CIVI 321: Civil Engineering Materials

- Need to understand material behavior in order to specify and design
- Materials must satisfy:
    - Economic factor
    - Mechanical properties
    - Production/construction
    - Aesthetic properties

1.1 Economic Factors

- Availability of material
- Manufacturing costs
- Transportation – add significant cost
- Maintenance*

1.2 Mechanical Properties

- Response of materials underload
- All materials deform under loading
- Failure – structural → collapse
    - Functional failure
        - Excessive deformation
        - Excessive deflection
- Loading conditions
    - Static: slowly applied and removed
        - Dead loads: structure itself
            - Mechanical equipment
            - Snow
        - Live loads: people, furniture
        - Dynamic: shock or vibration

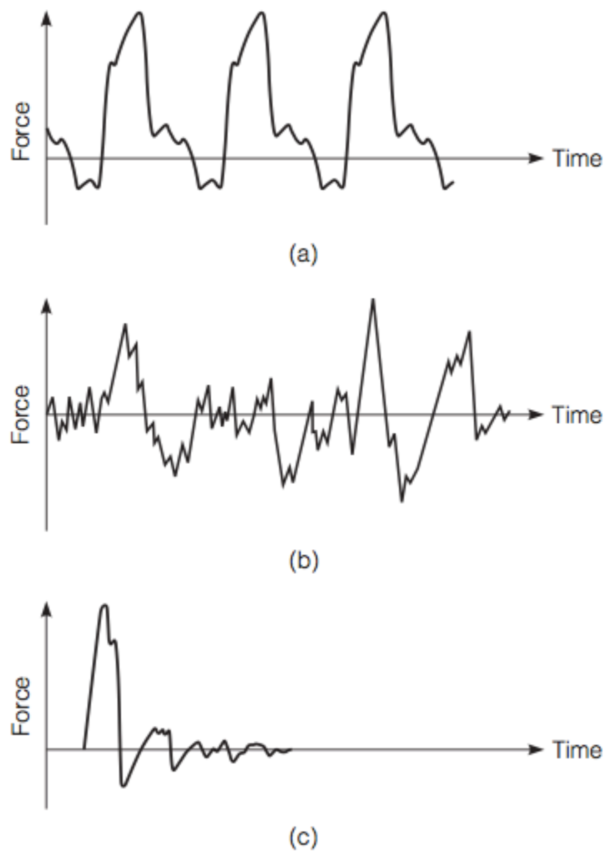
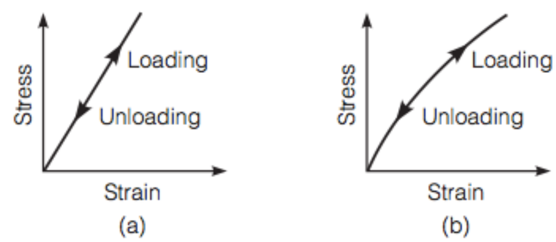


FIGURE 1.1 Types of dynamic loads: (a) periodic, (b) random, and (c) transient.

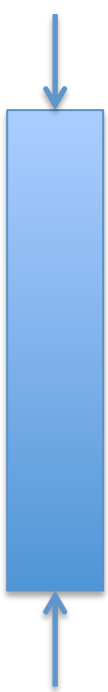
- Stress-Strain Relationships
  - Deformation is related to :
    - Strength (material property)
    - Geometry (size)
    - Stress = Load/Area
      - $\sigma = P/A$ [N/m²] = Pa → 10^6 Pa = MPa

- Strain = Δ length/original length
  - $\varepsilon = \delta L/L$ (unitless
  - typical strain 10^{-6} m/m (microstrain)
- Elastic Behaviour
  - Application of load will cause instantaneous deformation
  - Returns to original shape when load is removed
  - For a linear elastic material, $E = \sigma/\varepsilon$

FIGURE 1.4 Elastic behavior: (a) linear and (b) nonlinear.



- Poisson's Ratio



$V = -\varepsilon_{lateral}/\varepsilon_{axial}$

- V is 0 to 0.5

$\varepsilon = PL/AE$

- Elastic behavior can be linear or non-linear

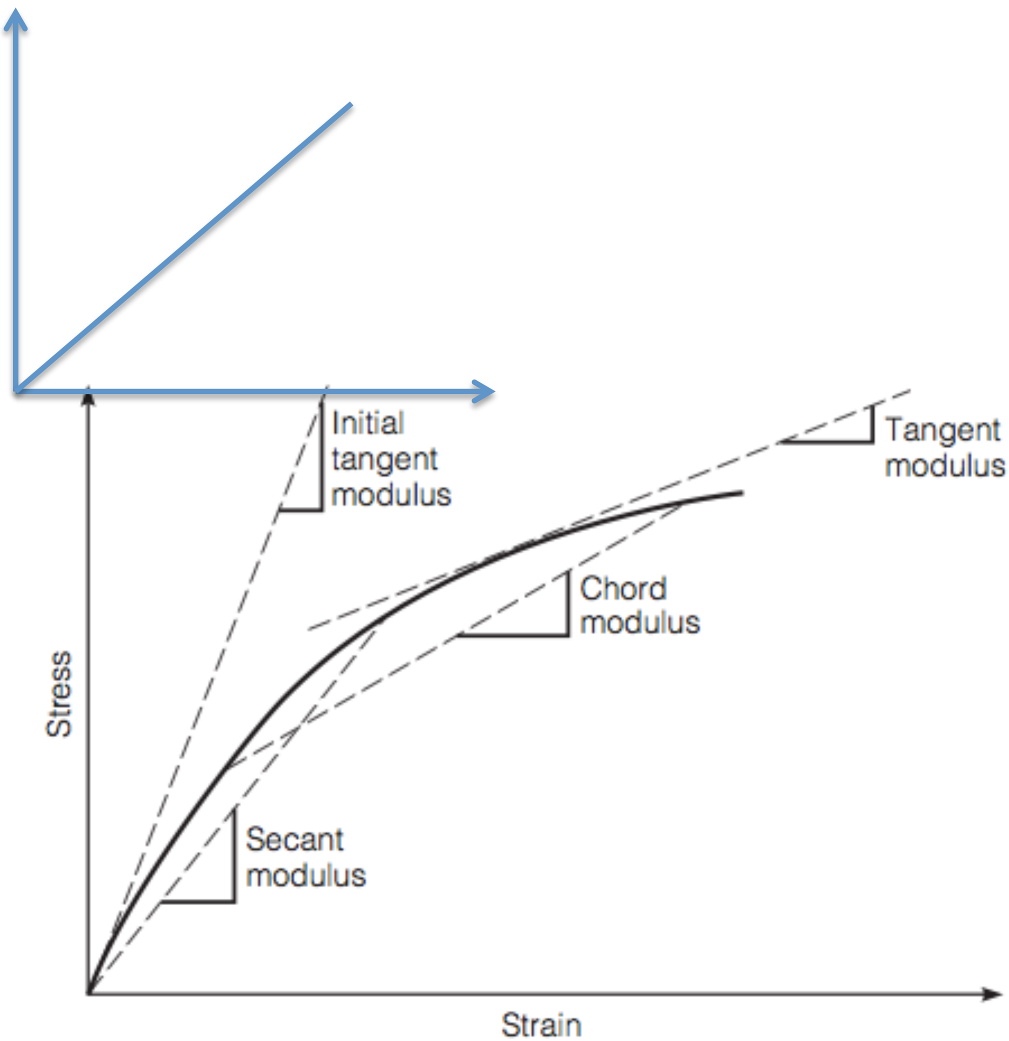


FIGURE 1.5 Methods for approximating modulus.

- Example: On a stress strain diagram, determine how you would find the modulus? Define one of the methods.

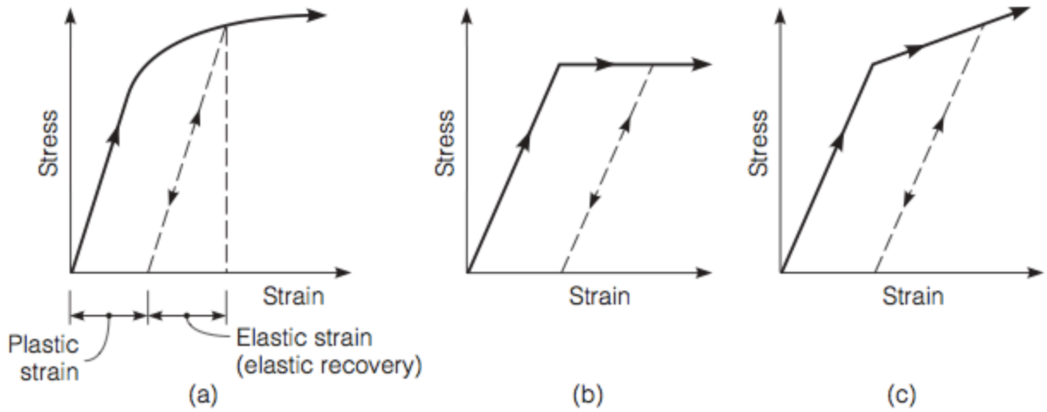


FIGURE 1.6 Stress–strain behavior of plastic materials: (a) example of loading and unloading, (b) elastic–perfectly plastic, and (c) elasto–plastic with strain hardening.

