14.13 *Compare thermoplastic and thermosetting polymers (a) on the basis of mechanical characteristics upon heating and (b) according to possible molecular structures.*

Answer

(a) Thermoplastic polymers soften when heated and harden when cooled, whereas thermosetting polymers, harden upon heating, while further heating will not lead to softening.

(b) Thermoplastic polymers have linear and branched structures, while for thermosetting polymers, the structures will normally be network or crosslinked.

14.1FE *What type(s) of bonds is (are) found between atoms within hydrocarbon molecules?*

*(A) Ionic bonds*

*(B) Covalent bonds*

*(C) van der Waals bonds*

*(D) Metallic bonds*

Answer

The correct answer is B. Covalent bonds are found between atoms within hydrocarbon molecules.

15.1 *From the stress–strain data for poly(methyl methacrylate) shown in Figure 15.3, determine the modulus of elasticity and tensile strength at room temperature [20°C (68°F)], and compare these values with those given in Table 15.1.*

Solution

From Figure 15.3, the elastic modulus is the slope in the elastic linear, or

$$E = \frac{\Delta(\text{stress})}{\Delta(\text{strain})} = \frac{\sigma_1 - \sigma_2}{\varepsilon_1 - \varepsilon_2}$$

From the plot in Figure 15.3 (20°C curve) let us assign

$\sigma_1$ = 30 MPa

$\sigma_2$ = 0 MPa

And their corresponding strains are

$\varepsilon_1 = 9 \times 10^{-3}$

$\varepsilon_2 = 0$

Thus, the value of the elastic modulus is determined as follows:

$$E = \frac{\sigma_1 - \sigma_2}{\varepsilon_1 - \varepsilon_2} = \frac{30\text{ MPa} - 0\text{ MPa}}{9 \times 10^{-3} - 0} = 3.3\text{ GPa} \quad (483{,}000\text{ psi})$$

The value range cited in Table 15.1 is 2.24 to 3.24 GPa (325,000 to 470,000 psi). Thus, the plotted value is a little on the high side.

The tensile strength corresponds to the stress at which the curve ends, which is 52 MPa (7500 psi). This value lies within the range cited in Table 15.1—48.3 to 72.4 MPa (7000 to 10,500 psi).

15.3 *For the nylon polymer whose stress–strain behavior can be observed in the Tensile Tests module of Virtual Materials Science and Engineering (VMSE), determine the following:*

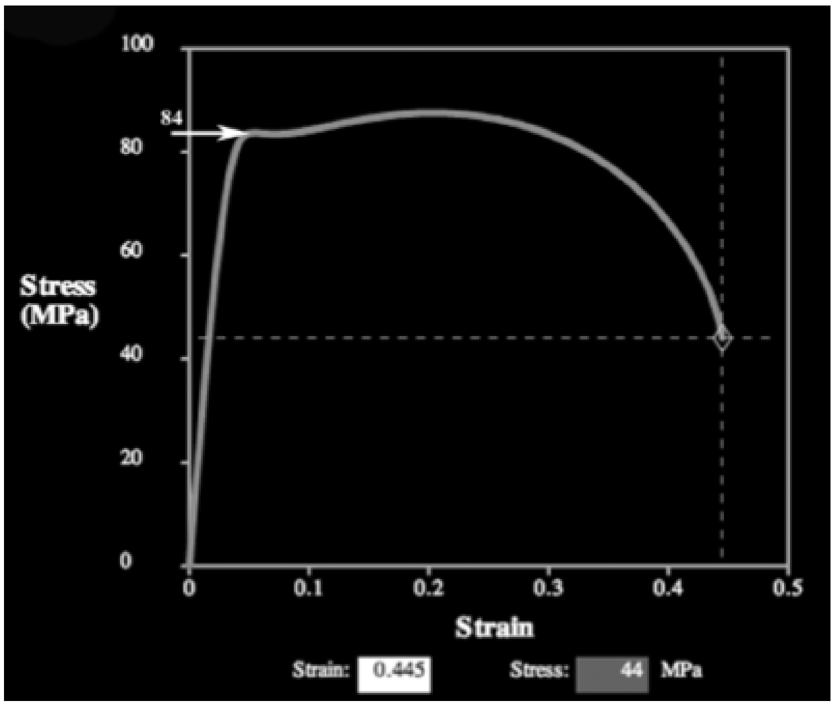
*(a) The yield strength*

*(b) The approximate ductility, in percent elongation*

*How do these values compare with those for the nylon material presented in Table 15.1?*

Solution

A screenshot of the stress-strain curve for nylon (to fracture) is shown below.




(a) The yield strength corresponds to the first maximum (just beyond the initial linear-elastic region) of the stress-strain curve; as noted in this plot, the value is 84 MPa.

