Chapter 2

Solutions for Chapter 2

Problem 2.1

Define and explain the following terms: strand, end, yarn, and roving.

Solution to Problem 2.1

See Section 2.4.3, "Strand, tow, end, yarn, and roving"

Problem 2.2

Does the use of glass reinforcement help the corrosion resistance of polyester resin?

Solution to Problem 2.2

See Section 2.6.1, "Polyester Resins"

Problem 2.3

Within the scope of the information provided in this chapter, select a resin to be used in a strongly acid environment.

Solution to Problem 2.3

Chlorendic Polyester

Problem 2.4

Within the scope of the information provided in this chapter, select a resin to be used in a strongly basic environment.

Solution to Problem 2.4

Bisphenol-A-Fumarate Polyester

Problem 2.5

Name two types of fibers and give the main advantage of each. The advantages have to be different so that the two types of fibers differ from each other.

Solution to Problem 2.5

Fiber types:

Glass fibers = low cost

Carbon fibers = high stiffness

Problem 2.6

Name two matrix types and give the main advantage of each. The advantages have to be different so that the two matrices differ from each other.

Solution to Problem 2.6

Matrix type:

Polyester = low cost

Epoxy = high mechanical properties

Problem 2.7

Compute the cross-sectional area occupied by a 36K tow of carbon fiber, with a fiber diameter of 7 microns.

Solution to Problem 2.7

A 36K tow has 36,000 fibers. Assuming the fiber to be 7 microns,

$$\text{Area} = \text{K}\frac{\pi d^2}{4} = 36,000\frac{\pi\left[7\left(10^{-6}\right)\right]^2}{4} = 1.385 \text{ mm}^2$$

Problem 2.8

Compute the cross-sectional area occupied by a roving of fiberglass with a Yield of 56 yards/lb. How many 112 Yield roving are needed to obtain the same cross-sectional area?

Solution to Problem 2.8

Using Eq. (2.3)

$$\text{TEX(g/km)} = \frac{496,238}{56 \text{ (yd/lb)}} = 8,861 \text{ g/km}$$

Using Eq. (2.4)

$$\text{Area} = \frac{(10^{-5})8,861 \text{ (g/km)}}{2.5 \text{ (g/cc)}} = 0.035 \text{ cm}^2$$

Therefore, 112/56 = 2, so two 112 yield roving are needed.

Problem 2.9

Compute the thickness of fiber in a CSM mat made out of 800 g/m^2 of E-glass fibers.

Solution to Problem 2.9

With a fabric weight $W = 800$ g/m^2, and density $\rho = 2.5$ g/cc $= 2.5(10^6)$ g/m^3,

$$t = \frac{W}{\rho} = \frac{800}{2.5(10^6)} = 0.32 \text{ mm}$$

Problem 2.10

A cylindrical pipe with diameter $d = 400$ mm is subject to internal pressure $p = 20\,MPa$. The pipe is free to expand along the length so that no axial stress develops in its wall. Only hoop stress develops. The pipe is hoop wound and it is assumed that the fibers carry all the load. Assume that the matrix does not contribute to the strength of the material. Apply a safety factor $R = 2$. Consider only Glass fibers from Table 2.1.

(a) What is the required thickness (t_f) and fiber type that yields minimum thickness?

(b) What is the required wall thickness and fiber type for minimum weight?

Solution to Problem 2.10

Let's denote with F_{fa} the average tensile strength of fibers, for which values are given in Table 2.1. For a cylindrical pipe, the hoop stress is calculated as

$$\sigma_H = \frac{p\,d}{2\,t}$$

(a) Assuming only the fibers carry the load, the stress in the fibers is

$$\sigma_f = \frac{R\,p\,d}{2\,t_f}$$

where t_f is the thickness occupied by the fibers only. Since the safety factor is already applied to the pressure, the stress should not exceed the strength of the fibers F_f. Therefore, the required thickness of fibers is

$$t_f = \frac{R\,p\,d}{2\,F_{fa}}$$

The fiber that allows minimum thickness is that that has maximum strength. In this case, that is S-glass with $F_{fa} = 4.8$ GPa from Table 2.1. Then, the required thickness is

$$t_f = \frac{2 \times 20 \times 400}{2 \times 4800} = 1.667 \text{ mm}$$

That thickness assumes a solid sheet of fiber material which in practice it is impossible because the fibers are circular. The best packing of circles is the hexagonal packing that achieves a packing fraction

$$\text{packing fraction} = \frac{\text{area circles}}{\text{total area occupied}} = \frac{\pi}{2\sqrt{3}} \approx 0.9$$

However, assuming the fibers form a solid sheet of material is often used as a first approximation. This methodd is called netting Analysis because if considers only the contribution of the fibers.

