Homework solutions for period 3

Solutions for Lecture 13

Review Questions

15.4 Name the three most common machining processes.

**Answer.** The three common machining processes are (1) turning, (2) drilling, and (3) milling.

15.5 What are the two basic categories of cutting tools in machining? Give two examples of machining operations that use each of the tooling types.

**Answer.** The two categories are (1) single-point tools, used in operations such as turning and boring; and (2) multiple-edge cutting tools, used in operations such as milling and drilling.

15.11 Name and briefly describe the four types of chips that occur in metal cutting.

**Answer.** The four types are (1) discontinuous, in which the chip is formed into separated segments; (2) continuous, in which the chip does not segment and is formed from a ductile metal; (3) continuous with built-up edge, which is the same as (2) except that friction at the tool-chip interface causes adhesion of a small portion of work material to the tool rake face, and (4) serrated, which are semi-continuous in the sense that they possess a saw-tooth appearance that is produced by a cyclical chip formation of alternating high shear strain followed by low shear strain.

16.2 Distinguish between generating and forming when machining workpart geometries.

**Answer.** Generating refers to the creation of work geometry due to the feed trajectory of the cutting tool; examples include straight turning, taper turning, and profile milling. Forming involves the creation of work geometry due to the shape of the cutting tool; common examples include form turning and drilling.

16.5 What is the difference between threading and tapping?

**Answer.** A threading operation is performed on a turning machine and produces an external thread, while tapping is normally performed on a drilling machine and produces an internal thread.

16.6 How does a boring operation differ from a turning operation?

**Answer.** Boring produces an internal cylindrical shape from an existing hole, while turning produces an external cylindrical shape.

16.13 What is the difference between peripheral milling and face milling?

**Answer.** In peripheral milling, cutting is accomplished by the peripheral teeth of the milling cutter and the tool axis is parallel...
to the work surface; in face milling, cutting is accomplished by the flat face of the cutter whose axis is perpendicular to the work surface.

16.14 Describe profile milling.

**Answer.** Profile milling generally involves the milling of the outside periphery of a flat part.

**Problems**

15.1 In an orthogonal cutting operation, the tool has a rake angle = 15°. The chip thickness before the cut = 0.30 mm and the cut yields a deformed chip thickness = 0.65 mm. Calculate (a) the shear plane angle and (b) the shear strain for the operation.

**Solution:**
(a) $r = t_o/t_c = 0.30/0.65 = 0.4615$
$\phi = \tan^{-1}(0.4615 \cos 15/(1 - 0.4615 \sin 15)) = \tan^{-1}(0.5062) = 26.85°$
(b) Shear strain $\gamma = \cot 26.85 + \tan (26.85 - 15) = 1.975 + 0.210 = 2.185$

15.3 In a turning operation, spindle speed is set to provide a cutting speed of 1.8 m/s. The feed and depth of cut are 0.30 mm and 2.6 mm, respectively. The tool rake angle is 8°. After the cut, the deformed chip thickness is measured to be 0.49 mm. Determine (a) shear plane angle, (b) shear strain, and (c) material removal rate. Use the orthogonal cutting model as an approximation of the turning process.

**Solution:**
(a) $r = t_o/t_c = 0.30/0.49 = 0.612$
$\phi = \tan^{-1}(0.612 \cos 8/(1 - 0.612 \sin 8)) = \tan^{-1}(0.6628) = 33.6°$
(b) $\gamma = \cot 33.6 + \tan (33.6 - 8) = 1.509 + 0.478 = 1.987$
(c) $R_{MR} = (1.8 \text{ m/s} \times 10^3 \text{ mm/m})(0.3)(2.6) = 1404 \text{ mm}^3/\text{s}$

15.4 The cutting force and thrust force in an orthogonal cutting operation are 1470 N and 1589 N, respectively. The rake angle = 5°, the width of the cut = 5.0 mm, the chip thickness before the cut = 0.6, and the chip thickness ratio = 0.38. Determine (a) the shear strength of the work material and (b) the coefficient of friction in the operation.

