METAL FINISHING SUPPLIERS' ASSOCIATION
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quality metal finishing guide

Tin and Tin Alloy Coatings

Volume I, No. 3

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INTRODUCTION

The Metal Finishing Suppliers Association, Inc. is a trade association of companies and individuals engaged in providing the metal finishing industry with the equipment, products and supplies used by that industry. A primary objective of the association, as stated in its By-Laws, is to promote the interest and further the welfare of its members and their customers while safeguarding the interests of the ultimate consumer. The Association along with other groups in the industry, has long realized that the public, the industrial buyer and the designer are not too well informed about metal finishing nor how to specify high quality coatings. When metal products are sold which are inadequately finished for long service life the result is harmful to all. Sales are retarded and competition by nonmetallic materials is promoted.

In 1960 the MFSA initiated action to upgrade the durability of metal finishes in a continuing program known as the "Quality Metal Finishing Project" or the "QMF". Its programs are aimed at:

1. Promoting the use of technically sound specifications or standards in cooperation with interested trade and technical societies.
2. Providing useful information to both producers and buyers of electroplated products through the medium of metal finishing clinics in the larger industrial centers.
3. Providing printed guides on established standards and specifications in condensed form readily usable by the design engineer, purchasing agent and others concerned with metal finishing.

   The present guide, the 4th in the series, like the others is a guide to the application of established standards to achieve a quality metal finish. Whereas the first dealt with copper–nickel–chromium finishes, the second with coatings of zinc and cadmium and their conversion coatings and the third with mass finishing, this volume presents information concerning the properties and uses of tin and its more common alloys. The information is presented in tables wherever possible to assist the reader in selecting the most suitable finish for his purpose.

One reason for the concern of the MFSA that high quality shall be achieved is that it is usually impossible to rate the quality of finished metal products by appearance alone. A coating which will preserve the eye appeal and utility of a metal article throughout its expected life may look exactly like one that is not thick enough to prevent corrosion when the part is put into service or possibly even before it leaves a dealer's shelves.

Much testing and evaluation had to be done to provide the technical data required before standards and specifications could be established for electroplated finishes. The MFSA wishes to acknowledge the valuable contributions of The American Society for Testing and Materials, the American Electroplaters' Society, the National Bureau of Standards, The Electrochemical Society, the Tin Research Institute and many industrial and independent laboratories which have participated in such programs for many years.

The QMF Project evaluates the status of existing and proposed quality standards, selects those that are supported by technically sound data, relates the specified quality level to various kinds and degrees of severity of service and then disseminates the information to those in industry who can and should use it. In additon, QMF provides information which can be used by producers to make it easier or less expensive to meet the standards, and to assist them in making recommendations to their customers, engineers or designers regarding the choice of finish. For example, it may be better to change to a different finish rather than to incur the expense of upgrading the present one. It may be more desirable to alter a design detail, which would facilitate the application of a more uniform finish, thereby lowering the cost, than to increase the thickness of the deposit to assure that a satisfactory thickness will be obtained in a recess or partially welded joint.

Quality

How much is quality worth?

Obviously, an industry can afford to pay more for improved quality of a given article than the amount spent on repair or replacement of defective units produced at an inferior quality level. Every unit which does not serve out its expected life with acceptable appearance and performance is a standing advertisement *against* further sales of the part. Good management requires that the right amount and type of quality finish be applied to guarantee the expected or promised service of the unit.

Tin and Tin Alloys

Tin metal is silver white, soft, ductile, nontoxic, with a low melting point, with excellent corrosion resistance in air, lubricity and the ability to form many useful alloys. Its utility has been known to man since prehistoric times. Copper artifacts coated with tin have been found dating back 2,000 years.

Hot dip tinning of iron began in the 14th century. In 1843, a British patent was granted for the electrodeposition of tin but it was not till after World War I that electrodeposited tin was able to compete technically or economically with the simple and well established hot dip method of coating. It was the need for economy of materials during World War II, however, that really accelerated the use of electroplated tin.

By far the largest use of tin is the plating of steel strip for the manufacture of "tin cans". It represents the largest single application in weight of product of any electroplated metal. Because of its very limited interest to platers in all other fields we will not attempt to describe the use of tin in this industry. Other uses, which utilize less tin, provide extremely valuable functions in the coating of copper conductor wires, electrical connectors, electronic components, fasteners, automotive accessories, food processing equipment and kitchen utensils.

The use of tin as an alloying element dates back to the "Bronze Age" but the application of tin alloy electrodeposits is a relatively recent development. While it is the nature of tin to alloy readily with many metals, the scope of this guide will permit us to consider only those alloys of tin with lead, nickel, zinc, cadmium and copper. Most of the applications for electrodeposited tin and its alloys are functional; however, tin–nickel, tin–copper (bronze) and bright acid tin are sometimes applied strictly as decorative finishes. The selection of a particular alloy in some instances would be very simple, if it were only necessary to choose between the use of tin or one of its alloys; however, the choice is complicated by competition with a diversity of metals and metallic coatings.

DESIGN FOR PLATING

The program to improve and control the quality of a metal product should start at the desk of the designer. Basic principles of mechanical finishing and electroplating impose important restrictions on the size and shape of components. The designer should know enough about these principles so that he can design to minimize costs of quality finishing while planning products which will have a long service life. Metal finishing processes are as complicated as metal stamping, casting or forging with which the designer is usually more familiar. Proper selection of finishes and processes offers many opportunities to improve quality, reduce costs, and increase production. ASTM Designation B-507 can provide the designer with helpful information.

Significant Surfaces

A most important term used when specifying metal finishes is "significant surface" because on many products the same standard of quality is not required at all points on the surface. The significant surfaces can be defined as those normally visible directly or by reflection which are essential to the appearance or serviceability of the article or which, if they are a source of corrosion products, can alter the appearance or performance of visible surfaces. Significant surfaces preferably should be agreed upon between purchaser and manufacturer and should be indicated on drawings. Furthermore points at which thickness measurements are to be made should be identified.

Design for Barrel Processing

Metal parts which are to be tin or tin alloy plated do not ordinarily require polishing with belts or wheels before plating. Those to be cleaned or smoothened are often treated by barrel finishing or tumbling or other vibrating processes. In designing to improve quality, consideration should be given to certain rules applicable to such processing, whether this be surface preparation or barrel plating:

- Avoid blind holes, recesses and joint crevices which can retain tumbling compounds and metal debris.
- Avoid intricate surface patterns which will be blurred by barrel finishing.
- Parts must be sturdy enough to withstand the multiple impacts of barrel rotation.
- Small flat parts which tend to nest together should be provided with ridges or dimples to prevent this.

- Design for good entry and drainage of solutions during rotation by using simple shapes.
- Significant surfaces must be exterior for barrel work in order to undergo proper mechanical preparation and cleaning or to receive their share of metal deposit. They should be convex, if possible, rather than recessed.

Design for Racking, Draining and Air Entrapment

There are design considerations other than the above for parts which are to be mounted on racks for processing in cleaning and electroplating tanks. Among them are the following:

- Products which would occupy a volume in processing tanks large in proportion to surface area should be designed to be plated in sections for assembly after coating.
- Consult the plating department to make certain that parts can be held securely on a plating rack with good electrical contact without masking any significant surface. Many difficult racking problems can be solved by design modification.
- Provide for good drainage of cleaning and other processing solutions from racked parts. Certain shapes tend to trap solution which then cause contamination by carryover, possible corrosion of the part and wastage of materials. Carryover also aggravates the problem of waste disposal. In design avoid rolled edges, blind holes and spot-welded joints. Provide drain holes in recessed areas.
- Avoid shapes which can trap air on entry into a processing tank if this air can prevent access of solutions to areas requiring treatment. Wherever air can be trapped, hydrogen or oxygen may also accumulate during cleaning and plating.

Design for Good Distribution of Electrodeposits

The most important factor determining the quality of a coating on metal parts is its thickness on significant surfaces. Fundamental laws of electrochemistry operate to prevent perfectly uniform deposition of an electrodeposit on a cathode of any useful shape and size. Portions of the work which are nearer to the anodes tend to receive a heavier deposit. Sharp edges or protrusions tend to steal a larger share of the current and receive a heavier deposit. The goal of the designer and the plater is to minimize thickness variations over significant surfaces. At the same time uneconomical wastage of metal by excessive build-up on non-significant areas must be avoided.

DESIGN FEATURES THAT INFLUENCE ELECTROPLATABILITY

The effect of the basic design of a product or component upon the effectiveness or durability of the plating used has been the subject of much study and research and many failures for which the plater has been blamed can be attributed to the original design.

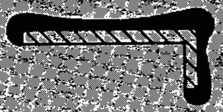
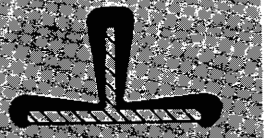
A major contribution to the plating industry was made by the Zinc Institute, Inc. when it sponsored a design study by Battelle Memorial Institute which has resulted in the establishment of basic design principles to be applied to zinc die castings.

The various shapes shown here provide the "do & don'ts" of design configurations and their relationship to electroplating quality.

Courtesy Zinc Institute, Inc.

INFLUENCE ON ELECTROPLATABILITY

The distribution of electroplate is indicated in an exaggerated fashion

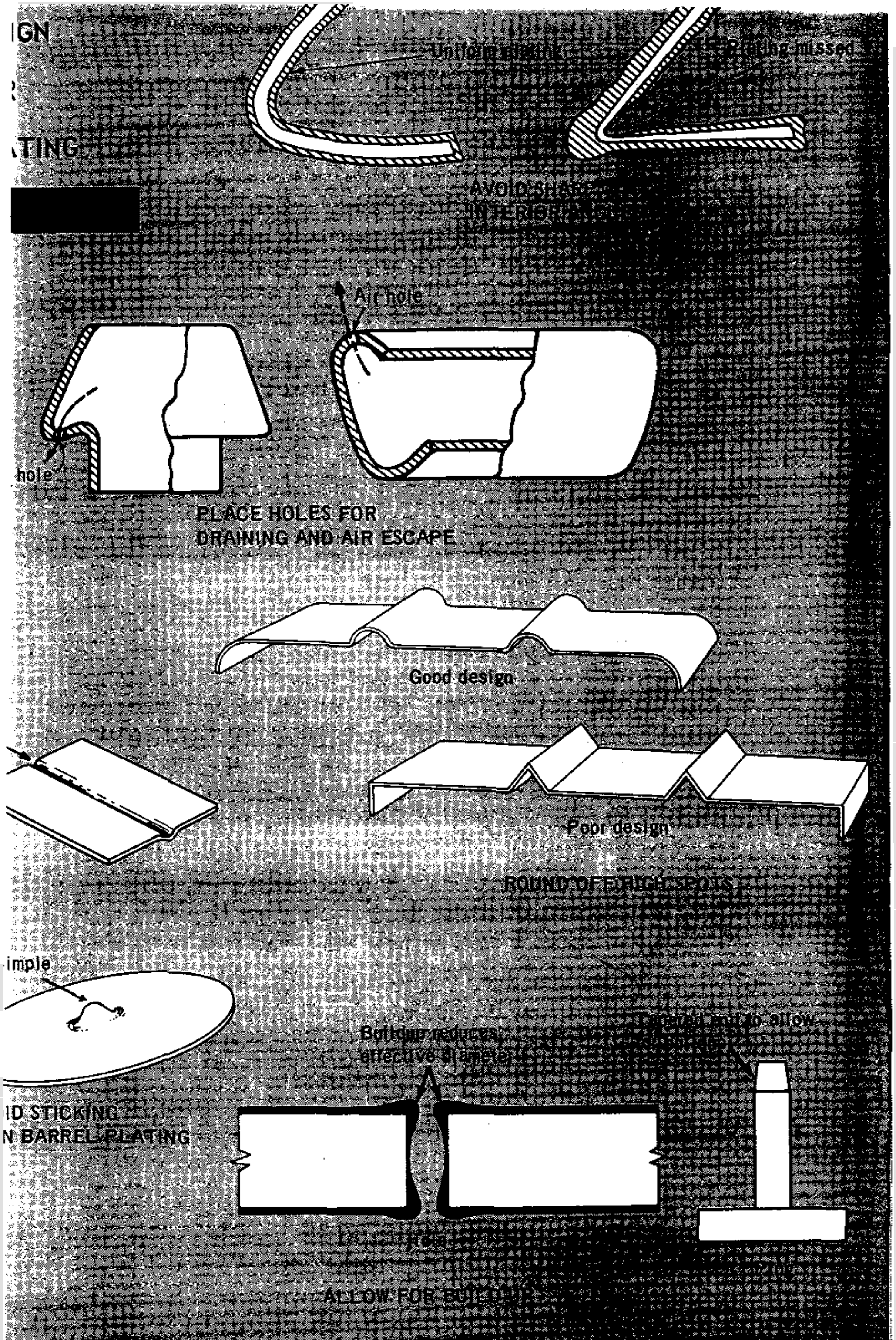
	Feature	INFLUENCE ON ELECTROPLATABILITY	Better Design
		Ideal shape. Easy to plate uniformly, especially where edges are rounded.	
aces		**Not as desirable as crowned surfaces. Use a .4mm/25.4mm (0.015 inch/inch) crown to hide undulations caused by uneven buffing.**	
		Undesirable. Reduced thickness at center areas and requires increased plating time for depositing a minimum thickness of durable electroplate. All edges should be rounded. (Edges that will contact painted surfaces should have a minimum radius of .8mm [1/32 inch]).	
		Large flanges with sharp inside angles should be avoided to minimize plating costs. Use a generous radius on inside angles and taper the abutment.	
		Narrow, closely spaced slots and holes reduce electroplatability and cannot be properly plated with corrosion-protective nickel and chromium unless corners are rounded.	
les		Must usually be exempted from minimum-thickness requirements. Where necessary limit **depth** to 50% of width. Avoid diameters less than 6mm (7/32 inch).	
tions		Increase plating time and costs for a specified minimum thickness and reduce the durability of the plated part.	

