20 February 2016

Lecture 1 - Introduction

CE 344
Materials of Construction

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CE 344 – Materials of Construction

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Course Objectives

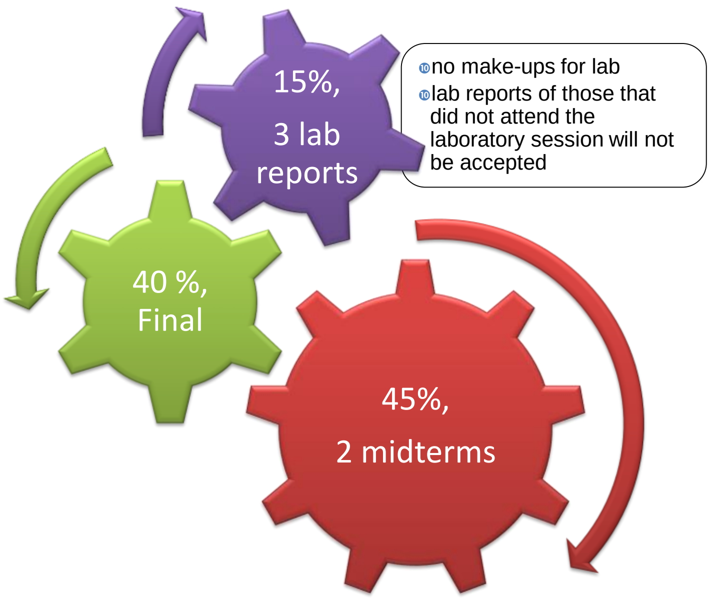
1. Introduce commonly used construction materials
2. Provide a basic understanding of their characteristics
3. For materials used at construction applications:
   - How do we produce this material?
   - Why do we use this material?
   - Where do we use this material?
   - How does this material behave?
   - What are the related standards and tests to use this material?

CE 344 – Tentative Outline

Week	Dates		Topic
1	22-Feb	26-Feb	**1. Introduction to materials of construction**
			2. Gypsum
2	29-Feb	4-Mar	3. Lime
3	7-Mar	11-Mar	4. Portland cement
4	14-Mar	18-Mar	(1st Lab around these dates)
5	21-Mar	25-Mar	
6	28-Mar	1-Apr	5. Pozzolans
	Specific date TBA		1st MIDTERM EXAMINATION
7	4-Apr	8-Apr	6. Aggregates
8	11-Apr	15-Apr	(2nd Lab around these dates)
9	18-Apr	22-Apr	7. Concrete
10	25-Apr	29-Apr	(3rd Lab around these dates)
11	2-May	6-May	
12	9-May	13-May	
	Specific date TBA		2nd MIDTERM EXAMINATION
13	16-May	20-May	8. Ferrous metals, alloys and concrete reinforcement
14	23-May	27-May	9. Polymers
			20. Clay bricks

(*) The detailed course schedule is available at the course web page.

Grading



Perspective

Housing/shelter

- a basic need for humans

~500,000 years ago

~1,000 years ago

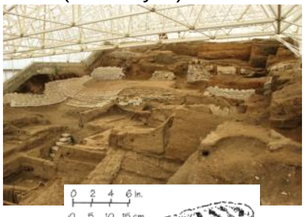
~400 years ago

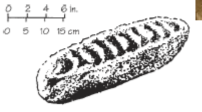
~1 year ago

Perspective

Historical perspectives

- **8000 BC** – Sun-dried clay mud brick (Catalhoyuk)
- **6000 BC** – Ceramic clay brick
- **5000 BC** – Mortar joints in brick pavements; Brick walls covered with gypsum plaster; Aggregates and fibers for reinforcement
- **4000 BC** – Framing the doors and wooden beams
- **3000 BC** – Glassware
- **1000 BC** – Lime and hydraulic lime mortar
- **0 AD** – Concrete with hydraulic lime and pozzolanic rock





