Chapter 25

Electroplating *

I. GENERAL

A. What Is Electroplating?

Electroplating is a process in which a metal is deposited onto a metallic substrate. The plated metal is normally of a thickness less than 0.002 in. and in most applications approximately 0.0001-0.0003 in. Metals are plated to afford the substrate properties that it would not otherwise have, such as improved corrosion resistance, aesthetic appeal, greater abrasion resistance, improved surface hardness, changed electrical characteristics, and adjusted dimension to tolerance, as well as imparting other desired properties.

The greatest use of plating is probably plating zinc on steel, thereby providing both a corrosion-resistant surface and one that is attractive in appearance. Such articles as nuts, bolts, washers, wire goods, castings, and numerous stampings are processed in this manner. Another extensive use of plating on steel is decorative chrome; this usually comprises a triplate of copper, nickel, and chromium. This finish has found widespread use on auto- motive and houseware applications where both a corrosion-resistant and an attractive surface must be provided.

Many metals other than steel are electroplated. Metal substrates, such as aluminum, brass, copper, and zinc, are plated to provide various desired properties.

Electroplating of plastic articles is finding increasing acceptance in industry. Items fabricated of molded plastics, such as automotive grilles, taillight assemblies, trim, and numerous household appliances, as well as plumbing fixtures, are being electroplated. A special process is required whereby the plastic part is metallized to make it conductive so that it can be plated to the desired finish.

The design engineer is able to select from numerous substrates to fabricate a part, considering such factors as strength, application, and cost. The part, once fabricated, can then be finished by electroplating or by other related processes to provide the desired properties and appearance.

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B. Fundamental Principles

The process used for electroplating is similar for all metals. The part to be processed is cleansed of all surface soil and then activated. The activated metal is placed immediately into plating solution where the actual electroplating is to be achieved. The exact plating cycle and various solutions used will vary somewhat depending upon the base metal and the type of plating to be done.

In the actual electroplating operation the parts to be plated are made cathodic in the plating solution. In a simplified operation these parts are suspended by a hook or wire (Fig. 25.1) from a cathode bar. Low-voltage direct current is supplied by a rectifier and is connected by a cable or buss bar to both the anode and cathode circuits in the plating tank. The anode and cathode bars are fabricated of copper and are positioned on, but insulated from, the tank rim. These bars are designed to carry the weights of the anodes and cathodes as well as to conduct the current that is applied.

The anodes are electrodes that are suspended in the plating solution. They are normally of the same metal that is to be plated, that is, copper anodes for copper plating nickel anodes for nickel plating. During the plating operation the anode dissolves to replenish the solution of metallic ions deplated by metal deposition on the cathode. This type of anode is known as a soluble anode. Certain situations, however, require an insoluble (inert) anode whose only purpose is to provide current to the electrolyte. Examples of typical insoluble anodes are carbon for certain processes and lead anodes for chromium plating. Insoluble anodes are used in situations where the electrolyte would dissolve the anode at a rate faster than the metal would be plated out of solution or in situations where the cost of a pure anode would be prohibitive.

During plating low-voltage direct current is supplied to the electrolyte by a rectifier. Generators are also used from time to time but have largely been replaced by the newer rectifiers (see Sec. IX). Depending upon the process, the current supplied by the rectifier is in the range of 6-12 V, with current density depending upon the surface area of the cathode. Typical current densities for many plating operations are 20-100 A/ft2 area to be plated. Hence a cathode area of 10 ft2 would require a rectifier capable of 200- 11000 A. In actual production plants, rectifiers with a capacity of 5000-20,000 A are quite usual.

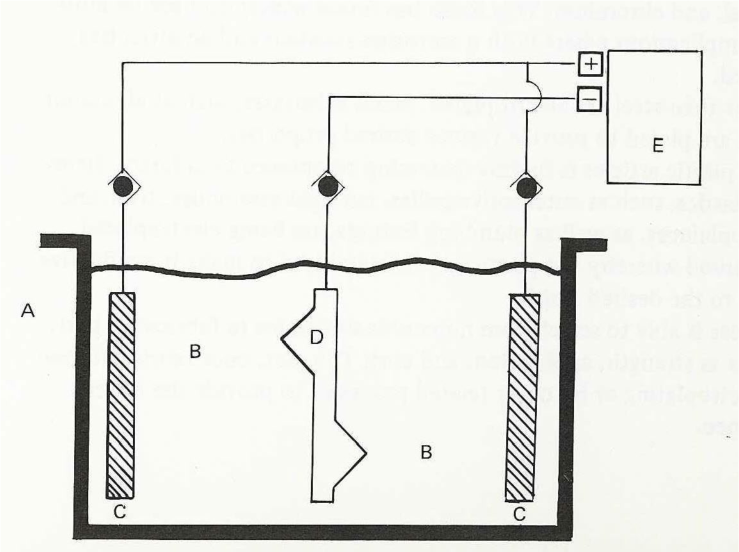

Fig. 25.1 Schematic diagram of a typical electroplating tank setup. Low-voltage direct current is supplied by a rectifier. (A) Plating tank. (B) Plating solution. (C) Anodes. (D) Cathode (work to be plated). (E) Rectifier

The plating solution, that is, the electrolyte, is generally an aqueous solution that contains dissolved salts of the metal to be plated and other chemicals as may be required. Some electrolytes are quite simple in nature and may contain as few as two ingredients. Acid copper plating, for example, uses a solution of only copper sulfate and sulfuric acid. Other electrolytes, however, may be quite complex. The solution for nickel plating may contain as many as six to eight ingredients, such as nickel sulfate, nickel chloride, boric acid, sulfuric acid, and wetting agents, as well as several organic addition agents.

These electrolytes are conductive media that allow the current to pass from anode to cathode. As direct current is applied to the anode (Fig. 25.2), metal is dissolved and ionized. The current causes these positively charged metallic ions to migrate toward the cathode, where they are reduced to the metallic state and deposited onto the cathode. For the most part the anode and cathode act independently of each other in the electrolyte. The simplified reaction also causes the migration of negatively charged ions to the anode where they are neutralized by the positive charge. By-products that are caused by this electrolysis include the release of oxygen at the anode and hydrogen at the cathode. Due to the complexity of some electrolytes numerous other side reactions may also occur.

Most plating electrolytes can be operated over an indefinite period of time and seldom if ever require discarding. As the plating process continues and various chemicals are consumed, replenishment is required in order to maintain the electrolyte within the prescribed concentration limits. The plating solution may become unbalanced during continued operation due to

1. Depletion of metallic ions
2. Incomplete reactions
3. Decomposition of ingredients
4. Drag-in from previous solutions
5. Drag-out of the plating solution
6. External contamination

Due to these factors it is important to have the electrolyte analyzed on a periodic basis with chemical additions or purification steps taken as may be required.

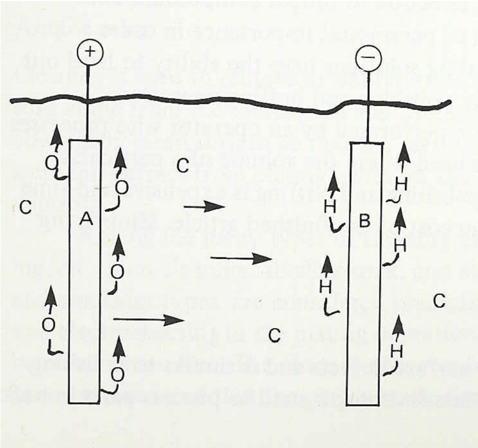

Fig. 25.2 Electrodeposition.
(A) Anode. (B) Cathode. (C) Electrolyte.

II. PREPARATION FOR FINISHING

A. Polishing and Buffing

Polishing and buffing are operations that are frequently performed on the workpiece prior to the plating operation. This is because after fabrication the article may contain numerous surface defects in the form of scale, pits, mold marks, grinding lines, tool marks, or scratches. These defects must be removed prior to plating if a satisfactory finished part is to be expected. The article is processed in the following sequence as may be required depending upon the surface defects that may be present.

1. Grinding
2. Polishing
3. Buffing
4. Electroplating

Grinding may be considered a machining operation; it is used to remove a substantial amount of metal from the surface. Grinding operations will generally leave the surface with a finish of 20 µin. rms or rougher.

Polishing is a continuation of the abrasion process; it is used to remove grinding lines as well as numerous other defects. Polishing is accomplished with either an abrasive belt or with a cloth wheel to which a suitable abrasive has been bonded. Polishing will also remove a substantial amount of metal from the surface but will leave the articles virtually free from undesirable defects. Common abrasives used in polishing include silicon carbide and aluminum oxide with grain sizes ranging from a #60 to #320 depending upon the amount of metal to be removed.

Buffing is also an abrasion process but with a much finer abrasive used. It has long been known that surface metal flow accompanies metal removal. The purpose of buffing is to produce a bright, smooth, and scratch-free surface, and it is used just prior to electroplating to provide a finished product of suitable surface quality. The buffing operation uses cloth wheels to which a compound is applied. These compounds usually contain glue or binder as well as an abrasive. The abrasives used in buffing may be similar to those used in polishing but are of a much finer particle size. Typical abrasives used in buffing range down to 8 µm particle size. The selection of proper compounds, abrasives, wheel type, wheel speed, and pressure is of paramount importance in order to pro- duce the desired finish. Some of the newer plating solutions have the ability to level out and cover surface defects, thereby avoiding the polishing and buffing operations.

Most polishing and buffing operations are performed by an operator who processes each individual part. Automated equipment is used where the volume of a particular run warrants the expense. For the most part polishing and buffing is expensive and time j consuming, thereby adding substantially to the cost of the finished article. Minimizing this cost is an important design objective.

B. Mass Finishing

Mass finishing is an operation used to remove surface defects and is similar to polishing and buffing in that it produces a like effect. Mass finishing is used to process parts in bulk as opposed to individual piece part operation. The parts to be processed are placed in either rotating barrels or in vibrating tubs. In addition to the parts, these vessels also con- an abrasive and a compound to produce the desired effect. Depending upon the abrasive used, a grinding, polishing, or buffing action may be achieved.

The only limiting factors in mass finishing are the size of the parts, their mass, and effect that sharp edges and other factors may have on other parts as they tumble or ate against each other and against the abrasive.

Where it can be used, mass finishing is a much less expensive way to remove surface defects than manual polishing and buffing. Generally used on smaller parts, mass finishing can lower costs by yielding higher productivity with decreased rejects.

III. PROCESSING CYCLES

After the article has been fabricated and has the desired surface finish it is ready for the plating operation. This operation comprises a number of steps that take the part through several sequences. These sequences and the solutions used will vary depending upon the finish to be applied. A typical sequence for zinc plating may be as follows.

Cycle	Operation
1	Load parts onto racks or barrels
2	Alkaline soak clean
3	Electroclean
4	Water rinse
5	Acid pickle activate
6	Water rinse
7	Zinc electroplate
8	Water rinse
9	Dry parts
10	Unload parts

In order to better understand the entire process each sequence is discussed individually.

A. Cleaning

Cleaning is used to remove unwanted soils, greases, and oils from the metal surface. These come from the fabrication and pre-finishing operations. The object is to achieve a chemically clean surface so that the plating deposit will adhere. Any residual surface will detract from plating adhesion and are a frequent cause of blistered and peeled deposits.

Among the many types of cleaning used today are solvent cleaning, vapor, degreasing, emulsion cleaning, alkaline soak, and electrocleaning. The first three, solvent, vapor, and emulsion types are considered pre-cleaners and are always followed by alkaline soak electrocleaning in the plating operation. A surface that is efficiently cleaned will water break free. The absence of water breaks will assure that all organic films have removed and that the part is ready for further processing.

Alkaline soak cleaning is used to remove most soils. The solution typically contains alkalis, phosphates, silicates, carbonates, soaps, and surfactants. Cleaning occurs by actions known as emulsification, saponification, and dispersion. Most soak cleaners are operated at a temperature of 150-2000p with the parts being immersed from 5 to 20 min.

After the bulk of the soil has been removed in the soak cleaner the parts are transferred to an electrocleaner. The electrocleaner serves the same purpose as the soak cleaner but to a much greater degree. In electrocleaning a charge is applied to the part much as in the plating operation. The charge, anodic for reverse cleaning and cathodic for direct cleaning, causes either oxygen or hydrogen to be released from the solution. The gas has a micro scrubbing action. The chemical composition, operating times, and temperatures are similar to those used in soak cleaning. Typical current densities for electrocleaning are 40-70 A/ft2 of surface processes.

In alkaline soak or direct or reverse electrocleaning, care should be exercised in selecting the cleaner formulation as well as the operating parameters. This is necessary so as to provide a chemically clean part while not degrading or eroding the base metal. During operation the cleaning solutions become saturated with oils and soils. This contamination necessitates either replenishment with fresh cleaner or replacement from time to time of the entire cleaning solution. Numerous plating defects have been traced to a cleaner that has not been maintained at the concentrations and/or parameters that were specified.

B. Activation

After the part has been thoroughly cleaned it must be activated prior to plating. This activation is accomplished by various acid solutions and is frequently termed "pickling." The purpose of activation is to remove oxides and scale from the metallic surface. These oxides are formed during fabrication, heat treating, handling, and storage of the parts. Steel and other metals will form a thin oxide layer during such handling and storage. Heat treating will cause a more severe form of oxide known as scale.

The acid solutions commonly used are sulfuric, hydrochloric, nitric, and hydro- fluoric or mixtures of these acids. The selection of the proper acid, dipping time, and temperature is dependent upon the metal being processed and the thickness of the oxide layer. Typical pickling acid formulations for a mild oxide condition on steel parts are as follows.

1. Hydrochloric acid, 20° Baume, at a concentration of 50% by volume. A temperature of approximately 700p is used for 2-15 min.
2. Sulfuric acid, 66° Baume, at a concentration of 15% by volume. A temperature of approximately l200p is used for 2-15 min.