The distribution of electroplate is indicated in an exaggerated fashion

	Feature	INFLUENCE ON ELECTROPLATABILITY	Better Design
Flat-bottom grooves		Inside and outside angles should be rounded generously to minimize costs.	
V-shaped grooves		Deep, V-shaped grooves cannot be satisfactorily plated with corrosion-protective nickel and chromium and should be avoided. Shallow, rounded grooves are better.	
Fins		Increase plating time and costs for a specified minimum thickness and reduce the durability of the plated part.	
Ribs		Narrow ribs with sharp angles usually reduce electroplatability; wide ribs with rounded edges impose no problem. Taper each rib from its center to both sides and round off edges. Increase spacing if possible.	
Concave recesses		Electroplatability is dependent upon dimensions.	
Deep scoops		Increase plating time and costs for a specified minimum thickness.	
Spearlike juts		Buildup on jut will rob corners from their share of electroplate. Crown the base and round off all corners.	
Rings		Electroplatability is dependent upon dimensions. Round off corners and crown from center line, sloping towards both sides.	

IGN

TING



gs Courtesy "Materials in Design Engineering"

It is possible to estimate metal distribution ratios from models or mock-ups, but there are also empirical rules which can guide the designer to improved uniformity of thickness, hence to improved quality with greater economy. The sketches illustrate the influence of design as it has been developed from practical experiences:

- Avoid concave or perfectly flat significant surfaces. Convex or crowned areas receive more uniform coating.
- Edges should be rounded.
- Reentrant angles or corners should be filleted with a generous radius. Make such radii as large as possible.
- Blind holes must usually be exempted from minimum thickness requirements.
- Protruding fins, knobs and ridges tend to rob current from surrounding areas, hence should be avoided or reduced in height.
- Assist the plater by clearly marking significant surfaces in part drawings.
- Avoid use of a variety of basis metals in any one part to be plated. The contact of dissimilar metals may interfere by galvanic action with covering power or with adhesion of the deposit.

Because of the excellent throwing power of all of the commonly used tin electroplating baths, the problem of product design for plating is somewhat less difficult than it is for many of the other metals. Tin is soft and usually applied in thicknesses of less than .0005" (12.7 micrometres), thus avoiding some of the problems with interference fits, machining or grinding some of the especially difficult to plate heavy deposits of copper, nickel or chromium on parts that are not well designed. The same design rules, such as avoiding sharp corners, deep recesses, narrow slots and broad flat surfaces generally apply, although the absence of good design is not always as harmful as it is with less tolerant plating baths.

DESCRIPTION OF THE TIN AND TIN ALLOY ELECTRODEPOSITED FINISHES

Tin

a) **Matte:** Very pure (99.75 to 99.99%) white tin deposited from either acid or alkaline tin baths without brighteners.

b) **Bright Acid Tin:** Specular deposits of pure tin containing very small quantities of organic material plated from either the sulfate or fluoborate solutions.

Tin-Lead

a) **Solder Plate**: The nominal 60% tin – 40% lead blue-white "matte" alloy deposited from the fluoborate solution will be understood except where otherwise noted.

b) **Bright Solder Plate**: The 60% tin – 40% lead alloy plated from a solution containing brighteners to produce a lustrous blue-white metallic deposit.

c) **High Tin – Low Lead Alloy**: A nominal 93% tin – 7% lead alloy specified for special electrical applications to eliminate the risk of growing "tin whiskers", a phenomenon sometimes encountered with pure tin deposits.

d) **Low Tin Bearing Alloy**: The nominal 10% tin – 90% lead bearing alloy is used primarily as a bearing surface on aluminum and steel plain bearings for connecting rods.

e) **Terne Plate**: The 12% tin – 88% lead alloy is commonly used but the tin content of terne plate may run as high as 50% tin for some applications. Usually "terne plate" refers to hot dip coated steel, but it may also be used for electroplated and reflowed tin-lead electroplated steel. Originally tin was added to this alloy to permit the bonding of the coating to the steel, since lead does not alloy with iron.

in-Zinc

he nominal 78% tin – 22% zinc white matte alloy which sacrificially rotects steel by virtue of some "free" zinc in the deposit.

in-Nickel

he nominal 65% tin – 35% nickel intermetallic compound, which produces right slightly pink colored metallic deposits over a wide range of plating onditions. The alloy appears to have the composition of NiSn. Many of its roperties do not resemble those of either tin or nickel.

in-Copper

a) **Bronze**: The nominal 12% tin – 88% copper, which may be electroplated bright to produce a decorative gold color, or which may be deposited as a matte finish when used as a functional deposit.

b) **Speculum**: A nominal 45% tin – 55% copper alloy which produces bright electrodeposits and has been used as a substitute for chromium in England.

Tin-Cadmium

The nominal 25% tin – 75% cadmium deposits in a white matte finish similar to matte tin or tin-zinc. The superiority of tin-cadmium to cadmium depends primarily on its excellent throwing power which results in better distribution of metal.

The alloy may be obtained by either direct deposition from any alloy bath or by diffusion of two consecutively applied layers of tin and cadmium when held at 335°F (168°C) for 30–45 minutes. Laminar deposits are attractive to many platers, because they can be deposited from conventional existing electroplating baths.

SELECTING THE COATING

(See Centerfold)

PROPERTIES OF THE DEPOSIT

Corrosion Resistance

Tin

This property describes the resistance of the deposit itself to corrosion as opposed to "rust prevention" or "corrosion protection" of other metals and alloys. Tin, for example, is remarkably resistant to corrosion under atmospheric conditions. Deposits of tin in excess of .0005" (12.7 micrometres) are essentially pore-free, and, under similar conditions, would be expected to outlast zinc when each is electroplated over steel. Zinc is normally selected for such applications, however, only because zinc protects iron "cathodically" or "sacrificially." This results in the zinc corroding more rapidly at pores, or wherever iron may be exposed. Under similar conditions, if the iron or steel were coated with tin, the iron would normally corrode at exposure sites and the tin coating would remain intact. Similarly, tin is usually cathodic to copper* and its alloys, so that they are also protected primarily by encapsulation or the barrier action of the tin coatings.

When tin or alloys containing tin are "reflowed" or "hot-dipped" some tin will alloy with either ferrous or copper basis metals. This alloy layer has been reported to improve the protective value of such coatings. The protection also results from a reduction in the number of pores due to the reflowing as well as greater protection at the remaining pore sites.

The relatively slow rate of attack of the atmosphere on tin and its cathodic reaction when combined with more active metals permits tin to be used as either an undercoating or a top coating with zinc or cadmium to selectively

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*Freshly deposited tin is usually anodic to copper, but tin soon forms a protective oxide coating in air that prevents it from protecting copper sacrificially.

improve the benefits of either. When used as a top coating the tin tends to protect the zinc from attack by the atmosphere. Tin over zinc improves the resistance of zinc to marine atmospheres, and tin over cadmium improves the resistance of cadmium to industrial atmospheres. The use of tin under zinc and cadmium tends to weaken the zinc-iron or cadmium-iron corrosion couple, thus reducing the rate at which the active metals corrode. The covering power and throwing power of the alkaline tin baths are superior to the best zinc or cadmium baths, which means that recesses are protected better (i.e. with a higher proportion of the average thickness of the deposit), that porosity is reduced, and that the total thickness of deposited metal can be reduced without sacrificing corrosion protection. Of course, these advantages are offset by the inconvenience and added cost of processing the work through extra operations and the need to maintain another plating bath. In spite of these disadvantages there are occasions when it may be desirable to use tin coatings with zinc or cadmium deposits to improve the corrosion resistance of a complex or critical part, or to economize on the total weight of deposited metal.

Tin-Zinc and Tin-Cadmium

Only the tin alloys containing zinc or cadmium are effective in protecting ferrous and copper base metals cathodically. As long as the zinc content of the 78% tin – 22% zinc alloy does not drop below the 8% level, which represents a eutectic alloy, there will be some "free" or uncombined zinc available to protect the exposed iron. The 75% cadmium – 25% tin alloy contains an ample surplus of free cadmium, and even a 50% tin alloy has been recommended for its excellent protective value. As might be expected, tin-zinc performs best in industrial areas, while tin-cadmium is preferred in marine environments.

Tin-Lead

Tin alloys containing lead are all very resistant to atmospheric corrosion and Terne plate has been used successfully for years as a roof flashing in industrial atmospheres. High lead alloys are particularly resistant to the action of dilute sulphuric acid, such as that used in storage batteries, due to the very limited solubility of lead sulfate. The solder coatings, used to protect circuit boards during the copper etching operation, resist all of the commonly used etchants except ferric chloride and cupric chloride.

Tin-Nickel

Tin-nickel behaves like a noble metal in its resistance to strong oxidizing acids such as nitric acid. It is the only low cost coating available as an etch-resist for printed boards, that will resist all of the etchants used to remove the unwanted copper from the boards. It is resistant to all atmospheric conditions, and is used in place of chromium as a decorative finish.

Tin-Copper

The tin-copper alloys have fairly good resistance to atmospheric corrosion but, like their metallurgically prepared counterpart, they do tarnish, and, therefore, are usually lacquered. The higher tin alloy, speculum, is more resistant to tarnishing than bronze and is sometimes used without the lacquer finish.

Conversion Coatings

The resistance of tin and its alloys to atmospheric corrosion and tarnishing is assisted by very thin oxide coatings that tend to retard further oxidation. The use of conversion coatings and passivating treatments are reported to be beneficial, particularly in the cases of tin-zinc and tin-cadmium. The need for conversion coatings on the tin alloys is not as great as it is with pure zinc and cadmium, since the presence of tin in the coatings tends to retard the severity of attack on the more active metals. Chromate and phosphate coatings are sometimes used on tin electrodeposits to prevent fingerprinting, and to retard the tendency to tarnish. Bright tin benefits more from conversion coatings than matte tin, probably because of the smoothness of the surface which facilitates the formation of continuous films. Chromate and phosphate coatings may be specified advantageously as preparation for subsequent painting or lacquering.

SOLDERABILITY

Tin

Tin and the tin alloys must be counted among the most readily solderable coatings. The basis for this favorable property lies in the fact that tin is the critical component of almost all solders. Not only does the electrodeposited tin tend to alloy with the solder readily, but it also alloys readily with most base metals. The result is a strong metallurgical bond.

If the electrodeposited tin is reflowed prior to the soldering operation, the tin will have already formed an intermetallic alloy layer with the base metal, thus decreasing the time required to form a bond between the parts being joined. It is apparent, therefore, that the time required for the soldering operation can be divided into two phases. First the solder must melt, and then the molten metal must "wet" the basis metal. In the reflowing operation, the basis metal is "pre-wet" by the tin or tin alloy, thus eliminating that phase of the soldering operation. Reflowing serves as a very valuable quality control test since poor adhesion is exposed and reflowed metal gives positive assurance that the surface will be solderable.

Other characteristics of electrodeposited tin that contribute to its excellent solderability are a low melting point, 450°F (232°C), the purity of the deposited metal and the excellent throwing power of the bath. While tin can alloy with many metals at temperatures below its melting point, the alloying action is accelerated when tin is in the molten state. An advantage of electrodeposited tin over hot dipped tin lies in the fact that a tin deposit remains pure, while in the hot-dip process the molten metal tends to pick up increasing quantities of basis metals until it must be discarded. Many of the contaminating metals tend to cause weak or brittle solder joints. Uniformity of electrodeposit thickness tends to provide uniform solder joints.

Because zinc alloys so readily with tin, it is essential that a barrier coat of copper or nickel be used between the tin and zinc-containing basis metals. Likewise it is essential to use a barrier coat of nickel over aluminum regardless of the preparatory system used, prior to depositing tin or tin alloys. Most barrier deposits should be .0001" (2.54 micrometres) thick. Bright tin solders satisfactorily, but, at the melting point, the included organic materials may cause a slight bubbling in the region just beyond the area over which the solder has spread. This effect is normally considered only a cosmetic defect.

Tin-Lead

Of all the electroplated coatings, it is safe to say that none excel the "solder" alloy for the ease at which it may be soldered. This does not mean that it is always the best deposit for all applications that require soldering, but, in general, it has more favorable characteristics than any other deposit. It melts at the lowest temperature, namely 358°F (181°C). It should be noted that the nominal 60% tin – 40% lead alloy includes the eutectic alloy which contains 63% tin. Therefore, there is almost no solid phase present at the melting point and it solidifies instantaneously on cooling, thus avoiding the danger of "cold" joints. Bright solder, unlike bright tin, is not prone to bubbling at the periphery of the solder flow area, possibly due to its lower melting point.

Tin-Zinc

This alloy must be ranked with tin and solder as among the most readily soldered coatings, and in some tests it has demonstrated superior retention of solderability on aging. Like tin and solder, its aging performance is usually improved by the use of copper or nickel undercoatings, especially over brass.

Tin-Cadmium

Although cadmium is frequently specified because it is considered to have excellent solderability, tin-cadmium usually exhibits better solderability than cadmium itself.

Tin-Copper

Unlike the preceding alloys, bronze is not considered to be a soluble coating, because it does not flow into or fuse with solder at soldering temperatures. Its solderability is excellent, however, and it can be classed with copper as one of the most solderable metals, when freshly deposited or properly activated. Its solderability is readily preserved by a deposit of tin or solder.