**Solution:**
(a) $\phi = \tan^{-1}(0.38 \cos 5/(1 - 0.38 \sin 5)) = \tan^{-1}(0.3916) = 21.38°$
$F_s = 1470 \cos 21.38 - 1589 \sin 21.38 = 789.3 \text{ N}$
$A_s = (0.6)(5.0)/\sin 21.38 = 3.0/.3646 = 8.23 \text{ mm}^2$
$S = 789.3/8.23 = 95.9 \text{ N/mm}^2 = 95.9 \text{ MPa}$
(b) $\phi = 45 + \alpha/2 - \beta/2$; rearranging, $\beta = 2(45) + \alpha - 2\phi$
$\beta = 2(45) + -2(21.38) = 52.24°$
$\mu = \tan 52.24 = 1.291$

15.6 In an orthogonal cutting operation, the rake angle = -5°, chip thickness before the cut = 0.2 mm and width of cut = 4.0 mm. The chip ratio
= 0.4. Determine (a) the chip thickness after the cut, (b) shear angle, (c) friction angle, (d) coefficient of friction, and (e) shear strain.

Solution: (a) \( r = t_o/t_c \), \( t_c = t_o/r = 0.2/.4 = 0.5 \text{ mm} \)

(b) \( \phi = \tan^{-1}(0.4 \cos(-5)/(1 - 0.4 \sin(-5))) = \tan^{-1}(0.3851) = 21.1^\circ \)

(c) \( \beta = 2(45) + -2(\phi) = 90 + (-5) - 2(21.8) = 42.9^\circ \)

(d) \( \mu = \tan 42.9 = 0.93 \)

(e) \( \gamma = \cot 31.8 + \tan(31.8 - 15) = 2.597 + 0.489 = 3.09 \)

15.10 A turning operation is made with a rake angle of 10°, a feed of 0.010 in/rev and a depth of cut = 0.100 in. The shear strength of the work material is known to be 50,000 lb/in\(^2\), and the chip thickness ratio is measured after the cut to be 0.40. Determine the cutting force and the feed force. Use the orthogonal cutting model as an approximation of the turning process.

Solution: \( \phi = \tan^{-1}(0.4 \cos 10/(1 - 0.4 \sin 10)) = \tan^{-1}(0.4233) = 22.9^\circ \)

\( A_s = (0.010)(0.10)/\sin 22.9 = 0.00256 \text{ in}^2 \)

\( F_s = A_sS = 0.00256(50,000) = 128 \text{ lb} \)

\( \beta = 2(45) + -2(\phi) = 90 + 10 - 2(22.9) = 54.1^\circ \)

\( F_c = 128 \cos (54.1 - 10)/\cos (22.9 + 54.1 - 10) = 236 \text{ lb} \)

\( F_t = 128 \sin (54.1 - 10)/\cos (22.9 + 54.1 - 10) = 229 \text{ lb} \)

16.1 A cylindrical workpart 200 mm in diameter and 700 mm long is to be turned in an engine lathe. Cutting speed = 2.30 m/s, feed = 0.32 mm/rev, and depth of cut = 1.80 mm. Determine (a) cutting time, and (b) metal removal rate.

Solution: (a) \( N = \frac{v}{\pi D} = \frac{(2.30 \text{ m/s})}{0.200 \pi} = 3.66 \text{ rev/s} \)

\( f_r = Nf = 6.366(0.3) = 1.87 \text{ mm/s} \)

\( T_m = \frac{L}{f_r} = 700/1.17 = 598 \text{ s} = 9.96 \text{ min} \)

Alternative calculation using Eq. (16.5), \( T_m = \frac{200(700)\pi}{(2,300 \times 0.32)} = 597.6 \text{ sec} = 9.96 \text{ min} \)

(b) \( R_{mr} = vfd = (2.30 \text{ m/s})(10^3)(0.32 \text{ mm})(1.80 \text{ mm}) = 1320 \text{ mm}^3/\text{s} \)

16.2 In a production turning operation, the foreman has decreed that a single pass must be completed on the cylindrical workpiece in 5.0 min. The piece is 400 mm long and 150 mm in diameter. Using a feed = 0.30 mm/rev and a depth of cut = 4.0 mm, what cutting speed must be used to meet this machining time requirement?

