13.11 A thermoforming mold with a convex form is called which one of the following: (a) a die, (b) a negative mold, (c) a positive mold, or (d) a three-plate mold?

Answer. (c).

13.12 The term encapsulation refers to which one of the following plastics shaping processes: (a) casting, (b) compression molding, (c) extrusion of hollow forms, (d) injection molding in which a metal insert is encased in the molded part, or (e) vacuum thermoforming using a positive mold?

Answer. (a).

13.13 The two most common polymer foams are which of the following: (a) polyacetal, (b) polyethylene, (c) polystyrene, (d) polyurethane, and (e) polyvinylchloride?

Answer. (c) and (d).

13.14 In which of the following properties do plastic parts often compare favorably with metals (two best answers): (a) impact resistance, (b) resistance to ultraviolet radiation, (c) stiffness, (d) strength, (e) strength-to-weight ratio, and (f) temperature resistance?

Answer. (a) and (e).

13.15 Which of the following processes are generally limited to thermoplastic polymers (two best answers): (a) blow molding, (b) compression molding, (c) reaction injection molding, (d) thermoforming, (e) transfer molding, and (f) wire coating?

Answer. (a) and (d).

13.16 Which of the following processes would be applicable to produce hulls for small boats (three best answers): (a) blow molding, (b) compression molding, (c) injection molding, (d) rotational molding, and (e) vacuum thermoforming?

Answer. (a), (d), and (e).

Problems

Extrusion

13.1 The diameter of an extruder barrel is 65 mm and its length = 1.75 m. The screw rotates at 55 rev/min. The screw channel depth = 5.0 mm, and the flight angle = 18°. The head pressure at the die end of the barrel is 5.0×10^6 Pa. The viscosity of the polymer melt is given as 100 Pa-s. Find the volume flow rate of the plastic in the barrel.

Solution: $Q_d = 0.5\pi^2(65\text{x}10^{-3})^2(55/60)(5\text{x}10^{-3})\sin 18 \cos 18 = 95{,}560\text{x}10^{-9}(0.3090)(0.9510)$
$= 28.081 \times 10^{-6}$ m^3/s

$p = 5$ MPa $= 5\text{x}10^6$ n/m^2

$Q_b = \pi(5\text{x}10^6)(65\text{x}10^{-3})(5\text{x}10^{-3})^3(\sin 18)^2/12(100)(1.75) = 5.804(10^{-6})$ m^3/s

$Q_x = 28.081 - 5.804 =$ **22.277 x 10^{-6} m^3/s.**

13.2 An extruder has a diameter of 5.0 in and a length to diameter ratio of 26. The barrel heats the polypropylene melt to 450°F, which provides a melt viscosity of 0.0025 lb-s/in^2. The pitch of the screw is 4.2 in and the channel depth is 0.15 in. In operation the screw rotates at 50 rev/min and a head pressure of 450 lb/in^2 is generated. What is the volume flow rate of polypropylene from the die at the end of the barrel?

Solution:

$A = \tan^{-1}(p/(\pi D)) = \tan^{-1}(4.2/(5\pi)) = 15°$

$Q_d = 0.5\pi^2 D^2 N d_c \sin A \cos A = 0.5\pi^2 (5.0^2)(50/60)\ 0.15 \sin 15 \cos 15 = 3.9$ in^3/sec

$Q_b = p\pi D d_c^3 \sin^2 A/(12\eta L) = 450\pi(5.0)(0.15^3)\sin^2 15/(12(0.0025)(5.0)(26)) = 0.41$ in^3/sec

$Q_x = Q_d - Q_b = 3.9 - 0.41 =$ **3.5 in^3/sec**

13.3 An extruder barrel has a diameter of 110 mm and a length of 3.0 m. The screw channel depth = 7.0 mm, and its pitch = 95 mm. The viscosity of the polymer melt is 105 Pa-s, and the head pressure in the barrel is 4.0 MPa. What rotational speed of the screw is required to achieve a volumetric flow rate of 90 cm^3/s?