Tin-Nickel

Although it can be readily soldered when freshly deposited, it has produced a wider scatter of solderability test results than any of the alloys previously discussed, and thus it probably rates as the least solderable of these alloys. Like bronze, it is not a soluble coating. Fortunately, however, its solderability can be improved by the application of a thin coating of tin, gold or solder plate, and the retention of solderability of such coatings is very good. The best coating for preserving the solderability of tin-nickel is a "flash" (1.0–1.5 microinches) of gold. This combination of deposited metals not only produces deposits that solder well and maintain their solderability for long periods of time, but it also ranks favorably in wear resistance, appearance and contact resistance with all competitive coatings.

TOXICITY

By any standards, tin must be ranked among the most widely used metals in the food handling, packaging and processing industries. Any of the pure tin deposits may be safely used in contact with neutral and mildly acidic foods; however, for low pH foods such as citrous fruits it is customary to use a protective lacquer over the tin to reduce the rate of attack.

Alloys containing lead or cadmium are definitely not acceptable for use in contact with food. While zinc is not rated as a poisonous metal, its use even in an alloy with tin would not be considered acceptable for most food handling equipment. Alloys of cadmium should not be welded, and good ventilation is essential if tin-zinc coated parts are to be welded. It should be noted, however, that tin and tin bearing alloy coatings tend to interfere with the strength of welded joints. Spot welding of tin plated steel is performed successfully, if the tin is not too thick – probably not over 100 microinches (2.54 micrometres).

Tin-nickel and bronze, because of their passivity, (like stainless steel or chromium), are sometimes used in decorative tableware. Often these alloys are protected by lacquer, although this is not always necessary in the case of tin-nickel.

ELECTRICAL PROPERTIES

Tin

As deposited, tin does not have as low a value of contact resistance as zinc, cadmium or gold, but when it is deposited in adequate thickness, (5–7.5 micrometers), it may retain a low value for a longer period of time. This is probably due to the fact that tin forms a very thin protective oxide that retards further oxidation and which may be readily broken to expose fresh tin when making a sliding contact. Bright tin, due to greater hardness and wear resistance, is preferred for such service. The use of tin on aluminum busbars demonstrates the value of tin in preserving low contact resistance on a metal well-known to be one of the best conductors of electricity. Without a deposit of tin, however, aluminum would soon oxidize to form a surface layer that would not pass any current at low voltages.

Tin-Zinc and Tin-Cadmium

These alloys both demonstrate low contact resistance when freshly deposited and retain this property well because of their corrosion resistance and their tendency to resist the formation of bulky corrosion products.

Tin-Lead

Solder plate generally demonstrates poorer electrical contact performance than pure tin because of the greater resistance of lead. The alloy also forms a tenacious protective oxide film but this film is thin and can be readily broken. It has been reported recently that bright tin-lead has served satisfactorily on the tabs of circuit boards, where contact must be made by sliding the tabs between spring contacts.

Tin-Copper

Bronze has a higher electrical resistance than either tin or copper, but in spite of this fact it may still be a superior surface for contacts. The reasons for this apparent anomaly lie in the fact that bronze is harder than tin or copper, demonstrates good corrosion resistance without the production of harmful corrosion films, and that bronze has a high resistance to arcing damage or welding of mating terminals.

Tin-Nickel

While tin-nickel probably exhibits the poorest electrical contact performance when used alone, it can be transformed into one of the best contact surfaces by the use of a thin deposit of gold. Bright acid tin over tin-nickel deposits also tends to greatly improve the usefulness of tin-nickel in this service.

HYDROGEN EMBRITTLEMENT

As in all electroplating operations, the deposition of tin and its alloys can lead to hydrogen embrittlement of hardened high strength steels. This condition may result from the hydrogen that is generated in acid pickling or activation of the basis metal or in cathodic alkaline cleaning. Even if these operations could be avoided completely, it would not be possible to completely avoid the discharge of a small amount of hydrogen at the cathode during the plating process, even though most of the processes for plating tin and its alloys are quite efficient.

It is essential, therefore, to follow the standard procedures for relief of hydrogen whenever high carbon or high strength alloy steels having a hardness greater than 35 Rockwell C must be plated. This usually entails baking the parts at 375°F (191°C) for four hours. Although tin-lead is not generally specified for such applications, it should be noted that the melting point of the 60% tin – 40% lead alloy is only 358°F (181°C) and the deposit would be reflowed during the bake-out operation.

It is possible to achieve some hydrogen embrittlement relief at 300°F (150°C), and thus avoid the reflowed condition if it is undesirable, although it would be necessary to obtain approval of the appropriate agency for such a deviation.

COVERING CASTINGS

Tin

All of the tin and tin alloy electroplating baths demonstrate exceptionally good covering and throwing power. It would be difficult, however, to find any plating baths equal to the alkaline tin baths in covering and throwing power. For this reason, the alkaline tin processes are usually favored for barrel plating of cast and malleable iron because of the low current densities that are normally used in this type of electroplating.

Tin-Zinc and Tin-Cadmium

Both of these alloys demonstrate superior coverage and throwing power to corresponding zinc and cadmium deposits. Indeed, these advantages account for the superior performance of these tin alloys in corrosion resistance on many complex shapes and difficult-to-cover castings.

Tin-Lead and Tin-Nickel

While these alloys are not quite as effective as those plated from alkaline solutions in covering cast and malleable iron, they are capable of obtaining adequate coverage when reasonable care is used in the preparation of the castings to avoid over-etching or over-pickling prior to plating.

Tin-Copper

Bronze has excellent covering and throwing power. Its primary functional application requires the covering of iron castings and forgings that require selective stop-off of some areas during nitriding or carburizing. Its ability to protect recesses better than the best throwing copper deposits is amply demonstrated.

FORMABILITY

Tin and its alloys are all readily formable. Most can be formed safely at any normally specified thickness of deposit. The possible exceptions to this statement are the bright deposits of tin and tin-lead which may become too brittle for good forming, if the deposits contain excessive amounts of brightener, or if the deposits exceed normally specified thicknesses. Tin-nickel and tin-copper are harder than the other deposits and more prone to be brittle but they are almost always more malleable than bright nickel in nickel-chromium decorative deposits, which are frequently formed.

Tin and tin-lead deposits on wire are sometimes brightened by die burnishing, a process of drawing the wire through a die that is slightly smaller than the coated wire. The process is quite effective, but stresses can be set up in tin, if the reduction is too severe, that reduce the fatigue strength and ductility of the copper wire.

SPECIFYING THE COATING

Tin

Having selected tin as the coating for a particular application, it is now necessary for the designer to specify the type of deposit, thickness, porosity tolerance, adhesion, solderability test requirements, temperature effects, risk of phase transformation (tin pest) or tin whiskers.

Thickness

Because tin is normally cathodic to iron and copper, its value as a corrosion barrier depends upon the continuity of the coating. Deposits less than .0005" (12.7 micrometres) thick are not likely to be completely pore-free on normal commercially finished basis metals. When tin is specified primarily for corrosion resistance, the common practice is to provide as heavy deposits as practical. For example, deposits .010" – .020" (254 – 381 micrometres) thick are plated on paper mill beater bars and used for breaking up pulp in the manufacture of paper. There are very few applications which justify the use of such heavy deposits, however, and TABLE II shows suggested minimum thicknesses for quality tin coatings for various service conditions. It should be noted that most applications requiring tin coatings have corrosion requirements that are classified as mild or moderate.

No effort to differentiate between the various types of pure tin coatings will be made, since the suitability of any coating specification depends entirely on the ability of the coating to pass the performance tests and it is intended to provide safe minimum standards that are valid for any tin deposit. Therefore, whether the deposit is matte or bright, it should conform to the suggested standards for thickness. The bright acid tin deposits normally perform better in salt spray corrosion tests than any of the matte tin deposits, but none of the published specifications, to date, recognize any difference between them. Likewise, because tin is cathodic to almost all of the commonly used base metals and undercoating metals, the same thicknesses should be applied to any of the commonly plated basis metals. The use of a copper or nickel undercoating does not justify the use of thinner tin deposits.

Comparison with Other Thickness Standards

The suggested standards listed in TABLE II provide the designer or purchaser of electrodeposited tin with a satisfactory guide for minimum thickness requirements for some of the more common applications and corrosion conditions. TABLE III shows the minimum thickness of tin specified or recommended by several of the most frequently used government and trade specifications.

TABLE II

SUGGESTED STANDARDS FOR QUALITY TIN COATINGS

Service Condition	Min. Thickness (mils) (micrometers)	Thickness Range (mils) (micrometers)	Typical Applications
VERY MILD – Little or no exposure to atmospheric conditions.	0.05 1.3	.05 – 0.1 1.3 – 2.5	Insulated copper wire. Pistons and other lubricated machine components.

MILD – Exposure to relatively clean indoor atmospheres.	0.1 2.5	0.1 – 0.2 2.5 – 5	Connectors, wires, etc. plated primarily for immediate solderability or where storage periods are short.
MODERATE – Exposure to average shop and warehouse atmospheres.	0.15 3.8	0.15 – 0.3 3.8 – 7.6	This range is considered best for any parts that must be reflowed. Connectors, circuit boards, wire, busbars. Deposits heavier than .3 mils may dewet.
	0.3 7.6	0.3 – 0.5 7.6 – 12.7	Connectors, fasteners, busbars, wire, transformer cans, chassis frames, adequate for good shelf life and in service.
SEVERE – Exposure to humid air, mildly corrosive industrial environments.	0.5 12.7	0.5 – 1.0 12.7 – 25.4	Connectors, wire, gas meter components, automotive air cleaners. Adequate as a nitride stop-off.
VERY SEVERE – Exposure to seacoast atmospheres, contact with certain chemical corrosives.	1.0 25.4	1.0 – 5.0 25.4 – 12.7	Water containers, oil drilling pipe couplings.

TABLE III

PUBLISHED SPECIFICATIONS FOR ELECTRODEPOSITED COATINGS OF TIN

Sponsor	Specification	Class or Type	Minimum Thickness (mils) (micrometers) On Steel		On Copper	
ASTM	B-545-83	SC 1	0.2	5	0.2	5
		SC 2	0.4	10	0.3	8
		SC 3	0.8	20	0.6	15
		SC 4	1.2	30	1.2	30
MILITARY	MIL-T-10727B	Type I (Electrodeposited)	As specified by contract			
		Type II (Hot Dipped)				

The application guide suggests thicknesses for the following service conditions:

Service Condition	Thickness Range (mils)	(micrometers)
Tin flash for soldering	0.1 - 0.25	2.5 - 6.4
Prevention of galling or seizing	0.2 - 0.4	5 - 10
Prevention of corrosion of basis metals	0.3 min.	7.6
Resistance to formation of case during nitriding	0.2 - 0.6	5 - 15

SAE	AMS2408B		As specified by a suffix number following the specification, for example:	
		AMS2408-1 designates	0.1 - 0.3	2.5 - 7.6

	AMS2408-6 designates		0.6 - 0.8	15 - 20
	A tolerance of 0.2 mils (5 micrometres) is understood unless otherwise specified			
	Flash electrolytic		Approx. 0.1	2.5
FEDERAL	QQ-T-435 B(1) (for both hot-dipped or electro-tinplate)	25	0.013	.3
		50	0.028	.7
		75	0.042	1.1
		100	0.054	1.4
MILITARY	MIL-STD-275 & MIL-STD-1495 (Printed wiring for electronic equipment)		0.3	7.6

TABLE IV

PUBLISHED SPECIFICATIONS FOR ELECTRODEPOSITED TIN ALLOYS

Alloy	Sponsor	Specification	Class or Type	Minimum Thickness (mils)	(micrometers)
Tin-Lead 60% 40%	IPC	IPC-ML-910		0.3	7.6
	MILITARY	MIL-P-81728A		0.3	7.6
	MILITARY	MIL-L-46064			
	MILITARY	MIL-STD-275 (Printed wiring for electronic equipment)		0.3	7.6
	ASTM	B579		Steel	
				(mils)	(micrometers)
			SC 1	0.2	5
			SC 2	0.4	10
			SC 3	0.8	20
			SC 4	1.2	30
				Copper	
				(mils)	(micrometers)
			SC 1	0.2	5
			SC 2	0.3	7.6
			SC 3	0.6	15
			SC 4	1.2	30
Tin-Cadmium 25% 75%	MILITARY	MIL-P-23408A	1	0.5	12.7
			2	0.3	7.6
			3	0.2	5
Lead-Tin 85% 15%	ASTM MILITARY	B-200 MIL-L-13808	SS Req. Hrs.	Agreement w/purchase	
		Thicknesses suggested for the listed salt spray requirement in hours per ASTM Method B117	24	0.24	6
			48	0.5	12.7
			96	1.0	25.4
			200	1.5	38

Tin-Zinc 78% 22%	SAE	AMS2420A 4. 3. 5 Plating aluminum for solderability		0.3	7.6

Alloy	Sponsor	Specification	Service Condition[1]	Minimum Thickness[2] (mils)	(micrometers)
Tin-Nickel 65% 35%	MILITARY	MIL-STD-275B For printed wiring use in electronic equipment		0.2	5
	ASTM	B605-82	Steel		
				(mils)	(micrometers)
			SC1	0.3	7.6
			SC2	0.6	15
			SC3	1.0	25.4
			SC4	1.8	46
			Copper		
				(mils)	(micrometers)
			SC1	0.15	3.8
			SC2	0.6	15
			SC3	1.0	25.4
			SC4	1.8	46
Tin-Nickel	I SO	2179	3 (severe)	1.0	25.4
			2 (moderate)	0.6	15
			1 (mild)	0.32	8

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1) Choice of service condition to be subject to agreement between purchaser and supplier.

2) All ferrous or zinc base metals must be coated with a minimum of .0003" (7.6 micrometers) of copper except for mild service conditions. Bronze, nickel or tin may be substituted for copper on ferrous base metals by agreement between the purchaser and the supplier.