Solution: Starting with Eq. (16.5): \( T_m = \frac{\pi D_o L}{vf} \).

Rearranging to determine cutting speed: \( v = \frac{\pi D_o L}{fT_m} \)

\( v = \pi(0.4)(0.15)/(0.30)(10^2)(5.0) = 0.1257(10^2) \text{ m/min} = 125.7 \text{ m/min} \)

16.6 A drilling operation is to be performed with a 12.7 mm diameter twist drill in a steel workpart. The hole is a blind hole at a depth of 60 mm and the point angle is 118°. The cutting speed is 25 m/min and the feed is 0.30
mm/rev. Determine (a) the cutting time to complete the drilling operation, and (b) metal removal rate during the operation, after the drill bit reaches full diameter.

**Solution:** (a) \[ N = \frac{v}{\pi D} = \frac{25(10^3)}{12.7\pi} = 626.6 \text{ rev/min} \]
\[ f_r = N f = 626.6(0.30) = 188 \text{ mm/min} \]
\[ A = 0.5D \tan \left(90 - \frac{118}{2}\right) = 0.5(12.7)\tan(90 - 118/2) = 3.82 \text{ mm} \]
\[ T_m = \frac{(d + A)}{f_r} = \frac{(60 + 3.82)}{188} = 0.339 \text{ min} \]

(b) \[ R_{MR} = 0.25\pi D^2 f_r = 0.25\pi(12.7)^2(188) = 23,800 \text{ mm}^3/\text{min} \]

16.8 A peripheral milling operation is performed on the top surface of a rectangular workpart which is 400 mm long by 60 mm wide. The milling cutter, which is 80 mm in diameter and has five teeth, overhangs the width of the part on both sides. Cutting speed = 70 m/min, chip load = 0.25 mm/tooth, and depth of cut = 5.0 mm. Determine (a) the actual machining time to make one pass across the surface and (b) the maximum material removal rate during the cut.

**Solution:** (a) \[ N = \frac{v}{\pi D} = \frac{70,000}{80\pi} = 279 \text{ rev/min} \]
\[ f_r = N n f = 279(5)(0.25) = 348 \text{ mm/min} \]
\[ A = (d(D-d))^{0.5} = (5(80-5))^{0.5} = 19.4 \text{ mm} \]
\[ T_m = \frac{(400 + 19.4)}{348} = 1.20 \text{ min} \]

(b) \[ R_{MR} = wdf_r = 60(5)(348) = 104,400 \text{ mm}^3/\text{min} \]

**Solution for Lecture 14**

17.2 Name the three modes of tool failure in machining.

**Answer.** The three tool failure modes are (1) fracture failure, (2) temperature failure, and (3) gradual wear.

17.3 What are the two principal locations on a cutting tool where tool wear occurs?

**Answer.** Wear occurs on the top face of the cutting tool as crater wear and on the side or flank of the tool, called flank wear. Portions of flank wear are often identified separately as notch wear, corresponding to the surface of the work; and nose radius wear, corresponding to the tool point.

17.4 Identify the mechanisms by which cutting tools wear during machining.

**Answer.** The important tool wear mechanisms are (1) abrasion, (2) adhesion, (3) diffusion, and (4) plastic deformation of the cutting edge.

17.7 Identify three desirable properties of a cutting-tool material.

**Answer.** Three desirable properties are (1) toughness to resist fracture failure, (2) hot hardness to resist temperature failure, and (3) wear resistance to prolong the life of the tool during gradual wear.

17.8 What are the principal alloying ingredients in high-speed steel?
**Answer.** Principal alloying ingredients in HSS are (1) either tungsten or a combination of tungsten and molybdenum, (2) chromium, (3) vanadium, and (4) carbon. Some grades of HSS also contain cobalt.

17.9 What is the difference in ingredients between steel cutting grades and nonsteel-cutting grades of cemented carbides?

**Answer.** In general, non-steel cutting grades contain only WC and Co. Steel cutting grades contain TiC and/or TaC in addition to WC-Co.

