2. Materials

CONCRETE COMPONENTS

PROPORTIONING & MIXING CONCRETE

QUALITY CONTROL

ADMIXTURES

PROPERTIES in COMPRESSION

PROPERTIES in TENSION

TIME DEPENDENT PROPERTIES

REINFORCING STEELS for CONCRETE

REINFORCING BARS

447.327
Theory of Reinforced Concrete and Lab. I
Spring 2008

2. Materials

MERRIAM-WEBSTER

Concrete; noun

1. a mass formed by concretion or coalescence of separate particles of matter in one body
2. a hard strong building material made by mixing a cementing material (as portland cement) and a mineral aggregate (as sand and gravel) with sufficient water to cause the cement to set and bind the entire mass
3. a waxy essence of flowers prepared by extraction and evaporation and used in perfumery

Handout 2-1

2. Materials

CONCRETE COMPONENTS

Cement
+
Water
+
Fine aggregate
+
Coarse aggregate
+
Additives

= Cement Paste

= Mortar

= CONCRETE

2. Materials

CONCRETE COMPONENTS

1. Cement (cementitious material)

   adhesive & cohesive properties

   ⇦ water is needed for chemical process*

   so-called *hydraulic cement*

*<u>*Hydration*</u>: chemical process in which the cement reacts with water and *sets* and *hardens* into a solid mass, bonding the aggregates together

⇨ *Heat of Hydration*

<u>Portland cement</u> (patented in GB in 1824)

$CaO + SiO_2 + Al2O_3$

2. Materials

How to Make Portland Cement

Raw materials	1. Limestone 2. Clay/Shale
Crushing Process	Limestone
Mixing & Grounding Process	Crushed Limestone + Clay + Sand + Iron ore
Heating Process	Mixed & Ground Compound at 1400 ~ 1600 °C
	Clinker
Final Ground & Mixing Process	Ground Clinker + Gypsum
	Portland Cement

2. Materials

CONCRETE COMPONENTS

Types of Portland Cement

- Type I (normal Portland cement)
  : 90%, needs 2 weeks for sufficient strength
- Type II (lower heat of hydration than Type I)
- Type III (high early strength cement)
  : 7~14 days
- Type IV (Low heat of hydration cement)
- Type V (Sulfate resisting cement)
  : structures exposed to soil with sulfate

2. Materials

CONCRETE COMPONENTS (cont.)

2. Aggregates

: occupy 70~75% of the volume

Fine aggregate vs. Coarse aggregate

5mm sieve

Maximum size of Coarse aggregate

- 1/5 of the narrowest dimension of form
- 1/3 of the depth of slab
- 3/4 of min. distance of reinforcing bars

2. Materials

2. Aggregates (cont.)

Lightweight aggregate

- unit weight of *normal* concrete ≈ 2,300kg/m^3
- chiefly used for insulation
- *processed aggregates* consist of expanded shale, clays, slates, slags, fly-ash, etc.

Heavyweight aggregate

- shielding against gamma & *X* radiation in N.R or counterweight of lift bridge
- unit weight > 3,000kg/m^3
- consist of iron ores, barite, etc.

2. Materials

PROPORTIONING & MIXING CONCRETE

Three Requisites for Good Proportioning

1. adequate strength
2. proper workability for placing
3. low cost
   : use of the min. amount of cement
   : use of better gradation of aggregates

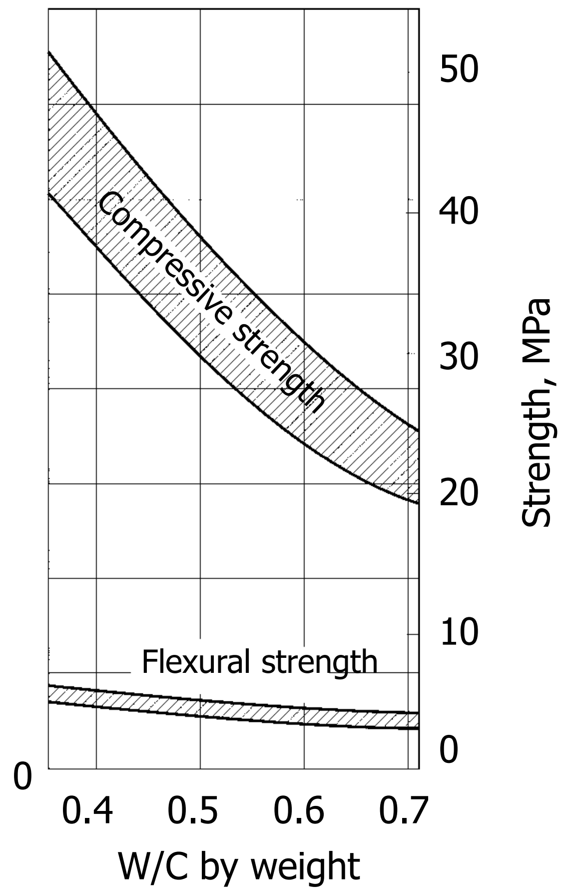
2. Materials

PROPORTIONING & MIXING CONCRETE

Water-Cement ratio (W/C)

- chief factor which controls the strength of the concrete
- water increase the plasticity & fluidity of the mix
- but decrease the strength of the concrete

⇦ large volume of voids created by the free water



2. Materials

PROPORTIONING & MIXING CONCRETE

Water-Cement ratio (W/C) (cont.)

