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mfsa

quality metal finishing guide

Copper-Nickel-Chromium
Nickel-Chromium and
Nickel-Iron-Chromium Coatings

Volume VII No. 1

mfsa **quality metal finishing guide**

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INTRODUCTION

In 1960 the Metal Finishing Suppliers' Association, Inc. initiated action to upgrade the durability of metal finishes in a program known as the "Quality Metal Finishing Project" or the QMF. This project has been so successful that it is being continued and enlarged. It consists of programs aimed at: (1) promoting technically sound specifications or standards in cooperation with interested trade and technical societies; (2) providing information to both producers and buyers of electroplated products through the medium of metal finishing clinics in the larger industrial centers; and (3) providing printed guides containing information on established standards and specifications in condensed form, readily accessible for day to day use by the design engineer, the purchasing agent and all those involved in the use of metal finishes.

The first volume of the series of guides dealt with standards for quality copper/nickel/chromium finishes. Published in 1965 that volume (Vol. I) has had several printings. It was followed by a second publication, Quality Metal Finishing Guide – Zinc and Cadmium Coatings. Because of the demand for more printings, the MFSA reissued both guides in a series of revisions constantly up-dated. In the decade of the 70's, QMF Guides on Mass Finishing and Tin and Tin Alloy Coatings were written and printed to further demonstrate our devotion to Quality.

The QMF Project evaluates the status of proposed quality standards for metal finishes, selects those that are supported by technically sound data, relates the specified quality levels to various kinds and degrees of severity of service and then brings this information to the attention of the people in industry who can use it. This revision presents information on how to achieve quality of articles finished with copper, nickel and chromium by attention to design details of the part itself, by selecting the best type of coating for the intended service, by supplying adequate specifications and by selecting methods of test which will assure compliance with the specifications.

Quality

The need for quality control has been accepted in almost all industries in which there is competition for sales. The consumer demands that every time he buys a certain food product, for example, it shall look the same, taste the same and last just as long on the shelf. Quality control does not require industry-wide effort but can be achieved within the individual organization.

What about the need to upgrade quality? As an association promoting the interest and welfare of the producers and customers of the metal finishing industry, MFSA realizes that all suffer loss when metal products are sold which are inadequately finished for the intended life. The consumer may be persuaded to shift to a non-metallic product. MFSA wishes to encourage management to build in the right amount and kind of high quality needed to guarantee the expected or promised service of the unit.

Management needs to know how a high quality metal finish can be achieved, how to select proper specifications for a given service and how to control the release of products to insure that they meet the standards. At the same time management must be confident that this know-how is based upon sound engineering principles and incorporates a reasonable factor of safety.

DESIGN FOR PLATING

A program to improve and control the quality of a metal product should start at the desk of the designer. The metal finisher is restricted in what he can do by certain basic principles of mechanical finishing and of electroplating. The engineer should understand the limitations imposed by shape and size of components to facilitate quality finishing at an acceptable cost. The designer can exert as much influence on the quality attainable in finishing a part as can the electroplater himself. ASTM Designation B-507 can provide the designer with helpful information.

Significant Surfaces

A most important term used in specifying metal finishes is "significant surfaces". In most products the same standard of quality is not required over every square inch of surface. Instead, the quality specifications apply and compliance is expected only for the so-called "significant surfaces" defined by mutual agreement between the producer and purchaser as follows:

> *Significant surfaces are defined as those normally visible (directly or by reflection) which are essential to the appearance or serviceability of the article when assembled in normal position; or which can be the source of corrosion products that deface visible surfaces on the assembled article. When necessary, the significant surfaces shall be the subject of agreement between purchaser and manufacturer and shall be indicated on the drawings of the parts, or by the provision of suitably marked samples.*

Design for Mechanical Finishing

Metal products which are to be coated with copper/nickel/chromium or nickel/chromium finishes are generally subjected to abrasive polishing with belts or wheels in preparation for the plating operations. This is done to aid in securing an attractive uniform, mirror-like or satin appearance on the finished part. Mechanical finishing is an expensive operation. To reduce costs and assist the metal finisher in improving the appearance and quality of the product the designer should consider certain rules applicable for parts requiring mechanical finishing.

- Avoid blind holes, recesses and joint crevices which can retain polishing compounds and metal debris.
- Avoid intricate surface patterns which will be blurred in polishing.

- Significant surfaces should be exterior, reachable by ordinary polishing wheels or belts.
- Avoid sharp edges and protrusions which cause excessive consumption of wheels and belts.

In small parts which are to be barrel processed the above rules apply plus a requirement that the 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 Racking, Draining and Air Entrapment

Most metal parts weighing more than a few ounces are not plated in bulk in barrels but are mounted on racks for processing in cleaning and electroplating tanks. Design considerations relating to racked parts include:

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 a significant surface. Many difficult racking problems can be solved by design modification.

Provide for good drainage of processing solutions from racked parts. Certain shapes tend to trap solution which then causes contamination by carryover, possible corrosion of the part and waste of materials. Carryover aggravates the problem of waste disposal. In design, avoid rolled edges, blind holes and spot-welded joints. Drain holes are especially important in irregular shapes and tubular parts.