Solution: $A = \tan^{-1}(p/(\pi D)) = \tan^{-1}(95/110\pi) = 15.37°$
$Q_d = 0.5\pi^2 D^2 N d_c \sin A \cos A = 0.5\pi^2(0.110)^2(N)(7.0\text{x}10^{-3})\sin 15.37 \cos 15.37$
$= 106.8\, N \text{ x } 10^{-6} \text{ m}^3/\text{s}$
$Q_b = \pi(4\text{x}10^6)(0.110)(7\text{x}10^{-3})^3(\sin 15.37)^2/12(105)(3.0) = 8.81 \text{ x } 10^{-6} \text{ m}^3/\text{s}$
$Q_x = Q_d - Q_b = 106.8\, N \text{ x } 10^{-6} – 8.81 \text{ x } 10^{-6} = 90 \text{ x } 10^{-6} \text{ m}^3/\text{s}$
$106.8\, N = 90.0 + 8.81 = 98.81$
$N = 98.81/106.8 =$ **0.9252 rev/s = 55.51 rev/min.**

13.4 An extruder has a barrel diameter of 2.5 in and a length of 6.0 ft. The screw has a channel depth of 0.25 in, a flight angle of 20°, and rotates at 55 rev/min. The material being extruded is polypropylene. At the present settings, the volumetric flow rate of the polymer melt is 1.50 in^3/sec and the head pressure is 500 lb/in^2. (a) Under these operating characteristics, what is the viscosity of the polypropylene? (b) Using Figure 13.2, approximate the temperature in °F of the polypropylene.

Solution: (a) $Q_d = 0.5\pi^2 D^2 N d_c \sin A \cos A = 0.5\pi^2(2.5^2)(55/60)(0.25)\sin 20 \cos 20$
$Q_d = 2.27 \text{ in}^3/\text{sec}$
$Q_b = Q_d – Q_x = 2.27 – 1.50 = 0.78 \text{ in}^3/\text{sec}$
$\eta = p\pi D d_c^3 \text{ in}^2 A/(12\, Q_b L) = 500\pi(2.5)(0.25^3)\sin^2(20)/(12(0.78)(6)(12)) =$ **0.011 lb-s/in²**

(b) X-axis is Log scale. Therefore LOG(0.011) = -1.96
This is very close to –2, which is at the 10^{-2} hash mark on the y-axis. This yields about 410°F.

13.5 An extruder has diameter = 80 mm and length = 2.0 m. Its screw has a channel depth = 5 mm, flight angle = 18 degrees, and it rotates at 1 rev/sec. The plastic melt has a shear viscosity = 150 Pa-s. Determine the extruder characteristic by computing $Q_{\max}$ and $p_{\max}$ and then finding the equation of the straight line between them.

Solution: $Q_{max} = Q_d = 0.5\pi^2(0.08)^2(1)(5\text{x}10^{-3})\sin 18 \cos 18 = 0.158 \text{ x } 10^{-3}(0.3090)(0.9510)$
$= 46.4 \text{ x } 10^{-6} \text{ m}^3/\text{s}$
$p_{max} = 6\pi(0.08)(1)(2)(150)(\cot 18)/(5\text{x}10^{-3})^2 = 452.4(3.077)/25\text{x}10^{-6} = 55 \text{ x } 10^6 \text{ Pa} = 55 \text{ MPa}$
$Q_x = 46.4 \text{ x } 10^{-6} - (46.4\text{x}10^{-6}/55)\text{p}$
$\boldsymbol{Q_x = 46.4 \text{ x } 10^{-6} - 0.8436 \text{ x } 10^{-6}\, p}$, where p has units of MPa

13.6 Determine the helix angle A such that the screw pitch p is equal to the screw diameter D. This is called the "square" angle in plastics extrusion - the angle that provides a flight advance equal to one diameter for each rotation of the screw.

