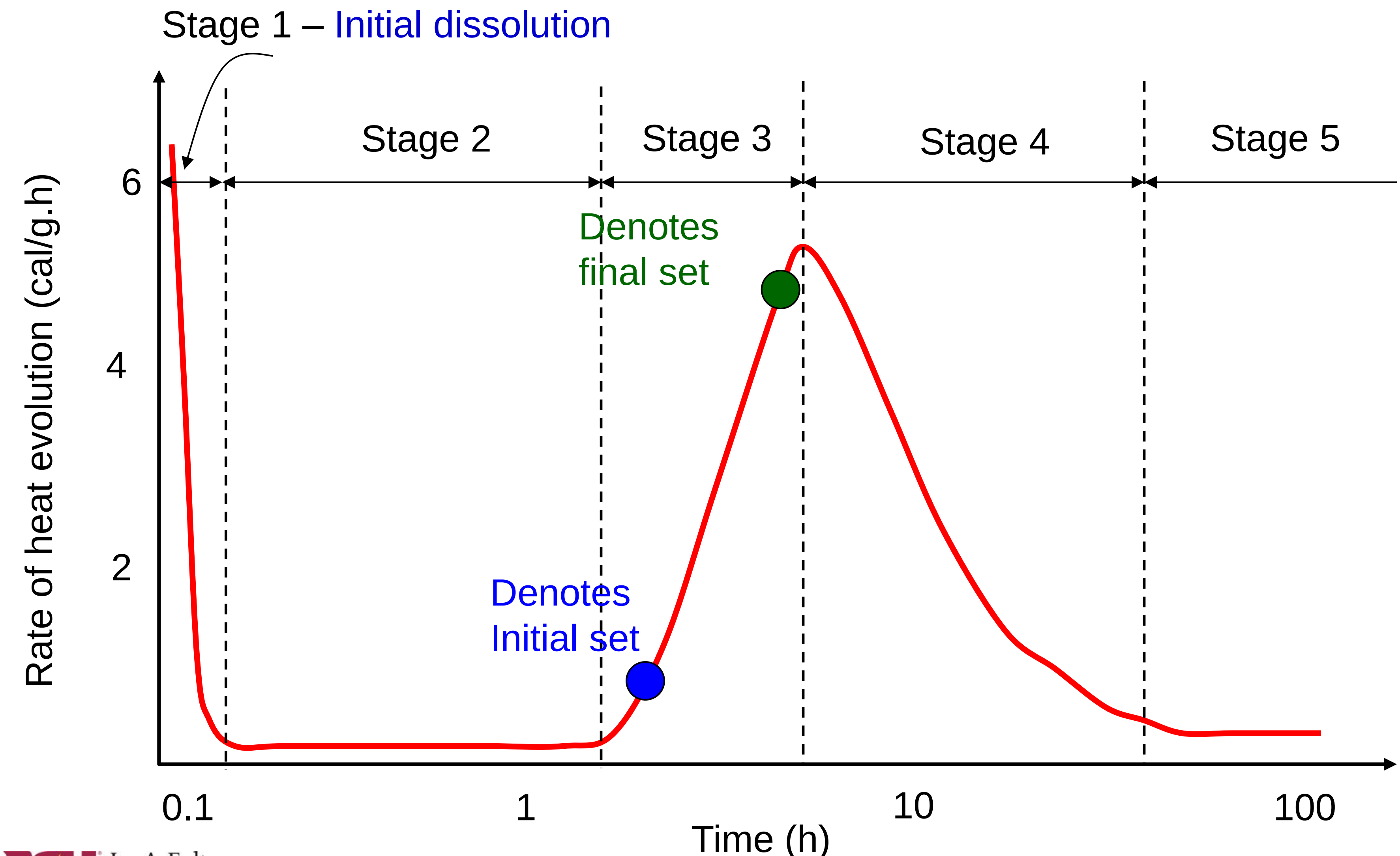
Pressure Method (ASTM C 231)

- Based on Boyle's law
- Relates pressure to volume
- Calibrated to read air contents directly

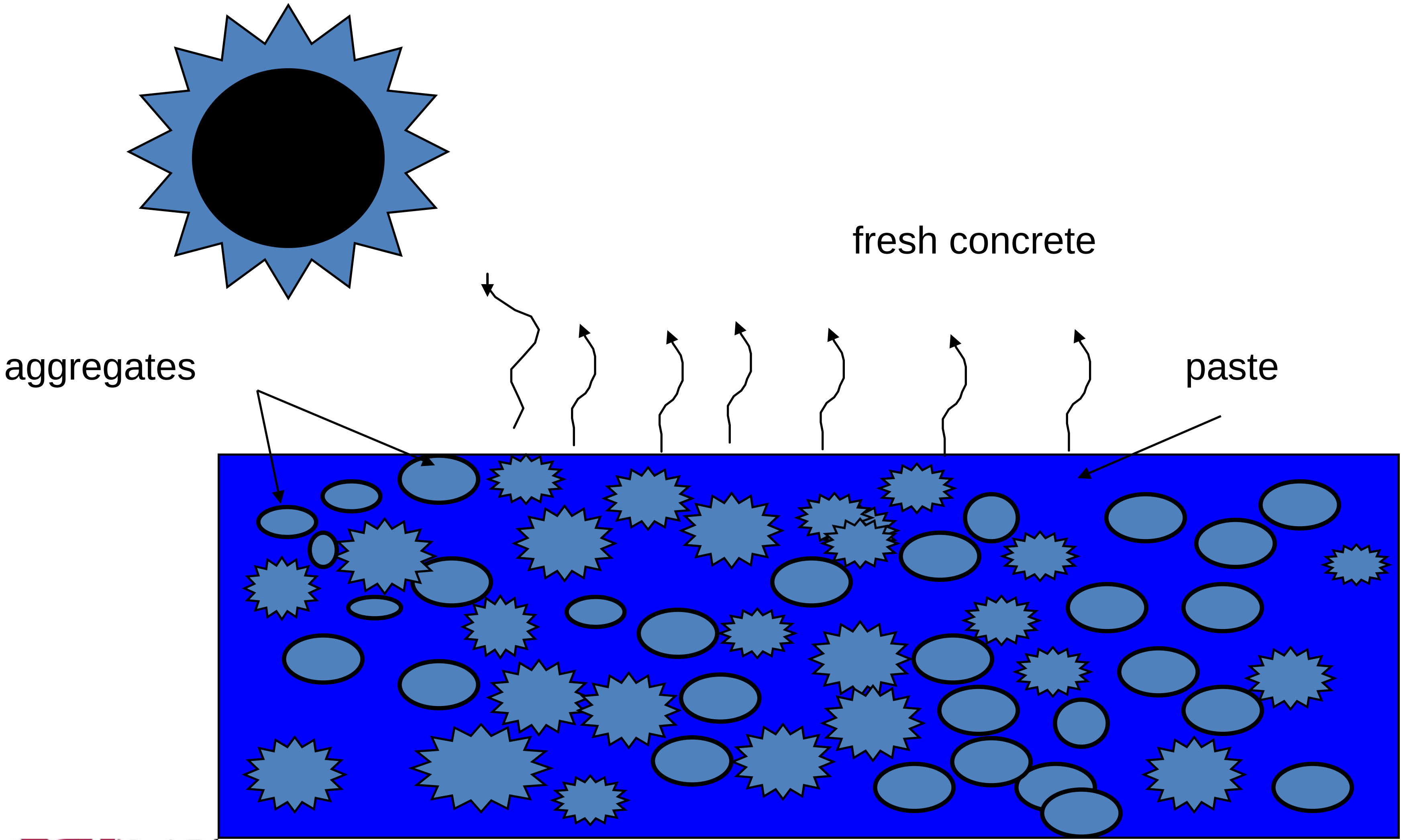
Volumetric Method (ASTM C 173)