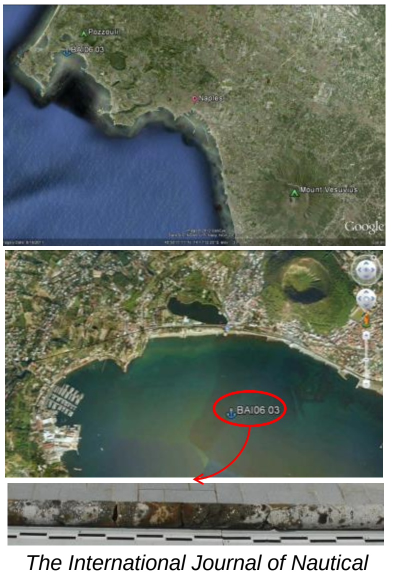
Pantheon, Rome, 126 AD

Concrete Core from Baianus Sinus

Estimated in early 1st century BC, the harbor of Baiae, or *Portus Baianus*, was built in Pozzuoli Bay within the central crater of Campi Flegrei.

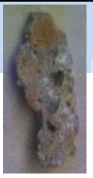
In 2006, as a part of ROMACONS project five cores were extracted from the sunken remains of the harbor.

A major accomplishment of Roman engineers was to construct enduring coastal underwater structures in seawater, which were important to long-distance trade and military endeavors. Two millennia later, the reasons for the extraordinary durability of the maritime structures remain enigmatic. The concretes are highly complex composites composed of relict lime, tuff and pumice clasts and pozzolanic reaction products. Calcium-chloroaluminate and sulfoaluminate minerals occur in certain relict voids.

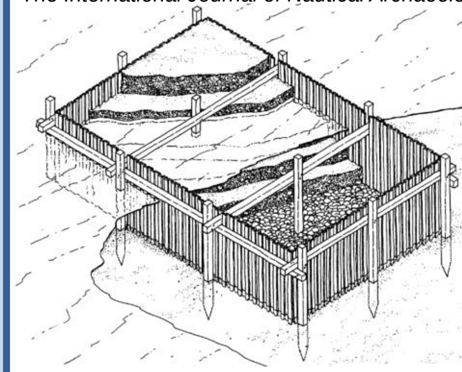


The International Journal of Nautical Archaeology (2008) **37** .2: 374–392

Building hydraulic Roman concrete



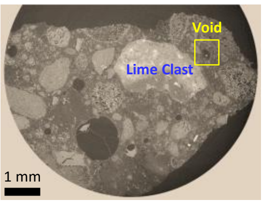
The International Journal of Nautical Archaeology (2004) **33**.2: 199–229



Hydraulic concrete hingredients

- *Calx, lime*
- Seawater
- *Pulvis*, pumiceous volcanic ash from Campi Flegrei
- *Caementa*, decimeter sized fragments of pumiceous tuff from Campi Flegrei

Vitruvius (2.6.1): " There is a kind of powdery sand [pulvis, i.e. pozzolana] which by its nature produces wonderful results. It is found in the neighbourhood of Baiae and in the lands of the municipalities around Mount Vesuvius. This material, when mixed with lime [calx] and rubble [caementum], not only furnishes strength to other buildings, but also, when piers are built in the sea, they set under water ... and neither the waves nor the force of water can dissolve them."



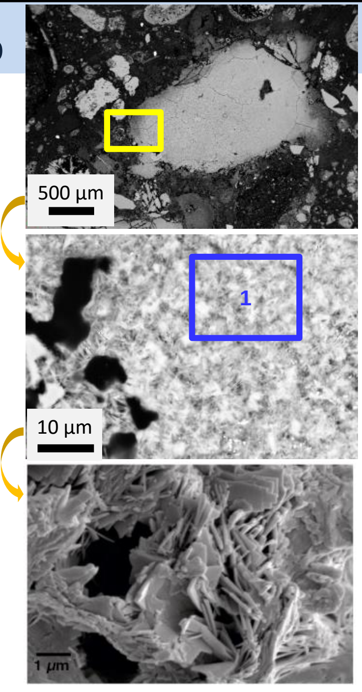
BSE/EDS SEM on a Polished Slab

Relict lime clast

Tobermorite, a hydrothermal alteration product of calcium carbonate rocks, due to contact metamorphism and metasomatism, fills the vesicles and cavities in basaltic rocks.