When activating metals with acids it is desirable to set the operating parameters so as to remove all oxide while not over-pickling, which, will remove excessive metal and can frequently cause smutting of the surface. Parts that are heavily scaled will require the use of an inhibitor (typically, an organic amine) in the acid solution. The purpose of an inhibitor is to provide a better wetting action to the acid, which helps dissolve and remove scale while slowing the acid attack on the fresh and exposed metal surface. Such inhibitors can effectively permit removal of scale while preventing the formation of smut or excessively removing metal.

C. Electroplating

After the parts are cleaned and acid activated they are ready for electroplating. The surface is rinsed in water and the part placed immediately into the plating solution. A fast transfer time is required here so that re-formation of an oxide layer is prevented.

Direct current electricity is then applied to the electrolyte, as shown in Fig. 25.2. The current is continued for a predetermined period of time until the desired amount of metal is deposited upon the cathodic workpiece.

The current is measured in amperes, coulombs, or faradays. A deposit of 1 g equivalent the metal will be deposited for each faraday. The equivalent weight equals 1 g weight divided by the valence of the metal. The valence is determined by the number of charges that the metal ion has. A faraday is a unit of electricity and is equal to 96,500 C (or ampere-seconds). Table 25.1 shows the amount of metal deposited at 100% efficiency. In order to determine the deposit thickness that will be achieved it is also important to consider the current distribution and the cathode efficiency.

A proper distribution is achieved when the anodes and cathodes are positioned in such a way as to have the current flow be uniform across the entire cathode surface. Area of a part, such as a protruding corner, that are closer to the anode than other areas will receive a higher current density and consequently a thicker deposit. Proper positioning and masking in the plating solution will alleviate this problem so that a deposit of uniform thickness is achieved. In most cases a current efficiency of 100% is not achieved. The cathode efficiency is the percentage of current that deposits metal. The balance of the current is consumed in parasitic actions, such as evolving hydrogen at the cathode surface. When the cathode efficiency is known the plating rate (grams of metal per unit area per unit time) can be calculated as follows:

$$\text{Plating rate} = \frac{\text{gram equivalents metal}}{\text{Area X time}}$$

$$= \frac{\text{faraday X \%efficiency}}{\text{Area X time}}$$

The plating engineer is also concerned with other features of the deposit. Metallurgical factors, such as hardness, residual stress, hydrogen embrittlement, and brightness, considered. Frequently agents are added to the plating solution in order to modify the deposit that would normally be obtained. By controlling the bath composition, the choice and concentration of addition agents, current density, and temperature, the plater is usually able to obtain deposits with the desired properties.

Metal	Valence	Atomic weight	Grams deposited per faraday
Cadmium	2	112.41	56.21
Chromium	6	52.01	8.67
Copper	1	63.57	63.57
Copper	2	63.57	31.78
Gold	1	197.20	197.20
Nickel	2	58.71	29.36
Silver	1	107.88	107.88
Tin	4	118.70	29.67
Zinc	2	65.38	32.69

D. Rinsing and Drying

After each step in the processing cycle the chemical film that remains on the workpiece surface must be rinsed off with suitably clean water. Certain parts may have areas that trap solution; these areas must be thoroughly rinsed. It is important to remove all chemicals from the surface prior to the next sequence in processing. This is to avoid unwanted reactions on the surface as well as to avoid solution contamination.

Water rinsing is normally done in a tank in the processing line. At least one rinse tank is used following each process. Frequently several rinse tanks are used for double or triple rinsing. Multiple rinses are used where a high work flow tends to contaminate the first rinse quickly. In multiple rinsing each rinse dilutes the surface film further until contaminants are removed to a tolerable level.

There are several types of rinse tanks, but they generally fall into two categories: running and still. A running rinse has a continuous supply of water to the tank and over- flows. This is used in high-production lines to keep the rinse water at a level of purity sufficient to avoid contamination of the next tank. Still rinsing has no water flow and is used only for small production runs.

To economize on water costs a conductivity controller is commonly used to control the contamination level in the rinse tank. With this device inlet water flows only when required to keep the tank water at the desired purity. For further water economy a cascade rinse is used in a mu1tibay tank. In a cascade rinse the water flows over and under baffles separating each bay so that it is used several times. Flowing water is used in the last bay with an overflow in the first bay. The work flow is opposite to the water flow so that the emerging work is rinsed by the purest water in the last bay.

Several methods of improving rinsing efficiency are used, such as heated water and air agitation. Merely submersing a part is not sufficient to maximize the rinsing operation unless contact is maintained for a long period of time. Warm water tends to dilute the surface film much quicker. By agitating the water with air the films are more quickly diluted. Spray rinsing directly over the process tank is frequently employed as a method of water conservation. A spray rinse will remove approximately 80% of the surface film and return the chemicals directly back into the process tank. Spray rinsing should be followed by normal tank rinsing to remove the balance of the surface film.

Today the e1ectrop1ater is concerned with regulations for pollution control. These regulations limit the amount of certain chemicals that may be discharged. A high-production plating line is capable of discharging substantial amounts of these controlled chemicals from the rinsing operations. This, coupled with high water costs, frequently dictates that a controlled water volume be used.

At the completion of the entire process and the final water rinse, the parts should be thoroughly dried. Complete drying is necessary if staining and rusting are to be prevented. All moisture should be removed from the surface as well as from recesses and crevices. Heated as well as forced air from a fan or blower is commonly used to effect complete drying. Other techniques include drying by absorption with ground corncobs. This is used frequently on small parts. Centrifuges and infrared equipment are also employed for drying certain parts.

IV. FACTORS IN PLATING

A. Electrode Position

Electricity follows the path of least resistance. Consequently, areas of a part that protrude, edges, and parts closest to the anode will receive the most current. These areas tend to have the thickest deposit. It is normally desirable to have a uniform deposit thickness across the entire part. Recesses or areas farthest away from the anode, on the other hand, will tend to have the thinnest deposit. Arranging the parts so that all areas approximately the same distance from the anode will maximize current distribution provide a uniform deposit. Figures 25.3 and 25.4 show this relationship. In some cases, however, it is impossible to arrange the parts in the most desirable position. In these situations a shield or "robber" can be used to obtain the proper distribution.

A shield is an inert material that is not electrically conductive. It is placed between anode and the cathode to redirect the current flow. Figure 25.5 shows the proper of a shield.

A robber is a conductive metallic article that is plated along with the workpiece. It is positioned in such a manner as to steal current from an area where it is not wanted. A robber will receive a deposit, as will the cathodic workpiece. Figure 25.6 shows the use of a robber.

Inasmuch as robbers receive a deposit, this represents a waste of valuable plating at. They also have to be stripped occasionally so that excessive buildup is avoided. These factors normally make the use of robbers expensive and unpractical. It is for this on that shields are in greater use for parts with troublesome areas.

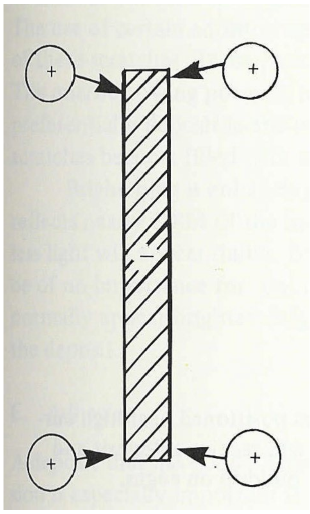

Fig. 25.3 Poor arrangement of electrodes favors deposition on edges.

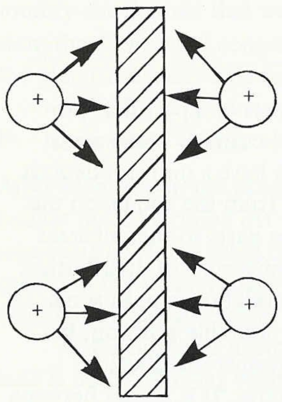

Fig. 25.4 Proper arrangement of electrodes favors a uniform deposition.

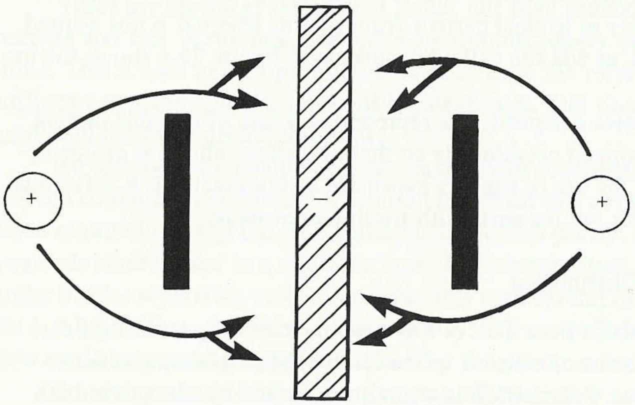

Fig. 25.5 The use of a shield directs the current flow.

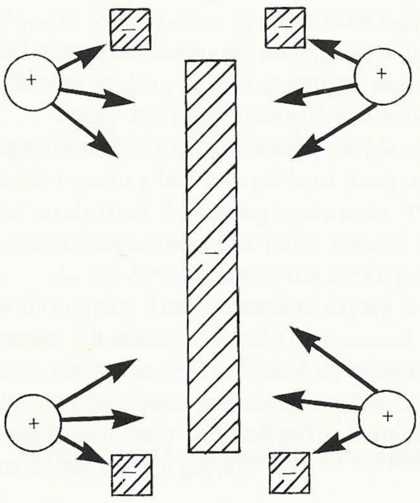

Fig. 25.6 Robbers positioned near high current density areas will receive a deposit and prevent unwanted buildup on edges.

B. Polarization and Current Distribution

Polarization is a term that explains the effect of a change in electrical potential of a plating solution. Normally it is not of concern to the electroplater unless a problem lops in the solution balance. Polarization is a condition caused by changes in bath concentration or changes within either the anode or cathode films. It is caused by the movement and discharge of ions. It is a force that is measured by a drop in voltage for a given ampere setting. Polarization is always present during electrolysis of a solution but is of concern when its effect becomes excessive. It can be caused by a depletion of near the electrode surface, as in concentration polarization, or resistance polarization which is caused by the formation of a diffusion layer surrounding the electrode. Polarization can be alleviated by the use of agitation in the plating solution. This maintains a uniform composition throughout the solution and consequently minimizes the effect of polarization. Current distribution at the beginning of the electroplating process prior to the onset of polarization changes during the first second or two of the current flow to the current distribution that prevails during the rest of the electroplating process. This distribution is more uniform along the cathode surface and tends to even out deposit buildup on edges and the center area of parts.

C. Throwing Power

Throwing power is the ability of an electrolyte to deposit metal of a uniform thickness across a cathode surface. This term is not to be confused with covering power, which is the ability of an electrolyte to deposit metal across an area regardless of thickness distribution. The two types of throwing power are micro and macro.

Microthrowing power is the ability of a bath to plate into small surface scratches, thereby filling them up with the deposit. A solution with good microthrowing power will to level out surface imperfections and provide a smoother surface. Microthrowing is affected by polarization. Where polarization is increased by the use of addition agents, metal will tend to deposit into surface imperfections and thereby produce a higher quality deposit.

Macrothrowing power is the ratio of deposit distribution in relation to the distance from anode to cathode. The area of a cathode that is spaced close to the anode would normally receive the thickest deposit, whereas the area farthest from the anode would receive the thinnest deposit. An electrolyte with 100% throwing power will deposit a uniform thickness regardless of anode to cathode spacing. As before, polarization is responsible for controlling this macrothrowing power.

D. Leveling and Brightening

As mentioned previously, leveling is the ability of an electrolyte to deposit metal so as to smooth out surface scratches and imperfections by filling them up with the deposit. The use of certain addition agents in the plating solution causes polarization at the peaks of these scratches. These peaks are high current density areas on a microscopic scale.
The microthrowing power is improved by these additives, and the deposit is caused to preferentially deposit in the valley of the scratches. As the plating continues these scratches become filled with metal and a leveled surface result.

Brightening is enhancing the ability of a deposit to reflect light. A deposit that reflects nearly 100% of the incident light will appear bright, whereas one that reflects less light will appear duller. Brightness is important in decorative applications and may be of no importance for functional applications. Although a deposit that is leveled will normally appear brighter, brightness is more a function of the crystalline structure of the deposit.

E. Adhesion

A deposit that has good adhesion will not peel or flake from the substrate. Good adhesion is especially important if the part is to be formed, bent, or stamped after electroplating. Adhesion is usually related to the activation prior to plating. A part that is cleaned and activated properly will exhibit good adhesion.

F. Deposit Growth

As the electroplating process continues and the deposit becomes increasingly thicker there is a tendency to produce growths around edges and other high current density areas. These undesirable growths are commonly termed "trees" or "nodules."

Trees are a deposit growth, normally forming around edges. They are quite angular and actually appear as a tree with its many branches. They are caused by local high current density accompanied by growth of the metal. A tree has a very thin structure; it will break off if touched and may cause a pinhole at its base. A nodule is a rounded bumpy kind of deposit that is usually more firmly attached due to the larger size of the base. Nodules do not usually pose a problem as regards adhesion but they are not desirable; a quality deposit should be smooth and nodule free. Trees and nodules are usually associated with thicker deposits of 0.0005 in. or more. They can, however, be present with thinner deposits if the plating electrolyte is not in proper balance. The use of certain addition agents in the plating bath is quite common to prevent trees and nodules from forming even with deposit thicknesses exceeding 0.005 in.

V. DESIGN CONSIDERATIONS

Plating and other finishes are usually last in the manufacturing process; frequently the effect of part design on finishing is totally overlooked. A part is frequently designed and specified in a way that adds considerable cost to the finishing step.

