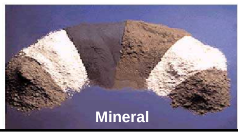
Admixtures

Section 6.11[†]

[†] Mamlouk, M.S., and Zaniewski, J.P. (2006). ***Materials for Civil and Construction Engineers***, 2nd ed., Prentice Hall

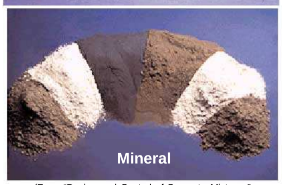


Use of Admixtures

- To reduce the cost of concrete construction
- To achieve certain properties more effectively
- To maintain quality of concrete from mixing to placement & curing in adverse weather

Types of Admixtures

- Chemical
  - < 4% by weight of cement
- Mineral
  - > 10% by weight of cement



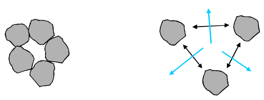
(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Summary of Chemical Admixtures

Type	Description	ASTM	Application
A	Water-reducing	C494	To get dense concrete, to improve workability
B	Retarding	C494	To delay setting & hardening; hot weather; large structures
C	Accelerating	C494	To accelerate setting & early strength development; cold weather
D	Water-reducing & retarding	C494	Similar to types A & B
E	Water-reducing & accelerating	C494	Similar to types A & C
F	Water-reducing, high-range	C494	To improve watertightness & workability; high-strength concrete
G	Water-reducing, high-range, & retarding	C494	Similar to types B & F
	Air-entraining	C260	To improve durability & workability
	Antifreeze		To minimize freezing of water in fresh concrete; cold weather

Water-Reducing Admixtures

- Reduce amount of mixing H_2O to produce concrete of high slump
  - by dispersing cement particles → reducing the viscosity



Types of Water-Reducing Admixtures

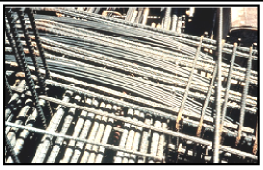
- Normal range
  - decreases H_2O requirement by 5-7%
- Mid-range
  - decreases H_2O requirement up to 12%
- High-range (superplasticizers)
  - decreases H_2O requirement by 12-30%

Applications of Flowing Concrete

- Thin-section placement
- Areas congested w/ reinforcement
- Underwater placement
- Pumped concrete
- Reduced handling costs

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

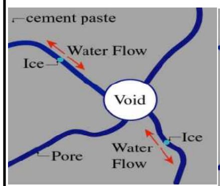
Applications of Flowing Concrete

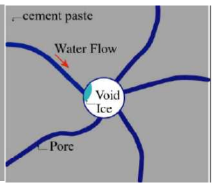



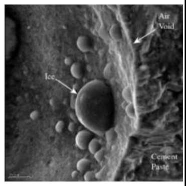

Flowing concrete as thin overlay

Air-Entraining Admixtures

- Introduce microscopic air bubbles in concrete
  - disruption of continuity of capillary pores
  - reduce internal stress caused by expansion of frozen pore H_2O

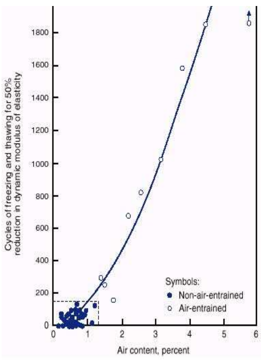






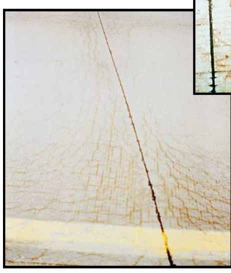
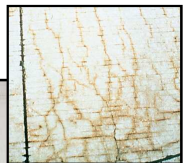
(From "Concrete: Microstructure, Properties and Materials" by P.K. Mehta and P.J.M. Monteiro)

