Period #11 Notes: MECHANICS OF PORTLAND CEMENT CONCRETE

A. Brief Overview

Portland cement concrete is a composite material consisting of aggregate particles and the hydrated cement paste matrix that binds them together. The mass density, stiffness, and strength properties of portland cement concrete (pcc) are thus functionally dependent on the properties of both the matrix material (i.e. the hcp) and the reinforcement material (the aggregate). In this course, we study at least three composite material systems: (1) pcc; (2) asphalt cement concrete (acc); and (3) fiber-reinforced plastics (FRPs). Since pcc is the first composite material on this list, we'll have to begin by introducing some basic ideas that apply to all composite materials.

B. Mass Density and Volume Fractions

When heavy materials are used in composites, the mass density of the composite increases, and vice versa.

Consider the schematic of the composite shown in Fig. 11.1 that consists of two materials:

(1) a particulate reinforcing phase (r); and

(2) the continuous matrix phase (m).

The total volume of the composite sample shown can be decomposed into that of the particulate reinforcing phase, and that of the continuous matrix phase.

$$V = V_r + V_m \qquad (11.1)$$

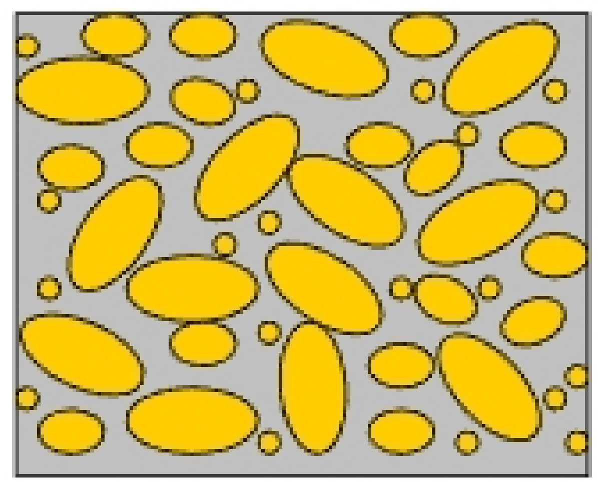

Fig. 11.1. Representative volume element of a two-phased composite material.

If one takes the volume equation (11.1) and divides through by the total volume V, the following equation results:

$$\frac{V}{V} = \frac{V_r}{V} + \frac{V_m}{V} \Rightarrow 1 = \phi_r + \phi_m \qquad (11.2a)$$

$$\text{where:} \quad \phi_r = \frac{V_r}{V} \quad \text{(the reinforcement volume fraction)} \qquad (11.2b)$$

$$\phi_m = \frac{V_m}{V} \quad \text{(the matrix volume fraction)} \qquad (11.2c)$$

It is common to discuss the composition of composite materials in terms of the volume fractions of the reinforcing phase and the matrix phase.

Generally in pcc, the aggregate volume fraction is between 60% and 80%, and the matrix volume fraction between 20% and 40%.

The total mass of a composite material is the sum of the masses of the reinforcement and matrix phases.

$$M = M_r + M_m \qquad (11.3a)$$

$$= \rho_r V_r + \rho_m V_m \qquad (11.3b)$$

The mass density of the composite is the total mass per total unit volume:

$$\rho = \frac{M}{V} = \rho_r \phi_r + \rho_m \phi_m \qquad (11.4)$$

C. Effective Stiffness of Composites

While the effective mass density of a composite is directly expressed by (11.4), it is much less straightforward to express the effective stiffness of a composite in terms of the stiffnesses and volume fractions of the constituent phases. For this reason, there are a variety of different models and assumptions that can be used to **estimate** the effective stiffness (or elastic moduli) of composites. Three models that will be presented here are:

1. The Voigt isostrain rule of mixtures;
2. The Reuss isostress rule of mixtures; and
3. The hybrid rule of mixtures.

1. The Voigt rule of mixtures

To understand the isostrain rule of mixtures, consider a representative volume element of the composite where the matrix and reinforcement phases have been separated into distinct regions as shown in Fig. 11.2.

Now assume that the composite is subjected to a one-dimensional stress loading of magnitude σ as shown.

Arranged and loaded as shown, the matrix and reinforcement phases are being loaded in parallel.

Loaded in parallel like this, the strain in both phases should be the same.

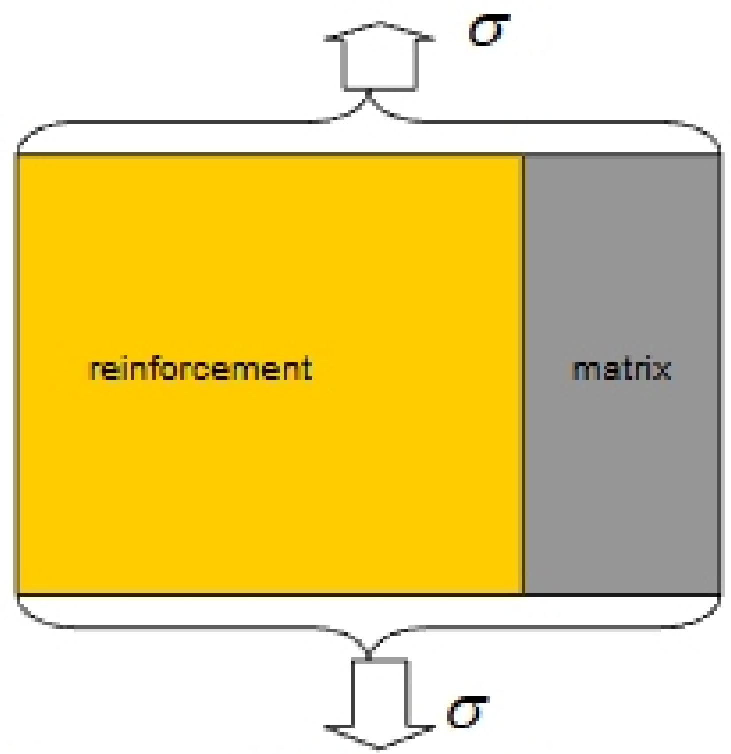

Fig. 11.2. Composite grouped into separate materials and loaded parallel to material allignment.