Whenever plating is specified the design engineer should identify the "significant surfaces" of a part. A significant surface receives a deposit of specified quality, that is, thickness, brightness, coverage, durability, and so on. A significant surface on a decorative part such as an automotive bumper or grille is the area normally seen by the consumer. A significant surface for engineering applications is the area that gives a part the particular properties the engineer needs for specified function. An example of a significant surface on engineering applications is the journal of a crankshaft plated with hard chromium. The journal is the bearing wear surface and, therefore, is a significant surface. The adjacent web area is of no concern for electroplating. Hence, the journal area is the only significant surface and should be specified to be l00% covered with a high -quality deposit.

When designing a part to be electroplated the engineer should consider the following.

1. Racking points
2. Drainage of the part
3. Air entrapment
4. Plating distribution

Racking is the method used to suspend a part through the various steps of the plating process. A place should be provided where electrical contact can be made on an insignificant surface. This racking point will not usually receive as good a deposit as the other areas due to the effect of having a conductor near the surface to be plated.

Drainage of the part for proper rinsing should also be considered. Frequently a part will have inside corners or curved surfaces that may trap the solution. This is undesirable and should be avoided whenever possible. When these corners and curved areas are necessary from a design standpoint, they present a significant problem to the electroplater. This problem can, however, be alleviated by placing a hole in the lowest position of that area so that good drainage can be accomplished.

Air entrapment is a problem of concern when racking of the part is considered. If a cupped area is positioned in the solution in such a manner that it will trap air, it is obvious that solution cannot contact that particular area. Solution contact is necessary the part is to be processed properly. Proper racking or placement of a hole will alleviate this problem and ensure a quality deposit.

Plating distribution is also of consideration to the design engineer. As mentioned previously, a part protrusion will tend to receive a greater deposit thickness than a recessed area. Complex shapes are always more costly to electroplate than are simple shapes.

The following guidelines should be followed, whenever possible, in designing a part to assure platability.

1. Avoid sharp or protruding edges. All edges should be rounded to a radius of 1/32 in. or more.
2. Inside corners should have as large a radius as is possible.
3. Slots, grooves, and concave recesses should have a depth no greater than one- half the width.
4. Blind holes should be avoided wherever possible. If they cannot be avoided the depth should be no more than one-half the width.

5. Perfectly flat areas should be avoided. Preferably a concave or convex surface should be provided.

VI. PROCESSING METHODS

There are several methods of processing available to the electroplater. They include rack, 1, basket, barrel, basket, and brush plating. Either automated or manual methods can be used depending upon the volume of work to be processed at one time.

A. Rack Processing

A plating rack is a device that holds the part in a fixed position during the plating cycle. It connects the part electrically via the bus bar to the dc power supply. The plating rack is usually fabricated of copper with phosphor-bronze contact tips to hold the workpiece. The rack is then coated with a plastisol to prevent the various solutions from corroding copper spines; the tips are left bare so as to make electrical contact with the part.

Racks should be designed so that the parts are held in a proper position with respect to the processing limitations that were previously discussed. The weight, volume, current requirement of parts to be processed at one time must also be considered when designing racks. The top of the rack is normally fabricated to form a hook. It is this hook and contact point that rest on the copper bus bar for electrical contact. The hook must be designed so as to assure a constant current flow. Plating racks are normally used for large parts that cannot be processed by other means. Due to the necessity for manually loading and unloading, the rack method is usually the most expensive.

B. Barrel Processing

Barrel processing is used for plating small parts in bulk. As a rule bulk processing is much less expensive than manually racking the parts. Items such as nuts, bolts, screws, washers, and other small parts can be effectively processed in barrels. These parts can be loaded in quantities of up to 250 lb in appropriately sized plating barrels.

Most plating barrels are of the horizontal type and are six sided. A removable door on one side allows for the loading and unloading of the parts. These barrels are now usually fabricated of polypropylene, thus providing strength to withstand the various loads, as well as, chemical resistance to the various solutions at the operating temperature. Plating barrels are perforated with small holes on the sides to allow for circulation of the electrolyte and electrical contact with the work inside. Electrical contact is made by flexible danglers through the side that touch the load inside. Plating barrels are either of the fully or partially submerged variety and are rotated slowly so that the load of parts is constantly in motion and all surfaces are coated with electrolyte and make contact electrically.

Due to the restriction of electrical flow, plating speed is slower with barrel processing than it is for rack processing. The larger volume of work with less labor usually makes barrel processing more economical for overall plating of small parts.

C. Basket Processing

Basket processing is similar to barrel in that the parts are processed in bulk. A conductive metallic basket is generally used. The basket is suspended by a hook from the cathodic bus bar. Basket processing is a manual operation due to the necessity of periodic shaking or mixing the load of parts so that all surfaces make contact and receive a uniform deposit. Due to higher labor requirements basket processing is not widely used in practice today. It has been almost entirely replaced by the more efficient barrel processing method.

D. Brush Processing

Brush plating is used for localized or selective plating. A normal plating tank is not used since the parts are either overly large or disassembly and removal of the part would be cost prohibitive, such as where a repair of plating is required.

A brush plating setup consists of a small dc rectifier, an ammeter, and a portable hand-held anodic brush wrapped with a material, such as cotton, nylon, or dynel, that absorbs the plating solution. The plating solution can be applied to the brush either by dipping or by pumping it through a hollow core. The part is made the cathode by a suitable electrical connection.

The brush containing the plating solution is manually moved over the entire surface to be plated until the desired thickness is achieved. Brush plating requires the same cleaning and activation steps that are used in more conventional methods. This cleaning and activation are, however, done manually.

Brush plating can be done on such substrates as steel, copper, or the stainless steels. It is not recommended for the more active substrates, such as aluminum, magnesium, or titanium, because they cannot be activated properly manually and poor adhesion can be expected. Brush plating is not economical for any considerable number of parts. It is only used on a one of a kind job, usually of large size, and one that may be plated in place without total disassembly.

VII. ELECTROPLATED METALS

A. Zinc and Cadmium

Zinc and cadmium are generally plated on iron and steel substrates. These metals are primarily as a protection against corrosion because they provide a sacrificial coating, thus providing galvanic protection to exposed surfaces. As long as the coating of zinc or cadmium remains on the part it will tend to corrode prior to the ferrous substrate. Corrosion products of zinc tend to be white and frequently form a crust like structure. Cadmium, on the other hand, does not form crust like corrosion products.

Cadmium is used extensively in military and aircraft applications where it shows excellent effectiveness in a marine environment (high humidity and salt content). Recent federal regulations have virtually prohibited the use of cadmium for other applications due to the toxicity of the metal in industrial waste discharges.

Zinc is the most commonly plated metal for protecting iron and steel against corrosion. It is used extensively for nuts, bolts, screws, washers, springs, castings, and stamping. Zinc is also much less costly than is cadmium.

Both zinc and cadmium have a white or bluish-white color. In the case of both metals, the use of addition agents in the plating bath will provide an extremely bright deposit that resembles chromium in appearance.

Acid, alkaline, or cyanide baths can be used for plating these metals. Acid baths are used where effluent treatment is of prime concern and where a leveled deposit is desired. Alkaline and cyanide baths are used where throwing power is of prime importance. The use of an alkaline or low-cyanide bath has the added advantage of lower waste treatment costs.

Typical bath formulations are as follows.

1. Zinc Plating Baths

a. Acid Formulation

Zinc sulfate	120 g/liter
Potassium chloride	55 g/liter
Boric acid	5 g/liter
Addition agent	1/2-2% by volume
pH	3.5-4.2
Temperature	18-30°C
Cathode current density	50-80 A/ft2 (540-864 A/m2)

b. Alkaline Formulation

Zinc metal	15 g/liter
Sodium hydroxide	90 g/liter
Sodium carbonate	40 g/liter
Addition agent	1/4-1/2% by volume
Temperature	25-30°C
Cathode current density	5-80 A/ft2 (54-864 A/m2)

c. Low-Cyanide Formulation

Zinc metal	109/liter
Free sodium cyanide	109/liter
Sodium hydroxide	75 g/liter
Sodium carbonate	40 g/liter
Addition agent	1/4-1% by volume
Temperature	20-40°C
Cathode current density	2-100 A/ft2 (21.6-1076 A/m2)

d. Full-Cyanide Formulation

Zinc metal	20 g/liter
Free sodium cyanide	35 g/liter
Sodium hydroxide	75 g/liter
Sodium carbonate	15 g/liter
Addition agent	1/4-1 % by volume
Temperature	20-40°C
Cathode current density	2-100 A/ft2 (21.6-1076 A/m2)

Although the acid formulation can plate all ferrous substrates and has a higher plating speed, the equipment for the acid bath is a good deal more expensive; the bath needs more care and attention in order to consistently produce quality deposits; and the parts being plated must be immaculately cleaned. The alkaline and cyanide baths, on the other hand, cannot plate malleable and cast iron directly. These baths, however, are capable of plating for long periods of time without purification, are less expensive to operate, and are the "workhorse" baths of the industry.

2. Cadmium Plating Bath

Cadmium metal	25 g/liter
Total sodium cyanide	130 g/liter
Sodium hydroxide	20 g/liter
Sodium carbonate	15 g/liter
Temperature	20-35°C
Cathode current density	5-80 A/ft2 (54-864 A/m2)

Both cadmium and zinc coatings are normally protected with an immersion chromate conversion coating after plating. This chromate coating provides additional corrosion protection. The thickness for most applications of zinc and cadmium is normally 0.0002-0.0005 in. Deposits thicker than this are used only for engineering applications.

B. Decorative Chrome

Chromium is a bluish-white metal that is quite lustrous in appearance. In itself, chromium is resistant to corrosion in most atmospheres but tends to form microscopic cracks due to stress. This exposes portions of the base metal to corrosive environments. Hence, decorative chrome is almost always plated on top of either nickel or nickel plated on copper. These underlying layers of copper and nickel are used to seal off the substrate so that the microcracked chrome deposit does not become an avenue for corrosion.

Decorative chromium deposits are used on such items as automobile bumpers and trim, household appliances, furniture, and many other articles that require a bright and aesthetic appearance. The customary thickness for decorative chromium plate is 0.000020-0.000070 in. The total deposit including the copper and nickel underlayers is, however, approximately 0.0005 in. thick.

The current efficiency of chromium plating baths is quite low, usually being approximately 15-20%. The metal is plated at conventional speeds by the use of high current densities.

A typical formulation for a decorative chromium bath is as follows.

Chromic acid	180 g/liter
Sulfate	1.5 g/liter
Catalyst A	1.5% by volume
Catalyst B	15 g/liter
Temperature	35-50°C
Cathode current density	20-400 A/ft2 (216-4320 A/m2)

The catalysts used in the bath promote deposition at higher speeds, greatly increase the throwing power, and tend to activate the sometimes passive nickel underlayer. However, chromium baths, in general, tend to have very poor throwing power; the deposits may appear burned on the edges, and there may be discoloration or lack of plating in the very low current density areas. These problems are overcome with proper racking techniques and anode control, as well as maintaining the optimum bath composition. These quality control techniques together with use of proper catalysts will produce a remarkable deposit of exceptional luster over the entire area.

C. Hard Chromium

Chromium is the hardest of the most commonly deposited metals. Hard chromium is used as a wear-resistant coating not only on steel but also on a wide variety of other metals. Hard chromium differs from decorative chrome not only in use but also in the large difference in deposit thickness. As noted previously, a decorative chrome deposit is quite thin, but a hard chrome deposit is 0.005-0.0100 in. thick. Typical deposits to provide a good wearing surface are 0.0050 in. thick.

Hard chrome deposits are referred to as "industrial" or "engineering" chrome due to the use of the parts. Typical deposits have a hardness of 64-72 Rc. Besides being resistant to abrasion, hard chromium provides corrosion protection, has a low coefficient of friction, and has high heat resistance as well as anti-galling properties. For this reason hard chrome is used on such parts as aircraft landing gears, bearing surfaces, cutting tools, dies, drills, engine cylinders, hydraulic shafts and pistons, molds, piston rings, and seats. The hardness of the metal is the same in hard chromium as for decorative chrome. The hard chromium appears to be harder due to its greater thickness. However, a deposit of at least 0.002 in. must be used before the intrinsic chromium hardness appears instead of reflecting that of the base metal.

Hard chrome is also frequently used as a buildup metal for expensive worn parts, such as large shafts and molds. Reclaiming worn dimensions with hard chrome is frequently easier and less expensive and provides a better wear surface than other methods. The most common application for hard chrome, however, is on new parts to protect the surface against wear.

The plating efficiency for normal hard chromium baths is quite low, 18-25%. Due to this low efficiency as well as the fairly thick deposits used, a knowledge of plating speeds is essential as many parts are plated directly to size.

The following chart illustrates typical speeds for several baths.

Bath type	Rate of deposit per hour at 2 A/in.2
Standard bath.	0.0006 in
Nonfluoride proprietary	0.0008 in.
High-speed bath	0.0012 in.

To understand hard chrome plating it is essential to have a knowledge of these three main bath types.

Standard bath	
Chromic acid	250 g/liter
Sulfate	2.5 g/liter
Temperature	55°C
Cathode current density	300 A/ft2 (3240 A/m2)

Nonfluoride proprietary	
Chromic acid	150-190 g/liter
Sulfate	1.4- 1.8 g/liter
Catalyst	1.5% by volume
Temperature	48-65°C
Cathode current density	150-700 A/ft2 (1620-7560 A/m2)

High-speed bath

Chromic acid	150-190 g/liter
Sulfate	0.90-0.11 g/liter
Fluoride catalyst	1.5% by volume
Temperature	48-65°C
Cathode current density	150-1200 A/ft2 (1620-12960 A/m2)

The catalysts used, both fluoride and nonfluoride, allow use of a lower chromic acid concentration thereby affecting a considerable cost saving as well as allowing for a wider temperature and current density range. These catalysts also greatly improve such metallurgical properties of the deposit as hardness, crack structure, and wearability. The use of a fluoride catalyst greatly improves these properties while also providing the fastest plating speed. A disadvantage is, however, that a fluoride-containing bath is extremely corrosive to the parts being plated. The presence of the fluoride ion promotes etching the base metal in bare and unplated areas. For this reason all unplated areas must be masked with either paint, plastic, tape, or wax to keep them from contact with the electrolyte.