- for complete hydration of a given amount of cement, W/C of 0.25 is needed chemically.
- for mobility for the water and workability of the concrete mix
- for *normal* concrete, W/C = 0.4~0.6

2. Materials

PROPORTIONING & MIXING CONCRETE

Mix Proportion

Relative ingredients quantities of concrete.

Representation method

- Expressed by ingredients quantities of $1m^3$ concrete

C	S	G	W	(kg/m^3)
300	720	1200	180	

- Expressed by relative ingredients quantities of concrete (the cement quantity is 1)

  C:S:G=1:2.4:4.0 W/C=0.6

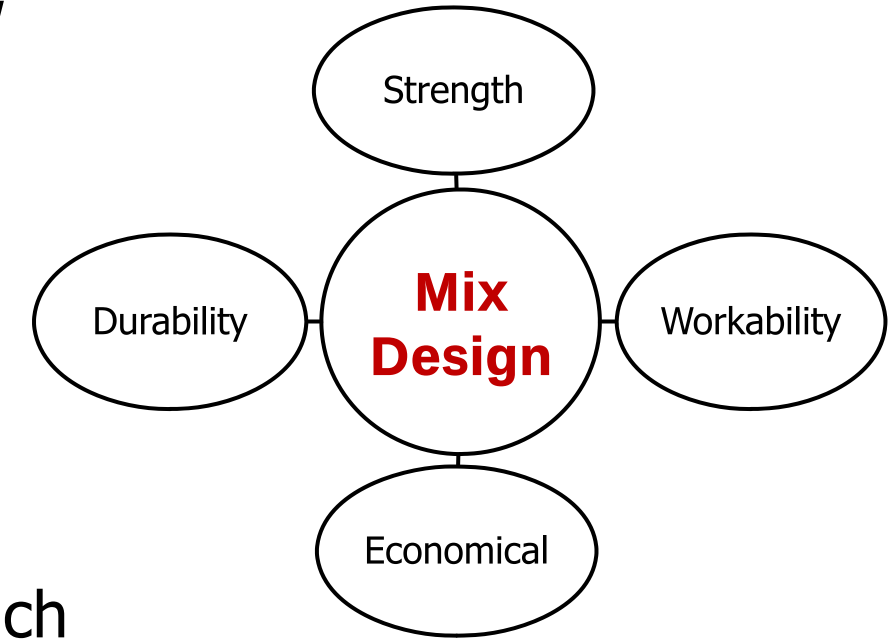
- Mix proportion can be expressed by the percentage of cement weight if *admixture* is blended

2. Materials

PROPORTIONING & MIXING CONCRETE

Mix Proportion Design

1. Choose the appropriate raw material according to;
   - technical properties
   - structure
   - construction
2. Ascertain the required technical economic index
3. Ascertain the quantity of each material



Basic Requirements

2. Materials

PROPORTIONING & MIXING CONCRETE

Basic Principle of Mix Design

Mix proportion design is based on the change rule of concrete performance.

Normal concrete mix proportion has FOUR basic variables
: C, W, S, G

Mix Proportion Design

with T.A. Handout 2-2

2. Materials

PROPORTIONING & MIXING CONCRETE

Terminology related to Fresh Concrete

1. **Segregation** - The tendency for the coarse particles to separate from the finer particles in handling.
2. **Bleeding** - A form of segregation in which some of the water in a mix tends to rise to the surface of freshly placed concrete
3. **Placing** - Pouring from conveying device to the form
4. **Air Content** - The amount of entrained or entrapped air in concrete or mortar, usually expressed as a percentage of total volume of concrete or mortar.

2. Materials

PROPORTIONING & MIXING CONCRETE

Terminology related to Fresh Concrete

5. **Slump** - A measure of the consistency of plastic concrete relative to the amount it falls when a slump cone filled with concrete is lifted vertically.
6. **Compacting** - consolidation by vibrator
7. **Vibration** - Energetic agitation of concrete to assist in its consolidation, produced by mechanical oscillating devices at moderately high frequencies.
8. **Curing** - Method of maintaining sufficient internal humidity and proper temperature for freshly placed concrete to assure proper hydration of the cement, and proper hardening of the concrete

2. Materials

QUALITY CONTROL

structural quality of concrete = compressive strength

KS F 2401 Method of sampling fresh concrete
KS F 2403 Method of making and curing concrete specimens
KS F 2405 Testing method for compressive strength of molded concrete

Frequency of Testing (KCI 2.3.3)

3 cylinders (150 x 300mm) should be sampled,

1) not less than once a day
2) for each 150m^3 of concrete
3) for each 500m^2 of surface area of slabs of walls

2. Materials

QUALITY CONTROL

Acceptance of Concrete (KCI 2.3.3)