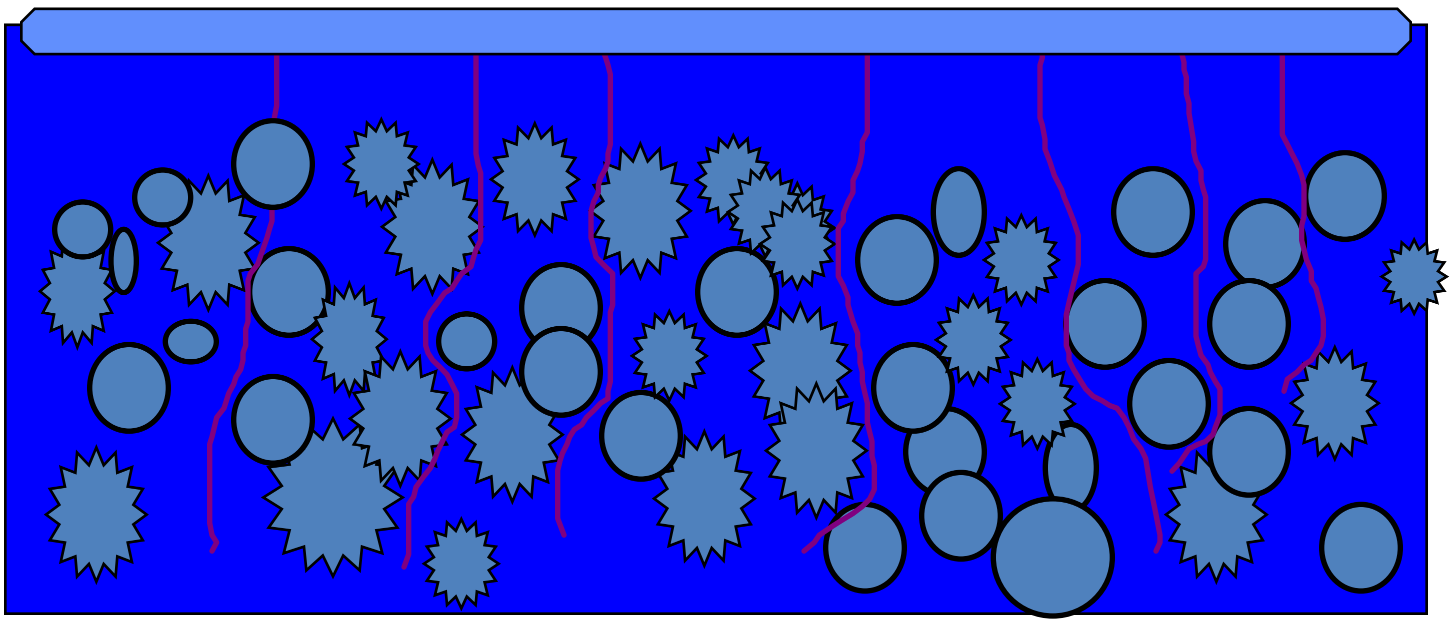
Heat evolution curve



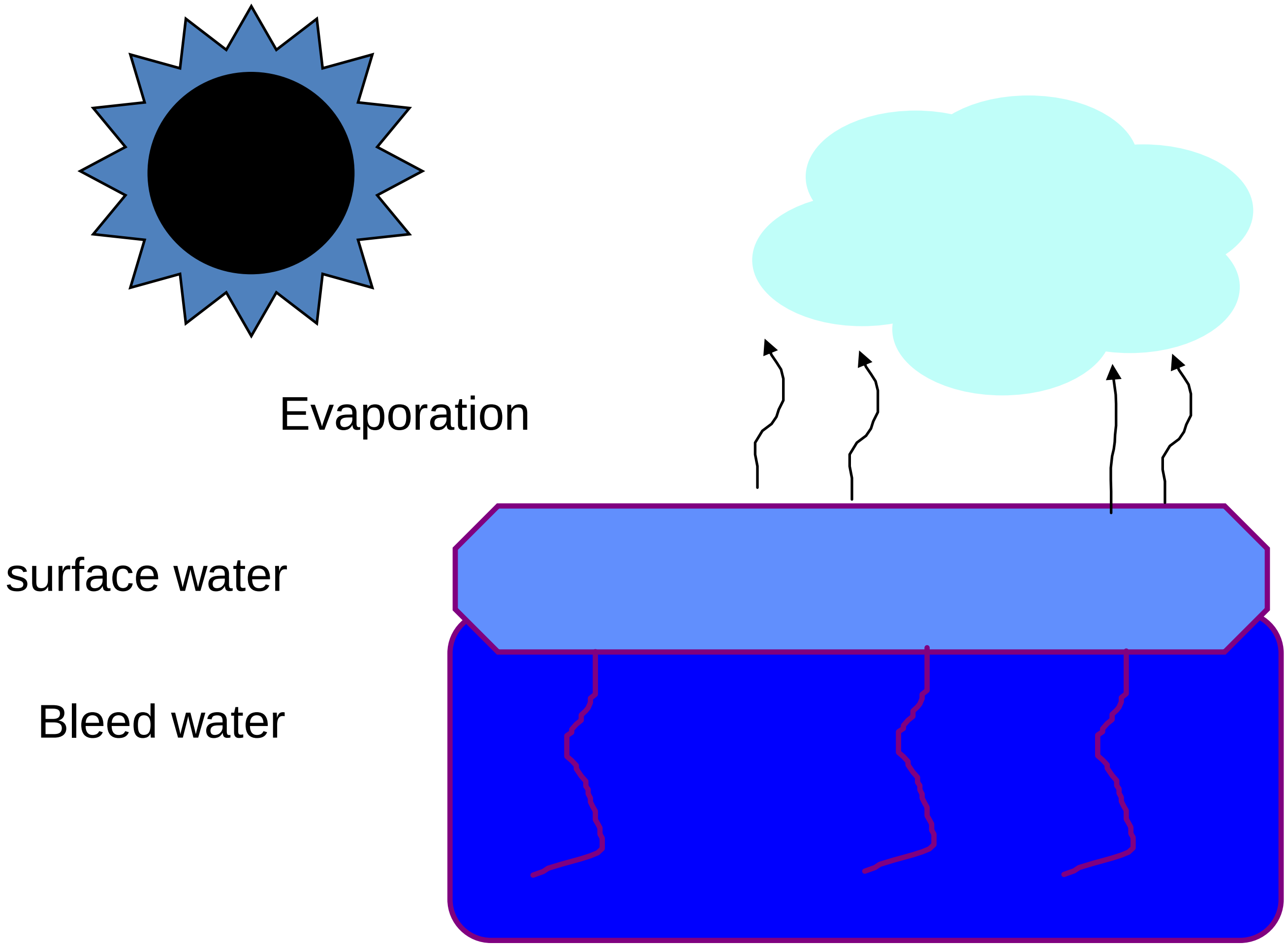
Temperature



Bleeding

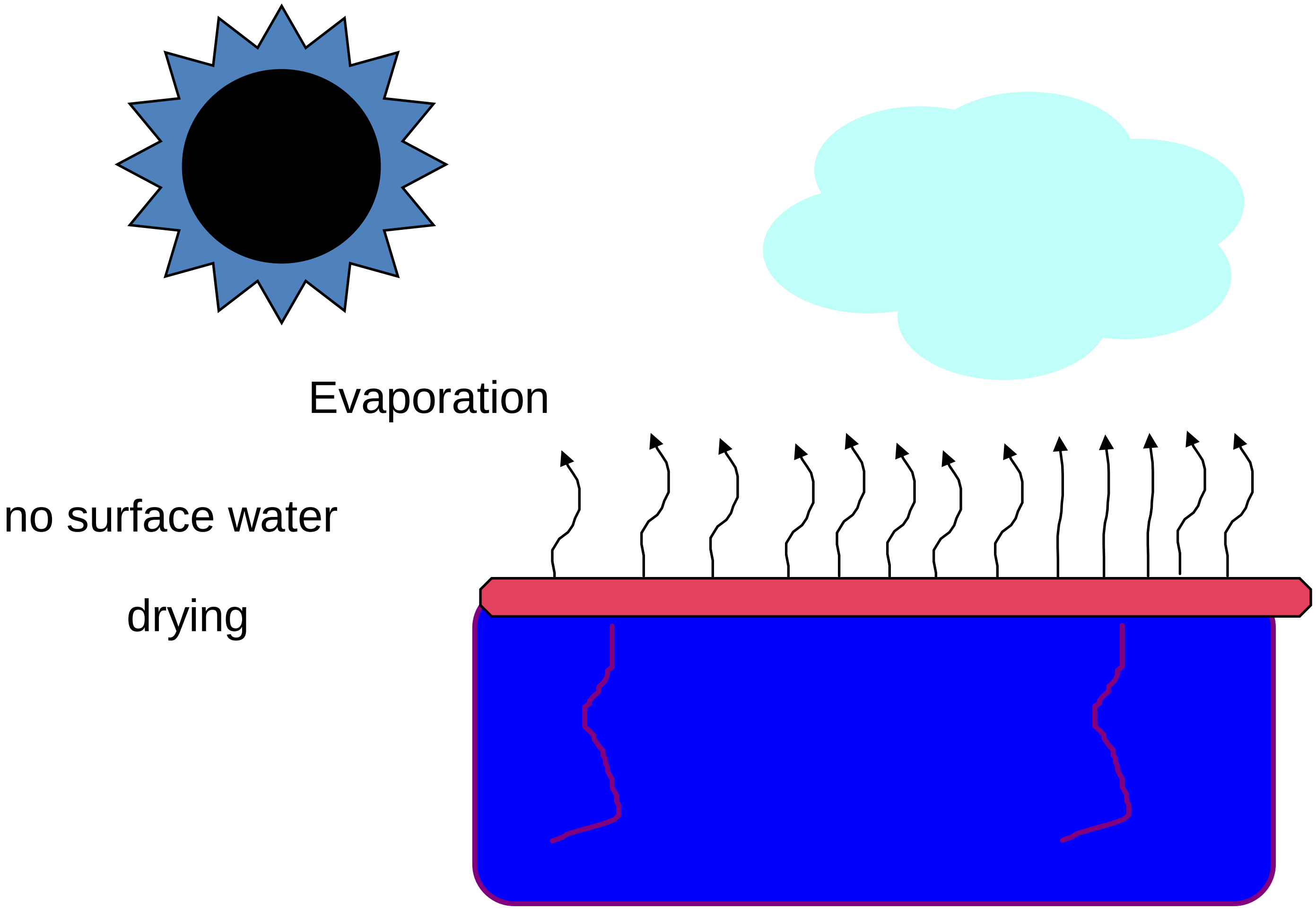


Interaction between bleeding and evaporation



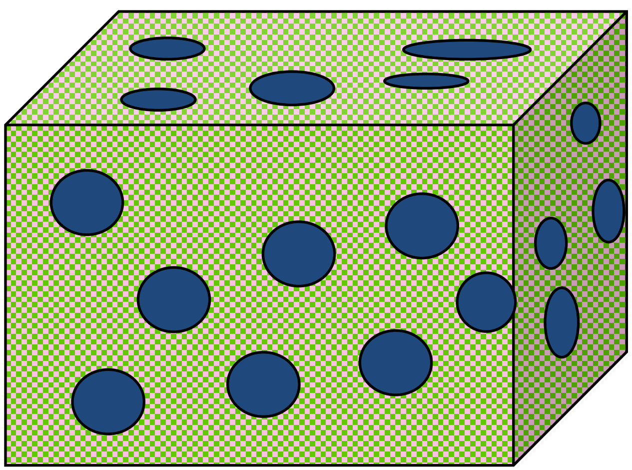
Bleed water = evaporation

Too much evaporation

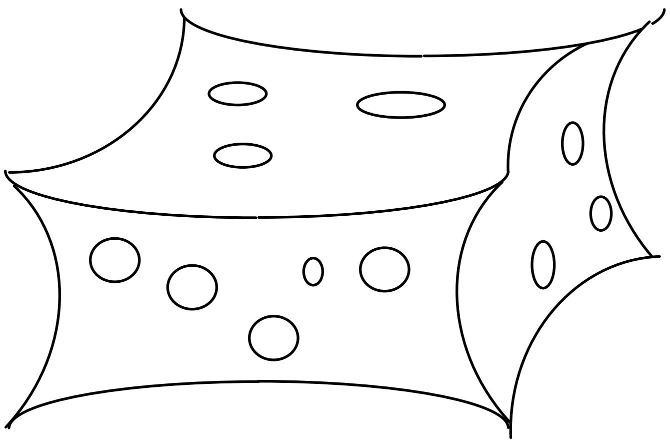


Bleed water < Evaporation

Free Shrinkage

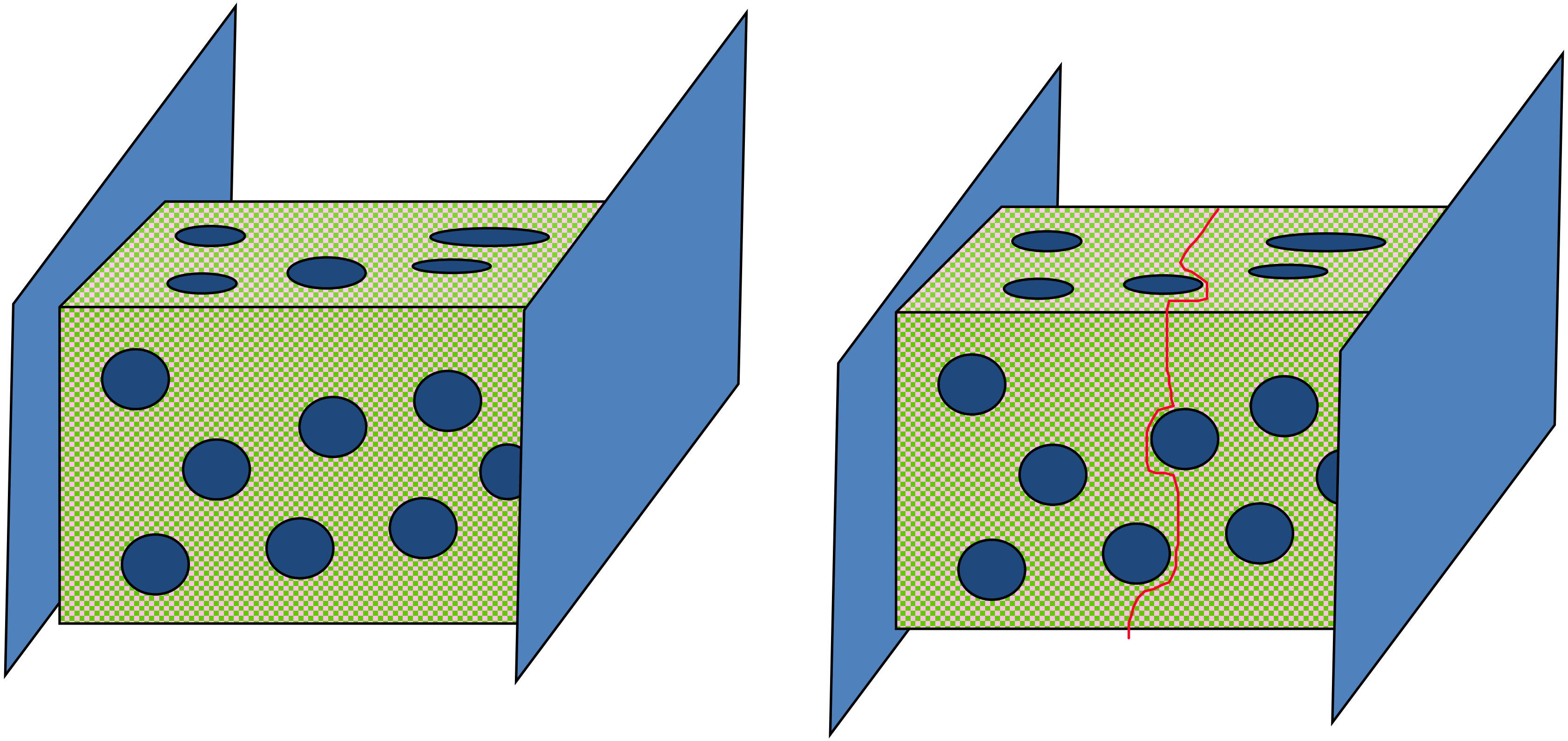


before shrinkage



After Shrinkage

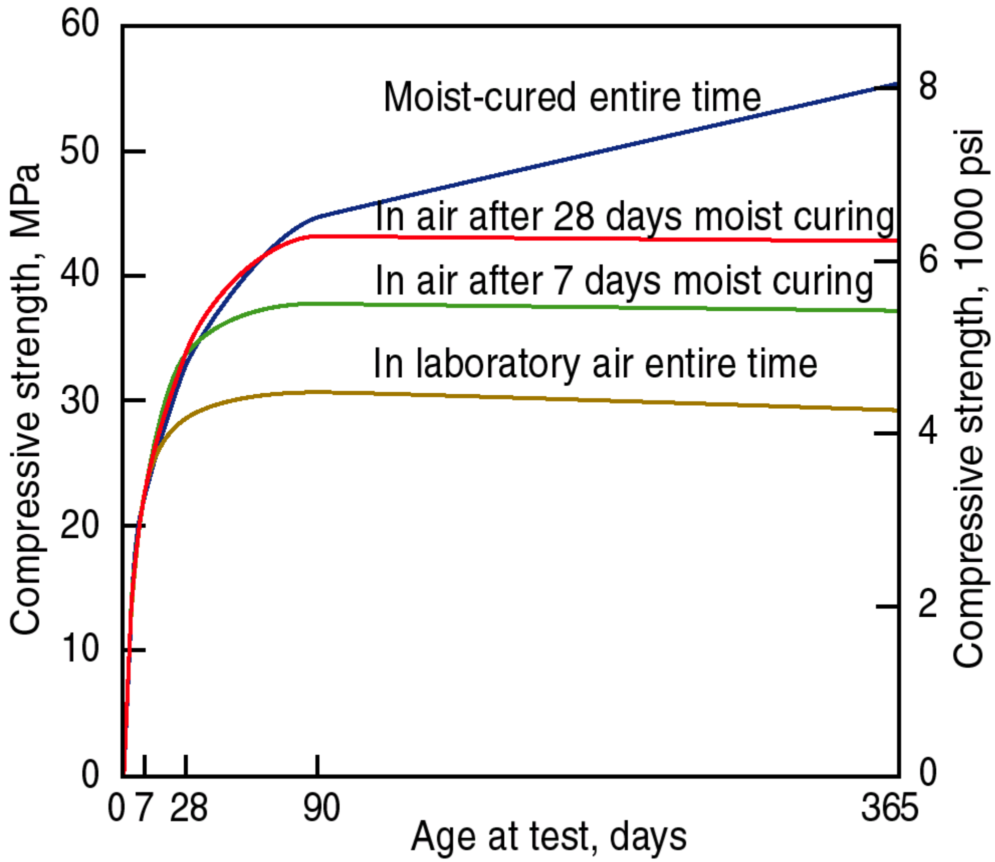
Restrained Shrinkage



Curing of Concrete

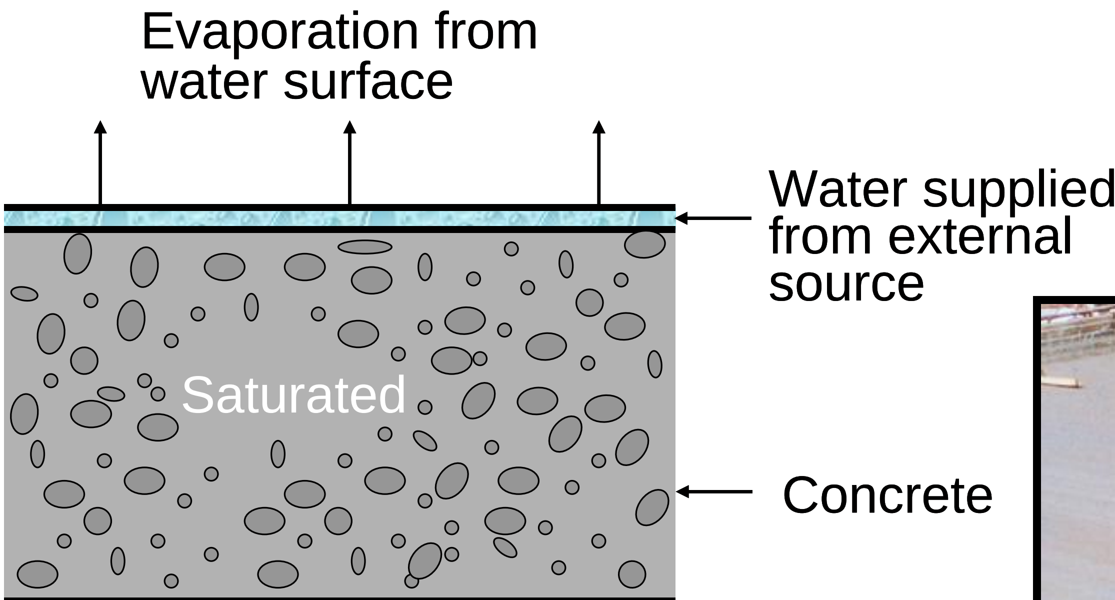
- Three most important aspects in curing
- TIME
  - Cure for as long as it is required
- TEMPERATURE
  - Cure at the right temperature for strength gain
- MOISTURE
  - Enough (or more) moisture

Importance of Curing



- Stronger concrete
- Impermeable concrete
- More resistant to stress, abrasion
- Resistance to freezing and thawing