Chromium plating baths are known to have inherently poor throwing power. Hence, conforming anodes are frequently used on parts with any kind of an intricate shape. These anodes are spaced approximately 1/4-1 in. away from the part and conform exactly to the surface configuration. With this type of anode it is possible to plate a uniform thickness over the entire part area.

The anodes, whether they be of the conforming or tank type, are made of a lead alloy. A chromium anode is not used for two reasons: (1) chromium would dissolve faster than it is plated out so the bath would continually increase in chromium concentration, and (2) a lead alloy anode has properties that keep the trivalent chromium ion at proper levels of concentration. A typical anode alloy is 7% tin and 93% lead. This alloy provides the best conductivity and oxidation properties. Long (more than 6 ft) anodes, or configurations that may tend to sag must be fabricated of 6% antimony and 94% lead, which provides additional rigidity. During plating the anodes tend to form a crust or scale that has insulating properties. This scale must be removed in a strong alkaline solution periodically so that it is able to conduct the proper current.

Due to the hydrogen that is co-deposited with the chromium, the hard chrome coating tends to form a microcracked structure. This cracking does not deter good adhesion and is in many ways an advantage. In bearing usage these cracks tend to fill with oil or lubricant and provide a low coefficient of friction. With variations in either the catalyst type or concentration it is possible to modify crack formation to serve particular design applications.

All hard chrome deposits tend to reduce the fatigue limit of parts. Shot peening of steels harder than 40 Rc prior to plating is a common method of minimizing this effect arid prolonging the life of the part.

In summary, hard chromium is an excellent coating for metals when properly applied for engineering applications.

D. Copper

Copper is a corrosion-resistant, ductile, and highly conductive metal. It is resistant to non- oxidizing acids but is susceptible to oxidation, forming green, brown, and black products.

For decorative applications, copper is used as an undercoat for nickel and chromium. It is also used for "antiqued" parts where it is intentionally oxidized to obtain a desired color. In industrial applications, copper is used as a stop-off for heat treating and in other specialty uses. Copper plating is also frequently used on zinc-based die castings as the initial coating as it has a tendency to tend to cover the pores in the die casting.

Copper is plated from an acid, cyanide, fluoborate, or pyrophosphate bath. The latter two are used primarily on circuit boards for improved conductivity. Both the acid and cyanide baths are used extensively for decorative and industrial applications.

Typical bath formulations are as follows.

1. Acid Bath

Copper sulfate	150-250 g/liter
Sulfuric acid	45-100 g/liter
Addition agent	3/4 to 2% by volume
Temperature	20-50°C
Cathode current density	20-150 A/ft2 (216-1620 A/m2)

2. Cyanide Bath

Strike plating

Copper cyanide	26 g/liter
Free sodium cyanide	15 g/liter
Sodium hydroxide	04 g/liter
Sodium carbonate	15 g/liter
Addition agent	1/4-1% by volume
pH	10.0-12.5
Temperature	45-55°C
Cathode current density	5-100 A/ft2 (54-1075 A/m2)

High-speed bath

Copper cyanide	75 g/liter
Free sodium cyanide	23 g/liter
Potassium hydroxide	23 g/liter
Sodium carbonate	15 g/liter
Addition agent	1/2-2% by volume
Temperature	60-80°C
Cathode current density	density 2-90 A/ft2 (21.5-967.5 A/m2)

The strike bath is used as an initial coating on steel parts and always precedes the acid bath. This is due to the fact that a deposit from the acid bath directly on steel may have poor adhesion due to precipitation plating.

The use of addition agents in both the acid and cyanide baths can provide full bright deposits that have the appearance of being buffed.

E. Nickel

Nickel is a moderately hard metal; it has good thermal properties and is fairly corrosion resistant**.** It is for these reasons that it is used extensively as an undercoating for decorative chromium. Although a chromium top layer may be porous, a nickel undercoat is continuous and makes a highly corrosion-resistant system. Nickel, however, will tarnish in urban atmospheres and, hence, must be coated with chromium for decorative applications. The nickel coating is probably the most important layer in the decorative copper- nickel-chromium plating process. The copper plate may be omitted entirely without appreciably affecting the corrosion resistance or quality of the final coating.

Nickel is also used extensively in electroforrning where an intricate mold or other part is fabricated entirely by electroplating.

There are numerous baths currently used for nickel plating. The leveling-watts type is, however, the most widely used. It is formulated as follows.

Nickel sulfate	300 g/liter
Nickel chloride	60 g/liter
Boric acid	45 g/liter
Wetting agent	1/4-1/2% by volume
Brightening agents	1/2-3% by volume
Leveling agent	1/8-1/4% by volume
pH	3.8-4.2
Temperature	60°C
Cathode current density	10-100 A/ft2 (107.5-1076 A/m2)

The wetting agent prevents pitting of the deposit from the evolution of hydrogen gas and bath contamination. Brightening agents, both primary and secondary, are used to refine the grain structure and promote brightness. Leveling agents are also used to improve the micro throwing power, thereby promoting fast brightening with minimal cost. This bright nickel bath requires frequent maintenance in terms of purification in order to consistently produce quality deposits.

Other nickel baths include a standard watts type, similar to the above formula, without the use of addition agents. It is used for engineering applications. A nickel strike bath that uses nickel chloride almost exclusively is used as a preplate on passive metals, such as stainless steel.

F. Precious Metals

Precious metal plating takes into account such metals as silver, gold, rhodium, platinum, and palladium, as well as other less common metals. Precious metals, such as silver and gold, are commonly used for aesthetic purposes, as on jewelry. They are also, as are all precious metals, finding increased use in industrial applications. Most precious metals have good chemical and physical properties, excellent electrical conductivity, and low contact resistance. By far the largest application of precious metal plating is in the electronics industry, where the conductivity of the metals is of prime importance. Table 25.2 lists these metals and their basic characteristics. These properties differ greatly among the precious metals. For each specific application, each metal should be studied in detail in order to select the best combination of properties.

Table 25.2 Precious Metals Used for Plating

Metal	Applications	Properties
Silver	Electrical, jewelry	Semioxidation resistant
Gold	Jewelry, dental, electrical	Oxidation resistant
Rhodium	Electrica	High-temperature resistant
Platinum	Jewelry, electrical	Oxidation resistant
Palladium	Electrical	Forms reactive oxide

These precious metals are plated from an acid, cyanide, or neutral bath, each having its own advantages.

G. Other Metals and Alloys

Such metals as cobalt, iron, lead, and tin, as well as common alloys, such as brass, bronze, 'and tin-lead, are frequently plated in order to obtain the specific properties each may have to offer.

Cobalt is very similar to nickel in its color and properties. It is, however, very much more expensive than is nickel. Cobalt is rarely plated by itself but is commonly alloyed with nickel, tungsten, molybdenum, gold, and phosphorus to provide desired features to the deposit.

Iron plating is used for buildup of ferrous substrates, where advantage can be taken of its properties as well as its low cost. Only a few practical applications of iron plating are in use today as other metals offer numerous advantages.

Lead is used somewhat for corrosion protection but more frequently for bearing applications. Lead has a low melting point and is somewhat resistant to non-oxidizing acids. Lead tends to quickly oxidize on the surface, thereby protecting the underlying metal structure. The most common application for lead is in the bearing industry, where it is plated as an alloy with tin, antimony, and bismuth to provide desirable properties.

Tin plate is frequently used due to its resistance to tarnish and corrosion and its ductility and solderability. It is also nontoxic and therefore is used in the canning industry for foods. Tin is also used in the electronics industry, as well as being frequently alloyed to produce a deposit of desired properties.

Plating of alloys, such as brass, bronze, and numerous other binary and multi-element coatings, is done both for aesthetic and engineering values. Many of these special alloys have been mentioned previously.

Brass and bronze are normally plated on lamps and other household goods to achieve an antique appearance or other cosmetic benefit. When considering the plating of an alloy it is important to be aware that alloy plating processes may be very difficult to control. Alloy baths can be of the acid or cyanide type, as well as other special compositions. The control problem with alloy plating is that there are two or more metal concentrations to monitor in the solution. These may or may not affect the deposit alloy depending upon the other chemicals used. However, it should be recognized that alloys will provide in many cases a combination of properties that may not be available from one metal alone.

VIII. RELATED FINISHES

A. Anodized Coatings

Anodizing is a process that is opposite to electroplating in that the part being processed is made anodic (hence, its name). The process works by anodic oxidation of the base metal. It is used mostly for aluminum, but also to some extent on magnesium and titanium.

A typical example, and the one in widest commercial use, is the anodizing of aluminum. Aluminum by itself will corrode in air, forming extensive white corrosion products. Anodized aluminum has a homogeneous, tightly adherent, and dense film that protects the underlayer of aluminum from corrosion.

A typical anodic coating is somewhat porous. It may be sealed by hot water treatment to augment corrosion protection. The building industry uses anodized aluminum almost exclusively for door and window frames on residential and industrial buildings. The porous anodic film is frequently dyed to match other trim. This dyed film is then finally sealed to provide the augmented corrosion resistance noted above.

B. Black Oxide Coatings

Black oxide coatings are used for ferrous parts. They are applied by simple immersion; that is, no electrolyte of the part is required. The solutions used are highly alkaline and usually contain nitrates or nitrites. The black oxide coating in itself is not a good corrosion barrier; it is somewhat thin and porous. The coating is frequently sealed with an oil or wax in order to extend the life of the parts. Black oxide is commonly used on non- critical areas of machine, tool, and optical parts.

C. Chromate Coatings

Chromating is a surface conversion process that is used on aluminum, brass, cadmium, copper, and zinc. It provides increased corrosion resistance to the surface of these metals. The chromate coating process is usually non-electrolytic (although one anodizing process needs a chromate bath) and occurs by simple immersion of the part in a solution of chromic acid and other salts. The chromate film is usually the last step in the plating process. This film can also provide color to the plated metal. Available chromate colors are clear, blue, yellow, green, brown, gold, and iridescent.

D. Electroless Plating

It is possible to deposit a metal on a substrate without the use of an electric current. The most common method is by a process known as electroless plating. In electroless plating the metal is reduced to the metallic state and deposited onto the substrate by the use of a reducing agent, such as sodium hypophosphite. Deposits of 0.0040 in. or greater may be obtained by this method. It should be recognized that the deposited metal contains an appreciable amount of phosphorus and is thereby different from metal deposited by a mirror-making process.

The primary advantage of electroless plating is that the deposit is not dependent upon current density, polarization, or throwing power. An electroless coating is uniform in thickness and composition without the limitations that apply to electroplating. A secondary advantage is the stability of the bath, which does not deposit metal for long periods of time unless a receptive substrate is present. This is also in contradistinction to a silvering or mirror-making process.

The most common metal plated electrolessly is nickel. Electroless nickel is used on dies, molds, valves, and other parts where a corrosion-resistant and good wearing surface is required. Although electroless nickel possesses similar properties to hard chrome, it is not to be confused with it for severe wear applications.

Electroless plating is also used as the first metallic layer for nonconductors. Plastic parts have become an important part of engineering design. A thin layer of either copper or nickel is electrolessly plated prior to normal electroplating. This makes the plastic surface electrically conductive so that the desired thickness of plate can be achieved by electroplating.

E. Electropolishing

Electropolishing is a method used to remove small burrs, surface scratches, and imperfections, as well as to brighten a metal surface. Such metals as copper, steel, and stainless steel are frequently electropolished to improve their surface characteristics. Electropolishing is much less expensive than manual polishing, and it should be remembered that manual methods will remove more metal, but mayor may not provide a better surface. The depth and nature of the undesired imperfections will decide which process should be used.

Eletropolishing is done in an acidic bath and has the opposite polarity of electroplating. In electropolishing the parts being treated are made anodic. A very small amount of metal is removed, mainly the micro high current density peaks of scratches, thus improving the smoothness and brightness of the metal part.

Eletropolishing is an optimum way to pretreat parts prior to electroplating to achieve a superior finish. Usually, however, electropolishing is used as the final finish on a nonplated base metal. Used prior to electroplating it may add to the total cost to such an extent to become prohibitive.

F. Galvanizing

Galvanizing is a hot-dip method of applying a coating of zinc onto ferrous substrates. The primary reason for a galvanized coating is for corrosion protection as the zinc provides a sacrificial surface to the ferrous base.

Items such as nails, reinforcing rods, anchor bolts, pipe and pipe fittings, refuse containers, and guardrails are typically galvanized. These parts require only the protection of zinc and not the additional luster that zinc electroplating can provide.

As with electroplating, any part to be galvanized must first be cleaned and activated. Galvanizing is accomplished by dipping the parts into zinc metal. At the high temperature used, three distinct zinc layers tend to form. These provide the base metal protection.

G. Phosphate Coatings

Phosphating is a process of producing an immersion coating on ferrous parts. It is done in a solution of phosphoric acid and metallic compounds at elevated temperatures. The two main types of coatings are zinc phosphate and magnesium phosphate, although iron phosphate is also used.

The phosphate coating is somewhat corrosion resistant and porous and granular in structure. It is almost always sealed with a wax or an oil to provide atmospheric protection. Due to its porous nature phosphating is also frequently used to produce a tough adherent base for painting. Phosphating is usually applied either by spray or by dipping onto articles, such as nuts, bolts, barrels, and other miscellaneous hardware.

IX. A NOTE ON DIRECT CURRENT POWER SUPPLY

The direct current used in the plating process can be supplied by either a low-voltage generator or a rectifier. At one time the low-voltage generator was used exclusively as the plating power source. These generators have been largely replaced with rectifier units to cut down on the high initial cost and the maintenance required during operation of the generators.