Al-Tobermorite

	Ca	Al	Si
Area 1	0.8	0.2	1.0



Ottomans…

Perspective

Historical perspectives

1750 AD | 1800 AD | 1850 AD | 1900 AD | 1950 AD | 2000 AD

1779
1st iron bridge

1793
1st hydraulic cement building
(Eddystone Lighthouse)

1824
Portland cement
(Aspdin)

1848
Reinforced concrete
(Monier, Béton armé)

1889
Eiffel Tower,
1st reinforced concrete bridge
(Alvord Lake Bridge)

1908
Alumina cement

1929
Prestressed concrete

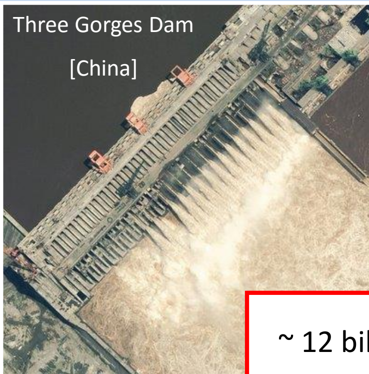
1936
1st concrete dam
(Hoover Dam)

1980
High performance concrete

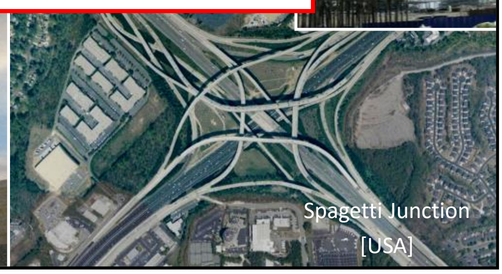
2000
Ultra high performance concrete

Concrete, the man made rock…

Concrete



~ 12 billion tons/year of Concrete



Why this much concrete?

Concrete

Concrete

- cheapest and most readily available material
- high resistance to cyclic loading
- ease in forming
- low maintenance
- high fire resistance
- excellent resistance to water

* Images courtesy of P.J.M. Monteiro

Concrete

Cement

+

Water

+

Fine Aggregate

+

Coarse Aggregate

→  → Concrete

Portland Cement

- 1824 AD: Joseph Aspdin, founder of today's Portland cement industry
  - Aspdin heated a mixture of finely ground *limestone* and *clay* in a furnace and ground the mixture into a powder to create a hydraulic cement.

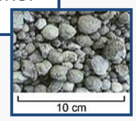
Limestone
source of lime

Clay
source of silica, alumina, iron

Cement

Portland Cement Production

Preheating → Kiln (~1450°C) → Clinker → Cooling



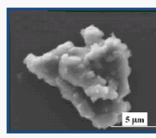
Crushing
Proportioning
Blending

Calcination
$CaCO_3 \rightarrow CaO + CO_2 \uparrow$

1 ton Cement
↓
0.5 ton CO_2

Grinding
(with ~4% Gypsum)

Limestone + Clay
(2 parts) (1 part)

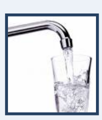


Portland Cement

Cement

Portland Cement Hydration

Hydrated Cement Paste



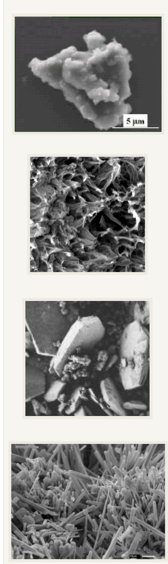
Cement + Water

Calcium Silicates
3(CaO).SiO_2
2(CaO).SiO_2

Calcium Aluminates
3(CaO).Al_2O_3

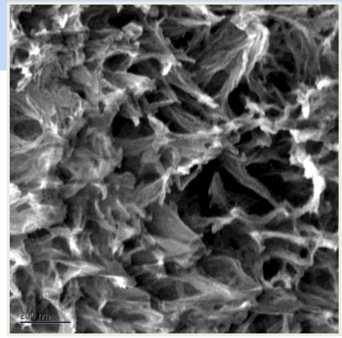
Calcium Aluminoferrites
4(CaO).Al_2O_3.Fe_2O_3

