Lecture 01 – Mechanical and non-mechanical properties of building materials

12.09.2016

Basic information

- **Instructors' contact information:**
  - Prof. Jussi Leveinen (Geomaterials)
  - Prof. Jouni Punkki (Cement Based Materials)
  - **Teacher:** D.Sc. Fahim Al-Neshawy
  - **Course assistant:** Kirsi Heikkinen
  - **E-mail:** firstname.surname@aalto.fi

- **Time:** 12.09 – 20.10.2016
- **Lectures:** Mondays and Tuesdays 14:00 to 16:00
- **Exercises:** Thursdays 8:30 to 10:00
- **Status of the course:** Master degree course
- **Academic Year, Period:** Autumn 2016 (Period I)
- **Location:** Otaniemi / Lecture hall R2
- **Language of Instruction:** English
- **Course Website:** [https://mycourses.aalto.fi/course/view.php?id=12977](https://mycourses.aalto.fi/course/view.php?id=12977)

Learning outcomes

1. **Knowledge:**
   - You will be able to learn basic theory about main building- and construction materials:
     - material composition / Properties
     - applications in buildings and structures

2. **Skills:**
   - You will be able to make right and well-founded choice of materials

3. **General competence:**
   - You understand how properties of materials can be related to the characteristics of the material.
Course content

1. Engineering concepts of building materials
2. Engineering properties of stones and aggregates
3. Cementitious materials and masonry products
4. Thermal insulation materials
5. Bituminous materials
6. Reinforcement steels and composite materials

Learning methods and activities

- Attending Lectures: 50%
- Weekly exercises – individual work
- Laboratory exercise – Group work
- Exam: 50% 

Course assessment

<table>
<thead>
<tr>
<th>Activity</th>
<th>Quantity</th>
<th>Points</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual and group work</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attending lectures</td>
<td>12</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Exercises</td>
<td>6</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Laboratory report</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Exam (5 Questions)</td>
<td>1</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Grading:
- 0 < 25 p
- 26 - 30
- 31 - 35
- 36 - 40
- 41 - 45
- > 45

For passing the course:
- a minimum grade of (1) is required for the individual and group work and
- a minimum grade of (1) is required for the exam.

Questions?

- Course content?
- How to pass the course?
- Teaching Staff?
- Anything else?
Lecture contents

Lecture 1. Mechanical and non-mechanical properties of building materials

1.1 History of building materials
1.2 Introduction to building materials
1.3 Fundamental Properties of Building Materials
   1.3.1 Parameters of state / structural characteristics
   1.3.2 Physical properties
   1.3.3 Mechanical properties

Lecture outcomes

1. Knowledge:
   * will be able to learn basic theory about main building- and construction materials:
     - material composition / Properties
     - applications in buildings and structures.

2. Skills:
   * be able to make right and well-founded choice of materials

3. General competence:
   * understand how properties of materials can be related to the characteristics of the material.

1.1 History of building materials

The Historical Timeline of Architecture

Arch. Kevin Espina - History of Architecture

- Before 3000 B.C.: Animal skins, wooden frames, animal bones
- 3000 – 2350 B.C.: Clay, soil, reeds, rushes
- 3050 – 332 B.C.: Stone, metal and timber were imported

Arch. Kevin Espina - History of Architecture
1.1 History of building materials

The Historical Timeline of Architecture

- **Greek**: 900 B.C. until the 1st century
  - Marble, Limestone, mud brick, masonry blocks, timber and terra cotta

- **Roman**: 100 B.C. – 400 AD
  - Stone sand, gravel, marble, earth for terra cotta and bricks

- **Gothic**: Europe 12th to 16th century
  - Red bricks, glazed bricks and white lime plaster

1.2 Introduction to building materials

What is Building Material?

- B.M. is any material which is used for construction purposes in the form of solid, semi-solid or liquid, processed or unprocessed (raw material).

  - **Natural Building materials**: clay, mud, rocks, sand, and wood, even twigs and leaves

  - **Man-made (synthetic) products**: fired bricks and clay blocks, ceramics, cement, composites, concrete, thermal and sound insulation, glass, metal, plastics, polymers, etc.