The dc power supply has undergone as much development over the years as the electrochemical process. In the early days of electroplating, around 1920, generators were the only available source of dc power. By 1950 the rectifier had almost exclusively replaced the generator due to its many advantages.

A rectifier is a device that converts alternating current from the plant source into direct current that is used in the plating process. A rectifier consists mainly of a trans-former to reduce the voltage, diodes to convert the current to dc, a voltage and current control for the output, overload protection, and a cooling device. Silicon is the most common material used in the diodes. Several diodes are used in order to handle the cur- rent load. Heat is generated during operation of a rectifier. This heat must be removed, and either fan or water cooling may be used.

When specifying a rectifier for electroplating it is important to specify a ripple of 5% or less. Several of the plating processes will not operate properly with a higher ripple factor.

Another factor to be considered when specifying a rectifier is the current wave form. A rectifier may be built to put out either a half-wave or full-wave current. It is important to use only a full-wave unit since many of the processes, especially chromium plating processes, will not operate properly with half-wave.

All rectifiers used in electroplating have a variable output control. Both tap switches and infinitely variable controls can be used. Fixed output units are available; they are somewhat less expensive, but are obviously not desirable due to the ever-changing load factors of a busy plating shop. Other controls that are available on modern rectifiers include automatic voltage, current, and current density control. These special options are becoming increasingly more popular as they provide a consistent output control for the plater.

The commercial use of a totally new power source, the pulse rectifier, was introduced in 1978. A pulse rectifier is essentially a switching device that turns the dc output on and off at millisecond intervals. It has a high-frequency square wave output that has been used to solve many deposition problems and has greatly improved the quality of electroplating. The important characteristic of a square wave output is that the rise time from zero power to full current is practically instantaneous. The power then remains on for a preset period of time, when it is then turned off for a preset period of time. Then the cycle repeats itself. This cycling can be set at intervals up to 1000 times per second.

A modern high-frequency square wave pulse rectifier has controls such that the output frequently can be set to the optimum conditions of the electroplating process. This optimum frequency is different for each process due to the specific electrochemical conditions associated with it. The pulse rectifier is effective due to its ability to control I polarization as well as the cathode film during deposition. This control has greatly improved throwing power, deposition rates, internal stress, and hardness of the deposit. Due to these advantages, pulse plating is finding wide acceptance in industry.

X. QUALITY CONTROL

Quality control is probably the most important single factor when considering high-grade electroplating. Due to the numerous variables, such as bath composition, time, temperature, current density, and base metal, it is necessary to monitor and control all phases of the process. As mentioned earlier in this chapter, a simple zinc-plating system may process parts through four or more solutions. Each of these solutions as well as the intermediate rinses must be controlled with concern for the variables mentioned. High-quality deposits can only be expected if these variable factors are all controlled. Whether a part is to be processed in-plant or sent out to a job shop plater, it is common sense to assure that quality control procedures are used.

XI. COST OF ELECTROPLATING

In most cases the cost of electroplating or related finishing is low compared with the value of the manufactured part. Plating is used to provide properties that the part would not otherwise have and as such is well worth the investment. Frequently a plated steel part can replace a much more expensive fabrication using a more exotic base metal.

The major costs of metal finishing are labor, equipment, and chemicals, in that order. Such factors as the metal being plated, the deposit thickness, the shape of the part, and the batch size directly affect costs. The engineer can be sure, however, that electroplating represents an economical way to improve the quality of his design.

B. Fundamental Principles

The process used for electroplating is similar for all metals. The part to be processed is cleansed of all surface soil and then activated. The activated metal is placed immediately into plating solution where the actual electroplating is to be achieved. The exact plating cycle and various solutions used will vary somewhat depending upon the base metal and the type of plating to be done.

In the actual electroplating operation the parts to be plated are made cathodic in the plating solution. In a simplified operation these parts are suspended by a hook or wire (Fig. 25.1) from a cathode bar. Low-voltage direct current is supplied by a rectifier and is connected by a cable or buss bar to both the anode and cathode circuits in the plating tank. The anode and cathode bars are fabricated of copper and are positioned on, but insulated from, the tank rim. These bars are designed to carry the weights of the anodes and cathodes as well as to conduct the current that is applied.

The anodes are electrodes that are suspended in the plating solution. They are normally of the same metal that is to be plated, that is, copper anodes for copper plating nickel anodes for nickel plating. During the plating operation the anode dissolves to replenish the solution of metallic ions deplated by metal deposition on the cathode. This type of anode is known as a soluble anode. Certain situations, however, require an insoluble (inert) anode whose only purpose is to provide current to the electrolyte. Examples of typical insoluble anodes are carbon for certain processes and lead anodes for chromium plating. Insoluble anodes are used in situations where the electrolyte would dissolve the anode at a rate faster than the metal would be plated out of solution or in situations where the cost of a pure anode would be prohibitive.

During plating low-voltage direct current is supplied to the electrolyte by a rectifier. Generators are also used from time to time but have largely been replaced by the newer rectifiers (see Sec. IX). Depending upon the process, the current supplied by the rectifier is in the range of 6-12 V, with current density depending upon the surface area of the cathode. Typical current densities for many plating operations are 20-100 A/ft2 area to be plated. Hence a cathode area of 10 ft2 would require a rectifier capable of 200- 11000 A. In actual production plants, rectifiers with a capacity of 5000-20,000 A are quite usual.

The plating solution, that is, the electrolyte, is generally an aqueous solution that contains dissolved salts of the metal to be plated and other chemicals as may be required. Some electrolytes are quite simple in nature and may contain as few as two ingredients. Acid copper plating, for example, uses a solution of only copper sulfate and sulfuric acid. Other electrolytes, however, may be quite complex. The solution for nickel plating may contain as many as six to eight ingredients, such as nickel sulfate, nickel chloride, boric acid, sulfuric acid, and wetting agents, as well as several organic addition agents.

These electrolytes are conductive media that allow the current to pass from anode to cathode. As direct current is applied to the anode (Fig. 25.2), metal is dissolved and ionized. The current causes these positively charged metallic ions to migrate toward the cathode, where they are reduced to the metallic state and deposited onto the cathode.For the most part the anode and cathode act independently of each other in the electrolyte. The simplified reaction also causes the migration of negatively charged ions to the anode where they are neutralized by the positive charge. By-products that are caused by this electrolysis include the release of oxygen at the anode and hydrogen at the cathode. Due to the complexity of some electrolytes numerous other side reactions may also occur.

Most plating electrolytes can be operated over an indefinite period of time and seldom if ever require discarding. As the plating process continues and various chemicals are consumed, replenishment is required in order to maintain the electrolyte within the prescribed concentration limits. The plating solution may become unbalanced during continued operation due to

1. Depletion of metallic ions
2. Incomplete reactions
3. Decomposition of ingredients
4. Drag-in from previous solutions
5. Drag-out of the plating solution
6. External contamination

Due to these factors it is important to have the electrolyte analyzed on a periodic basis with chemical additions or purification steps taken as may be required.

II. PREPARATION FOR FINISHING

A. Polishing and Buffing

Polishing and buffing are operations that are frequently performed on the workpiece prior to the plating operation. This is because after fabrication the article may contain numerous surface defects in the form of scale, pits, mold marks, grinding lines, tool marks, or scratches. These defects must be removed prior to plating if a satisfactory finished part is to be expected. The article is processed in the following sequence as may be required depending upon the surface defects that may be present.

1. Grinding
2. Polishing
3. Buffing
4. Electroplating

Grinding may be considered a machining operation; it is used to remove a substantial amount of metal from the surface. Grinding operations will generally leave the surface with a finish of 20 µin. rms or rougher.

Polishing is a continuation of the abrasion process; it is used to remove grinding lines as well as numerous other defects. Polishing is accomplished with either an abrasive belt or with a cloth wheel to which a suitable abrasive has been bonded. Polishing will also remove a substantial amount of metal from the surface but will leave the articles virtually free from undesirable defects. Common abrasives used in polishing include silicon carbide and aluminum oxide with grain sizes ranging from a #60 to #320 depending upon the amount of metal to be removed.

Buffing is also an abrasion process but with a much finer abrasive used. It has long been known that surface metal flow accompanies metal removal. The purpose of buffing is to produce a bright, smooth, and scratch-free surface, and it is used just prior to electroplating to provide a finished product of suitable surface quality. The buffing operation uses cloth wheels to which a compound is applied. These compounds usually contain a glue or binder as well as an abrasive. The abrasives used in buffing may be similar to those used in polishing but are of a much finer particle size. Typical abrasives used in buffing range down to 8 µm particle size. The selection of proper compounds, abrasives, wheel type, wheel speed, and pressure is of paramount importance in order to pro- duce the desired finish. Some of the newer plating solutions have the ability to level out and cover surface defects, thereby avoiding the polishing and buffing operations.

Most polishing and buffing operations are performed by an operator who processes each individual part. Automated equipment is used where the volume of a particular run warrants the expense. For the most part polishing and buffing is expensive and time j consuming, thereby adding substantially to the cost of the finished article. Minimizing this cost is an important design objective.

B. Mass Finishing

Mass finishing is an operation used to remove surface defects and is similar to polishing and buffing in that it produces a like effect. Mass finishing is used to process parts in bulk as opposed to individual piece part operation. The parts to be processed are placed in either rotating barrels or in vibrating tubs. In addition to the parts, these vessels also con- an abrasive and a compound to produce the desired effect. Depending upon the abrasive used, a grinding, polishing, or buffing action may be achieved.

The only limiting factors in mass finishing are the size of the parts, their mass, and effect that sharp edges and other factors may have on other parts as they tumble or ate against each other and against the abrasive.

Where it can be used, mass finishing is a much less expensive way to remove surface defects than manual polishing and buffing. Generally used on smaller parts, mass finishing can an lower costs by yielding higher productivity with decreased rejects.

III. PROCESSING CYCLES

After the article has been fabricated and has the desired surface finish it is ready for the plating operation. This operation comprises a number of steps that take the part through ral sequences. These sequences and the solutions used will vary depending upon the finish to be applied. A typical sequence for zinc plating may be as follows.

Cycle	Operation
1	Load parts onto racks or barrels
2	Alkaline soak clean
3	Electroclean
4	Water rinse
5	Acid pickle activate
6	Water rinse
7	Zinc electroplate
8	Water rinse
9	Dry parts
10	Unload parts

In order to better understand the entire process each sequence is discussed individually.

A. Cleaning

Cleaning is used to remove unwanted soils, greases, and oils from the metal surface. These come from the fabrication and prefinishing operations. The object is to achieve a chemically clean surface so that the plating deposit will adhere. Any residual surface will detract from plating adhesion and are a frequent cause of blistered and peeled deposits.

Among the many types of cleaning used today are solvent cleaning, vapor, degreasing, emulsion cleaning, alkaline soak, and electrocleaning. The first three, solvent, vapor, and emulsion types are considered precleaners and are always followed by alkaline soak electrocleaning in the plating operation. A surface that is efficiently cleaned will water break free. The absence of water breaks will assure that all organic films have removed and that the part is ready for further processing.

Alkaline soak cleaning is used to remove most soils. The solution typically contains alkalis, phosphates, silicates, carbonates, soaps, and surfactants. Cleaning occurs by actions known as emulsification, saponification, and dispersion. Most soak cleaners are operated at a temperature of 150-2000p with the parts being immersed from 5 to 20 min.

After the bulk of the soil has been removed in the soak cleaner the parts are transferred to an electrocleaner. The electrocleaner serves the same purpose as the soak cleaner but to a much greater degree. In electrocleaning a charge is applied to the part much as in the plating operation. The charge, anodic for reverse cleaning and cathodic for direct cleaning, causes either oxygen or hydrogen to be released from the solution. The gas has a micro scrubbing action. The chemical composition, operating times, and temperatures are similar to those used in soak cleaning. Typical current densities for electrocleaning are 40-70 A/ft2 of surface processes.

In alkaline soak or direct or reverse electrocleaning, care should be exercised in selecting the cleaner formulation as well as the operating parameters. This is necessary so as to provide a chemically clean part while not degrading or eroding the base metal. During operation the cleaning solutions become saturated with oils and soils. This contamination necessitates either replenishment with fresh cleaner or replacement from time to time of the entire cleaning solution. Numerous plating defects have been traced to a cleaner that has not been maintained at the concentrations and/or parameters that were specified.

B. Activation

After the part has been thoroughly cleaned it must be activated prior to plating. This activation is accomplished by various acid solutions and is frequently termed "pickling." The purpose of activation is to remove oxides and scale from the metallic surface. These oxides are formed during fabrication, heat treating, handling, and storage of the parts. Steel and other metals will form a thin oxide layer during such handling and storage. Heat treating will cause a more severe form of oxide known as scale.

The acid solutions commonly used are sulfuric, hydrochloric, nitric, and hydro- fluoric or mixtures of these acids. The selection of the proper acid, dipping time, and temperature is dependent upon the metal being processed and the thickness of the oxide layer. Typical pickling acid formulations for a mild oxide condition on steel parts are as follows.

1. Hydrochloric acid, 20° Baume, at a concentration of 50% by volume. A tem- perature of approximately 700p is used for 2-15 min.
2. Sulfuric acid, 66° Baume, at a concentration of 15% by volume. A tempera- ture of approximately l200p is used for 2-15 min.

When activating metals with acids it is desirable to set the operating parameters so as to remove all oxide while not overpickling, which, will remove excessive metal and can frequently cause smutting of the surface. Parts that are heavily scaled will require the use of an inhibitor (typically, an organic amine) in the acid solution. The purpose of an inhibitor is to provide a better wetting action to the acid, which helps dissolve and remove scale while slowing the acid attack on the fresh and exposed metal surface. Such inhibitors can effectively permit removal of scale while preventing the formation of smut or excessively removing metal.