Solution: Assume flight land = zero.
From Eq. (15.4), $\tan A = \text{pitch}/\pi D$
If pitch = D, then $A = \tan^{-1}(1/\pi)$ **= 17.66°**

13.7 An extruder barrel has a diameter of 2.5 in. The screw rotates at 60 rev/min; its channel depth = 0.20 in, and its flight angle = 17.5°. The head pressure at the die end of the barrel is 800 lb/in^2 and the length of the barrel is 50 in. The viscosity of the polymer melt is 122 x 10^{-4} $lb\text{-}sec/in^2$. Determine the volume flow rate of the plastic in the barrel.

Solution: $Q_d = 0.5\pi^2(2.5)^2(1)(.2)\sin 17.5 \cos 17.5 = 0.5(12.337)(0.3007)(0.9537) = 1.769 \text{ in}^3/\text{sec}$
$Q_b = \pi(800)(2.5)(.2)^3(\sin 17.5)^2/12(122\text{x}10^{-4})(50) = 0.621 \text{ in}^3/\text{sec}$
$Q_x = 1.769 - 0.621 =$ **1.148 in³/sec.**

13.8 An extruder barrel has a diameter of 4.0 in and an L/D ratio of 28. The screw channel depth = 0.25 in, and its pitch = 4.8 in. It rotates at 60 rev/min. The viscosity of the polymer melt is 100 x 10^{-4} lb-sec/in^2. What head pressure is required to obtain a volume flow rate = 150 in^3/min?

Solution: $A = \tan^{-1}(\text{pitch}/\pi D) = \tan^{-1}(4.8/4\pi) = 20.9°$
$Q_d = 0.5\pi^2(4)^2(1)(0.25)\sin 20.9 \cos 20.9 = 19.74(0.3567)(0.9342) = 6.578$ in^3/sec = 394.66 in^3/min
$Q_x = Q_d - Q_b = 394.66 - Q_d = 150$
$Q_b = 394.66 - 150 = 244.66$ in^3/min = 4.078 in^3/sec
$L = 4(28) = 112$ in.
$Q_b = \pi p(4)(0.25)^3(\sin 20.9)^2/(12(100\text{x}10^{-4})(112)) = 4.078$
$0.0018592\, p = 4.078$
$\boldsymbol{p = 2193.4}$ **lb/in^2**

13.9 An extrusion operation produces continuous tubing with outside diameter = 2.0 in and inside diameter = 1.7 in. The extruder barrel has a diameter = 4.0 in and length = 10 ft. The screw rotates at 50 rev/min; it has a channel depth = 0.25 in and flight angle = 16°. The head pressure has a value of 350 lb/in^2 and the viscosity of the polymer melt is 80 x 10^{-4} lb-sec/in^2. Under these conditions, what is the production rate in length of tube/min, assuming the extrudate is pulled at a rate that eliminates the effect of die swell (i.e., the tubing has the same OD and ID as the die profile)?

Solution: $Q_d = 0.5\pi^2(4)^2(50/60)(.25)\sin 16 \cos 16 = 16.45(0.2756)(0.9613) = 4.358$ in^3/sec
$Q_b = \pi(350)(4)(.25)^3(\sin 16)^2/(12(80\text{x}10^{-4})(120)) = 0.453$ in^3/sec
$Q_x = 4.358 - 0.453 = 3.905$ in^3/sec.
$A_x = 0.25\pi(2^2 - 1.7^2) = 0.872$ in^2
$v_x = 3.905/0.872 =$ **4.478 in/sec = 22.39 ft/min.**

13.10 Continuous tubing is produced in a plastic extrusion operation through a die orifice whose outside diameter = 2.0 in and inside diameter = 1.5 in. The extruder barrel diameter = 5.0 in and length = 12 ft. The screw rotates at 50 rev/min; it has a channel depth = 0.30 in and flight angle = 16°. The head pressure has a value of 350 lb/in^2 and the viscosity of the polymer melt is 90 x 10^{-4} lb-sec/in^2. Under these conditions, what is the production rate in length of tube/min, given that the die swell ratio is 1.25.