17.12 Identify the alternative ways by which a cutting tool is held in place during machining.

**Answer.** There are three principal ways: (1) solid shank, in which the cutting edge is an integral part of the tool shank, an example being high speed steel tooling; (2) brazed inserts, used for some cemented carbides; and (3) mechanically clamped inserts, used for most hard tool materials including cemented carbides, coated carbides, cermets, ceramics, SPD, and CBN.

17.13 Name the two main categories of cutting fluid according to function.

**Answer.** The two functional categories of cutting fluids are: (1) coolants and (2) lubricants.

**Problems**

17.1 Flank wear data were collected in a series of turning tests using a coated carbide tool on hardened alloy steel at a feed of 0.30 mm/rev and a depth of 4.0 mm. At a speed of 125 m/min, flank wear = 0.12 mm at 1 min, 0.27 mm at 5 min, 0.45 mm at 11 min, 0.58 mm at 15 min, 0.73 at 20 min, and 0.97 mm at 25 min. At a speed of 165 m/min, flank wear = 0.22 mm at 1 min, 0.47 mm at 5 min, 0.70 mm at 9 min, 0.80 mm at 11 min, and 0.99 mm at 13 min. The last value in each case is when final tool failure occurred. (a) On a single piece of linear graph paper, plot flank wear as a function of time for both speeds. Using 0.75 mm of flank wear as the criterion of tool failure, determine the tool lives for the two cutting speeds. (b) On a piece of natural log-log paper, plot your results determined in the previous part. From the plot, determine the values of \( n \) and \( C \) in the Taylor Tool Life Equation. (c) As a comparison, calculate the values of \( n \) and \( C \) in the Taylor equation solving simultaneous equations. Are the resulting \( n \) and \( C \) values the same?

**Solution:** (a) and (b) Student exercises. For part (a), at \( v_1 = 125 \) m/min, \( T_1 = 20.4 \) min using criterion \( FW = 0.75 \) mm, and at \( v_2 = 165 \) m/min, \( T_2 = 10.0 \) min using criterion \( FW = 0.75 \) mm. In part (b), values of \( C \) and \( n \) may vary due to variations in the plots. The values should be approximately the same as those obtained in part (c) below.

(c) Two equations: (1) \( 125(20.4)^n = C \), and (2) \( 165(10.0)^n = C \)

\[
\ln 125 + n \ln 20.4 = \ln 165 + n \ln 10.0 \\
4.8283 + 3.0155 \ln n = 5.1059 + 2.3026 \ln n \\
0.7129 \ln n = 0.2776 \\
n = 0.3894
\]

\[
(1) \ C = 125(20.4)^{0.3894} = 404.46 \\
(2) \ C = 165(10.0)^{0.3894} = 404.46 \quad C = 404.46
\]
17.3 Tool life tests on a lathe have resulted in the following data: (1) at a cutting speed of 375 ft/min, the tool life was 5.5 min; (2) at a cutting speed of 275 ft/min, the tool life was 53 min. (a) Determine the parameters \( n \) and \( C \) in the Taylor tool life equation. (b) Based on the \( n \) and \( C \) values, what is the likely tool material used in this operation? (c) Using your equation, compute the tool life that corresponds to a cutting speed of 300 ft/min. (d) Compute the cutting speed that corresponds to a tool life \( T = 10 \) min.

**Solution:** (a) \( VT^n = C \); Two equations: (1) \( 375(5.5)^n = C \) and (2) \( 275(53)^n = C \).

\[
\begin{align*}
375(5.5)^n &= 275(53)^n \\
\frac{375}{275} &= \left(\frac{53}{5.5}\right)^n \\
1.364 &= \left(\frac{9.636}{10}\right)^n \\
\ln 1.364 &= \ln 9.636 \\
0.3102 &= 2.2655 \\
n &= \frac{0.3102}{2.2655} = 0.137 \\
C &= 375(5.5)^{0.137} = 375(1.2629) = 474 \\
C &= 275(53)^{0.137} = 275(1.7221) = 474 \\
Check: C &= 275(53)^{0.137} = 275(1.7221) = 474 \\
\end{align*}
\]

(b) Comparing these values of \( n \) and \( C \) with those in Table 17.2, the likely tool material is high speed steel.