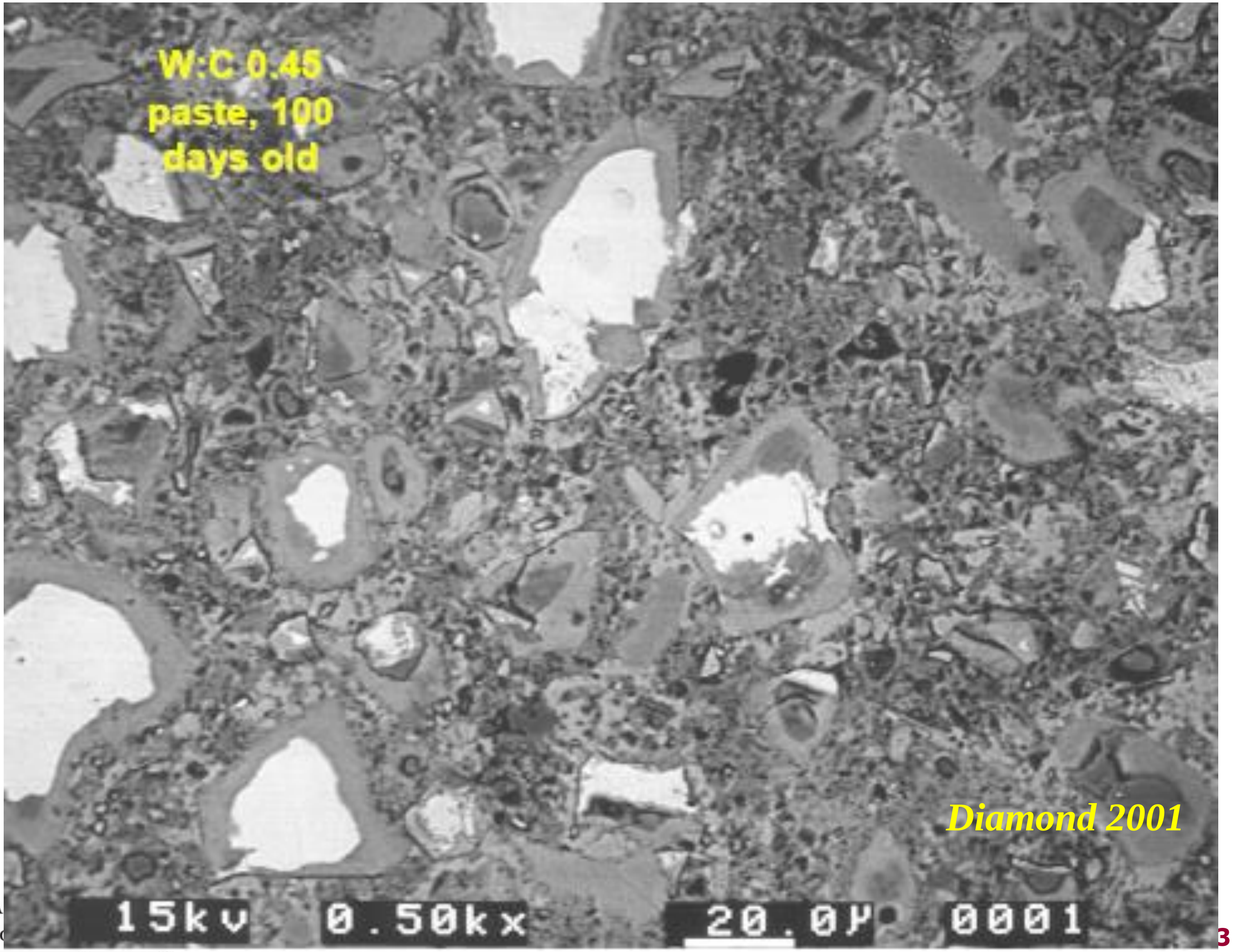
Method-I – maintaining the presence of water



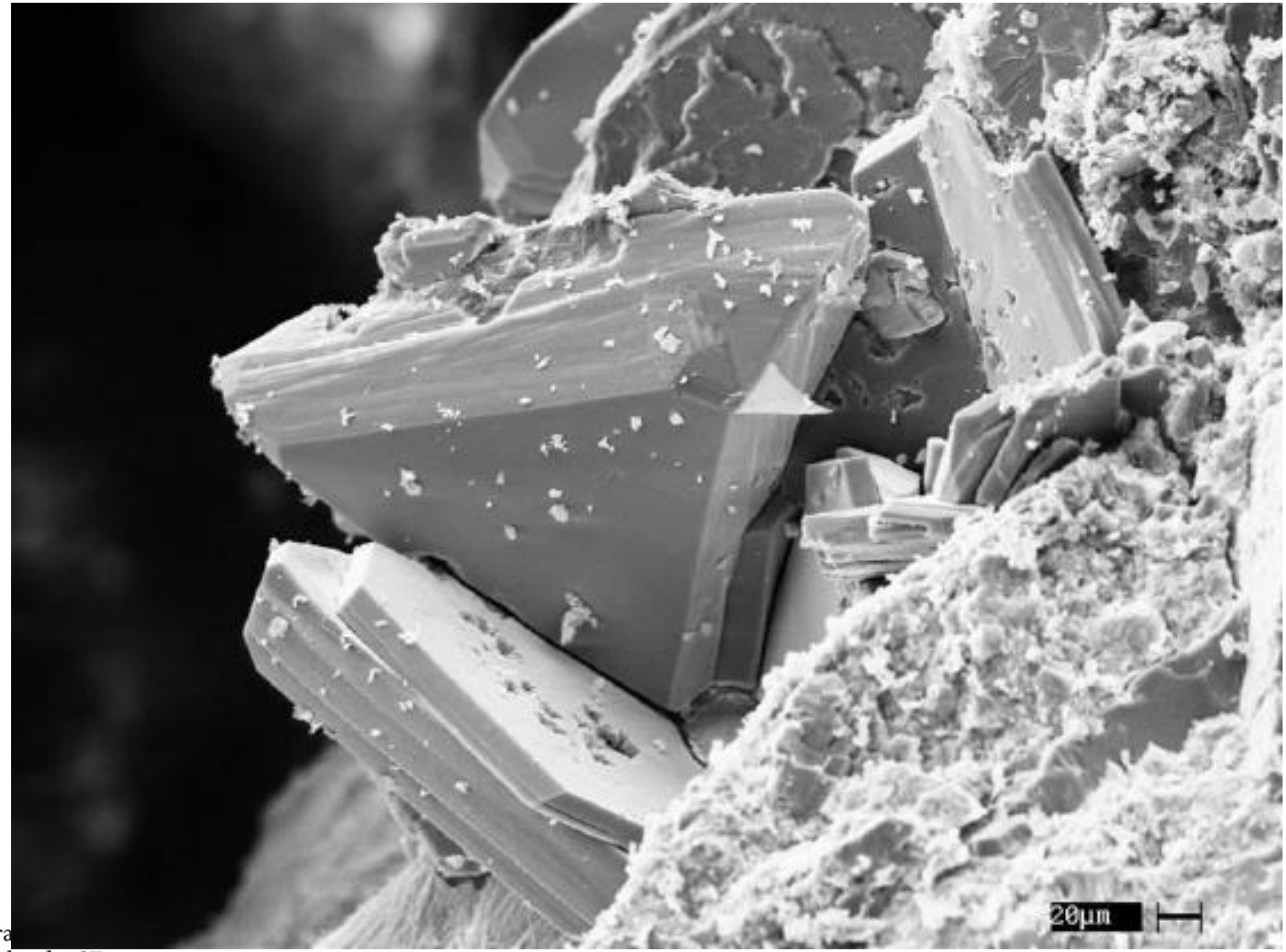
Method-II – Reduce loss of mixing water from the surface

