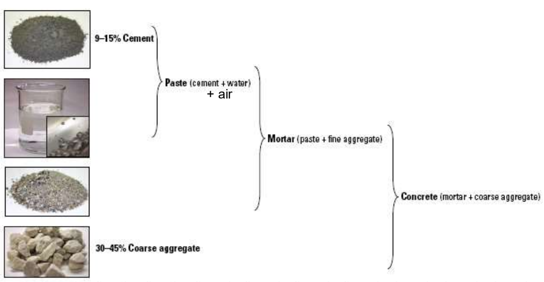
Section 3
Fundamentals of Concrete

WMTC Concrete Training & Certification Seminar

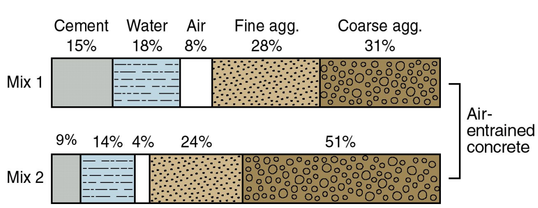
Concrete

A mixture of cementitous materials, water, air and aggregates



Cementitious materials = portland cement + supplementary cementitous materials
e.g., Fly Ash (Type F)

Rich and Lean Mixes



Paste binds aggregates into a rocklike mass.

Portland Cement

- Fine powder that reacts with water to form a rocklike mass
- **Hydration** - chemical reaction between portland cement & water

  Portland Cement + Water = Hydration Products + Heat

- Hydration products resembles color of natural limestone quarried on the Island of Portland
- Hydration begins as soon as cement comes into contact with water or moisture
- Favorable temperature and moisture conditions required for hydration to occur

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Types of Cement

Type I — **General purpose**
- suitable for all uses

Type II — **Moderate sulfate resistant or low alkali***
- protects against moderate sulfate attack
- generates less heat at slower rate than Type I

Type I/II — **Meets requirements of both Type I & II**

Type III — **High early strength**
- provides high strength at early period
- generates heat faster than Types I or II

Type IV — **Low heat of hydration**
- develops strength & heat at slower rate than other types

Type V — **High sulfate resistant**
- use when concrete exposed to severe sulfates
- gains strength slower than Type I or I/II

***Required for WYDOT Structural & Pavement Concrete** (SSRBC 801.1)

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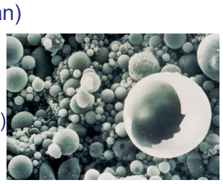
Fly Ash – Supplementary Cementitious Material (SCM)

- Used in over 50% of concrete placed in US
- By product of burning ground coal in power plants
- Types F and C (F is gray & C is tan)
- Small spherical shape (10um)
- Pozzolans – chemically reactive
- Mitigates ASR (alkali-silica reaction)
- Reduces water demand
- Setting time may be delayed
- Early strengths may be depressed
- Concrete permeability reduced (improved durability)



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Alkali-silica Reaction

Alkali Hydroxide + Reactive Silica = Reactive Product

Gel Reaction + Moisture = Expansion

Symptoms:
1. **Network of cracks**
2. **Relative displacements**
3. **Pieces breaking off**
4. **Closed or spalled joints, general deterioration**

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ASR

Factors
1. Reactive forms of silica in the aggregate
2. High-alkali (pH) pore solution
3. Sufficient moisture

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- **Water** (SSRBC 814.1)
  - Clean & free of oils, salt, acid, alkali, sugar, vegetable or other harmful substances
  - Potable water - no testing required
  - Unknown quality - Table 814.1.2-1
    Max. chloride ion content - 1000 PPM

    pH level between 4.5 & 8.5
  - If pH not within range, mortar bar comparison test, Table 814.1.2-2

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Water-Cementitious Materials Ratio

ratio of the amount of water, *minus water absorbed by the aggregates*, to the amount of cementitious materials in concrete

w/cm ratio = $\dfrac{\textbf{wt. of total water - wt of absorbed water}}{\textbf{wt. of cementitious materials}}$

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Advantages of Reducing W/CM Ratio

- Increased compressive strength
- Increased flexural strength
- Lower permeability - increased watertightness
- Increased resistance to weathering (freeze/thaw)
- Better bond between concrete lifts and rebar

W/CM Rule - Less water yields better concrete quality.