(c) At \( v = 300 \text{ ft/min} \), \( T = \left(\frac{C}{v}\right)^{1/n} = \left(\frac{474}{300}\right)^{1/0.137} = (1.579)^{7.305} = 28.1 \text{ min} \)

(d) For \( T = 10 \text{ min} \), \( v = \frac{C}{T^n} = \frac{474}{10^{0.137}} = \frac{474}{1.371} = 346 \text{ ft/min} \)

17.4 Tool life tests in turning yield the following data: (1) when cutting speed is 100 m/min, tool life is 10 min; (2) when cutting speed is 75 m/min, tool life is 30 min. (a) Determine the \( n \) and \( C \) values in the Taylor tool life equation. Based on your equation, compute (b) the tool life for a speed of 110 m/min, and (c) the speed corresponding to a tool life of 15 min.

**Solution:** \( VT^n = C \), (a) Two equations: (1) \( 100(10)^n = C \) and (2) \( 75(30)^n = C \).

\[
\begin{align*}
100(10)^n &= 75(30)^n, \quad 100/75 = (30/10)^n, \quad 4/3 = 3^n \\
\ln(4/3) &= n \ln 3 \\
n &= 0.26186 \\
C &= 100(10)^{0.26186} = 182.75 \\
Check: C &= 75(30)^{0.26186} = 182 \\
(b) 110 T^{0.26186} &= 182.75 \\
T &= \frac{182.75/110}{0.26186} = 6.9489 \text{ min} \\
(c) v (15)^{0.26186} &= 182.75 \\
v &= \frac{182.75/(15)^{0.26186}}{89.9 \text{ m/min}} \\
\end{align*}
\]

17.5 Turning tests have resulted in 1-min tool life at a cutting speed = 4.0 m/s and a 20-min tool life at a speed = 2.0 m/s. (a) Find the \( n \) and \( C \) values in the Taylor tool life equation. (b) Project how long the tool would last at a speed of 1.0 m/s.

**Solution:** (a) For data (1) \( T = 1.0 \text{ min} \), then \( C = 4.0 \text{ m/s} = 240 \text{ m/min} \)

For data (2) \( v = 2 \text{ m/s} = 120 \text{ m/min} \)

\[
\begin{align*}
120(20)^n &= 240 \\
20^n &= 240/120 = 2.0 \\
n \ln 20 &= \ln 2.0 \\
2.9957 &= 0.6931 \\
n &= \frac{0.6931}{2.9957} = 0.2314 \\
\end{align*}
\]

(b) At \( v = 1.0 \text{ m/s} = 60 \text{ m/min} \)

\[
60(T)^{0.2314} = 240 \]

6
(T)_{0.2314}^{0.2314} = \frac{240}{60} = 4.0

T = (4.0)^{1/0.2314} = (4)^{4.3215} = 400 \text{ min}

17.6 In a production turning operation, the workpart is 125 mm in diameter and 300 mm long. A feed of 0.225 mm/rev is used in the operation. If cutting speed = 3.0 m/s, the tool must be changed every 5 workparts; but if cutting speed = 2.0 m/s, the tool can be used to produce 25 pieces between tool changes. Determine the Taylor tool life equation for this job.

Solution: (1) \( T_n = \pi (125 \text{ mm})(0.3 \text{ m})/(3.0 \text{ m/s})(0.225 \text{ mm}) = 174.53 \text{ s} = 2.909 \text{ min} \)

\( T = 5(2.909) = 14.54 \text{ min} \)

(2) \( T_n = \pi (125 \text{ mm})(0.3 \text{ m})/(2.0 \text{ m/s})(0.225 \text{ mm}) = 261.80 \text{ s} = 4.363 \text{ min} \)

\( T = 25(4.363) = 109.08 \text{ min} \)

(1) \( v = 3 \text{ m/s} = 180 \text{ m/min} \)

(2) \( v = 2 \text{ m/s} = 120 \text{ m/min} \)

(1) \( 180(14.54)^n = C \)

(2) \( 120(109.08)^n = C \)

\( 180(14.54)^n = 120(109.08)^n \)

\( \ln 180 + n \ln(14.54) = \ln 120 + n \ln(109.08) \)