Membrane curing compounds

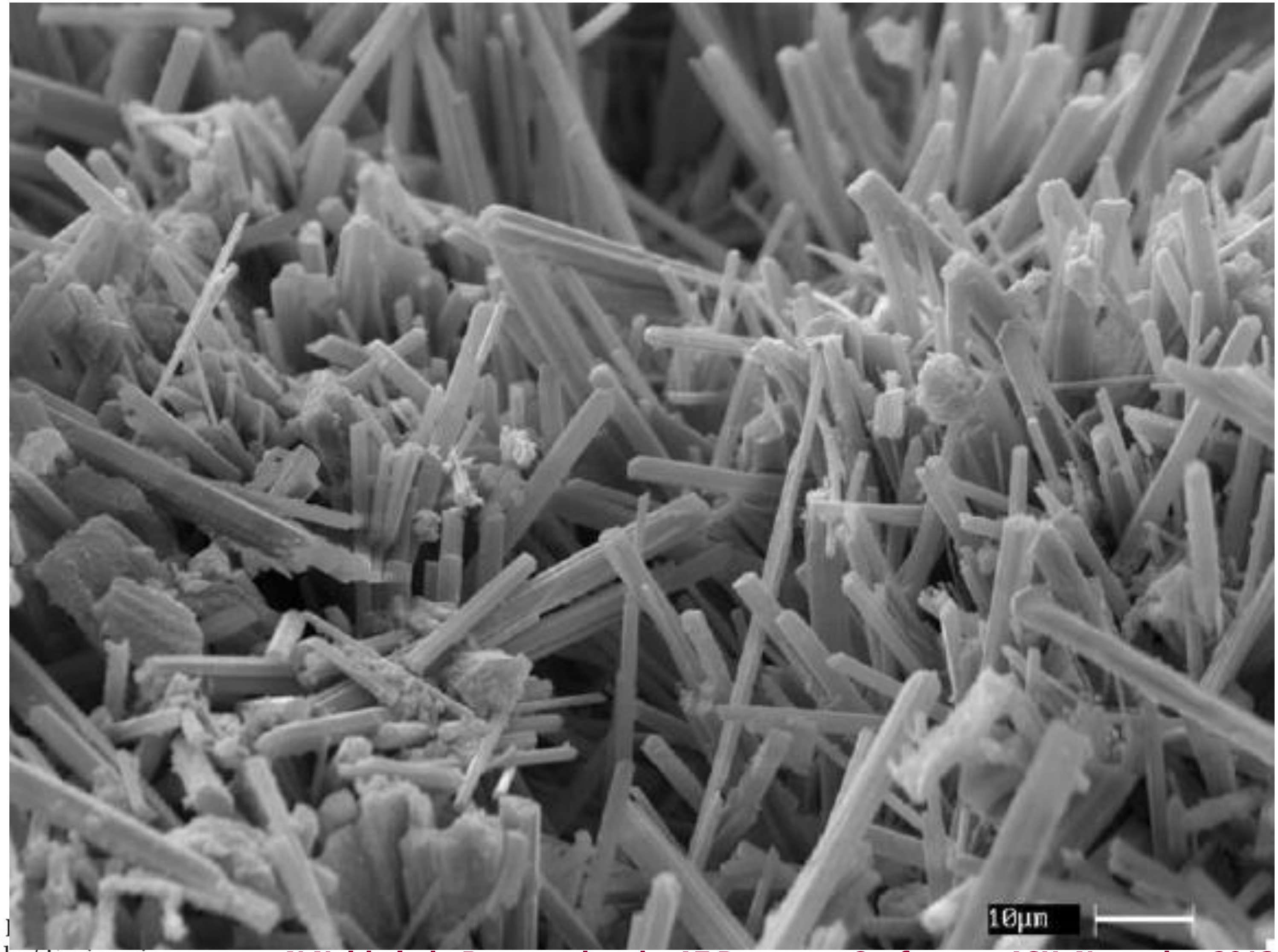
Hydration product - C-S-H



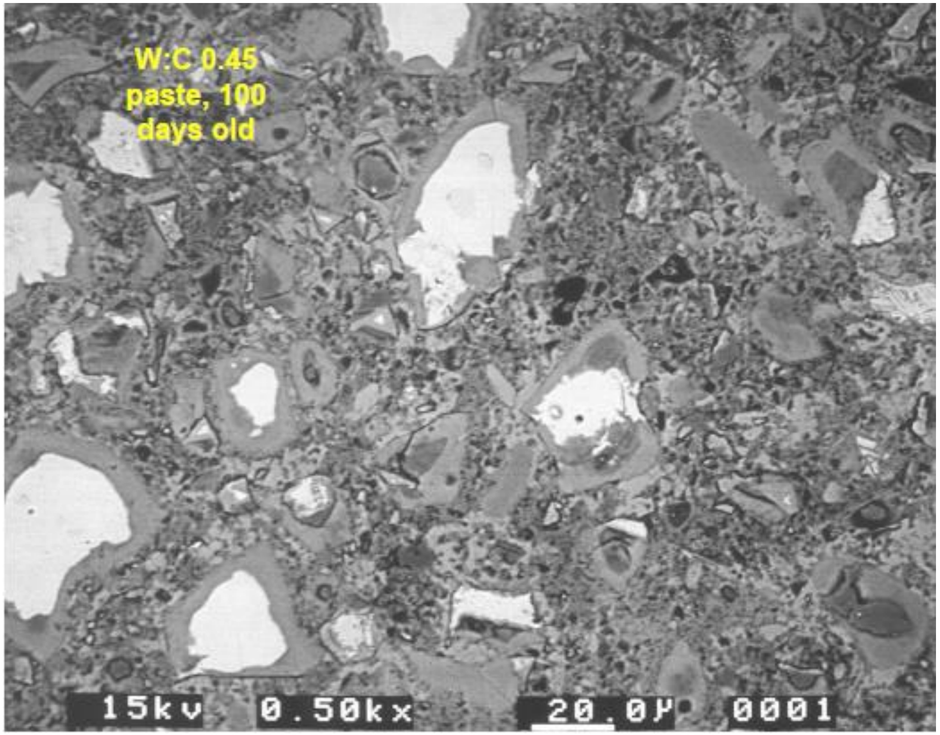
Hydration product - C-H

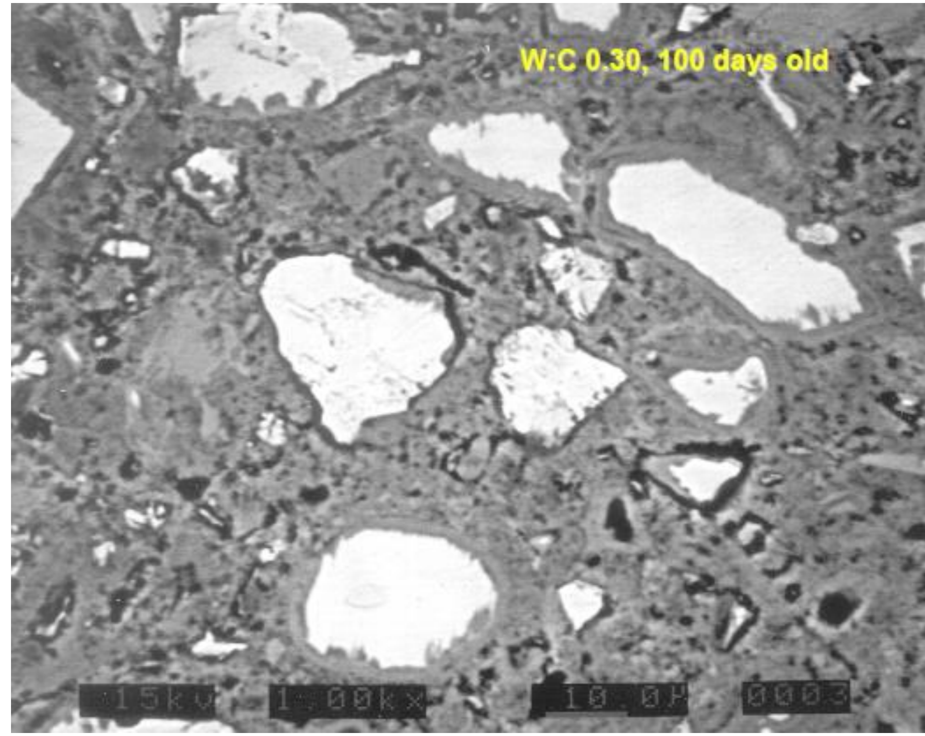


Hydration product - C-A-S-H



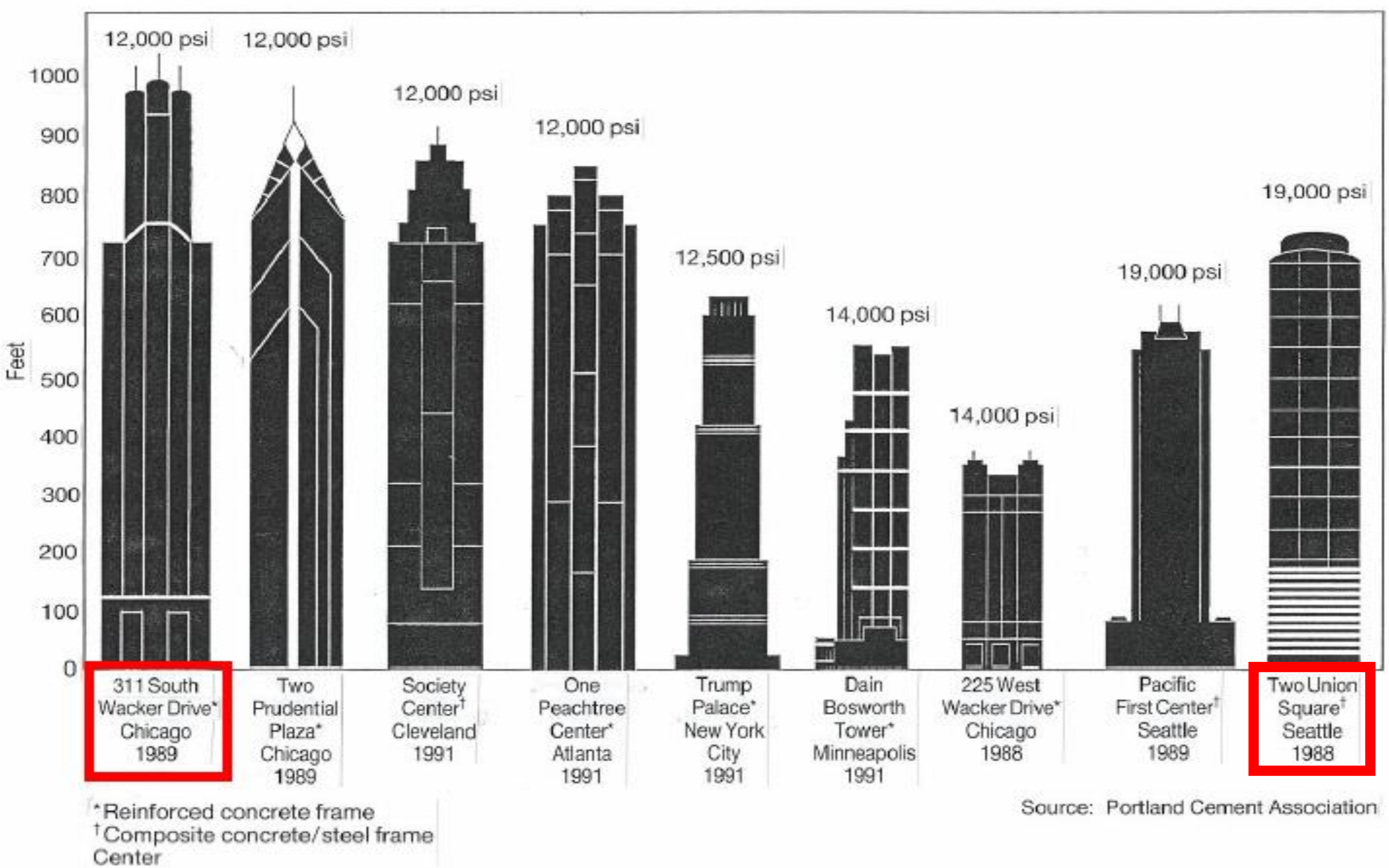
Paste Microstructure



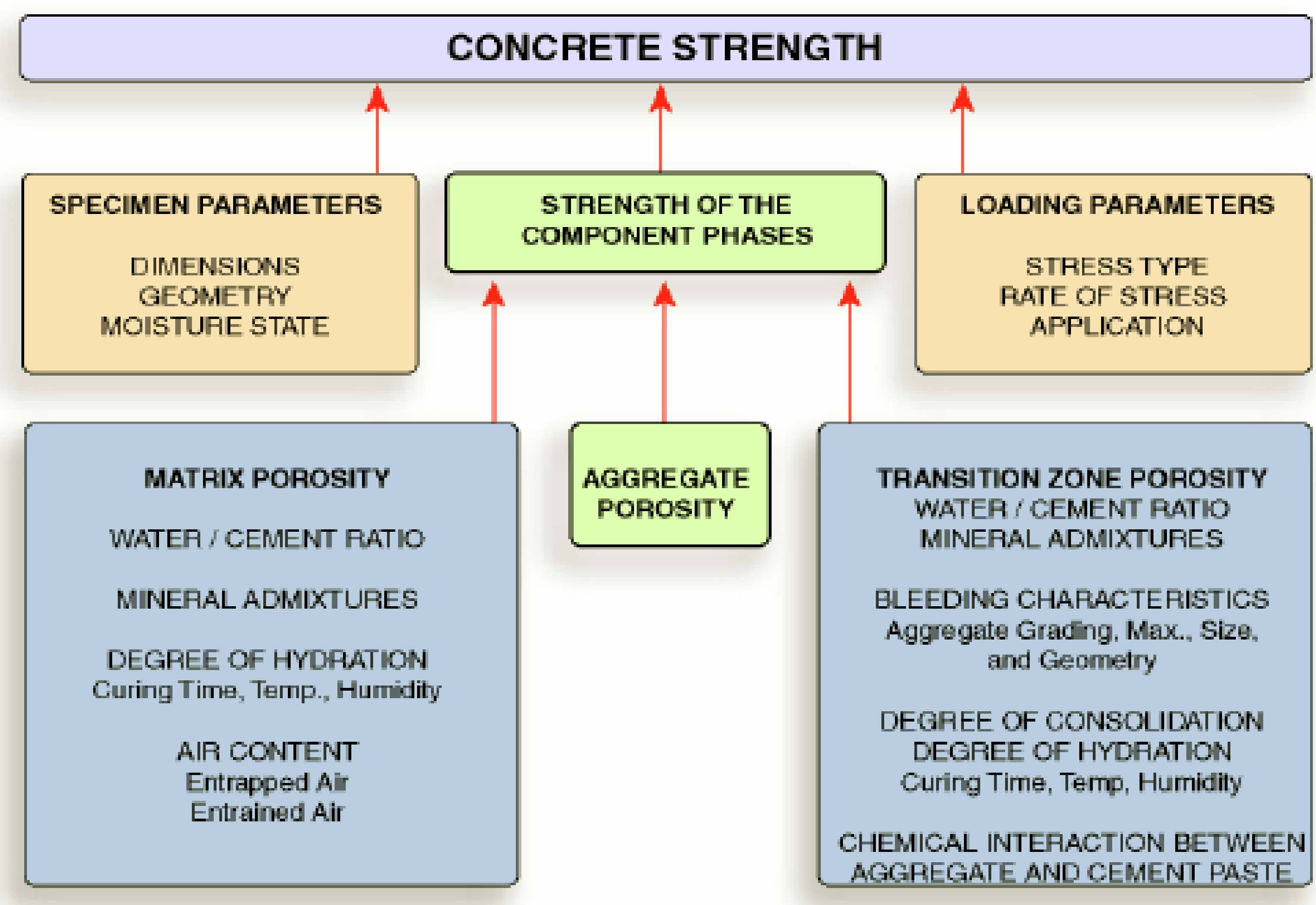


What is revealing in these pictures?

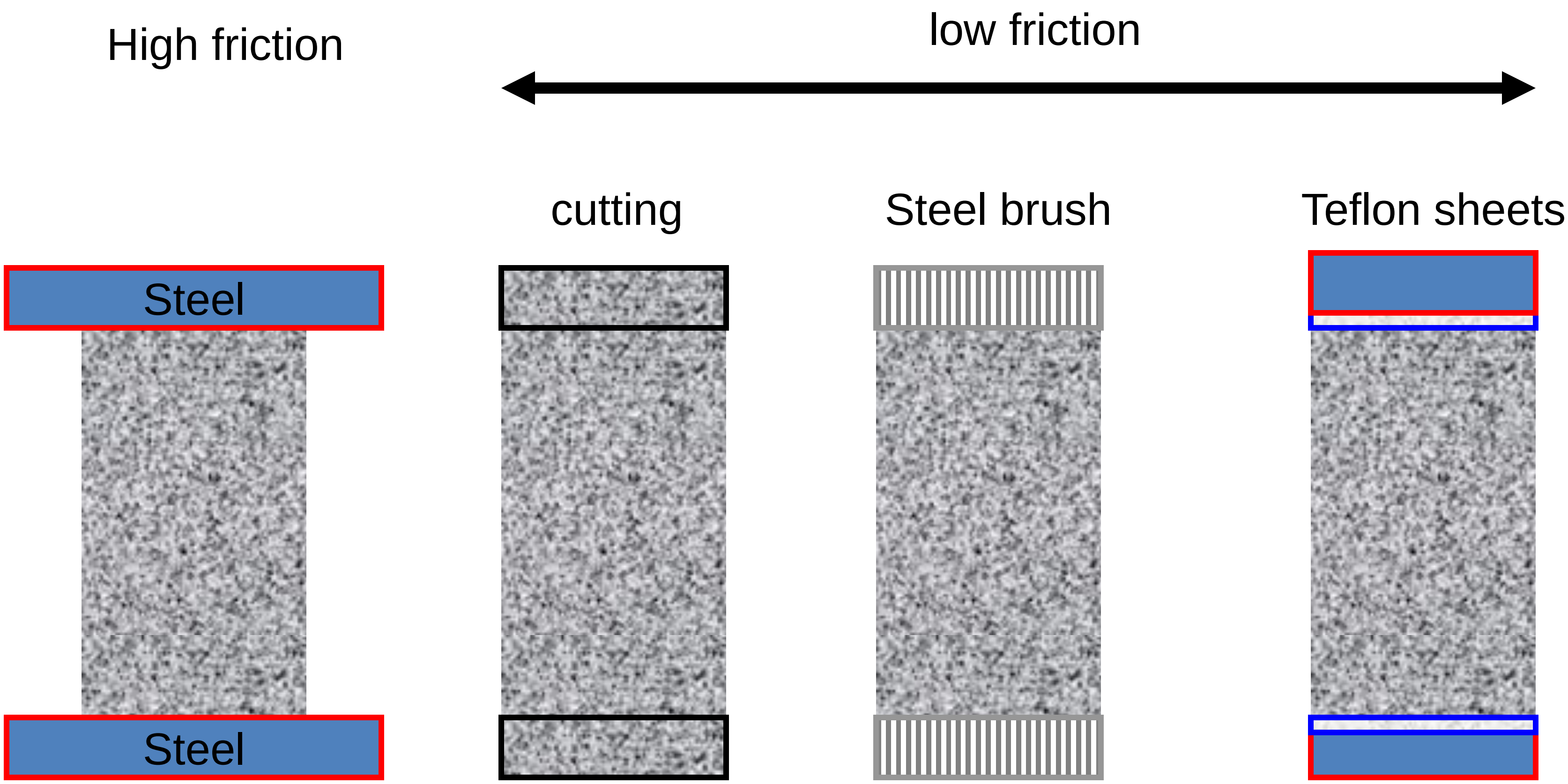
High Strength (Performance) Concrete Buildings



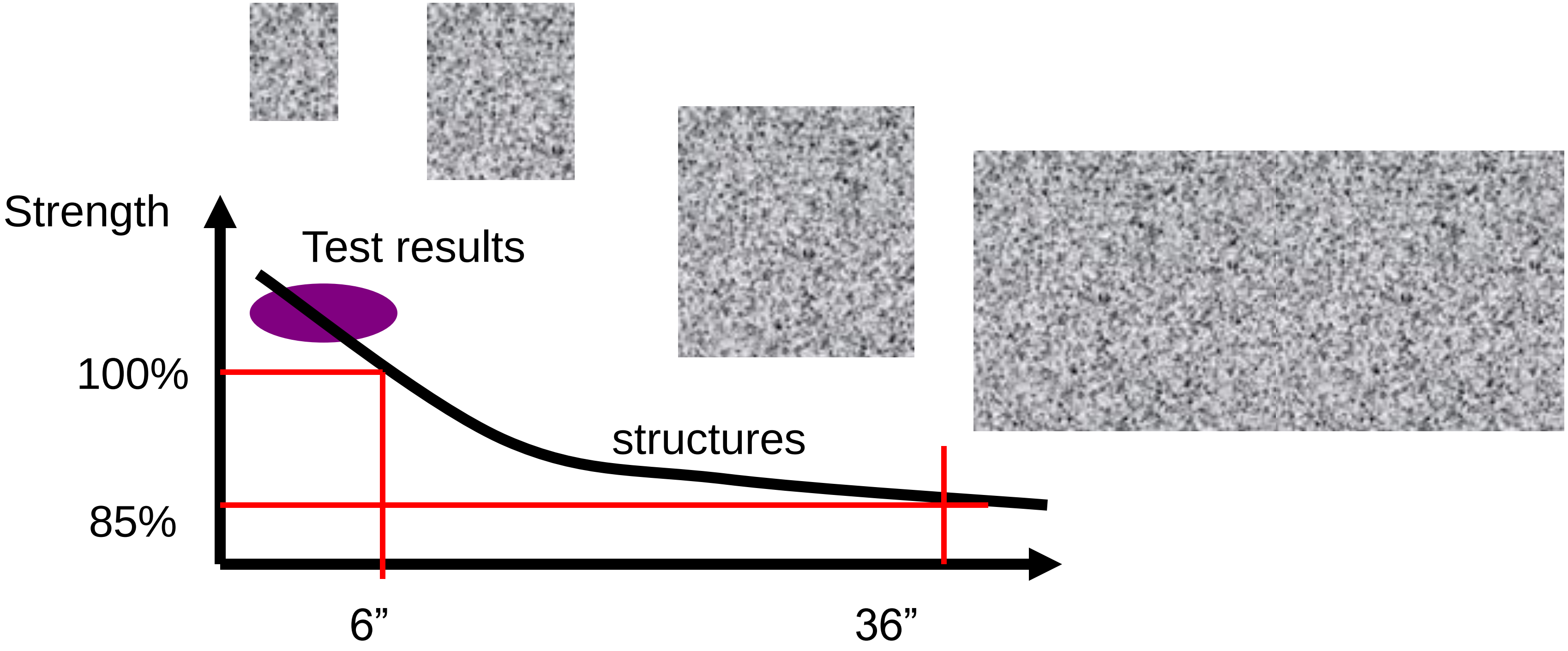
Interplay of strength determinants



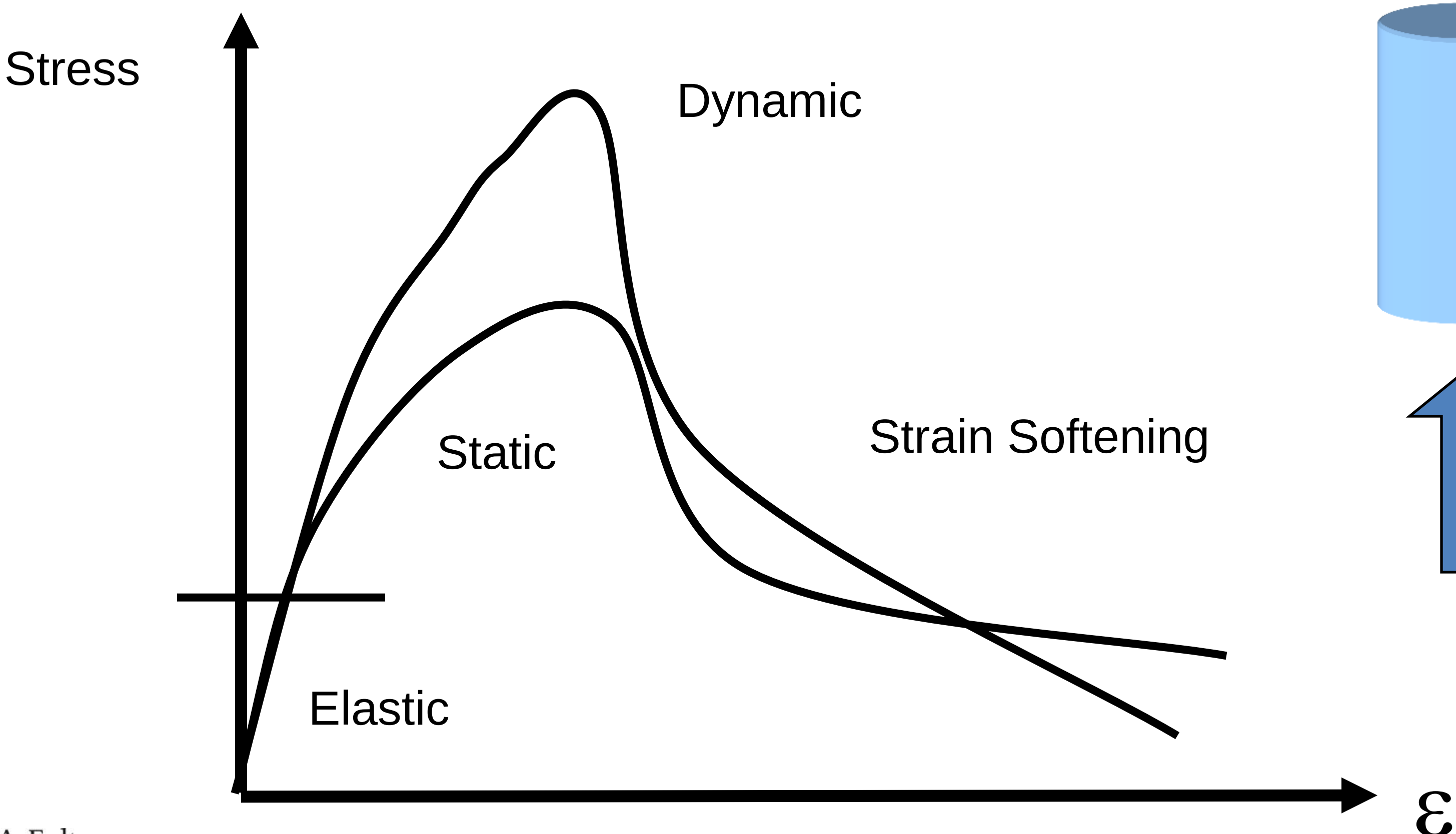
Reducing the friction results in a more uniform state of stress