Satisfactory if both of the following requirements are met,

1) Every average of any three consecutive strength tests equals or exceed f_{ck} (*specified compressive strength*)

2) No individual strength test falls below f_{ck}

by more than 3.5 MPa for $f_{ck} \leq 3.5$ MPa

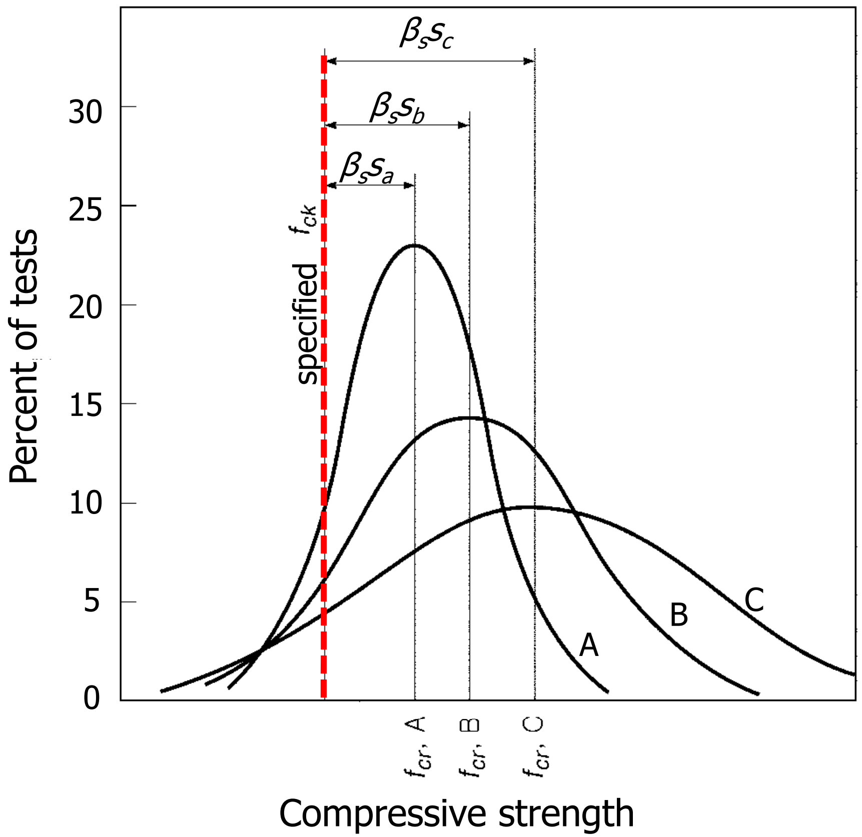
by more than $0.1 f_{ck}$ for $f_{ck} > 3.5$ MPa

If either of the above requirements is *not* met……?

2. Materials

QUALITY CONTROL

Required Average Compressive Strength f_{cr}



All three cases have the same probability of strength less than f_{ck}

The degree of control is measured by the standard deviation s.

$$f_{cr} = f_{ck} + \beta s$$

e.g.) β = 2.33 for a probability of 1 in 100

2. Materials

QUALITY CONTROL

Required Average Compressive Strength f_{cr} (KCI 5.3.2)

Specified Compressive Strength, f_{ck} MPa	Required Average Compressive Strength, f_{cr} MPa
$f_{ck} \le 35$	Use the larger value from the following two Eqs. $f_{ck} = f_{cr} + 1.34s$ $f_{ck} = (f_{cr} - 3.5) + 2.33s$
$f_{ck} > 35$	Use the larger value from the following two Eqs. $f_{ck} = f_{cr} + 1.34s$ $f_{ck} = 0.9f_{cr} + 2.33s$

This table is valid for when more than 30 tests are available

2. Materials

ADMIXTURES

used to improve concrete performance;

- Accelerate of retard setting and hardening
- Improve workability
- Increase strength
- Improve durability
- Decrease permeability
- In part other properties

2. Materials

ADMIXTURES

- Air-entrainment agent
  ; improves durability, workability, reduces bleeding, reduces freezing/thawing problems (e.g. special detergents)

- Superplasticizer
  ; increase strength by decreasing water needed for workable concrete (e.g. special polymers)

- Accelerating admixture
  ; speeds setting time, more early strength, offsets adverse low temp. weather (e.g. calcium chloride)

- Set-retarding admixture
  ; delays setting time, more long term strength, offsets adverse high temp. weather (e.g. sugar)

2. Materials

ADMIXTURES

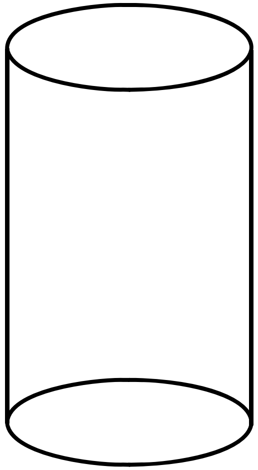
Partial replacement of cement

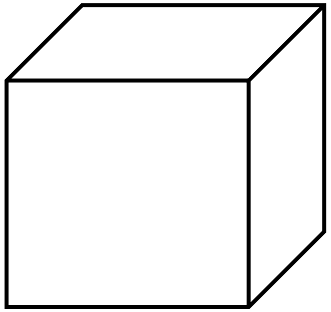
- Fly ash: by-product of coal-fired power plant
  increase the strength at ages over 28days
- Silica fume: by-product in electric-arc furnace
  gain strength at early ages