Solution: $Q_d = 0.5\pi^2(5)^2(50/60)(.3)\sin 16 \cos 16 = 30.84(0.2756)(0.9613) = 8.171$ in^3/sec
$Q_b = \pi(350)(5)(.3)^3(\sin 16)^2/(12(90\text{x}10^{-4})(144)) = 0.725$ in^3/sec
$Q_x = 8.171 - 0.725 = 7.446$ in^3/sec
Die swell ratio applied to OD and ID: OD = 2(1.25) = 2.5, ID = 1.5(1.25) = 1.875
$A_x = 0.25\pi(2.5^2 - 1.875^2) = 2.1476$ in^2
$v_x = 7.446/2.1476 =$ **3.467 in/sec = 17.34 ft/min**

13.11 An extruder has barrel diameter and length of 100 mm and 2.8 m, respectively. The screw rotational speed = 50 rev/min, channel depth = 7.5 mm, and flight angle = 17°. The plastic melt has a shear viscosity = 175 Pa-s. Determine: (a) the extruder characteristic, (b) the shape factor K_s for a circular die opening with diameter = 3.0 mm and length = 12.0 mm, and (c) the operating point (Q and p).

Solution: $Q_{max} = Q_d = 0.5\pi^2(.1)^2(50/60)(7.5\text{x}10^{-3}) \sin 17 \cos 17 = 308.4 \text{ x } 10^{-6}(0.2924)(0.9563)$
$= 86.2 \text{ x } 10^{-6}$ m^3/s
$p_{max} = 6\pi(.1)(50/60)(2.8)(175)(\cot 17)/(7.5\text{x}10^{-3})^2 = 44.75 \text{ x } 10^6$ Pa =44.75 MPa
$\boldsymbol{Q_x = 86.2 \text{ x } 10^{-6} - 1.926 \text{ x } 10^{-12} p}$, where p has units of Pa

(b) Given: $D_d = 3$ mm, $L_d = 12$ mm.
$K_s = \pi(3 \text{ x } 10^{-3})^4/(128(175)(12 \text{ x } 10^{-3})) =$ **0.9467 x 10^{-12}**

(c) $0.9467 \text{ x } 10^{-12} p = 86.2 \text{ x } 10^{-6} - 1.926 \text{ x } 10^{-12} p$
$2.8727 \text{ x } 10^{-12} p = 86.2 \text{ x } 10^{-6}$

p = **30.0 x 10^6 Pa = 30 MPa**
Q_x = 0.9467 x 10^{-12} (30 x 10^6) = **28.4 x 10^{-6} m^3/s**

Check with extruder characteristic: Q_x = 86.2 x 10^{-6} - 1.926 x 10^{-12} (30 x 10^6) = 28.4 x 10^{-6} m^3/s.

13.12 For Problem 13.11, assume the material is acrylic. (a) Using Figure 13.2, determine the temperature of the polymer melt. (b) If the temperature is lowered 20°C, estimate the resulting viscosity of the polymer melt. (Hint: the y-axis of Figure 13.2 is a log scale, not linear).

Solution: (a) When viscosity = 175 Pa-s, Log(175) = 2.243, and temperature is approximately 260°C.

(b) At 240°C, Log(viscosity) is approximately 2.7 and viscosity = 10$^{2.7}$ = 500 Pa-s. (Note: due to the log scale, small changes in the estimate will result in large changes in viscosity.

13.13 Consider an extruder in which the barrel diameter = 4.5 in and length = 11 ft. The extruder screw rotates at 60 rev/min; it has channel depth = 0.35 in and flight angle = 20°. The plastic melt has a shear viscosity = 125 x 10^{-4} lb-sec/in^2. Determine: (a) Q_{max} and p_{max}; (b) the shape factor K_s for a circular die opening in which D_d = 0.312 in and L_d = 0.75 in; and (c) the values of Q and p at the operating point.