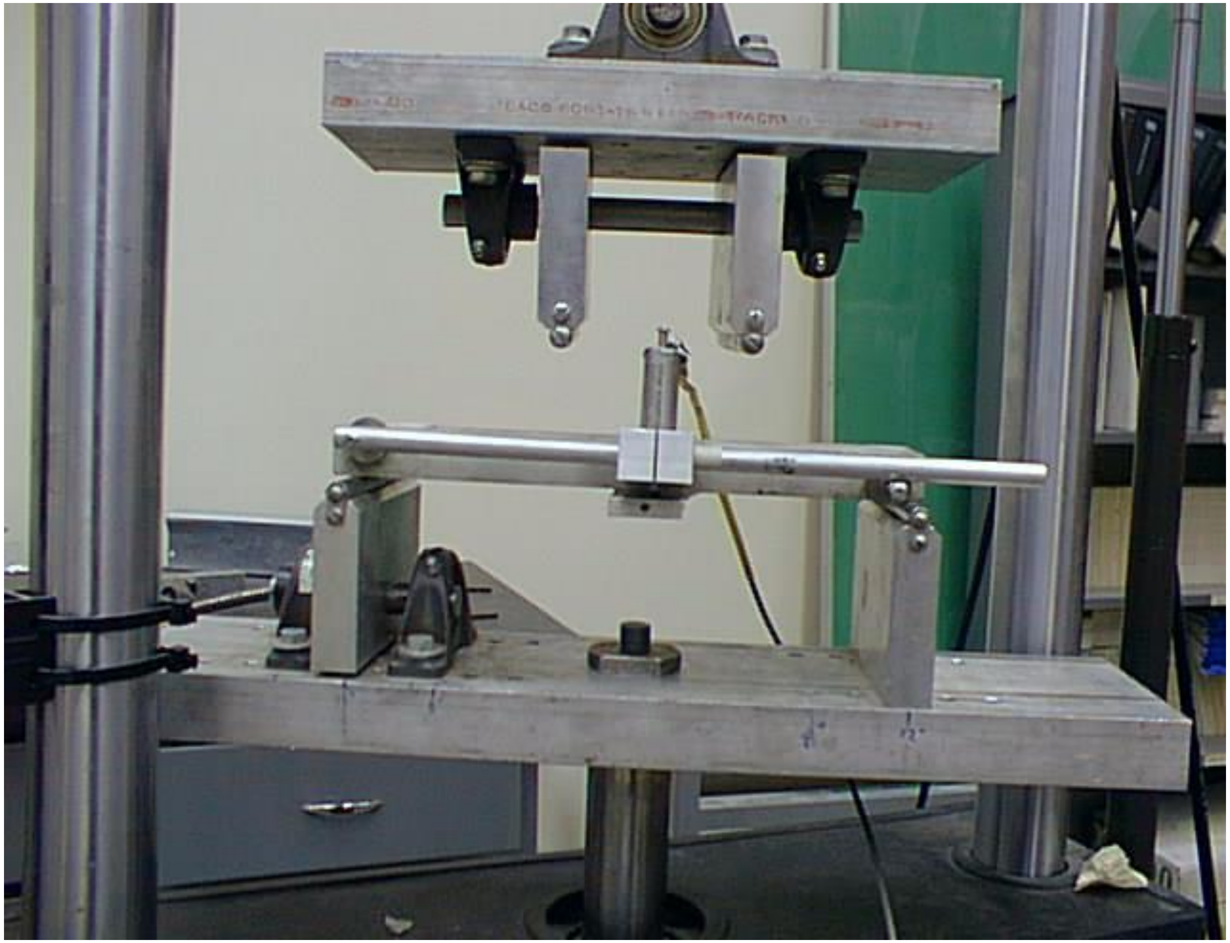
Size Effect



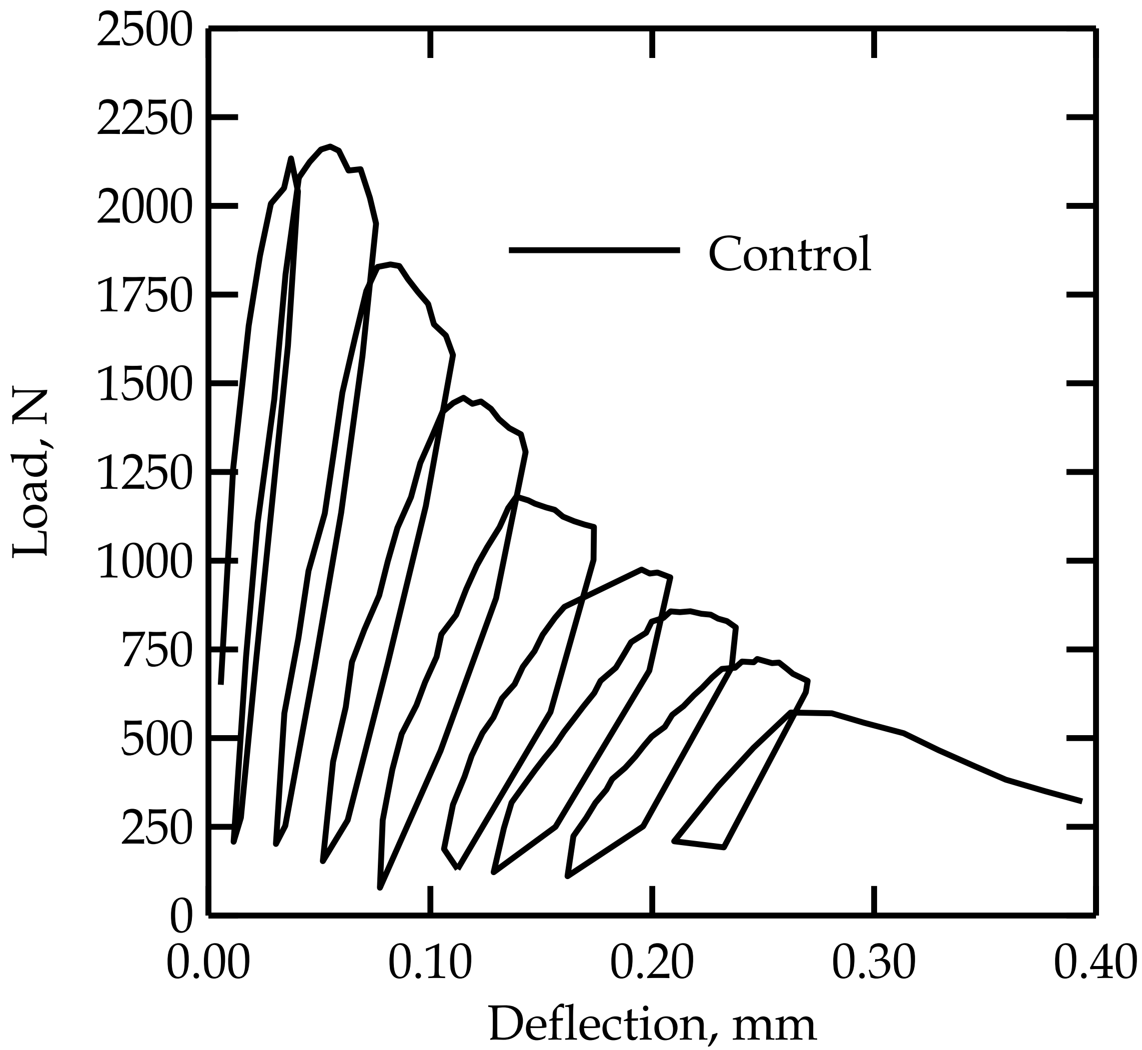
Loading Rate

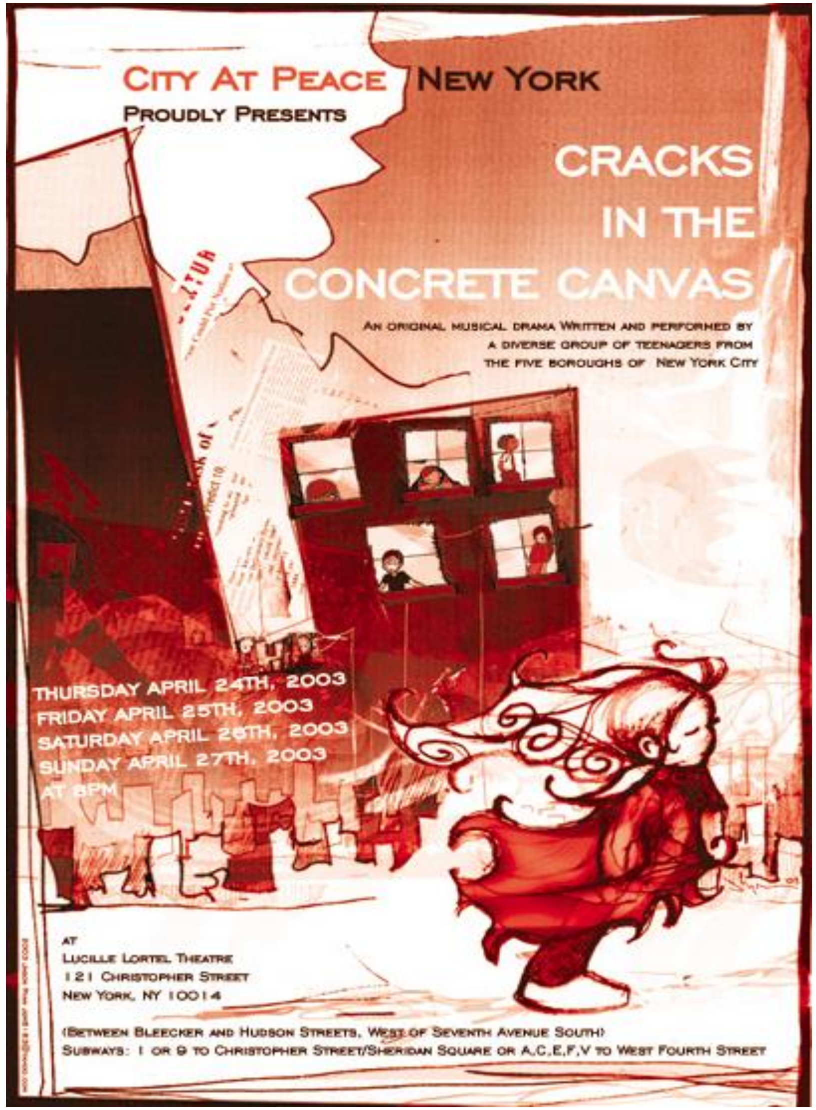


Flexural test

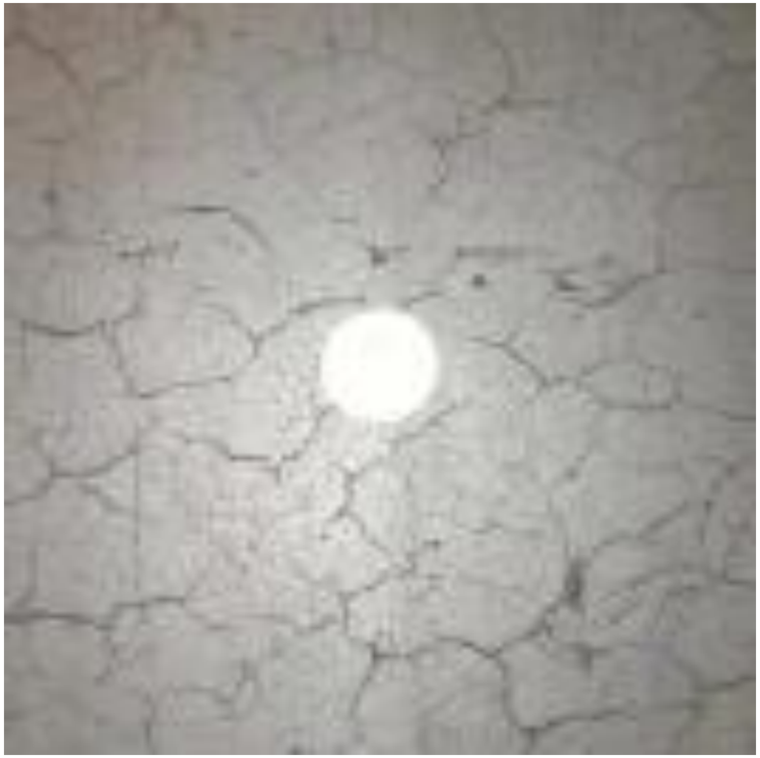


Flexural Test




City At Peace New York
Proudly Presents
Cracks in the Concrete Canvas
An original musical drama written and performed by a diverse group of teenagers from the five boroughs of New York City
Thursday April 24th, 2003
Friday April 25th, 2003
Saturday April 26th, 2003
Sunday April 27th, 2003
at 8PM
at
Lucille Lortel Theatre
121 Christopher Street
New York, NY 10014
(Between Bleecker and Hudson Streets, West of Seventh Avenue South)
Subways: 1 or 9 to Christopher Street/Sheridan Square or A,C,E,F,V to West Fourth Street