Responsibilities of material engineer:

- Selection of materials for structure elements (roofs, walls, floors, sub-structures, etc.)
- Specification of materials
- Quality control of materials
- These responsibilities fulfillment must meet certain criteria includes:
  - Climatic / culture conditions
  - Economic factors
  - Mechanical and non-mechanical properties
  - Production/Construction considerations
  - Aesthetic consideration
1.2 Introduction to building materials

- Aesthetic conditions
- Construction considerations
- Structural and visual conditions
- Economic factors

- Consistency and use of building, including building structure and the protection requirements
- Mechanical properties: mechanical properties, etc.
- Properties of material

Discussion (5 – 10 min)

- Family house
  - Structural elements?
  - Select suitable building materials for each element
  - Factors affecting your selection

1.3 Properties of Building Materials

- Structural characteristics
  - Density and unit weight
  - Porosity
1.3.1 Structural characteristics

**Density (ρ)**
- Density (AKA Practical density) is the mass of a unit volume of homogeneous material.
- Density of some building materials:

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick</td>
<td>2500 – 2800</td>
</tr>
<tr>
<td>Granite</td>
<td>2600 – 2900</td>
</tr>
<tr>
<td>Cement</td>
<td>2900 – 3100</td>
</tr>
<tr>
<td>Wood</td>
<td>1500 – 1600</td>
</tr>
<tr>
<td>Steel</td>
<td>7800 – 7900</td>
</tr>
<tr>
<td>Concrete</td>
<td>2400</td>
</tr>
</tbody>
</table>

\[ \rho = \frac{M}{V} \]  
\[ \rho = \frac{m}{V} \]  
\[ \rho = \frac{W}{V} \]

\( V \) is the volume under absolute compact conditions (cm³).

**Ways to determine density**

a) **Direct measurement of mass and volume**
- When measuring liquids and regularly shaped solids, mass and volume can be discovered by direct measurement and these two measurements can then be used to determine density.

b) **Indirect volume measurement**
- To calculate the density of solids with irregular surfaces:
  - Pour water into the graduated cylinder
  - Mark the original water level
  - Add the object to the water and record the new water level.
  - The difference between the new water level and the original level will be the object’s volume.

**Bulk Density (ρₚ)**
- Is the mass of a unit volume of material in its natural state (with pores and voids).

\[ \rhoₚ = \frac{M}{V + V_p} \quad \text{kg/m}^3 \]

\( V \) = volume of specimen in its natural state (m³)

\( V_p \) = volume of pores + volume of solid

- For most materials, bulk density is less than density.
- Properties like strength and heat conductivity are greatly affected by their bulk density.

**Specific Weight (γ)**
- Aka. (the unit weight) = the weight per unit volume of material, \( γ = \rho \cdot g \)
  - \( γ \) = specific weight (kN/m³)
  - \( ρ \) = density of the material (kg/m³)
  - \( g \) = gravity (m/s²)

- Specific weight can be used in civil engineering to determine the weight of a structure designed to carry certain loads while remaining un-broken and remaining within limits regarding deformation.

**Density Index (ρ₀)**
- Is the ratio, \( \rho₀ = \frac{ρₚ}{ρ} \)
  - It indicates the degree to which the volume of a material is filled with solid matter.
  - For almost all building materials, \( ρ₀ \) is less than 1.0
  - No absolutely dense bodies in nature.
1.3.1 Structural characteristics

**Specific Gravity (G_s)**

- S.G. of solid particles of a material is the ratio of weight/mass of a given volume of solids to the weight/mass of an equal volume of water at 4°C.

\[
G_s = \frac{\gamma_s}{\gamma_w} = \frac{\rho_s}{\rho_w}
\]

At 4°C \(\gamma_w = 1 \text{ g/cm}^3\) or 9.8 kN/m³

Specific gravity = \(\frac{\text{weight of a substance}}{\text{weight of equal volume of water}}\)

**Porosity (n)**

Porosity is the ratio of the volume of pores to that of the specimen.

\[
n = \frac{V_p}{V}
\]

- \(V_p\) = volume of voids
- \(V\) = total volume of the material

**Void Ratio (e)**

- is defined as the ratio of volume of voids \(V_p\) to the volume of solids \(V_s\)

\[
e = \frac{V_p}{V_s}
\]

\[
e = \frac{V_p}{V_s} = \frac{n}{1 + n}
\]

- \(e\) = void ratio
- \(n\) = porosity
- \(V_p\) = volume of voids
- \(V_s\) = the volume of solids
- \(V = V_p + V_s\)
1.4.2 Physical Properties

Physical properties

- Hydro-physical properties
- Thermal properties
- Viscosity

1.4.2 Physical Properties

Water absorption
- denotes the ability of the material to absorb and retain water.
- It is expressed as percentage in weight or of the volume of dry material

Water absorption test

- Sample
- Oven 72 h at 105°C
- Dry Sample (M)
- Wet Sample (Mw)

\[ W_a = \frac{M - M}{M} \times 100 \]

\[ W_v = \frac{M_w - M}{V} \times 100 \]

\[ M_1 = \text{mass of saturated material} \]

\[ M = \text{mass of dry material} \]

\[ V = \text{volume of material including the pores} \]

