9 COMPOSITE MATERIALS

Review Questions

9.1 What is a *composite material*?

Answer. A composite material is a material system consisting of two or more distinct phases whose combination results in properties that differ from those of its constituents.

9.2 Identify some of the characteristic properties of composite materials.

Answer. Typical properties include (1) high strength-to-weight and stiffness-to-weight ratios; (2) good fatigue properties and toughness; (3) anisotropic properties in many cases; and (4) other properties and features that are difficult or impossible to obtain with metals, ceramics, or polymers alone.

9.3 What does the term *anisotropic* mean?

Answer. Anisotropic means that the properties of a material vary depending on the direction in which they are measured.

9.4 How are traditional composites distinguished from synthetic composites?

Answer. Traditional composites have been used for decades or centuries; some of them are obtained from sources in nature, such as wood. Synthetic composites are manufactured.

9.5 Name the three basic categories of composite materials.

Answer. Metal matrix composites (MMCs), ceramic matrix composites (CMCs), and polymer matrix composites (PMCs).

9.6 What are the common forms of the reinforcing phase in composite materials?

Answer. The forms are: (1) fibers, (2) particles and flakes, and (3) an infiltrated phase in skeletal structures.

9.7 What is a *whisker*?

Answer. A whisker is a thin, hairlike crystal of very high strength.

9.8 What is meant by the term *interface* in the context of composite materials?

Answer. The interface is the boundary between the component phases in a composite material.

9.9 What are the two forms of sandwich structure among laminar composite structures? Briefly describe each.

Answer. The two forms are (1) foamed-core sandwich, in which the core is polymer foam between two solid skins; and (2) honeycomb, in which the core is a honeycomb structure sandwiched between two solid skins.

9.10 Give some examples of commercial products that are laminar composite structures.

Answer. Examples given in Table 9.2 are automotive tires, honeycomb sandwich structures, fiber reinforced polymer structures such as boat hulls, plywood, printed circuit boards, snow skis made from fiber reinforced polymers, and windshield glass.

9.11 What are the three general factors that determine the properties of a composite material?

Answer. Three factors are given in the text: (1) the component materials; (2) the geometric shapes of the constituents - the reinforcing phase in particular - and the resulting structure of the material; and (3) the interaction of the phases.

9.12 What is the *rule of mixtures*?

Answer. The rule of mixtures applies to certain properties of composite materials; it states that the property value is a weighted average of the property values of the components, the weighting being by proportions of the components in the composite.

9.13 What is a *cermet*?

Answer. A cermet is a composite material consisting of a ceramic and a metal. In the text, it is defined as a composite consisting of ceramic grains imbedded in a metallic matrix.

9.14 Cemented carbides are what class of composites?

Answer. A cemented carbide is a metal matrix composite, specifically a cermet.

9.15 What are some of the weaknesses of ceramics that might be corrected in fiber-reinforced ceramic matrix composites?

Answer. Weaknesses of ceramics include low tensile strength, poor toughness, and susceptibility to thermal cracking.

9.16 What is the most common fiber material in fiber-reinforced plastics?

Answer. E-glass.

9.17 What does the term *advanced composite* mean?

Answer. An advanced composite is a PMC in which carbon, Kevlar, or boron fibers are used as the reinforcing material.

9.18 What is a *hybrid composite*?

Answer. A hybrid composite is a fiber-reinforced PMC in which two or more fibers materials are combined in the FRP.

9.19 Identify some of the important properties of fiber-reinforced plastic composite materials.

Answer. Properties include high strength-to-weight ratio, high modulus-to-weight ratio, low density, good fatigue strength, good corrosion resistance, and low thermal expansion for many FRPs.

9.20 Name some of the important applications of FRPs.

Answer. FRPs are used in modern aircraft as skin parts, automobile body panels, printed circuit boards, tennis rackets, boat hulls, and a variety of other items.

Problems

Answers to problems labeled **(A)** are listed in an Appendix at the back of the book.

9.1 **(A)** (SI units) A fiberglass composite consists of a matrix of vinyl ester and reinforcing fibers of E-glass. The volume fraction of E-glass = 30%. The density of the vinyl ester = 0.882 g/cm^3, and its modulus of elasticity = 3.60 GPa. The density of E-glass = 2.60 g/cm^3, and its modulus of elasticity = 76.0 GPa. A section of composite 1.00 cm by 25.00 cm by 200.00 cm is fabricated with the E-glass fibers running longitudinal in the 200-cm direction. Assume there are no voids in the composite. Determine the (a) mass of vinyl ester in the section, (b) mass of E-glass fibers in the section, and (c) density of the composite.