Cycles of F/T vs. Air Content



(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Frost damage

Mineral Admixtures

- Commonly used to replace part of cement or sand
  - ***supplementary cementing materials*** (CSA A23.5)
- To improve workability, durability and cementing properties
- Added to concrete in larger quantities than chemical admixtures (10 – 35% by mass)

Summary of Mineral Admixtures

Type	Description	ASTM	Application
N	Raw or calcined natural pozzolan	C618	To improve durability & decrease permeability
F	Fly ash, bituminous coal origin	C618	To increase strength
C	Fly ash, lignite ash or subbituminous coal origin	C618	
SF	Silica fume		To improve watertightness; high-strength concrete
S	Blast-furnace slag		

Pozzolans

- When finely divided & in the presence of H_2O react w/ $Ca(OH)_2 \rightarrow$ **C-S-H**
  - ***pozzolanic reaction***
  - slower rate
  - lower strength at early age
  - ultimate strength is the same, if not greater

Benefits of Adding Pozzolans

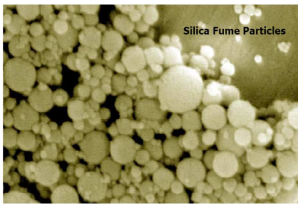
- Make concrete less permeable & more durable
- Lower heat of hydration & shrinkage
- As a finely divided material, it can:
  - reduce bleeding
  - decrease segregation
  - increase strength

Fly Ash

- Industrial by-product from burning powdered coal (dust-collection system)
- Finer than PC, small spheres
- Two types:
  - Type F (< 8% of lime)
  - Type C (CI: 8 – 20% of lime, CH: > 20% of lime)
- Cost ~ 1/3 of cement

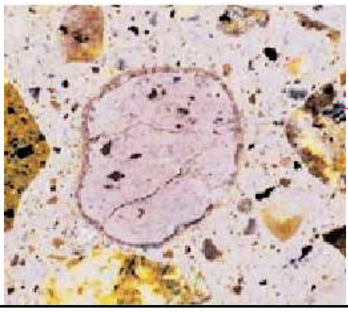
Silica Fume

- Industrial by-product of the manufacture of silicon
- Particles < 0.1 µm (100 x finer than cement)
- Contributes to development of high strength



(From "Concrete: Microstructure, Properties and Materials" by P.K. Mehta and P.J.M. Monteiro)

Durability of Concrete



What we are going to talk about …

- Durability
- Permeability
- Chemical attack
- Physical attack

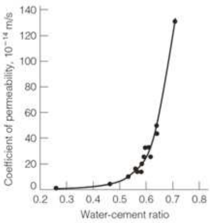
Durability

Ability to resist weathering action, chemical attack, abrasion, or any process of deterioration

Causes of Deterioration

- Chemical
  - Alkali-aggregate reaction
  - Sulphate attack
  - Reinforcement corrosion
- Physical attack
  - Freezing & thawing
  - Fire
  - Surface wear

W/C ratio and permeability

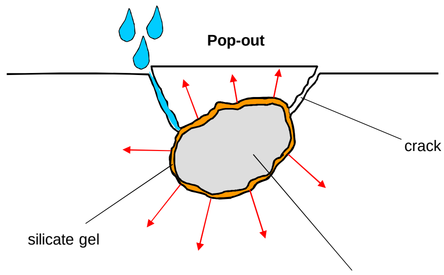


- w/c = 0.3 to 0.7:
- coefficient of permeability increases by a factor of 1000

Alkali-Aggregate Reaction

- Chemical reaction between active minerals in some aggregates & alkalis in hydrated PC
  - alkali-silica reaction (ASR)
  - alkali-carbonate reaction (ACR)
- Prerequisite:
  - alkali-reactive components in aggregates
    - contain alkali-reactive components: silica, carbonate
  - high-alkali content in cement
  - moisture to support reaction