Avoid shapes which can trap air on entry into processing tanks if this air could block access of solution to areas requiring treatment. Wherever air can be trapped, hydrogen or oxygen gas may also accumulate during a cleaning or plating step.

Design for Good Distribution of Electrodeposit

Experience and cost accounting show that simple shapes are always finished more uniformly and more economically than complex shapes. This is rule number one for the designer.

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 electrodeposited coating on a cathode of any practical shape and size. Portions of the work which are nearer the anodes tend to receive a heavier deposit. Sharp edges or protrusions tend to steal a larger share of the current. The goal of the designer and the plater is to make thickness variations as small as possible over significant surfaces. At the same time uneconomical wastage of metal by excessive build-up of both non-significant and significant areas must be avoided.

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 various sketches illustrate these principles as they have been learned from practical experience:

- Avoid concave or perfectly flat significant surfaces. Convex or crowned areas receive more uniform coatings. Use a 0.4mm per 25.4mm (0.015 inch per inch) crown – minimum.
- Edges should be rounded to a radius of at least .4mm (1/64 inch) preferably .8mm (1/32 inch).
- Reentrant angles or corners should be filleted with a generous radius. Make such radii as large as possible.
- Avoid concave recesses, grooves or slots with width less than one-half the depth.
- Minimize the number of blind holes because these must usually be exempted from minimum thickness requirements. Where necessary limit their depth to 50% of their width. Avoid diameters less than 6mm (7/32 inch).
- Countersink threaded holes to minimize electroplate thickness at their peripheries and facilitate insertion of fasteners after plating.
- If fins or ribs are required, reduce their height and specify generous radius, 1.6mm (1/16 inch) at each base. Round off tips with radii of at least 1.6mm (1/16 inch). Multiple parallel fins should have spacing between centers equal to four times width of fin. Broad hollow ribs are preferred over slender solid ones.
- Adopt recessed in preference to raised letters and insignia, but round off edges and provide gentle contours.

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.

Convex surfaces

Flat surfaces

Sharply angled edges

Flanges

Slots

Blind holes

Sharply angled indentations

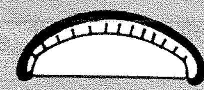
INFLUENCE ON ELECTROPLATABILITY

Feature

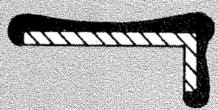
The distribution of electroplate is indicated in an exaggerated fashion

Better Design

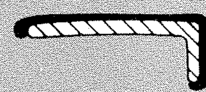
Ideal shape. Easy to plate uniformly, especially where edges are rounded.

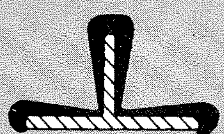


Not as desirable as crowned surfaces. Use a .4mm/25.4mm (0.015 inch/inch) crown to hide undulations caused by uneven buffing.

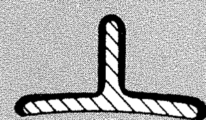


Undesirable. Reduced thickness at center areas and requires increased plating time for depositing a minimum thickness of durable electroplate. All edges should be rounded. (Edges that will contact painted surfaces should have a minimum radius of **.8mm [1/32 inch]**).

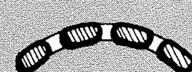


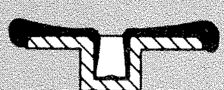


Large flanges with sharp inside angles should be avoided to minimize plating costs. Use a generous radius on inside angles and taper the abutment.

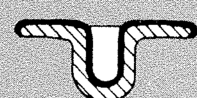


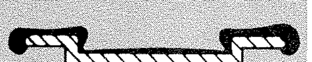
Narrow, closely spaced slots and holes reduce electroplatability and cannot be properly plated with corrosion-protective nickel and chromium unless corners are rounded.





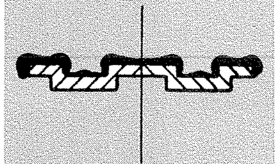
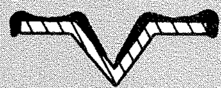
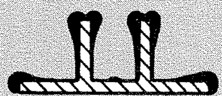
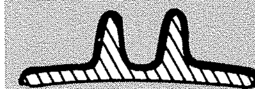
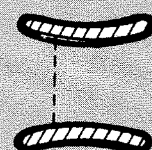
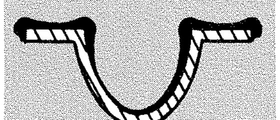
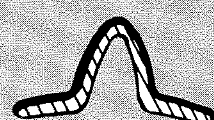
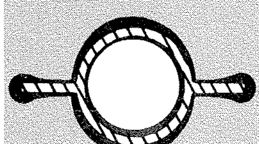
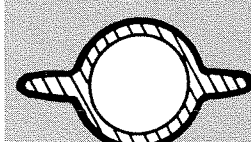
Must usually be exempted from minimum-thickness requirements. Where necessary limit **depth** to 50% of width. Avoid diameters less than **6mm (7/32 inch)**.





