

Plating Resources, Inc., Darlene Martin
20-25 minutes

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

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)

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/ft ² (54-864 A/m ²)

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/ft ² (21.6-1076 A/m ²)

Full-Cyanide Formulation

Zinc metal	20 g/liter
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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/ft ² (21.6-1076 A/m ²)

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
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Total sodium cyanide	130 g/liter
Sodium hydroxide	20 g/liter
Sodium carbonate	15 g/liter
Temperature	20-35°C
	5-80 A/
Cathode current density	ft ² (54-864 A/m ²)

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
	20-400 A/
Cathode	ft ²
current density	(216-4320 A/m ²)

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.

<u>Bath Type</u>	<u>Rate of deposit per hour at 2 A/in.square</u>
Standard Bath.	0.0006 in
High Efficiency	0.0013 in.
Fluoride 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 300 A/ft²

current density (3240 A/m²)

High Efficiency

Chromic acid 150-190 g/liter

Sulfate 1.4- 1.8 g/liter

Catalyst A 3% by volume

Catalyst B 15 g/l

Temperature 48-65°C

Cathode 150-700 A/ft²

current density (1620-7560 A/m²)

Fluoride Bath

Chromic acid 150-190 g/liter

Sulfate 0.90-0.11 g/liter

Catalyst A 3% by volume

Catalyst B 15 g/l

Temperature 48-65°C

Cathode 150-1200 A/ft²

current density (1620-12960 A/m²)

The catalysts used, both fluoride and non-fluoride, 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 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 and 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/ft ² (216-1620 A/ m ²)

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/ft ² (54-1075 A/m ²)
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	2-90 A/ft ² (21.5-967.5 A/m ²)

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 electroforming 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/ft ² (107.5-1076 A/m ²)

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	Semi-oxidation resistant
Gold	Jewelry, dental, electrical	Oxidation resistant
Rhodium	Electrical	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.