2. Materials

PROPERTIES in COMPRESSION

f_{cu} = uniaxial compressive strength at 28 days





Φ150×300mm cylinder

(ASTM, KS 2405)

200×200×200mm cube

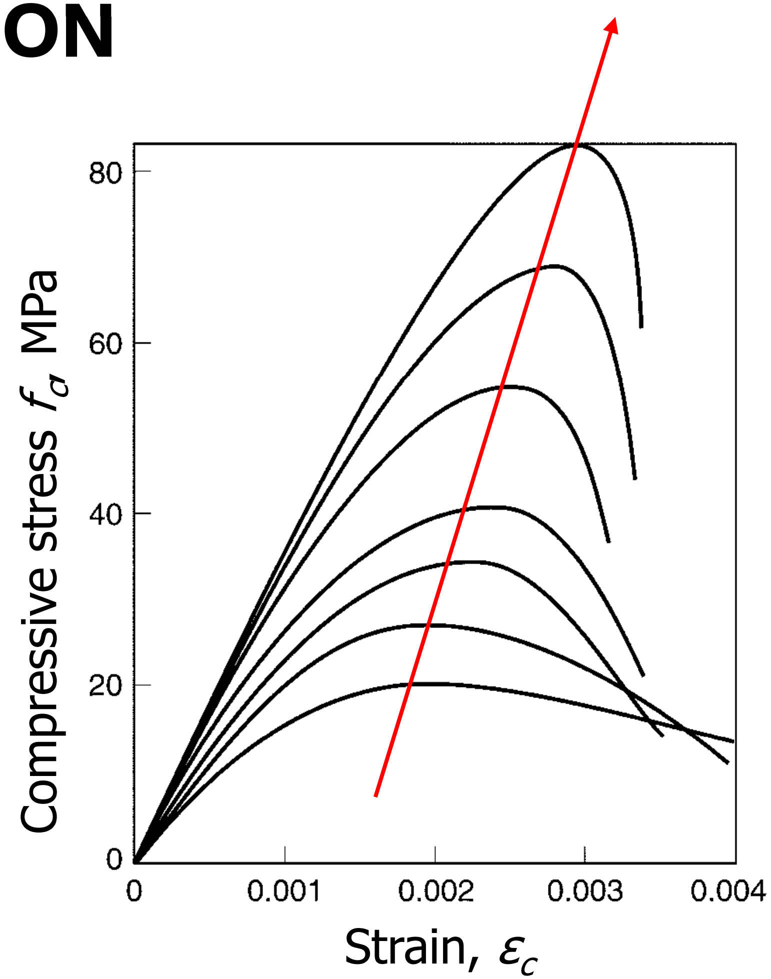
(Europe)

2. Materials

PROPERTIES in COMPRESSION

- at compressive strength strain ranges,
  - 0.002~0.003 (normal)
  - 0.003~0.0035 (lightweight)
- descending branch depends on test methods

f_{cu} = cylinder strength at 28days
f_{ck} = specified strength
f_{cr} = required ave. strength



2. Materials

PROPERTIES in COMPRESSION

Specified Strength f_{ck}

- 20~35 MPa - normal cast-in-place concrete
- ~55 MPa - precast prestressed concrete
- 100 MPa or more - high strength concrete (high rise bld. Long span bridge)

2. Materials

PROPERTIES in COMPRESSION

Modulus of Elasticity E_c (MPa, N/mm^2)

slope of the initial straight portion

- unit weight w_c = 1,450~2,500kg/m^3

$$E_c = 0.043 w_c^{1.5} \sqrt{f_{ck}} \qquad f_{ck} \le 30 \text{ MPa}$$

$$E_c = 0.03 w_c^{1.5} \sqrt{f_{ck}} + 7{,}700 \qquad f_{ck} > 30 \text{ MPa}$$

- for normal weight concrete w_c=2,300kg/m^3

$$E_c = 4{,}700 \sqrt{f_{ck}} \qquad f_{ck} \le 30 \text{ MPa}$$

2. Materials

PROPERTIES in COMPRESSION

Modulus of Elasticity E_c (KCI 3.4.3)

