Period #1 : CIVIL MATERIALS COURSE OVERVIEW

A. **Materials Systems to be Addressed**

- Metals and Alloys (steel and aluminum)
- Portland Cement Concrete
- Asphalt Cement Concrete
- Fiber Reinforced Composites
- Masonry
- Wood/Timber

Fundamental Questions Addressed for Each Material System:

- How is the material produced?
- What is its chemical composition?
- What are the material's physical and mechanical properties?
- What is the nature of its micro- and nano-structure?
- How does the material system behave in service?
- Relationships between physical, mechanical behavior and micro-structure?
- What are the durability issues?

B. Understanding of Material Systems

1. Three Complementary Approaches to Understanding of Materials
   a. Empiricism
      - Laboratory experiments (a significant part of this course)
      - Trial and error
   b. Craft
      - Accumulation of best practices built up over time and experience with materials;
      - Observations built up over years of experience
         - Example: crafting of Samurai Swords or Katana (see http://en.wikipedia.org/wiki/Katana#Forging)
         - Another example: the making of Roman concrete (http://www.romanconcrete.com/docs/spillway/spillway.htm)
   c. Scientific:
      - Study of material at different length scales:
         - Molecular level (sub-nano-meter scale)
         - Material structural level (micro-meter to milli-meter scale)
         - Engineering structural level (milli-meter to meter scales)
      - Chemistry
      - Scale effects

2. Proposed Sequential Treatment of Each Material System in this course
    a. Source of relevant raw materials and their chemical composition;
    b. Processing of the material and manufacturing;
    c. Material structure on multiple length scales with discussion of scale effects;
    d. Laboratory study (measurement of mechanical properties for different variations of the same system)
    e. Discussion of physical & mechanical properties relative to those of other materials.
    f. Durability issues and how to prolong service life of the material

C. Criteria For Comparison of Materials Systems

Generally, more than one material system can serve the required function for a given job. Our objective is to gain familiarity with all of the major systems, so decisions can be made based on relatively complete information.

- Fitness for purpose:
  - strong enough?
  - stiff enough?
  - sufficiently durable?
  - watertightness?
  - speed of construction?

- Other Factors
  - aesthetics
  - environmental considerations
  - experience with the material system?
  - do design and usage codes exist?
  - availability

- Cost Issues
  - first cost
  - lifecycle costs
  - energy costs (manufacture; transport; fabrication;)

- Material Quality
  - What is the variability in material properties?
  - What are the factors that contribute to variability?

D. States of Matter for Materials

1. Gases:
   - Particles (or molecules) are not in direct contact with each other
   - Gases typically expand to fill their container
   - Representative Constitutive Models:
     - Ideal Gas Law:
       PV = RT
     - Van der Waals Gas Law: $\left(P+\frac{a}{V^2}\right)(V-b)=RT$
   - Gas diffusion:
     - Gases readily diffuse into each other typically in accordance with Fick's Law, the 1-D form of which is: $J=-D\frac{\partial c}{\partial x}$
       - Where: J is the flux rate of the gas;
       - C is the concentration of the gas;
       - D is the gas diffusivity which increases with temperature; and
       - x is the spatial coordinate dimension

2. Fluids
   - Particles (molecules) are essentially in direct contact, but they move freely with respect to each other
   - Although fluids generally have a fixed volume they do take the shape of their container.

- Representative Constitutive Model for Fluids

shear behavior: $\tau = \eta\dot{\gamma}$ where:

τ is shear stress, η is viscosity, and $\dot{\gamma}$ is the rate of shear

volume behavior: $p = K\varepsilon_v$ where:

p is pressure, K is the bulk modulus, and ε_v is volumetric strain

- Fluid diffusion. Like gasses fluids diffuse into each other in accordance with Fick's Law. The diffusivity of liquids, however, is typically much lower than that of gases.
- Fluid flow: Fluids flow into porous solids in accordance with Darcy's Law.

3. Solids

- Molecules are do not move freely with respect to each other, and may be highly organized in crystalline lattice structures (as in metals).
- Solids generally have fixed volumes;
- They diffuse into each other in accordance with Fick's Law, although at very, very slow rates. The diffusivity increases with temperature.
- Representative Constitutive Behaviors
    - Generalized Hookes Law for Linear Elastic Solids: $\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$
    - Hookes Law for Linear Isotropic Solids

$$\sigma = E\varepsilon$$
$$p = K\varepsilon_v$$
$$\tau = \mu\gamma$$

4. Gels

- Gels are a state of matter intermediate to the liquid and solid states, and can involve phases in both the liquid and solid states;

- Solid particles are in suspension in fluids. The solid particles can bond with each other strongly or loosely.
- If the material is stressed, the bonds can either remain intact, or temporarily weaken leading to fluid-like behavior
- Hydrated portland cement paste is a gel in which the bonds remain intact under moderate stresses;
- Clays soils are gels in which the bonds weaken under moderate stresses.
  - When the bonds weaken, the clay behaves as a fluid.
  - When the stressing is removed, the bonds between the particles will re-establish. This behavior is labeled thixotropic.
- Polymers are gels
- Asphalt cement is a polymer and a gel that behaves both like a fluid and a solid
- Gels tend to exhibit viscoelastic constitutive behaviors. Some of their characteristics are fluid-like, and other characteristics are solid-like.