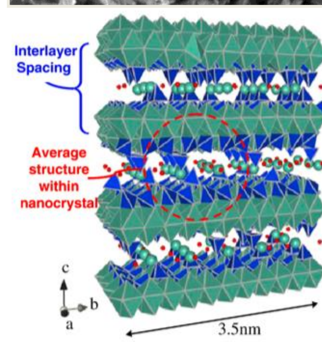
Unhydrated Cement Particle
+
Calcium Silicate Hydrates
+
Calcium Hydroxide
+
Calcium Sulfoaluminate Hydrates



Cement

Calcium Silicate Hydrates





- Notation: C-S-H
- A DISORDERED TOBERMORITE!
- Layered structure with very high surface area
  - High Van der Walls forces

    ↓
  - Highest contribution to strength
- 50-60% of solids in hydrated cement paste

* Meral et al., Cement and Concrete Research 41 (2011)

Cement

Calcium Hydroxide

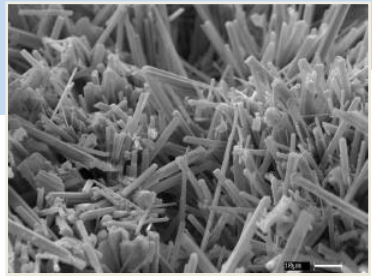
- Notation: CH
- Large, weak crystals with hexagonal – prism morphology
  - Lower Van der Walls forces

    ↓
  - Lower strength contribution
- 20-25% of solids in hydrated cement paste
- Contributes to increase PH

* Image courtesy of P.J.M. Monteiro

Cement

Calcium Sulfoaluminate Hydrates



- 15-20% of solids in HCP
- Ettringite
  - Trisulfate hydrate
  - Needle shaped prismatic crystals
- Monosulfate Hydrate
  - Hexagonal crystals

* Image courtesy of P.J.M. Monteiro

Challenges

Challenge 1 : Environmental Impact

~ 12 billion tons/year of concrete

↓

~ 2 billion tons of cement
~ 1 billion tons of water
~ 9 billion tons of aggregate

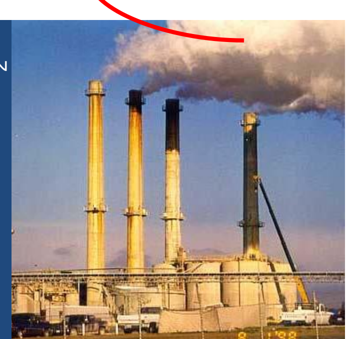
↓ ↓

Depletion of natural materials

Generation of 2 billion tons/year of CO_2

Problem!