C. Electroplating

After the parts are cleaned and acid activated they are ready for electroplating. The surface is rinsed in water and the part placed immediately into the plating solution. A fast transfer time is required here so that re-formation of an oxide layer is prevented.

Direct current electricity is then applied to the electrolyte, as shown in Fig. 25.2. The current is continued for a predetermined period of time until the desired amount of metal is deposited upon the cathodic workpiece.

The current is measured in amperes, coulombs, or faradays. A deposit of 1 g equivalent the metal will be deposited for each faraday. The equivalent weight equals 1 g weight divided by the valence of the metal. The valence is determined by the number of charges that the metal ion has. A faraday is a unit of electricity and is equal to 96,500 C (or ampere-seconds). Table 25.1 shows the amount of metal deposited at 100% efficiency. In order to determine the deposit thickness that will be achieved it is also important to consider the current distribution and the cathode efficiency.

A proper distribution is achieved when the anodes and cathodes are positioned in such a way as to have the current flow be uniform across the entire cathode surface. Area of a part, such as a protruding corner, that are closer to the anode than other areas will receive a higher current density and consequently a thicker deposit. Proper positioning and masking in the plating solution will alleviate this problem so that a deposit of uniform thickness is achieved. In most cases a current efficiency of 100% is not achieved. The cathode efficiency is the percentage of current that deposits metal. The balance of the current is consumed in parasitic actions, such as evolving hydrogen at the cathode surface. When the cathode efficiency is known the plating rate (grams of metal per unit area per unit time) can be calculated as follows:

$$\text{Plating rate} = \frac{\text{gram equivalents metal}}{\text{Area X time}}$$

$$= \frac{\text{faraday X \%efficiency}}{\text{Area X time}}$$

The plating engineer is also concerned with other features of the deposit. Metallurgical factors, such as hardness, residual stress, hydrogen embrittlement, and brightness, considered. Frequently agents are added to the plating solution in order to

Metal	Valence	Atomic weight	Grams deposited per faraday
Cadmium	2	112.41	56.21
Chromium	6	52.01	8.67
Copper	1	63.57	63.57
Copper	2	63.57	31.78
Gold	1	197.20	197.20
Nickel	2	58.71	29.36
Silver	1	107.88	107.88
Tin	4	118.70	29.67
Zinc	2	65.38	32.69

modify the deposit that would normally be obtained. By controlling the bath composition, the choice and concentration of addition agents, current density, and temperature, the plater is usually able to obtain deposits with the desired properties.

D. Rinsing and Drying

After each step in the processing cycle the chemical film that remains on the workpiece surface must be rinsed off with suitably clean water. Certain parts may have areas that trap solution; these areas must be thoroughly rinsed. It is important to remove all chemicals from the surface prior to the next sequence in processing. This is to avoid unwanted reactions on the surface as well as to avoid solution contamination.

Water rinsing is normally done in a tank in the processing line. At least one rinse tank is used following each process. Frequently several rinse tanks are used for double or triple rinsing. Multiple rinses are used where a high work flow tends to contaminate the first rinse quickly. In multiple rinsing each rinse dilutes the surface film further until contaminants are removed to a tolerable level.

There are several types of rinse tanks, but they generally fall into two categories: running and still. A running rinse has a continuous supply of water to the tank and over- flows. This is used in high-production lines to keep the rinse water at a level of purity sufficient to avoid contamination of the next tank. Still rinsing has no water flow and is used only for small production runs.

To economize on water costs a conductivity controller is commonly used to control the contamination level in the rinse tank. With this device inlet water flows only when required to keep the tank water at the desired purity. For further water economy a cascade rinse is used in a mu1tibay tank. In a cascade rinse the water flows over and under baffles separating each bay so that it is used several times. Flowing water is used in the last bay with an overflow in the first bay. The work flow is opposite to the water flow so that the emerging work is rinsed by the purest water in the last bay.

Several methods of improving rinsing efficiency are used, such as heated water and air agitation. Merely submersing a part is not sufficient to maximize the rinsing operation unless contact is maintained for a long period of time. Warm water tends to dilute the surface film much quicker. By agitating the water with air the films are more quickly diluted. Spray rinsing directly over the process tank is frequently employed as a method of water conservation. A spray rinse will remove approximately 80% of the surface film and return the chemicals directly back into the process tank. Spray rinsing should be followed by normal tank rinsing to remove the balance of the surface film.

Today the e1ectrop1ater is concerned with regulations for pollution control. These regulations limit the amount of certain chemicals that may be discharged. A high-production plating line is capable of discharging substantial amounts of these controlled chemicals from the rinsing operations. This, coupled with high water costs, frequently dictates that a controlled water volume be used.

At the completion of the entire process and the final water rinse, the parts should be thoroughly dried. Complete drying is necessary if staining and rusting are to be prevented. All moisture should be removed from the surface as well as from recesses and crevices. Heated as well as forced air from a fan or blower is commonly used to effect complete drying. Other techniques include drying by absorption with ground corncobs. This is used frequently on small parts. Centrifuges and infrared equipment are also employed for drying certain parts.

IV. FACTORS IN PLATING

A. Electrode Position

Electricity follows the path of least resistance. Consequently, areas of a part that protrude, edges, and parts closest to the anode will receive the most current. These areas tend to have the thickest deposit. It is normally desirable to have a uniform deposit thickness across the entire part. Recesses or areas farthest away from the anode, on the other hand, will tend to have the thinnest deposit. Arranging the parts so that all areas approximately the same distance from the anode will maximize current distribution provide a uniform deposit. Figures 25.3 and 25.4 show this relationship. In some cases, however, it is impossible to arrange the parts in the most desirable position. In these situations a shield or "robber" can be used to obtain the proper distribution.

A shield is an inert material that is not electrically conductive. It is placed between anode and the cathode to redirect the current flow. Figure 25.5 shows the proper of a shield.

A robber is a conductive metallic article that is plated along with the workpiece. It is positioned in such a manner as to steal current from an area where it is not wanted. A robber will receive a deposit, as will the cathodic workpiece. Figure 25.6 shows the use of a robber.

Inasmuch as robbers receive a deposit, this represents a waste of valuable plating at. They also have to be stripped occasionally so that excessive buildup is avoided. These factors normally make the use of robbers expensive and unpractical. It is for this on that shields are in greater use for parts with troublesome areas.

B. Polarization and Current Distribution

Polarization is a term that explains the effect of a change in electrical potential of a plating solution. Normally it is not of concern to the electroplater unless a problem lops in the solution balance. Polarization is a condition caused by changes in bath concentration or changes within either the anode or cathode films. It is caused by the movement and discharge of ions. It is a force that is measured by a drop in voltage for a n ampere setting. Polarization is always present during electrolysis of a solution but is of concern when its effect becomes excessive. It can be caused by a depletion of near the electrode surface, as in concentration polarization, or resistance polarization which is caused by the formation of a diffusion layer surrounding the electrode. Polarization can be alleviated by the use of agitation in the plating solution. This maintains a uniform composition throughout the solution and consequently minimizes the effect of polarization. Current distribution at the beginning of the electroplating process prior to the onset of polarization changes during the first second or two of the current flow to the current distribution that prevails during the rest of the electroplating process. This distribution is more uniform along the cathode surface and tends to even out deposit buildup on edges and the center area of parts.

C. Throwing Power

Throwing power is the ability of an electrolyte to deposit metal of a uniform thickness across a cathode surface. This term is not to be confused with covering power, which is the ability of an electrolyte to deposit metal across an area regardless of thickness distribution. The two types of throwing power are micro and macro.

Microthrowing power is the ability of a bath to plate into small surface scratches, thereby filling them up with the deposit. A solution with good microthrowing power will to level out surface imperfections and provide a smoother surface. Microthrowing is affected by polarization. Where polarization is increased by the use of addition agents, metal will tend to deposit into surface imperfections and thereby produce a higher quality deposit.

Macrothrowing power is the ratio of deposit distribution in relation to the distance from anode to cathode. The area of a cathode that is spaced close to the anode would normally receive the thickest deposit, whereas the area farthest from the anode would receive the thinnest deposit. An electrolyte with 100% throwing power will deposit a unoform thickness regardless of anode to cathode spacing. As before, polarization is responsible for controlling this macrothrowing power.

D. Leveling and Brightening

As mentioned previously, leveling is the ability of an electrolyte to deposit metal so as to smooth out surface scratches and imperfections by filling them up with the deposit. The use of certain addition agents in the plating solution causes polarization at the peaks of these scratches. These peaks are high current density areas on a microscopic scale.
The microthrowing power is improved by these additives, and the deposit is caused to preferentially deposit in the valley of the scratches. As the plating continues these scratches become filled with metal and a leveled surface result.

Brightening is enhancing the ability of a deposit to reflect light. A deposit that reflects nearly 100% of the incident light will appear bright, whereas one that reflects less light will appear duller. Brightness is important in decorative applications and may be of no importance for functional applications. Although a deposit that is leveled will normally appear brighter, brightness is more a function of the crystalline structure of the deposit.

E. Adhesion

A deposit that has good adhesion will not peel or flake from the substrate. Good adhesion is especially important if the part is to be formed, bent, or stamped after electroplating. Adhesion is usually related to the activation prior to plating. A part that is cleaned and activated properly will exhibit good adhesion.

F. Deposit Growth

As the electroplating process continues and the deposit becomes increasingly thicker there is a tendency to produce growths around edges and other high current density areas. These undesirable growths are commonly termed "trees" or "nodules."

Trees are a deposit growth, normally forming around edges. They are quite angular and actually appear as a tree with its many branches. They are caused by local high current density accompanied by growth of the metal. A tree has a very thin structure; it will break off if touched and may cause a pinhole at its base. A nodule is a rounded bumpy kind of deposit that is usually more firmly attached due to the larger size of the base. Nodules do not usually pose a problem as regards adhesion but they are not desirable; a quality deposit should be smooth and nodule free. Trees and nodules are usually associated with thicker deposits of 0.0005 in. or more. They can, however, be present with thinner deposits if the plating electrolyte is not in proper balance. The use of certain addition agents in the plating bath is quite common to prevent trees and nodules from forming even with deposit thicknesses exceeding 0.005 in.

V. DESIGN CONSIDERATIONS

Plating and other finishes are usually last in the manufacturing process; frequently the effect of part design on finishing is totally overlooked. A part is frequently designed and specified in a way that adds considerable cost to the finishing step.

Whenever plating is specified the design engineer should identify the "significant surfaces" of a part. A significant surface receives a deposit of specified quality, that is, thickness, brightness, coverage, durability, and so on. A significant surface on a decorative part such as an automotive bumper or grille, is the area normally seen by the consumer. A significant surface for engineering applications is the area that gives a part the particular properties the engineer needs for specified function. An example of a significant surface on engineering applications is the journal of a crankshaft plated with hard chromium. The journal is the bearing wear surface and, therefore, is a significant surface. The adjacent web area is of no concern for electroplating. Hence, the journal area is the only significant surface and should be specified to be lOO% covered with a high -quality deposit.

When designing a part to be electroplated the engineer should consider the following.

1. Racking points
2. Drainage of the part
3. Air entrapment
4. Plating distribution

Racking is the method used to suspend a part through the various steps of the plating process. A place should be provided where electrical contact can be made on an insignificant surface. This racking point will not usually receive as good a deposit as the other areas due to the effect of having a conductor near the surface to be plated.

Drainage of the part for proper rinsing should also be considered. Frequently a part will have inside corners or curved surfaces that may trap the solution. This is undesirable and should be avoided whenever possible. When these corners and curved areas are necessary from a design standpoint, they present a significant problem to the electroplater. This problem can, however, be alleviated by placing a hole in the lowest position of that area so that good drainage can be accomplished.

Air entrapment is a problem of concern when racking of the part is considered. If a cupped area is positioned in the solution in such a manner that it will trap air, it is obvious that solution cannot contact that particular area. Solution contact is necessary the part is to be processed properly. Proper racking or placement of a hole will alleviate this problem and ensure a quality deposit.

Plating distribution is also of consideration to the design engineer. As mentioned previously, a part protrusion will tend to receive a greater deposit thickness than a recessed area. Complex shapes are always more costly to electroplate than are simple shapes.

The following guidelines should be followed, whenever possible, in designing a part to assure platability.

1. Avoid sharp or protruding edges. All edges should be rounded to a radius of 1/32 in. or more.
2. Inside corners should have as large a radius as is possible.
3. Slots, grooves, and concave recesses should have a depth no greater than one- half the width.
4. Blind holes should be avoided wherever possible. If they cannot be avoided the depth should be no more than one-half the width.
5. Perfectly flat areas should be avoided. Preferably a concave or convex surface should be provided.

VI. PROCESSING METHODS

There are several methods of processing available to the electroplater. They include rack, 1, basket, barrel, basket, and brush plating. Either automated or manual methods can be used depending upon the volume of work to be processed at one time.

A. Rack Processing

A plating rack is a device that holds the part in a fixed position during the plating cycle. It connects the part electrically via the bus bar to the dc power supply. The plating rack is usually fabricated of copper with phosphor-bronze contact tips to hold the workpiece. The rack is then coated with a plastisol to prevent the various solutions from corroding copper spines; the tips are left bare so as to make electrical contact with the part.

Racks should be designed so that the parts are held in a proper position with respect to the processing limitations that were previously discussed. The weight, volume, current requirement of parts to be processed at one time must also be considered when designing racks. The top of the rack is normally fabricated to form a hook. It is this hook and contact point that rest on the copper bus bar for electrical contact. The hook must be designed so as to assure a constant current flow. Plating racks are normally used for large parts that cannot be processed by other means. Due to the necessity for manually loading and unloading, the rack method is usually the most expensive.

B. Barrel Processing

Barrel processing is used for plating small parts in bulk. As a rule bulk processing is much less expensive than manually racking the parts. Items such as nuts, bolts, screws, washers, and other small parts can be effectively processed in barrels. These parts can be loaded in quantities of up to 250 lb in appropriately sized plating barrels.