- Brittle – exhibit little to no deformation prior to failure
  - Ex: concrete (not reinforced)
- Ductile – have deformation
  - Ex: steel

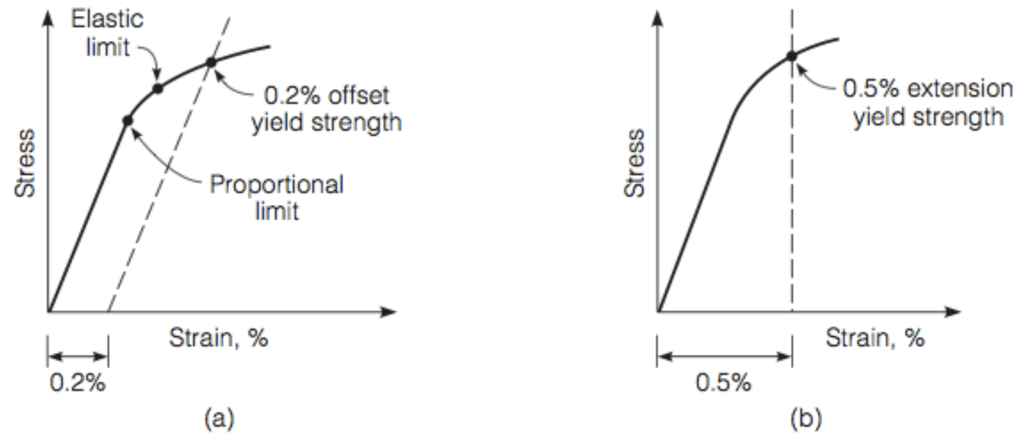


FIGURE 1.7 Methods for estimating yield stress: (a) offset method and (b) extension method.

- Yield stress - σy
  - Elastic behavior up to yield stress
  - Plastic behavior yield stress
- Certain material, ie. non-linear elastic, do not exhibit clear yield point
  - Offset – parallel to initial slope
  - Extension – vertical line
- Work and energy
  - Work = force x displacement
  - Stress = force/area
  - Strain = Δ L/L or displacement/length
  - Work / volume = σ x ε
  - Toughness = work/volume

- Time-depedent response
  - Sometimes materials deform with a delayed response
  - Creep – due to long-term loading
    - Ex. Wood, asphalt pavements

1. Elastic strain
   a. Instantaneous due to load
2. Creep – additional strain

3. Elastic rebound
4. Creep recovery (does not go back to zero strain)

- Rheological models – skip
- Temperature and time effects
- Temperature can affect mechanical response

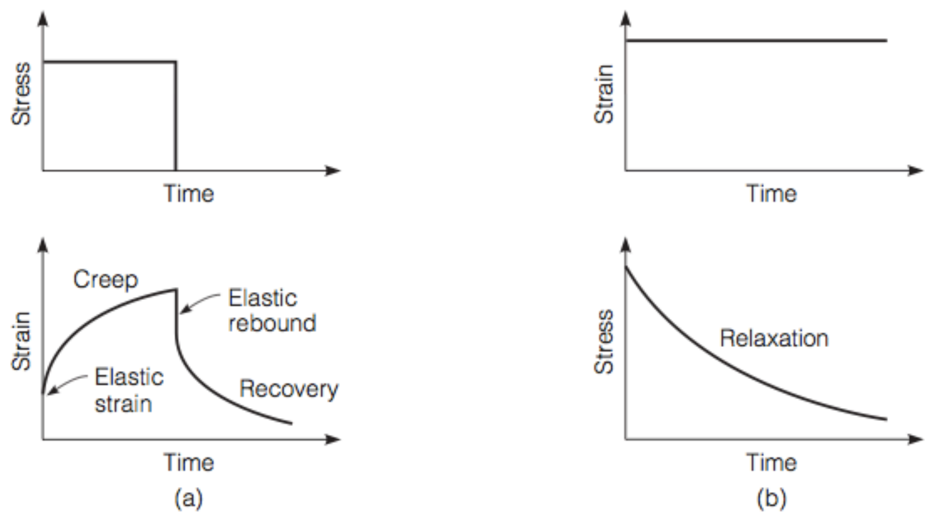
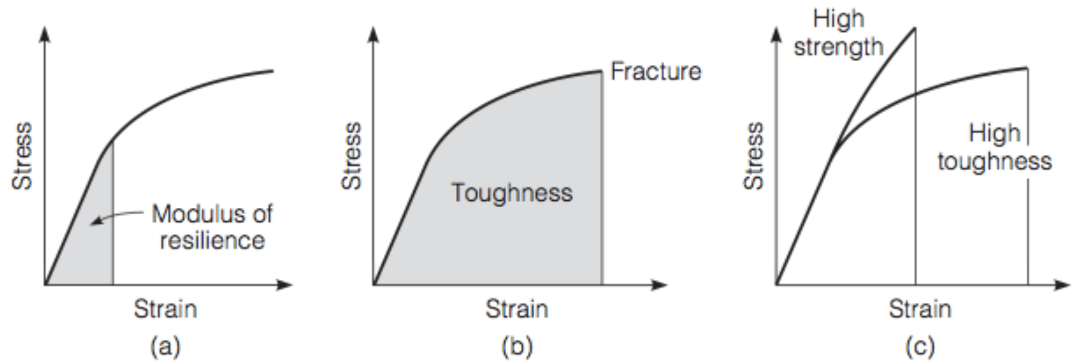


FIGURE 1.10 Behavior of time-dependent materials: (a) creep and (b) relaxation.

- Transition temperature defines brittle to ductile transition
- Impact testing
- Height of weight after impact determines toughness
- Failure and safety
    - Failure due to fatigue
    - Fatigue is due to repetitive loading and unloading
        - Fatigue testing
            - Multiple specimen with varying loads



- Factor safety
    - FS = σ failure/ σ allowable
- Factor of safety is a compromise low of safety-possible failure
- High factor if safety – cost more material

1.3 Non-mechanical proper

- Density and unit weight
    - Dead weifht can be significant
    - Density= mass/volume
    - p = m/V [kg/m^3]
- Specific gravity
    - SP= mass of material/mass of equal volume of water
- Thermal expansion
    - Material expand or contract with changes in temperature
    - α_L = (δL/δT) / L (Linear expansion)
    - α_v = (δL/δT) / V (Volumetric expansion)
    - $\alpha_v = 3\alpha_L$

1.4 Production and Construction

- Production
    - Availability
    - Fabrication
- Construction
    - Skill of workforce

1.5 Aesthetic Concerns

- Architects and engineers work together

1.6 Sustainable Design

- Takes ecological, social, and economic factors into consideration
- LEED- leadership in environment design
  - Developed in US
  - Came to Canada in 2004
  - Types of construction
    - New, core, and shell, existing
  - LEED has rating system
    - 100 possible points (you need a certain amount of points to get certification
    - 40 certified
    - 50 silver
    - 60 gold
    - 80 platinum
    - Area for points
      - Sustainable sites: construction control
      - Water efficiency: 20% less water than baseline
      - Energy and environment: minimum performance
      - Materials and resources: collect recyclables
      - Indoor environment quality: minimum performance (ASHRAE)
      - Innovation design: LEED professional
      - Regional priority: durable building

1.7 Material Variability

- Material possess variability
- Due to three (3) types of variability
  1. Inherent variability (unable to control)
  2. Variance from sampling (random sample)
  3. Testing method
     a. using standardized methods

   b. ASTM methods
   c. CSA (Canadian Standards Association)

- Precision: variability of repeated measurements (all measurements close to one value)
- Accuracy: conformity of results to true value

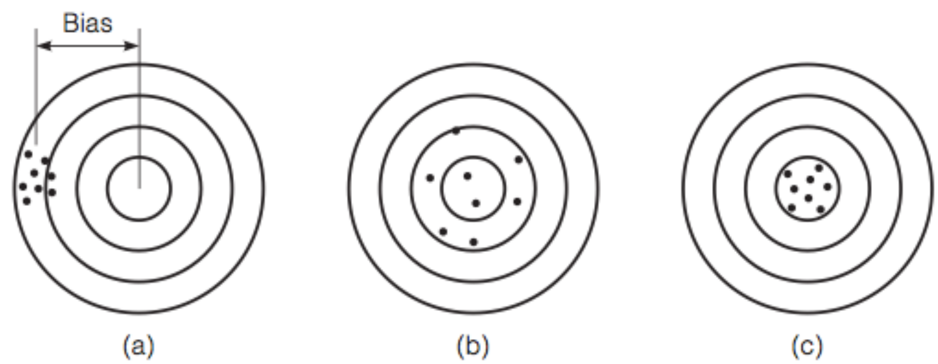


FIGURE 1.20 Exactness of measurements: (a) precise but not accurate, (b) accurate but not precise, and (c) precise and accurate.

- Bias: tendency to deviate in one direction
- Sampling
  - Random sample since it is impossible to test every piece
  - Must be representative
- Sample size: be reasonable

  - Mean $X = \Sigma x_i / n$
  - True mean
  - Standard Deviation
  - Normal distribution
    - Symmetric about the mean

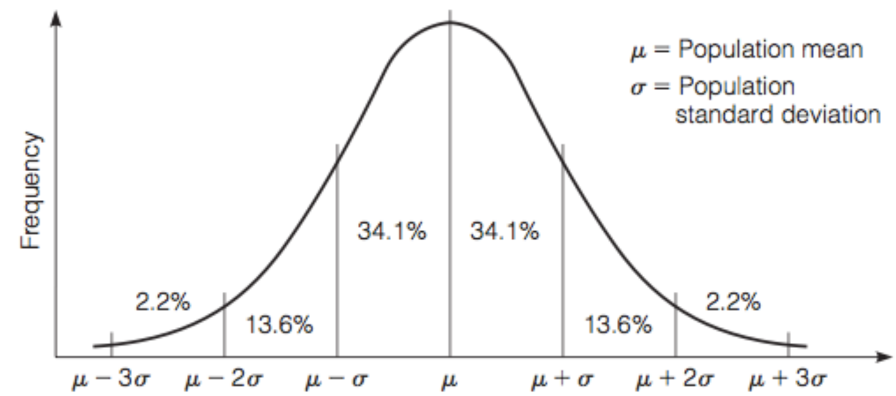


FIGURE 1.21 A normal distribution.