1 ton cement → 1 ton CO_2



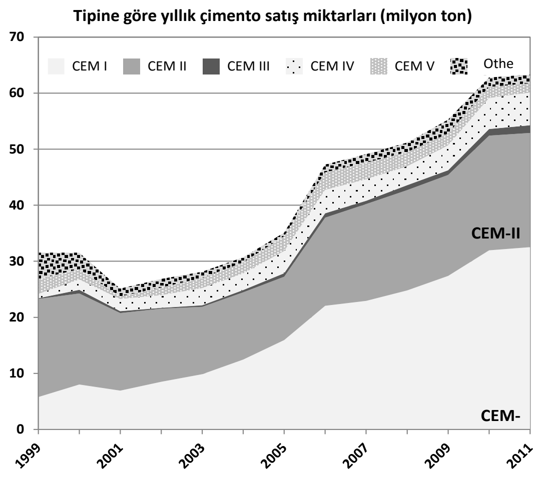
Calcination - 50%

Fuel - 40% | 10%

* Image courtesy of P.J.M. Monteiro

Turkey Cement Production / Sales

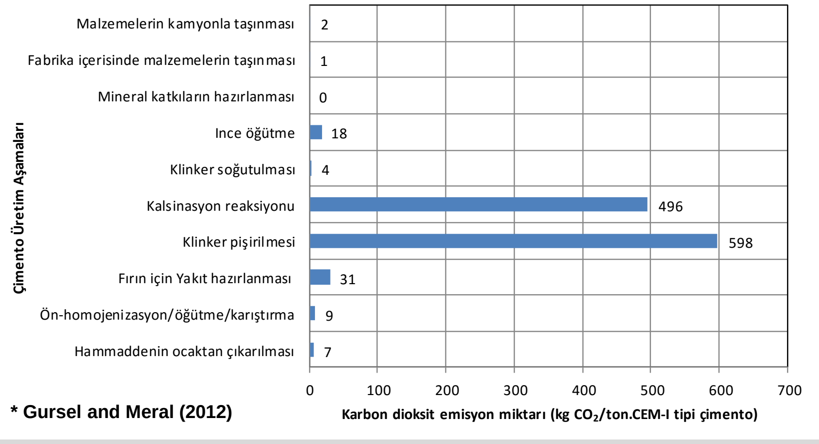
*** Gursel and Meral (2012)**



	Cement production (million tons)			
	1995	2000	2005	2011
China	446	583	1,040	2,000
India	70	95	145	210
USA	78	90	101	68
Turkey	33	36	43	64
Brazil	26	39	37	63

Turkey's CEM-I Production CO_2 emissions (kg CO_2/ton.CEM-I)

- In Turkey:
  - ~30 million ton CEM-I is produced at 2011
  - 1 ton CEM-I → ~1.165 ton CO_2



* Gursel and Meral (2012)