Porosity

The number of pores in electrodeposited tin decreases approximately in inverse proportion to the square of the deposit thickness. Above a thickness of 0.0005" (12.7 micrometres) only gross pits or defects originating in the basis metal are not completely sealed. The most common requirement for tin deposits is the ability to pass a required number of hours of salt spray without exposing more than a specified maximum number of corroded spots. Other quality control tests for porosity that have been used successfully involve exposure of the deposit to sulfur dioxide gas in a humid atmosphere, the ferricyanide-paper test, which reveals any exposed iron by the appearance of a blue color at each pore, and the hot water test which causes a rust spot to form at the site of any pore.

Adhesion

It is essential that all electrodeposits that are to be soldered have excellent adhesion. Deposits plated over oxidized or soiled surfaces cannot be successfully soldered. As soon as the coating reaches its melting point, or fusion with the solder begins, de-wetting will occur if the electrodeposit has not been properly bonded to basis metal. For this reason, one of the best adhesion tests of fusible electrodeposits consists of reflowing the deposit. Other specifications require bending the plated part repeatedly until it fractures, and then inspecting the fracture for signs of exposed basis metal. All of the adhesion tests for tin deposits, other than the reflow test, involve destruction of the deposit or the plated part.

Solderability

If tin deposits must be subsequently soldered, their solderability can be assured by requiring that the deposit be reflowed after plating, or, if this is not practical, that an agreed upon sample of each load be reflowed. Other tests for solderability require that the deposit be immersed in molten solder at standard conditions and be completely wetted within a prescribed period of time, or that a prescribed quantity of solder flow over a minimum area of the part at a controlled temperature in a standard period of time. Sound specification requires an agreement between the purchaser and the plater of the size of the sample from each lot to be tested and the suitability of the test selected for the type of work to be tested. (See ASTM B602.) The best test is usually one that most closely duplicates the actual soldering conditions for that particular part. The most common test in the printed circuit industry is the dip test, because it closely resembles the conditions that exist in "wave soldering".

To preserve solderability, it is essential to protect the surface of the tin from exposure to corrosive, humid or dirty atmospheres. This may be done by

TABLE I

TABLE I illustrates some of the uses of ten and its alloys and the properties that help to make each application successful. The letters refer to the preceding list of desirable properties.

//IDED								
vide a surface which will readily accept and maintain a lubricating film	To provide a "break-in" surface for closely fitted machined surfaces	k) To prevent fretting corrosion	l) To protect products from contamination	m) To protect food and drinks from contamination	n) To prevent seizing or galling	o) To reduce the torque required to apply load to threaded fasteners	p) To serve as a heat treat stop-off.	COMMENTS
			X	X				1) Steel is protected in cans, because tin is anodic to iron under anaerobic conditions. 2) The outside of cans must remain clean and attractive under a variety of storage conditions.
			X¹					1) Sulfur in rubber insulation may react with copper to corrode the copper and make the insulation more difficult to strip. 2) Tin assists in drawing operations.
								1) To prevent oxidation and corrosion of the aluminum in industrial and outdoor atmospheres. To reduce the effect of handling, storing and fabrication on contact resistance. 2) To eliminate incompatible metal couplings.
								1) Tin is effective in resisting corrosion by all copper etchants except ferric chloride. 2) Tin retains solderability longer than tin-lead under many conditions. 3) Bright tin is used on contacts to provide low contact resistance and wear resistance, for specific applications.
	X	X			X			1) Aluminum pistons are usually coated with an immersion tin deposit, while cast iron pistons are electroplated.
								1) On "plug-in" and other "wiping" contact connectors, wear resistance is provided by bright acid tin.
								1) Reflowed tin-lead (solder) is the most widely used etch resist for circuit boards. 2) Reflowed solder is resistant to all copper etchants, except ferric chloride and cupric chloride. 3) Reflowed solder provides the lowest soldering temperature of all etch resists. 4) Bright or re-flowed solder produces lustrous blue-white surfaces.
								1) Solder is used on connectors less frequently than tin because it is more prone to tarnish than pure tin.
								1) The High Tin — Low Lead alloy is used where the risk of tin whiskers must be avoided.
	X	X			X			1) The Low Tin Bearing alloy resists the formation of lead soaps from contact with breakdown products of lubricating oils. 2) Copper, antimony and other alloying elements are sometimes added to the tin-lead bearing alloys for the development of special properties.
		X			X	X		1) While tin-lead usually provides only barrier protection to ferrous and copper base metals, it is resistant to many chemicals and industrial atmospheres. 2) Bright or reflowed solder plate.
			X					1) Terne plate may be either hot dipped or reflowed electroplated steel.
								1) Excellent resistance to handling and perspiration. 2) The color of tin-nickel permits close matching of stainless steel components with easily machined brass parts plated with tin-nickel.
								1) Tin-nickel is favored as a decorative coating on instruments with complex shapes because of its pleasing color and the excellent throwing and covering power of the tin-nickel bath. 2) Valves and slides are plated because of the excellent wear properties of tin-nickel under light load conditions.
					X			1) Compatibility with stainless steel mating parts.
					X			1) Compatibility with stainless steel mating parts.
								1) Tin-nickel is resistant to all etchants used to strip copper from circuit boards. 2) Tin-nickel is usually flashed with gold or tin to improve and preserve solderability. 3) Because it serves as an etch resist equal to gold and can also provide excellent wear resistance on contacts, it provides a low cost—high quality coating.
			X	X				1) Because of its excellent throwing and covering power, tin-nickel saves racking and fixturing costs on complex shapes.
					X	X		1) The corrosion resistance of tin-zinc is better than cadmium in industrial atmospheres and better than zinc in marine air. 2) Tin-zinc is anodic to iron and finds its greatest use in preventing aluminum from becoming anodic to ferrous or copper base fasteners. 3) Chromate passivation is beneficial but not essential for many applications.
								1) Excellent throwing power permits difficult shapes to be electroplated satisfactorily with less risk of corrosion in recessed areas. 2) Solderability of tin-zinc is excellent, and the ability to retain solderability is outstanding. 3) Only cadmium approaches tin-zinc in combined corrosion resistance and solderability but at a greater cost.
								1) Tin-zinc is not only more protective than tin on ferrous alloys, but is reported to be much more resistant to "tin pest," the alpha phase transformation of gamma or white tin.
								1) Provides excellent corrosion resistance to salt spray with or without passivation. 2) Better throwing power than cadmium; provides more protection in threads for a given thickness. 3) Resistant to organic acids found in wood and other organic packing materials.
								1) Decorative gold color may be varied from red to white, but requires lacquer to prevent tarnishing.
								1) All decorative bronze finishes are usually applied over a bright copper or nickel undercoat.
							X¹	1) Excellent throwing power provides superior protection on complex shapes against carburizing and nitriding.
								1) Bronze is equal to or better than copper as a base for a reduced thickness of nickel and chromium. It is usually considered only during periods of nickel shortage.

TABLE I

TABLE I illustrates some of the uses of tin and its alloys and the properties that help to make each application successful. The letters refer to the preceding list of desirable properties.

To facilitate the selection of the best tin or tin alloy coating for any application, the designer must first establish all of the requirements expected of the coating. The following list includes many of the most common reasons for selecting tin or tin alloy electrodeposits:

METAL COATING	APPLICATIONS	a) To provide corrosion protection	b) To provide and maintain solderability	c) To provide a low coefficient of friction	d) To increase wear resistance	e) To provide a decorative finish	f) To provide a good base for paints, lacquers and other protective coatings	g) To reduce coating costs or to circumvent the use of another coating which may be in short supply	h) To provide and maintain low electrical contact resistance	i) To provide a surface which will readily adsorb and maintain a lubricating film	j) To provide a "break-in" surface for closely fitted machined surfaces	k) To prevent fretting corrosion	l) To protect products from contamination	m) To protect food and drinks from contamination	n) To prevent seizing or galling	o) To reduce the torque required to apply load to threaded fasteners	p) To serve as a heat treat stop-off.	COMMENTS
		PROPERTIES PROVIDED																
Tin	Tin plate for cans	x¹	x			x²	x						x	x				1) Steel is protected in cans, because tin is anodic to iron under anaerobic conditions. 2) The outside of cans must remain clean and attractive under a variety of storage conditions.
	Copper Wire	x¹	x	x²		x			x				x¹					1) Sulfur in rubber insulation may react with copper to corrode the copper and make the insulation more difficult to strip. 2) Tin assists in drawing operations.
	Aluminum Busbar	x¹,²	x			x			x¹									1) To prevent oxidation and corrosion of the aluminum in industrial and outdoor atmospheres. To reduce the effect of handling, storing and fabrication on contact resistanc 2) To eliminate incompatible metal couplings.
	Circuit Boards	x¹	x²		x³	x			x³									1) Tin is effective in resisting corrosion by all copper etchants except ferric chloride. 2) Tin retains solderability longer than tin-lead under many conditions. 3) Bright tin is used on contacts to provide low contact resistance and wear resistance, for specific applications.
	Pistons			x						x	x	x			x			1) Aluminum pistons are usually coated with an immersion tin deposit, while cast iron pistons are electroplated.
	Electrical Connectors	x	x		x¹	x			x									4) On "plug-in" and other "wiping" contact connectors, wear resistance is provided by bright acid tin.
Tin-Lead	Printed Circuit Boards	x²	x³			x⁴		x¹										1) Reflowed tin-lead (solder) is the most widely used etch resist for circuit boards. 2) Reflowed solder is resistant to all copper etchants, except ferric chloride and cupric chloride. 3) Reflowed solder provides the lowest soldering temperature of all etch resists. 4) Bright or re-flowed solder produces lustrous blue-white surfaces.
	Electrical Connectors	x¹	x			x		x										1) Solder is used on connectors less frequently than tin because it is more prone to tarnish than pure tin.
	Copper Wire, Etc.	x	x			x		x										1) The High Tin – Low Lead alloy is used where the risk of tin whiskers must be avoided.
	Bearings	x¹		x	x					x	x	x			x			1) The Low Tin Bearing alloy resists the formation of lead soaps from contact with breakdown products of lubricating oils. 2) Copper, antimony and other alloying elements are sometimes added to the tin-lead bearing alloys for the development of special properties.
	Fasteners	x¹	x	x		x²						x			x	x		1) While tin-lead usually provides only barrier protection to ferrous and copper base metals, it is resistant to many chemicals and industrial atmospheres. 2) Bright or reflowed solder plate.
	Gas Tanks	x	x				x						x					1) Terne plate may be either hot dipped or reflowed electroplated steel.
Tin-Nickel	Clock and Watch Components	x¹		x	x	x²				x								1) Excellent resistance to handling and perspiration. 2) The color of tin-nickel permits close matching of stainless steel components with easily machined brass parts plated with tin-nickel.
	Musical Instruments and Surgical Instruments	x¹		x²	x²	x				x²								1) Tin-nickel is favored as a decorative coating on instruments with complex shapes because of its pleasing color and the excellent throwing and covering power of the tin-nickel bath. 2) Valves and slides are plated because of the excellent wear properties of tin-nickel under light load conditions.
	Aircraft Brake Pistons	x			x¹					x					x			1) Compatibility with stainless steel mating parts.
	Mixing Valves	x			x¹					x					x			1) Compatibility with stainless steel mating parts.
	Circuit Boards	x¹	x²	x	x	x		x³	x									1) Tin-nickel is resistant to all etchants used to strip copper from circuit boards. 2) Tin-nickel is usually flashed with gold or tin to improve and preserve solderability. 3) Because it serves as an etch resist equal to gold and can also provide excellent wear resistance on contacts, it provides a low cost—high quality coating.
	Home appli. & Furn.	x				x		x¹					x	x				1) Because of its excellent throwing and covering power, tin-nickel saves racking and fixturing costs on complex shapes.
Tin-Zinc	Fasteners	x¹,²,³		x			x	x							x	x		1) The corrosion resistance of tin-zinc is better than cadmium in industrial atmospheres and better than zinc in marine air. 2) Tin-zinc is anodic to iron and finds its greatest use in preventing aluminum from becoming anodic to ferrous or copper base fasteners. 3) Chromate passivation is beneficial but not essential for many applications.
	Electrical Boxes and Cabinets	x¹	x²				x	x³										1) Excellent throwing power permits difficult shapes to be electroplated satisfactorily with less risk of corrosion in recessed areas. 2) Solderability of tin-zinc is excellent, and the ability to retain solderability is outstanding. 3) Only cadmium approaches tin-zinc in combined corrosion resistance and solderability but at a greater cost.
	Aircraft Landing Gear Members	x¹					x	x										1) Tin-zinc is not only more protective than tin on ferrous alloys, but is reported to be much more resistant to "tin pest," the alpha phase transformation of gamma or white tin.
Tin-Cadmium	Fasteners	x¹,²,³					x											1) Provides excellent corrosion resistance to salt spray with or without passivation. 2) Better throwing power than cadmium; provides more protection in threads for a given thickness. 3) Resistant to organic acids found in wood and other organic packing materials.
Tin-Cop. (Bronze)	Jewelry					x¹												1) Decorative gold color may be varied from red to white, but requires lacquer to prevent tarnishing.
	Household Furnishings					x¹												1) All decorative bronze finishes are usually applied over a bright copper or nickel undercoat.
	Gears and Shafts																x¹	1) Excellent throwing power provides superior protection on complex shapes against carburizing and nitriding.
	U/coat f/decor. chrom	x¹						x										1) Bronze is equal to or better than copper as a base for a reduced thickness of nickel and chromium. It is usually considered only during periods of nickel shortage.

providing a coating of protective organic material such as resin or stearic acid over the finished parts. Brass or zinc basis metals must receive a minimum thickness of 0.0001" (2.54 micrometres) of a copper or nickel undercoating before tin plating to prevent loss of solderability, due to the migration of zinc into the tin deposit. When the basis metal is copper or a copper alloy, or if these metals are used as an undercoating for tin or a tin alloy, the tin will slowly react with the copper to form a copper-tin alloy at the interface between the metals. At room temperature this reaction is very slow, but at elevated temperatures the reaction is rapid. It is essential, therefore, to assure that such parts are not stored in a location where they might be subjected to abnormally high temperatures, because the copper-tin alloy, by itself, does not provide a good base for soldering. As long as any free tin is available on the surface, however, the solderability will remain normally satisfactory.