- unit weight m_c = 1,450~2,500kg/m^3

$$E_c = 0.077 m_c^{1.5} \sqrt[3]{f_{cu}} \quad \text{(MPa)}$$

- for normal weight concrete m_c=2,300kg/m^3

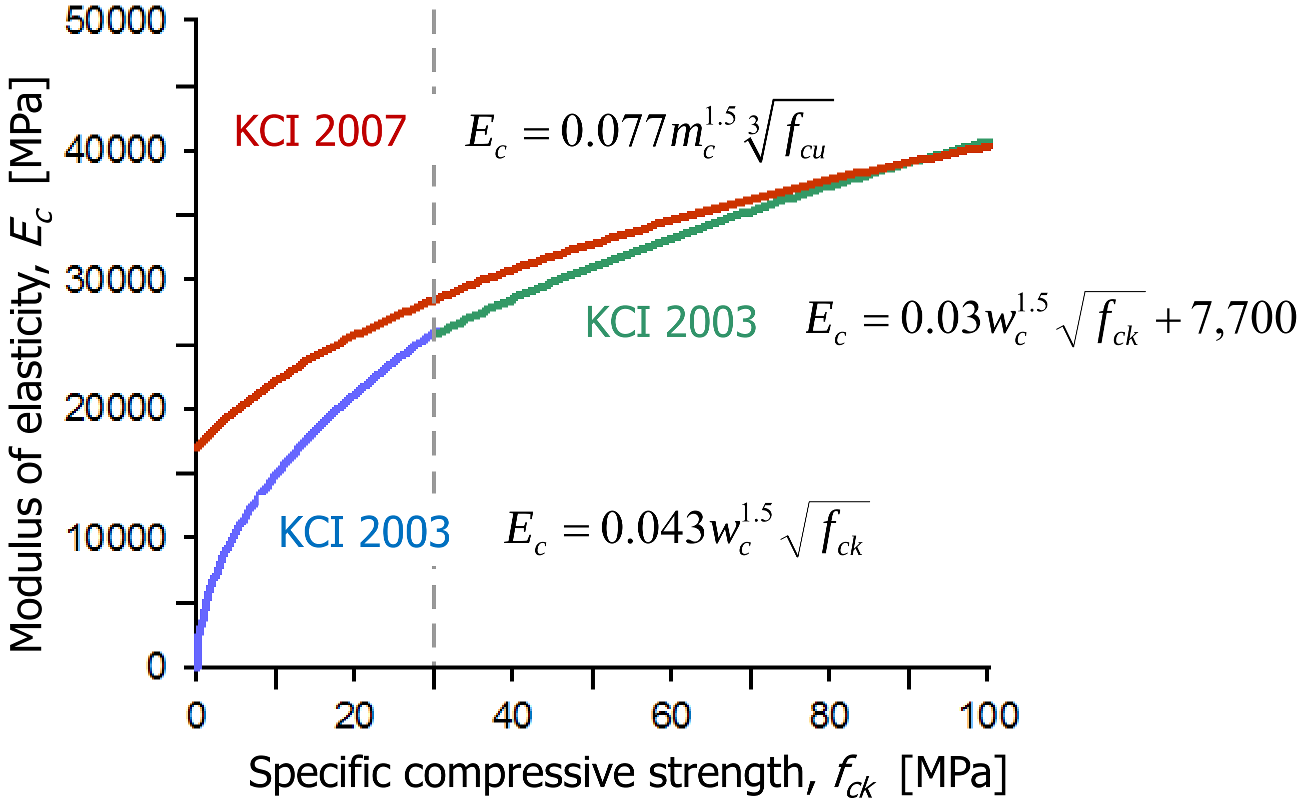
$$E_c = 8,500 \sqrt[3]{f_{cu}} \quad \text{(MPa)}$$

where, $f_{cu} = f_{ck} + 8$ (MPa)

2. Materials

PROPERTIES in COMPRESSION

Modulus of Elasticity E_c



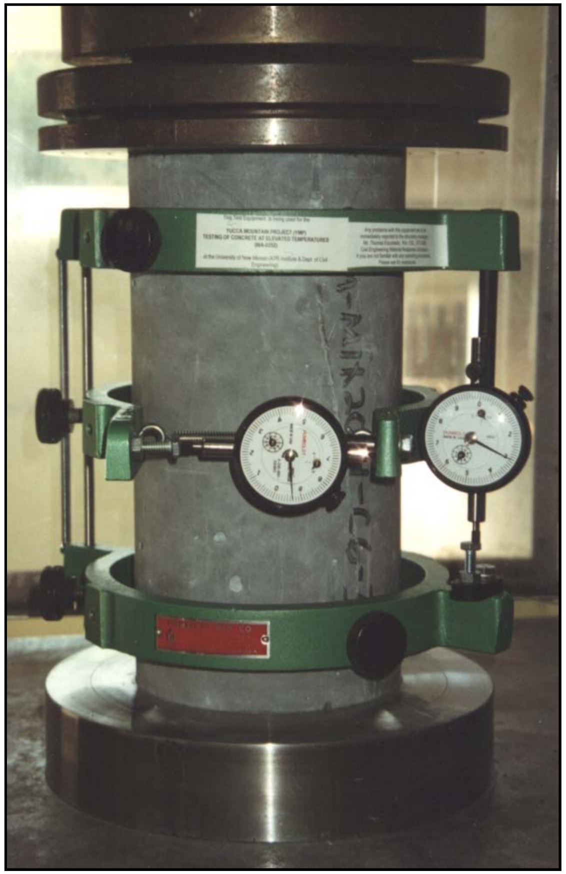
2. Materials

PROPERTIES in COMPRESSION

Poisson's Ratio ν

ratio of the transverse to the longitudinal strain

; 0.15 ~ 0.20



2. Materials

PROPERTIES in TENSION

Tensile Strength

difficult to measure the *true* tensile strength

- direct tension test
- split-cylinder test
- flexural tension test

(MPa)