Solution: (a) Q_{max} = 0.5π^2(4.5)^2(1)(0.35)sin 20 cos 20 = 34.975(0.342)(0.9397) = 11.24 in^3/sec
p_{max} = 6π(4.5)(1)(132)(0.0125)(cot 20)/(0.35)^2 = **3139 lb/in^2**

(b) Given: D_d = 0.312 in., L_d = 0.75 in.
K_s = π(0.312)^4/128(0.0125)(0.75) = **0.024808**

(c) From (a), $Q_x = Q_{max} - (Q_{max}/p_{max})p$ = 11.24 - 0.003581p
From (b), Q_x = 0.024808p
Combining, .024808p = 11.24 - .003581p
0.02839p = 11.24 p = 395.9 lb/in^2
Q_x = 11.24 - 0.003581(395.9) = **9.82 in^3/sec**

13.14 An extruder has a barrel diameter = 5.0 in and length = 12 ft. The extruder screw rotates at 50 rev/min; it has channel depth = 0.30 in and flight angle = 17.7°. The plastic melt has a shear viscosity = 100 x 10^{-4} lb-sec/in^2. Find: (a) the extruder characteristic, (b) the values of Q and p at the operating point, given that the die characteristic is Q_x = 0.00150 p.

Solution: (a) Q_{max} = 0.5π^2(5)^2(50/60)(0.3)sin 17.7 cos 17.7 = 30.84(0.3040)(0.9527) = 8.93 in^3/sec
p_{max} = 6π(5)(50/60)(144)(0.01)(cot 17.7)/(0.3)^2 = 3937.6 lb/in^2
$Q_x = Q_{max} - (Q_{max}/p_{max})p$ = **8.93 - 0.002268p**

(b) Given: die characteristic Q_x = 0.0015p
Q_x = 8.93 - 0.002268p = 0.0015p
0.00377p = 8.93 p = **2370 lb/in^2**
Q_x = 8.93 - 0.002268(2370) = **3.55 in^3/sec**

13.15 Given the data in Problem 13.14, except that the flight angle of the extruder screw is a variable instead of a constant 17.7°. Use a spreadsheet calculator to determine the value of the flight angle that maximizes the volumetric flow rate Q_x. Explore values of flight angle between 10° and 20°. Determine the optimum value to the nearest tenth of a degree.

Solution: The author's spreadsheet computations returned an optimum value of 13.5°.

13.16 An extruder has a barrel diameter of 3.5 in and a length of 5.0 ft. It has a screw channel depth of 0.16 in and a flight angle of 22°. The extruder screw rotates at 75 rev/min. The polymer melt has a shear viscosity = 65 x 10^{-4} lb-sec/in^2 at the operating temperature of 525°F. The specific gravity of the polymer is 1.2 and its tensile strength is 8000 lb/in^2. A T-shaped cross section is extruded at a rate of

0.11 lb/sec. The density of water is 62.5 lb/ft^3. (a) Find the equation for the extruder characteristic. (b) Find the operating point (Q and p), and (c) the die characteristic that is indicated by the operating point.

Solution: (a) $Q_{max} = 0.5\pi^2 D^2 N d_c \sin A \cos A$

$= 0.5\pi^2(3.5)^2(75/60)(0.16)\sin 22 \cos 22 = 4.199$ in^3/sec

$p_{max} = 6\pi DNL\eta \cot A/d_c^2 = 6\pi(3.5)(75/60)(60)(0.0065)(\cot 22)/(0.16)^2 = 989.8$ lb/in^2

$Q_x = Q_{max} - (Q_{max}/p_{max})p = \mathbf{4.199 - 0.004242}\boldsymbol{p}$

(b) Given: T-shaped cross section extruded at 0.14 lb/sec.
Density of polymer ρ = specific gravity of polymer x ρ_{water}=1.2(62.4 lb/ft^3) = 75 lb/ft^3
Convert to lb/in^3: ρ= 75 lb/ft^3 /(12^3 in^3/ft^3) = 0.0433 lb/in^3
Q_x = 0.11/0.0433 = 2.540 in^3/sec.
2.540 = 4.199 - 0.004242p
0.004242p = 4.199 – 2.540 = 1.659
$\boldsymbol{p}$ **= 391.1 lb/in^2**