Temperature Effects

Tin plated parts should not be used in service conditions that exceed 300°F (150°C) without determining the effects of such temperatures on the deposits or parts. While tin does not melt below 450°F (232°C), it may react with other metals to form alloys or with the atmosphere to form corrosion products. Service above 300°F (150°C) is possible but should be thoroughly tested out before specifying it.

If tin plated parts must be used at temperatures below the freezing point of water, 32°F (0°C), the tin deposit may be subject to a failure commonly known as "tin pest". "Tin Pest" describes a phase transformation of gamma white tin to a nonadherent powdery gray alpha form of tin. This problem may be prevented from occurring by alloying a very small quantity of bismuth, antimony or lead with the tin. A proprietary bath containing bismuth is available.

Whisker Growth

Electrodeposited pure tin, like cadmium and zinc, may grow thin needle-like crystals known as "whiskers" within a period after plating that may vary from a few weeks to several years. A whisker may measure up to .0001" (2.5 micrometres) in diameter, and grow spontaneously to a length of 0.375" (10mm). Conditions that tend to promote the growth of whiskers are compressive stresses and uniform temperatures for long periods of time. In most applications, these slender microscopic crystals would be unnoticed and harmless, but in closely spaced electronic circuits they are capable of carrying sufficient current at low voltages to cause serious short circuits or a corona discharge.

When the formation of whiskers is known to be a potential problem, the condition may be prevented by specifying that a small amount of lead be

included in the tin deposit. While 1 to 2
reduce the risk of whiskering, it is cust
alloy to assure that the alloy remains
conditions of electroplating to preven
quantities of antimony, copper or nick
reported to prevent the formation of wh

Reflowing a pure tin electrodeposit has
whisker formation, and deposits over .
less prone to form whiskers than thinn
pure tin electrodeposit in an inert gas
mize whisker growth.

TESTING T

Thickness

Nondestructive Methods

a) **Magnetic Tests** – Because ti
nonmagnetic, any of th
instruments suitable for testi
basis metals may be used t
normally accurate within 1
practice requires that the av
that any single reading tha
questioned. ASTM Designati
methods accepted by ASTM

b) **Direct Dimensional Measure**
tin alloys lend themselves
mechanical measurement su
ring gages, etc. The pro
dimension of a part befc
thickness by dimensional di
tin metals, care must be exe
rubbing of the surfaces wit
low readings resulting from

c) **Beta Backscatter Principle**
using this principle may be
deposits as well as normally
for measuring the thickne

providing a coating of protective organic material such as resin or stearic acid over the finished parts. Brass or zinc basis metals must receive a minimum thickness of 0.0001" (2.54 micrometres) of a copper or nickel undercoating before tin plating to prevent loss of solderability, due to the migration of zinc into the tin deposit. When the basis metal is copper or a copper alloy, or if these metals are used as an undercoating for tin or a tin alloy, the tin will slowly react with the copper to form a copper-tin alloy at the interface between the metals. At room temperature this reaction is very slow, but at elevated temperatures the reaction is rapid. It is essential, therefore, to assure that such parts are not stored in a location where they might be subjected to abnormally high temperatures, because the copper-tin alloy, by itself, does not provide a good base for soldering. As long as any free tin is available on the surface, however, the solderability will remain normally satisfactory.

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Electrodeposited pure tin, like cadmium and zinc, may grow thin needle-like crystals known as "whiskers" within a period after plating that may vary from a few weeks to several years. A whisker may measure up to .0001" (2.5 micrometres) in diameter, and grow spontaneously to a length of 0.375" (10mm). Conditions that tend to promote the growth of whiskers are compressive stresses and uniform temperatures for long periods of time. In most applications, these slender microscopic crystals would be unnoticed and harmless, but in closely spaced electronic circuits they are capable of carrying sufficient current at low voltages to cause serious short circuits or a corona discharge.

When the formation of whiskers is known to be a potential problem, the condition may be prevented by specifying that a small amount of lead be

included in the tin deposit. While 1 to 2% of lead is adequate to substantially reduce the risk of whiskering, it is customary to specify a 93% tin – 7% lead alloy to assure that the alloy remains sufficiently high in lead under all conditions of electroplating to prevent the formation of whiskers. Small quantities of antimony, copper or nickel in the tin deposit have also been reported to prevent the formation of whiskers.

Reflowing a pure tin electrodeposit has been shown to minimize the risk of whisker formation, and deposits over .0002" (5 micrometres) thick may be less prone to form whiskers than thinner coatings. Also, heat treatment of a pure tin electrodeposit in an inert gas atmosphere has been shown to minimize whisker growth.

TESTING THE FINISH

Thickness

Nondestructive Methods

a) **Magnetic Tests** – Because tin and all of the common tin alloys are nonmagnetic, any of the commercially available magnetic instruments suitable for testing nonmagnetic coatings over magnetic basis metals may be used to obtain quick measurements that are normally accurate within 10% of the measured thickness. Good practice requires that the average of several readings be taken and that any single reading that varies greatly from the majority be questioned. ASTM Designation B530-70 describes standard magnetic methods accepted by ASTM and AES.

b) **Direct Dimensional Measurement** – Functional deposits of tin and tin alloys lend themselves to all of the standard methods of mechanical measurement such as micrometers, calipers, plug gages, ring gages, etc. The procedure involves measuring the same dimension of a part before and after plating and finding the thickness by dimensional difference. In measuring the relatively soft tin metals, care must be exercised not to apply excessive pressure or rubbing of the surfaces with the measuring instrument to prevent low readings resulting from the burnishing effect.

c) **Beta Backscatter Principle** – Commercially available instruments using this principle may be applied to the measurement of very thin deposits as well as normally heavy deposits. This method is suitable for measuring the thickness of tin over copper, nickel or iron.

Particular care is required, when alloys are measured by this method, because differences in the alloy composition or the density of the deposit can result in significant errors. ASTM Designation: B567–72 describes this method.

Destructive Methods

a) **Coulometric Tests** – Commercial instruments are available which determine the thickness of tin and tin alloys on all of the common basis metals by this method. Caution must be exercised when measuring alloy deposits because differences in the alloy composition will result in significant errors. The method is applicable to very thin deposits and may be used to measure the moderate thicknesses that are usually specified for tin and its alloys. This method is defined in ASTM Designation B504.

b) **Microscopic Measurement** – The examination of carefully prepared cross sections of the electroplated deposit permits the direct reading of the coating thickness on metallurgical microscopes equipped with a filer eye piece. This method, described in ASTM Designation B487, has been widely used by the electroplater. It has the advantage of permitting delineation of several layers of plating and detection of alloying effects as well as showing the distribution of the deposits along a profile. Where there is disagreement in thickness measured by other methods, the microscopic method has been generally accepted as the referee test. Efforts are underway to replace the conventional microscopic method for this purpose by more accurate profilometer, interference or precise coating weight loss techniques. Each of these methods depends upon very carefully stripping a small spot on a plated surface without attacking the basis metal – using equipment similar to that used in the Coulometric test. The profilometer and interference methods provide direct measurement of the deposit thickness, while the coating weight loss method measures the weight loss from an accurately prescribed area from which the thickness may be calculated.

c) **Weight Loss on Stripping** – It is possible, by carefully stripping a coating from a basis metal and noting the difference in weight of the sample, to obtain an average thickness of the deposit. This information can be of value to the plater to help him to know how much metal he is depositing on a known amount of work. It does not show him how the coating is distributed, however, so this test is used in conjunction with one of the other test methods to accurately describe the thickness of the coatings.

Porosity

Due to the fact that tin and most of the tin alloys protect most basis metals by encapsulation rather than by favorable potential difference, freedom from porosity is very important to their protective value.

a) **Sulfur Dioxide Test** – This test is similar to the salt spray test in application and is suitable for use with tin and tin-nickel over ferrous basis metals. The samples are suspended above a weak solution of sulfur dioxide in a sealed cabinet for a period of twenty-four hours at 68°F ± 9°F (20° ± 5°C). Voids in the coating are exposed because iron corrosion products are formed at their location. The protective value of the coating is evaluated by counting the number of pores per unit area (5mm squares) on significant surfaces and finding the percentage of squares containing voids. This value can then be related to the serviceability of the part.

b) **Hot Water Test** – The test specimen is immersed in a thermostatically controlled aerated water bath at a temperature of 180° ± 5°F (82° ± 2°C), with a pH range of 6.0–6.5, for a period of 3 to 6 hours. Wherever iron is exposed, rust spots will appear on the surface of the coating. The coating is then evaluated by rating the number of spots per unit of area.

c) **Ferricyanide (Ferroxyl) Test** – The cleaned surface to be tested is covered by a piece of blotting paper saturated with a solution of sodium chloride and white gelatin for a period of ten minutes or more. The paper is then removed from the specimen and developed in a solution of potassium ferricyanide. Where iron is exposed, a blue spot appears on the paper. For best results the test must be performed in dust free surroundings. By duplicating the test on the same area, it is possible to eliminate the spots caused by extraneous airborne particles of iron, because only the spots which can be duplicated are allowed in the count. The test is not useful for positively identifying pores less than one-half mil in diameter. In an alternate version of the test, a blotting paper may be wetted with a solution of sodium chloride and ferricyanide, and the blue color will develop at the site of pore while the test is in progress.

d) **Salt Spray Tests** – Both the 20% salt spray test and the more recent 5% salt spray test, ASTM Designation B117-73, are used to evaluate tin and tin alloy coatings over ferrous basis metals. The number of hours acceptable before the appearance of rust may be determined for any specific service or product. A permissible number of corrosion spots after a fixed period of testing may be a criterion for acceptance of other specifications. The test is performed in a cabinet in which the cleaned parts are suspended or supported in such a

manner that a critical surface is suspended at an angle between 15 and 30° from the vertical and, if possible, parallel to the flow of fog through the cabinet. The salt solution is made up with distilled water containing not more than 200 ppm of total solids and sodium chloride, substantially free from nickel and copper, and containing not more than 0.1 per cent of sodium iodide and less than 0.3% total impurities. The pH of the collected salt solution after atomization must be in the range of 6.5–7.2. The cabinet must be maintained at
2 1.1
95 ± 3°F (35 ± 1.7°C). The test is expected to be continuous unless otherwise specified.

e) **Sodium Polysulfide Test** – This test is applicable to tin deposited over copper or copper alloys. It is primarily used in the evaluation of tin plated copper wire as described in ASTM Specification B-246. The plated item is immersed in hydrochloric acid, specific gravity 1.12, for one minute at 60°F, (15.6°C). After rinsing and wiping dry, the test piece is then immersed in a concentrated solution of sodium polysulfide saturated at 70°F, (21°C) containing flowers of sulfur in excess of 33 oz./gal. (250 g/l) diluted to specific gravity 1.142 at 60°F, (15.6°C). After 30 seconds immersion, the specimen is rinsed and wiped dry. It is then immersed for one minute in hydrochloric acid and after rinsing and drying again the test cycle is repeated. The blackening of any pores is considered cause for rejection.

Porosity tests may be used to measure the ductility of coatings by their application to specimens that have been stressed by bending or elongation. If the specimen shows a marked increase in porosity, after the application of a controlled stress to the deposit, it indicates that the deposit has cracked. Such tests are valuable in determining accurate ductility values.

Adhesion

Adhesion testing is very significant to the plater, since it can provide a measure of the quality of the cleaning and activation procedures being used. Fortunately, tin and many of its alloys are malleable and readily fusible, and these qualities lend themselves well to burnishing and reflow tests which are rapid and reliable.

a) **Burnishing Test** – This test consists of rapidly rubbing a small area, (less than one square inch, 650mm^2), with a smooth metal instrument, such as the edge of a buffed copper or steel disc, rubbed to and fro in a sideways direction with sufficient pressure to burnish without cutting or digging into the coating. The combination of stress applied by the heat and linear expansion of the coating will cause blisters to appear in a few seconds if the adhesion is defective.

b) **Quenching Test** – This is a nondestructive test that will reveal gross defects in adhesion. Its principal merit lies in its applicability to all electroplated surfaces without regard to size, shape, or accessibility. The parts to be tested are heated in an oven to 300° ± 25°F (150 ± 15°C) for a period of time sufficiently long for the parts to reach the oven temperature. They are then quenched in a generous volume of water at room temperature. Adhesion failure is indicated by blistering, cracking or peeling of the deposit.

c) **Reflow Test** – For some purposes, this test may be considered destructive; however, when reflowing is permissible or specified it is usually nondestructive. It is much more sensitive than the quenching test above. It has all the advantages of the quenching test, in addition to an extreme sensitivity to very minor adhesion defects. Parts to be tested are immersed in a bath of hot palm oil at temperatures of 455–500°F (235–260°C) for tin plated work or 400–500°F (200–260°C) for 60–40 tin lead alloy deposits. A smooth bright coating completely covering all significant surfaces indicates good adhesion.