- Area under curve gives a probability
- Control charts
    - Verify quality control used for ongoing processes
    - Used for ongoing processes
    - Plot results (average result, ie. 1 day) as they occur

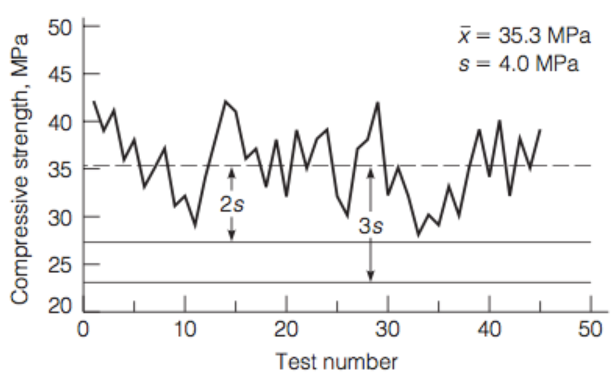


FIGURE 1.22 Control chart of compressive strength of concrete specimens.

CHAPTER 5: AGGREGATES

- Aggregates come from:

- crushed stone
- gravel
- sand

- In engineering used for:
    - Ashphalt pavement - >80%
    - Concrete (60-75%)
    - Under and around foundations under pavement
- Natural sources
    - Quarries: solid rock blasted, then crushed
    - Gravel pit: glacial deposit, water sat
    - Sand: river, beaches
- Manufactured sources
    - Waste materials
        - Slag→ by-product of steel production
        - Expanded shale and clay (heated)
            - Lightweight
        - Steel: heavyweight

Evaluation of Aggregates

- Aggregate varies with location even in one location varies
- Requires testing and sampling

Types of Tests

- Strength
- Particle shape, size, and size distribution
- Deleterious materials

Aggregate Properties

- Particle shape and surface texture
    - Shape can be rounded or angular

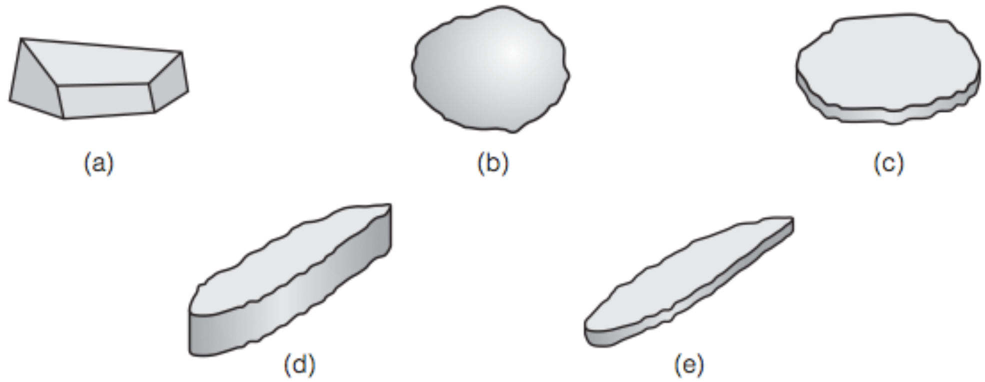
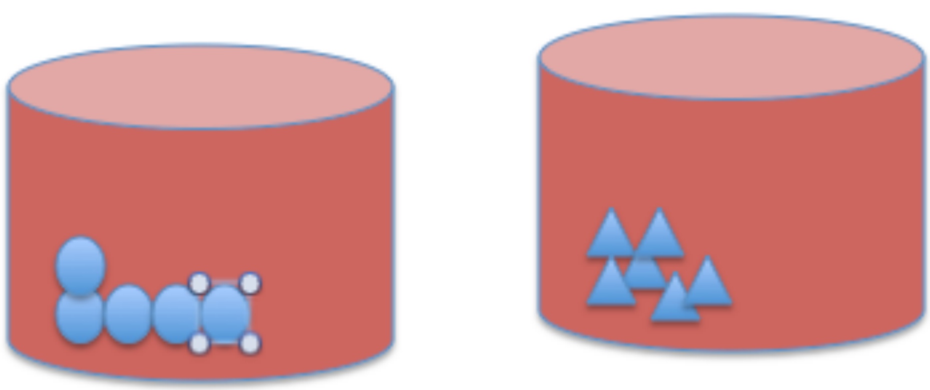


FIGURE 5.3 Particle shapes: (a) angular, (b) rounded, (c) flaky, (d) elongated, and (e) flaky and elongated.

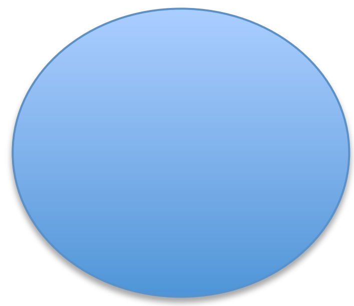
- Angularity: Effects particle packing



LESS SPACE MORE SPACE

- Effects relative movement
    - Round particles: move easily

  - Angular: less easily
  - Asphalt pavements: always angular
- Concrete:
  - Round: better before hardens, easier placement
  - Angular: better after hardening
- Flakiness: shape is in one dimension
  - Try to avoid
- Surface texture
  - Outer surface



ROUGH SMOOTH

- Important for Compaction
  - Smooth compacts easier, but not necessarily denser
- Important for bonding (to asphalt binder or cement)
- Rougher gives better bonding

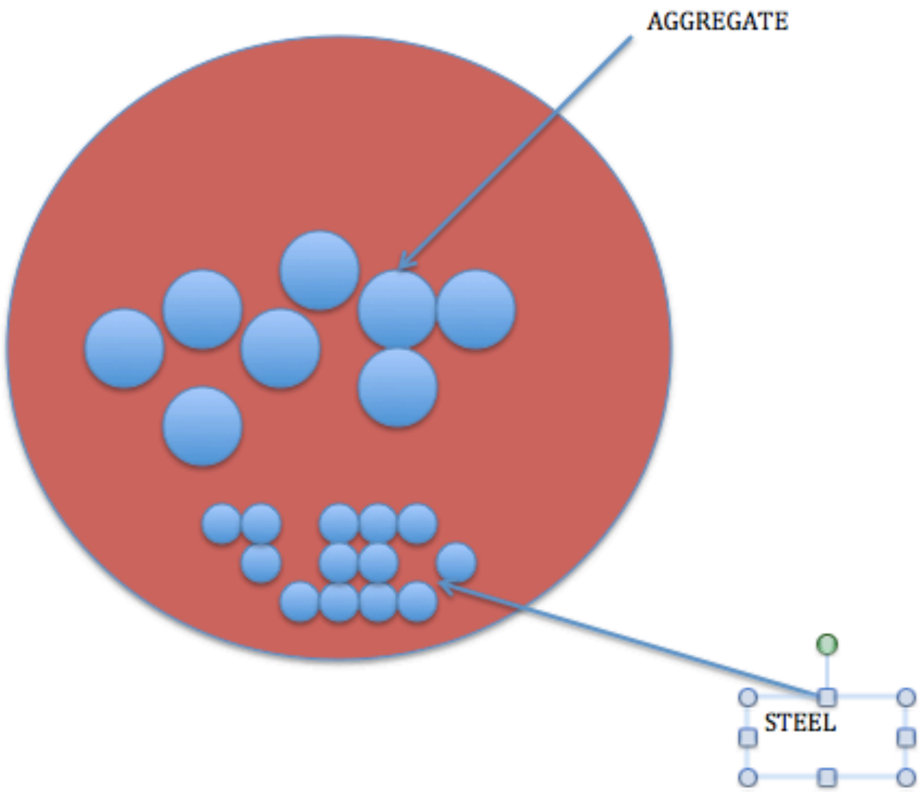
Soundness & Durability

- Ability to withstand freezing
- Measure particle size distribution before and after freezing

Toughness, Hardness, Abrasion

- Ability to withstand effects of loading
- Must withstand crushing while stockpiled or in use

Test using Los Angeles Abrasion



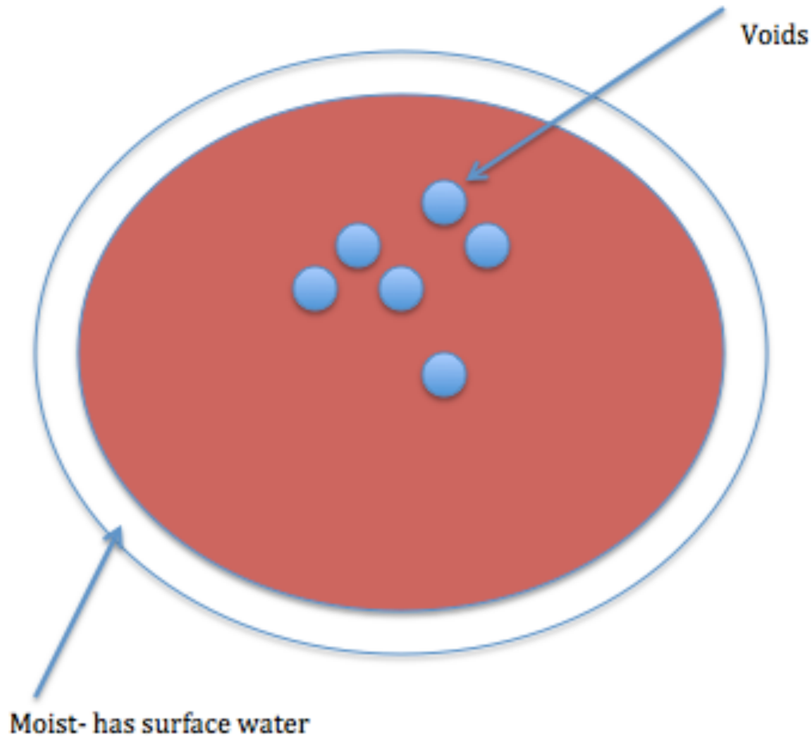
Absorption

- Important for Portland cement concrete
- Water absorbed by aggregate is not available to react with cement
- Water absorbed makes concrete less fluid
- For asphalt pavement, aggregate must be dry