But need enough water for workability ...

- Placing
- Consolidation
- Finishing

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Aggregates (SSRBC 803)

- Makes up about 60% to 75% of the total volume
- Strongly influence fresh & hardened properties
- Fine Aggregates - minus No. 4 sieve (4.75mm)
- Coarse Aggregate - plus No. 4 sieve (4.75mm)
- Gradation (particle-size distribution) requirements
- Desirable characteristics:
  - Clean
  - Hard
  - Strong
  - Free of chemicals & coatings of clay
  - Free of deleterious materials such as clay balls, weeds, sticks, grass, dead pigeons, etc.
  - Shall not contain an excess of thin, flat, elongated, soft or disintegrated aggregate pieces

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Fine Aggregate (SSRBC 803.2.1)

Max. Quantity of Deleterious Substances

	Max % by Weight
• Clay Lumps	1.0
• Coal & Lignite	1.0
• Matl. Passing # 200 (0.075 mm) Sieve	4.0
• Sum of above materials & other deleterious substances	4.0

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Fine Aggregate Gradation Requirements (SSRBC 803.2.1-2)

Sieve	% Passing, by Mass
3/8 inch (9.50 mm)	100
# 4 (4.75 mm)	95 - 100
# 16 (1.18 mm)	45 - 80
# 50 (0.300 mm)	10 - 30
# 100 (0.150 mm)	2 - 10
# 200 (0.075 mm)	0 - 4

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Coarse Aggregate (SSRBC 803.2.2-1)

Max. Quantity of Deleterious Substances

	Max % by Weight
• Shale & Coal	1.0
• Clay Lumps	0.5
• Matl. Passing #200 (0.075 mm) Sieve	2.0
• Other deleterious substances such as friable, thin, elongated or laminated pieces	3.0
• Sum of above materials & other deleterious substances	5.0

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Aggregation Gradation

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Aggregate Gradation Requirements

Table 803.2.2-3
Gradation Requirements: Coarse Aggregate for Concrete

Sieve	% Passing		
	Structural Concrete		Portland Cement Concrete Pavement[(1)]
	Classes A & B	Class S[(1)]	
2½ in [63 mm]	–	–	–
2 in [50 mm]	–	–	–
1½ in [37.5 mm]	100	–	100
1 in [25.0 mm]	95 to 100	100	95 to 100
¾ in [19.0 mm]	–	90 to 100	–
½ in [12.5 mm]	25 to 60	–	25 to 60
⅜ in [9.50 mm]	–	20 to 55	–
No. 4 [4.75 mm]	0 to 10	0 to 10	0 to 10
No. 8 [2.36 mm]	0 to 5	0 to 5	0 to 5
No. 200 [75 µm]	0 to 2	0 to 2	0 to 2

(1) For these, and for class A concrete used for pavement, ensure that at least 50 percent of the material retained on the No. 4 [4.75 mm] sieve has at least one fractured face.

Note: Gradation requirements depend on concrete class.

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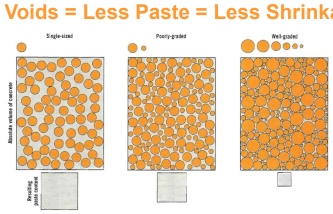
Paste

- Consist of cement, water & air voids
- Quality of paste affects quality of concrete
- Must coat each particle of aggregate
- Must fill all spaces between aggregate particles
- Required paste volume depends on aggregate gradation