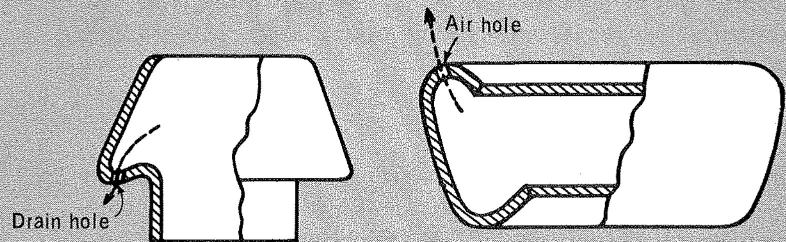
Increase plating time and costs for a specified minimum thickness and reduce the durability of the plated part.

INFLUENCE ON ELECTROPLATABILITY

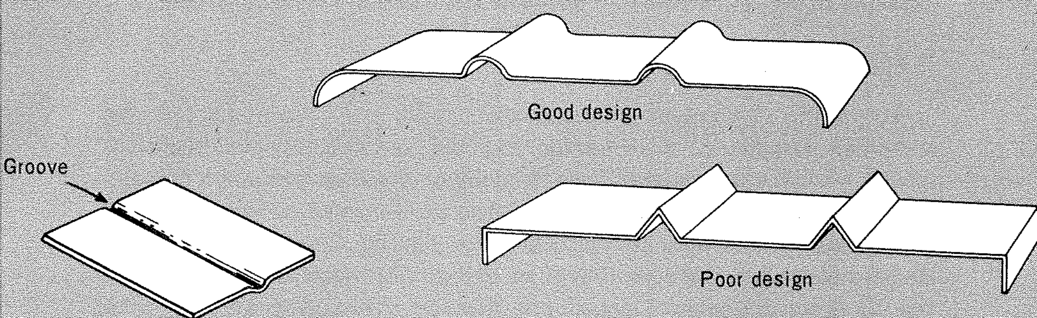
	Feature	The distribution of electroplate is indicated in an exaggerated fashion	Better Design
Flat-bottom grooves		Inside and outside angles should be rounded generously to minimize costs.	
V-shaped grooves		Deep, V-shaped grooves cannot be satisfactorily plated with corrosion-protective nickel and chromium 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.	

DESIGN FOR PLATING

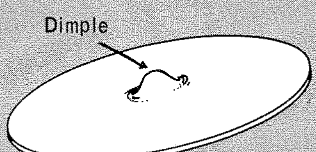
AVOID SHARP INTERIOR ANGLES



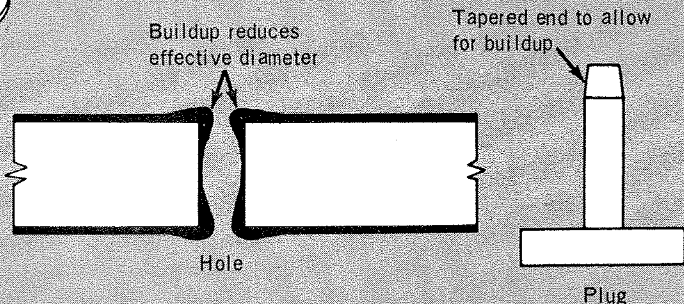
PLACE HOLES FOR DRAINING AND AIR ESCAPE



ROUND OFF HIGH SPOTS



AVOID STICKING WHEN BARREL PLATING



ALLOW FOR BUILD UP

Drawings Courtesy "Materials in Design Engeering" Manual #192
"Guide to Electroplated Coatings" February 1962

- Integrated studs for fasteners should be shortened as much as possible and inside angles at each base should be rounded generously. Tips should be similarly rounded.
- Studs or bosses with hollow centers should be shortened as much as possible and angled 90 degrees from the major plane of the part. All bosses should face the same direction.
- 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.

SELECTING THE FINISH

The designer should approach the problem of selecting the proper copper/nickel/chromium or nickel/chromium finish with a clear understanding of the requirements imposed on the plated product, the properties of the individual metals of the coating system and the service conditions to be satisfied. A properly selected decorative finish of high quality should be expected to perform acceptably throughout the service life of the product.

Requirements of the Finish

The prime requirement of a decorative finish is the maintenance of an acceptable appearance on a product exposed to various service conditions involving wear and corrosion. Even in mildly corrosive environments iron and steel rust rapidly, copper and brass tarnish and zinc and aluminum pit and develop corrosion stains. Scuffing, scratching, denting, frequent cleaning with abrasive cleaners for service typical of automotive bumpers, appliances and furniture, are examples of abuse to be tolerated. To protect the basis metal from corrosion and wear and provide a pleasing appearance, a decorative copper/nickel/chromium or nickel/chromium finish is the most widely preferred.

(a) Appearance

In this age of metals the consumer has shown a consistent demand for a lustrous metallic finish on a variety of products including automotive parts, appliances, plumbing fixtures, bicycles and tools. Chromium over suitable copper/nickel or nickel undercoats meets this need handsomely when high quality of the composite system is specified and achieved. Similarly, functional-decorative applications e.g. flashlights, floodlights, electrical heaters and instruments which require a high luster and mirror-like surface can be satisfied more economically by such finishes as compared with precious metal coatings. Satin and brushed surface effects can be produced as a more subdued finish. In contrast with bright and satin, chromium and nickel also can be deposited as a non-reflective black oxide coating and lustrous surfaces for various applications can be achieved.