Direct tensile strength	$0.25 \sim 0.40\sqrt{f_{cu}}$
Split-cylinder strength, f_{sp}	$0.50 \sim 0.70\sqrt{f_{cu}}$
Modulus of rupture, f_r	$0.65 \sim 1.00\sqrt{f_{cu}}$

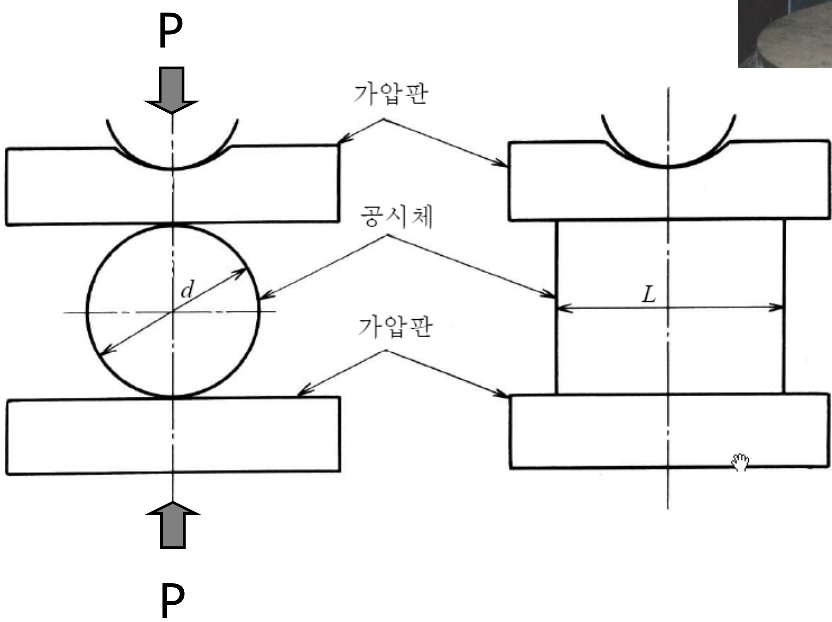
2. Materials

PROPERTIES in TENSION

Tensile Strength (cont.)

1. split-cylinder test (KS F 2423)

$$f_{sp} = \frac{2P}{\pi dL}$$



2. Materials

PROPERTIES in TENSION

Tensile Strength (cont.)

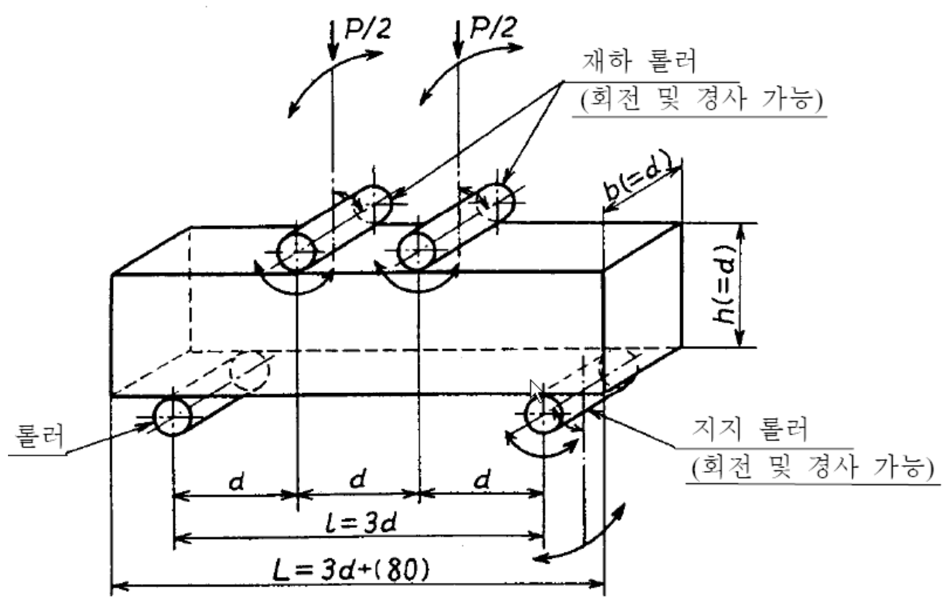
2. flexural tension test (KS F 2408)

Modulus of rupture, f_r

$$f_r = \frac{M}{I} y = \frac{3P}{h^2}$$

KCI Spec.