Most plating barrels are of the horizontal type and are six sided. A removable door on one side allows for the loading and unloading of the parts. These barrels are now usually fabricated of polypropylene, thus providing strength to withstand the various loads, as well as, chemical resistance to the various solutions at the operating temperature. Plating barrels are perforated with small holes on the sides to allow for circulation of the electrolyte and electrical contact with the work inside. Electrical contact is made by flexible danglers through the side that touch the load inside. Plating barrels are either of the fully or partially submerged variety and are rotated slowly so that the load of parts is constantly in motion and all surfaces are coated with electrolyte and make contact electrically.

Due to the restriction of electrical flow, plating speed is slower with barrel processing than it is for rack processing. The larger volume of work with less labor usually makes barrel processing more economical for overall plating of small parts.

C. Basket Processing

Basket processing is similar to barrel in that the parts are processed in bulk. A conductive metallic basket is generally used. The basket is suspended by a hook from the cathodic bus bar. Basket processing is a manual operation due to the necessity of periodic shaking or mixing the load of parts so that all surfaces make contact and receive a uniform deposit. Due to higher labor requirements basket processing is not widely used in practice today. It has been almost entirely replaced by the more efficient barrel processing method.

D. Brush Processing

Brush plating is used for localized or selective plating. A normal plating tank is not used since the parts are either overly large or disassembly and removal of the part would be cost prohibitive, such as where a repair of plating is required.

A brush plating setup consists of a small dc rectifier, an ammeter, and a portable hand-held anodic brush wrapped with a material, such as cotton, nylon, or dynel, that absorbs the plating solution. The plating solution can be applied to the brush either by dipping or by pumping it through a hollow core. The part is made the cathode by a suitable electrical connection.

The brush containing the plating solution is manually moved over the entire surface to be plated until the desired thickness is achieved. Brush plating requires the same cleaning and activation steps that are used in more conventional methods. This cleaning and activation are, however, done manually.

Brush plating can be done on such substrates as steel, copper, or the stainless steels. It is not recommended for the more active substrates, such as aluminum, magnesium, or titanium, because they cannot be activated properly manually and poor adhesion be expected. Brush plating is not economical for any considerable number of parts. It is only used on a one of a kind job, usually of large size, and one that may be plated in place without total disassembly.

VII. ELECTROPLATED METALS

A. Zinc and Cadmium

Zinc and cadmium are generally plated on iron and steel substrates. These metals are primarily as a protection against corrosion because they provide a sacrificial coating, thus providing galvanic protection to exposed surfaces. As long as the coating of zinc or cadmium remains on the part it will tend to corrode prior to the ferrous substrate. Corrosion products of zinc tend to be white and frequently form a crust like structure. Cadmium, on the other hand, does not form crust like corrosion products.

Cadmium is used extensively in military and aircraft applications where it shows excellent effectiveness in a marine environment (high humidity and salt content). Recent federal regulations have virtually prohibited the use of cadmium for other applications due to the toxicity of the metal in industrial waste discharges.

Zinc is the most commonly plated metal for protecting iron and steel against corrosion. It is used extensively for nuts, bolts, screws, washers, springs, castings, and stamping. Zinc is also much less costly than is cadmium.

Both zinc and cadmium have a white or bluish-white color. In the case of both metals, the use of addition agents in the plating bath will provide an extremely bright deposit that resembles chromium in appearance.

Acid, alkaline, or cyanide baths can be used for plating these metals. Acid baths are used where effluent treatment is of prime concern and where a leveled deposit is desired. Alkaline and cyanide baths are used where throwing power is of prime importance. The use of an alkaline or low-cyanide bath has the added advantage of lower waste treatment costs.

Typical bath formulations are as follows.

1. Zinc Plating Baths

a. *Acid Formulation*

Zinc sulfate	120 g/liter
Potassium chloride	55 g/liter
Boric acid	5 g/liter
Addition agent	1/2-2% by volume
pH	3.5-4.2
Temperature	18-30°C
Cathode current density	50-80 A/ft2 (540-864 A/m2)

b. Alkaline Formulation

Zinc metal	15 g/liter
Sodium hydroxide	90 g/liter
Sodium carbonate	40 g/liter
Addition agent	1/4-1/2% by volume
Temperature	25-30°C
Cathode current density	5-80 A/ft2 (54-864 A/m2)

c. Low-Cyanide Formulation

Zinc metal	109/liter
Free sodium cyanide	109/liter
Sodium hydroxide	75 g/liter
Sodium carbonate	40 g/liter
Addition agent	1/4-1% by volume
Temperature	20-40°C
Cathode current density	2-100 A/ft2 (21.6-1076 A/m2)

d. Full-Cyanide Formulation

Zinc metal	20 g/liter
Free sodium cyanide	35 g/liter
Sodium hydroxide	75 g/liter
Sodium carbonate	15 g/liter
Addition agent	1/4-1 % by volume
Temperature	20-40°C
Cathode current density	2-100 A/ft2 (21.6-1076 A/m2)

Although the acid formulation can plate all ferrous substrates and has a higher plating speed, the equipment for the acid bath is a good deal more expensive; the bath needs more care and attention in order to consistently produce quality deposits; and the parts being plated must be immaculately cleaned. The alkaline and cyanide baths, on the other hand, cannot plate malleable and cast iron directly. These baths, however, are capable of plating for long periods of time without purification, are less expensive to operate, and are the "workhorse" baths of the industry.

2. Cadmium Plating Bath

Cadmium metal	25 g/liter
Total sodium cyanide	130 g/liter
Sodium hydroxide	20 g/liter
Sodium carbonate	15 g/liter
Temperature	20-35°C
Cathode current density	5-80 A/ft2 (54-864 A/m2)

Both cadmium and zinc coatings are normally protected with an immersion chromate conversion coating after plating. This chromate coating provides additional corrosion protection. The thickness for most applications of zinc and cadmium is normally 0.0002-0.0005 in. Deposits thicker than this are used only for engineering applications.

B. Decorative Chrome

Chromium is a bluish-white metal that is quite lustrous in appearance. In itself, chromium is resistant to corrosion in most atmospheres but tends to form microscopic cracks due to stress. This exposes portions of the base metal to corrosive environments. Hence, decorative chrome is almost always plated on top of either nickel or nickel plated on copper. These underlying layers of copper and nickel are used to seal off the substrate so that the microcracked chrome deposit does not become an avenue for corrosion.

Decorative chromium deposits are used on such items as automobile bumpers and trim, household appliances, furniture, and many other articles that require a bright and aesthetic appearance. The customary thickness for decorative chromium plate is 0.000020-0.000070 in. The total deposit including the copper and nickel underlayers is, however, approximately 0.0005 in. thick.

The current efficiency of chromium plating baths is quite low, usually being approximately 15-20%. The metal is plated at conventional speeds by the use of high current densities.

A typical formulation for a decorative chromium bath is as follows.

Chromic acid	180 g/liter
Sulfate	1.5 g/liter
Catalyst A	1.5% by volume
Catalyst B	15 g/liter
Temperature	35-50°C
Cathode current density	20-400 A/ft2 (216-4320 A/m2)

The catalysts used in the bath promote deposition at higher speeds, greatly increase the throwing power, and tend to activate the sometimes passive nickel underlayer. However, chromium baths, in general, tend to have very poor throwing power; the deposits may appear burned on the edges, and there may be discoloration or lack of plating in the very low current density areas. These problems are overcome with proper racking techniques and anode control, as well as maintaining the optimum bath composition. These quality control techniques together with use of proper catalysts will produce a remarkable deposit of exceptional luster over the entire area.

C. Hard Chromium

Chromium is the hardest of the most commonly deposited metals. Hard chromium is used as a wear-resistant coating not only on steel but also on a wide variety of other metals. Hard chromium differs from decorative chrome not only in use but also in the large difference in deposit thickness. As noted previously, a decorative chrome deposit is quite thin, but a hard chrome deposit is 0.005-0.0100 in. thick. Typical deposits to provide a good wearing surface are 0.0050 in. thick.

Hard chrome deposits are referred to as "industrial" or "engineering" chrome due to the use of the parts. Typical deposits have a hardness of 64-72 Rc. Besides being resistant to abrasion, hard chromium provides corrosion protection, has a low coefficient of friction, and has high heat resistance as well as antigalling properties. For this reason hard chrome is used on such parts as aircraft landing gears, bearing surfaces, cutting tools, dies, drills, engine cylinders, hydraulic shafts and pistons, molds, piston rings, and seats. The hardness of the metal is the same in hard chromium as for decorative chrome. The hard chromium appears to be harder due to its greater thickness. However, a deposit of at least 0.002 in. must be used before the intrinsic chromium hardness appears instead of reflecting that of the base metal.

Hard chrome is also frequently used as a buildup metal for expensive worn parts, such as large shafts and molds. Reclaiming worn dimensions with hard chrome is frequently easier and less expensive and provides a better wear surface than other methods. The most common application for hard chrome, however, is on new parts to protect the surface against wear.

The plating efficiency for normal hard chromium baths is quite low, 18-25%. Due to this low efficiency as well as the fairly thick deposits used, a knowledge of plating speeds is essential as many parts are plated directly to size.

The following chart illustrates typical speeds for several baths.

Bath type	Rate of deposit per hour at 2 A/in.2
Standard bath.	0.0006 in
Nonfluoride proprietary	0.0008 in.
High-speed bath	0.0012 in.

To understand hard chrome plating it is essential to have a knowledge of these three main bath types.

Standard bath	
Chromic acid	250 g/liter
Sulfate	2.5 g/liter
Temperature	55°C
Cathode current density	300 A/ft2 (3240 A/m2)

Nonfluoride proprietary	
Chromic acid	150-190 g/liter
Sulfate	1.4- 1.8 g/liter
Catalyst	1.5% by volume
Temperature	48-65°C
Cathode current density	150-700 A/ft2 (1620-7560 A/m2)

High-speed bath	
Chromic acid	150-190 g/liter
Sulfate	0.90-0.11 g/liter
Fluoride catalyst	1.5% by volume
Temperature	48-65°C
Cathode current density	150-1200 A/ft2 (1620-12960 A/m2)

The catalysts used, both fluoride and nonfluoride, allow use of a lower chromic acid concentration thereby effecting a considerable cost saving as well as allowing for a wider temperature and current density range. These catalysts also greatly improve such metallurgical properties of the deposit as hardness, crack structure, and wearability. The use of a fluoride catalyst greatly improves these properties while also providing the fastest plating speed. A disadvantage is, however, that a fluoride-containing bath is extremely corrosive to the parts being plated. The presence of the fluoride ion promotes etching the base metal in bare and unplated areas. For this reason all unplated areas must be masked with either paint, plastic, tape, or wax to keep them from contact with the electrolyte.

Chromium plating baths are known to have inherently poor throwing power. Hence, conforming anodes are frequently used on parts with any kind of an intricate shape. These anodes are spaced approximately 1/4-1 in. away from the part and conform exactly to the surface configuration. With this type of anode it is possible to plate a uniform thickness over the entire part area.

The anodes, whether they be of the conformirlg or tank type, are made of a lead alloy. A chromium anode is not used for two reasons: (1) chromium would dissolve faster than it is plated out so the bath would continually increase in chromium concentration, and (2) a lead alloy anode has properties that keep the trivalent chromium ion at proper levels of concentration. A typical anode alloy is 7% tin and 93% lead. This alloy provides the best conductivity and oxidation properties. Long (more than 6 ft) anodes, or configurations that may tend to sag must be fabricated of 6% antimony and 94% lead, which provides additional rigidity. During plating the anodes tend to form a crust or scale that has insulating properties. This scale must be removed in a strong alkaline solution periodically so that it is able to conduct the proper current.

Due to the hydrogen that is co-deposited with the chromium, the hard chrome coating tends to form a microcracked structure. This cracking does not deter good adhesion and is in many ways an advantage. In bearing usage these cracks tend to fill with oil or lubricant and provide a low coefficient of friction. With variations in either the catalyst type or concentration it is possible to modify crack formation to serve particular design applications.

All hard chrome deposits tend to reduce the fatigue limit of parts. Shot peening of steels harder than 40 Rc prior to plating is a common method of minimizing this effect arid prolonging the life of the part.

In summary, hard chromium is an excellent coating for metals when properly applied for engineering applications.

D. Copper

Copper is a corrosion-resistant, ductile, and highly conductive metal. It is resistant to non- oxidizing acids but is susceptible to oxidation, forming green, brown, and black products.

For decorative applications, copper is used as an undercoat for nickel and chromium. It is also used for "antiqued" parts where it is intentionally oxidized to obtain a desired color. In industrial applications, copper is used as a stop-off for heat treating and in other specialty uses. Copper plating is also frequently used on zinc-based die castings as the initial coating as it has a tendency to tend to cover the pores in the die casting.

Copper is plated from an acid, cyanide, fluoborate, or pyrophosphate bath. The latter two are used primarily on circuit boards for improved conductivity. Both the acid and cyanide baths are used extensively for decorative and industrial applications.

Typical bath formulations are as follows.

1. Acid Bath

Copper sulfate	150-250 g/liter
Sulfuric acid	45-100 g/liter
Addition agent	3/4 to 2% by volume
Temperature	20-50°C
Cathode current density	20-150 A/ft2 (216-1620 A/m2)

2. Cyanide Bath

Strike plating	
Copper cyanide	26 g/liter
Free sodium cyanide	15 g/liter
Sodium hydroxide	04 g/liter
Sodium carbonate	15 g/liter
Addition agent	1/4-1% by volume
pH	10.0-12.5
Temperature	45-55°C
Cathode current density	5-100 A/ft2 (54-1075 A/m2)

High-speed bath	
Copper cyanide	75 g/liter
Free sodium cyanide	23 g/liter
Potassium hydroxide	23 g/liter
Sodium carbonate	15 g/liter
Addition agent	1/2-2% by volume
Temperature	60-80°C
Cathode current density	density 2-90 A/ft2 (21.5-967.5 A/m2)

The strike bath is used as an initial coating on steel parts and always precedes the acid bath. This is due to the fact that a deposit from the acid bath directly on steel may have poor adhesion due to precipitation plating.