(c) $Q_x = K_s p$
$K_s = Q_x/p$ = 2.540/391.1 = 0.00649
$\boldsymbol{Q_x} = \mathbf{0.00649}\ \boldsymbol{p}$

Injection Molding

13.17 Compute the percentage volumetric contraction of a polyethylene molded part, based on the value of shrinkage given in Table 13.1.

Solution: S = 0.025 for polyethylene from Table 13.1.
Volumetric contraction = 1.0 - (1 - .025)^3 = 1.0 - 0.92686 = **0.07314 = 7.314%**

Note that we are not using the parameter S from Table 13.1 in the way it was intended to be used. Its intended use is to compute the oversized dimension of a mold cavity in injection molding. Instead, we are using the shrinkage term to calculate the amount of (volumetric) reduction in size of the part after the polymer is injected into the cavity. In fact, a slightly different shrinkage parameter value may apply in this case.

13.18 The specified dimension = 225.00 mm for a certain injection molded part made of ABS. Compute the corresponding dimension to which the mold cavity should be machined, using the value of shrinkage given in Table 13.1.

Solution: S = 0.006 for ABS from Table 13.1.
D_c = 225.00 + 225.00(0.006) + 225.00(0.006)^2 = 225.00 + 1.35 + 0.0081 = **226.36 mm.**

13.19 The part dimension for a certain injection molded part made of polycarbonate is specified as 3.75 in. Compute the corresponding dimension to which the mold cavity should be machined, using the value of shrinkage given in Table 13.1.

Solution: S = 0.007 for polycarbonate from Table 13.1.
D_c = 3.75 + 3.75(0.007) + 3.75 (0.007)^2 = 3.75 + 0.0263 + 0.0002 = **3.7765 in.**

13.20 The foreman in the injection molding department says that a polyethylene part produced in one of the operations has greater shrinkage than the calculations indicate it should have. The important dimension of the part is specified as 112.5 ±0.25 mm. However, the actual molded part measures 112.02 mm. (a) As a first step, the corresponding mold cavity dimension should be checked. Compute the correct value of the mold dimension, given that the shrinkage value for polyethylene is 0.025 (from Table 13.1). (b) What adjustments in process parameters could be made to reduce the amount of shrinkage?

Solution: (a) Given: S = 0.025, D_c = 112.5 + 112.5(.025) + 112.5(.025)^2 = **115.383 mm**

(b) Adjustments to reduce shrinkage include: (1) increase injection pressure, (2) increase compaction time, and (3) increase molding temperatures.

13.21 An injection molded polyethylene part has a dimension of 2.500 in. A new material, polycarbonate, is used in the same mold. What is the expected corresponding dimension of the polycarbonate molding?

Solution: For polyethylene the shrinkage is 0.025 in/in (from Table 13.1).
Die Cavity = $D_c = D_p + D_pS + D_pS^2$ = 2.500 + 2.500(0.025) + 2.500(0.025)^2 = 2.564 in
For polycarbonate, the shrinkage is 0.007 in/in
Part dimension = $D_c/(1 + S + S^2)$ = 2.564/(1 + 0.007 + 0.007^2) = **2.546 in**

Other Molding Operations and Thermoforming

13.22 The extrusion die for a polyethylene parison used in blow molding has a mean diameter of 18.0 mm. The size of the ring opening in the die is 2.0 mm. The mean diameter of the parison is observed to swell to a size of 21.5 mm after exiting the die orifice. If the diameter of the blow molded container is to be 150 mm, determine (a) the corresponding wall thickness of the container and (b) the wall thickness of the parison.