Mechanism of ASR



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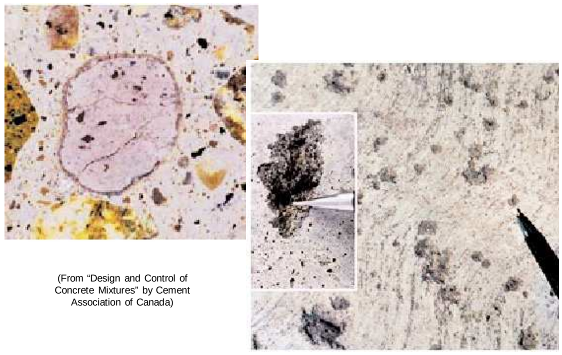
Alkali-Silica Reaction (ASR)



(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

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How to Minimize ASR

- Avoid reactive aggregates (ASTM C227 can determine potential reactivity of aggregates)
- Use of mineral admixtures (supplementary cementing materials: fly ash, blended cements ...)
- Keep concrete as dry as possible (reaction needs water)

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Effects of ASR

- Because deterioration is a slow process the risk of catastrophic failure is low
- Causes serviceability problems, which may result in high maintenance/rehabilitation costs
- Can worsen other deterioration mechanics (frost, chloride, sulphate exposure)

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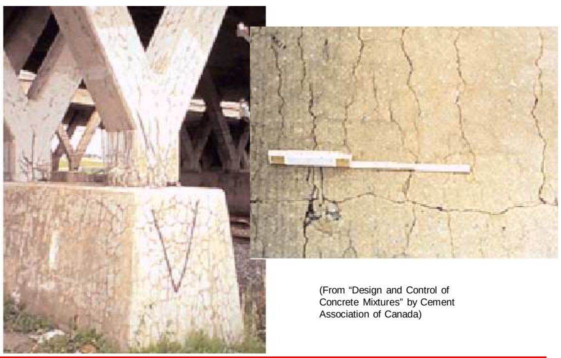
Visual Symptoms of ASR (1)



(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

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Visual Symptoms of ASR (2)

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

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Visual Symptoms of ASR (3)

(From "Concrete" by Mehta & Monteiro)

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Sulphate Attack

Sulphate ions:

- penetrate concrete from surrounding
- react with hydrated C_3A
  - ✓ volume expansion takes place
  - ✓ generation of internal stresses
  - ✓ scaling & cracking of concrete

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Field Performance in Sulphate Environment

12-yr old concrete
(Type 50, w/c = 0.65)

16-yr old concrete
(Type 50, w/c = 0.39)

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

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How to Minimize Sulphate Attack

- Use of cement with low C_3A
  - Type MS (< 7.5%)
  - Type HS (< 3.5%)
- Use of concrete with low w/c
- Use of mineral admixtures

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Reinforcement Corrosion

- In concrete with reinforcing steel, deterioration can also be caused by corrosion of the reinforcement
- Corrosion of reinforcement is an electrochemical process (4 components)
- Corrosion requires the presence of:
  - Moisture
  - Oxygen

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Depassivation of Reinforcement

- Concrete is highly alkaline (pH>13) → provides passive oxide film on reinforcing steel
- This limits access of **oxygen** and **moisture** to steel → prevents corrosion
- When concrete pH < 11.5 → passive iron oxide layer is destroyed (**Depassivation**)

$$Ca(OH)_2 + CO_2 \xrightarrow{H_2O} CaCO_3 + H_2O$$

- Corrosion can initiate (cycle begins!)

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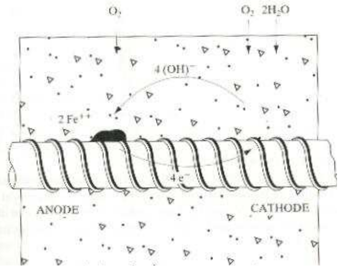
Reinforcement Corrosion



- Anode

  $2Fe \rightleftarrows 2Fe^{++} + 2e^-$
- Cathode

  $4e^- + O_2 + 2H_2O \rightleftarrows 4OH^-$
- Conductor (rebar)
- Electrolyte (pore solution)

$$Fe^{2+} + 2(OH)^- \rightarrow Fe(OH)_2$$

$$2Fe(OH)_2 \xrightarrow{O_2,\, H_2O} 2Fe(OH)_3 \rightarrow Fe_2O_3 \cdot nH_2O$$