(b) Corrosion Behavior

To satisfy the prime requirement of maintaining an acceptable appearance a decorative coating necessarily must effectively resist deterioration of itself and protect the basis metal from corroding. There are a multitude of finishes which can protect a basis metal from rusting or tarnishing in the broad family of paints, lacquers, sprayed metals and plastics and other plated coatings. However, where a durable bright metallic finish is desired the choice is limited. Chromium provides a top coating having excellent resistance to tarnish in atmospheric exposure and the copper/nickel or nickel undercoat provides the proper foundation for the lustrous chromium finish and the corrosion protection of the underlying steel, zinc or other basis metal.

(c) Wear and Abrasion

If the part must resist cleaning and handling or abrasive wear, copper/nickel/chromium or nickel/chromium finishes are usually specified in preference to softer metallic and organic coatings.

Coating Metals Considerations

(a) Rust Retardation

There are two classes of plated coatings which retard rusting or other corrosion of the basis metal. They do so by different mechanisms. The distinction arises from different electrochemical relationships between the coating and the basis metal when these are in contact with moisture, as can happen at a pore or other discontinuity in the coating. If the finish is anodic to the basis metal when exposed to a corrosive medium, then corrosion of the basis metal will be inhibited. This is the way in which zinc and cadmium coatings retard rusting of steel. The other class of finishes, represented by copper/nickel/chromium and nickel/chromium coatings, show an opposite electrochemical behavior, since copper, nickel and chromium are generally cathodic to common basis metals. Such finishes actually tend to promote galvanic corrosion when only a few pores or cracks are present in the coating.

It is obvious that cathodic coatings must resist corrosive attack which could create pores or pits extending to the basis metal. From outdoor exposure tests it has long been known that a prime factor of quality of nickel/chromium finishes is thickness. The thicker the coating the longer the basis metal is protected. However, it was found that increasing the nickel thickness up to two or three mils did not keep pace over the years with increasing severity of some outdoor urban environments. Then followed the discovery that multiple layers of nickel of differing composition give superior protection. These, together with modifications of the chromium plate, provided the means for spectacular improvement in protective value.

(b) **Chromium**

Chromium offers good corrosion resistance and abrasion resistance in the family of the commonly plated metals. Thin chromium coatings over suitable undercoats provide excellent decorative systems. Furthermore, special chromium types can be deposited over copper/nickel or nickel undercoats so that the overall corrosion protective value of the system is increased.

Corrosion protection can be improved by the use of special types of chromium coatings. The useful life of the finish can be extended by the use of *microporous* or *microcracked* chromium. These invisible pores or cracks may be achieved by employing one of several existing process techniques. The corrosion resistance is significantly increased and this improvement is particularly beneficial in such industries as automotive and marine hardware.

Chromium may be deposited from baths with the metal in either the hexavalent or trivalent state.

(c) **Nickel**

The function of nickel is to provide a tough, durable and ductile undercoat. Nickel protects the basis metal from corrosion and in combination with the chromium top coat results in a lasting decorative finish. Nickel levels micro-roughness in the basis metal, providing a smoother, brighter finish.

In double-layer nickel undercoats for chromium finishes the metal immediately under the chromium is bright nickel containing sulfur while the layer under that is semi-bright nickel essentially free of sulfur. In any galvanic electrolytic cell set up with the chromium, the bright nickel reacts anodically to the purer semi-bright nickel. If microscopic corrosion sets in through pores in the chromium layer and penetrates the bright nickel layer, galvanic action between the two kinds of nickel tends to cause the microscopic pit to spread laterally in the outer nickel layer. The net effect is to retard penetration toward the basis metal, hence, to lengthen the useful life of the coating.

The above galvanic corrosion system can be further enhanced by use of three layers of nickel of different sulfur contents at a slightly greater cost.

(d) **Nickel-Iron**

Bright nickel-iron alloy coatings containing up to 50% iron are sometimes used as an economical substitute for single layer bright nickel deposits for mild or moderate service conditions. These coatings are more active than all nickel ones and generally are more ductile and cover better with chromium.

(e) **Copper Undercoat**

Nickel/chromium coatings may be deposited over a copper undercoat. ASTM specifications have been established for copper-nickel-chromium coatings where microporous or microcracked chromium is used. The difficulty in depositing nickel coatings directly on zinc base diecastings requires an initial copper coating.

The excellent buffability of copper permits obtaining a high finish, and buffed copper coatings are employed when buffing costs can be justified. As with nickel deposition, leveling copper processes can be used to upgrade the basis metal finish, and thus contribute to the overall improvement in the appearance of the final chromium finish. Ductile copper plate improves the apparent ductility of overlying nickel-chromium coatings. Bright leveling acid copper plate can minimize the undesirable effect of basis metal porosity by filling and bridging pores and also because of its superior microthrowing power, will plate into sharp angles. Such copper deposits are currently being used on some zinc diecastings following a thin copper plate deposited from a cyanide bath.