Moisture States

- Oven dry: dried to >100°C
    - No water – perfectly dry
    - Saturated surface dry (SSD)

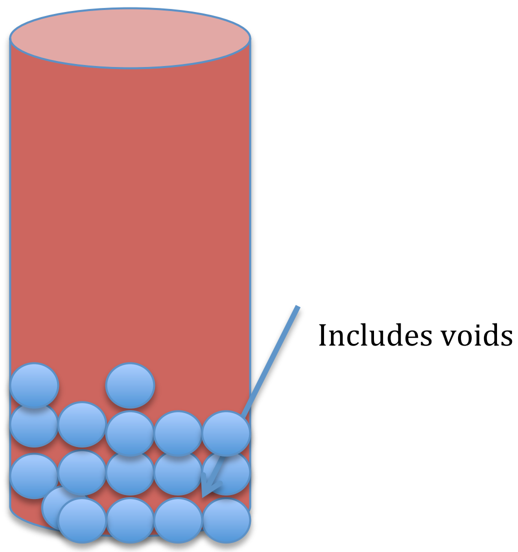
        - Interior – voids filled in water
    - Outside surface – no excess water
        - Testing – do not over (dry surface)
            - Use damp rag



- Absorption
    - Water required to reach SSD
    - Absorption = mass of water absorbed/ mass of dry aggregate = (SSD – dry) / dry
- Absorption is typically

Specific Gravity

- S.G = mass of material/mass of equal volume of water

- S.G= dry weight/particle volume x δ_w
- In your lab, volume determined by buoyancy
- Dry/ (SSD-suspended)
- Bulk unit weight δ_b = mass of aggregate/volime of container
- Not equal to unit weight : δ = mass of aggregate/volume of solids
- 

$$\text{Bulk Dry Sp. Gr.} = \frac{\text{Dry Weight}}{(\text{Total Particle Volume})\gamma_w} = \frac{W_s}{(V_s + V_i + V_p)\gamma_w} \tag{5.2}$$

$$\text{Bulk SSD Sp. Gr.} = \frac{\text{SSD Weight}}{(\text{Total Particle Volume})\gamma_w} = \frac{W_s + W_p}{(V_s + V_i + V_p)\gamma_w} \tag{5.3}$$

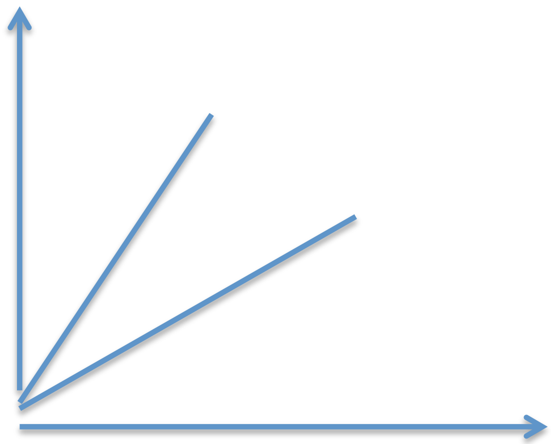
$$\text{Apparent Sp. Gr.} = \frac{\text{Dry Weight}}{(\text{Volume Not Accessible to Water})\gamma_w} = \frac{W_s}{(V_s + V_i)\gamma_w} \tag{5.4}$$

$$\text{Effective Sp. Gr.} = \frac{\text{Dry weight}}{(\text{Volume not accessible to asphalt})\gamma_w} = \frac{W_s}{(V_s + V_c)\gamma_w} \tag{5.5}$$

Strength and Modulus

- For Portland cement concrete strength of aggregate is limiting factor
- For high strength concrete, you must use high strength aggregate

- Strength based on core of rock
- Modulus=stress/strain



E1> E2

Gradation and Maximum Size

- gradation: particle size distribution sieve analysis used to determine particle size distribution

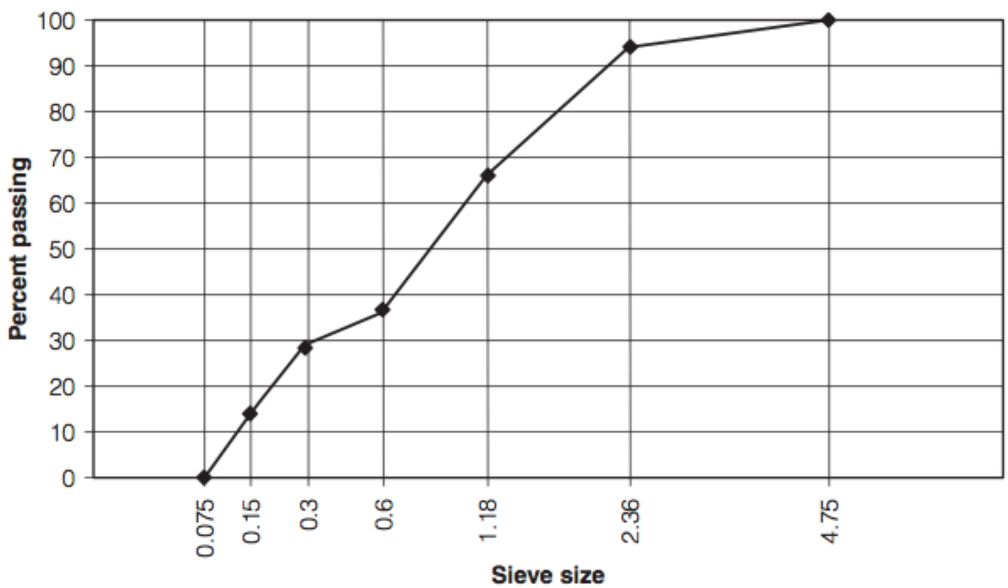
Figure : Sieve Analysis

- Sieves stacked with larger openings on top
- Each sieve has openings to allow some particles to be retained, rest pass through to smaller sieves
- Gradation shown as cumulative passing versus size (log scale)
- Example:

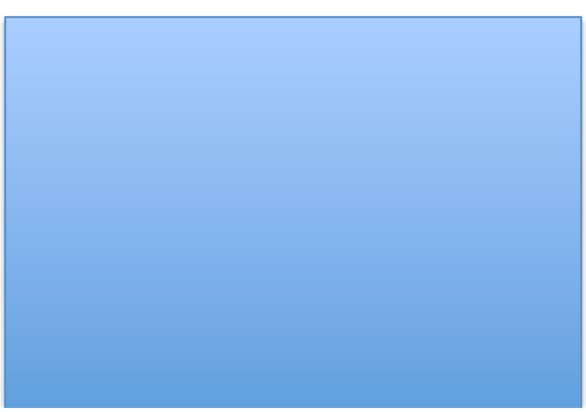
SIEVE ANALYSIS

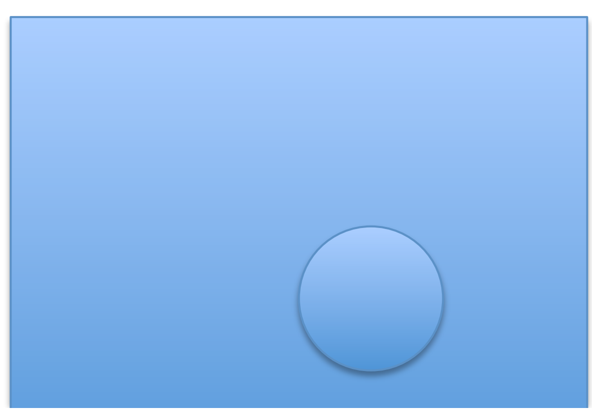
Sieve Size (mm)	Mass retained (g)	% Retained	Cumulative % Retained	Cumulative % Passing
4.75	0	0	0	100-0 = 100
2.36	241.9	11.9	11.9	100-11.9
1.18	388.9	19.1	11.9+ 19.1	100-31.0
0.60	505.5			
0.30	543.5			
0.15	340.8			
Pan	11.3			

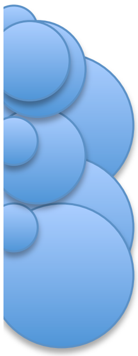
- % Retained = mass in one sieve/ total mass
  241.9/2013.8 = 11.9%
- cumulative % passing = 100- cumulative % retained



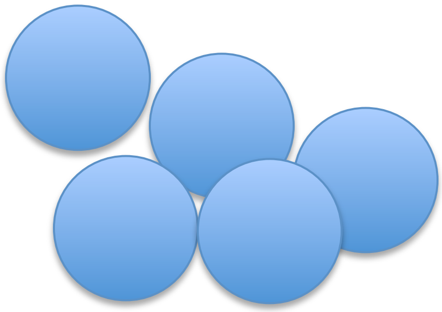
- well graded: results in smooth “S” curve
- one-sized : most of all particles one sized







Well-graded (Fewer voids)



One sized

- Particle size specifications
    - Fine aggregate → ASTM C33
-

Sieve (mm)	% Passing
9.5	100
4.75	95-100
2.36	80-100
1.18	50-85
0.60	25-60
0.30	10-30
0.15	2-10

- Maximum size
    - For fine aggregates – 5mm (4.75 mm)
    - For coarse aggregates (depends on application)
    - Maximum size – smallest sieve that passes is 100%
    - Nominal maximum – largest sieve to retain up to 10 %

Fineness Modulus

- Measure of fine aggregate
- FM = Σ Cumulative % retained/ 100
- Ideally for concrete: 2.3 < FM < 3.1