The reflow test is not only an excellent test for adhesion, but it also serves as a good test for solderability, because any contaminants within the interface that interfere with smooth relowing of the deposit will usually prevent good soldering.

d) **Bend Test** – This is a destructive test that is most suitable to the adhesion testing of wire and sheet although it can be applied to any part that can be readily bent. The test specimen is bent over a mandrel with the plated surface being tested on the outside (away from the mandrel). The mandrel should have a diameter or width equal to the diameter or thickness of the sample. The bending of the sample must continue until the two legs of the specimen are parallel (180° bend). Examination at 4X magnification should reveal no evidence of peeling or cracking of ductile deposits. Brittle deposits or some basis metals may crack, but it should not be possible to dislodge the deposit at these cracks.

e) **Microscopic Examination** – This method requires the cross sectioning of the deposit and the preparation of a small section by metallographic polishing and etching. Careful examination of the interface between the basis metal and the deposit at magnifications of 400–1000 X can reveal considerable information concerning the quality of the bond between the two metals. Evidence of debris, or of a damaged crystalline structure at the interface is a strong indication of a poor bond.

f) **Knife and Chisel Tests** – Among the oldest and most common tests of the practical plater are the methods which involve prying with a sharp instrument at the edges of corners wherever the interface may be exposed. Very poor adhesion can be readily exposed by these methods.

g) **Examination of Feathered Edges** – By grinding or filing through the deposit at a small angle until the basis metal is exposed, similar to a thickness examination by the chord method, a relatively long section of the interface is obtained. Low power examination (3–30X) can reveal any tendency of the deposit to peel at the thinned edges. A smooth fine finish and light etching may reveal a poor bond when the deposit is a soft metal that may be smeared by the cutting process.

Solderability Testing

Due to the unique solderability of tin and most of its alloys, a variety of tests are used to determine the suitability of the plated work for its intended service. The close relationship between good adhesion and solderability has been mentioned, but it must be stated that good adhesion is a prerequisite of good solderability. The simplest and most reliable tests are based on either the extent of wetting or the time of wetting under controlled test conditions.

a) **Dip Tests** – A small part or a portion cut from a large piece coated with a noncorrosive flux are dipped into a solder pot containing solder of a specified alloy at a specified temperature, for a specified period of time. After dipping in a carefully skimmed solder pot the test piece is removed from the solder pot, allowed to air cool until the solder solidifies, and examined for uniformity, smoothness, adherence and freedom from nonwetting and dewetting. Typical solder alloys used in the test pot may vary from 40% to 60% tin. The flux used is usually a nonactivated rosin diluted with isopropyl alcohol to a controlled specific gravity. The temperature is usually specified to be in the range of 400–500°F (200–260°C). The time of immersion in the hot solder may vary from 1 to 10 seconds. Uniform immersion and withdrawal rates are recommended, but cannot be readily achieved in a manual method.

The automated dip test was devised to eliminate the unavoidable errors in the timing of the dipping operation. The IPC specification IPC–S–801 illustrates a simple cam operated device for providing the correct speeds of entrance and withdrawal and the correct dwell time to meet the solderability test specifications for printed wiring boards.

The dip tests may be modified by shortening the cycle to a point at which the work will not accept a smooth solder coat. Thus, by introducing the time of wetting factor the test is made much more sensitive, permitting the grading of electroplated surfaces for solderability.

b) **Spread Tests** – In this test, a uniform volume or weight of specified solder, in the form of a pellet, is placed on the test specimen with a few drops of a nonactivated rosin flux. The part is then heated at a controlled temperature for a definite period of time in an oven. A hot plate may be used for rough evaluation of solderability but the rate of heating will then be less consistent with a resultant decrease in reliability. After heating, the area of spread can be measured with a planimeter, and the height of the solder blob by a micrometer or a height gage. From the area of spread in square centimeters, and the volume of solder in cubic centimeters, it is possible to calculate the contact angle of the solder according to the following equation:

$$\text{Contact Angle} = 7.12\ \left(\frac{\text{Volume}}{\sqrt{\text{Area}}}\right)$$

The smaller the value of the contact angle, the better the solderability of the surface under test. Contact angles smaller than 12 are considered to be very good.

Another equation utilizes the height measurement of the solder expressed as the diameter of a sphere that is equal to the volume of solder used in the test. The spread factor is then calculated as follows:

$$\text{Spread Factor} = \frac{\text{Sphere Diameter} - \text{Height}}{\text{Sphere Diameter}} \times 100$$

The larger the spread factor, the better the solderability of the surface under test. Spread factors greater than 80 are considered to be very good.

c) **The Globule Test** – This test is especially well suited to test the rapid evaluation of wires and component leads for solderability. The fluxed wire is lowered horizontally into a molten globule of solder resting on a carbon block. The time required for the solder to flow around the wire is used as the measure of solderability. The shorter the time, the better the solderability. The test may be repeated in the same spot, after wiping off the excess solder, to determine whether dewetting will occur.

d) **Artificial Aging** – The solderability of any electroplated surface is usually best immediately after plating. Unfortunately, many plated parts cannot be assembled for many months, and occasionally for years, after the plating operation has been performed. It is therefore sometimes necessary or desirable to try to determine what effect aging may have on an electroplated component.

One method of accelerating the aging process consists of hanging the specimen in a covered container, at least 2 inches (50mm) above the surface of boiling water. The specimen should be located in such a manner that the condensate from the cover cannot drip on it. After 24 hours, the test piece is air dried and tested for solderability by one of the methods given above.

Other methods of accelerated aging may consist of simply placing the test piece into an oven, at an elevated temperature, but which is below the melting point of the deposit, for a definite period of time. The atmosphere may be air, inert or reducing gas, depending upon the requirements of the part. These conditions of elevated temperature not only affect the deposit surface, but also accelerate the rate of alloying the deposit with the basis metal or undercoating.

Deposits containing brighteners are generally affected adversely to a greater degree by elevated temperatures than deposits of pure metals. Tin alloy deposits may undergo a loss of tin by the readiness with which tin alloys with many basis metals. Such a loss of tin will not usually affect the solderability significantly, until the loss of tin in the deposit is almost complete in any given area. From this, it can be seen that heavier coatings of an alloy deposit may be more resistant to aging than thinner deposits. Thin undercoatings of pure tin may also help to extend the period of satisfactory solderability of many tin alloy deposits.

Thin coatings of rosin or palm oil are sometimes specified for the purpose of preserving the solderability of tin and its alloys. Their function is to protect the surface from any contamination by exposure to the atmosphere.

GLOSSARY OF METAL FINISHING TERMS

Adhesion – The attractive force that exists between an electrodeposit and its substrate that can be measured as the force required to separate an electrodeposit and its substrate.

Anode – The electrode in electrolysis at which negative ions are discharged, positive ions are formed, or other oxidizing reactions occur.

Anodic Chromate Coating – A chromate conversion coating produced by making the work the anode of an electrolytic cell containing a chromate solution.

Barrel Plating – Electroplating of small parts in bulk in a rotating container.

Basis Metal – Metal upon which coatings are deposited.

Bridging – The formation of a conductive path between conductors.

Bright Dip – A solution used to produce a bright surface on a metal.

Bright Plating – A process that produces an electrodeposit having a high degree of specular reflectance in the as-plated condition.

Cathode – The electrode in electrolysis at which positive ions are discharged, negative ions are formed, or other reducing reactions occur.

Chromate Conversion Coatings – A coating produced by chemical or electrochemical treatment of a metallic surface that gives a superficial layer containing compounds of the metal and the chromium constituents of the processing solution.

Coloring – (1) The production of desired colors on metal surfaces by chemical or electrochemical action. (2) Light buffing of polished metal surfaces for the purpose of producing a high luster.

Conversion Coating – A coating produced by chemical or electrochemical treatment of a metallic surface that gives a superficial layer containing a compound of the metal.

Corrosion – (1) Gradual solution or oxidation of a metal. (2) Solution of anode metal by the electrochemical action in the plating cell.

Covering Power – The ability of a plating solution under a specified set of plating conditions to deposit metal on the surfaces of recesses or deep holes. (Distinguished from throwing power).

Dewetting – A condition which results when the molten solder has coated the surface and then receded, leaving irregularly shaped mounds of solder separated by areas covered with a thin solder film without exposing the basis metal. Dewetting may be caused by electrodeposits of tin or solder that are too heavy.

Drag-Out – The solution that adheres to articles removed from a processing tank.

Electrolysis – Production of chemical changes by the passage of current through an electrolyte.

Electrolyte – (1) A conducting medium in which the flow of current is accompanied by movement of matter. Most often an aqueous solution of acids, bases, or salts, but includes many other media, such as fused salts, ionized gases, some solids, etc. (2) A substance that is capable of forming a conducting liquid medium when dissolved or melted.

Electroplating – The electrodeposition of an adherent metallic coating upon an electrode for the purpose of securing a surface with properties or dimensions different from those of the basis metal.

Eutectic Alloy – An alloy having the composition indicated by the eutectic point on an equilibrium diagram characterized by a sharp melting point.

Fretting Corrosion – Surface damage created, especially in a corrosive environment when there is relative motion and strong contact between mating surfaces.

Flux – A material used to prevent the formation of oxides or to dissolve and facilitate their removal along with any other substances that might interfere with soldering.

Hot-Dip Coating – The method of applying a metallic coating by briefly immersing a clean fluxed article in a tank of molten metal or alloy.

Hydrogen Embrittlement – Embrittlement of a metal or alloy caused by absorption of hydrogen during pickling, cleaning or plating.

Immersion Coating – A metallic deposit produced in an aqueous solution by chemical or electrochemical action without the use of externally applied current.

Interference Fit – Prescribed limits resulting in interference on assembly. Used where accuracy of location is of prime importance.

Mechanical Plating – The formation of an adherent metallic coating upon a basis metal by impingement of solid particles of the coating metal.

Metal Distribution Ratio – The ratio of the thicknesses of deposit upon two specified areas of a cathode. See throwing power.

Microinch – One millionth of an inch, 0.000001 in. = 0.001 mil.

Micron (Micro-meter) – One millionth of a meter.

Mil – One thousandth of an inch, 0.001 in. = 25.4 microns.

Peeling – The detachment or partial detachment of an electrodeposited coating from a basis metal or undercoat.

Pit – A small depression or cavity produced in a metal surface during electrodeposition or by corrosion.

Printed Circuit Board (PCB) – A mass produced product, manufactured from a plastic laminate on the surface of which circuitry is formed by selectively etching away unwanted copper from a foil laminated to the plastic or by building up the circuitry by selectively plating copper on the board.

Reflowing or Flow Brightening – The process of melting an electrodeposit of a fusible metal or alloy prior to soldering. The reflowed deposit is usually smoother, brighter and less porous than the original deposit.

Sacrificial Protection – The form of corrosion protection wherein one metal corrodes in preference to another, thereby protecting the latter from corrosion.

Slivering – In circuit board plating, the tendency of brittle electrodeposited etch resists to break off thin slivers of metal after etching has caused the deposit to overhang the "undercut" copper circuitry.

Solderability – The ability of a surface to be wetted readily by a fusible metal or alloy. Further definition of this property may be provided by specifying the time required for wetting to occur under controlled conditions or measuring the area of spread of a fixed quantity of fusible alloy under standard conditions.

Tarnish – (1) Dulling, staining or discoloration of metals due to superficial corrosion. (2) The film so formed.

Throwing Power – The improvement of the coating (usually metal) distribution over the primary current distribution on an electrode (usually cathode) in a given solution, under specified conditions. The term may also be used for anodic processes for which the definition is analogous.

Work (Plating) – The material being plated or otherwise finished.

SOURCES OF INFORMATION

Societies and Association

American Electroplaters & Surface Finishers Society, Inc.
12644 Research Parkway
Orlando, Florida 32826

American Society of Electroplated Plastics
1000 Vermont Avenue, N.W.
Washington, D.C. 20005

American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

The Institute of Printed Circuits
7380 Lincoln Avenue
Lincoln, Illinois 60646-1705

Metal Finishing Suppliers Association, Inc.
1025 East Maple Road
Birmingham, Michigan 48011

National Association of Metal Finishers
111 East Wacker Drive
Chicago, Illinois 60601

Tin Research Institute
1353 Perry Street
Columbus, Ohio 43201

Zinc Institute, Inc.
292 Madison Avenue
New York, New York 10017

MFSA MEMBERSHIP ROSTER

AS OF

NOVEMBER, 1987

AA-GEM Corporation
4221 N. Lawndale Avenue
Chicago, Illinois 60618
(312) 539-9303

ACI Chemicals, Inc.
140 Industrial Street
Lancaster, Texas 75134
(214) 227-2241

A Brite Company
8005 Sovereign Row
Dallas, Texas 75247
(214) 638-0465

Abtrex Industries Incorporated
28530 Reynolds Avenue
Inkster, Michigan 48141
(313) 728-0550

Acme Manufacturing Company
650 W. 12 Mile Road
Madison Heights, Michigan 48071-2484
(313) 564-6000

Ad-Tech Associates
7115 Ashlawn Drive
Brecksville, Ohio 44141
(216) 526-1116

Advanced Chemical Systems, Inc.
2515 Three Mile Road, N.W.
Grand Rapids, Michigan 49504
(616) 453-3470

Aeon Corporation
7202 N. Shadeland Avenue
Indianapolis, Indiana 46250
(317) 841-0288

Agate Lacquer Manufacturing Co., Inc.
11-13 Forty-Third Road
Long Island City, New York 11101
(212) 784-0660

Aldoa Company
12727 Westwood Avenue
Detroit, Michigan 48223
(313) 273-5705

Aldonex, Inc.
2917 St. Charles Road
P. O. Box 148
Bellwood, Illinois 60104
(312) 547-5663

Allied-Kelite Division
Witco Chemical Corporation
2701 West Lake Street
Melrose Park, Illinois 60160
(312) 344-4300

Allied Plating Supplies, Inc.
A Chromadyne Corporation
5000 East 10th Court
P. O. Box 2127
Hialeah, Florida 33012
(305) 681-8531