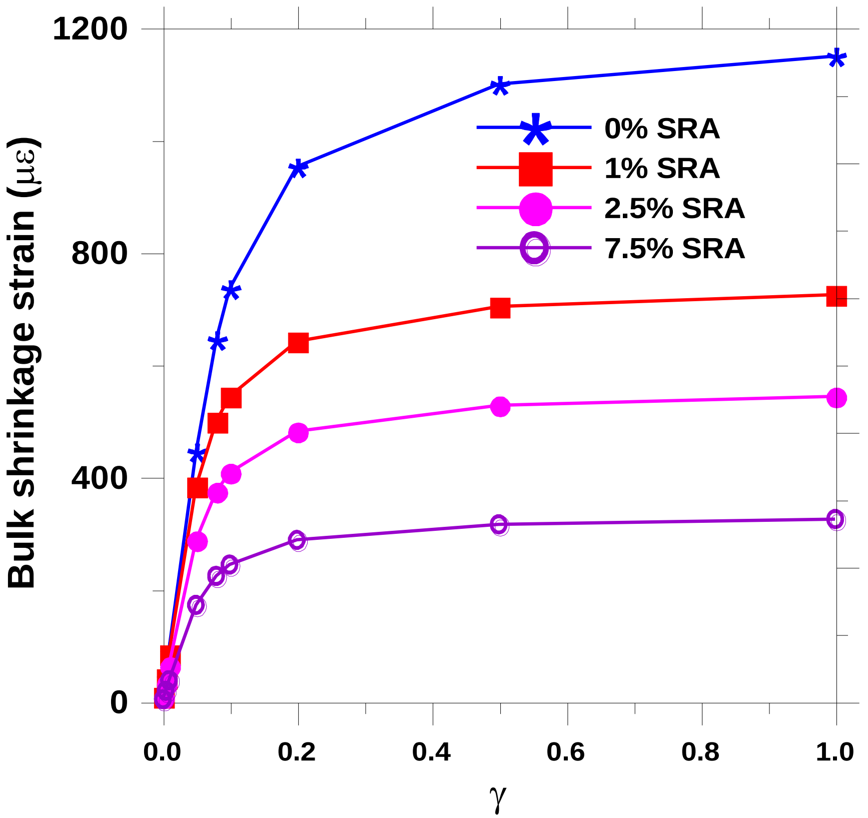
Aesthetically unpleasing



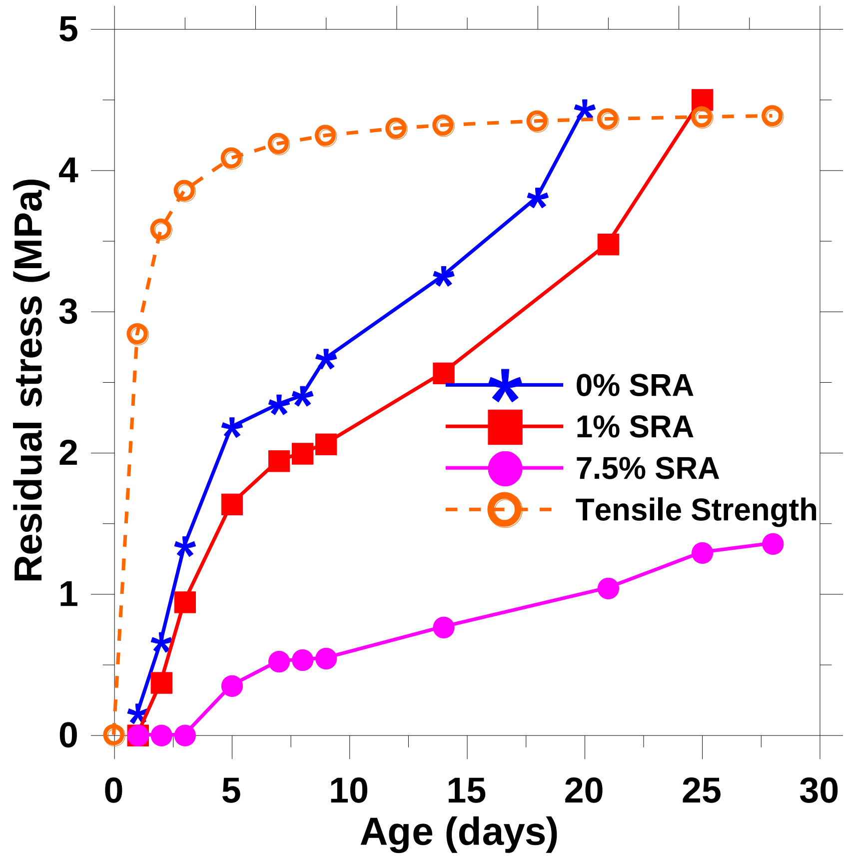
Why is Shrinkage important ?

- Transverse cracking observed in 100,000 + bridges in the US
- Early age cracking an important issue for state DoTs
- Cracks enhance the risk for further durability problems like corrosion, sulfate attack etc.
- Increased maintenance costs, reduced life

Influence of SRAs



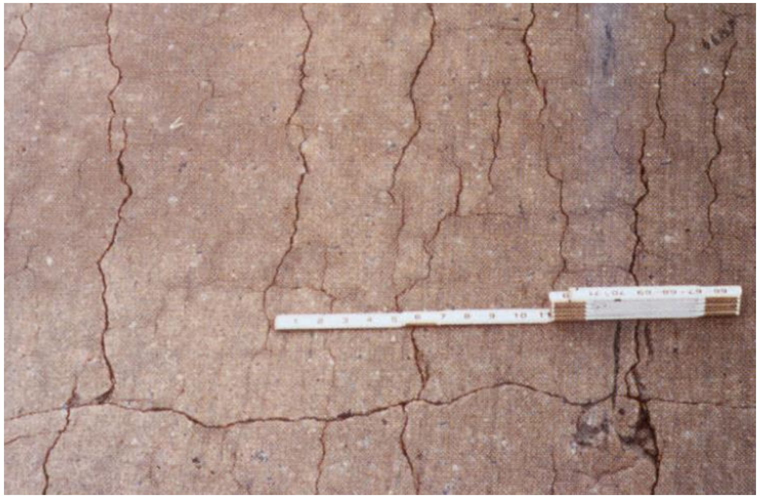
= f (time, Diffusion coefficient)



$$\gamma = 2\sqrt{D_m t}$$

Neithalath et al. 2005

Concerns with Durability



Concerns with Structural integrity

Freezing and thawing damage

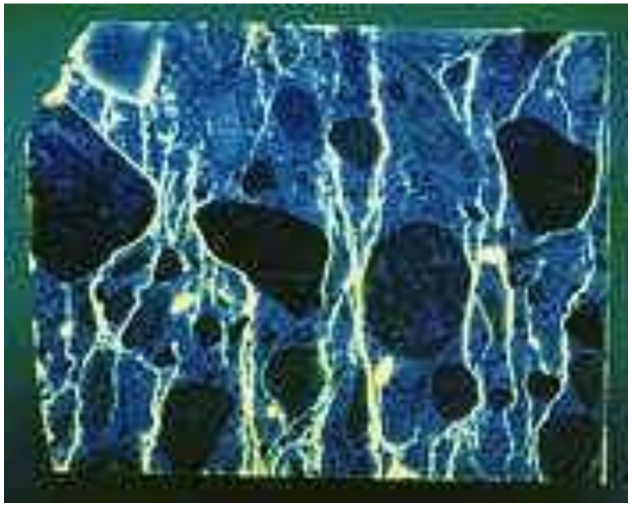
Freeze – Thaw Deterioration

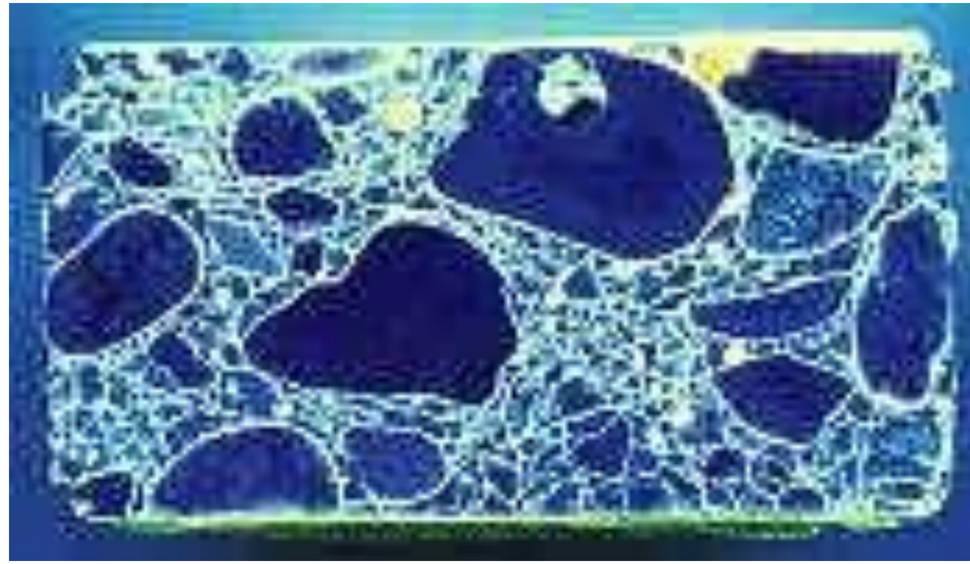
In northern climates, concrete's most persistent problem is deterioration caused by freezing and thawing.

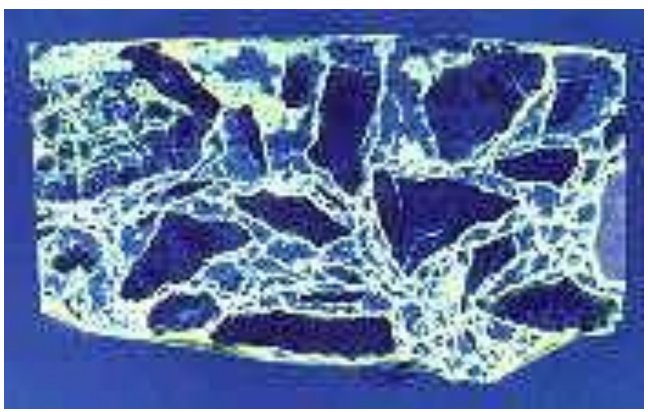
F-T exposure

Fig. 8-3. Effect of weathering on boxes and slabs on ground at the Long-Time Study outdoor test plot, Project 10, PCA, Skokie, Illinois. Specimens at top are air-entrained, specimens at bottom exhibiting severe crumbling and scaling are non-air-entrained. All concretes were made with 335 kg of Type 10 (Type I) portland cement per cubic metre. Periodically, calcium chloride deicer was applied to the slabs. Specimens were 40 years old when photographed (see Klieger 1963 for concrete mixture information). (69977, 69853, 69978, 69854)

Concrete subjected to F-T



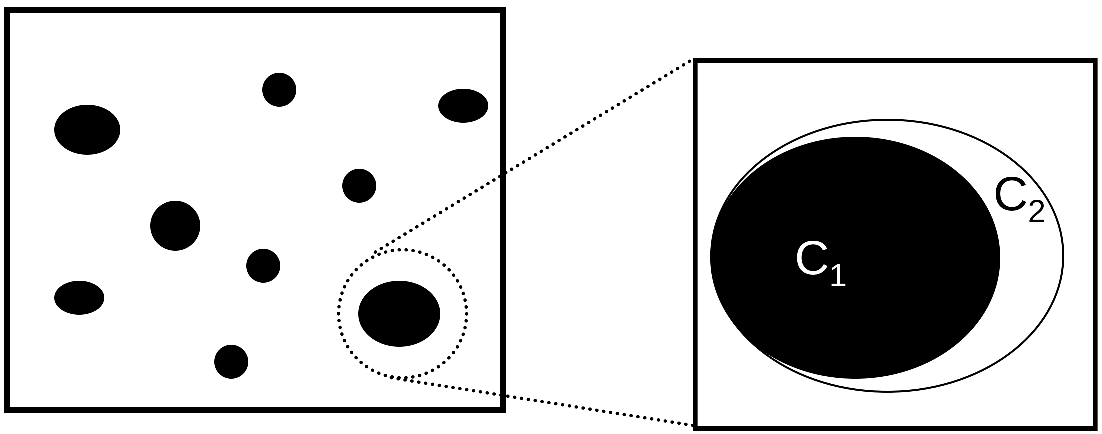




Frost / F-T Action in Concrete

Volume of Ice > Volume of water

$C_2 > C_1$



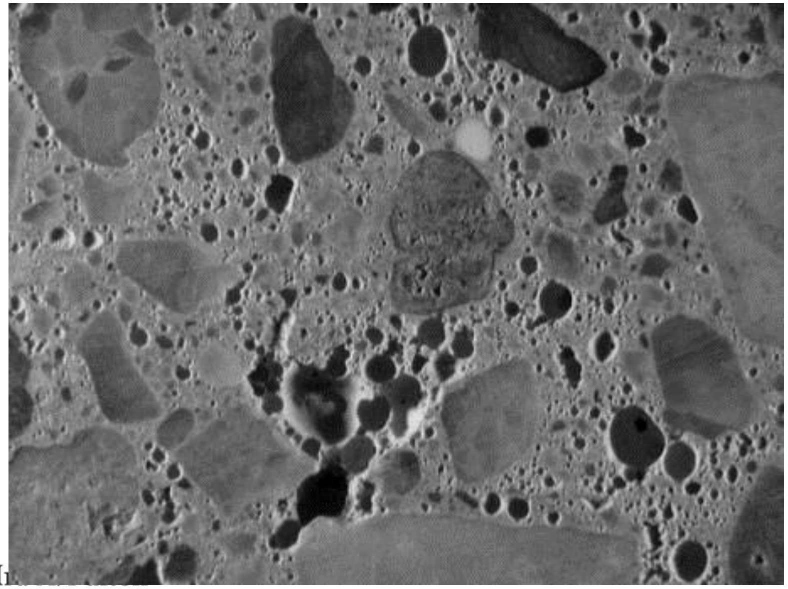
As water freezes,
It expands by 9% -
Hydraulic Pressure

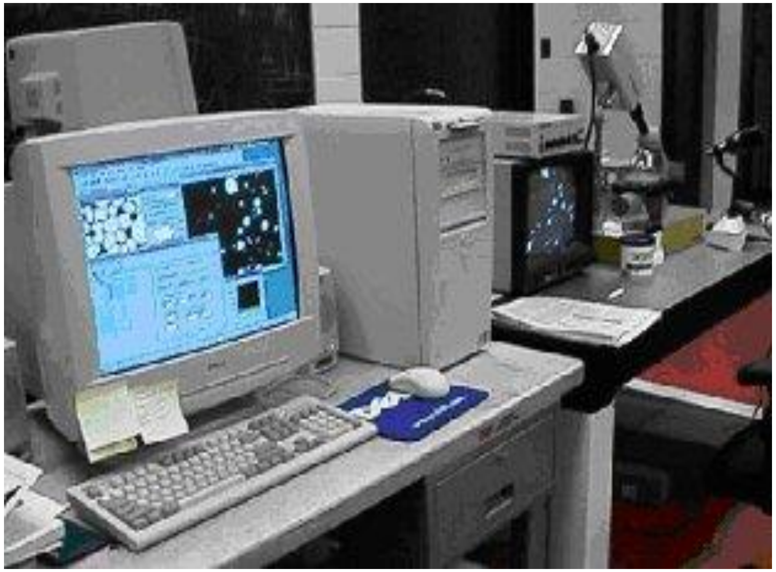
Pore water in concrete
is Ionic
Osmotic Pressure