(f) **Formability**

Although basis metals with bright nickel/chromium finishes have been successfully drawn, stamped and otherwise formed, the bright nickel-chromium layer is relatively brittle. Decorative coatings that withstand forming operations well usually include a very ductile nickel coating that is buffed or satin finished and plated with a thin chromium deposit.

SPECIFYING THE FINISH

Having selected copper/nickel/chromium or nickel/chromium as the coating system for a steel, brass, zinc or other product, the designer must now specify the type, thickness and other characteristics desired in the coating. He aims to achieve high quality by specifying the types of layers to be applied, their individual thicknesses, protective value and adhesion, and the appearance of the finished surface. For specific subjects refer to the ASTM Annual Book of Standards, which covers Electrodeposited Coatings.

Type and Thickness

By type is meant the number and sequence of layers of copper, nickel and chromium which constitute the coating. The multiple-layer decorative finishes developed by the various suppliers differ, but are all superior in protective value to a single layer of bright nickel covered by conventional chromium. The large number of deposit types and combinations of layers can economically meet any performance specification. See Tables I and II for types and thicknesses to meet various service requirements.

Explanation of Tables I and II

(1) **Service Conditions**

There are four service conditions which define the environment to which the plated part will be exposed.

(2) Classification

The classification letters shown in the tables indicate the type of deposit to be provided in the nickel and chromium layers of the coating. The type of nickel is designated as follows:

b—for nickel deposited in the fully bright condition.

p—for dull or semi-bright nickel requiring buffing to give full brightness, and relatively free of sulfur.

d—for a double-layer or triple-layer nickel coating of which the bottom layer contains less than 0.005% sulfur and the top layer contains more than 0.04% sulfur. The sulfur-free layer should be from 60% to 75% of the total nickel thickness. If there are three layers, the intermediate one shall contain more sulfur than the top layer and shall be less than 10% of the total nickel thickness.

The type of chromium is designated as follows:

r—for regular (i.e., conventional) chromium

mc—for microcracked chromium having more than 300 cracks per cm. (750/in.) in any direction over significant surfaces.

mp—for microporous chromium containing a minimum of 10,000 pores per sq. cm. (65,000/in.^{2}) invisible to the unaided eye.

(3) Use of Copper

Copper undercoats are needed for deposits on plastic, zinc diecastings and aluminum, and are sometimes specified for steel.

(4) Typical Applications

The lists of typical applications will help the designer or purchaser select a suitable coating specification if he is not certain of the service conditions to be met. In case of doubt as to the severity of a planned application a classification should be specified suitable for the next more severe type of exposure conditions.

Protective Value

The problem of specifying performance of decorative coatings involving copper/nickel/chromium and nickel/chromium composites has intrigued the metal finishing industry continually since the turn of the century. The factors controlling corrosion are so numerous that the only valid test is exposure to actual service conditions. The conventional salt spray test, devised in 1914, has been generally discredited as an accelerated corrosion test for these decorative coatings largely because of lack of reproducibility of results and questionable correlation with service. It is recognized, however, that the test is still used in some segments of the plating industry because it can serve as an inspection tool to reveal gross defects in the coating, and bare areas.

In more recent years several accelerated tests have been developed which have shown fair correlation with the performance of copper/nickel/chromium and nickel/chromium coated parts in severe outdoor urban service. There are available copious data to support the specification of the number of hours resistance to these accelerated corrosion tests, as shown in Table III, as a measure of minimum quality acceptable in coatings intended for a given type of service. The tests themselves are described under the heading "Testing the Finish." The CASS and CORRODKOTE tests are generally preferred because they are so much quicker than the acetic/salt spray test.

Adhesion

It can be specified that the coating shall be sufficiently adherent to the basis metal, and the separate layers of composite coatings shall be sufficiently adherent to each other, that the finished part will pass the adhesion tests described under the heading "Testing the Finish".

Appearance

Appearance cannot be readily specified because it involves factors such as brightness, roughness and uniformity of color which are not easily assessed objectively. Location and extent of surface defects may influence acceptability – it is suggested that samples be prepared which are acceptable to both manufacturer and purchaser as standards of quality in appearance.

Ductility

If the product is to be used in such a way that the coating will be formed or will be deformed in service it may be desirable to specify ductility requirements.

TESTING THE FINISH

Thickness

There are several methods for measuring the thickness of copper/nickel/chromium and nickel/chromium coatings, some being destructive of the part tested, others not.

(1) Microscopical Method

The part under test is cut on a plane perpendicular to a significant surface and is mounted for metallographic examination. The cross-section is polished and etched to contrast the plated coating with the basis metal. The thickness is then measured optically with a microscope at a magnification great enough to permit measurements of thickness with an accuracy of plus or minus one micrometre (0.00004 inch) or one percent of the coating thickness, whichever is greater. The method is obviously destructive, is time consuming and skill is required by the operator. Despite these disadvantages it is used to some extent for production testing. When there is disagreement in thickness measured by other methods the microscopical method is sometimes selected as the referee test. This method has been accepted by the ASTM and the AES as described in ASTM Standard B-487.