$$f_r = 0.63\sqrt{f_{ck}}$$



2. Materials

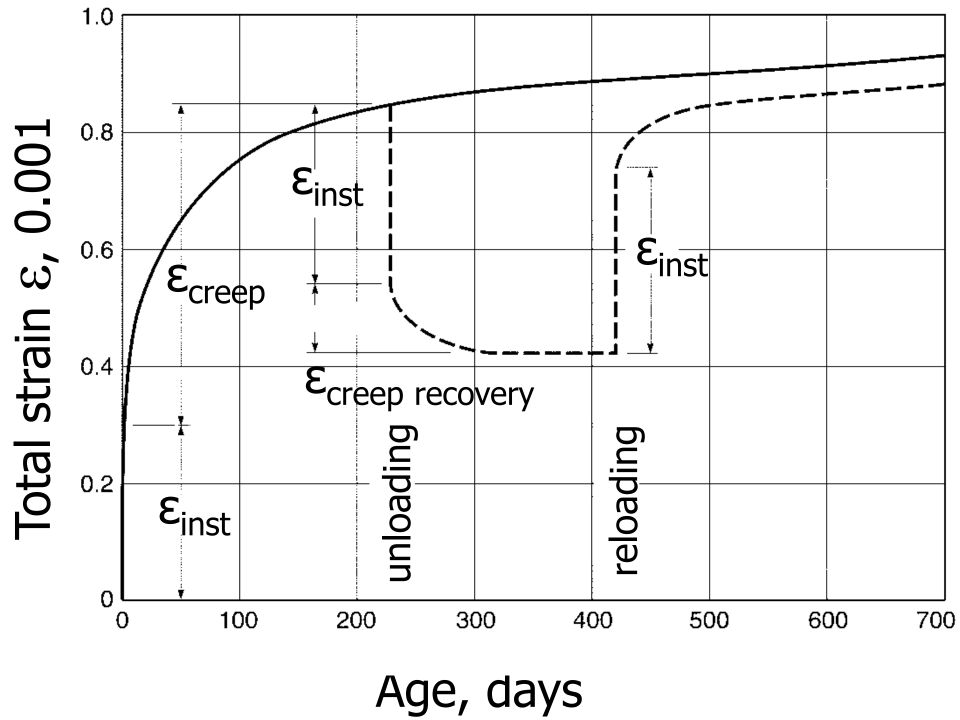
TIME DEPENDENT PROPERTIES

Creep

slow deformation of a material over considerable lengths of time at constant stress or load

creep depends on,

- stress level
- concrete strength
- ambient relative humidity
- type of cement & aggre.
- age of concrete



2. Materials

TIME DEPENDENT PROPERTIES

Shrinkage

volume change due to water loss to atmosphere (200~600 microstrain)

shrinkage depends on,

- W/C ratio
- aggregate type and amount
- volume/surface ratio
- type of cement
- ambient relative humidity

**not* related to the applied load

Types of shrinkage

- Plastic shrinkage
- Autogenous shrinkage
- Drying shrinkage

2. Materials

REINFORCING STEELS FOR CONCRETE

Best Combination

ordinary reinforcing steel is 15times of the compressive strength of concrete and over 100times its tensile strength

steel is very expensive

⇨ concrete (compression) + steel (tension)

bond for full composite action can be achieved,

- chemical adhesion between concrete-steel interface
- natural roughness of hot-rolled reinforcement
- rib-shaped deformation

2. Materials

REINFORCING STEELS FOR CONCRETE

Best Combination (cont.)

additional features that make for the satisfactory joint performance,

1. similar thermal expansion coefficients

   12×10^{-6} (concrete) $\approx 10 \times 10^{-6}$ (steel)

