27 SURFACE PROCESSING OPERATIONS

Review Questions

27.1 What are some important reasons why manufactured parts must be cleaned?

Answer. The reasons include (1) to prepare the surface for subsequent industrial processing, (2) to improve hygiene conditions, (3) to remove contaminants which might chemically react with the surface; and (4) to enhance product appearance and performance.

27.2 Mechanical surface treatments are often performed for reasons other than or in addition to cleaning. What are those reasons?

Answer. Reasons for mechanical surface treatments include deburring, improving smoothness, adding luster, and enhancing surface properties.

27.3 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.

27.4 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.

27.5 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 cold working the metallic surface.

27.6 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.

27.7 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.

27.8 What is *calorizing*?

Answer. Calorizing is the diffusion of aluminum into carbon steel, alloy steels, and the alloys of nickel and cobalt. The process is also known as aluminizing.

27.9 Why are metals coated?

Answer. Reasons for coating metals are to (1) provide corrosion protection, (2) enhance appearance, (3) provide a specific color, (4) increase electrical conductivity, (5) increase electrical resistance, (6) prepare surface for subsequent processing, and (7) rebuild worn or eroded surfaces.

27.10 Identify the most common types of coating processes.

Answer. The common coating processes are (1) plating, (2) chemical conversion coatings, such as anodizing, (3) vapor deposition processes such as PVD and CVD, (4) organic coating, such as painting, (5) porcelain enameling, and (6) thermal and mechanical coating processes.

27.11 What are the two basic mechanisms of corrosion protection provided by hot dipping?

Answer. The mechanisms are (1) barrier protection, in which the coating simply covers the substrate to protect it, and (2) sacrificial protection, in which the coating metal corrodes sacrificially to protect the substrate.

27.12 What is the most commonly plated substrate metal?

Answer. Steel.

27.13 How does electroless plating differ from electrochemical plating?

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

27.14 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.

27.15 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.

27.16 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.

27.17 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 work part. 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.

27.18 What are some of the applications of PVD?

Answer. PVD applications include: decorative coatings on trophies and automotive trim, antireflection coatings on optical lenses, deposition of metal in electronic connections, and coatings on cutting tools.

27.19 Name the commonly used coating materials deposited by PVD onto cutting tools.

Answer. The common coating materials deposited by PVD onto cutting tools are titanium nitride (TiN), titanium carbide (TiC), and aluminum oxide (Al_2O_3). TiN is probably the most common.

27.20 What are some of the advantages of chemical vapor deposition?

Answer. Advantages of CVD include (1) capability to deposit refractory materials at temperatures below their melting or sintering temperatures, (2) grain size control, (3) process is performed at atmospheric pressure, and (4) good bonding to substrate surface.

27.21 What are the two most common titanium compounds that are coated onto cutting tools by chemical vapor deposition?

Answer. TiC and TiN.

27.22 Identify the four major types of ingredients in organic coatings.

Answer. The major ingredients are (1) binder, which are polymers, (2) dyes or pigments, which provide color, (3) solvents, and (4) additives such as surfactants and plasticizers.

27.23 What is meant by the term *transfer efficiency* in organic coating technology?

Answer. Transfer efficiency is the proportion of the organic coating liquid that is deposited on the target surface. The rest is waste.

27.24 Describe the principal methods by which organic coatings are applied to a surface.

Answer. The main methods include brushing and rolling, spraying, immersion (dip coating), and flow coating.

27.25 The terms *drying* and *curing* have different meanings. What is the distinction?

Answer. Drying means evaporation of solvents in the organic coating liquid. Curing involves a chemical change in the organic resin (polymerization and/or cross-linking) which hardens the coating.

27.26 In porcelain enameling, what is *frit*?

Answer. Frit is glassy porcelain prepared as fine particles (powders) by crushing and milling.

Problems

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

Electroplating

27.1 **(A)** (SI units) A sheet metal steel part with surface area = 185 cm^2 is to be zinc-plated. What average plating thickness will result if 15 amps are applied for 10 min in a chloride electrolyte solution?

Solution: From Table 27.1, $C = 4.75 \times 10^{-2}$ mm^3/A-s, cathode efficiency E = 95%.
Volume $V = ECIt = 0.95(4.75 \times 10^{-2}\ mm^3/A\text{-}s)(15\ A)(10\ min)(60\ s/min) = 406.125\ mm^3$
Area $A = 185\ cm^2 = 18{,}500\ mm^2$
Plating thickness $d = 406.125\ mm^3/18{,}500\ mm^2 = \mathbf{0.022\ mm}$

27.2 (USCS units) A steel sheet metal part has total surface area = 40 in^2. How long will it take to deposit a 0.001-in-thick copper plate onto the surface if 12 amps of current are applied?

Solution: From Table 27.1, $C = 2.69 \times 10^{-4}$ in^3/A-min, cathode efficiency E = 98%.
Required volume of plate metal = 40(0.001) = 0.040 in^3
Plated volume $V = ECIt = 0.98(2.69 \times 10^{-4}$ in^3/A-min)(12 A) t = 0.00316 t in^3
0.00316 t = 0.040 t = 0.040/0.00316 = **12.64 min**

27.3 (USCS units) A batch of 75 parts is to be nickel-plated in a barrel plating operation. The parts are identical, each with a surface area A = 5.3 in^2. The plating process applies a current = 120 amps, and the batch takes 20 min to complete. Determine the average plating thickness on the parts.