(2) Magnetic Methods

Since the magnetic properties of the basis metal and the various layers of copper/nickel/chromium finishes differ, it is possible to use these differences to determine the thickness of coatings. Instruments are available that measure the force necessary to detach a small magnet from the surface of the finished part. Other instruments utilize the reluctance of a magnetic flux passing through the coating and basis metal to measure the thickness. Both types of instruments are calibrated against the standards of known thickness. The tests are non-destructive and rapid. Results are within 10 percent of the true thickness. These instruments cannot measure the thickness of nickel if there is an undercoat of copper present. ASTM Standard B-499 covers the magnetic methods.

(3) Coulometric Method

This method depends upon measuring the number of ampere-minutes or coulombs required for a controlled anodic current to dissolve a coating from a small fixed area of the surface. The test is destructive but instruments are available which record the current flow automatically so that they are simple to operate and are fast. The thickness of chromium, nickel and copper coatings can be determined by these instruments. ASTM Standard B-504 provides particulars on this method.

A procedure for simultaneously determining both thickness and electrochemical potential of individual layers in multi-layer nickel deposits was developed by E. P. Harbulak. These measurements can be used to indicate the corrosion protection offered by the overall system.

(4) Spot Test Method for Chromium

Like other chemical methods the spot test for chromium thickness is destructive. A circular spot of the surface is exposed to a drop of hydrochloric acid solution which attacks the chromium at a known rate. The time required for penetration through the chromium layer is a measure of the thickness. Precision of about plus or minus 10 percent can be achieved. Details of the test method are given in ASTM Standard B-556.

(5) Weight Loss on Stripping

It is often possible to strip or dissolve a coating, chemically or anodically, without appreciable dissolution of the basis metal. By weighing the specimen before and after the stripping and estimating its surface area, the average thickness of the coating can be calculated. Sometimes, the entire sample, basis metal and coatings, is dissolved and the solution analyzed for nickel,

TABLE I

RECOMMENDED STANDARDS FOR QUALITY NICKEL/CHROMIUM FINISHES ON STEEL, IRON AND ZINC PRODUCTS

Service Conditions	Classification Ni	Classification Cr	Minimum Thickness – in micrometres Nickel	Minimum Thickness – in micrometres Chromium	Typical Applications
MILD Exposure indoors in normally warm, dry atmospheres with coating subject to minimum wear or abrasion.	b	r	10	0.1	Toaster bodies, rotisseries, waffle bakers, oven doors and liners, interior auto hardware, trim for major appliances, hair driers, fans, inexpensive utensils, coat and luggage racks, standing ash trays, interior trash receptacles, inexpensive light fixtures
	p	r	10	0.1	
	d	r	10	0.1	
	b	mc	10	0.3	
	p	mc	10	0.3	
	d	mc	10	0.3	
	b	mp	10	0.3	
	d	mp	10	0.3	
	p	mp	10	0.3	
MODERATE Exposure indoors in places where condensation of moisture may occur: for example, in kitchens and bathrooms.	b	r	20	0.3	Steel & iron: stove tops, oven liners, home, office and school furniture, bar stools, golf club shafts. Zinc alloys: bathroom accessories, cabinet hardware
	p	r	20	0.3	
	d	r	20	0.3	
	b	mc	15	0.3	
	p	mc	15	0.3	
	d	mc	15	0.3	
	b	mp	15	0.3	
	p	mp	15	0.3	
	d	mp	15	0.3	
SEVERE Exposure which is likely to include occasional or frequent wetting by rain or dew or possibly strong cleaners and saline solutions.	d	r	30	0.3	Patio, porch and lawn furniture, bicycles, scooters, wagons, hospital furniture, fixtures and cabinets.
	d	mc	25	0.3	
	d	mp	25	0.3	
	p	r	40	0.3	
	p	mc	30	0.3	
	p	mp	30	0.3	
VERY SEVERE Service conditions which include likely damage from denting, scratching or abrasive wear in addition to corrosive media	d	r	40	0.3	Auto bumpers, grilles, hub caps and lower body trim. Light housings.
	d	mc	30	0.3	
	d	mp	30	0.3	

Note: 5 micrometres copper required on zinc and zinc alloys prior to nickel-chromium.