Alloycraft Limited
12 Raitherm Road
Toronto, Ontario, Canada M6B 15G
(416) 789-7091

American Chemical & Refining Inc.
A Handy & Harman Company
P. O. Box 120
Waterbury, Connecticut 06720
(203) 757-9231

American Chemical Works Company
365 Charles Street
P. O. Box 6031
Providence, Rhode Island 02940
(401) 421-0828

American Plating Systems
2304 S. Castle Harbor Place
Ontario, California 91761
(714) 947-8388

Americhem Div.
International Metals & Chemicals, Inc.
5129 Unruh Avenue
Philadelphia, Pennyslvania 19135
(215) 335-0990

s Metal Products Company
323 South Western Blvd.
hicago, Illinois 60609
312) 523-3230
300) 255-6937

tek, Inc.
aveg Division
00 Greenbank Road
Vilmington, Delaware 19808
302) 995-0400

co Environmental Processes, Inc.
95 Commerce Drive
mherst, New York 14150
716) 691-2100

logic, Incorporated
0 Devine Street
orth Haven, Connecticut 06473
203) 248-8959

Equipment Corp.
451 East Chevy Chase Drive
uite #202
lendale, California 91206
318) 240-7060

ntes Chemical Systems Inc.
03 Silver Spring Road
onroe, Texas 77303
409) 856-4515

F Corporation Chemicals Division
419 Biddle Avenue
Vyandotte, Michigan 48192-3736
313) 246-6409

Baker Enterprises, Inc.
lain Street
lelvin Village, New Hampshire 03850
603) 544-2011

r Brothers/Systems
ivision of Systems Eng. & Mfg. Corp.
ox 507
4 Campanelli Parkway
toughton, Massachusetts 02072
617) 344-1700

M. E. Baker Company
25 Wheeler Street
Cambridge, Massachusetts 02138
(617) 547-5460

T. H. Baylis Company
61 Glenham Avenue
Warwick, Rhode Island 02886
(401) 739-8110

Belanger, Inc.
Coated Abrasive Division
455 East Cady Road
P. O. Box A
Northville, Michigan 48167
(313) 349-7010

Belke Manufacturing Company
947 North Cicero Avenue
Chicago, Illinois 60651
(312) 626-4606

Benchmark Chemical Corporation
8425 Zionsville Road
P. O. Box 68809
Indianapolis, Indiana 46268-0809
(317) 875-0051

Benchmark, Inc.
4660 13th Street
Wyandotte, Michigan 48192
(313) 285-0900

Betz Laboratories
4636 Somerton Road
Trevose, Pennsylvania 19047
(215) 355-3300

T. E. Betz Co., Inc.
10940 Ferndale Road
Dallas, Texas 75238
(214) 341-1819

Bewt Metal Recovery Systems Limited
1390 Hopkins Street, Unit #4
Whitby, Ontario, L1N 2C3, Canada
(416) 668-1182

Birchwood Casey
Div. of Birchwood Laboratories, Inc.
7900 Fuller Road
Eden Prairie, Minnesota 55344
(612) 937-7931

Bison Corporation
1935 Allen Avenue, S.E.
Canton, Ohio 44707-9987
(216) 455-0284

BroCo Products, Inc.
23800 Commerce Park Road
Cleveland, Ohio 44122
(216) 464-2441

The Buckeye Products Company
7020 Vine Street
Cincinnati, Ohio 45216
(513) 764-7100

CP Chemicals Inc.
One Parker Plaza
Fort Lee, New Jersey 07024
(201) 944-6020

C & S Ball Bearing Machinery Corp.
956 Old Colony Road
Meriden, Connecticut 06450
(800) 272-2557
(203) 235-5727

Camac Industries
18 Commerce Road
Fairfield, New Jersey 07006
(201) 575-1831

Canada Colors and Chemicals Limited
80 Scarsdale Road
Don Mills M3B 2R7, Ontario, Canada
(416) 449-7750

Chautauqua Metal Finishing Supply
43 Forest Avenue
Jamestown, New York 14701
(716) 664-4114

Chemethon, Inc.
933 W. Auburn
Rochester, Michigan 48063
(313) 852-6050

Chemical Equipment Fabricators Ltd.
16 Estate Drive
Scarborough, Ontario M1H 2Z1, Canada
(416) 438-9266

Chemical Finishing, Inc.
Westfield Industrial Park Road
Westfield, Massachusetts 01085
(413) 562-7066

Chemical Systems, Inc.
1735 West Fullerton Avenue
Chicago, Illinois 60614
(312) 248-6767

Chemisphere Technologies, Inc.
P. O. Box 250
Boonton, New Jersey 07005
(201) 335-6972

The Chemithon Corporation
5430 W. Marginal Way S.W.
Seattle, Washington 98106-1598
(206) 937-9954

Chemix Corporation
330 West 194th Street
Glenwood, Illinois 60425
(312) 754-2150

Chemray Corporation
9842 Roosevelt Road
Westchester, Illinois 60153
(312) 626-0222

ChemSys Inc.
43 Upton Road
Scarborough, Ontario M1L 2C1, Canada
(416) 752-0915

Clover Chemical Co., Inc.
176 Sunnyside Avenue
Woonsocket, Rhode Island 02895
(401) 765-1300

Columbia Chemical Corp.
837 East Highland Road
Macedonia, Ohio 44056
(216) 468-0706

Commercial Industrial Chemicals Inc.
711 W. 12th Street
Flint, Michigan 48503
(313) 233-0951

und Technology, Inc.
E. King Street
. Box 1904
k, Pennsylvania 17405
7) 845-8646

lled Power Company
5 Stephenson Highway
y, Michigan 48083
3) 528-3700

g Glass Works
ning Process Systems
Flats, New York 14814
7) 974-0299

s Minerals Corporation
6 Via Alondra
marillo, California 93010
5) 482-9825

orporation
Tidal Way
. Box 1088
t Mill, South Carolina 29715
3) 548-0853

A. Day Manufacturing Co., Inc.
39 Niagara Street
ffalo, New York 14213
6) 881-3030

a Corporation
4 New Era Drive
uth Plainfield, New Jersey 07080
1) 757-6500

Corporation
0. Box 5111
uthfield, Michigan 48086-5111
3) 358-5800

o Corporation
40 National Avenue
dison, Illinois 60101
12) 628-0700

ey Wyandotte Metals
06 John A. Papalas Drive
ncoln Park, Michigan 48146
13) 383-0515

Dober Chemical Corp.
14461 Waverly Avenue
Midlothian, Illinois 60445
(312) 388-7700
(800) 323-4983

Donald Sales & Mfg. Co.
N96 W14313
County Line Road
Menomonee Falls, Wisconsin 53051
(414) 255-7414

E. I. DuPont deNemours & Company, Inc.
Industrial Chemicals Div.
Chemicals & Pigments Dept.
10th and Market Streets
Wilmington, Delaware 19898
(302) 774-5135

Dynapower Corporation
29199 Orchard Lake Road
P. O. Box 3180
Farmington Hills, Michigan 48018
(313) 553-4300

E & G Equipment and Chemical Co.
1171 Woodruff Street
Southington, Connecticut 06489
(203) 621-2230

EG&G Rotron
Industrial Division
Sawyer Industrial Park, North Street
Saugerties, New York 12477
(914) 246-3401

EPI Electrochemical Products, Inc.
1700 W. Lincoln Avenue
New Berlin, Wisconsin 53151
(414) 786-9330

Eco-Tec Limited
925 Brock Road South
Pickering, Ontario, L1W 2X9, Canada
(416) 831-3400

Elcometer, Inc.
1180 E. Big Beaver
Troy, Michigan 48083
(313) 528-0611

Electrochemicals
751 Elm Street
Youngstown, Ohio 44502
(216) 746-0517

Empire Buff Company Limited
1425 Tellier Street
St. Vincent de Paul
Laval, Quebec, Canada H7C 2H1
(514) 664-1200 / 325-3673

The Enequist Chemical Co., Inc.
100 Varick Avenue
Brooklyn, New York 11237
(718) 497-1200

Engelhard Canada Limited
100 Engelhard Drive
P. O. Box 340
Aurora, Ontario, Canada L4G 3N1
(416) 727-3191

Engelhard Corporation
Electronics Products Group
33 Wood Avenue South
Menlo Park CN28
Edison, New Jersey 08818
(201) 632-6610

Enthone/Canada
Division of Federated Metals Canada Limited
1235 Shawson Drive
Mississauga, L4W 1C4, Ontario, Canada
(416) 677-1316, 677-1553

Enthone, Incorporated
Subsidiary of ASARCO Incorporated
P. O. Box 1900
New Haven, Connecticut 06508
(203) 934-8611

FPI Systems
50 Devine Street
North Haven, Connecticut 06473
(203) 281-6161

Fabrico Mfg. Corp.
4222 Pulaski Road
Chicago, Illinois 60632
(312) 890-5350

The Fairbank Corporation
Box 1265
Hato Rey, Puerto Rico 00919
(809) 763-2828

Falconbridge Limited
P. O. Box 40
Commerce Court West
Toronto, Ontario M5L 1B4, Canada
(416) 863-7260

Falconbridge U.S. Incorporated
Twin Towers, Ste. 245
4955 Steubenville Pike
Pittsburgh, Pennsylvania 15205-9642
(412) 787-0220

Fanta Equipment Company
6521 Storer Avenue
Cleveland, Ohio 44102
(216) 281-1515

Fidelity Chemical Products Corp.
470 Frelinghuysen Avenue
Newark, New Jersey 07114
(201) 242-4110

Finima
16 Rue Sainte-Victoire
78000 Versailles
France
(1) 30.21.56.56

Finishing Equipment, Inc.
3640 Kennebec Drive
St. Paul, Minnesota 55122
(612) 452-1860

W. D. Forbes Company, Inc.
129 Sixth Avenue, S.E.
P. O. Box 14828
Minneapolis, Minnesota 55414
(612) 378-1917

Ford New Holland, Inc.
500 Diller Avenue
New Holland, Pennsylvania 17557
(717) 354-1458

Formax Manufacturing Corporation
3178 Bellevue Avenue
Detroit, Michigan 48207
(313) 921-7030

l. Fotheringham, Inc.
21 Forest Avenue
uffalo, New York 14213
716) 885-9087 – 88 – 89

re Technologies Unlimited Corp.
23 Mason Street
reenwich, Connecticut 06830
03) 661-7773

Metals and Chemicals Corporation
535 E. 28th Street
os Angeles, California 90058
13) 582-0685

ral Chemical Corporation
East Halsey Road
O. Box 3705
rsippany, New Jersey 07054-3705
01) 515-1834

Goad and Company
0 Old State Road
. Louis, Missouri 63011
14) 394-6334

irav-I-Flo Corporation
0 Norwood Avenue
urgis, Michigan 49091
16) 651-5467

rick Gumm Chemical Company, Inc.
8 Forest Street
arny, New Jersey 07032
01) 991-4171

Equipment Corporation
00 Supply Avenue
s Angeles, California 90040
13) 726-3033

den Color & Chemical Company
6 Memorial Drive
ringfield, Massachusetts 01101
3) 732-2112

n Inc.
Vansco Road
ronto, Ontario M8Z 5J7, Canada
6) 255-1371

Hardwood Line Mfg. Co.
4045 N. Elston Avenue
Chicago, Illinois 60618
(312) 463-2600

Harshaw Chemical of Canada, Ltd.
6616 Campobello Road
Mississauga, Ontario L5N 2L8, Canada
(416) 821-3325

Harshaw/Filtrol Partnership
30100 Chagrin Blvd.
Cleveland, Ohio 44124
(216) 292-9200

Harstan Chemical Division
Chemtech Industries Inc.
1655 Des Peres Road
St. Louis, Missouri 63131
(800) 325-3332

Haviland Products Company
421 Ann Street, N.W.
Grand Rapids, Michigan 49504
(616) 361-6691

Jacob Hay Company
4014 West Parker Avenue
Chicago, Illinois 60639
(312) 227-8800

Heatbath Corporation
P. O. Box 2978
Springfield, Massachusetts 01101
(413) 543-3381

The A. F. Holden Company
2195 S. Milford Road
Box 429
Milford, Michigan 48042
(313) 685-1591

Hubbard-Hall, Inc.
P. O. Box 790
Waterbury, Connecticut 06720
(203) 756-5521

Imperial Industries, Inc.
5850 Sheldon Road
Belleville, Michigan 48111
(313) 397-1400
(800) 521-3540

Imperial Smelting Corporation
1031-65 East 103rd Street
Chicago, Illinois 60628
(312) 264-5900

Inco Limited
P. O. Box 44
Royal Trust Tower
Toronto Dominion Centre
Toronto, Ontario M5K 1N4, Canada
(416) 361-7776

Industrial Chemical & Equipment Company
2205 E. Hennepin Avenue
Minneapolis, Minnesota 55413
(612) 378-7581

Industrial Chemical Products of Detroit, Inc.
12801 Newburgh Road
Livonia, Michigan 48150
(313) 464-4555

Industrial Filter & Pump Mfg. Co.
5900 Ogden Avenue
P. O. Box 151
Cicero, Illinois 60650
(312) 242-1180

International Nickel Inc.
Park 80 West, Plaza Two
Saddle Brook, New Jersey 07662
(201) 843-8600

Intrepid Industries, Inc.
P. O. Box 443
Whitehouse Station, New Jersey 08889
(201) 534-5300

Ionics, Incorporated
Separations Technology Division
65 Grove Street
Watertown, Massachusetts 02172
(617) 926-2500

JWI, Inc.
2155 112th Avenue
Holland, Michigan 49424
(616) 772-9011

Jackson Buff
A Unit of Jason Incorporated
Highway 70 East
P. O. Box 699
Conover, North Carolina 28613
(704) 464-1376