Challenges

Challenge 2: Long-term durability

~ 12 billion tons/year of concrete

↓

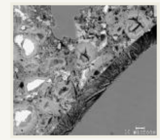
Deterioration mechanisms

↓

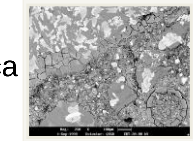
Significantly reduced life cycle

Corrosion

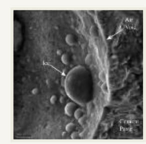
Sulfate attack



Alkali Silica Reaction

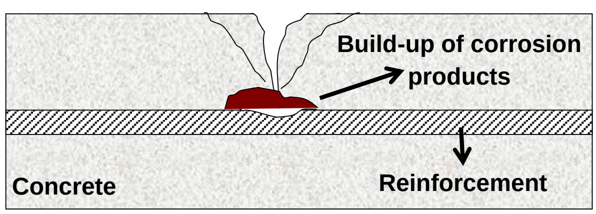


Frost Action



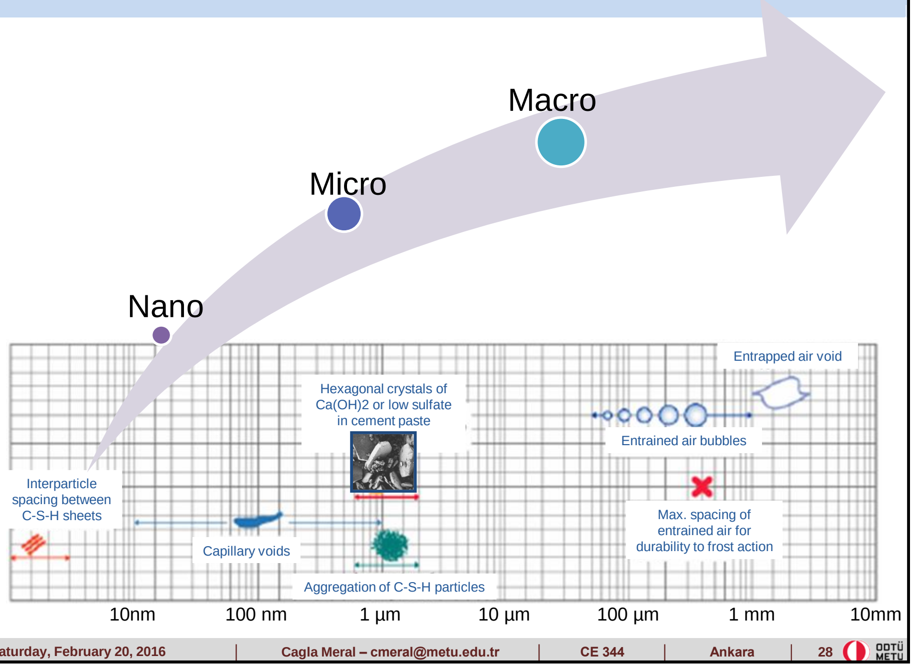
Durability of reinforcing steel

- Direct consequences of corrosion:
- reduction of bond between reinforcement and concrete
- change of reinforcement mechanical properties
- change of concrete properties
- loss of reinforcement cross section
- cracking and spalling of concrete



Corrosion of commercial steel

Multi-scale Problem



How much do you remember from CE241?

- So, let's revise…

Bond length

Q

- Two ions are separated by an infinite amount of space. When the two ions are brought close to one another, they begin to interact with attractive and repulsive forces.
- When in an equilibrium position, which of the following statements most accurately describes the "bond length."

  i. the distance between the two ions where F_{net} is zero.

  ii. the distance between the two ions where F_{net} is maximum.

  iii. the distance between the two ions where U_{net} is zero.

  iv. the distance between the two ions where U_{net} is minimum.

a) i. and iii.	c) ii. and iii.
b) i. and iv.	d) ii. and iv.

1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20

Ionic bonding

Q

- Can an ionic bond form between atoms of the same element, Yes or No?

1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20

Covalent solids

Q

- Which one of the following statements is not applicable to covalent solids?
  a) The units that occupy the lattice points are atoms.
  b) The binding forces in covalent solids are shared electrons.
  c) Covalent solids have low melting points.
  d) Covalent solids are very hard.
  e) Covalent solids do not conduct electric current well.

1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20

Amorphous solids

Q

- Amorphous solids are characterized by all the following statements except:
  a) Amorphous solids have no well-defined, ordered structure.
  b) The intermolecular forces between their particles are constant throughout the solid.
  c) Some amorphous solids are able to flow, like liquids.
  d) Amorphous solids do not exhibit sharp melting points.
  e) Amorphous solids shatter irregularly.

1 11
2 12
3 13
4 14
5 15
6 16
7 17
8 18
9 19
10 20

Crystalline solids

Q

- In a body-centered cubic lattice, how many atoms are contained in a unit cell?
  a) One
  b) two
  c) Three
  d) Four
  e) five

1 11
2 12
3 13
4 14
5 15
6 16
7 17
8 18
9 19
10 20

Crystalline solids

Q

- In a face-centered cubic lattice, how many atoms are contained in a unit cell?
  a) One
  b) two
  c) Three
  d) Four
  e) five

1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20

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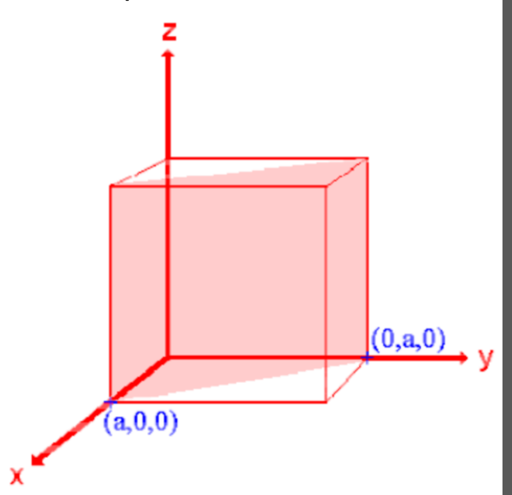
Miller indices

Q

- Miller indices for this plane:



1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20

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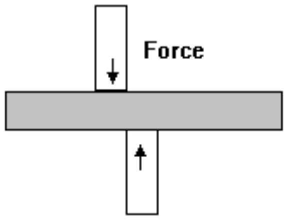
Force/Stress

Q
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20



- Calculate the force needed to guillotine a sheet of metal 5 mm thick and 0.8 m wide given that the ultimate shear stress is 50 MPa.