25.4 micrometres = 1.0 mil

Adapted from ASTM Standard B-456

TABLE II

RECOMMENDED STANDARDS FOR QUALITY
NICKEL/CHROMIUM FINISHES ON COPPER AND COPPER ALLOYS

Service Conditions	Classification Ni	Classification Cr	Minimum Thickness – in micrometres Nickel	Minimum Thickness – in micrometres Chromium	Typical Applications
MILD	b	r	5	0.1	
Exposure indoors in normally warm, dry atmospheres with coating subject to minimum wear or abrasion.	p	r	5	0.1	Toaster bodies and similar appliances oven doors and liners, interior auto hardware, trim for major appliances receptacles, light fixtures
	d	r	5	0.1	
	b	mc	5	0.3	
	p	mc	5	0.3	
	d	mc	5	0.3	
	b	mp	5	0.3	
	p	mp	5	0.3	
	d	mp	5	0.3	
MODERATE	b	r	15	0.3	
Exposure indoors where condensation of moisture may occur: for example, in kitchens and bathrooms	p	r	15	0.3	Plumbing fixtures, bathroom accessories, hinges, light fixtures, flashlights and spotlights
	d	r	15	0.3	
	b	mc	10	0.3	
	p	mc	10	0.3	
	d	mc	10	0.3	
	b	mp	10	0.3	
	p	mp	10	0.3	
	d	mp	10	0.3	
SEVERE	d	r	25	0.3	
Exposure which is likely to include occasional or frequent wetting by rain or dew; or possibly by strong cleaners and saline solutions.	d	mc	20	0.3	Patio, porch and lawn furniture and light fixtures, bicycle parts, hospital and laboratory fixtures
	d	mp	20	0.3	
	p	r	25	0.3	
	p	mc	20	0.3	
	p	mp	20	0.3	
	b	r	30	0.3	
	b	mc	25	0.3	
	b	mp	25	0.3	
VERY SEVERE Service conditions which include likely damage from denting, scratching or abrasive wear in addition to corrosive media	d	r	30	0.3	Boat fittings, auto trim, hub caps lower body trim
	d	mc	25	0.3	
	d	mp	25	0.3	

Note: 25.4 micrometres = 1.0 mil

chromium, copper and the ingredients of the basis metal. Again, the average thickness is what is obtained from the calculations. This method is often used in testing the quality of the finish on small barrel-plated parts.

Protective Value

The accelerated corrosion tests specified in Table III are means of controlling the continuity and quality of nickel/chromium coatings, but the duration of such tests does not necessarily correlate with the service life of the finished article. Details of the test methods are to be found in the corresponding ASTM Standards. The designer and purchasing agent need only know the general methods employed which can be briefly described as follows:

The acetic acid salt spray test (ASTM Standard B-287) consists of exposure of the plated part to a fog of droplets of a five percent sodium chloride solution containing enough acetic acid to maintain the pH in the acidic range of 3.1 to 3.3.

The CASS test (ASTM Standard B-368) involves exposure to a fog of droplets of a similar acidified salt solution containing a small amount of cupric chloride to accelerate corrosion.

The CORRODKOTE test (ASTM Standard B-380) is conducted by applying a slurry of corrosive salts and kaolin to the significant surfaces of the specimen, allowing the slurry to dry, and then exposing the slurry-coated part to a highly humid atmosphere for a specified period of time.

After subjecting an article to the corrosion test for the specified time, it is examined for evidence of corrosion of the basis metal or blistering of the coating. If such evidence is found then the finish has failed to pass the test. Surface deterioration of the coating itself is expected to occur during the testing of some types of coatings. The extent to which such surface alteration will be tolerated should be subject to agreement between purchaser and manufacturer.

These corrosion tests were developed to measure protection of the basis metal and are not reliable for predicting surface *appearance* after use.

Adhesion

There is no accepted quantitative standard test for adhesion. Qualitative tests are suggested in ASTM Standard B-571. A bend test involves repeated flexing or deformation of the plated product until fracture occurs. Any evidence of separation of the layers or coating constitutes failure. In the file test a piece is cut out of the part with a saw, then a coarse file is applied to the cut edge of the coating so as to attempt to raise or separate it. There is also a quenching test in which the finished article is heated in an oeven to an elevated temperature and then is quenched in cold water.

Ductility

ASTM provides two recommended practices for evaluating ductility. B-489 describes a procedure that consists of bending over a mandrel a narrow strip cut from a metal plated article. An elongation measurement is obtained from the smallest diameter mandrel that does not cause the deposit to fracture. When the shape is such that a suitable specimen cannot be cut from the plated part, a test panel may be prepared of appropriate basis metal, with the same coating system in the same baths.

B-490 is suitable only for evaluation of deposits having low ductility. It describes a procedure for measuring the ductility of electrodeposited foils. The recommended practice consists of measuring the bend of a foil held between the jaws of a micrometer; these are closed until fracture or cracks appear.

COPPER/NICKEL/CHROMIUM FINISHES ON OTHER BASES

Aluminum Alloys

Aluminum usually requires special conditioning treatments to remove the natural oxides and alloying elements prior to plating. The natural oxide is replaced by either metallic coatings or a special anodized film. The zincate, stannate or phosphoric acid anodize processes are used for this purpose. A bronze strike is applied to the stannate treated surface, whereas copper strikes are applied to zincate. After striking, normal electroplating procedures may be followed. SAE Standard J207 specifies types and thicknesses of copper, nickel, chromium coatings on aluminum.

Although there are many other fine proprietary preparatory solutions on the market, some typical practices used on aluminum are given in Table V.

Plastics

Plastics and some non-conductors can be finished by electroplating operations once the article is made conductive. The electroplate type can be selected as the user desires.