Combined Gradation

Less Voids = Less Paste = Less Shrinkage



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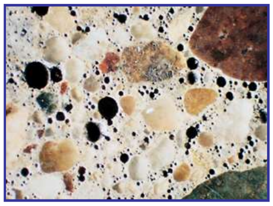
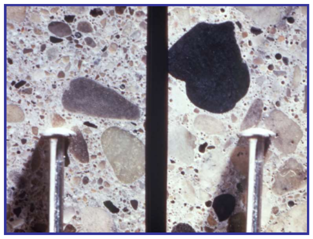
Air Voids

1. Entrapped - naturally occurring, irregular shaped accidental air voids (1 mm or larger in size)

2. Entrained - microscopic, spherical air bubbles intentionally incorporated during mixing (0.010 to 1.0 mm in size)





Air Content - volume of total air voids in concrete expressed as a percentage (%) of total volume of concrete & excludes aggregate pore spaces

Total Air Content = Entrapped Air + Entrained Air

Tests for (Total) Air Content

1. **Pressure Method (ASTM C231)**
   Use with relatively dense aggregates only

2. **Volumetric Method (ASTM C173)**
   Used with any type of aggregate

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Entrained Air

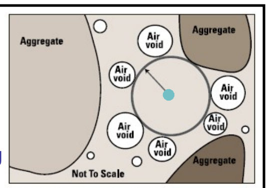

Figure 3-16. Spacing factor is the average distance from any point to the nearest air void. (Ozyildirim)

- improves resistance to freeze-thaw damage
- improves resistance to scaling
- improves workability
- reduces bleeding
- reduces compressive strength (2 to 6% per 1% air)
- reduces flexural strength (2 to 4% per 1% air)
- reduces unit weight
- increases slump (1 in. per 1/2 to 1% air)
- WYDOT requires 4.5 to 7.5% air for pavement & structural concrete (SP400 414.4.7 & SSRBC 513.4.4)

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Admixtures

- Ingredients in concrete other than portland cement, water & aggregates
- Added before, during or after mixing
- Alters fresh and/or hardened concrete properties

Admixtures can ...

- Adjust set times (accelerate or retard)
- Reduce water demands
- Increase workability
- Entrain air
- Adjust other fresh & hardened properties

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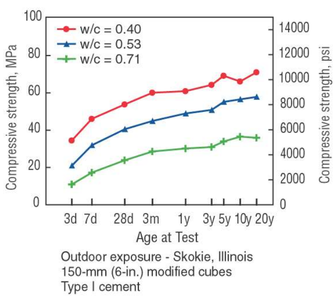
Concrete Strength



Concrete strength increases with age as long as moisture and a favorable temperature are present for hydration of cement.

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Strength Gain

A function of ...

- Time
- Temperature
- Moisture
- Cement composition & fineness
- Admixtures

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Principal Factors Affecting Strength

- w/cm ratio
  - *decreasing w/cm ratio increases strength*
- Age or time
  - *strength increases with age*
- Curing conditions
  - *ideal moisture & temperature conditions increase strength*
- Air content
  - *increasing air content decreases strength*
- Aggregates
  - *aggregate strength & aggregate/paste bond can limit concrete strength*
- Cementitious materials
  - Portland cement - *type & content*
  - *Supplementary cementitious materials (fly ash – Type F)*
- Admixtures
  - *water reducers, accelerator & retarders*

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Freezing & Thawing

Water → Ice → Expansion → Stresses → Cracking → Failure

Factors affecting freeze-thaw resistance ...

•w/cm ratio
•Air content (air void system)
•Drying prior to exposure
•Overall Quality
  - strength
  - watertightness
  - curing conditions
  - finishing techniques
  - etc.
•Exposure conditions
  - number of freeze/thaw cycles
  available water (drainage, runoff)

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Permeability

Definition: Ability to resist water penetration

Primary factors affecting permeability...
- Aggregate gradation
- Aggregate permeability
- Proportions of paste & aggregates
- **w/cm ratio**
- **Curing conditions**
- Amount of consolidation
- Cracking

Decreasing concrete permeable ...
- Increases difficulty to re-saturate concrete
- Increases freeze/thaw resistant
- Increases sulfate resistance
- Increases resistant to other chemicals
- Improves overall quality

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Abrasion Resistance

Definition: Ability of the concrete surface to resist being worn away by rubbing and friction

Primary factors affecting abrasion resistance...