Solution: From Table 27.1, $C = 1.25 \times 10^{-4}$ in^3/A-min, cathode efficiency E = 95%.
Volume $V = ECIt = 0.95(1.25 \times 10^{-4})(120)(20) = 0.285$ in^3
Area A = 75(5.3) = 397.5 in^2
Plating thickness d = 0.285/397.5 = **0.00072 in**

27.4 **(A)** (SI units) A batch of 40 identical parts is to be chrome-plated using racks. Each part has a surface area = 12.7 cm^2. If it is desired to plate an average thickness = 0.008 mm on the surface of each part, how long should the plating operation be allowed to run at a current = 100 amps?

Solution: From Table 27.1, $C = 2.5 \times 10^{-2}$ mm^3/A-s, cathode efficiency E = 15%.
Volume $V = ECIt = 0.15(2.5 \times 10^{-2}$ mm^3/A-s)(100 A)t = 0.375t mm^3
With Q = 40 pieces and average area per piece = 12.7 mm^2, total area A = 40(12.7) = 508 cm^2 = 50,800 mm^2
Plating thickness $d = V/A$ = (0.375 t mm^3)/(50,800 mm^2) = 0.0738(10^{-4}) t mm
Given that d = 0.008 mm, 0.0738 (10^{-4}) t = 0.008
Thus, t = 0.008/0.0738 (10^{-4}) = **1084 s = 18.07 min**

27.5 (USCS units) One hundred jewelry pieces, each with a surface area = 0.35 in^2, are to be gold-plated in a batch plating operation. (a) What average plating thickness will result if 8 amps are applied for 15 min in a cyanide bath? (b) What is the value of the gold that will be plated onto each piece if 1 oz of gold is valued at $1300? The density of gold = 0.698 lb/in^3.

Solution: (a) From Table 27.1, $C = 3.87 \times 10^{-4}$ in^3/A-min, cathode efficiency E = 80%.
Volume $V = ECIt = 0.80(3.87 \times 10^{-4})(8)(15) = 0.03715$ in^3
Q = 100 pieces and average area per piece = 0.35 in^2, total area A = 100(0.35) = 35 in^2
Plating thickness d = 0.03715/35 = **0.00106 in**

(b) Given density for gold ρ = 0.698 lb/in^3
Weight of plated gold = (0.698 lb/in^3)(0.03715 in^3) = 0.0259 lb = 0.415 oz
At $1300/oz, the total value of plated gold = $1300(0.415) = $539.50
The value per piece is $539.50/100 = **$5.40**

27.6 (USCS units) A low-carbon steel, sheet metal part with surface area = 118 in^2 is to be nickel- and chrome-plated. What total average plating thickness will result if the part is submersed in the nickel plating tank for 10 min at a current = 15 amps and then in the chrome plating tank for 12 min at a current = 75 amps?

Solution: From Table 27.1, $C = 1.25 \times 10^{-4}$ in^3/A-min, cathode efficiency E = 95% for nickel; and $C = 0.92 \times 10^{-4}$ in^3/A-min, cathode efficiency E = 15% for chromium.

Volume of nickel plate $V = ECIt = 0.95(1.25 \times 10^{-4})(15)(10) = 0.0178$ in^3
Nickel plating thickness = 0.0178/118 = 0.000151 in
Volume of chrome plate $V = ECIt = 0.15(0.92 \times 10^{-4})(75)(12) = 0.01242$ in^3
Chrome plating thickness = 0.01242/118 = 0.00011 in
Total plating thickness d = 0.000151 + 0.000105 = **0.000256 in**

Electroforming

27.7 (SI units) In an electroforming operation, determine the (a) the volume (cm^3) and (b) weight (g) of tin that is deposited onto a cathodic pattern if 45 amps of current are applied for 60 min.

Solution: From Table 27.1, $C = 4.21 \times 10^{-2}$ mm^3/A-s, cathode efficiency E = 90%.
Volume $V = ECIt = 0.90(4.21 \times 10^{-2}$ mm^3/A-s)(45 A)(60 min)(60 s/min) = **6138.2 mm^3**
V **= 6.1382 cm^3**
Density of zinc from Table 4.1 ρ = 7.15 g/cm^3. Weight W = 6.1382(7.15) = **43.88 g**

27.8 (SI units) The production of copper foil used in printed circuit boards is accomplished by an electroforming operation in which a slowly rotating titanium drum acts as the cathode to plate copper onto its surface (Section 34.2.2). The drum diameter = 500 mm and its width = 450 mm. At any moment during the process, 35% of the drum's circumferential surface area is submerged in the electrolytic bath (the ends of the drum are insulated to prevent plating). As the copper foil exits the bath, it is peeled from the drum surface. If the thickness of the foil = 0.04 mm on the drum surface when it is peeled, and the process operates at a current of 450 amps, determine the rotational speed of the drum.

Solution: From Table 27.1, $C = 7.35 \times 10^{-2}$ mm^3/A-s, cathode efficiency E = 98%.
Area of the drum = $\pi DL = \pi(500)(450)$ = 706,858 mm^2
50% of this area (submerged in bath) = 0.35(706,858) = 247,400 mm^2
As the drum rotates into the electrolytic bath, the plated copper thickness starts at zero and gradually increases to the exit thickness of 0.04 mm. Thus, the average thickness on the submerged surface of the drum = one-half the final thickness.
Average volume of copper plated V = 0.04(247,400)/2 = 4,948 mm^3
The volume of copper plated as a function of time:
$V = ECIt = 0.98(7.35 \times 10^{-2}$ mm^3/A-s)(450 A)t = 32.41t mm^3
32.41t = 4,948, so t = 152.65 s = 2.54 min
Surface speed of drum = πDN, = 500πN mm/min, where N = rotational speed, rev/min
The drum rotates 35% of its circumference in 2.54 min = 0.35(500π) = 549.8 mm
Surface speed = 549.8 mm/2.54 min = 216.1 mm/min
500πN = 216.1, so N = 216.1/500π = **0.1376 rev/min**