

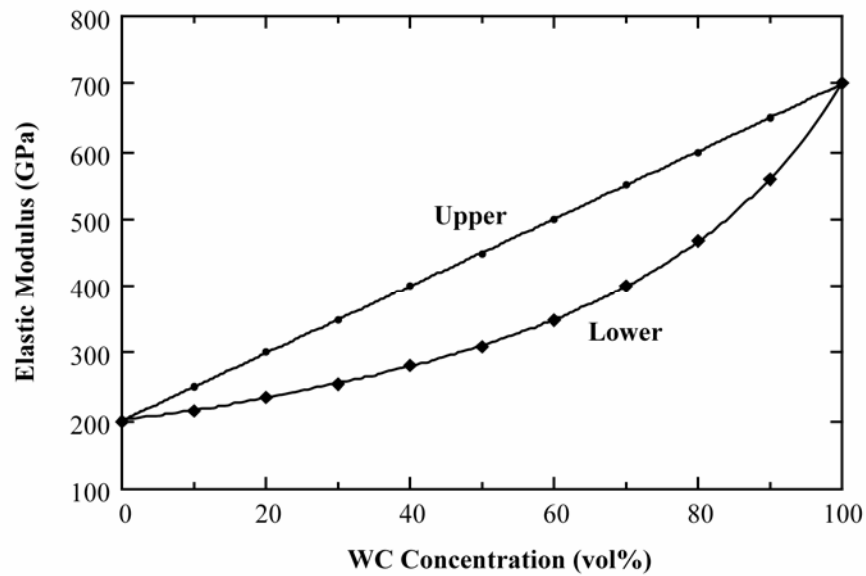
## CHAPTER 16

## COMPOSITES

## PROBLEM SOLUTIONS

**Large-Particle Composites**

16.1 The elastic modulus versus volume percent of WC is shown below, on which is included both upper and lower bound curves; these curves were generated using Equations 16.1 and 16.2, respectively, as well as the moduli of elasticity for cobalt and WC given in the problem statement.



16.4 (a) Concrete consists of an aggregate of particles that are bonded together by a cement.

(b) Three limitations of concrete are: (1) it is a relatively weak and brittle material; (2) it experiences relatively large thermal expansions (contractions) with changes in temperature; and (3) it may crack when exposed to freeze-thaw cycles.

(c) Three reinforcement strengthening techniques are: (1) reinforcement with steel wires, rods, etc.; (2) reinforcement with fine fibers of a high modulus material; and (3) introduction of residual compressive stresses by prestressing or posttensioning.

16.12 (a) Given some data for an aligned and continuous carbon-fiber-reinforced nylon 6,6 composite, we are asked to compute the volume fraction of fibers that are required such that the fibers carry 97% of a load applied in the longitudinal direction. From Equation 16.11

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m} = \frac{E_f V_f}{E_m (1 - V_f)}$$

Now, using values for  $F_f$  and  $F_m$  from the problem statement

$$\frac{F_f}{F_m} = \frac{0.97}{0.03} = 32.3$$

And when we substitute the given values for  $E_f$  and  $E_m$  into the first equation leads to

$$\frac{F_f}{F_m} = 32.3 = \frac{(260 \text{ GPa})V_f}{(2.8 \text{ GPa})(1 - V_f)}$$

And, solving for  $V_f$  yields,  $V_f = 0.258$ .

(b) We are now asked for the tensile strength of this composite. From Equation 16.17,

$$\begin{aligned} \sigma_{cl}^* &= \sigma_m'(1 - V_f) + \sigma_f^* V_f \\ &= (50 \text{ MPa})(1 - 0.258) + (4000 \text{ MPa})(0.258) \\ &= 1070 \text{ MPa (155,000 psi)} \end{aligned}$$

since values for  $\sigma_f^*$  (4000 MPa) and  $\sigma_m'$  (50 MPa) are given in the problem statement.