The success of plated plastics is largely related to the development of etch systems which produce a roughness on the plastic substrate. The strength of this bond can be measured by an adhesion or peel test, whereby a mechanical pull is used to determine the force per linear inch required to separate the coating from the plastic. This test indicates that the plated plastic article has the capability to withstand the forces imposed by temperature variations. The temperature expansion coefficient of plastic is three to five times greater than the metal plate, causing considerable stress by the plastic on the electrodeposit. The metal to plastic bond is instrumental in

ACCELERATED TEST REQUIREMENTS FOR COPPER/NICKEL/CHROMIUM COATINGS

Basis Metals	Service Conditions	Corrosion Test (duration in hours) CASS ASTM B368-68	CORRODKOTE ASTM B380-65	Acetic—Salt ASTM B287-74
Steel, zinc alloy, copper or copper alloy	MILD	—	—	8
	MODERATE	4	4	24
	SEVERE	22	16	96
	VERY SEVERE	44	32*	144

*Two 16 hr. cycles

TABLE IV

RECOMMENDED STEPS AND OPERATING CONDITIONS TO PREPARE THE PLASTIC SURFACE FOR ELECTROPLATING

Operation	Time Range Minutes	Temperature Range (°C)
A. CLEAN		
(1) Alkaline	1 - 5	43—60 (110—140)
(2) Acid	1 - 3	54—65 (130—150)
Rinse		
B. ETCH	1 - 10	60—71 (140—160)
Rinse		
C. NEUTRALIZE	1 - 5	21—60 (70—140)
Rinse		
D. CATALYZE	1 - 3	24—32 (75— 90)
Rinse		
E. ACCELERATOR	1 - 5	24—52 (75—125)
Rinse		
F. ELECTROLESS PLATE		
(1) Copper	7 - 10	24—29 (75— 85)
(2) Nickel	5 - 10	24—35 (75— 95)
Rinse To Electroplating Operations		

the ability of the article to withstand wide temperature ranges, a stringent range in the case of ABS is 82°C to –34°C (180°F to –30°F). The integrity of the finished article is determined by thermal cycling testing, and, generally, the article must pass at least three cycles.

Among the plastic substrates which have been successfully electroplated in production are acrylonitrile butadiene styrene (ABS), polyphenylene oxide, polypropylene and polysulfone. The substrate most widely used today is ABS. The plastics mentioned all require different preparatory techniques.

The "preplate" operations prepare the plastic surface for electroplating. The techniques used are mostly proprietary and complicated enough to preclude discussion in detail here. However, some of the steps and usual operating conditions are shown on Table IV.

The electroplating structure on plastic substrates is essentially the same as plated on metal substrates. While plastic substrates do not corrode in the same manner as metal, the galvanic relationships of the electroplate layers in the coating is the same whether the substrate is metal or plastic. Therefore when an article is exposed to corrosive atmospheres, the electroplate structure is selected to withstand corrosion penetration.

When plating plastics there is one layer that must be given special consideration; that is the copper electroplate. Copper plating serves two primary functions:

1) It effectively levels the etched, micro-roughened surface.
2) Its ductility serves as a cushion to absorb the temperature induced movement, between the plastic and the coating.

Generally, 12 to 25 micrometres (0.0005 to 0.001 inch) of copper is deposited. The copper electroplating bath must provide a levelled and ductile deposit. ASTM Standard B-554 covers measurements of thickness of metallic coatings on non-metallic substrates.

Decorative applications for copper/nickel/chromium finishes on plastics include: Small appliance trim, automotive interior trim, automotive grilles and light bezels, plumbing faucet trim, knobs and shower heads, marine hardware, camera parts, candlestick holders, fashion trim on handbags and shoes and nameplates. ASTM Standard B-604 covers the specification for "Decorative Electroplated Coatings of Copper/Nickel/Chromium on Plastic."

TABLE V
ALUMINUM PREPARATORY SOLUTIONS

	Operation		Time Range (Minutes)	Temperature Range °C (°F)
A)	Non etch clean		3 – 5	60–71 (140–160)
B)	**Precondition**			
	1)	50 vol % Nitric Acid (for commercial purity alloys) Rinse	1/4 – 1/2	21–24 (70– 75)
	2)	15 vol % Sulfuric Acid (for high magnesium content alloys) Rinse	2 – 3	82–88 (180–190)
	3)	3:1 mixture concentrated Nitric and Hydrofluoric Acids (for high silicon content alloys) Rinse	1/3 – 1/2	21–24 (70– 75)
C)	**Condition**			
	1)	Stannate No rinse	1/6 – 1	24–29 (75– 85)
	2)	Zincate Rinse	1/2 – 1	16–27 (60– 80)
	3)	Phosphoric Acid Anodize Rinse (Time and temperature are varied for different alloys)	5 – 15	24–35 (75– 95)

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.

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

Basis Metal — Metal upon which coatings are deposited.

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.

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.

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. (To be distinguished from throwing power).

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.

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

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.

Micrometre (Micron) 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.

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

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.

* Above definitions have been taken from ASTM B-374, Definitions of Terms Relating to Electroplating and have been abbreviated where appropriate for this test.

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877 S. Adams
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Youngstown, Ohio 44502

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Nashville, Tennessee 37210

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Subsidiary of ASARCO Incorporated
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Division of Federated Metals Canada Limited
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