Hydraulic Pressure
Osmotic Pressure → **Stresses**
Cracking and Spalling

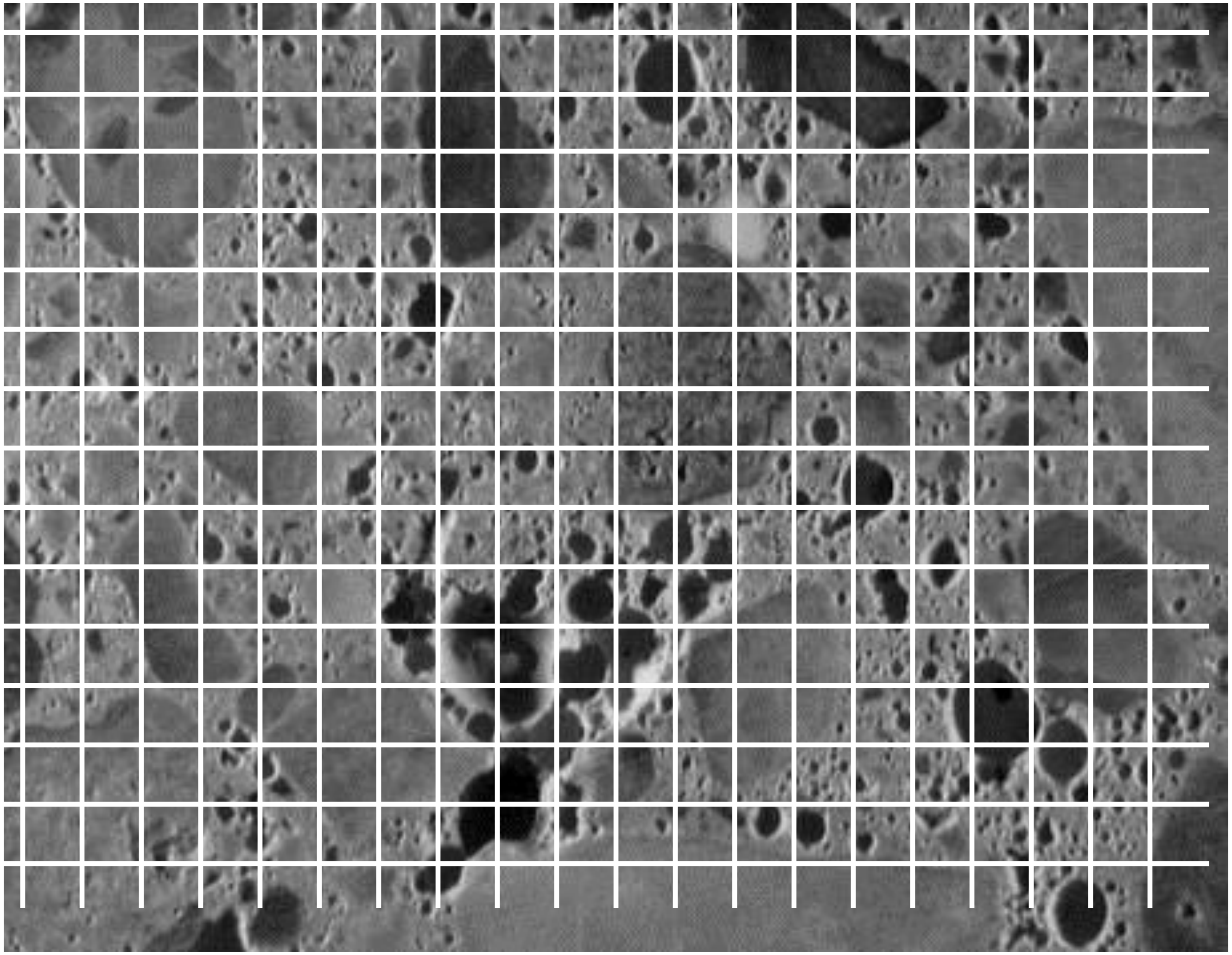
Air void size and distribution

- Hardened concrete analysis – polished section
- Air void content in the hardened state may be different from that in the fresh state – field changes
- Air void size, spacing also important to achieve good F-T resistance





ASTM C 457 – Point Count or Linear Traverse



Scaling of Concrete

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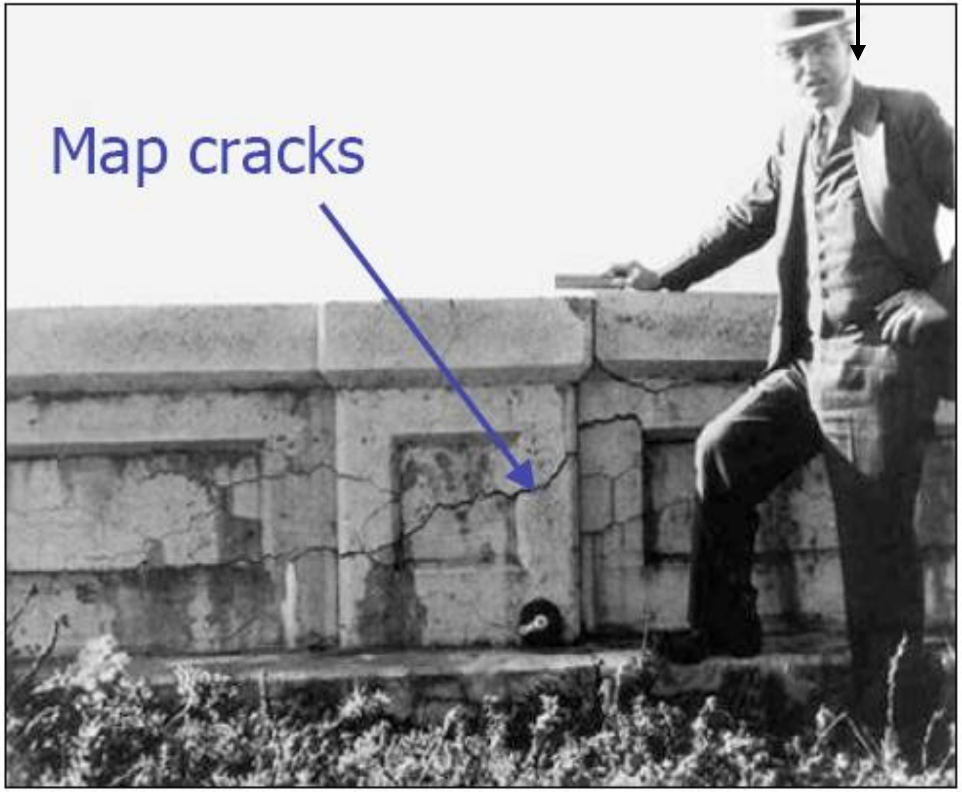
Alkali-Silica Reaction (ASR)

Damages in California Highway system

Thomas E. Stanton

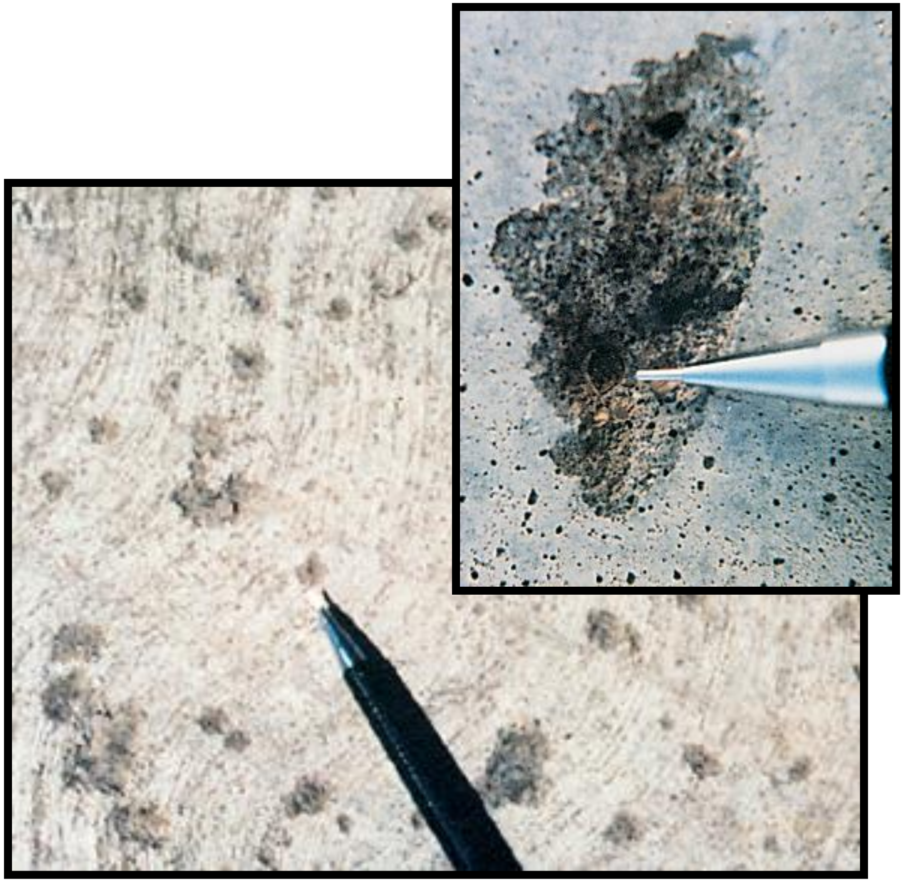


Vertical cracks

California, 1936

Mehta and Monteiro 2005

Alkali-Silica Reaction (ASR)



- Visual Symptoms
  - Network of cracks
  - Closed or spalled joints
  - Relative displacements
  - Fragments breaking out of the surface (pop-outs)

Mechanism

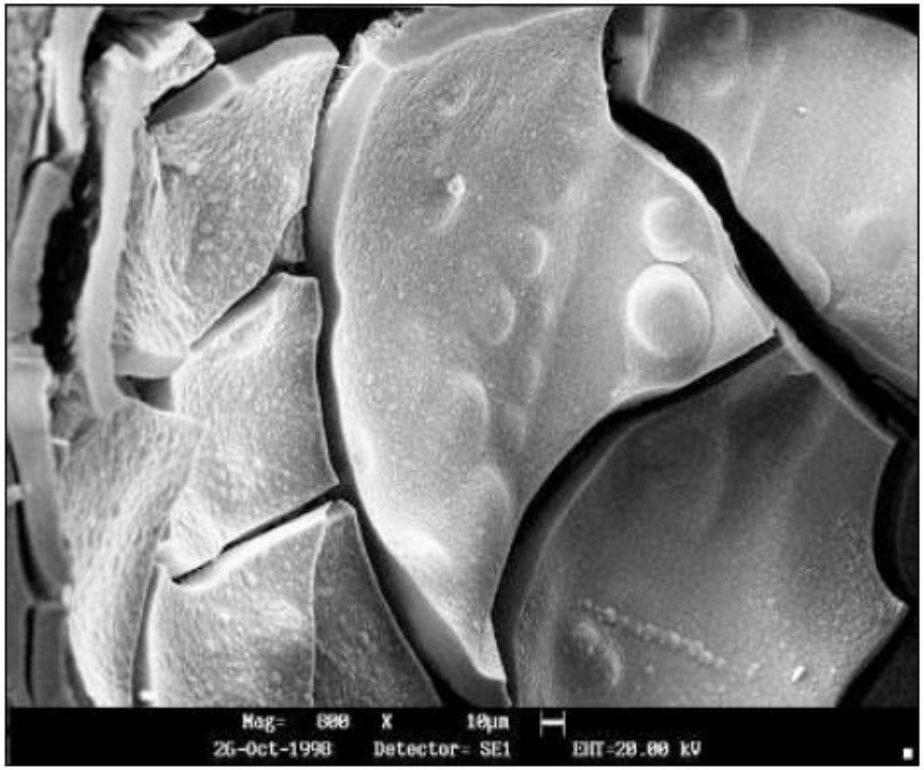
1. Alkali hydroxide + reactive silica gel ⇒ reaction product (alkali-silica gel)
2. Gel reaction product + moisture ⇒ expansion