Isotropy

Q
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20

- Explain why most often polycrystalline materials exhibit isotropic properties.

Deformation Mechanisms

Q

- Can a purely hydrostatic state of stress cause slip in a crystal?

1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20

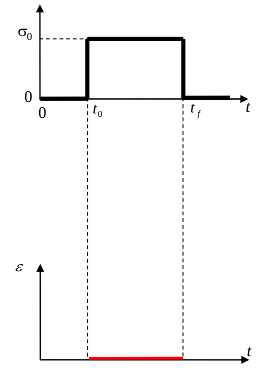
Deformation Mechanisms

Q

- Which of the following does not correctly describe viscosity?
  a. Viscosity is the resistance to flow of a liquid.
  b. Viscosity can be measured with a viscometer.
  c. The greater the ability of a liquid to hydrogen bond, the higher the viscosity.
  d. The smaller the molecule, the higher the viscosity.

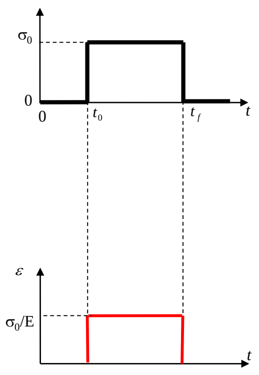
1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20

Stress-strain



- If a material is subjected to the step loading on your left, schematically draw the strain-time plots of a <u>rigid</u> material on the provided graphs.
  - Indicate the important points.
  - Note that the dashed lines locate the beginning and end of loading, and respectively.

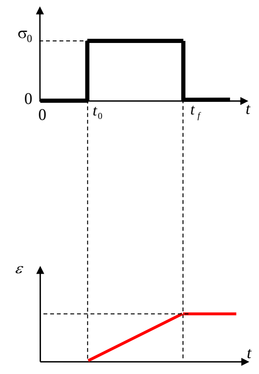
Stress-strain



- If a material is subjected to the step loading on your left, schematically draw the strain-time plots of a linearly <u>elastic</u> material on the provided graphs.
  - Indicate the important points.
  - Note that the dashed lines locate the beginning and end of loading, and respectively.

Stress-strain

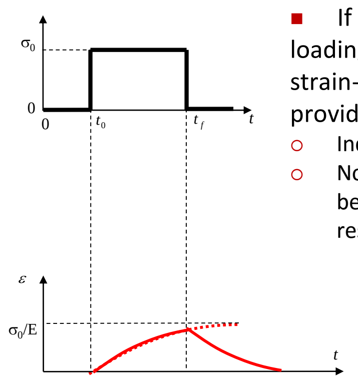
Q
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20



- If a material is subjected to the step loading on your left, schematically draw the strain-time plots of a viscous material on the provided graphs.
  - Indicate the important points.
  - Note that the dashed lines locate the beginning and end of loading, and respectively.

Stress-strain

Q
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20



- If a material is subjected to the step loading on your left, schematically draw the strain-time plots of a kelvin material on the provided graphs.
  - Indicate the important points.
  - Note that the dashed lines locate the beginning and end of loading, and respectively.

Hardness / toughness

Q

1 2 3 4 5 6 7 8 9 10

11 12 13 14 15 16 17 18 19 20

- What is the difference between hardness and toughness?

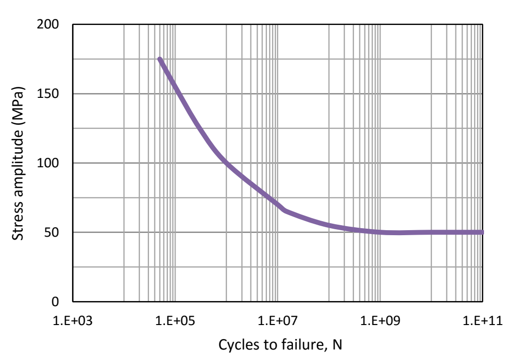
Fatigue

Q

1 2 3 4 5 6 7 8 9 10

11 12 13 14 15 16 17 18 19 20

- How long would the following material last under a cyclic load of 47 MPa?



Next lecture…

- Introduction to construction materials