- Strength
  - **w/cm ratio**
  - **curing**
- Aggregate type & hardness
- Surface finish

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Approximate Rules of Thumb

by Ray Zaremba

For Adjusting Concrete Mix Proportions:
There are a number of handy, practical rules which are used in making adjustments in concrete mix proportions. While the rules are useful for making quick changes in concrete mixes, the adjustments should only be used for emergencies and considered a temporary measure until the mix can be exactly redesigned.

Cement:
Cement content decreased 25 pounds per cubic yard - increase sand 21 pounds (S.G. 2.65)

Sand:
F.M. of sand increases 0.10 - increase sand 25 pounds per cubic yard & decrease coarse aggregate 25 pounds
S/A ratio increases 1% - increase water 2.5 pounds & cement 4 pounds

Coarse Aggregate:
D.R.W. increased 1 pound - increase coarse aggregate 20 pounds & decrease sand 20 pounds

Water:
Water increased 1 gallon - slump increased 1 inch - cement increased 15 pounds

Concrete:
1% reduction in cement content equals 50 psi compressive strength loss (500 Port. Cement. per cubic yard)

1" increase in slump equals 150-200 psi compressive strength loss

1% increase in sand/aggregate ratio equals 40 psi compressive strength loss

10°F increase in concrete temperature equals 7 pound increase in water content to maintain equal slumps

10°F increase in concrete temperature equals 1% decrease in air content

10°F increase in concrete temperature equals 150-200 psi compressive strength loss

1% increase in air content over design equals 3-5% compressive strength loss (med. & rich mixes)

Perhaps You've Forgotten...
That if you add only ONE gallon of water to a yard of properly designed 3000 psi concrete mix:

... you increase the slump about one inch

... you reduce the compressive strength by as much as 200 psi

... you waste the effect of 1/4 bag of cement

... you increase the shrinkage potential about 10%

...you increase the possibility of seepage through the concrete by up to 50%

... you decrease the freeze-thaw resistance by 20%

... you decrease the resistance to attack by de-icing salts

... you lower the quality ot the concrete in many other ways

If more workability is needed, ask the lab. That designed the mix to adjust it. It may not need more water.

That a drop of only 1% in the entrained air (say from 5% to 4%) will almost certainly...

... reduce the yield by over 1/4 cubic foot per yard, a loss of one cubic yard in a hundred

... have the same effect on workability as leaving out about 50 pounds of sand per yard

... reduce the slump by ½ inch

... increase the water demand by up to 4% or about one gallon per yard for the average 3000 psi mix

... increase the chances for segregation and bleeding

... decrease durability by about 10%

... decrease resistance to action of de-icing salts

Since many factors such as temperature, mixing time, aggregate size and shape, sand gradation and other things affect the amount of air entrained by a given quality of air-entraining agent, it pays to check the air content frequently and keep it at the designed level.

Approximate Concrete Strength Relationships:
Compressive strength can be used as an index of flexural strength once the empirical relationship between them has been established for the materials involved. The flexural strength or modulus of rupture of normal-weight concrete is often given as 8 to 10 times the square root of the compressive strength (PCA> Waddel's Concrete Construction Handbook cites a modulus of rupture range between 12 and 20 percent of the 28-day compressive strength and averages about 15% for concrete with a compressive strength of 3,500 psi.

The origin of some of these "rules of thumb" is unknown and no attempt has been made to identify the originating source. Suffice to say they are merely approximate values which have gained acceptance in the industry and should be continued to be used with discretion.

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Many Factors Affect Durability

Examples:

- **Strength**
- **Air Entrainment (Air-void System)**
- **W/CM Ratio**
- **Curing**
- **Permeability**
- **Gradation and Paste Content**
- **Abrasion Resistance for Pavement**

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