ASR Gel

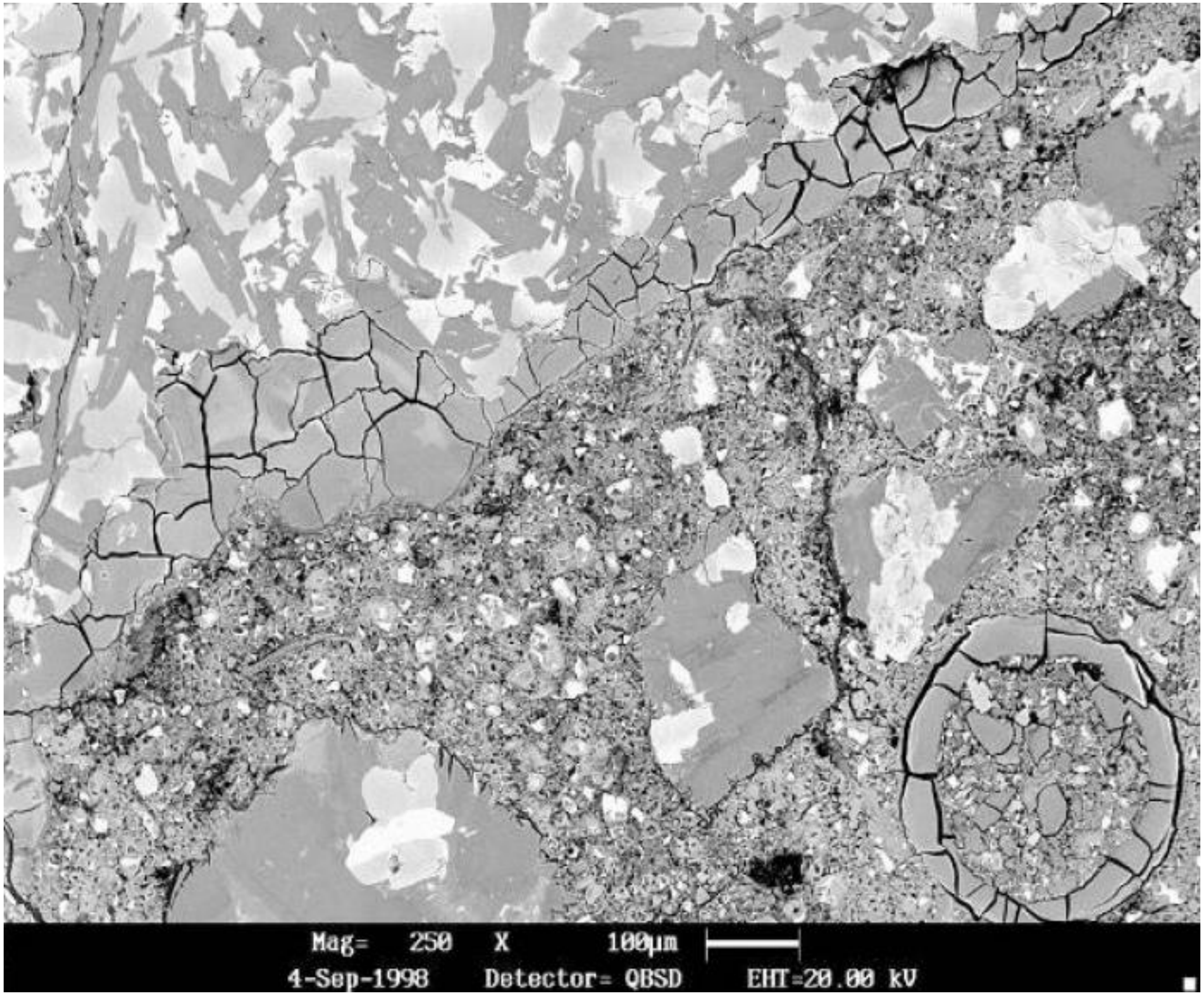

ASR gel
quartzite particle
ASR reaction with quartzite particle

PCA

Reaction products

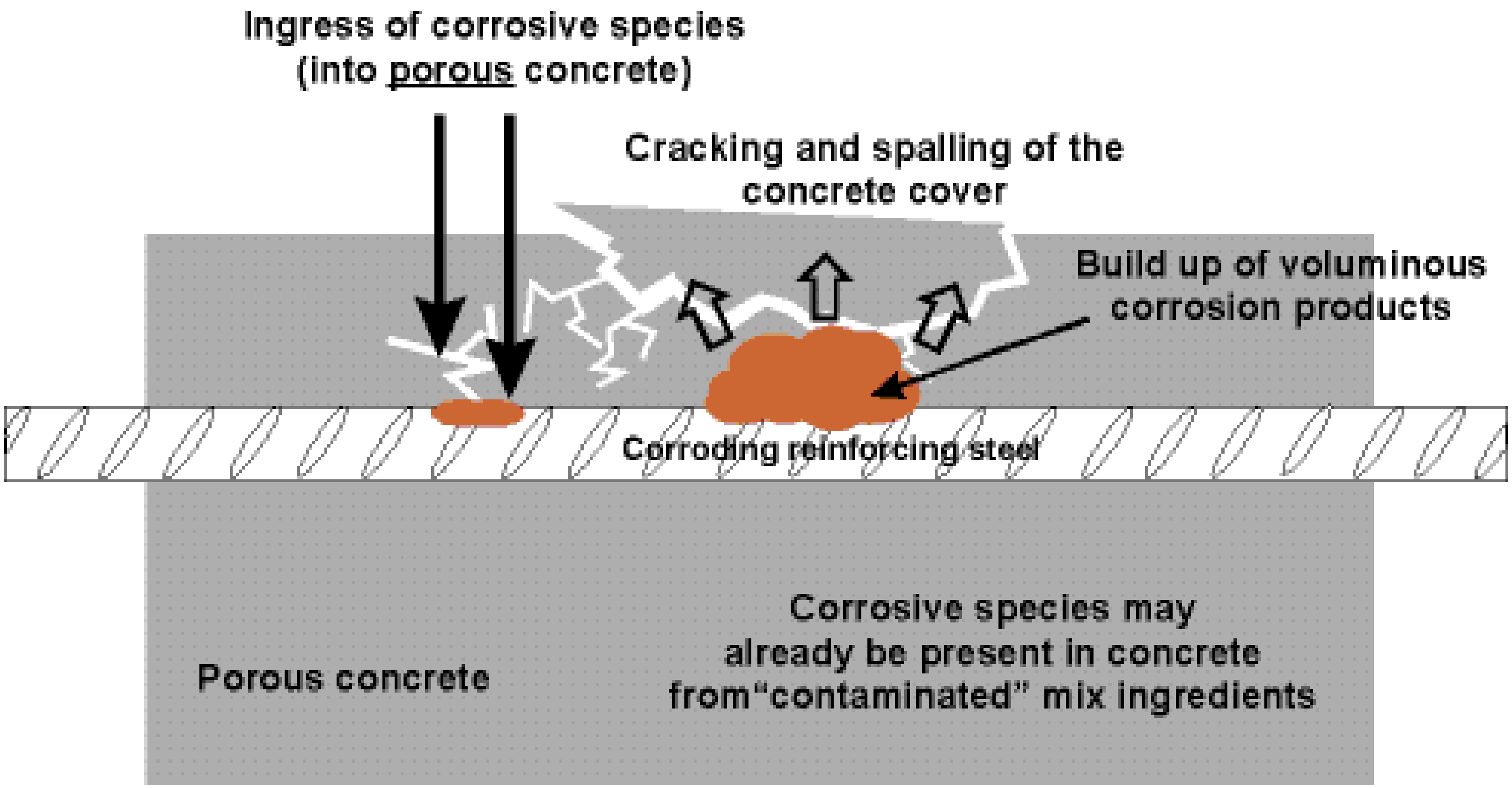


Backscattered SEM image

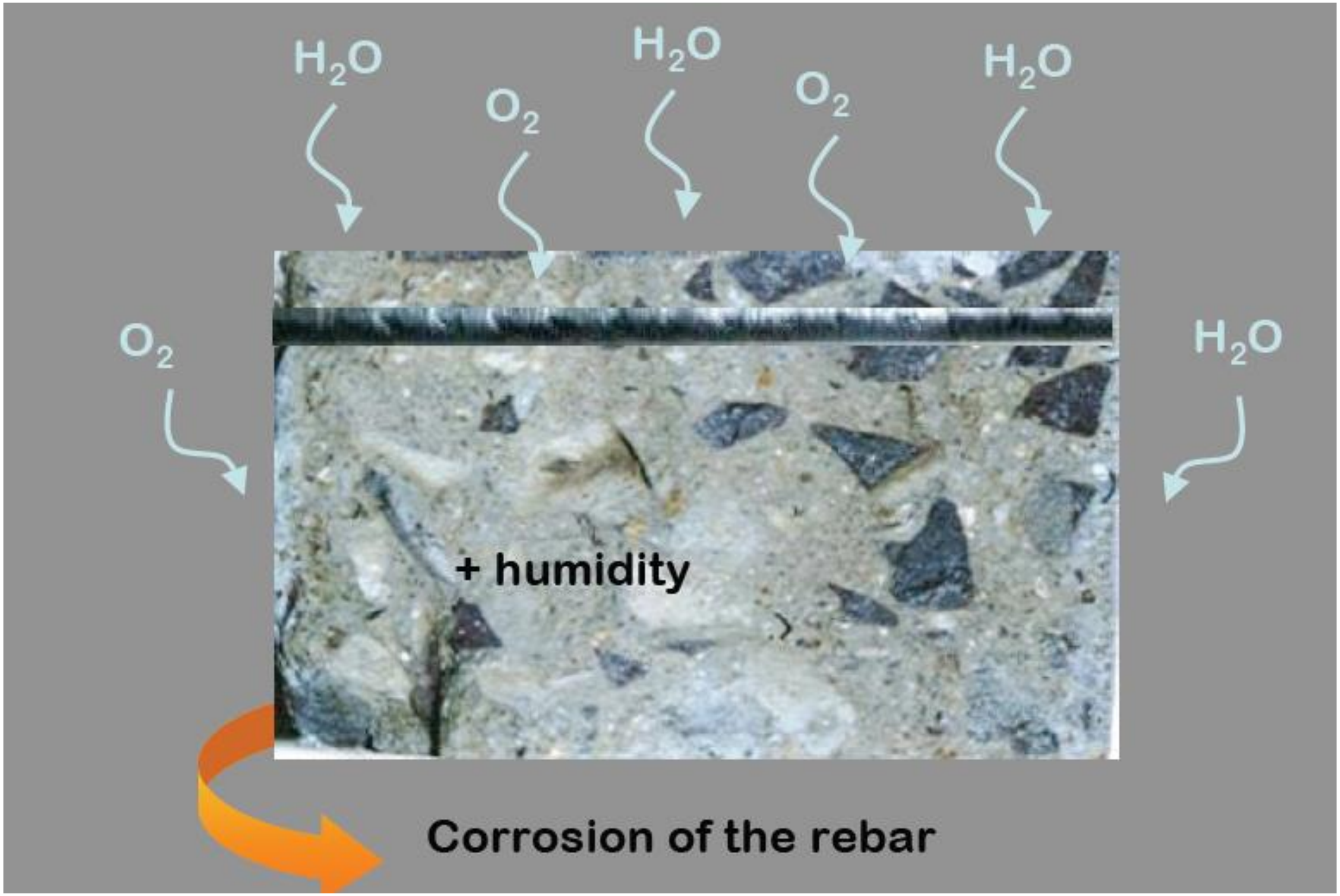


Mehta and Monteiro 2005

Reinforcing Steel Corrosion 101



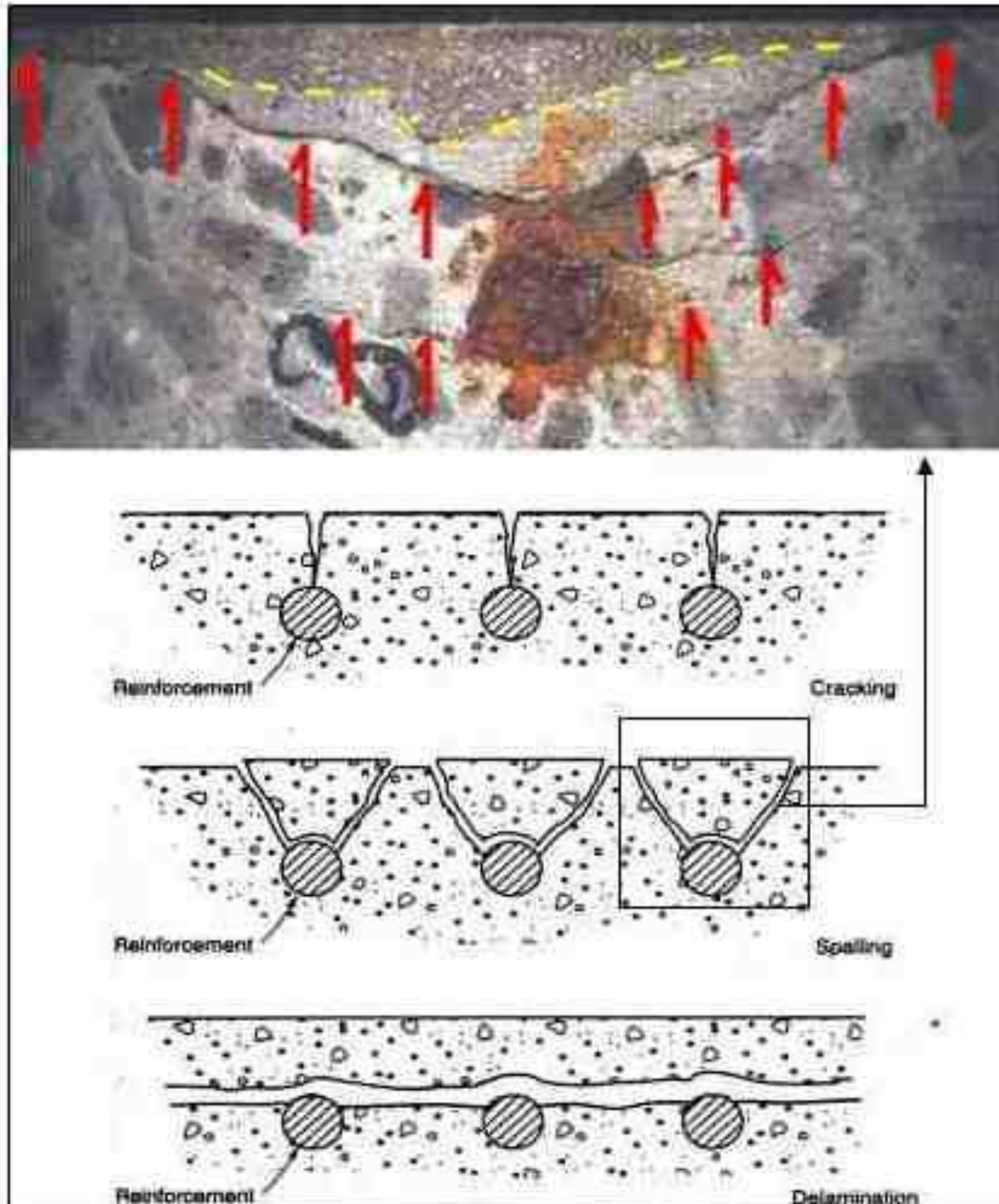
Factors needed for corrosion



Effects of Corrosion

Corrosion of Steel

Delamination due to corrosion



Pop outs and Corrosion spalling

Chloride Penetration into Concrete

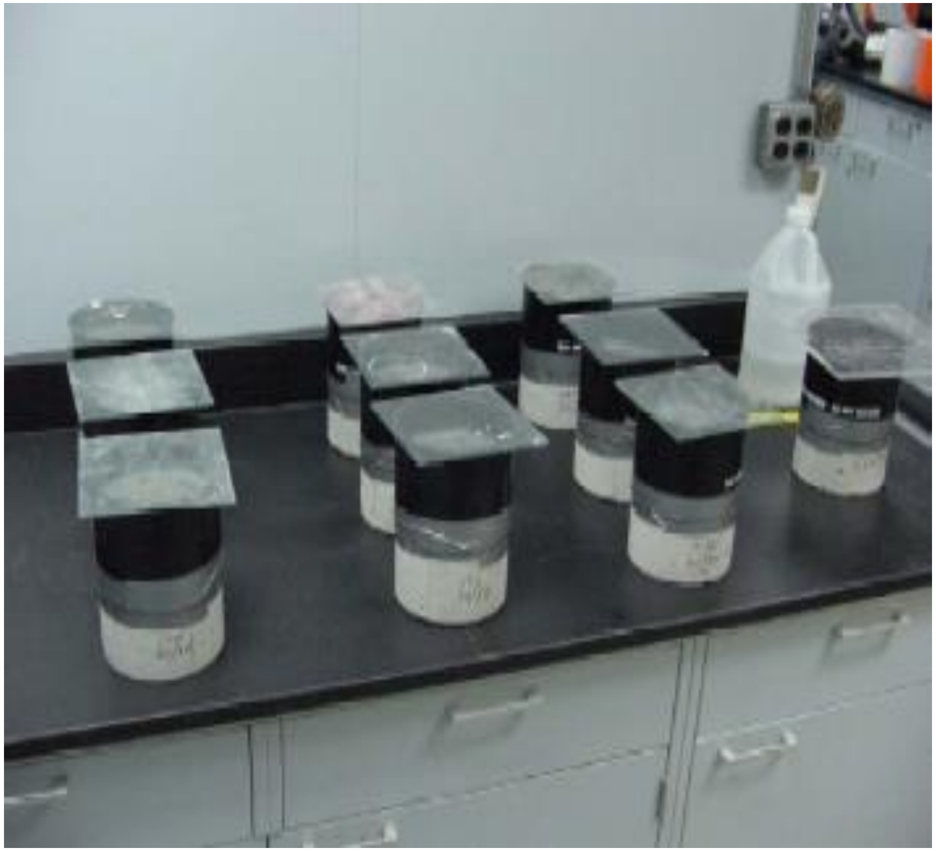
Rapid Chloride Permeability Test

- Slices 2" thick from cores used for RCPT
- ASTM C 1202
- Allowing chloride ions to pass through concrete under a concentration gradient
- Measuring the chloride ion passage in terms of electrical charge passed (Coulombs)

Chloride Penetration into Concrete

- Ponding the surface of concrete with solution rich in chlorides
- Represented as lbs/cy absorbed after a certain amount of time

Chloride Ponding Test



Tips for good bridge and pavement concretes

- Workability
  - Aggregate gradation
  - Cement replacement materials
  - Admixtures
- Hydration
  - Right amount of cement (cracking because of heat)
  - Cement replacement materials / secondary reaction
  - Fillers
  - Temperature
  - Curing

Tips for good bridge and pavement concretes

- Strength
  - Cement content, packing of particles, water content
  - Curing
  - Cement replacement materials/fillers
- Volume changes (Shrinkage)
  - Cement and water contents
  - Paste properties
  - Admixtures
- Durability
  - Cement and water contents
  - Replacement materials