\( 5.1929 + 2.677 n = 4.7875 + 4.692 n \)

\( 5.1929 - 4.7875 = (4.692 - 2.677) n \)

\( 0.4054 = 2.0151 n \)

\( n = 0.2012 \)

\( C = 180 (14.54)^{0.2012} \)

\( C = 308.43 \)

Solution for Lecture 15

10.1 Name some of the reasons for the commercial importance of powder metallurgy technology.

Answer. PM is important because (1) parts can be made to net or near net shape, (2) parts can be made with a controlled level of porosity, (3) certain metals difficult to process by other methods can be processed by PM, and (4) PM allows the formulation of unusual alloys not easily obtained by traditional alloying methods.

10.2 What are some of the disadvantages of PM methods?

Answer. Disadvantages include (1) high tooling costs, (2) metal powders are expensive, (3) difficulties in storing and handling metallic powders, (4) certain limitations on part geometry imposed by the uniaxial press methods, and (5) variations in density in a PM component can be troublesome.

10.3 What are the principal methods used to produce metallic powders?

Answer. The powder production methods are (1) atomization - the conversion of molten metal into droplets which solidify into powders; (2) chemical reduction - reducing metallic oxides by use of reducing agents which combine with the oxygen to free the metals in the form of powders; and (3) electrolysis - use of an electrolytic cell to deposit particles of the metal onto the cathode in the cell.

10.4 What are the three basic steps in the conventional powder metallurgy shaping process?
Answer. The steps are (1) blending and/or mixing, (2) pressing, and (3) sintering.

10.5 What is the technical difference between blending and mixing in powder metallurgy?

Answer. Blending refers to combining particles of the same chemistry but different sizes, whereas mixing means combining metal powders of different chemistries.

10.7 What is meant by the term green compact?

Answer. The green compact is the pressed but not yet sintered PM part.

10.8 Describe what happens to the individual particles during compaction.

Answer. Starting with the initial powder arrangement, the particles are first repacked into a more efficient arrangement, followed by deformation of the particles as pressure is increased.

10.9 What are the three steps in the sintering cycle in PM?

Answer. The three steps in the cycle are (1) preheat, in which lubricants and binders are burned off, (2) sintering, and (3) cool down.

10.11 What is the difference between impregnation and infiltration in PM?

Answer. Impregnation is the term used when oil or other fluid (e.g., polymer melt) is permeated into the pores of a sintered PM part, whereas infiltration is an operation in which the pores of the PM part are filled with a molten metal whose melting point is below that of the PM part.

10.12 How is isostatic pressing distinguished from conventional pressing and sintering in PM?

Answer. Isostatic pressing applies hydrostatic pressure to all sides of the mold, whereas conventional pressing is uniaxial.

10.14 What are the two basic classes of metal powders as far as chemistry is concerned?

Answer. The two classes are (1) elemental powders - powders of pure metal such as iron or copper, and (2) pre-alloyed powders - powders of alloys such as stainless steel or brass.

10.15 Why is PM technology so well suited to the production of gears and bearings?

Answer. The reasons are (1) the geometries of these parts lend themselves to conventional PM pressing, which consists of pressing in one direction, and (2) the porosity allows impregnation of the PM parts with lubricants.

Problems

10.1 In a certain pressing operation, the metallic powder fed into the open die has a packing factor of 0.5. The pressing operation reduces the powders to 2/3 of their starting volume. In the subsequent sintering operation, shrinkage amounts to 10% on a volume basis. Given that these are the only factors that affect the structure of the finished part, determine its final porosity.
Solution: Packing factor = bulk density / true density
Density = (specific volume)^-1
Packing factor = true specific volume / bulk specific volume
Pressing reduces bulk specific volume to 2/3 = 0.667
Sintering further reduces the bulk specific volume to 0.90 of value after pressing.
Let true specific volume = 1.0
Thus for a packing factor of 0.5, bulk specific volume = 2.0.
Packing factor after pressing and sintering = 1.0/(2.0 x .667 x .90) = 1.0/1.2 = 0.833
By Eq. (18.7), porosity = 1 - 0.833 = 0.167

Solution for Lecture 16

Review Questions

21.2 Mechanical surface treatments are often performed for reasons other than or in addition to cleaning. What are the reasons?
Answer. Reasons for mechanical surface treatments include deburring, improving smoothness, adding luster, and enhancing surface properties.