2. corrosion resistance of bare steel is poor

   ⇨ surrounding concrete is excellent corrosion protection

3. concrete has relatively low thermal conductivity

   ⇨ fire resistance

2. Materials

REINFORCING BARS

Grades and Strength

Handout 2-3

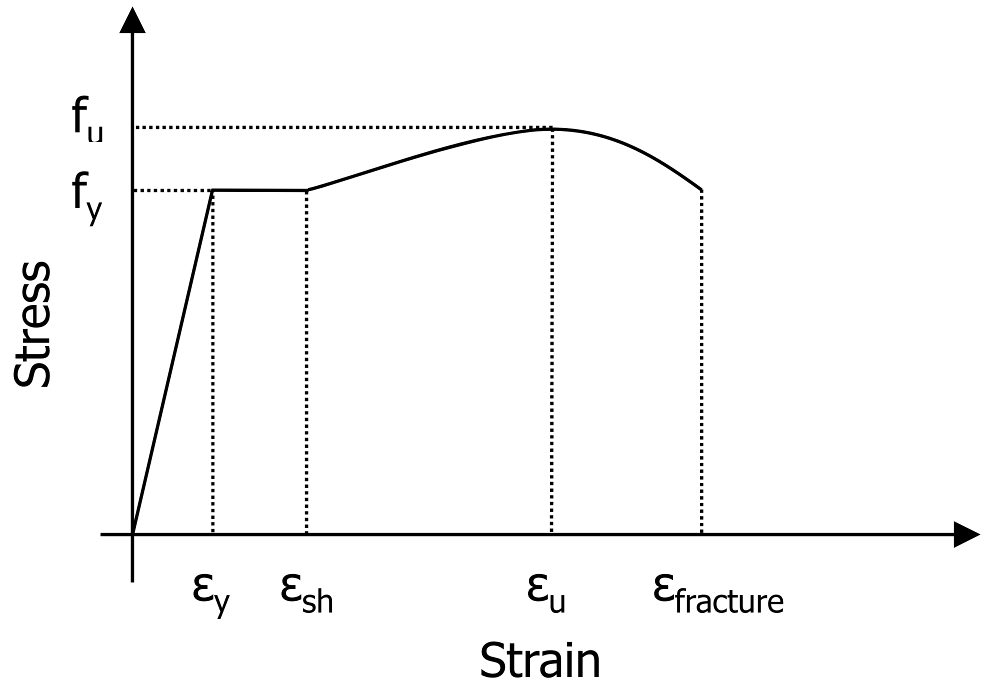
2. Materials

REINFORCING BARS

Stress Strain Curves

- Yield point
- Yield strength
- Yield plateau
- Strain hardening
- Tensile strength
- Modulus of elasticity

$E_s = 2.0 \times 10^5$ (MPa)



2. Materials

REINFORCING BARS

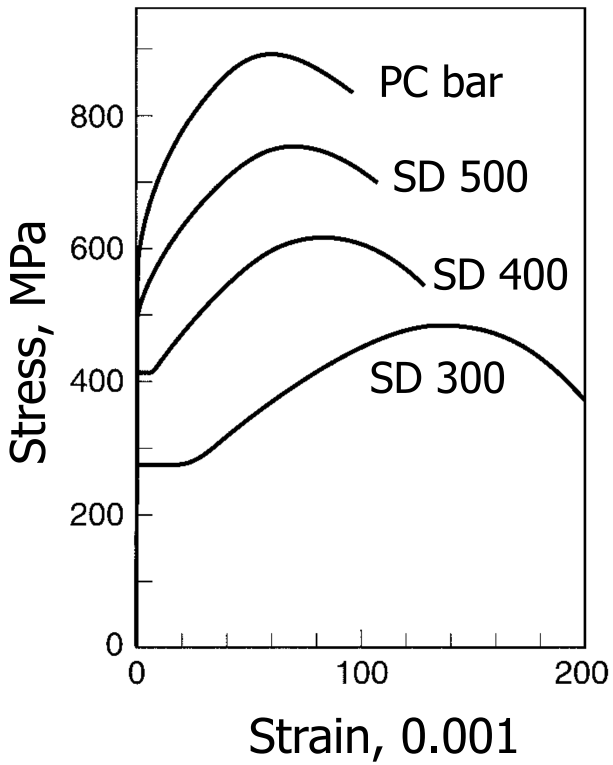
Stress Strain Curves (cont.)

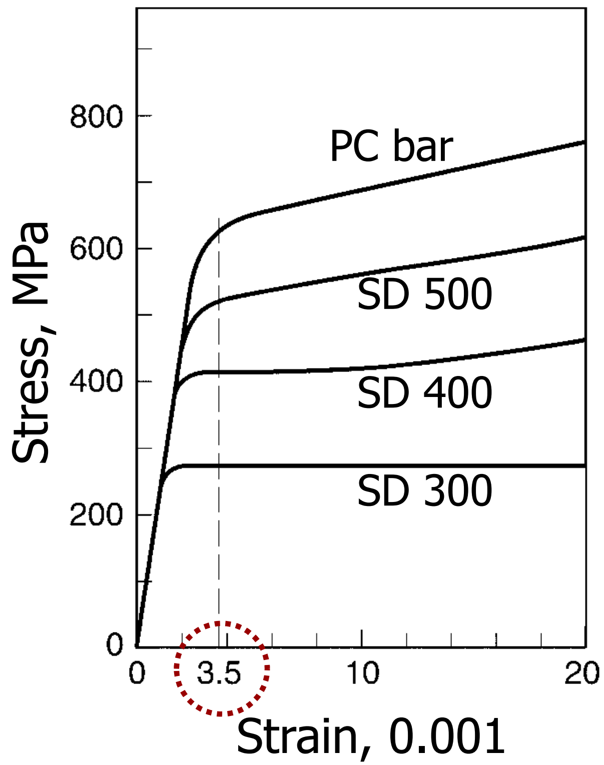
- SD300, SD400 rebars have a well-defined yield plateau
- SD400 less ductile than SD300
  ε_{frac} = 12~15%   vs. ε_{frac} = 20%
- $f_u = 1.5 f_y$
- $\varepsilon_{sh} = (6{\sim}10)\ \varepsilon_y$

2. Materials

REINFORCING BARS

Stress Strain Curves (cont.)





2. Materials

REINFORCING BARS

Coated Bar

- Member exposed to severe environment (coast, de-ice salt) are susceptible to corrosion
- Epoxy-coated bars are commonly used in practice
- Epoxy-coated bars have a smoother surface and thus a reduced bond strength
  - ⇨ longer anchorage length are required