(b) For minimum weight we want to calculate the weight per unit length of pipe

$$\frac{W}{L} = \pi\,d\,t_f\,\rho_f$$

and substituting t_f

$$\frac{W}{L} = \pi\,d^2\,R\,p\,\frac{\rho_f}{F_{fa}}$$

so that minimum weight corresponds to minimum ρ_f/F_{fa}. Using the data from Table 2.1, conservatively we find that the lightest is again S-glass, due to its high strength and the fact that the density of glass is almost constant among all glass types. using S-glass

$$\frac{W}{L} = \pi \times 40^2 \times 2 \times 20 \times \frac{2.49}{4,800} = 521.5 \text{ g/cm}$$

Scilab code for this problem is available on the instructor's Website [2].

```
// Pb. 2.10 Glass fibers
mode(0)
d = 400; // mm
p = 20; // MPa
R = 2; // safety factor applied to the load (pressure)
Ff = [3.45, 4.8, 4.4, 3.31, 2.5]*1E3; // MPa, Glass fibers
rhof = [2.59, 2.49, 2.55, 2.56, 2.14]; // g/cc, Glass fibers
max(Ff)
tf = R*p*d/2*Ff.^-1;
min(tf)
WL = %pi*d^2*R/10*p/2.*rhof.*Ff.^-1
min(WL)
```

Problem 2.11

Select the appropriate matrix to fabricate fiber-reinforced pipe depending on the substance it will carry. Consider each case separately.

(a) a solution of sulfuric acid at room temperature

(b) an alkaline solution at room temperature

(c) hot water

(d) hot gas, up to 140°C.

Solution to Problem 2.11

Approrpiate matrix for each use:

(a) Polyester or Chlorendic resins

(b) Bisphenol

(c) Epoxy

(d)Chlorendic

Problem 2.12

For each of the following criteria, select the appropriate matrix that meets the criterion (taken separately).

(a) high fracture toughness

(b) very low flammability and low smoke production under heat and fire

(c) low water absorption

(d) maximum possible operating temperature

(e) good resistance to UV and appropriate for translucent panels

(f) low shrinkage during curing of the part for good dimensional tolerances in the product

Solution to Problem 2.12

Matrix to satisfy each criterion:

(a) PEEK

(b) Phenolic

(c) Epoxy

(d) Bismaleimide and Thermoplastics

(e) Polyester resins with styrene/MMA blends

(f) Epoxy

Problem 2.13

Name three parameters that must be reported along with experimental data of stiffness and strength of PMC.

Solution to Problem 2.13

Temperature, humidity, and loading rate.

Problem 2.14

Do PMC operate at temperatures (a) below, (b) at, or (c) above the glass transition temperature?

Solution to Problem 2.14

Below.

Problem 2.15

What class of polymers has a melting temperature?

Solution to Problem 2.15

Thermoplastics.

Problem 2.16

Compare the strength and stiffness data at 149°C (dry) of Epoxy 9310/9360 with an extrapolation of the room temperature data using the retention ratio.

Solution to Problem 2.16

Equation (2.7) can be used for this purpose.

From Table 2.14, the glass transition temperature of the dry polymer is $T_{gd} = 185$ °C (dry). Room temperature is $T_o = 23$°C.

Since there is no moisture change, $T_{gw} = T_{gd}$, and the retention ratio is

$$\text{retention ratio} = \left[\frac{185 - 149}{185 - 23}\right]^{1/2} = 0.471$$

From Table 2.13

tensile modulus at 23 °C = 3.12 GPa

tensile strength at 23 °C = 75.8 MPa

Then,

tensile modulus at 149 °C = $0.471 \times 3.12 = 1.47$ GPa

tensile strength at 149 °C = $0.471 \times 75.8 = 35.7$ MPa

Comparison with values from Table 2.13, which provide values of modulus 1.4 GPa and strength 26.2 MPa at 149C, shows that the predictive equations yield somewhat reasonable values.

Problem 2.17

Compare the flexural modulus and strength at 249°C (dry) of clear cast bismaleimide 792/TM-123 with an extrapolation of the room temperature data using the retention ratio.

Solution to Problem 2.17

Equation (2.7) can be used for this purpose.