(b) The approximate percent elongation corresponds to the strain at fracture ("0.445" as noted in the "Strain" box) multiplied by 100 (i.e., 44.5%) minus the maximum elastic strain (i.e., value of strain at which the linearity of the curve ends multiplied by 100—in this case about 4%); this gives a value of about 40%EL.

For nylon 6,6, the range of values of yield strength presented in Table 15.1 is 44.8 MPa to 82.8 MPa; therefore, the value for the *VMSE* nylon lies slightly above the upper value. The ductility range for nylon 6,6 is 15%EL to 300%EL; therefore, our value (40%EL) lies within this range.

15.6 *For some viscoelastic polymers that are subjected to stress relaxation tests, the stress decays with time according to*

$$\sigma(t) = \sigma(0)\exp\left(-\frac{t}{\tau}\right) \qquad (15.10)$$

*where σ(t) and σ(0) represent the time-dependent and initial (i.e., time = 0) stresses, respectively, and t and τ denote elapsed time and the relaxation time, respectively; τ is a time-independent constant characteristic of the material. A specimen of a viscoelastic polymer whose stress relaxation obeys Equation 15.10 was suddenly pulled in tension to a measured strain of 0.5; the stress necessary to maintain this constant strain was measured as a function of time. Determine* $E_r(10)$ *for this material if the initial stress level was 3.5 MPa (500 psi), which dropped to 0.5 MPa (70 psi) after 30 s.*

Solution

In order to determine $\sigma(10)$, it is first necessary to compute $\tau$ from the data provided in the problem statement. In order to solve for $\tau$ from Equation 15.10 it is first necessary to take natural logarithms of both sides of the equation as follows:

$$\ln\sigma(t) = \ln\sigma(0) - \frac{t}{\tau}$$

And solving this expression for $\tau$ leads to the following expression:

$$\tau = \frac{-t}{\ln\sigma(t) - \ln\sigma(0)} = \frac{-t}{\ln\left[\frac{\sigma(t)}{\sigma(0)}\right]}$$

The problem statement provides the following values:

$\sigma(0)$ = 3.5 MPa

$\sigma(t) = \sigma(30)$ = 0.5 MPa

$t$ = 30 s

Therefore, the value of $\tau$ is equal to

$$\tau = \frac{-t}{\ln\left[\frac{\sigma(t)}{\sigma(0)}\right]}$$

$$= \frac{-30\text{ s}}{\ln\left[\frac{0.5\text{ MPa}}{3.5\text{ MPa}}\right]} = 15.4\text{ s}$$

Using Equation 15.10 we compute the value of $\sigma(10)$ (that is, the value of $\sigma$ when $t$ = 10 s), as follows:

$$\sigma(10) = \sigma(0)\exp\left(-\frac{10 \text{ s}}{\tau}\right)$$

$$= (3.5 \text{ MPa}) \exp\left(-\frac{10 \text{ s}}{15.4 \text{ s}}\right) = 1.83 \text{ MPa}$$

We now compute the value of $E_r(10)$ using Equation 15.1 as follows:

$$E_r(10) = \frac{\sigma(10)}{\varepsilon_0} = \frac{1.83 \text{ MPa}}{0.5} = 3.66 \text{ MPa} \quad (522 \text{ psi})$$

15.13 *In your own words, describe the mechanisms by which semicrystalline polymers*

*(a) elastically deform*

*(b) plastically deform*

*(c) by which elastomers elastically deform.*

(a) and (b) The mechanisms by which semicrystalline polymers elastically and plastically deform are described in Section 15.7.

(c) The explanation of the mechanism by which elastomers elastically deform is provided in Section 15.9.

15.15 *Briefly explain how each of the following influences the tensile or yield strength of a semicrystalline polymer and why:*

*(a) molecular weight*

*(b) degree of crystallinity*

*(c) deformation by drawing*

*(d) annealing of an undeformed material*

<u>Answer</u>

(a) The tensile strength of a semicrystalline polymer increases with increasing molecular weight. This effect is explained by increased chain entanglements at higher molecular weights.

(b) Increasing the degree of crystallinity of a semicrystalline polymer leads to an enhancement of the tensile strength. Again, this is due to enhanced interchain bonding and forces; in response to applied stresses, interchain motions are thus inhibited.

(c) Deformation by drawing increases the tensile strength of a semicrystalline polymer. This effect is due to the highly oriented chain structure that is produced by drawing, which gives rise to higher interchain secondary bonding forces.

(d) Annealing an undeformed semicrystalline polymer produces an increase in its tensile strength.

15.1FE *Amorphous thermoplastics are formed above their*

*(A) glass transition temperatures*

*(B) softening points*

*(C) melting temperatures*

*(D) none of the above*

Answer

The correct answer is A. Amorphous thermoplastics are formed above their *glass transition temperatures*.