16.17 In this problem, for an aligned glass fiber-epoxy matrix composite, we are asked to compute the longitudinal tensile strength given the following: the average fiber diameter (0.015 mm), the average fiber length (2.0 mm), the volume fraction of fibers (0.25), the fiber fracture strength (3500 MPa), the fiber-matrix bond strength (100 MPa), and the matrix stress at composite failure (5.5 MPa). It is first necessary to compute the value of the critical fiber length using Equation 16.3. If the fiber length is much greater than  $l_c$ , then we may determine  $\sigma_{cl}^*$  using Equation 16.17, otherwise, use of either Equations 16.18 or 16.19 is necessary. Thus,

$$l_c = \frac{\sigma_f^* d}{2\tau_c} = \frac{(3500 \text{ MPa})(0.015 \text{ mm})}{2(100 \text{ MPa})} = 0.263 \text{ mm} \quad (0.010 \text{ in.})$$

Inasmuch as  $l > l_c$  (2.0 mm > 0.263 mm), but since  $l$  is not much greater than  $l_c$ , then use of Equation 16.18 is necessary. Therefore,

$$\begin{aligned} \sigma_{cd}^* &= \sigma_f^* V_f \left( 1 - \frac{l_c}{2l} \right) + \sigma_m' (1 - V_f) \\ &= (3500 \text{ MPa})(0.25) \left[ 1 - \frac{0.263 \text{ mm}}{(2)(2.0 \text{ mm})} \right] + (5.5 \text{ MPa})(1 - 0.25) \\ &= 822 \text{ MPa} \quad (117,800 \text{ psi}) \end{aligned}$$

**The Fiber Phase****The Matrix Phase**

16.19 (a) For polymer-matrix fiber-reinforced composites, three functions of the polymer-matrix phase are: (1) to bind the fibers together so that the applied stress is distributed among the fibers; (2) to protect the surface of the fibers from being damaged; and (3) to separate the fibers and inhibit crack propagation.

(b) The matrix phase must be ductile and is usually relatively soft, whereas the fiber phase must be stiff and strong.

(c) There must be a strong interfacial bond between fiber and matrix in order to: (1) maximize the stress transmittance between matrix and fiber phases; and (2) minimize fiber pull-out, and the probability of failure.

16.20 (a) The matrix phase is a continuous phase that surrounds the noncontinuous dispersed phase.

(b) In general, the matrix phase is relatively weak, has a low elastic modulus, but is quite ductile. On the other hand, the fiber phase is normally quite strong, stiff, and brittle.

16.22 (a) The four reasons why glass fibers are most commonly used for reinforcement are listed at the beginning of Section 16.8 under "Glass Fiber-Reinforced Polymer (GFRP) Composites."

(b) The surface perfection of glass fibers is important because surface flaws or cracks act as points of stress concentration, which will dramatically reduce the tensile strength of the material.

(c) Care must be taken not to rub or abrade the surface after the fibers are drawn. As a surface protection, newly drawn fibers are coated with a protective surface film.

## Processing of Fiber-Reinforced Composites

16.28 Pultrusion, filament winding, and prepreg fabrication processes are described in Section 16.13.

For pultrusion, the advantages are: the process may be automated, production rates are relatively high, a wide variety of shapes having constant cross-sections are possible, and very long pieces may be produced. The chief disadvantage is that shapes are limited to those having a constant cross-section.

For filament winding, the advantages are: the process may be automated, a variety of winding patterns are possible, and a high degree of control over winding uniformity and orientation is afforded. The chief disadvantage is that the variety of shapes is somewhat limited.

For prepreg production, the advantages are: resin does not need to be added to the prepreg, the lay-up arrangement relative to the orientation of individual plies is variable, and the lay-up process may be automated. The chief disadvantages of this technique are that final curing is necessary after fabrication, and thermoset prepreps must be stored at subambient temperatures to prevent complete curing.

## **Laminar Composites**

### **Sandwich Panels**

16.29 Laminar composites are a series of sheets or panels, each of which has a preferred high-strength direction. These sheets are stacked and then cemented together such that the orientation of the high-strength direction varies from layer to layer.

These composites are constructed in order to have a relatively high strength in virtually all directions within the plane of the laminate.

16.30 (a) Sandwich panels consist of two outer face sheets of a high-strength material that are separated by a layer of a less-dense and lower-strength core material.

(b) The prime reason for fabricating these composites is to produce structures having high in-plane strengths, high shear rigidities, and low densities.

(c) The faces function so as to bear the majority of in-plane tensile and compressive stresses. On the other hand, the core separates and provides continuous support for the faces, and also resists shear deformations perpendicular to the faces.