21.3 What are the basic types of contaminants that must be cleaned from metallic surfaces in manufacturing?
Answer. Basic contaminant types mentioned in the text are (1) oil and grease, (2) solid particles, such as metal chips, abrasive grits, shop dirt, and dust, (3) buffing and polishing compounds, and (4) oxide films, rust, and scale.

21.4 Name some of the important chemical cleaning methods.
Answer. The chemical cleaning methods can be categorized as follows (1) alkaline cleaning, (2) emulsion cleaning, (3) solvent cleaning, (4) acid cleaning and pickling, and (5) ultrasonic cleaning.

21.5 In addition to surface cleaning, what is the main function performed by shot peening?
Answer. Shot peening is primarily used to improve the fatigue strength of metals by introducing cold working the metallic surface.

21.6 What is meant by the term mass finishing?
Answer. In mass finishing, parts are mechanically cleaned and deburred in bulk, usually in a barrel by the mixing action of an abrasive media.

21.7 What is the difference between diffusion and ion implantation?
Answer. Diffusion is a process in which atoms or molecules move across a boundary between two contacting materials. Ion implantation produces a similar result, but the process involves penetration of high-velocity ions into the surface of a substrate material.

21.9 Why are metals coated?
Answer. Reasons for coating metals include (1) to provide corrosion protection, (2) to enhance appearance, (3) to provide a specific color, (4) to increase electrical conductivity, (5) to increase electrical resistance, and (6) prepare surface for subsequent processing.
21.13 How does electroless plating differ from electrochemical plating?

Answer. Electroless plating uses only chemical reactions to form the plating; electroplating uses electrolysis.

21.14 What is a conversion coating?

Answer. A conversion coating is a thin coating produced by chemical reaction of the metallic surface. The most common conversion coatings are phosphates, chromates, and oxides.

21.15 How does anodizing differ from other conversion coatings?

Answer. Anodizing uses electrochemical processing methods to convert the metallic surface. The best example is aluminum anodizing.

21.16 What is physical vapor deposition?

Answer. Physical vapor deposition (PVD) refers to a family of processes in which a material is converted to its vapor phase in a vacuum chamber and condensed onto a substrate surface as a very thin film.

21.17 What is the difference between physical vapor deposition (PVD) and chemical vapor deposition (CVD)?

Answer. In PVD, the coating vapors are synthesized by heating the coating material and allowing it to condense as a thin film on the surface of the workpart. In CVD a coating is formed on a heated substrate by the chemical reaction or dissociation of vapors and/or gases; the reaction product nucleates and grows on the substrate surface.

Problems

21.1 What volume (cm$^3$) and weight (g) of zinc will be deposited onto a cathodic workpart if 10 amps of current are applied for one hour?

Solution: From Table 21.1, $C = 4.75 \times 10^{-2}$ mm$^3$/A-s, cathode efficiency $E = 95\%$.

Volume $V = ECIt = 0.95(4.75 \times 10^{-2}$ mm$^3$/A-s)(10 A)(1 hr)(3600 s/hr) = $1624.5$ mm$^3$

Density of zinc from Table 3.10 $\rho = 7.15$ g/cm$^3$. Weight $W = 1.6245(7.15) = 11.615$ g

21.2 A sheet metal steel part with surface area = 100 cm$^2$ is to be zinc plated. What average plating thickness will result if 15 amps are applied for 12 minutes in a chloride electrolyte solution?

Solution: From Table 21.1, $C = 4.75 \times 10^{-2}$ mm$^3$/A-s, cathode efficiency $E = 95\%$.

Volume $V = ECIt = 0.95(4.75 \times 10^{-2}$ mm$^3$/A-s)(15 A)(12 min)(60 s/min) = $487.35$ mm$^3$

Area $A = 100$ cm$^2 = 10,000$ mm$^2$

Plating thickness $d = 487.35$ mm$^3$/10,000 mm$^2 = 0.049$ mm