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Corroded Reinforcement

(Courtesy of Dr. D. Cusson, National Research Council Canada)

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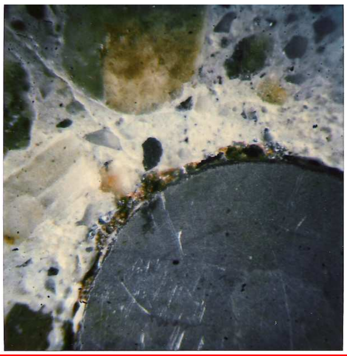
Corrosion Build-Up



(Courtesy of N. Mailvaganam, National Research Council Canada)

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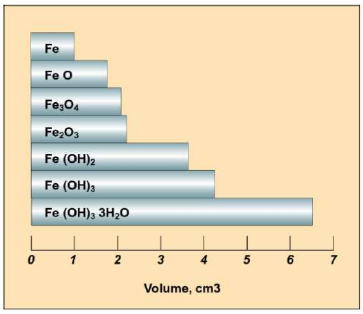
Volume of Corrosion Products



(From "Concrete: Microstructure, Properties and Materials" by Mehta and Monteiro)

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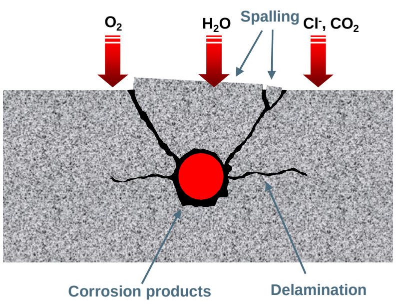
Stages in Corrosion-Induced Damage



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Effect of Carbonation

- **CO_2** causes **carbonation of concrete → Depassivation**
- Using adequate concrete "cover" for reinforcement will prevent corrosion due to carbonation

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

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Carbonation of Concrete

Spraying with **phenolphtalein**

Concrete exposed to CO_2

Carbonated concrete

(From "Concrete: Microstructure, Properties and Materials" by Mehta and Monteiro)

Methods to Reduce Corrosion (1)

- Reduction of permeability of concrete
  - Low w/c, proper curing, mineral admixtures
  - Increasing concrete cover (≥ 60 mm)
- Protective membranes on concrete
  - Concrete overlays (LMC, LSDC, SF)
  - Surface treatments with water-repellent materials
  - Sealers

Methods to Reduce Corrosion (2)

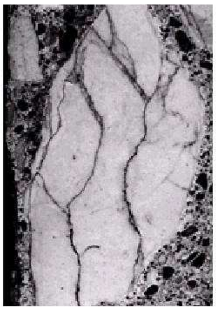
- Protective coatings on steel
  - Epoxy-coated reinforcing steel
  - Galvanized (zinc-coated) reinforcing steel
  - Stainless-steel reinforcement
- Suppression of electrochemical process
  - E.g. Cathodic protection

Epoxy-Coated Reinforcing Steel

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Freezing of Aggregates

- Porous aggregates also susceptible to freeze/thaw damage
- Build-up of hydraulic pressure as water freezes in pores



(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Scaling From Freeze-Thaw Action

(Courtesy Mr. N. Mailvaganam, National Research Council Canada)

Fire Resistance

- Concrete exposed to high temperatures:
  - is incombustible
  - does not emit toxic fumes
  - retains strength for some time
- For T > 500ºC, strength degradation high
  - Evaporation of water within concrete
  - Differential expansion between paste & agg.
  - Breakdown of hydrates

Durable Concrete

- Cement paste with high density & low permeability
- Entrained air to resist freezing & thawing
- Strong & inert aggregates
- Minimum amount of impurities in concrete mix
- Proper curing (basic curing + 4d or $0.7f'_c$)