The use of addition agents in both the acid and cyanide baths can provide full bright deposits that have the appearance of being buffed.

E. Nickel

Nickel is a moderately hard metal; it has good thermal properties and is fairly corrosion resistant**.** It is for these reasons that it is used extensively as an undercoating for decorative chromium. Although a chromium top layer may be porous, a nickel undercoat is continuous and makes a highly corrosion-resistant system. Nickel, however, will tarnish in urban atmospheres and, hence, must be coated with chromium for decorative applications. The nickel coating is probably the most important layer in the decorative copper- nickel-chromium plating process. The copper plate may be omitted entirely without appreciably affecting the corrosion resistance or quality of the final coating.

Nickel is also used extensively in electroforrning where an intricate mold or other part is fabricated entirely by electroplating.

There are numerous baths currently used for nickel plating. The leveling-watts type is, however, the most widely used. It is formulated as follows.

Nickel sulfate	300 g/liter
Nickel chloride	60 g/liter
Boric acid	45 g/liter
Wetting agent	1/4-1/2% by volume
Brightening agents	1/2-3% by volume
Leveling agent	1/8-1/4% by volume
pH	3.8-4.2
Temperature	60°C
Cathode current density	10-100 A/ft2 (107.5-1076 A/m2)

The wetting agent prevents pitting of the deposit from the evolution of hydrogen gas and bath contamination. Brightening agents, both primary and secondary, are used to refine the grain structure and promote brightness. Leveling agents are also used to improve the micro throwing power, thereby promoting fast brightening with minimal cost. This bright nickel bath requires frequent maintenance in terms of purification in order to consistently produce quality deposits.

Other nickel baths include a standard watts type, similar to the above formula, without the use of addition agents. It is used for engineering applications. A nickel strike bath that uses nickel chloride almost exclusively is used as a preplate on passive metals, such as stainless steel.

F. Precious Metals

Precious metal plating takes into account such metals as silver, gold, rhodium, platinum, and palladium, as well as other less common metals. Precious metals, such as silver and gold, are commonly used for aesthetic purposes, as on jewelry. They are also, as are all precious metals, finding increased use in industrial applications. Most precious metals have good chemical and physical properties, excellent electrical conductivity, and low contact resistance. By far the largest application of precious metal plating is in the electronics industry, where the conductivity of the metals is of prime importance. Table 25.2 lists these metals and their basic characteristics. These properties differ greatly among the precious metals. For each specific application, each metal should be studied in detail in order to select the best combination of properties.

Table 25.2 Precious Metals Used for Plating

Metal	Applications	Properties
Silver	Electrical, jewelry	Semioxidation resistant
Gold	Jewelry, dental, electrical	Oxidation resistant
Rhodium	Electrica	High-temperature resistant
Platinum	Jewelry, electrical	Oxidation resistant
Palladium	Electrical	Forms reactive oxide

These precious metals are plated from an acid, cyanide, or neutral bath, each having its own advantages.

G. Other Metals and Alloys

Such metals as cobalt, iron, lead, and tin, as well as common alloys, such as brass, bronze, 'and tin-lead, are frequently plated in order to obtain the specific properties each may have to offer.

Cobalt is very similar to nickel in its color and properties. It is, however, very much more expensive than is nickel. Cobalt is rarely plated by itself but is commonly alloyed with nickel, tungsten, molybdenum, gold, and phosphorus to provide desired features to the deposit.

Iron plating is used for buildup of ferrous substrates, where advantage can be taken of its properties as well as its low cost. Only a few practical applications of iron plating are in use today as other metals offer numerous advantages.

Lead is used somewhat for corrosion protection but more frequently for bearing applications. Lead has a low melting point and is somewhat resistant to nonoxidizing acids. Lead tends to quickly oxidize on the surface, thereby protecting the underlying metal structure. The most common application for lead is in the bearing industry, where it is plated as an alloy with tin, antimony, and bismuth to provide desirable properties.

Tin plate is frequently used due to its resistance to tarnish and corrosion and its ductility and solderability. It is also nontoxic and therefore is used in the canning industry for foods. Tin is also used in the electronics industry, as well as being frequently alloyed to produce a deposit of desired properties.

Plating of alloys, such as brass, bronze, and numerous other binary and multielement coatings, is done both for aesthetic and engineering values. Many of these special alloys have been mentioned previously.

Brass and bronze are normally plated on lamps and other household goods to achieve an antique appearance or other cosmetic benefit. When considering the plating of an alloy it is important to be aware that alloy plating processes may be very difficult to control. Alloy baths can be of the acid or cyanide type, as well as other special compositions. The control problem with alloy plating is that there are two or more metal concentrations to monitor in the solution. These may or may not affect the deposit alloy depending upon the other chemicals used. However, it should be recognized that alloys will provide in many cases a combination of properties that may not be available from one metal alone.

VIII. RELATED FINISHES

A. Anodized Coatings

Anodizing is a process that is opposite to electroplating in that the part being processed is made anodic (hence, its name). The process works by anodic oxidation of the base metal. It is used mostly for aluminum, but also to some extent on magnesium and titanium.

A typical example, and the one in widest commercial use, is the anodizing of aluminum. Aluminum by itself will corrode in air, forming extensive white corrosion products. Anodized aluminum has a homogeneous, tightly adherent, and dense film that protects the underlayer of aluminum from corrosion.

A typical anodic coating is somewhat porous. It may be sealed by hot water treatment to augment corrosion protection. The building industry uses anodized aluminum almost exclusively for door and window frames on residential and industrial buildings. The porous anodic film is frequently dyed to match other trim. This dyed film is then finally sealed to provide the augmented corrosion resistance noted above.

B. Black Oxide Coatings

Black oxide coatings are used for ferrous parts. They are applied by simple immersion; that is, no electrolyte of the part is required. The solutions used are highly alkaline and usually contain nitrates or nitrites. The black oxide coating in itself is not a good corrosion barrier; it is somewhat thin and porous. The coating is frequently sealed with an oil or wax in order to extend the life of the parts. Black oxide is commonly used on non- critical areas of machine, tool, and optical parts.

C. Chromate Coatings

Chromating is a surface conversion process that is used on aluminum, brass, cadmium, copper, and zinc. It provides increased corrosion resistance to the surface of these metals. The chromate coating process is usually nonelectrolytic (although one anodizing process needs a chromate bath) and occurs by simple immersion of the part in a solution of chromic acid and other salts. The chromate film is usually the last step in the plating process. This film can also provide color to the plated metal. Available chromate colors are clear, blue, yellow, green, brown, gold, and iridescent.

D. Electroless Plating

It is possible to deposit a metal on a substrate without the use of an electric current. The most common method is by a process known as electroless plating. In electroless plating the metal is reduced to the metallic state and deposited onto the substrate by the use of a reducing agent, such as sodium hypophosphite. Deposits of 0.0040 in. or greater may be obtained by this method. It should be recognized that the deposited metal contains an appreciable amount of phosphorus and is thereby different from metal deposited by a mirror-making process.

The primary advantage of electroless plating is that the deposit is not dependent upon current density, polarization, or throwing power. An electroless coating is uniform in thickness and composition without the limitations that apply to electroplating. A secondary advantage is the stability of the bath, which does not deposit metal for long periods of time unless a receptive substrate is present. This is also in contradistinction to a silvering or mirror-making process.

The most common metal plated electrolessly is nickel. Electroless nickel is used on dies, molds, valves, and other parts where a corrosion-resistant and good wearing surface is required. Although electroless nickel possesses similar properties to hard chrome, it is not to be confused with it for severe wear applications.

Electroless plating is also used as the first metallic layer for nonconductors. Plastic parts have become an important part of engineering design. A thin layer of either copper or nickel is electrolessly plated prior to normal electroplating. This makes the plastic surface electrically conductive so that the desired thickness of plate can be achieved by electroplating.

E. Electropolishing

Electropolishing is a method used to remove small burrs, surface scratches, and imperfections, as well as to brighten a metal surface. Such metals as copper, steel, and stainless steel are frequently electropolished to improve their surface characteristics. Electropolishing is much less expensive than manual polishing, and it should be remembered that manual methods will remove more metal, but mayor may not provide a better surface. The depth and nature of the undesired imperfections will decide which process should be used.

Eletropolishing is done in an acidic bath and has the opposite polarity of electroplating. In electropolishing the parts being treated are made anodic. A very small amount of metal is removed, mainly the micro high current density peaks of scratches, thus improving the smoothness and brightness of the metal part.

Eletropolishing is an optimum way to pretreat parts prior to electroplating to achieve a superior finish. Usually, however, electropolishing is used as the final finish on a nonplated base metal. Used prior to electroplating it may add to the total cost to such an extent to become prohibitive.

F. Galvanizing

Galvanizing is a hot-dip method of applying a coating of zinc onto ferrous substrates. The primary reason for a galvanized coating is for corrosion protection as the zinc provides a sacrificial surface to the ferrous base.

Items such as nails, reinforcing rods, anchor bolts, pipe and pipe fittings, refuse containers, and guardrails are typically galvanized. These parts require only the protection of zinc and not the additional luster that zinc electroplating can provide.

As with electroplating, any part to be galvanized must first be cleaned and activated. Galvanizing is accomplished by dipping the parts into zinc metal. At the high temperature used, three distinct zinc layers tend to form. These provide the base metal protection.

G. Phosphate Coatings

Phosphating is a process of producing an immersion coating on ferrous parts. It is done in a solution of phosphoric acid and metallic compounds at elevated temperatures. The two main types of coatings are zinc phosphate and magnesium phosphate, although iron phosphate is also used.

The phosphate coating is somewhat corrosion resistant and porous and granular in structure. It is almost always sealed with a wax or an oil to provide atmospheric protection. Due to its porous nature phosphating is also frequently used to produce a tough adherent base for painting. Phosphating is usually applied either by spray or by dipping onto articles, such as nuts, bolts, barrels, and other miscellaneous hardware.

IX. A NOTE ON DIRECT CURRENT POWER SUPPLY

The direct current used in the plating process can be supplied by either a low-voltage generator or a rectifier. At one time the low-voltage generator was used exclusively as the plating power source. These generators have been largely replaced with rectifier units.

to cut down on the high initial cost and the maintenance required during operation of the generators.

The dc power supply has undergone as much development over the years as the electrochemical process. In the early days of electroplating, around 1920, generators were the only available source of dc power. By 1950 the rectifier had almost exclusively replaced the generator due to its many advantages.

A rectifier is a device that converts alternating current from the plant source into direct current that is used in the plating process. A rectifier consists mainly of a trans-former to reduce the voltage, diodes to convert the current to dc, a voltage and current control for the output, overload protection, and a cooling device. Silicon is the most common material used in the diodes. Several diodes are used in order to handle the cur- rent load. Heat is generated during operation of a rectifier. This heat must be removed, and either fan or water cooling may be used.

When specifying a rectifier for electroplating it is important to specify a ripple of 5% or less. Several of the plating processes will not operate properly with a higher ripple factor.

Another factor to be considered when specifying a rectifier is the current wave form. A rectifier may be built to put out either a half-wave or full-wave current. It is important to use only a full-wave unit since many of the processes, especially chromium plating processes, will not operate properly with half-wave.

All rectifiers used in electroplating have a variable output control. Both tap switches and infinitely variable controls can be used. Fixed output units are available; they are somewhat less expensive, but are obviously not desirable due to the ever-changing load factors of a busy plating shop. Other controls that are available on modern rectifiers include automatic voltage, current, and current density control. These special options are becoming increasingly more popular as they provide a consistent output control for the plater.

The commercial use of a totally new power source, the pulse rectifier, was introduced in 1978. A pulse rectifier is essentially a switching device that turns the dc output on and off at millisecond intervals. It has a high-frequency square wave output that has been used to solve many deposition problems and has greatly improved the quality of electroplating. The important characteristic of a square wave output is that the rise time from zero power to full current is practically instantaneous. The power then remains on for a preset period of time, when it is then turned off for a preset period of time. Then the cycle repeats itself. This cycling can be set at intervals up to 1000 times per second.

A modern high-frequency square wave pulse rectifier has controls such that the output frequently can be set to the optimum conditions of the electroplating process. This optimum frequency is different for each process due to the specific electrochemical conditions associated with it. The pulse rectifier is effective due to its ability to control I polarization as well as the cathode film during deposition. This control has greatly improved throwing power, deposition rates, internal stress, and hardness of the deposit. Due to these advantages, pulse plating is finding wide acceptance in industry.

X. QUALITY CONTROL

Quality control is probably the most important single factor when considering high-grade electroplating. Due to the numerous variables, such as bath composition, time, temperacurrent density, and base metal, it is necessary to monitor and control all phases of the process. As mentioned earlier in this chapter, a simple zinc-plating system may process parts through four or more solutions. Each of these solutions as well as the intermediate rinses must be controlled with concern for the variables mentioned. High-quality deposits can only be expected if these variable factors are all controlled. Whether a part is to be processed in-plant or sent out to a job shop plater, it is common sense to assure that quality control procedures are used.

XI. COST OF ELECTROPLATING

In most cases the cost of electroplating or related finishing is low compared with the value of the manufactured part. Plating is used to provide properties that the part would not otherwise have and as such is well worth the investment. Frequently a plated steel part can replace a much more expensive fabrication using a more exotic base metal.

The major costs of metal finishing are labor, equipment, and chemicals, in that order. Such factors as the metal being plated, the deposit thickness, the shape of the part, and the batch size directly affect costs. The engineer can be sure, however, that electroplating represents an economical way to improve the quality of his design.