- Larder number means towards coarser

Blended Aggregates

- When gradation from one source does not meet limits
    - Combine two sources

Deleterious Substances

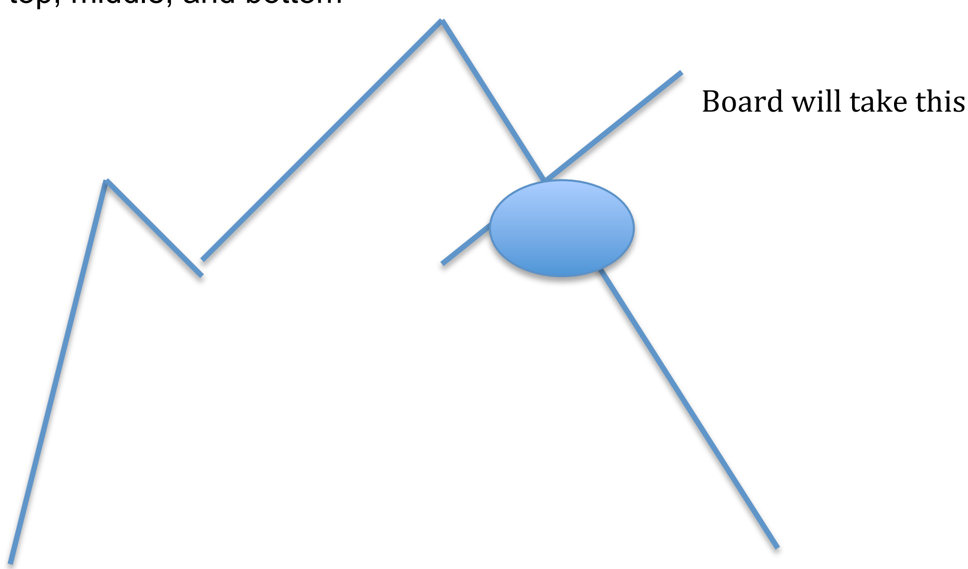
- Adversely affects concrete (Portland or asphalt)
    - Organic matter (soil) – delays set and reduces strength
- Particles < 0.075 mm
    - Weakness bond withbinder
- Coal, low density materials, clay lumps, soft particles
- Affects strength
- Affects durability
- Affects pop-outs, stains

Handling Aggregates

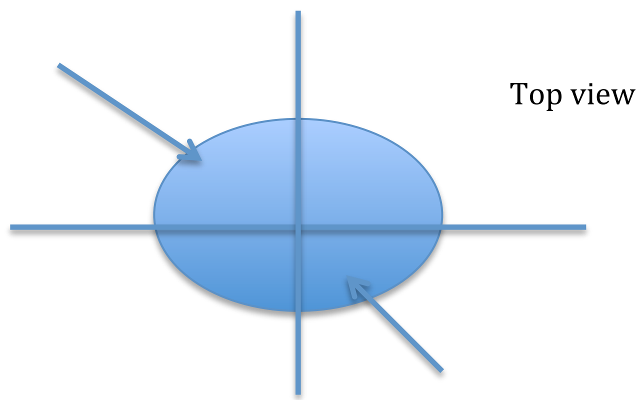
- Handled and stores in a way to minimize:
    - segregation – particle sizes separate
    - degradation – break apart
    - contamination – by other material

Sampling Aggregates

- must be representative
- take from top, middle, and bottom



- board prevents material aoce from falling into the sample
- larger sample can be split
- splitting techniques:
  - quartering – lay out pile on to flat area



  - splitting
-

Alkali-Aggregate Reactivity

- common in montreal
- two types:
  - alkali-silica reaction
  - alkali-carbonate reaction
- problematic aggregate contains amorphous (non-crystalline) silica
- cement contains alkali sodium or potassium
- problemative cement has high alkalis

- alkali and silica react to form – an expansive by-product
- expansion causes cracks
    - "map cracking" (no order)

Figure: Map cracking

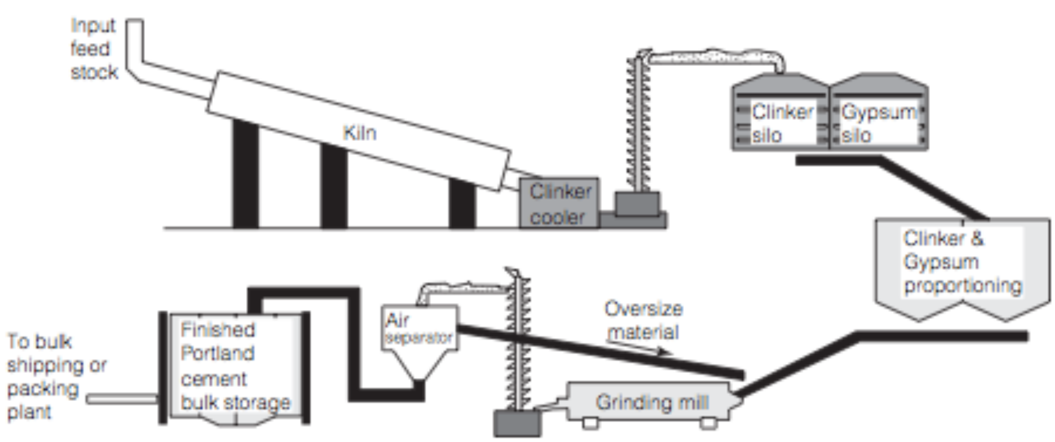
- minimize ASR by:
    - limiting alkali content
    - low alkali cement
    - replace cement by other materials
- aggregate must be checked for reactivity:
    - field history
    - lab tests
- moisture-induced problems:
    - affinity for asphalt if water gets into asphalt
    - pavement → stripping
    - weakens bond between aggregate and ashphalt binder

CHAPTER 6: PORTLAND CEMENT

- Portland cement concrete is most widely used construction materials
- It is one of few materials that are manufactured on site
- It is under control of civil (building) engineers.
- Patented in 1824 (UK or Hull, Quebec)
- Two basic raw materials
  - Calcareous - limestone
  - Argillaceous – clay or shale

6.1 Process

- Get materials
- Break and grind to smaller size
- Heat in kiln to 1400-1600 degrees



- Clinker ground into powder

- Add gypsum (to control set)

6.2 Chemical composition

- Raw materials
    - Lime (CaO), Silica (S or Si), and Aluminum (A or Al) [from clay]
    - Iron (from impurities in materials) [Fe or F]
- Cement chemistry uses special "shorthand"
- 4 elements heat and recombine to form 4 cement compounds
    - C_3S: tricalcum silicate (45-60%) [gives concrete its strength < 7 days]
    - C_2S: dicalcium silicate (15-30%) [gives concrete its strength later]
    - C_3A: tricalcium aluminate (6-12%) [problematic for sulphate attack]
    - C_4AF: tetracalcium alluminoferrite (6-8%) [gives grey colour]
- Other minor components:
    - Only a few percent by mass
    - Most do not affect use
        - Alkalis = Na_2O, K_2O, for ASR
    - Limit for MgO
- Specifications for ASTM C150

6.3 Fineness

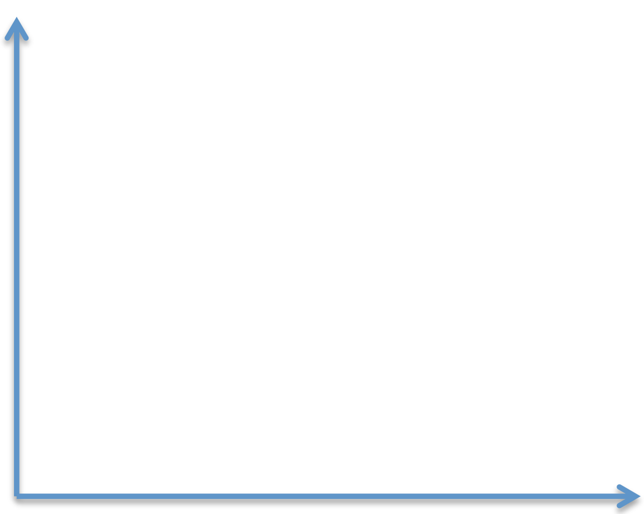
- Clinker and gypsum ground to varying sizes
- As particles become finer (smaller)
- Smaller sizes increases surface area/volume
- Blaine is used to measure fineness
- Range = 300-500 m^2/kg
- Average cement particle ~ 0.01 (~10 μm)
- Reaction between cement and water is called hydration
- Fineness increases rate of hydration increases and strength gain increases
- More costly to produce finer cement

6.4 Specific Gravity

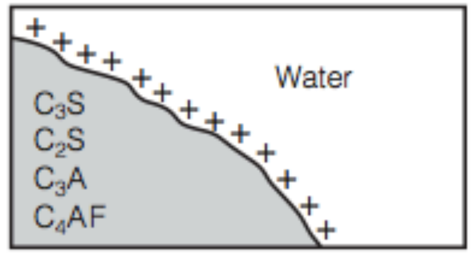
- Cement has specific gravity of 3.15 (solids only)
- Bulk unit weight varies
- Cement sold and measured by mass

6.5 Hydration

- Chemical reaction
- 4 cement compounds react at different rate
- C_3A – reacts immediately and releases significant heat (exothermic)
    - Leads to "flash" set
    - Adds gypsum to delay set of C_3A
    - $CaSO_4 \times 2H_2O$
- Hydration of silicates
    - C_3S and C_2S react to form calcium silicate hydrate
        - C – S – H (CSH)
        - H is shorthand for water
- Hydration starts with addition of water
- Continues as long as water and unhydrated cement remain
- Cement and water = "glue" + byproducts
    - $C_3S + H \rightarrow C - S - H + CH$ [$CA(OH)_2$]
    - $C_2S + H \rightarrow C - S - H + CH$ [
    - C – S – H provide strength
    - CH – can be problematic
- Structure development
    1. Contact with water. Water becomes highly alkaline (pH ~13)
    2. Volume of cement particle reduces
    3. Hydrates occupy more volume than original cement particle
        a. Interlock hampers ability of particles to move
        b. Initial set ~45 minutes
        c. Final set (2-4 hours)

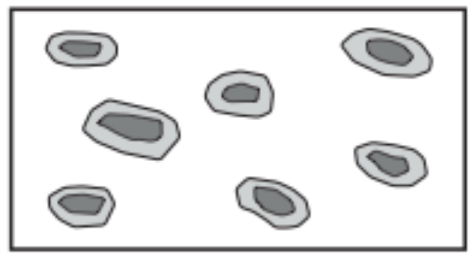


The C-S-H phase is initially formed. C_3A forms a gel fastest.



