# 53:086 Civil Engineering Materials

**Dept. of Civil & Environmental Engineering**
**The University of Iowa**
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## Question #1: Bituminous Materials (30 points)

Please answer the following questions briefly in your exam booklet. Questions e) and beyond are true/false and should be answered by entering either "true" or "false" in you exam booklet. If you find the question to be worded ambiguously, you may provide a more extensive answer.

a) Name two bituminous materials used as binders in pavements.
b) What is a reasonable range for VMA in compacted HMA?
c) What is a common target range for VTM in compacted HMA?
d) What is a common range of VFA for compacted HMA?
e) Asphalt can be obtained from distillation of coal, while tar can be obtained from distillation of crude petroleum.
f) Asphalt cement concrete is not used as a structural material in civil engineering structures (as pcc is) because it is too weak and too temperature sensitive.
g) Tar is soluble in most refined petroleum products.
h) In HMA it is typically most desirable to use a well-graded, rounded aggregate with an absolute minimum of crushed particles.
i) A performance grade asphalt binder with the designation PG 70-40 would be suitable in a region where the high design temperature for a pavement is 70ºC and the low design temperature is -40ºC.
j) In emulsions, asphalt binder is combined with more volatile phases of petroleum that will eventually evaporate away, leaving the asphalt binder behind.
k) A typical mixing temperature for HMA is about 135ºC or 275ºF.
l) Some age hardening of asphalt cement will occur during the HMA mixing process and this can be simulated with the RTFO procedure.
m) A characteristic of viscoelastic materials like asphalts is that they are sometimes very compliant when loaded slowly and comparatively stiff when loaded rapidly.
n) As asphalt cement ages, it tends to become increasingly fluid and this will lead to increasing problems with rutting and bleeding of a pavement.
o) The aging that occurs during 5-10 years or service life is usually simulated with the Precision Asphalt Volumetric (PAV) test.

## Question #2: Fiber-Reinforced Polymers (20 points)

a) Thermoplastic polymers are often used in structural FRPs due to their higher temperature resistance than thermoset polymers.
b) In structural FRPs, the polymer matrix tends to provide most of the composite stiffness and strength, and the fibers are a low-cost filler item to keep the overall cost down.

c) Two common "mixing rules" used to estimate the stiffness and strength properties of fibrous composites are the Voigt iso-strain rule and the Reuss iso-stress rule. It is appropriate to use the Voigt iso-strain rule when considering loading parallel to aligned fibers, and to use the Reuss iso-stress rule when considering loading transverse to aligned fibers.
d) Common structural polymers used in FRPs are generally stiffer than steel.
e) A-36 structural steel has a higher tensile strength than the common structural fibers used in FRPs (glass, graphite, Kevlar).
f) The modulus estimate produced by the Reuss iso-stress rule of mixtures is usually smaller than that produced by the Voigt iso-strain rule of mixtures.
g) The strength and stiffness properties of FRP composites with aligned fibers tend to be strongly anisotropic.
h) When making plate or shell structures with FRPs, it is common to use multi-ply laminates to reduce the in-plane anisotropy of the material.
i) Two obstacles to widespread adoption of FRPs for usage in the civil infrastructure are: (1) lack of familiarity with FRPs by practicing civil engineers; and (2) lack of design codes for FRPs similar to those for steel and concrete.
j) While FRPs may never be used as extensively as steel and pcc in the civil infrastructure, they are being used in many instances to retro-fit and repair existing infrastructure.

**Question #3: Masonry (20 points)**

a) In masonry, "units" is a term that represents the bricks, blocks, or stones that are arranged to form the structural system.
b) The term "dry masonry" typically refers to masonry in which the units are bonded together with mortar joints.
c) Hollow cells or holes are often incorporated in both clay and concrete units to make them lighter and more thermally resistive (better insulators).
d) Concrete masonry units are generally made in factory conditions with wetter pcc mixes than are used in typical cast-in-place concrete applications.
e) If concrete masonry units were made with very dry pcc mixes, they would tend to shrink less over time than cast-in-place concrete that shrinks over time due to loss of moisture to the atmosphere.
f) Clay bricks made with a "soft mud" process typically have a higher dimensional precision than clay bricks made with a "stiff plastic" process.
g) Clay bricks, although they undergo a firing process, retain some of the characteristics of clay soils to suck in moisture and to gradually expand over time.
h) The primary difference between clay bricks that can be used in weathering conditions and those that can be used only for interior-non-weathering applications relates to their moisture absorption characteristics. Bricks that have the capacity to absorb more moisture can be used in weathering conditions. Those with low absorption capacity must be used strictly in non-weathering applications.

i) Efflorescence of masonry is the appearance of a whitish carbonate deposit on the exterior wall faces and is usually indicative of inadequate control of moisture getting into the wall and drainage.
j) Cavity walls involve single-wythe construction with hollow units.