From Table 2.14, the glass transition temperature of the dry polymer is $T_{gd} = 260$ °C (dry). Room temperature is $T_o = 24$°C.

Since there is no moisture change, $T_{gw} = T_{gd}$, and the retention ratio is

$$\text{retention ratio} = \left[\frac{260 - 249}{260 - 24}\right]^{1/2} = 0.2159$$

From Table 2.14

flexural modulus at 24 °C = 3.582 GPa

Then,

flexural modulus at 249 °C = $0.2159 \times 3.582 = 0.7733$ GPa

Comparison with values from Table 2.14, which provide values of flexural modulus 2.48 at 249C, shows that the predictive equation is not accurate for this material system, over such a wide range of temperature.

Problem 2.18

What is the detrimental effect of an incompletely cured thermoset matrix on the life of a PMC?

Solution to Problem 2.18

It reduces the corrosion resistance of the PMC.

Problem 2.19

Explain how the matrix influences the extent of chemical attack on the fibers. Explain the effect of the applied load.

Solution to Problem 2.19

The matrix protects the fibers from chemical attack. Mechanical loads may induce cracking of the matrix, thus accelerating the ingress of chemicals that may attack the fiber.

Problem 2.20

What is the effect of temperature and moisture on the mechanical properties of a polymer? Use empirical formulas to plot the estimated stiffness and strength variation of Epoxy 9420/9470(A) from room temperature to high temperature.

Solution to Problem 2.20

From Table 2.14, the reference temperature is $T_0 = 24°C$ and the glass transition temperature (dry) is $T_{gd} = 260°C$.

To account for moisture, Eq. (2.6) can be used to predict

$$T_{gw} = \left(1 - 0.1\ m + 0.005\ m^2\right) T_{gd}$$

To account for temperature, Eq. (2.7)

$$\text{retention ratio} = \left[\frac{T_{gw} - T}{T_{gd} - T_0}\right]^{0.5}$$

From Tables 2.13 and 2.14 and using (2.6) and (2.7) we get Table 2.1 and Figure 2.1.

Table 2.1: Temperature (T), modulus (E), and strength (F) for dry polymer, Problem 2.20.

T	23	149	30	50	70	90	110	130	150
E	3.12	75.8	3.0518483	2.8481573	2.6287302	2.3892351	2.1228911	1.8179353	1.4502107
F	1.4	26.2	1.3694191	1. 2780193	1.1795584	1.0720927	0.9525793	0.8157402	0.6507356

Scilab code for this problem is available on the instructor's Website [2].

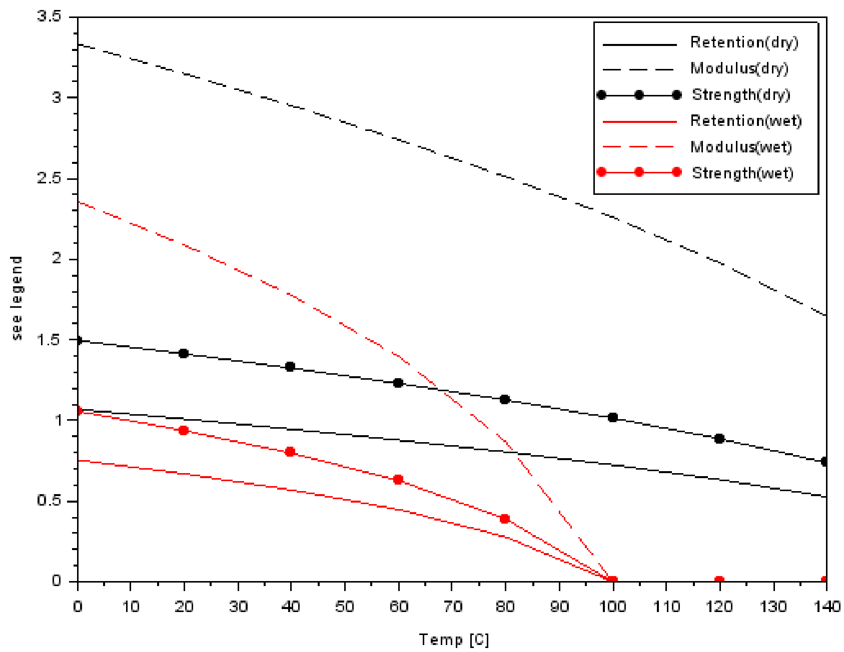

Figure 2.1: Retention ratio (RR), modulus (E), and strength (F) for dry and 10% moist polymer, Problem 2.20.