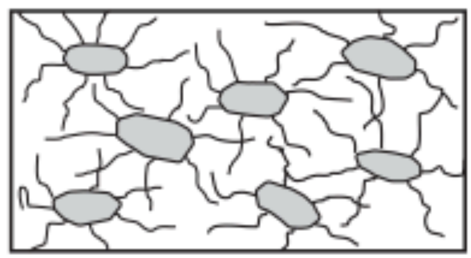
(a)

The volume of cement grain decreases as a gel forms at the surface. Cement grains are still able to move independently, but as hydration grows, weak interlocking begins. Part of the cement is in a thixotropic state; vibration can break the weak bonds.



(b)

The initial set occurs with the development of a weak skeleton in which cement grains are held in place.

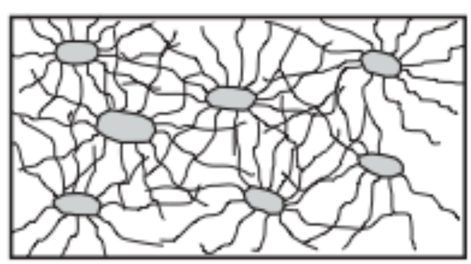


(c)

Final set occurs as the skeleton becomes rigid, cement particles are locked in place, and spacing between cement grains increases due to the volume reduction of the grains.

(d)

Spaces between the cement grains are filled with hydration products as cement paste develops strength and durability.



(e)

- Cement and water is cement paste
- Cement and water and sand is mortar
- Cement and water and sane and stone is concrete

6.6 Voids in Hydrated Cement Paste

- Space not filled with hydrates (C-S-H)
    - Space or voids filled with liquid (alkaline solution) or filled with air
- Gel pores are withing and between layers of C-S-H
    - Very small (0.5-2.5 nm) Water molecule 3A
- Capillary voids
    - Remnants of water-filled space
    - More cement, less voids.
    - Amount and size of capillary voids depends on
        - Initial separation of cement (water to cement ratio)
        - Time since continued hydration fills these pores
    - <50nm affects shrinkage
    - >50nm affect shrinkage and durability
    - most important voids in concrete
- Entrapped air – from mixing process (1-2%)
- Entrained air – purposed air to contract expansion of freezing water (4-9%)
    - Air bubbles provide space for water to expand
    - Entrained air reduces strength
- Compaction voids – poor workmanship
    - Larger voids few mm and larger
    - Try to avoid with consolidation

6.7 Properties of Hydrated Cement

- ASTM specifications control the quality of cement
- Setting
    - Change from fluid to solid state
    - Set time determined by testing
    - VICAT test

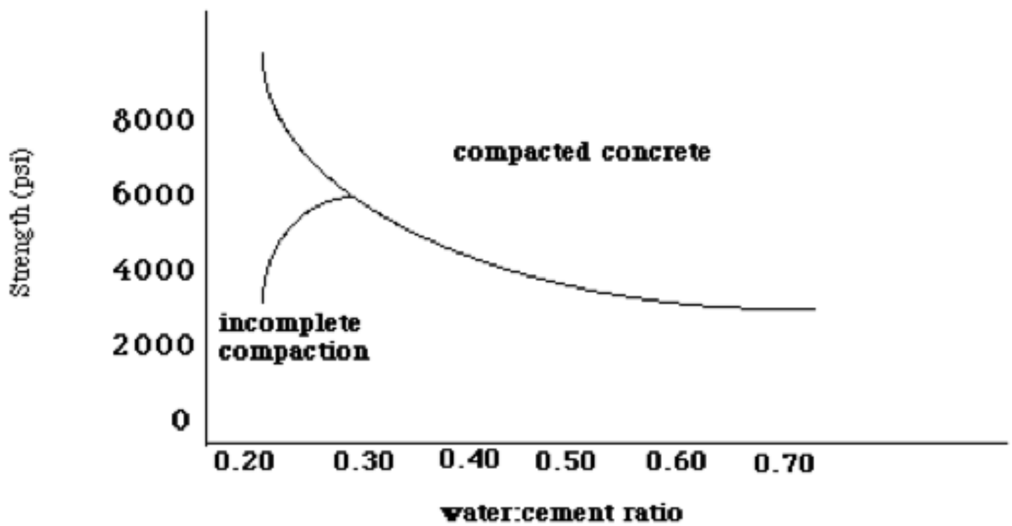
FIGURE 6.5 Vicat set time apparatus. (Courtesy of Humboldt Mfg. Co.)

- Drop needle assembly into surface of cement paste
- Measure penetration into surface

- At 25 mm is defined as intial set (~45 minutes)
- No visible penetration is final set (2-4 hours)
- Soundness
    - The ability to retain volume after setting
    - MgO will cause expansion
    - Use autoclave (Steam and pressure)
    - Make small prisims 25 x 25 x 250 mm
    - Temperature and pressure accelerates reaction (expansion)
    - Limits on expansion (0.8%)
- Compressive strength
    - For quality control of cement
    - cubes 50x50x50mm cubes
    - use standard sand (ASTM C109 sand)

6.8 Water to Cement Ratio

- As water cement ratio decreases, capillary voids decrease.
- As water cement ratio decreases, strength increases.
-



- Hydration of cement requires 0.22-0.25 water/1kg cement
- W/C = 0.22-0.25
- Addition of water added for placement (workability)

6.9 Types of Cement

- Types of different applications
- Types are made by changing:

- Raw materials
- Temperature

STANDARD TYPES

US Type	Canadian Type	New type CSA	Application	
I	10	GU	General use	(most; 90% of the time)
II	20	MS/MH	Moderate heat/moderate sulphate	Low C_3A
III	30	HE	High early strength	High Fineness C_3S
IV	40	LH	Low heat of hydration	Lower C_3S
v	50	HS	High sulphate resistance	Lowest C_3A

Type 1 (10 or GU)

- Produced most often
- Other types require plant shut-down (need other materials equipment)
- Sometimes locally produced
    - Ex: HS in California (sulphate-rich soil)
- Most often equivalent cements are made by blending general-use cement with other cement replacements

6.10 Mixing Water

- Normally potable/drinkable water is used (acess to water treatment plant)
- Using well-water or surface- water (ie untreated) may be a problem
    - Impurities in water can cause problems with:
        - Set (too early or too late setting
        - Strength (initial or overall)
        - Potentially durability
- Limits

  - Chloride
    - High chloride is bad
    - Prestressed concrete = 500 ppm max. (other = 1000 ppm mac)
      - Rebar: stretched, concrete poured and set, rebar rebound = compression of
    - Chloride causes steel corrosion
  - Sulphate
    - Limit = 3000 ppm max.
  - Alkalis
    - 1000 ppm max.
  - total solids
    - 50000 ppm max.
- must test water before use
  - make mortar cubes (like in lab 50x50x50)
  - 1 set with acceptable water
  - 1 set with water under investigation (source of water)
  - test for strength and set-time
    - set-time: no more than one hour earlier or 1.5 hour later
    - strength: at least 90% of control set made with acceptable water

Disposal and Reuse of Concrete Wash Water

- empty ready-mixed trucks must be cleaned
- environmental regulations prohibit immediate disposal (oe: in streams, lakes, sewage system)
  - often used to make new concrete
    - place water in a settling pond and allow aggregates to settle
- sometimes water is left in the truck and add a hydration admixture (prevents the aggregate in the truck from hydrating)

6.11 Admixtures

- ingredients other than cement, water and aggregate
- used to improve properties in fresh or hardened state
- four major reasons
  1. reduce cost
  2. achieve properties (ie: control set)
  3. ensure equality concrete (ie: more workable, placed easier)

4. overcome emergencies (ie: prevent premature hydration)

- Two types of admixtures: mineral and chemical
- chemical admixtures
    - usually in liquid form
    - used in small amounts ($1L/m^3$)

Air Entrainers

- produce tiny air bubbles (0.01-1mm size) via chemical reaction
- used to prevent damage due to freezing (gives room for water to freeze, therefore expansion of water/ice causes less damage)
- bubbles should be small and well dispersed
- typically 4-9% air
- air entrainer is always used in cold climates for concrete exposed outfoors (ie: most of Ca
- air entrainer is always used in cold climates for concrete exposed outdoors (ie: most of Canada)
- increases workability (slump)
- prevent other deterioration: salt scaling, alkali-sulphate reaction (ASR), sulphate attack
- disadvantage: decrease in strength
    - 1-2% air = up to 5% decrease in strength
    - reduce water to cement ratio to counteract strength reduction