Solution: Volume V = (1.00 cm)(25.00 cm)(200.00 cm) = 5,000 cm^3

(a) $V_m = f_m (V_c) = 0.70(5{,}000 \text{ cm}^3) = 3{,}500 \text{ cm}^3$
$m_m = 3500 \text{ cm}^3 (0.882 \text{ g/cm}^3) =$ **3087 g**

(b) $V_r = f_r (V_c) = 0.30(5{,}000 \text{ cm}^3) = 1{,}500 \text{ cm}^3$
$m_r = 1500 \text{ cm}^3 (2.60 \text{ g/cm}^3) =$ **3,900 g**

(c) $\rho_c = = f_m \rho_m + f_r \rho_r = 0.70(0.882) + 0.30(2.60) =$ **1.397 g/cm^3**

9.2 (SI units) For the data in the previous problem, determine the modulus of elasticity in (a) the longitudinal direction of the glass fibers and (b) the perpendicular direction to the glass fibers.

Solution: Given $f_m = 0.70$, $f_r = 0.30$, $E_m = 3.60$ GPa, and $E_r = 76.0$ GPa
(a) $E_c = f_m E_m + f_r E_r$
$E_c = 0.70(3.60) + 0.30(76.0) =$ **25.3 GPa**

(b) $E_c' = E_m E_r/(f_m E_r + f_r E_m)$
$E_c' = 3.60(76.0)/(0.70(76.0) + 0.30(3.60)) = 273.6/(53.2 + 1.08) =$ **5.04 GPa**

9.3 (SI units) A polymer matrix composite consists of polyester reinforced with Kevlar-29 fibers. The volume fractions of polyester and Kevlar are 60% and 40%, respectively. The Kevlar fibers have a modulus of elasticity = 60 GPa in the longitudinal direction and 3 GPa in the transverse direction. The polyester matrix has a modulus of elasticity = 5.6 GPa in both directions. Determine the modulus of elasticity for the composite in the (a) longitudinal direction and (b) transverse direction.

Solution: $f_m = 0.60$, $f_r = 0.40$, $E_m = 5.6$ GPa, and $E_r = 60$ GPa (longitudinal) and 3 GPa (transverse)

(a) $E_c = f_m E_m + f_r E_r$ $\quad E_c = 0.60(5.6) + 0.40(60) =$ **27.4 GPa**

(b) $E_c' = E_m E_r/(f_m E_r + f_r E_m)$ $\quad E_c' = 5.6(3)/(0.60\times 3 + 0.40\times 5.6) =$ **4.16 GPa**

9.4 **(A)** (USCS units) A rod made of carbon-reinforced epoxy has a diameter = 1.0 in, length = 36.0 in, and mass = 1.45 lb. The carbon fibers have a modulus of elasticity = $50(10^6)$ lb/in^2 and a density = 0.069 lb/in^3. The epoxy matrix has modulus of elasticity = $0.61(10^6)$ lb/in^2 and a density = 0.042 lb/in^3. Assume there are no voids in the rod. What is the volume fraction of (a) the carbon fibers and (b) the epoxy matrix in the rod? Also, what is the predicted value for the modulus of elasticity in the (c) longitudinal direction and (d) direction perpendicular to the carbon fibers?

Solution: $V_c = \pi D^2 L/4 = 0.25\pi(1.0)^2(36.0) = 28.27 \text{ in}^3$
$\rho_c = m_c/V_c = 1.45/28.27 = 0.0513 \text{ lb/in}^3$

(a) $f_m = 1 - f_r$
$\rho_c = f_m\rho_m + f_r\rho_r$

$\rho_c = (1 - f_r)\rho_m + f_r\rho_r$
$\rho_c = \rho_m - f_r\rho_m + f_r\rho_r = \rho_m - f_r(\rho_m - \rho_r)$
$f_r = (\rho_m - \rho_c)/(\rho_m - \rho_r) = (0.042 - 0.0513)/(0.042 - 0.069) = \mathbf{0.344 = 34.4\%}$

(b) $f_m = 1 - f_r$ $\quad f_m = 1 - 0.30 = \mathbf{0.656 = 65.6\%}$

(c) $E_c = f_mE_m + f_rE_r$
$E_c = 0.656(0.61\times10^6) + 0.344(50.0\times10^6) = \mathbf{17.6 \times 10^6\ lb/in^2}$

(d) $E_c' = E_mE_r/(f_mE_r + f_rE_m)$
$E_c' = 0.61(10^6)(50.0(10^6)/(0.656(50.0\times10^6) + 0.344(0.61\times10^6)) = \mathbf{0.924 \times 10^6\ lb/in^2}$