Solution: (a) $r_s = D_p/D_d$ = 21.5/18.0 = 1.194
$t_m = t_p\, D_p/D_m = r_s\, t_d\, D_p/D_m$ = (1.194)(2.0)(21.5)/150.0 = **0.342 mm**

(b) $t_p = r_s\, t_d$ = (1.194)(2.0) = **2.388 mm**

13.23 A parison is extruded from a die with outside diameter = 11.5 mm and inside diameter = 7.5 mm. The observed die swell is 1.25. The parison is used to blow mold a beverage container whose outside diameter = 112 mm (a standard size 2-liter soda bottle). (a) What is the corresponding wall thickness of the container? (b) Obtain an empty 2-liter plastic soda bottle and (carefully) cut it across the diameter. Using a micrometer, measure the wall thickness to compare with your answer in (a).

Solution: (a) D_d = (11.5 + 7.5)/2 = 9.5 mm, and t_d = (11.5 - 7.5)/2 = 2.0 mm
t_m = (1.25)^2(2.0)(9.5)/112 = **0.265 mm (= 0.010 in)**

(b) Measured value should be close to calculated value. Some wall thicknesses are less.

13.24 A blow-molding operation is used to produce a bottle with a diameter of 2.250 in and a wall thickness of 0.045 in. The parison has a thickness of 0.290 in. The observed die swell ratio is 1.30. (a) What is the required diameter of the parison? (b) What is the diameter of the die?

Solution: (a) $D_p = t_mD_m/t_p$ = (0.045)(2.250)/0.290 = **0.349 in**

(b) $D_d = D_p/r_s$ = 0.349/1.30 = **0.268 in**

13.25 An extrusion operation is used to produce a parison whose mean diameter = 27 mm. The inside and outside diameters of the die that produced the parison are 18 mm and 22 mm, respectively. If the minimum wall thickness of the blow-molded container is to be 0.40 mm, what is the maximum possible diameter of the blow mold?

Solution: D_d = (22 + 18)/2 = 20 mm, and t_d = (22 - 18)/2 = 2 mm
r_s = 27/20 = 1.35
Rearranging Eq. (13.22) in text, $D_m = r_{sd}{}^3 t_dD_d/t_m$ = (1.35)^2(2)(20)/(0.40) = **182.25 mm**

13.26 A rotational molding operation is to be used to mold a hollow playing ball out of polypropylene. The ball will be 1.25 ft in diameter and its wall thickness should be 3/32 in. What weight of PP powder should be loaded into the mold in order to meet these specifications? The specific gravity of the PP grade is 0.90, and the density of water is 62.4 lb/ft^3.

Solution: Density ρ = specific gravity of polymer x ρ_{water} = 0.90(62.4 lb/ft^3) = 56.2 lb/ft^3

Convert to lb/in^3: ρ = 56.2 lb/ft^3 /(1728 in^3/ft^3) = 0.0325 lb/in^3

Volume = $\pi(D_o^3 - D_i^3)/6 = 0.16667\pi[(1.25\text{x}12)^3 - (1.25\text{x}12 - 3/16)^3]$ = 10.91 in^3

Weight W = (10.91)(0.0325) = **0.355 lb.**

13.27 The problem in a certain thermoforming operation is that there is too much thinning in the walls of the large cup-shaped part. The operation is conventional pressure thermoforming using a positive mold, and the plastic is an ABS sheet with an initial thickness of 3.2 mm. (a) Why is thinning occurring in the walls of the cup? (b) What changes could be made in the operation to correct the problem?

Solution: (a) As the starting flat sheet is draped over the convex cup-shaped mold, the portion contacting the base of the cup experiences little stretching. However, the remaining portions of the sheet must be stretched significantly to conform to the sides of the cup. Hence, thinning in these sides results.

(b) The problem could be solved by either: (1) fabricating a negative mold to replace the current positive mold, since a negative mold will distribute the material more uniformly and result in approximately equal thinning throughout the sheet; or (2) prestretch the sheet as in Figure 13.38 in the text.