Jelco Finishing Equipment Corp.
60 Franklin Avenue
Brooklyn, New York 11205
(718) 625-3400

Jessup Engineering, Inc.
2745 Bond Street
Auburn Heights, Michigan 48057
(313) 853-5600

Jim's Plating Supply, Inc.
11110 Deerfield Road
Cincinnati, Ohio 45242
(513) 984-6400

J. Mark Systems, Inc.
1352 Baldwin Street
Jenison, Michigan 49428
(616) 457-5430

A. Johnson (Canada) Inc.
Process Equipment Division
10161 Cote de Liesse
Dorval, Quebec H9P 1A3, Canada
(514) 636-8712

Key Chemicals, Inc.
4346 Tacony Street
Philadelphia, Pennsylvania 19124
(215) 744-5858

Keytech Water Management Inc.
20-20 Steckle Place
Kitchener, Ontario N2E 2C3, Canada
(519) 894-3440

Kiesow International Corporation
201 Greer Drive
P. O. Drawer 808
Mauldin, South Carolina 29662
(803) 963-5808

ico Incorporated
845 Kinsman Road
. O. Box 193
ewbury, Ohio 44065
16) 564-9111

spor Abrasives, Inc.
. O. Box 2367
ickory, North Carolina 28603-2367
04) 322-3030

ur Company
800 South St. Louis Avenue
hicago, Illinois 60632
312) 847-1111

t Chemical Company
975 N. Hawthorne Avenue
lelrose Park, Illinois 60160
312) 345-8210

s & Wolfe Chemical Company, Inc.
60 Close Avenue
ronx, New York 10473
212) 842-1500

ina, Inc.
0 N. 8th Avenue
laywood, Illinois 60153
312) 343-1690

y International, Inc.
81 Thorn Hill Road
Varrendale, Pennsylvania 15086-7527
412) 772-0044

Lea Manufacturing Company
37 East Aurora Street
. O. Box 71
Vaterbury, Connecticut 06720
203) 753-5116

Products Company Inc.
355 Jean Valets Avenue
Montreal, Quebec H1E 3H4, Canada
514) 325-4522

Ronal, Inc.
72 Buffalo Avenue
Freeport, New York 11520
516) 868-8800

Liquid Development Co. Inc.
3748 East 91st Street
Cleveland, Ohio 44105
(216) 641-9366

Luster-On Products, Inc.
54 Waltham Avenue
P. O. Box 90247, Highland Station
Springfield, Massachusetts 01139
(413) 739-2543

M & T Chemicals, Inc. (Executive Offices)
One Woodbridge Center
Woodbridge, New Jersey 07095
(201) 499-2555

M & T Chemicals, Ltd.
1180 Corporate Drive
Burlington, Ontario L7L 5R6, Canada
(416) 332-0111

MacDermid Chemicals Inc.
1275 Crestlawn Drive
Mississauga, Ontario L4W 1A9, Canada
(416) 624-1065

MacDermid Incorporated
245 Freight Street
Waterbury, Connecticut 06702
(203) 575-5700

Manderscheid Company
624 W. Adams
Chicago, Illinois 60606
(312) 782-8662

The Matchless Metal Polish Company
840 West 49th Place
Chicago, Illinois 60609-5196
(312) 924-1515

Maurer-Shumaker, Inc.
37025 Industrial Road
Livonia, Michigan 48150
(313) 591-0800

McGean-Rohco, Inc.
1250 Terminal Tower
Cleveland, Ohio 44113
(216) 621-6425

Mechanical Finishing Company
Div. of The Harper Company
363 Ellington Road
East Hartford, Connecticut 06108
(203) 289-7471

Metal Finishing Magazine
One University Plaza
Hackensack, New Jersey 07601
(201) 487-3700

Met-Pro Corporation
Systems Division
160 Cassell Road
P. O. Box 144
Harleysville, Pennsylvania 19438
(215) 723-6751

Micel, Inc.
1176 Osprey Circle
Anaheim, California 92807
(714) 630-4050

Michigan Platers Equipment Inc.
1885 E. Laketon Avenue
Muskegon, Michigan 49442-6196
(616) 773-3287

Midwest Air Products Company Inc.
405 S. Delaney Road
P. O. Box 188
Owosso, Michigan 48867
(517) 723-8881

Millhorn Chemical and Supply Company
6142 Walker Avenue
P. O. Box 460
Maywood, California 90270
(213) 771-8301

Missouri Electrochem, Inc.
10958 Lin-Valle
St. Louis, Missouri 63123
(314) 894-9300

The Mitchell-Bate Company
Berky Rack - A Mitchell-Bate Affiliate
P. O. Box 1707
Waterbury, Connecticut 06720
(203) 754-4181

The Mitchell-Bradford International Corp.
160 Wampus Lane
Milford, Connecticut 06460
(203) 878-0671

Monarch Chemicals, Inc.
37 Meadow Street
Utica, New York 13502
(315) 732-6151

Myron L Company
6231 C Yarrow Drive
Carlsbad, California 92009
(619) 438-2021

NCA Systems, Inc.
7207 114th Avenue North
Largo, Florida 34643
(813) 541-1550

Napco Inc.
P. O. Box 26
Terryville, Connecticut 06786
(203) 589-7800

Niacet Corporation
47th St. & Niagara Falls Blvd.
Niagara Falls, New York 14304
(716) 285-1474

Oakite Products, Inc.
50 Valley Road
Berkeley Heights, New Jersey 07922
(201) 464-6900

Occidental Chemical Corporation
360 Rainbow Blvd. South
Niagara Falls, New York 14303
(716) 286-3360

Occidental Chemical Corporation
ED&S Division
Chromium Chemicals Section
P. O. Box 344
Niagara Falls, New York 14302
(716) 278-7210

Palm Commodities International, Inc.
P. O. Box 17264
Nashville, Tennessee 37217
(615) 333-2700

n-O Co., Inc.
000 Washington Avenue
:. Louis, Missouri 63103
314) 241-3387

Chemical Company
074 Military Avenue
etroit, Michigan 48204
313) 895-7215

er+Amchem
2100 Stephenson Highway
adison Heights, Michigan 48071
313) 583-9300

on Corporation
. O. Box 408399
ort Lauderdale, Florida 33340-8399
305) 974-6610

in Chemical Co., Inc.
6 Alexander Street
onkers, New York 10701
914) 476-7000

, Inc.
100 Grand Avenue
leveland, Ohio 44104
216) 231-5600

Surface Chemicals, Inc.
35 A Robbins Lane
yosset, New York 11791
516) 822-7860

Permutit Company, Inc.
. 49 Midland Avenue
aramus, New Jersey 07652
201) 967-6000

rs Supply Company
030 Midway Drive
Twinsburg, Ohio 44087-1974
216) 425-4291

Plating Products, Inc.
40 Colfax Avenue
. O. Box 368
Kenilworth, New Jersey 07033
201) 241-5040

Plating Systems Inc.
756 McDonald Avenue
Brooklyn, New York 11218
(718) 871-1331

Plating Systems & Technologies, Inc.
1410 West Ganson Street
Jackson, Michigan 49202
(517) 783-4776

Poly Products Corporation
P. O. Box 151
Atwood, California 92601
(714) 538-0701

Precision Finishing, Inc.
708 Lawn Avenue
P. O. Box 272
Sellersville, Pennsylvania 18960
(215) 257-6862

Process Technology, Inc.
7010 Lindsay Drive
Mentor, Ohio 44060
(216) 946-9500

Products Finishing Magazine
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Cincinnati, Ohio 45244
(513) 231-8020

Programmed Machine Systems Inc.
P. O. Box 567
Madison Heights, Michigan 48071
(313) 588-6501

Pro Rac Company, Inc.
Highway 64 East
P. O. Box 208
Lawrenceburg, Tennessee 38464
(615) 762-6507

Purity Zinc Alloys & Mfg. Inc.
Aspen & Belmont Street
Easton, Pennsylvania 18042
(215) 253-3636

Quadra Chemicals Ltd.
2121 Argentia Road
Suite 303
Mississauga, Ontario L5N 2X4, Canada
(416) 858-3340

Quin-Tec Inc.
14057 Stephens
Warren, Michigan 48089
(313) 774-8010

Rack Processing Company, Inc.
2350 Arbor Blvd.
Dayton, Ohio 45439
(513) 294-1911

Rand-Bright Corp.
2940 S. 166th Street
New Berlin, Wisconsin 53151
(414) 784-1978

Rapid Power Technologies, Inc.
Graysbridge Road
Brookfield, Connecticut 06804
(203) 775-0411
(800) 332-1111

Redux Corporation
1601 Manufacturers Drive
Fenton, Missouri 63026-2838
(314) 343-0030

Republic Lead Burning and Equipment Company
7930 Jones Road
P. O. Box 05070
Cleveland, Ohio 44105
(216) 641-2575

Reynolds & Co.
1605 E. Central
Arlington Heights, Illinois 60005
(312) 640-9495

W. A. Reynolds Corporation
2522 Pearl Buck Road
Bristol, Pennsylvania 19007
(215) 785-4500

Rin, Inc.
4831 South Whipple
Chicago, Illinois 60632
(312) 523-0784

Rit-Chem Co., Inc.
109 Wheeler Avenue
P. O. Box 435
Pleasantville, New York 10570
(914) 769-9110

Robbins and Craig Sales Corporation
2050 N. Durfee Avenue
South El Monte, California 91733
(818) 443-4105

Ruco, Inc.
111 Westboro Street
P. O. Box 255
Dayton, Ohio 45401-0255
(513) 224-7434

Stan Sax Corp.
101 S. Waterman Street
Detroit, Michigan 48209
(313) 841-7170

Schaffner Manufacturing Company, Inc.
Schaffner Center
Emsworth
Pittsburgh, Pennsylvania 15202
(412) 761-9902

Schering Aktiengesellschaft
Electroplating
Muellerstrasse 170-178
1000 Berlin 65
West Germany
(030) 468-0

John Schneider & Associates, Inc.
10620 North Port Washington
Mequon, Wisconsin 53092
(414) 241-3200

Serfilco, Ltd.
1234 Depot Street
Glenview, Illinois 60025
(312) 998-9300
(800) 323-5431

Sethco Div. Met-Pro Corp.
70 Arkay Drive
Hauppauge, New York 11788
(516) 435-0530

The Shepherd Chemical Company
4900 Beech Street
Cincinnati, Ohio 45212
(513) 731-1110

y Company Inc.
0 Washington Street
wton, Massachusetts 02162
7) 969-5500

eastern Chemicals, Inc.
07 Camden Street
attanooga, Tennessee 37406-2804
15) 622-5154

lty Polymers, Inc.
Francis Street
ominster, Massachusetts 01453
17) 537-4071

ton Company
50 West 12th Street
ng Beach, California 90813
13) 437-0541

ite Industries, Inc.
3 N. Wright Street
elavan, Wisconsin 53115
14) 728-5551

te Chemicals, Inc.
19 West North Avenue
hicago, Illinois 60622
12) 772-2278

tutz Company
450 West Carroll Avenue
hicago, Illinois 60624
12) 287-1068

mit Scientific Corp.
1 Dwight Place
airfield, New Jersey 07006
01) 227-6190

T., Inc.
5 Valley Street
. O. Box 152
ristol, Connecticut 06010
203) 583-5756

o Metals
201 Unruh Avenue
hiladelphia, Pennsylvania 19135
215) 333-6800

Taskem, Inc.
8525 Clinton Road
Cleveland, Ohio 44144
(216) 281-3500

Technic, Inc.
P. O. Box 965
Providence, Rhode Island 02901
(401) 781-6100, 3100

Thomas Abrasive Products, Inc.
1137 North Service Road East
Oakville L6H 1A7, Ontario, Canada
(416) 842-6584

Tilton Rack & Basket Corp.
66 Passaic Avenue
Fairfield, New Jersey 07006
(201) 226-6010

Tiodize Co., Inc.
15701 Industry Lane
Huntington Beach, California 92649
(714) 898-4377

Tiree Industries Ltd.
3285 Mainway
Unit #2
Burlington, Ontario L7M 1A6, Canada
(416) 336-5278

Turco Products, Inc.
Subsidiary Pennwalt Corporation
7300 Bolsa Avenue
Westminster, California 92684-3600
(714) 890-3600

Unipure
1501 E. Orangethorpe Avenue
Suite 150
Fullerton, California 92631
(714) 525-9225

Univertical Corporation
14841 Meyers Road
Detroit, Michigan 48227
(313) 491-3000

Van Industries, Inc.
1285 Wordsworth
Ferndale, Michigan 48220
(313) 398-6990

VeeMetCo, Inc.
P. O. Box 329
Westport, Connecticut 06881
(203) 226-1162

Vic Supply Co.
2316 N. 17th Avenue
Franklin Park, Illinois 60131
(312) 455-8980

Vulcanium Corporation
3045 Commercial Avenue
Northbrook, Illinois 60062
(312) 498-3111

Water Management Inc.
2300 Hwy. 70 East
Hot Springs, Arkansas 71901
(501) 623-2221

W. W. Wells, Limited
1236 Birchmount Road
Scarborough M1P 2C8, Ontario, Canada
(416) 751-5555

Western Reserve Manufacturing Co., Inc.
5311 W. River Road, North
Lorain, Ohio 44055
(216) 277-1226

Western Technology Associates
2897 E. LaCresta Avenue
Anaheim, California 92806
(714) 632-8740

Western Thermal Sales, Inc.
3152-H E. LaPalma Avenue
Anaheim, California 92806
(714) 630-4220

Bill Young & Co., Inc.
11411 Williamson Road
P. O. Box 41509
Cincinnati, Ohio 45241
(513) 489-3888

Frank N. Youngman Co.
1703 S.W. Clay Street
Portland, Oregon 97201
(503) 227-1844