RECALL

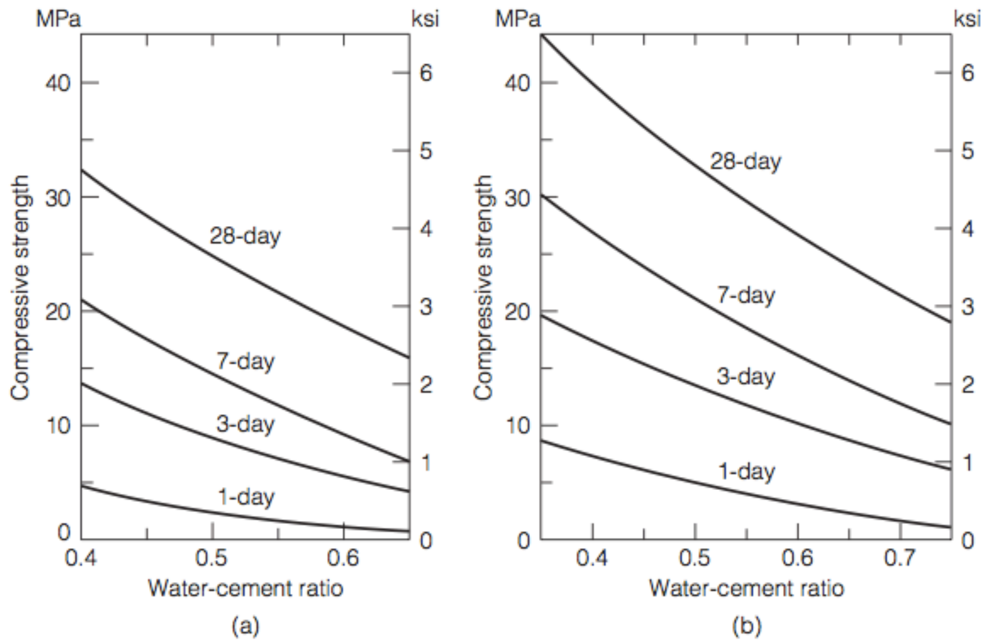


FIGURE 6.8 Typical age-strength relationships of concrete based on compression tests of 0.15 × 0.30 m (6 × 12 in.) cylinders, using Type I portland cement and moist-curing at 21°C (70°F): (a) air entrained concrete, (b) non-air entrained concrete. (Courtesy of Portland Cement Association)

Chemical Admixtures

- Water reducers increase workability without adding water
  - Workability – measured by slump test
- Types of water reducers
  - Conventional ("old") ~5%
  - mid-range ~10%
  - high-range (super plasticizers) ~20%
- mechanism
  - all solids have surface charge unlike charges cause flocculation

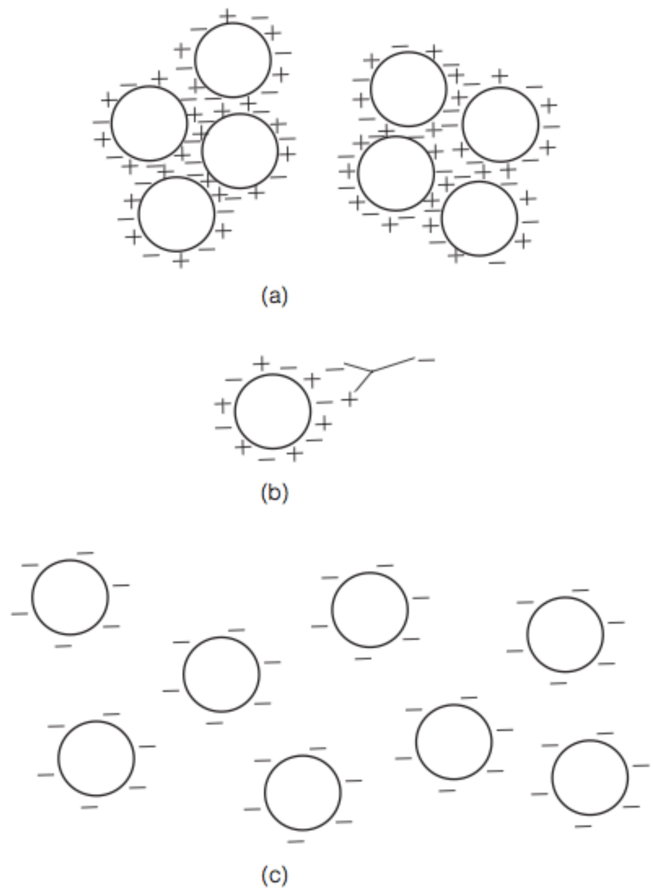
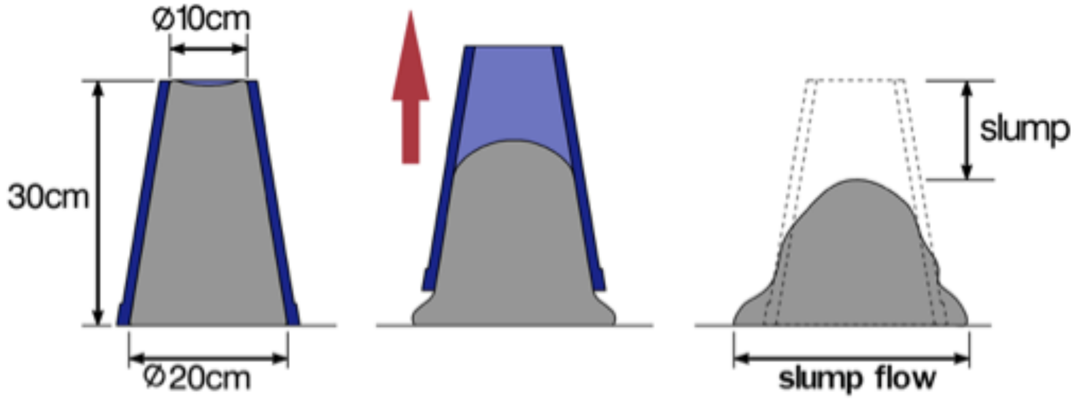


FIGURE 6.10 Water reducer mechanism: (a) clustering of cement grains without water reducer, (b) molecule of water reducer, and (c) better distribution of cement grains due to the use of water reducer.

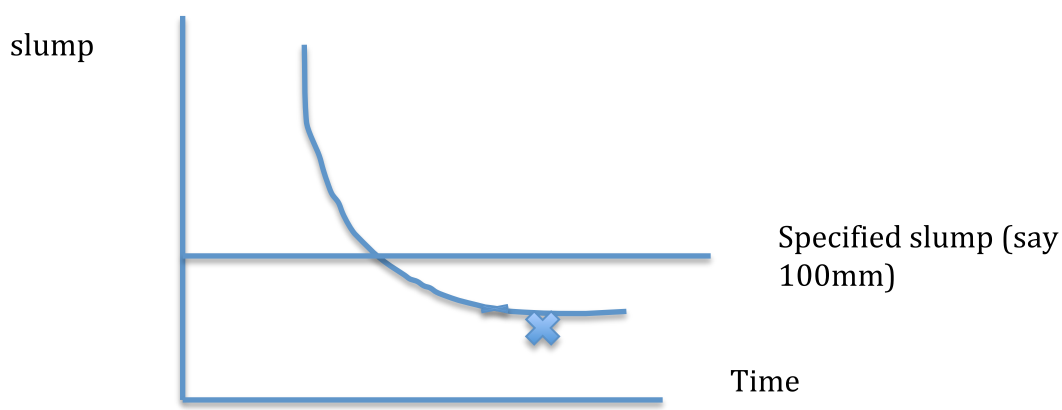
The grains of cement repelled by water reducer helps workability and helps hydration

- Water reducers are long-chain molecules
  - they have one positive end and one negative end (polar molecules: one has a positive charge and one has a negative charge)
- Used in three (3) ways
  1. Increases workability – no change to water to cement ratio (w/c)
  2. Increases strength – decrease in water to cement ratio (w/c) and no change in the workability
  3. Decreases cost – reduces water and reduces cement (cement content limits)
     -
- Super plasticizers
  - increases workability significantly (5-10cm to 20-25cm)

- it can also reduce water 12-30%
-



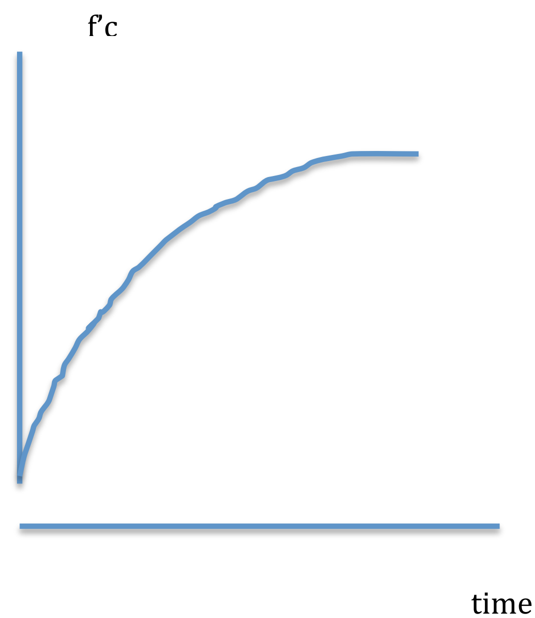
- used for:
  - placement around closely spaced reinforcement
  - high strength concrete (60 MPa+)
  - placing thin sections
  - pumping
- super plasticizers
  - short life 30-60 minutes
  - add some superplasticizer when mixing
  - add more to truck at job site



<u>Retarders</u>

  - delays set, slows hydration

- used for
  - hot weather (simmer) at the time of placement
  - reduces curing time
  - increases strength gain
    - slower hydration leads to higher later

- 

- unusual placement or long haul
- exposed aggregate finish
  - add retarder to surface
- disadvantage – reduces strength for first few days (1-3)

<u>Accelarators</u>

- increases hydration (first few days)
- used during cold placement temperatures
- used to increase early strength at other temperatures
- plugs leaks under hydraulic pressure
- calcium chloride – cheap accelerator
  - not allowed in reinforced concrete

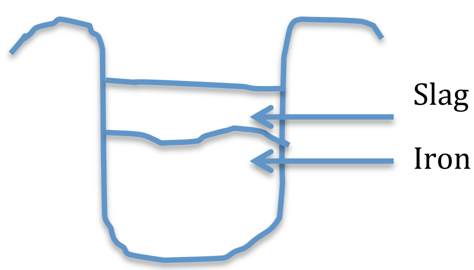
<u>Hydration Control</u>

- used to completely stop and later reactivate hydration
    - stabilizer – completely stops hydration up to 72 hours
    - activator – neutralizes stabilizer
- used for:
    - job site emergencies
    - very long hauls
    - concrete wash water