**Question #4: HMA Problem (20 points)**

An aggregate blend is composed of 53% coarse aggregate by weight ($G_s$=2.702), 43% fine aggregate ($G_s$=2.621), and 4% filler ($G_s$=2.779). The compacted specimen contains 6% asphalt binder ($G_b$=1.052) by total weight of the mix and has a bulk density of 145.2 lb/ft$^3$. Ignoring absorption, compute:

a. the maximum theoretical specific gravity of the mix, $G_{mm}$;
b. the bulk specific gravity of the mix, $G_{mb}$;
c. the percent voids in the total mix (VTM);
d. the percent voids in the mineral aggregate (VMA); and
e. the percent voids filled with asphalt (VFA).

**Question #5: FRP Problem (20 points)**

A composite is made with long, aligned Type I graphite fibers ($E_f$=345 GPa; $\sigma_{fu}$=2.00 GPa; $\rho_f$=1.92g/cm$^3$) and a polyester matrix ($E_m$=3.0 GPa; $\sigma_{mu}$=60 MPa; $\rho_m$=1.28g/cm$^3$ The fiber volume fraction in the composite is 60%. Calculate:

a. the mass density of the composite;
b. the effective Young's modulus in the fiber direction;
c. the effective Young's modulus in the transverse direction;
d. the strength of the composite in the fiber direction; and
e. the strength of the fiber in the transverse direction.

**Question #6: Properties Comparison Problem (20 points)**

Rank (least to greatest) the materials listed below with respect to the criteria provided:

- A-36 steel
- normal weight pcc
- fired SW clay brick
- the composite of Question 4 with properties in the fiber direction.

a) stiffness
b) strength
c) ductility (or strain to failure)
d) mass density

**Question #7: PCC (10 points)**

a) Increases of water/cement ratio beyond about 0.40, lead to reduced strength of hcp and thus reduced strength of pcc.

b) Aggregate is an inexpensive filler in pcc that increases the stiffness and reduces the tendency to shrink over time due to loss of moisture.
c) It is generally best to use high early strength portland cement in large concrete pours so that the forms can be removed as soon as possible.
d) Usage of cement replacement materials in pcc tends to make the final product both stronger and more durable.
e) The primary reason for air entrainment in pcc in cold climates is to increase the pcc's thermal resistivity or to reduce its thermal conductivity.

**Question #8: Steel (10 points)**

a) Fine grained metals can be achieved by very slow cooling from the molten state;
b) Fine-grained steels generally tend to be weaker, but more ductile than more coarse-grained steels.
c) Carbon is a common component in steel due to its usage in the steel-making process to remove oxygen from raw iron ores.
d) Steels with low carbon contents are said to be mild steels and tend to have lower strengths and higher strengths than high-carbon steels.
e) When considering heat-treated steels that have been welded, caution should be exercised with respect to the material strength in the heat-affected-zone (HAZ).

**Bonus Question: Viscoelasticity (20 extra points)**

An asphalt binder has a shear modulus G= 4 MPa, a viscosity η=20 MPa·s and its constitutive behavior is governed by the following differential equation: $\tau = G\gamma + \eta\dot{\gamma}$. Assume that the binder is subjected to an oscillatory strain-controlled dynamic shear-rheometer test as follows: $\gamma = \gamma_0 e^{i\omega t}$ where the strain amplitude $\gamma_0 = 0.01$. For a loading frequency of $\omega = 10 rad \cdot s^{-1}$, calculate the amplitude of the resulting shear stress, and the phase angle between the shear stress and strain. (Assuming that $\tau = \tau_0 e^{i(\omega t+\delta)}$, compute $\tau_0$ and $\delta$).

**Extra Information:**

Voigt Rule of Mixtures: $E^*_{Voigt} = \left(\phi_f E_f + \phi_m E_m\right)$

Reuss Rule of Mixtures: $E^*_{\mathrm{Re}uss} = \left(\frac{\phi_f}{E_f} + \frac{\phi_m}{E_m}\right)^{-1}$