Thermal Conductivity (k or \(\lambda\))

- is the material ability to conduct heat.
- The faster heat flows through a material, the more conductive it is.

\[ k \text{ or } \lambda = \frac{q \times L}{A \times \Delta T} \]

- \( k \) = the thermal conductivity of the material (W/mK).
- \( q \) = the resultant heat flow (Watts)
- \( A \) = the surface area through which the heat flows (m²)
- \( \Delta T \) = the temperature difference between the warm and cold sides of the material (K)
- \( L \) = the thickness / length of the material (m)

Thermal Expansion

- \( \alpha_l \) = coefficient of linear thermal expansion
- \( \alpha_v \) = coefficient of volumetric thermal expansion

\[ \alpha_l = \frac{L_f - L_i}{L_i \Delta T} \]

\[ \alpha_v = \frac{V_f - V_i}{V_i \Delta T} \]

where:

- \( L_i \) = initial length
- \( L_f \) = final length
- \( V_i \) = initial volume
- \( V_f \) = final volume
- \( \Delta T \) = change in temperature
1.4.2 Physical Properties

- **Viscosity** is a measure of the resistance of a fluid which is being deformed by either shear or tensile stress.
- In everyday terms (and for fluids only), viscosity is "thickness" or "internal friction".
- Thus, water is "thin", having a lower viscosity, while honey is "thick", having a higher viscosity.

- Viscosity describes a fluid’s internal resistance to flow and may be thought of as a measure of fluid friction.

- Plastic viscosity of concrete is critical for the concrete industry because it affects placement and workability.

1.4.3 Mechanical Properties

### Mechanical properties

- Strength / Loadings
- Stress–strain relations
- Elastic behavior
- Elastoplastic behavior
- Viscoelastic behavior
- Ductility

#### Types of loadings:

- Transverse
- Axial loading
- Torsional loading

#### Produced stress

- Direct stress (direct tensile stress or direct compressive stress)
- Bending stress (tensile stress or compressive stress)
- Shearing stress,
- Torsional stress, or
- A combination of the different stresses.

#### Loading conditions:

- **Periodic load**, repeats itself with time. For example, rotating equipment in a building can produce a vibratory load.
- **Random load**, the load pattern never repeats, such as that produced by earthquakes
- **Transient load** is an impulse load that is applied over a short time interval, after which the vibrations decay until the system returns to a rest condition. For example, bridges must be designed to withstand the transient loads of trucks.
1.4.3 Mechanical Properties

Stress–strain relations

- Stress-strain curve - basic relationship that describes mechanical properties for static stresses to which materials can be subjected:
  1. Tensile - stretching the material
  2. Compressive - squeezing the material
  3. Shear - causing adjacent portions of the material to slide against each other

Stress = Force / Original area

\[ \varepsilon = \frac{L - L_0}{L_0} \]

Elastic behavior

- Material returns to its original length when stress is removed
- Relationship between stress and strain is linear
  Hooke’s Law:
  \[ \sigma = E \varepsilon \]
  where \( E \) = modulus of elasticity
1.4.3 Mechanical Properties

Yield Point in Stress-Strain Curve
- As stress increases, a point in the linear relationship is finally reached when the material begins to yield.
  
  - Yield point $Y$ can be identified by the change in slope at the upper end of the linear region.
  - Other names for yield point:
    - Yield strength
    - Yield stress
    - Elastic limit

Plastic Region
- Yield point marks the beginning of plastic deformation.
- The stress-strain relationship is no longer guided by Hooke's Law.
- As load is increased beyond $Y$, elongation proceeds at a much faster rate than before, causing the slope of the curve to change dramatically.

Viscoelastic behavior
- Viscosity can be defined using two parallel plates separated by a distance $d$ and a fluid fills the space between the two plates.
- Typical viscoelastic materials used in construction applications are asphalt and plastics.
- Some of the properties of viscoelastic materials are their ability to:
  - creep
  - recover
  - undergo stress relaxation
  - absorb energy.

Ductility
- Ability of material to undergo large deformations without rupture before failure.
- Beneficial to the users of the structures as it will undergo large deformations before failure and thus provides warning to the occupants.
### Summary

**We discussed:**
- The history of using building materials
- Types of materials used by engineers
- The criteria of selecting suitable building material
- The material properties important to civil engineering:
  - Structural characteristics
  - Physical properties
  - Mechanical properties

- Next Lecture: Sustainable design, Material variability, and Nature of materials