6.12 Supplementary Cementitious Materials

- Also called mineral admixtures
- By-products of other industries
- Advantages:
    - Reduce costs by reducing cement (not all SCM are cheaper)
    - Improve properties (durability)
    - Reduce CO_2 ($CaCO_3 \rightarrow CaO + CO_1$ increases)
    - Uses waste materials
- Most common types
    - Fly ash (Maritimes or USA)
        - Most commonly used worldwide
        - By-product of coal-fired power generation
        - Collected from exhaust
        - Small, spherical particles (same size as cement)
        - Primarily SiO_2, Al_2O_3, Fe_2O_3, CaO
        - Similar components to cement
        - Cement + water = C-S-H + CH
        - CH + fly ash = $(C\text{-}S\text{-}H)_2$ (Secondary C-S-H)
        - Class F – up to 10% CaO (In Quebec, class F is more common)
        - Class C – up to 30% CaO
        - Classification based on CaO
        - The classification is dependent on raw ingredients (types of coal that is being burnt)
        - Quebec uses 20% of class F in blended cements (80% GU cement)
        - Replacement levels typically 10-30%
        - Reacts with CH to produce secondary C-S-H
        - Reduces capillary porosity, therefore the durability increases
        - Disadvantages

            - Low early strength (due to time to produce CH)
            - Reduces entrained air (add more air entrainer)
    - Slag (Ontario)
        - Also known as ground-granulated blast furnace slag
        - By-product of steel manufacture
        - Slag is impurities in iron ore
        - Can be used as aggregate
        - More valuable as supplementary material
        - Must be cooled rapidly (becomes amorphous; amorphous = reactive)
        - Ground to useable size; same size as the cement
        - Reacts with water + CH
        - Usually used at 30-45% replacement
        -
    -



    - Silica fume
        - By-product of silicon metal
        - Collected from exhaust
        - Particles very small; 1/100 of cement
        - They can cause problems if inhaled
        - Almost always pre-blended with cement- typically ~7-8% silica fume
        - Generally used 5-10%
        - Small size – fits between
            - Cement particles
            - Cement-aggregate interface

- Natural Pozzonlans
  - Volcanic ash, lime
  - Silica and aluminum

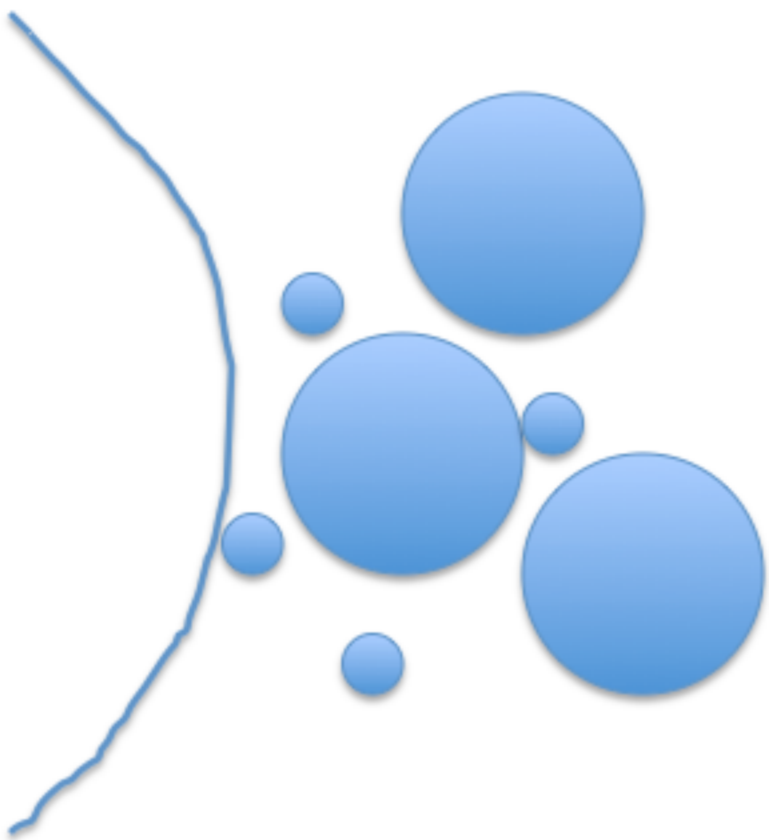


Figure: Silica Fume

CHAPTER 7: PORTLAND CEMENT CONRETE

- Desirable qualities
  - Acceptable workability
  - Strength and durability

Basic Steps in Concrete Mixture Design

1. Determine strength

2. Determine water to cement ratio
3. Determine coarse aggregate size and quantity
4. Determine air requirements
5. Determine workability
6. Determine water content
7. Determine cement content
8. Determine chemical admixtures

9. Determine fine aggregate
10. Determine the moisture correction (one of the important ones)
    a. add or subtract water
11. Do trial mixtures (test for air content, slump, etc..)

1. Strength

- Material variability
    - Design 30 MPa

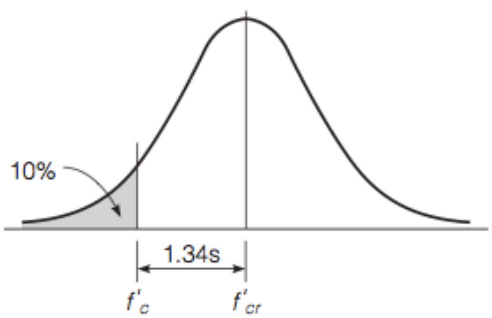


FIGURE 7.1 Use of normal distribution and risk criteria to estimate average required concrete strength.

- Need to know
    - Specified strength (design)
    - Variability – standard deviation
    - Allowable risks – ACI 318 is 10%
- Two equations to determine strength f'cr (critical)
    - $f'cr = f'c + 1.34s$
    - $f'cr = f'c + 2.33s - 3.45$ (MPa)
- S is determined at ready-mix plant
    - For each mixture design
    - Every time materials change

- Should be determine with > or = 30 samples
  - Modification factor ← f'cr
    - 15 1.16
    - 20 1.08
    - 25 1.03
  - If <15 samples
    - <21MPa f'c +7.0
    - 21-35MPa f'c +8.5
    - >35MPa f'c +10.0

2. Water to Cement Ratio (W/C)

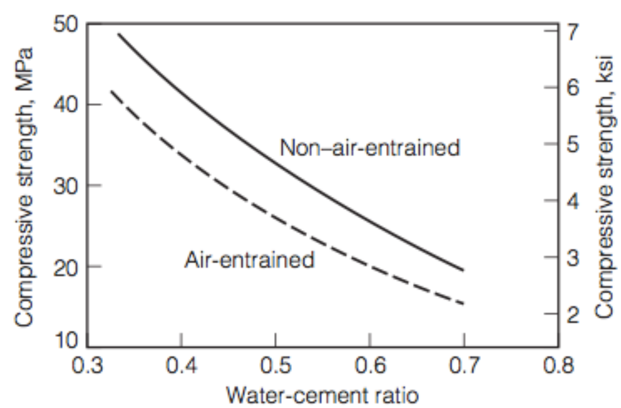


FIGURE 7.2 Example trial mixture or field data strength curves (Kosmatka et al., 2008).

a. Strength
   i. If no curve, use three trial mixtures
b. Durability (exposure conditions)
   i. 3 primary exposures
      1. chlorides (C)
      2. freezing and thawing (F)
      3. sulphate (S)
   ii. Use tables to find the w/c. Use lower w/c based on STRENGTH AND DURABILITY

3. Coarse Aggregate (Size and Volume)

- Size limits
  - Form dimensions – 1/5 of clear distance

    - Reinforcing or prestressing or rebar and form – ¾ of clear distance (if you distance is 40, then use 30mm aggregate)
- Unreinforced slab – 1/3 of thickness
- Select maximum size then use nominal size for remaining steps
    - For example, if the maximum is 25, then use 19mm
- Volume is determined by size (nominal) and fineness modulus of sand

TABLE 7.5 Bulk Volume of Coarse Aggregate per Unit Volume of Concrete*

Nominal Maximum Size of Aggregate, mm (in.)	Bulk Volume of Dry-Rodded Coarse Aggregate Per Unit Volume of Concrete for Different Fineness Moduli of Fine Aggregate**			
	Fineness Modulus			
	2.40	2.60	2.80	3.00
9.5 (3/8)	0.50	0.48	0.46	0.44
12.5 (1/2)	0.59	0.57	0.55	0.53
19 (3/4)	0.66	0.64	0.62	0.60
25 (1)	0.71	0.69	0.67	0.65
37.5 (1 1/2)	0.75	0.73	0.71	0.69
50 (2)	0.78	0.76	0.74	0.72
75 (3)	0.82	0.80	0.78	0.76
150 (6)	0.87	0.85	0.83	0.81

*American Concrete Institute (ACI 211.1).
**Bulk volumes are based on aggregates in a dry-rodded condition as described in ASTM C29 (AASHTO T19).

- Table give bulk volume

- 0.87 (1500kg/m^3) / density

4. Air Entrainment

- Do we need it?
- Used for freezing and deicers
- Need coarse aggregates
- As coarse size increases, amount of air decreases
- Air entrainment is related to cement paste volume

5. Workability

- For placing, consolidation and finishing
- Use slump test as measure of workability
- Workability depends on type of structure

6. Water Content

- Depends on the workability (slump)
- Depends on the aggregate size and shape
- Depends on air entrainment

Aggregate Shape	Reduction in Water Content, kg/m^3 (lb/yd^3)
Subangular	12 (20)
Gravel with crushed particles	21 (35)
Round gravel	27 (45)

Note: angular has no water reduction

7. Cement (Cementing Materials)

- Determined by w/c and water content
- Cement has limits
  - Flatwork 334 kg/m^3
  - underwater 385 kg/m^3

8) Admixtures – Chemical

- air entrainer, water reducer, etc…
- manufacturer recommended dosage
    - gives a wide range